The Federal Office for the Safety
of Nuclear Waste Management (BASE)
with support from the Federal Office
for Radiation Protection (BfS)

Expert response to the report by the EU Commission`s Joint Research Centre *“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

June 2021 – editorially revised in September 2021

Expert response to the report by the EU Commission`s 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’”*

Imprint

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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. 205ff) 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 high-level 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 the use of 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 evaluates the taxonomy capability of nuclear energy use in an argumentatively complete and comprehensible manner – 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 is published as an annex of this version of the experts` response text section. Before, it had not been attached for editorial reasons. The bibliography of the tabulated review is included in the bibliography 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 addressed (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 sub-headlines** denote the comments 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 on 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. Moreover, the JRC does not include these topics in its assessment of the DNSH criteria or create any link with the Taxonomy Regulation.

To technically and scientifically examine whether nuclear energy can be added to the taxonomy register it would be necessary 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 would be 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 addressed 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 also considers these aspects in section 6.

Other reasons for an expanded framework of observation

The implications and consequences of using nuclear energy for society as a whole 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 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 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 addressed 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 fatalities.

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 verifiable 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 is determined as the product of two numbers, which – as a limiting case of the respective model – are, on the on hand, extremely low and, on the other hand, 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 with reference to 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 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 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 ensured without any restrictions for the underlying periods of isolating the waste from the environment (JRC Report, Part B 5.1, p. 244, p. 246 and p. 247 and Part B 5.2.2, p. 250 and Part B 5.2.4, p. 260) – also neglects to mention the fact that there are different disposal concepts, sites with different topographical and geological conditions, safety and assessment concepts and national regulatory safety requirements within and outside the countries that are planning to have one or more repositories for radioactive waste (Charlier, 2019).

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 sub-statutory 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 repository and 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 open 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.

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

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. 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 is 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 (OECD, 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 a discussion of these arguments. This incompleteness and one-sidedness runs through the entire report and can be observed not only in some details. For 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 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" (CO_2) 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 CO_2 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

Part A 3.2.1, p. 35ff and 3.2.2, p. 39ff of the JRC Report presents an assessment of using nuclear energy in terms of its contribution to climate protection according to Article 10 Para. 1 of the Taxonomy Regulation. The JRC Report compares the contribution made to climate protection by generating nuclear energy and other energy generation options in Part A 3.2.3, 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 line with the political goals to reach zero 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 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. Moreover, development periods are rather long – 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 CO_2 emissions because of its high capital intensity. Otherwise, this capital could be used to expand alternative energy sources like sun, wind and water (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 CO_2 emissions can be broken down into the construction of nuclear power plants (12%), 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 nuclear power plants have electrical output in the range of 1000–1600 MWe. SMR concepts, in contrast, envisage planned electrical outputs of 1.5–300 MWe. In order to provide the same electrical power capacity, the number of units would need to be increased by a factor of 3–1000. Instead of having about 400 reactors with large capacity today, it would be necessary to construct many thousands or even tens of thousands of SMRs (BASE, 2021; BMK, 2020). 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 conventional 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.

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

International safety standards would particularly be required, if an SMR was delivered by one country, where the SMR was manufactured, to another country, where it will be used. This will be particularly important if the "user country" is a newcomer in nuclear terms. 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, agree to accept special monitoring measures (IAEA safeguards). The risks of proliferation increase too against a background of a theoretically higher number of SMRs at various sites, some of them very remote, as already mentioned, and the use of fuels with greater levels of enrichment. At the same time, the time and effort for the monitoring measures increases if there is a need to monitor a large number of SMRs, special designs and regular transport operations of complete nuclear power plants or replaceable reactor cores. Many of the standard methods for monitoring fissionable material do not directly match the special features of SMR concepts (BASE, 2021).

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. Le Monde diplomatique et al., 2019; OECD and IAEA, 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 environmentally-friendly. 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 and 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 m^3 of radioactively contaminated water escaped into the Puerco River in this tailings pond accident. The Church Rock disaster released the largest amounts of radioactivity ever in the USA. The surrounding area and its residents are still suffering from the consequences of the accident (Knutson, 2021). The impact of the disaster, which is still continuing today, and the intensive uranium mining around Church Rock, i. e. serious environmental and health problems, are described in the Report of the Church Rock Uranium Monitoring Project 2003–2007, which has been published by the Southwest Research and Information Center (SRIC). In contrast, the long-term, negative consequences of the Church Rock disaster are not even mentioned in the JRC Report.

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 until 2019 (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 reducing the size of a repository for high-level radioactive waste.

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.

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 Directiveeither. The safety objectives mentioned there only apply to existing nuclear power plants as a reference value for the timely implementation of safety improvements 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” (EU Direcitve 2014/87/EURATOM).

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 worldwide (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, 2014a). 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) (IAEA, 2014a). Entombment basically is a 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 (µSv). 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 repositories below 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 interim storage of radioactive waste in comparison with other activities when using nuclear technology is not the crucial activity in terms of the DNSH criteria – is therefore not clearly deduced (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 interim storage of high-level radioactive waste in dual purpose casks 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 activities, 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 is 300 years. It also asserts that the material behaviour of the technical barriers is well-known during this period and it is therefore possible to predict that the barriers will be sufficiently reliable.

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 incomprehensible. Near surface

repositories are believed to be more susceptible to human intrusion than deep geological repositories (IAEA, 2012). Aspects like robustness, accessibility, protection, loss of knowledge etc. must also be taken into account when judging their safety. 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 prediction regarding social and political developments, the danger of accidents (e.g. caused by a lack of maintenance), and attacks caused by war or terrorism, the risk of proliferation, the huge organisational effort and financial expenditure for future generations and climate uncertainties (KOM, 2016). 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, shows 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 area, 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 intermediate-level 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 intermediate-level 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.

First of all, it should be noted 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 later 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” (CO_2) 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 in France the licence application from the operational company has already been delayed on several occasions. Both countries are still years away from starting to operate the facilities.

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 interim 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 (pre- operational, 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 facilities 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

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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

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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 (OECD, 1995 and OECD, 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, but are presented as 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 Radiation Protection Ordinance) can still cause damage to people’s health. The statement in the JRC Report “and will never exceed the limit below which they can cause no harm” is therefore contradictory. The impact of low doses of radiation is still being discussed. 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.” At the end of the regulatory period – 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

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inadequate, apart from other things, because of the different site situations, specific general conditions like the waste characteristics, 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 repositories 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 long-term consequences of disposal of HLW and this is consistent with the state-of-the-art of science and technology. However, the assumptions and requirements for the system associated with this are presumed to have been implicitly met, although uncertainties exist in their implementation and their long-term effect.

Despite their central significance for the method, the TSCs are only presented in a very general way and require further specification (e.g. dose criteria for radiological assessment). 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; therefore, the corresponding risks cannot be excluded, 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 interim 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; OECD/ 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 basic 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 of the brief description, major topics are not mentioned or only mentioned in passing (e.g. uncertainties, human activities including human intrusion, and long-term documentation). 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, 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 further 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 are available from a very recent investigation project that looked at 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". It is important, however, to consider both aspects in order to assess the sustainability of the disposal of radioactive waste. Both aspects represent sustainability goals in the United Nations' 2030 Agenda (UN, 2015). The 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) call for a separate consideration of the issues of intergenerational justice and participation 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 is also at the expense of future generations – ranging from restrictions or non-usage possibilities in the affected areas and even the planned dismantling of the damaged reactor block and disposing of the retrieved nuclear fuel.

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 be possible that no consensus is reached 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 about a site election procedure were resumed 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.

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

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. Today, the international discussions can 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 repositories 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. The final report of the initiative (OECD, 2019) presents, among other things, a toolbox involving 35 “mechanisms” for preservation of records, knowledge and memory – 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. In the course of using nuclear energy and the supply and disposal of fuels associated with it, an elaborate network of international controls has therefore been created to minimise the risk of military misuse by state or non-state players. This particularly applies to fissionable material like uranium-235 and plutonium-239, which are used when generating nuclear energy or produced in power reactors. In addition to this, significant risks are also created by other radioactive substances if they are stolen and used in an improper manner ("dirty bombs").

Processes that are particularly important for proliferation are created when manufacturing nuclear fuel (uranium enrichment) and reprocessing spent nuclear fuel materials: the technologies for uranium enrichment can be used with modifications to produce highly enriched uranium to build a nuclear weapon. During reprocessing, plutonium is separated and it can be used for nuclear weapons. 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 whether the discussion about sustainable mining has any repercussions for investigating the environmental effects of uranium mining. However, it is important in terms of other sustainability goals or the minimum safeguards laid down in Article 18 of the Taxonomy Regulation (cf. BMK, 2020, p. 22 too).

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

Directories

Abbreviations

AkEnd	Arbeitskreis Auswahlverfahren Endlagerstandorte
AKS	Arbeitskreis Szenarienentwicklung
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)
BMK	Bundesministeriums für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie (Republik Österreich) (Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (Republic of Austria)
BMU	Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)
BMUB	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
EAF	energy availability factor
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 Reaktorsicherheit (Society for Plant and Reactor Safety)
HAW	high-active waste – see below “HLW”
HI	Human Intrusion
HLW	high-level waste – also referred to as “HAW”
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
KOM	EU Commission
kWh	Kilowatt hour
LCA	life cycle assessment
LLW	low-level waste
mSv	millisievert
MTO	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 – Nuclear Energy Agency
P&T	Partitioning and Transmutation
SDAG Wismut	Wismut Soviet/German joint stock company
SEWD	Disruptive action or other effects caused by third parties
SMA	Low- and intermediate-level radioactive waste
SMR	Small modular reactors
StandAG	Site Selection Act
StrlSchV	Radiation Protection Ordinance
TEG	Technical Expert Group on Sustainable Finance
TSC	Technical screening criteria
TWh	Terawatt hour
UBA	German Environment Agency
UCF	unit capability factor
UN	United Nations
UVP	Environmental impact assessment
VLLW	very low-level waste
W&T	Science and technology
WAA	Reprocessing plant
WENRA	Western European Nuclear Regulators Association

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EU Taxonomy / Annex to the expert response by BASE and BfS to the JRC Report

Tabulated review of the JRC Report

The page numbers given in the tabular review of the JRC report refer to the version published by the JRC in March 2021.

GENERAL ISSUES

No. 1

Source:
Entire report (focus on geological disposal of radioactive waste)
Reference text:
Entire text

Scientific evaluation:
The TEG report cites a lack of long-term in-situ empirical data and evidence as the main reasons for not having performed a robust DNSH analysis with respect to nuclear energy. The TEG therefore did not recommend the inclusion of nuclear energy in taxonomy and proposed that more extensive technical work be undertaken by a group of technical experts in the field.

As regards geological disposal, the present report proposes that the DNSH analysis can be based on safety cases (esp. safety assessments) from mature European programmes (for radiological effects) and on environmental impact assessments (for non-radiological effects). This generally constitutes a reasonable approach. However, this key methodological decision is not adequately explained and its consequences are not discussed.

The theory is presented that if all the stakeholders adhere to the accepted regulations (e.g. legislation, guidelines, etc.), then deep geological disposal must by definition be safe. No discussion is, for example, dedicated to the possibilities that, for whatever reasons, the regulations might be imperfect or not followed. The uncertainties associated with implementation and long-term development are not addressed. In addition, a few critical comments are made regarding specific details of implementing this strategy (as discussed later in this table).

No. 2

Source:
Entire report
Reference text:
Entire text

Scientific evaluation:
The overriding methodology used in this report can be summarised as follows (JRC Report, Part A 1.3.2):

1. Verify whether any technology (nuclear power generation) "contributes significantly" to climate change mitigation. If so, proceed to the next step (otherwise reject it from further analysis).
2. Carry out a life cycle analysis of all the elements of nuclear power generation with the aim of identifying processes/activities that generate potential threats (in the light of the environmental taxonomy objectives). Based on industrial standards (e.g. EU directives, BAT, reference documents, etc.), evaluate whether these potential threats can (in principle) be prevented or mitigated. If not, the process/activity must be eliminated from any further consideration. Otherwise, the activity/process is further considered in the next assessment step.
3. If an activity or process from the previous step is found to be suitable, Technical Screening Criteria (TSC) are developed. If these screening criteria are met, then by definition the activity/process also meets the relevant criteria and must therefore be included in taxonomy.

The analysis is carried out up to and including step 2 (see JRC Report, Part A Chapters 3 and 4 in Part A) in relative detail. The TSC for nuclear power generation (Part A 5) are presented as being in a stage of "development" (especially for radioactive waste storage and disposal) and have not been applied as assessment criteria. Therefore, the proposed methodology has not been finalised and the report does not offer an authoritative recommendation on whether or not nuclear power generation should be included in taxonomy.

Notably, no overall conclusions are found in Part A 5, nor throughout the rest of Part A. Although statements are made in the Executive summary regarding "no scientific grounds" for rejecting nuclear energy generation from EU taxonomy, no final statement is made whether the technology should formally be included under taxonomy.

No. 3

Source:

Entire report

Reference text:

Entire text

Scientific evaluation:

In the life cycle assessment, key importance is placed on whether an activity generates threats that can be prevented/mitigated or not. In view of this, it is surprising that little consideration is given (especially in the context of deep geological disposal) to events that potentially have extreme consequences (disasters). Such events by definition cannot be predicted – and mitigating their impact may be extremely difficult or impossible using current technology. The potential impact of such events should be discussed, not only from a health point of view, but other points of view too (e.g. economic).

In this context, it is remarkable that only five pages (JRC Report, Part A 3.5) are dedicated to the discussion of the impact of severe accidents (focusing on the operation of NPPs) in a report spanning nearly 400 pages.

Abstract

/

Executive summary

No. 4

Source:

Executive summary S. 11

Reference text:

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.

Scientific evaluation:

This statement is written in an oversimplified manner. Generally, the multi- barrier system will undergo natural degradation over long periods of time and some limited release of radionuclides into the biosphere cannot be ruled out. It is therefore all the more important that the safety assessment of the repository should convincingly demonstrate that any discharge lies well below the regulatory limits and therefore does not pose an inacceptable risk for future generations.

No. 5

Source:

Executive summary, p. 7

Reference text:

- The protection of people and the environment in countries with nuclear installations relies on the existence of a solid regulatory framework […]
- The EU and its Member States have developed and established a comprehensive regulatory framework to ensure the safety of nuclear installations […]

Scientific evaluation:

Important for determining the review standard, cf. no. 8.

No. 6

Source:

Executive summary, p. 7

Reference text:

- The analyses did not reveal any science-based evidence that nuclear energy does more harm to human health or to the environment than other electricity production technologies already included in the Taxonomy as activities supporting climate change mitigation.

Scientific evaluation:

Important for determining the review standard, cf. no. 8.

No. 7

Source:

Executive summary, p. 8

Reference text:

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

Scientific evaluation:

Provided that the JRC is referring to the events that need to be considered according to the requirements of state regulations, this statement is comprehensible. Cf. nos. 5 and 6.

In regard to severe accidents the statement cannot be accepted, as they involve very improbable events with a huge impact in terms of damage and their costs definitely cannot be described as "reasonable" in this sense. The general comment that an introductory definition of the incidents that need to be considered would significantly improve the comprehensibility of the report applies here too.

No. 8

Source:

Executive summary, p. 8

Reference text:

- The radiological impact of nuclear energy lifecycle activities, including radioactive waste management and disposal, is regulated by law in the Member States, setting the maximum allowed releases and radioactivity exposure to the professionally exposed groups, to the public and to the environment. Respecting these limits, establishing the boundaries below which no significant harm is caused to human life and to the environment, is a precondition for any nuclear lifecycle activity to be authorized and is subsequently monitored by independent authorities.

Scientific evaluation:
This statement implicitly outlines the JRC's interpretation of the DNSH criteria.

The JRC either identifies the DNSH stage as identical to the state regulations or believes that they are more than met by them. The JRC Report therefore follows the statements in the TEG report.
The statements in the previous fundamental points (here nos. 5/6) ensure that this condition is met.
This means that the DNSH criteria have been fulfilled if an activity meets an appropriate state regulation – and is therefore approved.
Please note that this does not mean that any activity in the field of nuclear power automatically satisfies the criteria, but it is possible that these criteria can be met for the activity in question through approval and certification procedures.

In addition to the statements about taxonomy and the report by the TEG (TEG, 2020a, b), it is also necessary to mention the discussion about applying taxonomy in (NABU, 2021). This publication uses examples to make clear that for any in principle sustainable activity an assessment related to the DNSH criteria must take place on an individual basis in relation to the laws etc. in order to prove that the DNSH criteria have been met.
In this regard the statement that the technical screening criteria are similar or identical to regulatory requirements, is also shared outside the TEG.

However, the (NABU, 2021) source also raises the question of whether particular classes of activities should be included in an exclusion list for taxonomy.

Sources:
(TEG, 2020a,b), (NABU, 2021)

No. 9

Source:
Executive summary, pp. 8–9
Reference text:

- An important outcome from the report is the demonstration of the development of appropriate Technical Screening Criteria (TSC) for nuclear energy-based electricity generation according to the approach practised by the TEG in their work. The TSC published here are preliminary proposals, illustrating that adequate criteria can be compiled to ensure that the application of nuclear energy does no significant harm to human health and the environment.

Scientific evaluation:
Cf. comments on no. 8.

No. 10

Source:
Executive summary, p. 9
Reference text:

- The average annual exposure to a member of the public […]

Scientific evaluation:
Specifying the average effective doses per head of the population does not match the latest standard in radiation protection for nuclear facilities and installations. According to the latest recommendations of the International Commission on Radiological Protection (ICRP), the so-called "representative person" as defined by the ICRP has to be considered, i. e. a member of the public, who is exposed to higher levels of radiation because of their lifestyle.

Sources:
(ICRP, 2006), (ICRP, 2007)

No. 11

Source:
Executive summary, p. 9
Reference text:
- According to the LCIA (Life Cycle Impact Analysis) studies analysed in Chapter 3.4 of Part A […]

Scientific evaluation:
These studies were only briefly mentioned in chapter 3.4 of the JRC Report, but not analysed in any detail.

No. 12

Source:
Executive summary, pp. 9–10
Reference text:
- With regard to public exposure in case of accidents, severe accident fatality rates and maximum consequences (fatalities) are compared in Figure 3.5-1 of Part A. The current Western Gen II NPPs have a very low fatality rate ($\approx 5 \cdot 10^{-7}$ fatalities/GWh). This value is much smaller than that characterizing any form of fossil fuel-based electricity production technology and comparable with hydropower in OECD countries and wind power (only solar power has significantly lower fatality rate).

Scientific evaluation:
Please refer to the comments on risk indicators in no. 128, as only numbers of fatalities or fatality rates are used here.

No. 13

Source:
Executive summary, p. 10
Reference text:
- Severe accidents with core melt did happen in nuclear power plants and the public is well aware of the consequences of the three major accidents, namely Three Mile Island (1979, USA), Chernobyl (1986, Soviet Union) and Fukushima (2011, Japan). The NPPs involved in these accidents were of various types (PWR, RBMK and BWR) and the circumstances leading to these events were also very different. Severe accidents are events with extremely low probability but with potentially serious consequences and they cannot be ruled out with 100% certainty.

Scientific evaluation:
This statement is crucial for the fundamental question of what the JRC's assessment standard for DNSH is, cf. no. 9. The JRC presented the current assessment standard, in which severe accidents are not included. This is not comprehensible with regard to the precautionary principle (cf. no. 8) listed by the TEG and a scientific review as required by the Taxonomy Regulation, taking into account the uncertainties (cf. recital (40) and Article 19 Para. 1 f of the Taxonomy Regulation).

No. 14

Source:
Executive summary, p. 10

Reference text:

- The consequences of a severe accident at a nuclear power plant can be significant both for human health and the environment. Very conservative estimates of the maximum consequences of a hypothetical severe nuclear accident, in terms of the number of human fatalities, are presented in Chapter 3.5 of Part A and are compared with the maximum consequences of severe accidents for other electricity supply technologies.

Scientific evaluation:
Cf. no 13.

No. 15

Source:
Executive summary, p. 10 as well as A 3.5, p. 178 and A 4.4, p. 188
Reference text:
Executive summary and Chapter 3.5:

- While the number of human fatalities is an obvious indicator for characterising the maximum severity of accident consequences, nuclear accidents can lead to other serious direct and indirect impacts that might be more difficult to assess. Whereas the public is well aware of the devastating consequences on property and infrastructure, as well as on the natural environment, from historical cases of anthropogenic catastrophes, the disaster and risk aversion might be perceived somehow differently for nuclear related events. Evaluating the effects of such impacts is not in the scope of the present JRC report, although they are important for understanding the broader health implications of an accident.

Chapter 4.4:
It can therefore be concluded that all potentially harmful impacts of the various nuclear energy lifecycle phases on human health and the environment can be duly prevented or avoided. The nuclear energy-based electricity production and the associated activities in the whole nuclear fuel cycle (e.g. uranium mining, nuclear fuel fabrication, etc.) do not represent significant harm to any of the TEG objectives, provided that all specific industrial activities involved fulfil the related Technical Screening Criteria.

Scientific evaluation:
No consideration is given as to whether the risk profile for nuclear energy is different from other industrial activities or forms of energy generation.

If we compare, e.g. the key figures such as the average lethality per generated TWh for nuclear energy and fossil fuel energy generation, it must be noted that the lethal impacts occur almost continually when generating energy with fossil fuels, but most lethal impacts in conjunction with nuclear energy take place through rare, but severe events. Beyond that, there is an additional component geared towards the future by the contribution made by fossil energy generation to climate change. As a result, nuclear accidents are on average much more costly than accidents in other fields of technology (Sovacool et al., 2015).

This fact may be mentioned at several points in the report (cf. left column and the comments on disaster aversion in Chapter 3.5 on p. 179). However, it is explicitly omitted when developing screening criteria.

Source:
(Sovacool et.al., 2015)

No. 16

Source:
Executive summary, p. 10
Reference text:

- While the number of human fatalities is an obvious indicator for characterising the maximum severity of accident consequences, nuclear accidents can lead to other serious direct and indirect impacts that might be more difficult to assess. Whereas the public is well aware of the devastating consequences on property and infrastructure, as well as on the natural environment, from historical cases of anthropogenic catastrophes, the disaster and risk aversion might be perceived somehow differently for nuclear related events. Evaluating the effects of such impacts is not in the scope of the present JRC report, although they are important for understanding the broader health implications of an accident.

Scientific evaluation:
Cf. nos. 13 and 14 as well as 15.

It is necessary to add here that the JRC once again states that the crucial question, i. e. how to deal with damage scenarios emerging from potential severe accidents, is not conclusively considered in the JRC Report.

No. 17

Source:
Executive summary, p. 10–11
Reference text:

- The long-term potential impacts of radioactive waste relevant to the “do no significant harm” criteria, are of a radiological nature. Due to its potential to cause harm, radioactive waste and spent fuel must be managed aiming at radionuclide containment and isolation from the accessible biosphere for as long as the waste remains hazardous. The maximum radioactive dose limits to humans and to the environment due to waste management activities and disposal facilities are set by the relevant regulations.

Scientific evaluation:
The long-term safety assessment for a repository is carried out for a specified period of time that is prescribed by the law. In Germany this period of time is set to one million years. The statement that the radioactive waste is non-toxic after the expiry of the period under review cannot be supported. The radiotoxicity of high-level radioactive waste can be seen in Figure 2.4–1 of the JRC Report, Part B. It shows a radiotoxicity level of 10^5 Sv per ton of spent fuel after the period of one million years.

Sources:
JRC Report, Figure B2–4.1

No. 18

Source:
Executive summary, p. 11
Reference text:

- The safety of radioactive waste and spent fuel during storage before disposal is ensured by adequate passive safety features (containment, shielding, etc.), but also relies upon active monitoring and control by the operators of the facilities.

Scientific evaluation:
Reference is made here more precisely to the regulatory framework for interim

storage, which is generally mentioned in no. 8.
In the light of the JRC's standard, the DNSH criteria are met for interim storage. Whether this standard is adequate, is questionable (cf. No. 13).

No. 19

Source:
Executive summary, p. 11
Reference text:

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

Scientific evaluation:
It is not clear what "standard tailings and waste rock handling measures" are. It is not explained in a comprehensible manner which specific measures have to be taken in order to achieve harmlessness.

No. 20

Source:
Executive summary, p. 11
Reference text:
The multi-barrier configuration of the repository prevents radioactive species from reaching the biosphere over the time span required.

Scientific evaluation:
The statement that a multi-barrier-system prevents the spread of radionuclides reaching the surface is oversimplified and generalised description. The max. spread of radionuclides (given in a wide variety of measurement units, sometimes even given as the risk of spreading) must be restricted to an expected degree set in advance (cf. § 1 section 2 Site Selection Act). Any potential discharge, which falls below this regulatory standard, cannot generally be ruled out, but must be assessed in terms of the expected effects on people and the environment according to current standards (cf. § 4 of the Order for Safety Requirements for Disposing of High-Level Radioactive Waste).

No. 21

Source:
Executive summary, p. 12
Reference text:
[...] nuclear accidents can lead to other serious direct and indirect impacts that might be more difficult to assess

Scientific evaluation:
The report completely ignores any non-radiological consequences of a nuclear disaster. It is now indisputable that the psychosocial health consequences of a nuclear disaster like Fukushima or Chernobyl by far exceed the direct deterministic and random consequences of radiation. These events also lead to serious social and economic upheavals, which must not be ignored here.

Sources:
(Bromet and Havenaar, 2007), (Maeda and Oe, 2017) (Shigemura et al., 2017)

No. 22

Source:

Executive summary, Key conclusions, pp. 7–8,
(together with the tables 3.3.1-1 and 3.3.1-2, p. 80–81)

Reference text:

- With regard to potential radiological impacts on the environment and human health, the dominant lifecycle phase of nuclear energy significantly contributing to potential radiological impacts on the environment and human health are: uranium mining and milling (ore processing) [...]
- Related analyses demonstrate that appropriate measures to prevent the occurrence of the potential harmful impacts or mitigate their consequences can be implemented using existing technology at reasonable costs.

Scientific evaluation:

The summary (viewed together with the tables mentioned and also Annex 4.2) reveals a contradiction in the JRC Report when it comes to observing and assessing uranium mining: the environmental dangers may be mentioned, but there is no effort to point out that uranium mining creates significant interference with the environment and people's lives in many of its aspects and manifestations. Especially in the field of uranium mining it is questionable if past and current measures for the protection of the environment and human well-being were sufficiently implemented. What has been written so far has clearly demonstrated that the uranium mining industry has not made the necessary efforts in the past to comply with the environmental objectives in EU taxonomy.

The JRC Report does not emphasise the absolute necessity of consistent government actions to demand and implement environmental standards either.

No. 23

Source:

Executive summary, Key conclusions

Reference text:

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Scientific evaluation:

The "Key conclusions" in the "Executive summary" simply appear to be only loosely connected to the actual text of the report or not at all.

The report does mention the problem of having to store radioactive waste "for a very long time" (low, intermediate and high-level), but it only uses the short-term deep geological storage of CO_2 when comparing it with "competitors", only to then boldly conclude that comparable risk potential exists here too. This is comparing what is incomparable and, in this regard, is both incorrect and inadmissible.

Part A: Review of the state-of-the-art to assess nuclear energy generation under the "do no significant harm" (DNSH) criterion

A 1: Introduction, motivation, approach, structure

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A 2: Lifecycle assessment: methods, benefits and limitations

/

A 3: Summary of results from state-of-the art LCA studies on nuclear energy

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A 3.2: Comparison of impacts of various electricity generation technologies

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No. 24

Source:

A 3.2.1., p. 35

Reference text:

According to the International Atomic Energy Agency (IAEA) [3.2-1], at the end of 2018 there were altogether 451 nuclear power plant (NPP) units in operation all over the world with a total electricity generating capacity of 396.9 GW.

Scientific evaluation:

The assertion that 451 nuclear power plants were operating around the world in 2018 is too high. Source 3.2-1 refers to information from the IAEA PRIS database. The JRC Report takes the numbers of “operational reactors” from source 3.2-1 [Table 1 in the source]. According to the glossary of the PRIS database, “operational reactors” are defined as: “A reactor is considered as 'operational' from its first grid connection to permanent shutdown. Thus, when a reactor is temporarily not generating electricity because of outages for, e.g. refuelling, maintenance, repair, large refurbishment or political decision, the reactor is still categorized as operational. The only exception to this classification is when the reactor’s status is declared as 'suspended operations', where it is excluded from the list of operational reactors even though it has not yet reached permanent shutdown status.” This means that the reactors in Japan, which were switched off after the accident in Fukushima, but are not operating commercially because of ongoing refitting measures, are classified as “operational”. According to source 3.2-1, there were 39 “operational” reactors in Japan at the end of 2018. Table 14 of source 3.2-1 makes clear that only 9 of these reactors were operating commercially and provided information about their energy availability factor (EAF 2014-2018) or their unit capability factor (UCF 2014-2018). Other sources consider the aforementioned restriction and mention that 9 nuclear power plants were in operation in Japan [World Nuclear Industry Status Report, Edition 2019 and Edition 2020].

Sources:

(WNI, 2019), (WNI, 2020), (IAEA, 2021)

No. 25

Source:

A 3.2.1., pp. 35-36

Reference text:

The LWR type is dominant with 353.9 GW installed capacity (89% of total installed capacity: 71% PWR and 18% BWR), while about half of the remaining 11% is generated in PHWR units such as the Canadian CANDU design. The rest is produced in gas-cooled reactors (2%), LWGRs (2%, also called RBMK) and Fast Breeder Reactors (1%) [...]

According to the 2018 World Energy Outlook published by the International Energy Agency (IEA), in 2017 [3.2–3], the total electricity generation of the world amounted to 25 640 TWh [...]

Figure 3.2–1. Electricity generation by fuel type in 2017

Scientific evaluation:
At several points in the JRC Report it is possible to discover minor discrepancies in numerical values when recalculated based on the information from the underlying sources
Of the 11% of installed capacity, which is not due to PWRs or BWRs, more than half (6.2%) is accounted for by PHWRs, 2% by GCRs, 2% by LWFRs and 0.4% by FBRs [3.2–1].
The total energy generation around the globe in 2017 amounted to 25,679 TWh [3.2–3]. The percentages in the table in Figure 3. 2–1 are correctly shown only for oil-generated electricity worldwide and in OECD countries. All the other numerical values deviate in the decimal places in the recalculations [3.2–4].

No. 26

Source:
A 3.2.1., p. 35
Reference text:
As shown in Figure 3.2–1, the worldwide share of nuclear was 10.4%.

Scientific evaluation:
It is unclear why different sources are used for indicating global electricity production in TWh [3.2–3] and for the share of nuclear energy in electricity generation [3.2–4]. If source [3.2–3] in the report is used, the share of nuclear electricity production in 2018 amounted to 10.3%.

The JRC Report does not contain any information that the share of nuclear energy in global electricity generation has continually declined since the 1990s up to the year 2017. This is easily visible if the source quoted [3.2–3] is examined more carefully. Table 1–4 in the source still indicates a share of 16.8% for nuclear energy in global electricity generation for the year 2000.

No. 27

Source:
A 3.2.1., p. 37
Reference text:
Figure 3.2–3. Projection of the electricity generation by source in the EU

Scientific evaluation:
The graphic shown in figure 3.2–3 is based on a model calculation. Specific numeric values in the projection for electricity production in the EU up to 2050 are shown without specifying possible deviations. The shown projection of a constant share for nuclear energy of 22% up to 2050 at a time when overall electricity production will increase presupposes a massive expansion of nuclear energy in Europe. The appropriate projection is shown in greater detail in the next graphic.
The IAEA also publishes projections of the future share of nuclear energy in electricity production annually. These projections consider the development of nuclear energy worldwide and contain a high-case and low-case scenario. In the high-case scenario, nuclear electrical generating capacity is projected to increase by about 20% by 2030 and by about 80% by 2050 compared with 2019 capacity. In the low-case scenario, nuclear electrical generating capacity is projected to gradually decline by about 10% until 2040 and then rebound, resulting

in only a 7% reduction by 2050. In both the low- and the high-case scenario, the share of nuclear in total electrical generating capacity is expected to decrease by 2050. A reduction of 3 percentage points is expected in the low-case scenario, a reduction of less than 1 percentage point is expected in the high-case scenario. If it is assumed that these global projections can roughly be transferred to the EU, it can be stated that the IAEA's scenarios are lower than those outlined in the JRC Report, even in the most favourable case.

Source:
(IAEA, 2020a)

No. 28

Source:
A 3.2.1, p. 38
Reference text:
Figure 3.2–4. Evolution of the nuclear installed capacity in the EU

Scientific evaluation:
It should be noted that the United Kingdom is still included in the information for the countries described as EU28. The United Kingdom left the European Union on 31 January 2020. As regards nuclear power plants, the United Kingdom currently has 15 reactors in operation with an installed capacity of 8.9 GWe and therefore made a major contribution to the installed capacity of nuclear power plants in service within the EU.
The figure represents the installed capacity on the basis of newly built nuclear power plants in a very optimistic light. According to the figure, about 20 GW is estimated to come from newly built nuclear power plants by the year 2030 alone. Based on the assumption that these could be nuclear power plants with a capacity of approx. 1.6 GWe – similar to the EPRs under construction in France and Finland – this would mean about 12 nuclear power plants. Therefore, 12 nuclear power plants with high electrical output would have to be built and commissioned by 2030. This is not predictable at the moment. Only two such power plants are currently under construction in the EU – one EPR in Finland since 2005 and one EPR in France since 2007.
In the EU two further nuclear power plant units with significantly lower capacity (440 MWe each) are under construction in Slovakia. Construction started there in 1987. The average construction time for all the nuclear power plants commissioned worldwide during the last 10 years was 11.6 years. Work to construct another nuclear power plant has not started in any other country in the EU. If any expansion of nuclear energy in the EU can be expected during the next few decades, it will not proceed at the rate described here.
The forecast presented assumes new buildings, but also extensive retrofitting of the ageing nuclear power plants within the EU. Most of the nuclear power plants currently in operation in the EU are more than 30 years old. The nuclear power plants were originally designed for an operating life of between 30 and 40 years. Many of the units have already reached or exceeded this operating lifetime. 84% of the nuclear power plants in the EU are more than 30 years old, 12% are actually more than 40 years old.

The degree to which national authorities will actually approve a license for a lifetime extension to 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. 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.

Sources:
(IAEA, 2020b), (INRAG, 2021)

No. 29

Source:
A 3.2.1., p. 38
Reference text:
Moreover, there is an increasing interest in smaller scale nuclear power reactors, so-called Small Modular Reactors (SMRs).

Scientific evaluation:
The JRC Report refers to SMRs, which are being intensively discussed in many countries. Considering international or national definitions, the scope of the concepts, which are included under the term SMR, range from "today's" reactors with low capacity (mainly water-cooled reactors) to novel kinds of concepts, for which there is little industrial experience so far (e.g. high-temperature or molten salt reactor concepts). Reactors with capacity of up to 300 MWe are normally classified under the term SMR. Most of the very diverse SMR concepts around the world are still at the concept study stage. The two Russian KLT-40S reactors at the so-called Akademik Lomonossov floating nuclear power plant have been in operation as SMRs since 2020. This installation is used to supply electricity and heat to the northern Siberian town of Pevek. Three research/demonstration reactors are currently in operation as SMRs with an electrical power output less than 300 MWe: the CEFR in China for developing fast reactors, the HTR-10 in China for continuing to develop the concept of a gas-cooled pebble bed high-temperature reactor and the HTTR experimental reactor in Japan for developing gas-cooled high-temperature reactors with prismatic fuel. There are also two other pilot plants classified as SMRs that have been under construction for some time: the HTR-PM in China for the further development of the modular concept since 2012 and the CAREM-25 in Argentina as a prototype for a CAREM reactor with larger capacity since 2014. There is no evidence of any widespread introduction of SMR reactor concepts on the market.
Within the EU, apart from the United Kingdom, which is no longer part of the EU, active SMR developments are only taking place in Denmark, the Czech Republic, Sweden, Luxembourg and France. However, a subsidiary of the US-American Hydromine Group is pursuing the active SMR development in Luxembourg. A concept described as SMR is being developed by a consortium in Italy known as IRIS (International Reactor Innovative and Secure), but its capacity is set to be 335 MWe, which is outside the narrower definition of a SMR with an electrical output of less than or equal to 300 MWe.
For so-called passive countries, which are seeking to import SMRs, it is difficult to objectively assess how seriously and credibly cooperation agreements are being pursued because of the available data. Some EU countries have definitely indicated their interest in SMRs. However, only in Estonia definite agreements to import SMRs have been signed. The Fermi Energia company there has signed cooperation agreements with Fortum, Tractebel and Vattenfall (Sweden) with the aim of building and operating SMR reactors in Estonia.
Many unresolved questions still have to be resolved before SMRs can be built in an EU member state. They range from matters of safety, transportation or decommissioning to issues related to storage and disposal of radioactive waste and even new questions that arise for the responsible regulatory authorities.

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 conventional nuclear power plants with a larger electrical output, as they have a lower radioactive inventory and make greater use of passive safety systems. In the light of this, various SMR concepts postulate 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 a SMR automatically has an increased safety level is not proven. The safety of a specific reactor unit depends on the safety-related properties of the individual reactor and its functional effectiveness and must be carefully analysed – taking into account the possible range of events or incidents. 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 a 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 a 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 a SMR was delivered by one country, where the SMR was manufactured, to another country, where it will be used. This will be particularly important if the "user country" is a newcomer in nuclear terms. When drawing up or adapting the regulations, it is not only necessary to cover the central issues of the design and safe operations for a 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).

The ideas postulated for SMRs regarding their contribution to combating the dangers of climate change and their lower costs and shorter construction times must be viewed very critically.

Sources:
(Pistner et al., 2021), (SMR Regulators' Forum, 2018),
(SMR Regulators' Forum, 2019), (IAEA, 2020c), (BASE, 2021)

No. 30

Source:
A 3.2.1, p. 38
Reference text:
However, despite these additional costs, lifetime extension of existing plants remains an economically very attractive option and one that is already implemented or planned in several EU Member States.

Scientific evaluation:
Any new construction of nuclear power plants has become too expensive as a result of continually low raw material prices, the constant development of renewable energy sources and the stipulated onward development of safety technology. As the decommissioning, dismantling and disposal of existing nuclear power plants is very protracted and expensive, extending the operating life of nuclear power plants appears an attractive possibility. However, cost criteria then determine what kind of retrofitting work takes place if the lifetime is extended.

Theoretically, retrofitting work provides the regulatory authority with the possibility of demanding safety improvements that are technically possible to a certain degree. However, safety requirements in line with the state of the art of science and technology cannot be fully implemented within the design of old nuclear power plants. Fundamental weak points in the outdated safety concepts cannot be eliminated, as major elements in the safety standards are determined during the design of the nuclear power plant.

The economic sense of extending operating terms is only possible (if at all) on the grounds of the lower safety standards, which apply to nuclear power plants that were put into service before 2014, according to Section 8a of the EU Nuclear Safety Directive. This directive and the relevant extensions to operating terms represent a significant additional risk to nuclear safety in Europe.

Source:
(INRAG, 2021)

No. 31

Source:
A 3.2.1, p. 38-39
Reference text:
Figure 3.2–5 shows the generation costs of different technologies. Considering the existing capacities, nuclear power represents the lowest generation costs in 2030. The cost increases when considering new installed capacities, but nuclear remains competitive and close to the levelised cost of the current power mix.

Scientific evaluation:
The electricity generation costs shown here explicitly ignore additional costs that will accrue, some of them quite considerable, e.g. the costs for disposing of the nuclear waste. The source quoted refers to this situation. The cited comparison of costs therefore provides little, if any information.

Source:
(EC, 2019)

No. 32

Source:
A 3.2.2, p. 39
Reference text:
More importantly, the gaseous diffusion process has been phased out and replaced by the centrifuge enrichment process, which is up to 50 times less energy costly than the gaseous diffusion process.

Scientific evaluation:
The statement in the JRC Report that the gaseous diffusion process for uranium enrichment uses much more energy compared to enrichment using centrifuges is supported by the sources mentioned in 3.2–12 and 3.2–13.
The statement made in the JRC Report about abandoning gaseous diffusion technology is true of the EU. France has now switched uranium enrichment to the centrifuge technology. The Georges Besse I plant, which used the gaseous diffusion technology, operated until May 2012. It was gradually replaced by the Georges Besse II plant. Georges Besse II has been commissioned in April 2011 and uses ultra-centrifugation for uranium enrichment. Apart from France, uranium enrichment plants are still being operated in the EU in Germany (Urenco Deutschland in Gronau) and in the Netherlands (Urenco Nederlands in Almelo) or in Great Britain (Urenco UK in Capenhurst) until the country left the EU [source 3.2–12 in the JRC Report]. All these uranium enrichment plants use centrifuge technology.

Sources:
(ASN, 2020), (URENCO, 2021)

No. 33

Source:
A 3.2.2, pp. 39–40
Reference text:
Figure 3.2–6, from reference [3.2–7], is the result of a secondary research compilation of twenty-one credible sources in which lifecycle GHG emissions of different electricity generation technologies have been assessed.

Scientific evaluation:
The JRC Report has reproduced information from source 3.2–7 in an imprecise and abbreviated form.
Not all 21 publications from the years 1997–2010 were evaluated with regard to nuclear energy for Figure 3.2–6, but just 14. The JRC Report does not mention either that source 3.2–7 lists many factors that contribute to the observed variations in the greenhouse gas emissions that are presented. One important factor according to source 3.2–7 is the different definition of “life cycle” in the publications used. Some of the publications consider waste management and waste treatment in the life cycle, while others do not.

No. 34

Source:
A 3.2.2, pp. 39–40
Reference text:
The figure shows that lifecycle GHG emissions from nuclear energy are among the lowest of all the technologies, comparable with (or slightly greater than) wind and hydroelectricity and lower than solar PV. That this is typical of the results from

other credible LCAs can be seen from references 3.2–8, 9, 10, 11 among many others.

Scientific evaluation:
The information in the JRC Report about solar energy is presented too negatively – further developments and therefore declining greenhouse gas emissions are not mentioned. The statement in the JRC Report that the life cycle-based greenhouse gas emissions from nuclear energy are lower than those for solar power is classified by source 3.2–7. Source 3.2–7 dates back to 2011 and points out that the large variations in greenhouse gas emissions for solar energy are based on the rapid, further developments in solar power units, which have already taken place, and that greenhouse gas emissions from solar power modules will continue to decline through further increases in efficiency and the manufacturing processes. If we also consider source 3.2–11, it is clear that while the median CO_2 emissions caused by solar power are higher than those caused by nuclear energy, but the maximum CO_2 emissions from both technologies are about the same.
The JRC Report also refers to some very special sources to support its statements. Source 3.2–10 selects 26 technologies, which can be classified as "optimistic/realistic" for possible electricity generation sources in 2050 in order to examine the procedures for selecting the environmental impact indicators and the methods for a life cycle assessment (LCA), which have been used for assessment purposes as part of the integrated NEEDS Project. As far as nuclear energy is concerned, source 3.2–10 particularly considers the EPR technology (European Pressurised Reactor) and the EFR technology (European Fast Reactor). Neither technology is yet operating in the EU; source 3.2–10 at least does refer to the uncertainties associated with developing the EFR technology. In addition, source 3.2–10 only refers to offshore wind turbines when talking about wind power. In contrast to the JRC Report, source 3.2–10 does consider the ongoing developments related to solar energy. Figure 4 of source 3.2–10 shows that the greenhouse gas emissions with the EPR technology are about the same as the greenhouse gas emissions from a special solar energy technology, where cadmium telleride is applied to the silicone wafer as an extremely thin coating and which is expected to be available on a building-integrated scale by 2050.

No. 35

Source:
A 3.2.2, p. 40
Reference text:
Lifecycle GHG emissions for the existing French nuclear reactor fleet in 2010, at that time using the gaseous diffusion process supplied by nuclear energy, was assessed to be 5.29 gCO_2-eq/kWh [3.2–8]. Uranium ore grades corresponded to the current production from the mining activities supplying the French fuel cycle, which were all higher than 0.1% [3.2–18]. According to [3.2–8], nuclear power plants (including construction, operation and decommissioning) are responsible for 40% of the lifecycle GHG emissions, uranium mining for 32% and enrichment 12%.

Scientific evaluation:
The information provided here in the JRC Report relates to a special case in France. The information in source 3.2–8 is based on the "twice through cycle" for the fuel, which is normal in France when using nuclear energy. France relies on reprocessing spent fuel elements and reusing the reprocessed uranium and plutonium in MOX fuel elements to generate power.
The JRC Report rightly states that data from 2010 was used in source 3.2–8 when the gaseous diffusion method was still being used in France. However, source 3.2–8 does not hide the fact that the enrichment stage only has small effects on greenhouse gas emissions (0.63 gCO_2-eq/kWhe), as three nuclear reactors are envisaged for providing the power for the enrichment facilities. This effect may

be different in other countries. Source 3.2–8 cites as an example that the total volume for the enrichment stage would increase to 55 gCO_2-eq/ kWhe if all the enriched uranium was supplied by the USEK coal power station. Furthermore, source 3.2–8 makes it clear that the information about greenhouse gas emissions caused by nuclear energy is in the lower range of the usual reference data at 5.29 gCO_2-eq/kWh.

No. 36

Source:
A 3.2.2, p. 40
Reference text:
According to the foregoing, lifecycle GHG emissions from nuclear electricity generation are comfortably within the 100 gCO_2-eq/kWh emissions intensity threshold proposed by the TEG for electricity generation, and will remain so for at least the next 50 years, thereby satisfying the TEG definition for a substantial contribution to climate change mitigation.

Scientific evaluation:
This statement in the JRC Report can easily be misinterpreted. Source 3.2–6 specifies in chapter 4 in terms of criteria 100 gCO_2-eq/kWh as the threshold for CO_2 emissions when generating electricity. However, source 3.2–6 clearly points out that this threshold will be reduced every five years – in line with the political goals of achieving net zero emissions by 2050. The threshold of 100 gCO_2-eq/kWh will therefore not remain constant during the next 50 years. However, this might be deduced from the JRC Report.
The statement in the JRC Report is too optimistic. The JRC Report refers to the extremely low greenhouse gas emissions when generating electricity by nuclear energy (5.29 gCO_2-eq/kWh according to source 3.2–8 or 4.25 gCO_2-eq/kWh according to sources 3.2–10 and 3.2–14) in the previous paragraphs. Together with the increase by 26 gCO_2-eq/kWh if the U_3O_8 content in the mined ore is reduced, the impression is given that there is a large cushion up to the threshold of 100 gCO_2-eq/kWh. The JRC Report does not take into account that, firstly, the threshold will be reduced in the foreseeable future and, secondly, many other studies on the life-cycle-based greenhouse gas emissions when generating electricity with nuclear energy have much higher numerical values. For example, source 3.2–15 quotes a value of 60 kgCO_2-eq/MWh when considering the use of uranium with less U_3O_8 content. Source 3.2–17 cites an average life-cycle-based figure for greenhouse gas emissions of 65 gCO_2-eq/kWh for LWR and HWR. Looking at the range of 10 to 130 gCO_2-eq/kWh quoted in source 3.2–17 the threshold currently suggested by the TEG of 100 gCO_2-eq/kWh has already been exceeded.

No. 37

Source:
A 3.2.4, p. 48–53
Reference text:
Whole section

Scientific evaluation:
The issues of a circular economy and sustainability are the responsibility of the Federal Environment Agency in Germany. In this sense, any assessment regarding the relevance, completeness and correctness of the statements or the need for further observations are far removed from BASE’s expertise.
However, here is some information about aspects that are possibly missing.

No. 38

Source:

A 3.2.4, p. 48

Reference text:

In accordance with article 17 of the Taxonomy Regulation, an economic activity shall be considered to cause significant harm to the transition to a circular economy, including waste prevention and recycling, where:

(i) that activity leads to significant inefficiencies in the use of materials or in the direct or indirect use of natural resources such as non-renewable energy sources, raw materials, water and land at one or more stages of the lifecycle of products, including in terms of durability, reparability, upgradability, reusability or recyclability of products;
(ii) that activity leads to a significant increase in the generation, incineration or disposal of waste, with the exception of the incineration of non-recyclable hazardous waste; or
(iii) the long-term disposal of waste may cause significant and long-term harm to the environment

Scientific evaluation:

Radioactive waste is exclusively considered in terms of quantities, and not even any distinction is made between LILW (low- and intermediate-level waste) and HLW (high- level waste). No consideration is given to the extra work and hazards when handling and disposing of this waste.

No. 39

Source:

A 3.2.4, p. 50

Reference text:

Currently known reserves of uranium, used in the same way, extend this time frame to a few millennia.

Scientific evaluation:

The source used in the JRC Report "[3.2–9]" specifies that current reserves of uranium will be adequate for another 80 years. An extension to millennia is explicitly only mentioned in conjunction with the switch to breeder technology, which does not match the current state of developments (as mentioned in other places in the report too, e.g. p. 35: 89% of the installed capacity and 94% of the reactors being built are LWR; breeder reactors only account for approx. 1% of the installed capacity).

Source:

(Stamford and Azapagic, 2012)

No. 40

Source:

A 3.2.4, p. 50

Reference text:

For nuclear energy, the fact that a proportion of the materials become too activated for reuse is taken into account in the assessment, and this proportion, which is less than 5%, is excluded.

Scientific evaluation:

The assessment of whether it is possible to recycle the materials accruing when nuclear power plants are decommissioned ignores the social acceptance of any further use of these materials. Even disposing of cleared, i. e. non-radioactive waste, can trigger considerable resistance in the local population. The state government in Schleswig-Holstein had to make use of the legal instrument of

court allocation in order to guarantee the disposal of waste.
Even if reuse is technically possible, macrosocial aspects could prevent this.

Source:
(State government of Schleswig-Holstein, 2021)

No. 41

Source:
A 3.2.4, p. 52
Reference text:
Land occupation by offshore wind (Stamford & Azapagic), nuclear and gas are negligible.

Scientific evaluation:
Regarding the issue of land use, from the information given, it is not clear whether influences due to any severe accidents, which can lead to widespread contamination, have been considered.

No. 42

Source:
A 3.2.4, p. 53
Reference text:
Note that some countries (e.g. France) do not consider spent fuel to be waste. Spent fuel comprises large amounts of recoverable uranium and plutonium that can be used in fast breeder reactor fuel. While fast breeder reactors are not deployed yet on a large-scale commercial basis, they are very much an option for the future for some countries, and so the uranium and plutonium within the spent fuel is considered a valuable resource. Poinssot et al [3.2–8] calculates the total amount of radioactive waste requiring geological disposal at about 1.5 m^3/TWhe for the current French nuclear fleet with plutonium recycled once in MOX fuel. This strategy reduces the amount of waste requiring geological disposal, which is almost an order of magnitude less than the amount shown in Figure 3.2–17. This reflects the fact that spent fuel elements (including spent MOX fuel elements) are not included in the waste stream in France.

Scientific evaluation:
The French declaration that does not classify HLW as waste at all is taken over indiscriminately. This provides an incorrect picture of the actual quantities of waste.

A 3.3: Detailed assessment of the impacts of nuclear energy in its various life cycle phases

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No. 43

Source:
A 3.3, from p. 62–167
Reference text:
Whole section

Scientific evaluation:
The report only describes the pure process of manufacturing fuel elements. Transporting enriched uranium hexafluoride to the power plants is not considered.
Measures relevant to decommissioning are not considered.
Incidents can also occur at these facilities. They are not considered either.

No. 44

Source:

A 3.3.1.1, p. 64

Reference text:

In 2018, this 53.500 metric tons of uranium was sufficient to cover the decisive portion of fuel supply needs of the 451 NPP units operated at that time around the world and providing approximately 400 GW electric power […]
In comparison, a coal-fired power plant of 1 GW electric power consumes 9000 metric tons of coal per day!

Scientific evaluation:

Uranium mining causes environmental damage just like coal mining. The JRC Report states this too. It also mentions the possibility of "green" and sustainable mining (cf. no. 50 below).
However, coal mining and uranium mining cannot be compared with each other. The former involves mining hydrocarbons (coal) and the latter ore extraction (uranium). The mining and processing techniques differ significantly. Uranium mining in particular causes radioactive waste and requires significantly more laborious waste management than coal mining.

The fact that the most promising uranium deposits have now been fully exploited and opening new mines and ISL operations (cf. no. 45) are becoming increasingly expensive, because the extracted ore has less and less material suitable for fission, makes the matter even more complicated. 7 kg of fissionable 235uranium can currently be extracted from 10,000 t of uranium ore (Le Monde diplomatique et al., 2019 = Uranatlas). These figures are likely to deteriorate in future and land consumption, CO_2 emissions and mining costs will all increase.

Sources:

(Uranium Mining Industry Info, 2021), (DIIS, 2015)

No. 45

Source:

A 3.3.1.1, p. 65

Reference text:

Chemical leaching is a mining method which is gaining ground gradually: the basic principle of the "in situ leaching" (ISL) method is that a liquid substance containing acidic (sulphuric acid) or alkaline (sodium carbonate) […] .

Scientific evaluation:

The description of in situ leaching (ISL) – also known as in situ recovery (ISR) – is very superficial here and in the following text. The environmental risks such as groundwater contamination are not described in any detail or with case examples. This would be necessary, however, for an in-depth discussion of the EU Taxonomy environmental objective no. 3 "the sustainable use and protection of water and marine resources". Serious environmental incidents such as those in Königstein (Saxony), Stráz pod Ralskem (Czech Republic; Andel and Pribán, 1996) or Devladovo (Ukraine; Molchanov et al. 1995) are not mentioned in the JRC Report.

The superficial treatment of ISL technology in the JRC Report is regrettable, as ISL is described as a beneficial technique in comparison with classic mining, as no large waste tips are created and no widespread open cast mining has to be used either. The JRC Report does admit that the fluids used for leaching can be harmful, but the frequency of any such damage and the actual risk associated with ISL are not explicitly mentioned, proven by examples or quantified. On the contrary: if we just consider Fig. 3.3.1–11 briefly, ISL seems to be a technique that poses almost no risks to the environment. It is true that the critical significance of ISL for groundwater is indicated by a red colour scheme; however, this issue is almost submerged by the other operating aspects of less importance marked in blue.

Sources:
(Andel und Pribán, 1996), (Molchanov et al., 1995)

No. 46

Source:
A 3.3.1.2, p. 67
Reference text:
Figure 3.3.1–8 illustrates the [...] the tailings of the Schlema-Alberoda underground mine [...]. These huge uranium ore tailings [...] have now been removed and the affected area has been completely remediated.

Scientific evaluation:
Wismut GmbH was obliged after German reunification to clean up the mining areas that were owned by SDAG Wismut on 30 May 1990. Most of the decontamination work performed by Wismut GmbH has been funded by taxpayers. The storage structures and their radioactive content will require constant monitoring for many years.

No. 47

Source:
A 3.3.1.2.2 and A 3.3.1.2.3, p. 68–72
Reference text:
Non-radioactive impacts (Kapitel 3.3.1.2.2) vs. Radioactive impacts (Kapitel 3.3.1.2.3)

Scientific evaluation:
The separation of the chapter entitled “Identification of key potential impacts on the environment and human health” into the two subsections “Non-radioactive impacts” and “Radioactive impacts” is not consistently followed. The non-radioactive effects of uranium mining on the environment are compared to those of “conventional” ore mining, particularly at the beginning of subsection 3.3.1.2.2. The (radioactive) contamination of surrounding soil by tip dust is then a topic in the same subsection entitled “Non-radioactive impacts”. Even the tailing pond disaster at Church Rock (New Mexico, USA), which was a significant accident with high knock-on effects within the USA, is not mentioned in the non-radioactive factors, although the radioactive contamination of the surrounding area caused by the dam breach at Church Rock on 16 July 1979 is the main problem.
The paragraph about Church Rock on page 70 (final paragraph in Part A 3.3.1.2.2 and the first paragraph on p. 71) illustrates clearly how the JRC Report may mention the negative consequences of uranium ore mining, but never fully or in relation to the potential violation of the environmental objectives in taxonomy or in line with the “DNSH” criteria. Details about the Church Rock disaster and the effects on the environment, which can still be felt today, and the health of the residents can be found in the SRIC Report (2007) and in Knutson (2021). The JRC Report should take into account this dimension to be able to correctly assess the significance of the individual risks associated with uranium mining.

Sources:
(SRIC, 2007), (Brugge et al., 2007), (Arnold, 2014), (Knutson, 2021)

No. 48

Source:
A 3.3.1.2, p. 78
Reference text:
If radioactive impacts are considered, then uranium mining and milling operations first of all must pay special attention to eliminating the human hazards […]

Scientific evaluation:
The style used to describe the necessary measures to meet environmental standards is problematic. Obvious measures, like those stressed as absolutely necessary in the quotation above, are often mentioned without explaining in any detail how damage to people can be averted, as in the example. At another point, the report states that environmental hazards can be prevented by suitable measures.
It would, however, be more comprehensible to mention specific environmental measures – and also how they can be monitored, which authority is responsible for them and which punishments are due if they are not followed. It is true that the JRC Report mentions that uranium waste tips can be covered with clay and that waste has to be sealed downwards, but it does not explain precisely how successful sealing measures can be completed and which residual risks will remain. Specific examples for successfully designating environmental standards or for successfully completing planning approval procedures etc. are missing too. The same applies in the opposite direction: there are no “best practice examples” or “worst practice examples” either.

No. 49

Source:
A 3.3.1.3, p. 74
Reference text:
e.g. heading for Fig. 3.3.1–13: […] total LC of nuclear energy […]

Scientific evaluation:
This subsection discusses factors that affect the complete nuclear cycle, although chapter 3.3.1 is actually devoted to uranium mining and ore processing. However, the broader view makes sense in order to be able to correctly classify the factors arising from uranium mining and processing ore. This makes it clear that uranium mining has the greatest influence on the environment within the complete nuclear cycle. However, the correct taxonomic conclusions are ultimately not drawn from this fact (cf. the next point no. 50 too).

No. 50

Source:
A 3.3.1.4, p. 76
Reference text:
As mentioned before “green mining” or “sustainable mining” gradually gains ground also in the uranium mining industry. The principles and practices of environmental friendly mining are being promoted by the International Council of Mining and Metals (ICMM). Mining companies that decided to operate as a “sustainable mine” must adhere to the ICMM principles of sustainable development.

Scientific evaluation:
The term “sustainability” is not clearly defined in the “Best Practices” of the ICMM. The report wishes to stand by the definition of the Brundtland Commission, but profits and sustainability have to be reconciled (principle I: considering sustainable development). This therefore gives rise to the question about what sustainability is in a sector that exploits minerals that cannot readily grow again. The debate about this has sparked controversy (e.g. Gorman and Dzombak, 2018;

Lahiry, 2017; Tyson, 2020). Gorman and Dzombak (2018) focus on the need to view sustainability throughout the usage cycle of a mining operation and apply existing environmental rules for sustainability. That sounds like the taxonomy environmental objective no. 4 “Transition to a circular economy, preventing waste and recycling”. Lahiry (2017) calls for strong supervision by government authorities to enforce sustainability and reliable environmental standards. Tyson (2020) emphasises that genuine sustainability cannot naturally be achieved in the mining sector – since it is ultimately a mining activity and not one involving any regrowth. However, a specific type of sustainability for mining can be achieved if ALL the players (or stakeholders) are included in the definition process for sustainability (and its implementation) in a just and fair manner. However, individual players involved in mining activities do not play a role in the JRC Report – apart from the operators. This is particularly true of the indigenous population, although a large number of uranium mines are located on land belonging to indigenous groups (mainly in the USA and Canada, but also in Australia). These people must be granted access to the resources that are necessary for life. They need to be able to express their view about the way that the land where they live is used. Stagl (2020) refers to this in her report on the role of nuclear energy in the light of the EU’s Taxonomy Regulation for the Austrian Federal Ministry for Climate Action, the Environment, Mobility, Innovation and Technology.

The JRC Report does not discuss the role of authorities and government offices when approving uranium mining projects or when examining whether sustainability standards are being followed in the chapter on uranium mining and does not define this role either (not in the chapter mentioned here, Part A 3.3.1.4, nor at a different point in Part A 3.3.1 or Part A 5.5 or in the Annex 4.2 associated with this). However, this would be very important for classifying environmental regulation measures in the sense of EU taxonomy.

Sources:
(Gorman and Dzombak, 2018), (Lahiry, 2017), (Tyson, 2020),
(Le Monde diplomatique et al., 2019), (Stagl, 2020) (DIIS, 2021)

No. 51

Source:
A 3.3.2.2.2, p. 86
Reference text:
short-lived decay products coming from the ^{238}U decay chain.
[…]

Scientific evaluation:
As this involves natural uranium at this stage in the production chain, it is not possible to describe the daughters Pa-231 or Th-230 or Ra-226 as “short-lived” in the transient balance arising from the uranium/radium sequence.

No. 52

Source:
A 3.3.2.2.2, p. 86
Reference text:
The plant personnel may receive direct radiation impacts – through gamma radiation – during handling and/or inspection of the UF_6 storage cylinders. These impacts must be duly monitored and controlled.

Scientific evaluation:
Not exclusively. If there are any leaks in the uranium/radium decay series (within the complete process), exposure to Rn-222 is also possible. The chemical state of the uranium is insignificant in this regard.

No. 53

Source::

A 3.3.2.2.2, p. 86

Reference text:

Calcination gases are treated and filtered to recover uranium and other elements before releasing them to the atmosphere

Scientific evaluation:

It remains unclear whether the Rn-222 is held back during the gas washing process. This is almost impossible technically. There is no mention that significant quantities of radon (as a part of the uranium/radium decay series) are released into the environment.

Source:

(Tetyana and Voitsekhovych, 2013)

No. 54

Source:

A 3.3.2.5.2, p. 89

Reference text:

Short-lived isotopes disappeared from the contaminated calcium fluoride, the uranium can be recovered and the remaining CaF_2 can either be reused or disposed of as technological (non-radioactive) waste.

Scientific evaluation:

Th-230 and Ra-226 are the main nuclides in this waste. They have half-lives of 75,000 years or 1,600 years. CaF_2 cannot be released from supervisory controls under any circumstances.

Source:

(Abdelouas, 2006)

No. 55

Source:

A Table 3.3.2–1., p. 90

Reference text:

Gaseous RA releases ++ Proper handling of UF_6 Only accidental releases cylinders

Scientific evaluation:

The release of Rn-222 from the power plant during normal operations has clearly not been considered within this criterion.

No. 56

Source:

A 3.3.3.2.2, p. 98

Reference text:

As mentioned above, the enrichment process generates large amounts of depleted uranium which can be considered as a by-product for future use or as waste. UF_6 can be stored in steel containers for long periods of time (i. e. for decades), provided that there is a suitable periodic surveillance programme in place to ensure the long-term integrity of the containers. Alternatively it can be “deconverted” to depleted U_3O_8, which is a more stable substance, better suited for storage or disposal, allowing also the recovery of high purity hydrofluoric acid for industrial use. Deconversion can also save a significant amount of uranium mining. Alternatively, the HF is neutralized into CaF_2 for storage or for industrial use.

Scientific evaluation:
It is hard to understand why the deconversion of depleted uranium will significantly reduce the uranium obtained through mining.

The deconversion of depleted uranium involves recirculating the uranium hexafluoride into U_3O_8 and special fluoride gases and anhydrous hydrofluoric acid, for the purpose of reducing the risks of disposing of U_3O_8 and using fluoride compounds commercially.

No. 57

Source:
A 3.3.3.5.1, p. 99
Reference text:
The UF_6 feedstock, the enriched end-product and the remaining depleted uranium (tailings) are all stored in standard transport cylinders. For these cylinders the highest potential risk is represented by those accidents when the integrity of the cylinders is lost. Therefore all UF_6 cylinder handling and storage operations must be conducted in a manner that minimizes the chances of accidents

Scientific evaluation:
Depleted uranium hexafluoride is stored at an open-air storage site next to the uranium enrichment plant at Urenco in Gronau. There were about 22,000 t of uranium hexafluoride (approx. 1850 containers) there on 15 August 2019. This kind of storage requires a high level of integrity in the containers against any damage caused by weather. If this integrity is lost, there is a risk that uranium hexafluoride, which is extremely toxic, will be released.
A more detailed description is necessary here to illustrate which measures should be adopted to prevent any discharge of uranium hexafluoride and guarantee the integrity of the containers. There are also special challenges in protecting the uranium hexafluoride at an open-air storage site.

Sources:
(Manual for Reactor Safety and Radiation Protection (RSH), (2004)
(Manual for Reactor Safety and Radiation Protection (RSH), (1979)

No. 58

Source:
A 3.3.3.3, p. 99
Reference text:
There are no atmospheric or liquid radioactive discharges and no significant amount of solid radioactive waste is produced in any waste category. Note that the depleted uranium is usually not considered as radioactive
waste, because later it is either deconverted to uranium oxide and HF (hydrofluoric acid) or reused again for enrichment.

Scientific evaluation:
The JRC assumes in this statement that UF_6 serves as a “material” for synthesising hydrochloric acid. However, the “removed” $U_3$08 is in fact waste. The uranium is or was used to manufacture trim weights (high density) or armour-piercing ammunition based on the pyrophoric property of uranium. Most of the depleted uranium (>90%), however, cannot be fed back into the reusable material cycle and is intended for disposal. In the light of this, the statement about “no waste” is at least not complete.

Sources:
(Croff et al., 2000), (Priest, 2001), (Betti, 2003), (Abu-Quare and Abou-Donia, 2002)

No. 59

Source:
A 3.3.3.5.2, p. 100
Reference text:
Although the specific activity of the materials handled during the enrichment process is usually low, these substances represent a threat to human health if inhaled or ingested. Therefore the enrichment technology has to apply strict health protection and worker's safety measures during the whole process to avoid such effects. If radiological environmental impacts are considered, then prevention of water and air pollution by radioactive materials is the main protection measure to avoid the emergence of such effects.

Scientific evaluation:
No incidents are considered – because radioactive materials may be released when operating a uranium enrichment plant.

Source:
(Manual for Reactor Safety and Radiation Protection (RSH), 2004)

No. 60

Source:
A 3.3.4.2, p.103
Reference text:
Since the fabrication of fuel is done at high-temperatures, the fuel production is an energy-intensive process. However, the required energy relative to the amount of energy generated from the fuel is very small.

Scientific evaluation:
If the energy required to produce the complete fuel element is considered, which takes into account extraction, purification, alloying, rolling, drawing, annealing and welding the cladding tube made of zirconium alloys as well as the production of all the fuel element structural parts made of chrome-plated steel, the margin becomes much smaller. No detailed energy expenditure analysis was performed for this expert report. The situation is compounded by the fact that the metal parts of the fuel element (approx. 350 kg) have to be disposed of as HLW, as well as the fuel itself. It is not possible to feed this back into the material cycle. The lower the final burnup of the fuel element and the electrical degree of efficiency at the power plant, the less "positive" the energy balance is.

"To meet current industry demands, 10 to 15 million feet/year (3 to 4 1/2 million m/yr) of cladding must be manufactured. Increased complexity in manufacturing a given cladding design will tend to increase the cost of the cladding and increase the cost of fuel operation." (Lahoda and Franceschini, 2011)

Source:
(Lahoda and Franceschini, 2011)

No. 61

Source:
A 3.3.4.4, p. 105
Reference text:
Nuclear installations, such as fuel fabrication plants, are subjected to periodic controls, audits and environmental monitoring. Controls and continuous improvements of processes and operational practices further reduce the potential impacts.

Scientific evaluation:
Incidents or accidents may occur when operating fuel element factories. Criticality accidents are possible too. This may lead to the uncontrolled release of radioactivity or other toxic substances (HF_6).

A detailed description is required here.

Source:
(Manual for Reactor Safety and Radiation Protection (RSH), 1997a)

No. 62

Source:
A 3.3.5.1.2, p. 106
Reference text:
Its main potential can be realised by future fast neutron reactors in which the predominantly fertile content of the RepU can be transformed into fissile isotopes and burned in the same reactors. If fast neutron reactors are used with full recycling of plutonium and uranium, current uranium reserves would permit at least 5 000 years of operation at present global levels of nuclear power generation.

Text in footnote 61, p. 106:
“A second recycling in LWRs is feasible, but multiple recycling of plutonium in present day LWRs is limited as the fraction of fissile plutonium isotopes decreases at each
recycling”

Scientific evaluation:
Two of the expert reports commissioned by BASE on the subjects of “Partitioning and Transmutation” and “Small Modular Reactors” have shown that any further use of recycled uranium and plutonium causes more unresolved problems (risks).

The statement made in the JRC Report must therefore be questioned. Cf. also footnote 61 in the report.

Sources:
(BASE, 2021), (Friess et al. 2021)

No. 63

Source:
A 3.3.5.1.3, p.107
Reference text:
“In comparison to the open cycle, a partially closed cycle [Anm.: Einfache Wiederaufbereitung] is not expected to give a major reduction of the footprint of a geological repository, as there will be a need to also dispose of the spent recycled MOX fuel elements. For a fully closed cycle, with total recycling of the plutonium and uranium, the needed repository size for the high level waste is reduced by 40% [3.3.5-3].”

Scientific evaluation:
It is unclear whether the size refers to the area or the volume. The statement seems to contradict the statement in 3.3.5.2.

The statement is made in this section that the necessary energy specific volume for HLW when using simple reprocessing declines from 1.17 to 0.36 m^3/TWh in contrast with an open cycle (-69%).

It is not clear why greater repository space is necessary for HLW if the waste is recirculated on several occasions than with simple reprocessing.

No. 64

Source:

A 3.3.5.1.3, p. 107

Reference text:

[...] reprocessing brings benefits in terms of the quantities, heat load and radiotoxicity of radioactive wastes requiring geological disposal.

[...] In comparison to the open cycle, a partially closed cycle is not expected to give a major reduction of the footprint of a geological repository,[...]

Scientific evaluation:

Cf. the previous statement no. 63.

Source:

Cf. sources for 62

No. 65

Source:

A 3.3.5.1.4, p. 108

Reference text:

Figure 3.3.5-1

Scientific evaluation:

The graphic shows that the costs of waste management with an “all fast neutron reactor strategy” are negligible. The reduction of these costs compared to an open cycle cannot be understood on the basis of the JRC Report or the source that is used. The source states that if a closed fuel cycle is used with transmutation, the volume of the repository can be reduced by 70% (p. 23); however, the operating time for the disposal site also increases (80–100 years compared to 30–60 years; pages 14/15).

Please note: in my understanding of the “do no significant harm” criteria, economic aspects are not relevant. In this respect, this paragraph is probably irrelevant.

Source:

(EC-JRC, 2014)

No. 66

Source:

A 3.3.5.1.6, p. 110

Reference text:

Shearing of the fuel pins, as well as dissolution of the fuel in the nitric acid, release gaseous fission products including the noble gases krypton (Kr) and xenon (Xe), as well as iodine (I)70 and carbon-14 (14C) in the form of CO_2. The gas stream is scrubbed prior to release and ensures that statutory emission limits are respected.

The noble gases krypton and xenon are released to the environment. They do not contribute significantly to the radiation dose of the workers or the public. The total radiation doses to members of the public from reprocessing operations in Europe are very low, as will be shown in Chapter 3.3.5.2.1, below (see in particular Figures 3.3.5-6 and 3.3.5-7).

Scientific evaluation:

Marginal note: it is unclear why there is no further discussion about iodine nuclides and C-14. The authors point out in Figure 3.3.5-6 that C-14 accounts for about 60% of the share of the dose.

No. 67

Source:

3.3.5.2.1, p. 110, 116

Reference text:

"For comparison, about 40 PBq of 137Cs was released to the marine environment from the Sellafield and Cap de la Hague reprocessing plants, the majority in the 1970s and early 1980s."

Scientific evaluation:

Whether accumulated activities of more than 40 PBq are small amounts is debatable.

Cf.: Chernobyl emitted 16 PBq of Cs-137.

No. 68

Source:

A 3.3.5.1.5, p. 109

Reference text:

It is of note that the plutonium discharged from commercial nuclear power plants is of poor quality in respect of fabrication of efficient atomic weapons due to its isotopic composition [68]. The plutonium is nevertheless submitted to all applicable international control measures; the reasoning is that even low grade materials could be of interest

Scientific evaluation:

There is an extremely abbreviated presentation of the technical nuclear security aspects of the interim storage or nuclear fuels in the JRC Report.
As an intelligent counterparty must be assumed for technical protection issues, determining a risk for the population here is fundamentally different than in the field of safety. In order to maintain an appropriate degree of safety for the population in security issues, it is not only essential for the party that is responsible for protection to pay attention to scientific and technical findings, but also to scientific and technical findings from a potential counterparty. The observations made in this regard must be translated into estimates about the current risk situation and they need to be constantly updated. Particularly in the field of interim storage, because of the assumed storage periods lasting many years, statements about the future effectiveness of protection measures can only be made to a limited degree. It is true that a framework is being defined through international agreements and requirements (CPPNM, Security Series), but it can be assumed that permanent protection cannot be guaranteed on this basis. As no unlimited statement about protection can be made for the reasons outlined here, an abbreviated consideration, as in the specified chapter, does not seem adequate to do full justice to the varied and complex scenarios and the associated dangers caused by any misuse of radioactive material.

Furthermore, it should be noted that the nuclide composition of plutonium from power reactors enables military use in the form of nuclear weapons.

Source:

(BMU, 2012)

No. 69

Source:

A 3.3.5.2.1, p. 113

Reference text:

High-level waste (HLW), in the case of the twice-through cycle, is only produced by the spent fuel reprocessing operations. It includes the fission products and minor actinides which are vitrified and stored in canisters for final disposal. Compared to the open cycle, in which fuel elements are encapsulated for disposal without reprocessing, the total volume of HLW is reduced considerably [72].

In France, HLW and ILW-LL are intended for disposal in geological repositories. The combined volume of thesetwo categories of waste for the open and twice-through fuel cycles are as follows:
- Open fuel cycle: 1.49 m^3/TWhe (0.32 m^3/TWhe ILW-LL & 1.17 m^3/TWhe HLW)
- Twice-through: 1.53 m^3/TWhe (1.18 m^3/TWhe ILW-LL & 0.36 m^3/TWhe HLW)

It can be seen that the total volume of waste to be disposed of in a geological repository is not very different for the two fuel cycle options. However, HLW requires a greater excavated volume and surface area of geological repository than ILW-LL and also contributes more to the long-term radiotoxicity. As a result, according to [3.3.5–9], the estimated repository volume is 3.4 times higher for the open fuel cycle compared to the twice-through cycle.

Scientific evaluation:
The source forming the basis for this statement seems to simply feed in vitrified waste and process waste for disposal if reprocessing is used. The spent MOX fuel elements and fairly large amounts of uranium are simply put into “storage” without any explanation about what should then happen (Poinssot et al., 2014, p. 200). In this sense, a comparison is made here where considerable amounts of waste are not considered at all if reprocessing is used. The JRC Report explains that if this was considered, the savings would probably not be relevant (p. 113 – footnote 72).

Source:
(Poinssot et al., 2014)

No. 70

Source:
A Figure 3.3.5–6., p.114
Reference text:
It can be seen that while 85Kr is responsible for almost 90% of radiological releases in (kBq/kWhe) from the reprocessing stage, it contributes less than 15% to the dose (in Sv) to the public. Carbon-14 is released in much smaller quantities, but contributes more than 50% to the public dose.

Scientific evaluation:
The two nuclides discussed are beta emitters that are inert and are not reabsorbed (Kr-85) or are caused in relatively large quantities by cosmic radiation (C-14). The Figure is misleading. The greatest exposure may come from the two nuclides, but they are less harmful in comparison with the other nuclides that have improved biological availability (e.g. Sr- 90, Cs-137, I-129, Ru-106). The consequences of any intake of the nuclides are drastically different to any external exposure. This is particularly dramatic in the case of the alpha emitters Am-241 and Pu-239, which already account for 3–5%.

No. 71

Source:
A 3.3.5.2.1, p. 115
Reference text:
Figure 3.3.5.7

Scientific evaluation:
The figure presents the individual dose per generated GWa for various sources (mining, reprocessing, nuclear power stations). The doses shown here are only

relatively suitable, to compare the effects of reprocessing plants with those of mining activities and operating reactors. The background to this is that no consideration is given to the fact that some nuclear power plants do not use any MOX fuels and therefore no reprocessing is required.
It would be more appropriate here if the focus was simply on the amount of electricity that was made available with the aid of MOX fuels.

No. 72

Source:
A 3.3.5.2.2, p. 117
Reference text:
Other solids: after the shearing and dissolution of the fuel rods, the separated metallic structural materials and claddings are compacted and put into waste drums. This waste is classified as ILW-LL.

A comparative study of the once-through cycle (OTC) with the twice-through cycle (TTC; nuclear fuel being reprocessed once) concluded that the geological deep repository (GDR) volume needed for the OTC is about 3.4 times higher than the GDR volume needed for the TTC. This is mainly explained by the lower HLW volume in the TTC (see [3.3.5–9] for details).

Scientific evaluation:
Cf. commentary on no. 69 regarding p. 113. The reduction in the repository volume does not result from reducing the volume, but from the fact that some elements of the waste are not considered.

It is not only necessary to consider the volume of the waste, but particularly its decay heat when determining the size of any repository.

No. 73

Source:
A 3.3.5.3, p. 118
Reference text:
The construction, operation and decommissioning of a reprocessing plant can potentially have significant effects on the environment and therefore the following environmental EU legislation is relevant in the case of new projects, or changes to existing projects, [...]

Scientific evaluation:
Aspects of decommissioning and dismantling are not considered to the necessary degree.

No. 74

Source:
A 3.3.5.5, p. 119
Reference text:
In the light of the above analysis it can be concluded that industrial activities associated with reprocessing of spent nuclear fuel do not represent significant harm to human health or to the environment. They do not represent significant harm to any of the TEG objectives, provided that the associated industrial activities satisfy appropriate Technical Screening Criteria.

Scientific evaluation:
It is striking that only emissions from normal operations (both from reprocessing and nuclear power plants) are considered. No estimate is made about how great the risk of a disaster is.

Emissions during the dismantling phase are not considered either.

It is unclear whether this is relevant at all within the methodology.

No. 75

Source:
A 3.3.6.2, p. 122
Reference text:
Due to its higher radiotoxic effects, fabrication of MOX fuels requires strict working conditions, stricter than UO_2. In the production facility three barriers are present:

- The under-pressured glove boxes, to confine the material and avoid contamnation. In addition, lead-glass shielding reduces the radiation dose. The air from the glove box is filtered with high efficiency.
- The under-pressure laboratory, in which an eventual contamination can be contained. Again the air from the laboratory is filtered with high efficiency.
- The reinforced building to protect the installation from external influences.

The potential impacts of MOX fabrication are not different from those of UO_2 fuel listed in Chapter 3.3.4,but the higher radiotoxicity of plutonium translates into smaller quantities, which can be processed in a single batch.

Scientific evaluation:
There is no description of the measures needed to prevent criticality.

Source:
(Manual for Reactor Safety and Radiation Protection (RSH), 1997b)

No. 76

Source:
A 3.3.7, p. 123
Reference text:
The power generation phase includes the construction, operation and decommissioning of nuclear power plants.

Scientific evaluation:
Assigning the decommissioning of nuclear power plants to a general phase of power generation is factually incorrect, as a power station consumes energy when being decommissioned. The report then correctly distinguishes between operations and decommissioning. However, ambiguities remain in certain cases (cf. nos. 97 and 141 too).

No. 77

Source:
A 3.3.7.1.2, p. 125
Reference text:
Most of the potential environmental impacts of NPP operation are related either to radioactive emissions or to the use of cooling water.

Scientific evaluation:
The report simply considers “normal NPP operations”. However, it does not deal with accident scenarios. The same is true for decommissioning. Any comprehensive assessment of using nuclear energy would have to include an evaluation of the risks.

No. 78

Source:
A 3.3.7.1.2, p. 125
Reference text:
Most of the potential environmental impacts of NPP operation are related either to radioactive emissions or to the use of cooling water.

Scientific evaluation:
When operating nuclear power plants, incidents or severe accidents can also lead to significantly greater effects on the environment beyond the potential effects on the environment outlined here caused by the controlled discharge of radioactive materials or through cooling water; this is particularly true for any uncontrolled release of radioactive materials. The nuclear regulatory framework envisages a defence-in-depth concept (WENRA, 2014; BMUB, 2015). These possible releases and the associated effects on the environment, however, are not considered here and need to be added to any assessment of the “do no significant harm” criteria.

Sources:
(WENRA, 2014), (BMUB, 2015)

No. 79

Source:
A 3.3.7.1.2, p. 125
Reference text:
In either case, most radionuclides remain within the structural materials (and will be later treated as solid waste during the decommissioning phase) or can be removed by the waste management systems of the nuclear plants, so that the radioactivity released to the environment during normal operation is minimised, and in any case below the authorised limits.

Scientific evaluation:
Even during normal operations at nuclear power plants, some radioactive materials may be discharged into the surrounding area during special occurrences or events and they may lead to the limits set by the authorities being exceeded. It is true, for example, that the German regulatory framework (BMUB, 2015) requires that any discharge of radioactive materials into air or water must take place in a controlled way along the discharge paths envisaged for this at safety levels 1 and 2 and, considering all the circumstances in the individual case, must be kept as low as possible, below the limits in the Radiation Protection Ordinance; however, it is impossible to categorically rule out any breach of the limits set by the authorities. This is incorrectly presented in the JRC Report using the words “in any case below the authorised limits”. More information needs to be added regarding possible breaches of limits set by the authorities when assessing the “do no significant harm” criteria.

Source:
(BMUB, 2015)

No. 80

Source:
A 3.3.7.1.3, p. 128
Reference text:
The great majority of structures, systems and components (SSCs) in a nuclear power plant are replaceable. Some may be replaced routinely during normal maintenance procedures. The replacement of others may involve significant investment and extended plant outages. For the purposes of managing the condition of the plant, the replaceable SSCs can be classified as “critical” or “non-critical” for continued safe and efficient operation of the plant.

Non-critical SSCs are those that can be allowed to fail without causing concerns for safety or reliability of the plant. In most cases, they can simply be replaced or repaired when a fault is detected. Critical SSCs, on the other hand, include those that would cause safety or reliability issues if they were to fail. Preventive and predictive maintenance programmes are designed to ensure that such SSCs are replaced or repaired long before there is a significant risk of their failure.

Scientific evaluation:
Even purely operational components, which do not have any safety function, can indirectly affect the safety of a plant.

Any malfunction of operating components may, for example, be the starting point for sequences of events, for which safety systems would need to be added to control them. In terms of probability, any increase in the unreliability of operating components may increase the risk that the unit poses.

This is also reflected in the concept of graduated safety levels (Safety Requirements for Nuclear Power Stations 2015, Section 2.1 (1)). Even at safety level 1 (normal operations), facilities and measures are envisaged to "prevent incidents from occurring".

Accordingly, the influence of operating components should not be omitted when considering extensions to operating terms. Consequently, these components are also modelled in probabilistic safety analyses and their influence is included.

Source:
(BMUB, 2015)

No. 81

Source:
A 3.3.7.1.3, p. 128
Reference text:
The condition of other systems, structures and components can be ensured by proper ageing management (including inspection, monitoring, maintenance and repair or replacement).

Scientific evaluation:
In the whole chapter 3.3.7.1.3 about lifetime extensions or long-term operations for nuclear power plants, only the technical aspects are considered, particularly structures, systems and components. Reference is also made to the ageing management. The important non-technical aspects, which go beyond the technical aspects, are, however, omitted. For example, the safety reference level used by WENRA points out that there must be a "long-term staffing plan for activities that are important to safety" (WENRA, 2014). The German regulatory framework also demand consideration be given to non-technical aspects, particularly in ageing managing, such as the qualifications and skills and preservation of know-how among personnel (KTA, 2017a, in connection with KTA, 2017b).

Overall, the non-technical aspects of a lifetime extension or long-term operations are not considered in the complete section. More information needs to be added in order to assess the "do no significant harm" criteria.

Sources:
(WENRA, 2014), (KTA, 2017a), (KTA, 2017b)

No. 82

Source:
A 3.3.7.1.4, p. 129
Reference text:
There are three main strategies for decommissioning of nuclear facilities: immediate dismantling, deferred dismantling, also called safe enclosure, and entombment. In the first case, a facility is dismantled right after its shutdown. In the second case, the facility is kept in a state of safe enclosure for several decades followed by dismantling. In the third case, the facility is encapsulated and kept isolated until the radionuclides decay to levels that allow release from nuclear regulatory control. The present trend is in favour of the immediate dismantling.

Scientific evaluation:
“Entombment” according to the IAEA is not one of the decommissioning strategies (e.g. IAEA GSR Part 6), but is only considered as an exception (e.g. after accidents). The description that the end of “entombment” means removal from supervision under the Atomic Energy Act is misleading. In fact, “entombment” rather resembles a permanent local disposal of radioactive waste.

Source:
(IAEA, 2014a)

No. 83

Source:
A 3.3.7.1.4, p. 129
Reference text:
“Green field” (or "unrestricted use"): the site hosting the decommissioned plant is released free of any constraints linked to the past nuclear activity after it has been cleaned from any trace of artificial radioactivity and eventually restored to the previous conditions

Scientific evaluation:
The statement “[…] after it has been cleaned from any trace of artificial radioactivity […] ” is incorrect. When dismissing plant sites from supervision under the Atomic Energy Act, clearance levels are normally set and the measurements must be verifiably lower than them. Then any further use of the plant site is quite safe from a radiological point of view. That cannot be equated with the elimination of “any trace of artificial radioactivity”, as the report states.

Source:
The process of clearance in Germany is regulated in the Ordinance on Radiation Protection (StrlSchV); the discharge figures are found in Table 1 of Annex 4.

No. 84

Source:
A 3.3.7.1.4, pp. 129–130
Reference text:
The main steps of the decommissioning process (see figure) are: […]

Scientific evaluation:
The following list of the main stages in the decommissioning process does not explicitly mention the “removing the nuclear fuel from the plant” or “interim storage for the radioactive waste” stages.

No. 85

Source:
A 3.3.7.2.2, p. 135
Reference text:
The following table shows the radioactivity released by nuclear plants through liquid and gaseous releases during normal operation, broken down by reactor technology. […]

As far as the effect on human health is concerned, the impact of these releases is better measured in terms of individual or collective doses, as this effect depends not only on the radioactivity level, but also on the physical and chemical form of the radioisotope involved.

The individual dose to the public, normalised to the unit of electricity produced and considered for a characteristic individual (living at 5 km from the point of discharge and with the typical food and behavioural patterns in the region) has been estimated to be 1.3·10–3 mSv/(GWa) [3.3.7–40] in Europe[84], a value much lower than the reference value for effective dose for public exposure of 1 mSv/year used by the international safety standards (i. e.: IAEA GSR Part 3).

[84] Differing values across continents reflect the different proportion of reactor types in each region, as well as differences in food habits. Values estimated by [3.3.7–40] for all other areas are lower than for Europe.

Scientific evaluation:
When operating nuclear power plants, incidents or severe accidents may cause uncontrolled release into the air or water. These releases can then cause individual doses for people in the population, which are several magnitudes higher than the specified figures, even if emergency protection measures are adopted immediately. For example, the JRC Report also lists the doses quoted in GSR Part 3 IAEA of 20–100 mSv as a reference level (IAEA, 2014b). This aspect of possible higher individual doses is not considered here and should be added when assessing the “do not significant harm” criteria.

Source:
(IAEA, 2014b)

No. 86

Source:
A 3.3.7.2.4, p. 139
Reference text:
Non-radiological impacts
The non-radioactive impacts of decommissioning can be considered similar to the conventional construction/demolition activities, and in particular they include:

- Release of gaseous and liquid effluents;
- Acoustic emissions;
- Waste production;
- Increase induced in traffic.

Scientific evaluation:
The aspect of energy consumption should be mentioned here – as specified in section NPP construction on p. 132:
“Impacts related to the electricity and fuel consumption during the decommissioning” (quotation from the JRC Report)

No. 87

Source:
A 3.3.7.2.4, p. 139
Reference text:
Due to these considerations the attitude has changed in recent decades and now the preferred strategy is immediate decommissioning after shut-down [3.3.7–28].

Scientific evaluation:
Any general, global abandonment of the “deferred decommissioning” strategy cannot be deduced from the source specified in the report [3.3.7–28]. On the contrary, the source cites many examples where “deferred decommissioning” has been used and the relevant arguments of both choices of a decommissioning strategy are discussed. Having said this, the IAEA describes immediate decommissioning as the preferable strategy in GSR Part 6, which governs decommissioning (IAEA, 2014a).

Sources:
(IAEA, 2018), (IAEA, 2014a)

No. 88

Source:
A 3.3.7.2.4, p. 140
Reference text:
Figure 3.3.7–8. Quantities of materials from decommissioning in Germany;
Source: [3.3.7–48]

Scientific evaluation:
The Figures shown are not found in the source cited here [3.3.7–48]. On the contrary, the Figures have been taken from the GRS brochure, GRS-S-58. This GRS brochure is listed in a footnote on p. 139, but not in the bibliography.

Sources:
[3.3.7–48] ARTEMIS peer-review report – Germany, 2019

Footnote on p. 139: Decommissioning of Nuclear Facilities,
GRS-S-58, 2nd edition (2017), figures cf. Fig. 31 und Fig. 32.

No. 89

Source:
A 3.3.7.2.4, p. 140
Reference text:
Discharge limits for the decommissioning phase are generally reduced to the level of radiological non-relevance (de minimis dose). This means that the sum of authorised discharges (gaseous and liquid) should not produce the effective dose to any individual member of the public superior to 10 µSv in a year (trivial dose that represents a level of risk which is generally accepted as being of no significance to an individual, or in the case of a population, of no significance to society).

Scientific evaluation:
The dose limit of 10 µSv per annum, which is quoted here, for discharges (gaseous and liquid) is incorrect in this context. On the contrary, this figure relates to dismissing materials from supervision under the Atomic Energy Act, cf. e.g. directive 2013/59/Euratom. The dose limits for discharges are normally higher, e.g. the maximum allowed dose limit for the effective dose for radioactive materials due to exposure for individuals in the population caused by discharges into air and water is 0.3 millisieverts (mSv) per calendar year (cf. Para. 99 Sec. 1 of the Ordinance on Radiation Protection [StrlSchV]).

Source:
Directive 2013/59/EURATOM

No. 90

Source:
A 3.3.7.2.4, p. 141
Reference text:
[…] Moderate quantities of intermediate level waste might come from the most activated parts of the reactor (such as internals of the vessel and biological shield), whereas generally no HLW is generated in this step, since spent fuel is removed from the plant before starting the decommissioning.

Scientific evaluation:
Dismantling also may be licensed in Germany, when fuel elements are still in the plant (fuel elements in the fuel element pond).

No. 91

Source:
A 3.3.7.3, p. 143
Reference text:
Table 3.3.7-6. Environmental impacts from NPP phases according to different sources

Scientific evaluation:
The sources used are not mentioned.

No. 92

Source:
A 3.3.7.4, p. 144
Reference text:
The most relevant international treaties and agreements for nuclear power plants are the following:

- Convention on Nuclear Safety, adopted in Vienna in 1994, entered into force in 1996, signed by 89 Contracting Parties (current status)

[…]

Scientific evaluation:
The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management was clearly not used as the basis here (missing from the list), although it is extremely relevant for decommissioning.

Source:
(IAEA, 1997)

Nr. 93

Source:
A 3.3.7.5.2, p. 146
Reference text:
(d) Atmospheric and liquid radioactive effluents
Radioactive releases to the atmosphere are subject to legal limits, set in agreement with international guidance so that radiation will not result in any harm for the population or the environment. Utilities continuously monitor the effluents and report the data obtained to the regulatory authority.

Scientific evaluation:
When operating nuclear power plants, incidents or severe accidents can cause uncontrolled release into the air or water and they can cause the legal limits to be exceeded (IAEA, 2014b). This could be associated with harming the population or damaging the environment. This aspect is not considered here and should be added when assessing the "do no significant harm" criteria.

Source:
(IAEA, 2014b)

Nr. 94

Source:
A 3.3.7.6, p. 148
Reference text:
[...] For this reason, the life extension of NPPs tends to reduce the environmental load, as the impacts from construction and decommissioning can be distributed over a larger lifetime production, with only marginal increases due to the investments associated to the life extension process.

Source:
A 3.3.7.2.3, p. 138
Reference text:
[...] This clearly results from the additional energy that will be generated by the plant, while the construction activities and materials, and the decommissioning waste, will increase only marginally, due only to the need to replace some SCs for the life extension period.

Scientific evaluation:
It is unclear whether this statement takes into account the fact that when extending operation of nuclear power plants for an additional period of time, there tends to be greater activation and contamination in the power plant (e.g. possibly through damage to the fuel elements). When the plant is shut down, the expenditure for decontamination and radiological characterisation is then higher and more radioactive waste is created. Was this considered or assessed during this review?

No. 95

Source:
A 3.3.7.6, p. 148
Reference text:
The results of the LCA surveyed show that the operation of the plants represent a limited fraction of the total environmental impact. For this reason, the life extension of NPPs tends to reduce the environmental load, as the impacts from construction and decommissioning can be distributed over a larger lifetime production, with only marginal increases due to the investments associated to the life extension process.

Scientific evaluation:
By lifetime extension and the increasing ageing effects associated with this, the probability of incidents or severe accidents increases significantly (INRAG, 2021). This also increases potential effects on the environment. Appropriate measures have to be adopted to prevent such potential negative effects, such as ageing management programmes and/or retrofitting. A review of whether it is possible to extend the licence for the operating life is then the responsibility of the individual EU member states. This is associated with the results of periodic safety reviews in many countries, for example. These aspects are not considered here and should be added to any assessment of the "do no significant harm" criteria.

Source:
(INRAG, 2021)

No. 96

Source:
A 3.3.7.6, p. 148

Reference text:
In the light of the above analysis it can be concluded that NPP operation activities[97] do not represent unavertable harm to human health or to the environment. They do not represent significant harm to any of the TEG objectives, provided that the associated industrial activities satisfy appropriate Technical Screening Criteria.

[97] Note that the "NPP operation" lifecycle phase includes the construction, operation and decommissioning of nuclear power plants, as well as the long-term operation of these facilities

Scientific evaluation:
When operating nuclear power plants (in this paragraph "operating" is a general term for erection, operating and decommissioning), incidents or severe accidents may occur. The nuclear regulatory framework envisages a defence-in-depth concept to prevent such incidents or severe accidents (WENRA, 2014) (BMUB, 2015). Chapter 3.5 of the JRC Report admits that such accidents may occur. However, this is only mentioned briefly and not examined in detail. Uncontrolled release of radioactive substances can cause considerable effects on the environment, for example. A detailed consideration of incidents and severe accidents should be added to any assessment of the "do no significant harm" criteria.

Sources:
(WENRA, 2014), (BMUB, 2015)

No. 97

Source:
A 3.3.7.6, p. 149

Reference text:
Table 3.3.7–7. Importance of NPP operation impacts on the TEG environmental objectives

Scientific evaluation:
It is not clear in this table whether the phrase "NPP operation impact" also includes decommissioning (cf. no. 43). The footnote on p. 148 suggests this; if so, the table's title needs to be more precise: Importance of NPP life cycle effects on the TEG's environmental objectives.

No. 98

Source:
A 3.3.8.1, p. 155

Reference text:
The typical envisaged duration of interim storage is a few decades. For instance, interim storage of spent fuel dual purpose casks in Germany is licensed for 40 years; the interim storage duration will have to be extended since operation licences of the storage facilities will expire between 2034 and 2047, and the disposal repository will not be available before 2050. In Spain, the interim storage facilities are licensed for 20 years. In France, vitrified HLW packages will require a minimum storage time of 60 to 70 years, depending on the specific decay heat [3.3.8–6].

Scientific evaluation:
Any time delay in the provision of a repository has a direct influence on interim storage. A number of issues such as the ageing of materials and the integrity of casks need to be clarified in conjunction with the possible renewal of licences for interim storage and the casks. Alongside the aspects already mentioned, any interim storage that goes beyond what has been planned also represents a challenge with regard to securing the units and facilities storing the radioactive waste.

No. 99

Source:
A 3.3.8.2, p. 155
Reference text:
The typology of the facilities associated with the back end of the nuclear fuel cycle includes the interim storage facility, the spent fuel encapsulation plant and the geologic repository for final disposal. [...]
The applicant must demonstrate that the facility complies with the relevant regulatory requirements set by the national safety authority and that it will not generate any significant environmental or health consequences in the future.

Scientific evaluation:
According to the statements mentioned, the applicant has to prove that the nuclear facilty (including repositories) satisfy the regulatory requirements and no harmful environmental or health consequences will arise from the facility in future. The second part of the statement in particular evades the need to provide evidence about a repository at least in one aspect – human intrusion (HI) into a repository. There is general agreement that it is impossible to forecast human behaviour and actions, including any intrusion into a repository (NAS, 1995; Seitz, 2016). This statement is crucial for a number of other general conditions or decisions when considering HI and verifying safety. On the basis of this statement, for example, any unintentional human intrusion into a repository cannot be ruled out if knowledge about the geographical site has been lost (ICRP, 2013). As a consequence of this, it is impossible to rule out contamination of the environment if human intrusion takes place during the post-closure phase of a repository (ICRP, 2013). This aspect applies to each disposal site – and particularly for near-surface ones (IAEA, 2012), where the number of possibilities for intrusion are much higher than with deep geological repositories. However, the isolation periods considered here are much lower because of the waste spectrum envisaged for near-surface repositories.

Sources:
(NAS, 1995), (Seitz et al., 2016), (ICRP, 2013), (ICRP, 2013), (IAEA, 2012)

No. 100

Source:
A 3.3.8.2, p. 156
Reference text:
In the following, the Environmental Impact Statement for the Swedish interim storage, spent fuel encapsulation and final disposal facilities [3.3.8–2] is frequently used as a reference, as it provides a good example of an integrated assessment exercise. The aspects considered are listed in Table 3.3.8.2.1.

Scientific evaluation:
The JRC uses the example of Sweden to describe the environmental effects caused by a repository. These effects will definitely vary according to the site and disposal concept and depend on the specific general conditions that exist.
No classification of the environmental effects for the post-closure phase of a

repository were conducted as part of the strategic environmental review performed in Germany for the National Disposal Programme (Öko, 2015).
The reasons for this are cited here:
"Slight emissions of radioactive substances or other harmful materials from repositories during the post-closure phase cannot be ruled out. However, they are restricted by the stipulations in the safety requirements for disposing of radioactive waste that develops heat and the Water Resources Act. As this phase continues for an extremely long period of 1,000,000 years and it is impossible to reliably forecast how elements needing protection, which could potentially be affected by the environmental consequences, will develop, the assessments cannot directly be compared to those for other projects. No classification of the effects on the environment into the assessment categories that are normally used has therefore been made for the post-closure phase of a repository." (Öko, 2015, Summary, p. 11)

Source:
(Öko, 2015)

No. 101

Source:
A 3.3.8.3, p. 156
Reference text:
On-site or centralized dry storage facilities do not generate any release of radioactive substances, since the spent fuel is contained in sealed canisters. Discharges to the air or release into water are negligible, due to the leak-tightness criteria for storage casks and the existing rules for surface contamination on the outside of the casks, which do not allow transportation of a surface-contaminated cask outside of the controlled area of the nuclear power plant.

Scientific evaluation:
The statement made by the JRC clearly only relates to normal operations at interim storage facilities. The events needing to be considered in the associated licensing procedures, particularly incidents and beyond-design accidents, are not considered. This is a shortcoming, primarily in the light of the fact that all the events, which are taken into account in the regulations associated with each activity, are at least indirectly considered in the technical screening criteria. The JRC Report does not uniformly state which events overall have been considered and which must be included in taxonomy, in the JRC's view. It should have been necessary to include this kind of statement in the report, particularly for the results derived by the JRC in the Executive summary.

Sources:
(TEG, 2020a), (TEG, 2020b)

No. 102

Source:
A 3.3.8.5, pp. 159–162
Reference text:
Whole section

Scientific evaluation:
The assessment is particularly made on the basis of the country examples in Sweden, Finland and France. This has numerous effects – for example, only two types of potential host rocks are considered. It is possible that different conclusions would be drawn if other host rocks or national plans for disposal had been considered.

No. 103

Source:
A 3.3.8.5, p. 159
Reference text:
Impact of the spent fuel, HLW final repository

Scientific evaluation:
The heading for this chapter relates to the effects of spent fuel elements at HLW repositories.
However, the statements in this chapter do not mention the effects. Conceptual procedures are simply outlined in part using the countries of Sweden, Finland and France as examples. However, no reliable statement can be deduced about an assessment of radioactive impact indicators on this basis (cf. JRC Report, Part A 3.3.8.9). It has already been stated with regard to chapter 3.3.8.2 that no classification of the environmental effects for the post-closure phase of a repository were conducted as part of the strategic environmental review performed in Germany for the National Disposal Programme (Öko, 2015).

Source:
(Öko, 2015)

No. 104

Source:
A 3.3.8.5, p. 159
Reference text:
The final disposal of spent fuel and vitrified waste (HLW) will occur in a deep geologic repository.

Scientific evaluation:
One of the illogical leaps in the chain of arguments in the report is evident in this sentence. There is widespread agreement that the option of disposal within deep geological formations is the best solution. The projects in Finland, Sweden and France are not yet finalised or tested. Planning, building and agreement are, however, condensed down to a single fact, which is no longer correct in this form.

Source:
The JRC Report itself

No. 105

Source:
A 3.3.8.5, p. 159
Reference text:
Since the relevant time spans are of the order of some hundred thousand years or more, exceeding human civilization records, the repository is designed to fulfil its safety function without the need for active human monitoring, control and intervention.

Scientific evaluation:
The statement about “some hundred thousand years” is imprecise and partly incorrect. There are shorter relevant time spans in Sweden too, e.g. 1,000 years for the integrity of the casks.

Source:
(SKB, 2011)

No. 106

Source:

A 3.3.8.5, p. 161

Reference text:

In the case of the Swedish repository, the construction of the facility will last 7 years and employ 300–400 workers. Approximately 1.6 million metric tons of rock spoil will be excavated during the construction phase.

The rock spoil will be temporarily stored in a rock heap within the industrial area. It is believed that the excess rock material not needed in the project can be sold in the region.

The operating phase of the Forsmark repository will consist of a trial operation and a routine operation subphase, which will require a specific licence from the Swedish Radiation Safety Authority (SSM). The routine operation is expected to last ~45 years. The main activities during routine operation are detailed characterization, mining of deposition tunnels, deposition of canisters, and subsequent backfilling and plugging of deposition tunnels. During the operating phase, ~ 6 000 filled canisters will be transported by ship from the encapsulation plant to the final repository and emplaced in the deposition tunnels.

Also in Olkiluoto during the operational period the monitoring of the repository, including both the disposal facility bedrock conditions and the surface environment, will continue on a regular basis, resulting in annual reports that will be submitted to the Finnish Radiation and Nuclear Safety Authority STUK.

Scientific evaluation:

The sources to support the aspects presented are not mentioned here.

Source:

(DFG, 2019)

No. 107

Source:

A 3.3.8.5, p. 161

Reference text:

No radiologically relevant release or impact to the public is expected during the construction and the operation of the final repository. As long as the sealed canister remains intact, all radioactive substances will be contained. The canister is designed to retain its integrity and tightness during normal operation, disturbances and mishaps. However, adequate radiation shielding will be used to protect the personnel from gamma and neutron radiation. The radiation emitted by the canister will not be noticeable outside of the final repository. [...]

No radiologically relevant release or impact to the public is expected during the construction and the operation of the final repository.

Scientific evaluation:

As mentioned earlier, neither this chapter nor Chapter 5.2 of Part B offer any detailed discussion on operational safety. In particular, the risks associated with potential accidents (e.g. leaking casks, fires, criticality events) or misuse of the fissile material (e.g. terrorist attacks, theft, etc.) are not assessed or even mentioned. Furthermore, no information about an operational safety assessment (similar to what is presented for the post-closure phase) is available.

No. 108

Source:

A 3.3.8.5, p. 162

Reference text:

Long term post-closure safety will be achieved by means of a system of passive barriers that interact to contain, prevent or retard the dispersal of radioactive substances. The barriers may be engineered or natural (see part B of the present report).

Scientific evaluation:
Statements are made about long-term safety during the post-closure phase without describing or questioning possible relevant developments, which have an effect on the safety of a repository. When considering the long-term safety of a repository, it should be noted that corresponding safety statements must always be viewed in relation to the underlying regulatory requirements or general conditions. The following quotation, related to long-term safety, illustrates that uncertainties exist with a safety statement, even in very favourable geological circumstances, and they cannot be fully eliminated (OECD, 1995 and OECD, 2012): "It must be acknowledged that the most robust and passively safe system that can be devised by current generations may ultimately be compromised by the actions of a future society, through inadvertent intrusion."

Sources:
(OECD, 1995), (OECD, 2012)

No. 109

Source:
A 3.3.8.5, p. 162
Reference text:
Long term post-closure safety will be achieved by means of a system of passive barriers that interact to contain, prevent or retard the dispersal of radioactive substances. The barriers may be engineered or natural (see part B of the present report). The protective function of the final repository against harm caused by radiations is set by relevant regulations. For instance, the time scale for the safety assessment of the Swedish final repository for spent nuclear fuel should cover a period of one million years after closure. The risk criterion set by SSM in Sweden in simplified terms says that people in the vicinity of the repository may not be exposed to greater risks than the equivalent of one-hundredth of the natural background radiation in Sweden today [3.3.8–2]. The Finnish nuclear law [3.3.8–8] states that a final repository under normal operations may not cause a dose to the most exposed member of the public higher than 0.01 mSv/year.

Scientific evaluation:
The licensing thresholds for repositories specified in this paragraph match the state of the art of science and technology and are therefore a basis for consensus. They are also found in a similar form in the German radiation protection laws. However, they are presented here only in abbreviated form. Many parts of the report only mention "intended operations" and derive the possibility of complying with the DNSH criteria from them. This is formally correct in the light of the task of the report, but fails to systematically deal with the question of what the assessment would have been like if "non-intended operations" or beyond-design circumstances at a power plant had been included in the assessment.

No. 110

Source:
A 3.3.8.6, p. 162–163
Reference text:
Entire section

Scientific evaluation:
The discussion about potentially harmful non-radiological effects of deep geological disposal of spent fuel and HLW takes place on the basis of a selection

of results from the Swedish environmental impact assessment. This implicitly assumes that this document provides an assessment that is generally relevant to any type of repository at any location (e.g. climate, geography, biosphere, etc.). There is no justification to back up this claim. For example, the potential impact on water resources will depend on the specific climatic, land use and hydrological conditions. This is connected to a broader problem of having limited practical experience in operating a deep geological repository (as discussed earlier).

No. 111

Source:
A 3.3.8, 3.3.8.6–3.3.8.10, pp. 162– 167
Reference text:
Entire section

Scientific evaluation:
Practically no statements are made about ILW and LLW. The report only mentions near-surface repositories for short-lived LLW and LIWL where it can be assumed that the background activity level has been reached after no more than 300 years. By “omitting” the issue of waste in the LLW and ILW fields, which is active for longer periods, a major part of the potential negative effect on the environment is simply ignored. This omission in turn ensures that the negative influences of nuclear energy are systematically underestimated in any direct comparison with other forms of generating energy.

No. 112

Source:
A 3.3.8.6, pp. 162– 163
Reference text:
Entire section

Scientific evaluation:
The non-radiological effect is exclusively derived from the environmental impact assessment in one Swedish case.

No. 113

Source:
A 3.3.8.8, p. 164
Reference text:
There is international consensus that very low level waste, low level waste and short-lived intermediate level waste can be safely disposed of in near-surface facilities at a depth of no more than 30 m. The underlying assumption is that the radioactivity of such waste types will decay to background levels within about 300 years, i. e. before institutional control is lost.

Scientific evaluation:
This statement suggests that general consensus exists that safe near-surface disposal is possible for VLLW, LLW and short-lived ILW, if certain conditions are met. These conditions include the fact that the radioactive waste has decayed within 300 years and the remaining radioactivity matches the generally existing environmental radioactivity. In conjunction with the period of 300 years, it is stated that, for example, institutional controls have not yet been abandoned by then. No further evidence of the aforementioned general consensus is given in this statement. It is also assumed that the institutional controls will remain for a period of 300 years. Even if this time period is very low compared to the assessment period that normally forms the basis for geological disposal sites for HLW, no guarantees can be given that institutional controls will definitely be

maintained. This circumstance is due to the fact that there is no scientific basis for a forecast of human behaviour and social actions (NAS, 1995).

Source:
(NAS, 1995)

No. 114

Source:
A 3.3.8.8, p. 164
Reference text:
There is international consensus that very low level waste, low level waste and short-lived intermediate level waste can be safely disposed of in near-surface facilities at a depth of no more than 30 m.

Scientific evaluation:
Germany has stipulated that all kinds of radioactive waste (including low- and intermediate-level waste) will be taken to deep geological repositories. Cf. nos. 175 and 201. The situation described here is more like what is happening in France, for example.

No. 115

Source:
A 3.3.8.8, p. 164–165
Reference text:
Entire section

Scientific evaluation:
This chapter does not consider the situation in Germany.
All kinds of radioactive waste, which cannot be deregulated, are to be placed in deep geological repositories in Germany.

Source:
(BMU, 2020)

No. 116

Source:
A 3.3.8.9, p. 165
Reference text:
"The disposal [...] does not contribute (the results are zero or negligible) to those indicators representative of the impacts to the Taxonomy Regulation objectives of sustainable use and protection of water and marine resources, pollution prevention and control, and protection and restoration of biodiversity and ecosystems"

Scientific evaluation:
Based on the information presented in Part A 3 of the JRC Report, this statement is premature and hard to defend. The results of the analyses outlined in Part A 3 are discussed in the light of the basic principles and objectives of taxonomy only in the following chapter (Part A 4).

No. 117

Source:
A 3.3.8.9, p. 165
Reference text:
The deep geological disposal facility aims at isolating and containing the radioactive waste until its radioactivity decays to harmless levels.

Scientific evaluation:
This is not quite correct. After the relevant time in the regulations in Sweden (100,000 years), the waste is still harmful.

Source:
The JRC Report itself
Fig. 2.4–1

No. 118

Source:
A 3.3.8.9, p. 167
Reference text:
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. They do not represent significant harm to any of the TEG objectives, provided that the associated industrial activities satisfy appropriate Technical Screening Criteria.

Scientific evaluation:
This states that it is possible to draw the conclusion through analysis that activities related to storing and disposing of conventional and radioactive waste or spent fuel elements do not imply any significant risk to human health or the environment. The analysis mentioned in this justification cannot be recognised for the post-closure phase of repositories. Statements about procedures used in different countries as examples and presenting general results are inadequate here, among other things, because of the different site situations, specific general conditions like the spectrum of waste, the repository concept, the safety concept and the regulatory requirements. It is therefore impossible to clearly reach the conclusion mentioned here. The remarks about the inability to rule out any HI and possible related effects on people and the environment and other uncertainties regarding the development of repositories in the post-closure phase do not permit this kind of firm conclusion either.

The following should also be noted:
The JRC Report, Part A 5.7 points out that no TSCs have been developed for LLW and ILW and the TSCs for HLW and spent fuel elements are adequate. If the TSCs for HLW and spent fuel elements are used for LLW and ILW too, which is taken to near-surface repositories, the aforementioned condition for complying with the TSCs is not completely met to draw this conclusion (cf. statements on Part A 5.7 for more here).

No. 119

Source:
A 3.3.8.9, Table 3.3.8.3, pp. 166–167
Reference text:
Table

Scientific evaluation:
The table qualitatively assesses the importance of effects of disposing of radioactive waste. However, all three radiological effects (production of solid radioactive waste, discharge of gaseous radioactivity and discharge of liquid radioactivity) are assigned the lowest relevance.
In particular, the report states with regard to any liquid and gaseous radioactive discharges that they involve ‘insignificant discharges during the operating phase.’ This is a statement for which insufficient evidence exists in this report. The statement ignores the potential risks associated with operating accidents and does not discuss them at all.

No. 120

Source:
A 3.3.8.9, p. 167
Reference text:
They [i. e. activities related to storage and disposal – Reviewer] do not represent significant harm to any of the TEG objectives, provided that the associated industrial activities satisfy appropriate Technical Screening Criteria.

Scientific evaluation:
This statement can be seen as misleading. The TSCs, as discussed above, have not yet been finalised.

No. 121

Source:
A 3.3.8.9, p. 167
Reference text:
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.

Scientific evaluation:
This statement is not supported by the discussions presented in Part A 3 (and the following chapters) – cf. previous comments. The results of the analyses outlined in Part A 3 are discussed in the following chapter (Part A 4) using the basic principles and objectives of taxonomy.

A 3.4: Impact of ionizing radiation on human health and the environment

No. 122

Source:
Part A, Chapter 3.4.1, p. 168
Reference text:
Poinssot et al [3.4–6] provide data […] different release pathways
(see Chapter 3.3.5.2.1).

Scientific evaluation:
From a scientific point of view, the effect of radionuclides on people with low exposure to radiation can only be quantified by the effective dose or in the case of Rn-222 and its progenies by the activity concentration of Rn-222 in the air that we breathe (or using 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.

Sources:
Last sentence of the reference text: “However, the effects of a 1 Bq radioactive release in terms of the resulting dose (in Sv) to members of the public vary considerably for different radionuclides and different release pathways” (see Chapter 3.3.5.2.1).

Relevant publications by the IAEA, e.g.: (IAEA, 2001).

Relevant publications by the ICRP, e.g. on dose coefficients for the general population.

No. 123

Source:
Part A, Chapter 3.4.1, pp. 171–172, including Figure 3.4-4
Reference text:
For comparison with the figures given by UNSCEAR [...] as well as remediation of legacy installations.

Scientific evaluation:
Specifying average effective doses per head of the population does not match the latest standard in radiation protection, for nuclear facilities or 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, i. e. a member of the public, who is exposed to higher levels of radiation because of their lifestyle.

Sources:
(ICRP, 2006), (ICRP, 2007)

A 3.5: Impact of severe accidents

No. 124

Source:
A 3.5, p. 175
Reference text:
Human health impacts of different energy generation technologies were compared in Chapter 3.2.5 for normal operation situations. In addition to the impacts from normal operation, the possible consequences on the environment and human health of potential severe accidents in the energy sector are not negligible, and it is important to consider these in any comparative assessment.

Scientific evaluation:
In the introduction to Part A 3.5, there is no assessment of whether the “severe accidents” within taxonomy are events needing to be considered according to the definitions and the derived technical screening standards. This once again makes clear that the JRC Report does not have a clear definition or derivation for the range of events that need to be considered. It would be desirable for this kind of report – or even absolutely essential – if there was a clear definition at the beginning about which events or groups of events need to be considered with regard to the DNSH criteria. The Executive summary at the start of the report only implicitly contains this kind of definition, but it is not explicitly explained in the report.

No. 125

Source:
A 3.5, p. 175
Reference text:
Human health impacts of different energy generation technologies were compared in Chapter 3.2.5 for normal operation situations. In addition to the impacts from normal operation, the possible consequences on the environment and human health of potential severe accidents in the energy sector are not negligible, and it is important to consider these in any comparative assessment.

Scientific evaluation
There is no assessment in Part A 3.5 of whether the “severe accidents” at nuclear power plants are events needing to be considered within taxonomy in line with the definitions and the derived technical screening standards.

No. 126

Source:
A 3.5, p. 175ff and A 4.3, p. 186
Reference text:
A 3.5.:
The methodological approach to evaluating accident risks differs according to the extent of data available in the database. For fossil energy chains (coal, oil and gas) there is extensive historical accident data available to provide a strong basis for the risk evaluation. For hydropower limited historical data for OECD countries is supplemented by modelling of hypothetical dam failures. For new renewables, for which historical data is limited, a hybrid approach is adopted, in which available historical data, modelling and expert judgement are used. For nuclear energy, due to the very low number of historical severe nuclear accidents and their significance for risk assessment, an approach based on the use of a simplified, site-specific, Level 3 Probabilistic Safety Assessment (PSA) is used to quantify the risks associated with hypothetical severe accidents.

The methodology provides its results in terms of two risk indicators, both based on fatalities. The first is the fatality rate, which is defined as the expected number of fatalities due to severe accidents normalised to the amount of electricity generated in GWh (fatalities/GWh). The second is the maximum credible number of fatalities in a single accident, which provides a measure of risk aversion.

A 4.3:
If severe accident fatality rates are compared (see Figure 3.5–1), then the current Western Gen II NPPs 10–7 fatalities/GWh). This value is much smaller than that characterizing any form of fossil fuel-based electricity production technology and comparable with hydropower in OECD countries and wind power (only solar power has significantly lower fatality rate).

These latest technology developments are reflected in the very low fatality rate for the Gen III EPR design 10–10 fatalities/GWh, see Figure 3.5–1). The fatality rates characterizing state-of-the art Gen III NPPs are the lowest of all the electricity generation technologies.

In addition to the “fatality rate per GWh” metric, severe accidents potentially occurring in the electricity generation industry are characterized by another metric, called maximum consequences. Conservatively estimated values of this metric are rather high for both Gen II and Gen III plants, comparable to the hydropower in non-OECD countries (see Figure 3.5–1). For the EPR design, the quoted reference study predicts 30 000 fatalities as upper bound.

Note that in Figure 3.5–1 the “maximum consequences” data for the non-nuclear electricity production technologies are real historical data reflecting the officially registered number of casualties (e.g. after a major hydropower-dam accident). Contrary to this, for nuclear energy the “maximum consequences” values correspond to calculated data which were derived by using highly conservative assumptions (e.g. application of a simplified Level 3 PSA model, dense population in the 100 km region around the plant, no off-site mitigation measures, see Ref. [4–5] for more details). In addition, more than 95% of the calculated fatalities can be attributed to latent (i. e. long-term cancer) fatalities, which are strongly influenced by site-specific population data and model-specific assumptions.
The consequence analysis outlined in Ref. [4–6] was prepared in the US NRC

SOARCA project and it takes into account the effect of on-site and off-site severe accident mitigation measures, as well. Some related results of the SOARCA project are shown in Figure 3.5–3.
Note that the data plotted in Figure 3.5 3

Scientific evaluation:
This section is restricted to assessment standards in terms of human fatalities as a consequence of a serious accident at a nuclear power plant.
Other standards that are relevant to taxonomy, such as the contamination of soil and water, non-lethal effects on human health, biodiversity and other effects on flora and fauna, are not considered. These kinds of effects are, however, to be expected and should be studied for the sake of any complete assessment.
The report diverts just as little attention to the significant economic consequences (Ashley et al., 2017) of a severe accident or the social and political consequences that result from such an accident and can have a direct and indirect effect on key performance indicators that are relevant to taxonomy.

One example to be mentioned is that the replacement power plants to compensate for the nuclear units that were switched off after the accident in Fukushima in Japan were readily available units that were often powered by fossil fuels like diesel on a large scale and were in use for a fairly long time. Germany's abandonment of nuclear energy as a consequence of the accident as an alternative to an accelerated withdrawal from using fossil fuels could be used here as a consequence needing to be considered as regards its effects on taxonomy objectives that are relevant to climate.

Probabilistic calculations are used to estimate the maximum conceivable number of fatalities as a result of serious accidents at nuclear power plants – and in terms of the generated energy units. The numbers obtained in this manner are compared with the figures obtained for other technologies in a different way.

Probabilistic safety analyses (PSA) are bound to have uncertainties. The methods used or more precise data affect the results and also the range of causal events and power plant conditions that are considered. PSAs are particularly used to recognise changes within a plant, and whether and to what degree these changes (e.g. retrofitting) affect safety. The absolute figures in terms of probabilities for core meltdowns or discharges are, however, accompanied by uncertainties that should be presented too. The information provided by the absolute figures without considering their uncertainties is therefore only informative to a restricted degree, particularly when comparing risk assessments related to other technologies, which have been obtained in a different way. It would therefore be more expedient to use a comparison of analyses that have been performed with a strictly defined methodology in all cases; or at least a comparison that specifies the relevant uncertainties.

Source:
(Ashley et al., 2017)

No. 127

Source:
A 3.5, p. 175
Reference text:
The methodological approach to evaluating accident risks differs according to the extent of data available in the database. For fossil energy chains (coal, oil and gas) there is extensive historical accident data available to provide a strong basis for the risk evaluation. For hydropower limited historical data for OECD countries is supplemented by modelling of hypothetical dam failures. For new renewables, for which historical data is limited, a hybrid approach is adopted,

in which available historical data, modelling and expert judgement are used. For nuclear energy, due to the very low number of historical severe nuclear accidents and their significance for risk assessment, an approach based on the use of a simplified, site-specific, Level 3 Probabilistic Safety Assessment (PSA) is used to quantify the risks associated with hypothetical severe accidents.

Scientific evaluation:
Using data that has been obtained in different ways to compare the risks is possible in principle, but the JRC fails to explain in detail the different forms of data and their advantages and disadvantages. Particularly any uncertainties, which result from different sources in the data that is mentioned, must be presented in a sensible manner prior to any comparison in order to make it possible to estimate the robustness of the derived statements.

Estimates purely based on historically gathered data (i. e. based on descriptive statistics) automatically have the risk of not being able to appropriately estimate very rare events, as the potential maximum extent or severity of those scenarios is either hard to estimate based on this data or has to be obtained using different analyses.
The selection of the underlying distribution function for extrapolation in the direction of very improbable events is also a source of uncertainty here (cf. e.g. BfS, 2012) too). However these results are generally marred by slight uncertainties for frequent events, if the basic principles for the events do not change (e.g. through technical improvements, which can make older data obsolete).

Purely probabilistically based procedures, which are generally supposed to map complex sequences, are basically able to map events that are very improbable, but contain potential uncertainties, which need to be adequately considered, because of the modelling process (cf. e.g. BfS, 2012)).

Hybrid approaches, which combine several strategies, can in principle use the advantages of all the methods that are used, but can potentially highlight all the disadvantages of these methods for the same reason, particularly if they are used because no reliable database is available.

Any use of expert assessments in particular must be given special consideration with regard to uncertainties (cf. e.g. NUREG, 1997)).

To what extent the data and methods used here have considered the uncertainties is not explicitly indicated. An estimate of the uncertainties of the events is at least specified in qualitative terms in (HIR, 2016). Some reproduction of these facts would have been desirable in the JRC Report.

Lastly, it is necessary to state that the PSA method, which is used to assess nuclear power, represents a qualified and resilient procedure that was particularly developed to determine risks at nuclear power plants (cf. e.g. BfS, 2005 on this matter).

Sources:
(Hirschberg, 2016), (BfS, 2012), (NUREG, 1997), (BfS, 2005)

No. 128

Source:
A 3.5 , pp. 175–176
Bezugstext:
The methodology provides its results in terms of two risk indicators, both based on fatalities. The first is the fatality rate, which is defined as the expected number of fatalities due to severe accidents normalised to the amount of electricity

generated in GWh (fatalities/GWh). The second is the maximum credible number of fatalities in a single accident, which provides a measure of risk aversion.

Scientific evaluation:
It would have been useful to include an evaluation of the fields of application for these risk indicators. Only the first one ("fatality rate") is used in nuclear technology (particularly during the licensing procedure). This can be recognised by the fact that in general associated probabilities of occurrence are defined for the thresholds needing to be followed, for example, so that this combination then matches the definition of a risk in a scientific sense.

However, as the events referred to here are outside the events needing to be considered, the use of a different standard is thoroughly acceptable.

It should also be noted that simply focussing on the fatality rate or the number of fatalities in an accident does not represent the only potential risk indicators. One study, for example, (Sovacool et al., 2016) confirms that hydroelectric power has caused the largest number of deaths by far (in percentage terms) when considering events during the last 65 years and wind power the most frequent accidents (however, with low numbers), but nuclear power has easily caused the greatest economic damage.

Source:
(Sovacool et al., 2016)

No. 129

Source:
Part A, chapter 3.5, pp. 175–176
Reference text:
The methodology provides its results in terms of two risk indicators, both based on fatalities.

Scientific evaluation:
Only fatalities caused by radiation are counted here. No consideration is given to so-called "disaster-related deaths", as they were calculated for the reactor accident at Fukushima. These calculations must be questioned, both regarding the methodology and their exact quantifiability, but there are no doubts about the fundamental high importance of "disaster-related deaths".

Source:
(Hayakawa, 2016)

No. 130

Source:
Part A, chapter 3.5, p. 176 (Figure 3.5-1)
Reference text:
Severe accident fatality rates and maximum consequences (black points) assessed for selected electricity supply technologies with the associated energy chains.

Scientific evaluation:
This sentence is comparing probabilities with frequencies, which is conceptually questionable. The product of the probability of damage (very low) and the amount of damage (very high) cannot be compared with the risks derived from measured frequency levels and real damage.

No. 131

Source:

A 3.5, p. 177

Reference text:

The maximum credible number of fatalities from a hypothetical nuclear accident at a Generation III NPP calculated by Hirschberg et al [3.5-1] is comparable with the corresponding number for hydroelectricity generation, which is in the region of 10,000 fatalities due to hypothetical dam failure. In this case, the fatalities are all or mostly immediate fatalities and are calculated to have a higher frequency of occurrence.

Scientific evaluation:

The comparison of these two events is very hard to assess without a more precise statement about the underlying assumptions. The report should at least specify here which assumptions have been accepted for the modelling procedures in each case.

No. 132

Source:

A 3.5, p. 177

Reference text:

Figure 3.5-2, from the same Hirschberg et al study [3.5-1], compares the frequency-consequence curves for selected full energy chains in OECD and non-OECD countries. The curves for coal, oil, gas and hydro are based on historical data from the period 1970-2008. In all cases the data concern immediate fatalities. The curves for nuclear energy are based on a simplified level 3 PSA.
[...]
However, the shape of the curves does not indicate that the maximum consequences have been reached, and extrapolation of the curves to lower frequencies would suggest that higher consequences would be likely.

Scientific evaluation:

As has already been stated regarding the methods used for determining data, this discussion does not consider or present any uncertainties.

The statements about the curves, which are based on collected data, show that a more precise presentation about the limitations of the procedures would have been sensible here.
In principle, the same applies to the modelling results from the PSAs, as they do not contain any information about uncertainties. The uncertainties are at least assessed qualitatively in (Hirschberg, 2016) and make it easier to understand the robustness of the comparison. These illustrations make it clear that the uncertainties are not so great that they cast doubt on the fundamental statement.

Source:

(Hirschberg, 2016)

No. 133

Source::

A 3.5, p. 179

Reference text:

An accident at a Generation III nuclear power plant with the kind of consequences shown in Figure 3.5-1 is a highly improbable event. The calculated frequency of such consequences corresponds to about 10-10 per reactor year, or once in ten billion years of operation per reactor. However, such a number of fatalities, even if based on very pessimistic assumptions, has an impact on public perception due to disaster (or risk) aversion.

Scientific evaluation:
The JRC raises a crucial point in its assessment of these kinds of events, but avoids drawing the obvious – and crucial – conclusion: the question of whether and which standard should be used for these kinds of events.

Nr. 134

Source:
A 3.5, p. 179
Reference text:
Disaster aversion refers to an apparent higher importance attached, by some, to a large number of deaths in a single, low-frequency accident compared to an equal number of deaths spread over a larger number of more frequent types of accident.

Scientific evaluation:
The JRC could have provided different illustrations here, as there are at least examples of how this aspect can be handled. For example, risk acceptance curves, where the scientific definition of a risk equals the degree of damage times the probability of occurrence is modified to such a degree that the degree of damage often has an exponent of > 1 (2 is often used here) and this therefore gives the degree of damage greater weighting for incidents that cause major effects (cf. e.g. (ESCIS, 1996 Annex 2)). By implication, this means that frequent cases of minor damage are given significantly lower weighting.
However, these kinds of risk acceptance curves are not standard and have not been defined in all countries either (cf. e.g. DTU, 2009)), so that the aforementioned example is purely illustrative for the question that is raised here.

Sources:
(ESCIS, 1996), (DTU, 2009)

No. 135

Source:
A 3.5, p. 179
Reference text:
[…] the following are representative of the number of fatalities that occur each and every year due to the mentioned causes:

Scientific evaluation:
The examples listed by the JRC draw attention from the actual topic of DNSH and can only be viewed as a fundamental observation that the perception of any risks is significantly different, depending on the area involved.

This is basically a continuation of the remarks in no. 134, as the presentation describes the fact that frequent events (so frequent here that they occur statistically to a predictable extent within the observation period) are socially acceptable or at least tolerated, while more major damaging events are assessed and perceived differently by society, even if they take place at lower levels in comparison with the aforementioned events (cf. (DTU, 2009) too). This is the intersection point, from which any purely scientific and sober calculation and assessment encounters a social and political assessment and ultimately the decision cannot be made here (solely) on a scientific basis.

The references to air pollution caused by fossil fuels or tobacco consumption are particularly out of place, as the former is not a sustainable activity and the latter is provided with warnings, not without good reason.

Only the example of road traffic could be an activity, which could potentially be sustainable – if we assume that it is completely emission-free – and this would

raise the question of whether any expected number of fatalities on the scale that is mentioned could possibly still meet the DNSH criteria statistically.
The analogy about constant improvements to safety in this field could be used to make it easier to understand the differences between the results for generation II and generation III power plants with a view to statistics.

No. 136

Source:
A 3.5, pp. 175–180
Reference text:
Whole section

Scientific evaluation:
Section 3.5 has some shortcomings in its presentation and the conclusions that are drawn and particularly does not provide any independent assessment in terms of the DNSH criteria.

As listed above in no. 3 (and later in no. 21), severe accidents are not included in the events, which need to be considered for the DNSH criteria, according to the JRC; Section 3.5 is simply a sensible addition to the overall consideration without any relevance for the assessment results.

The comparison with results from fossil energy generation does not make sense, as they are not sustainable by definition and therefore having a better balance sheet than these cannot be used as the basis for any direct classification as being sustainable.

The use of risk indicators should therefore be restricted to those activities for which taxonomy has confirmed sustainability and therefore compliance with the DNSH criteria. A positive statement would be possible if we stay within the effects of the defined thresholds. A negative statement would only be possible if an activity, which clearly violates the DNSH criteria, has been identified and has performed better than nuclear power, according to the standard being used.

A 4: Summary DNSH assessment for nuclear energy and recommendations

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A 4.1: Main conclusions of the analyses outlined in Chapter 3.2

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A 4.2: Main conclusions of the analyses outlined in Chapter 3.3

No. 137

Source:
A 4.2.2, p. 185
Reference text:
Figure 4.2.2–1. Contributions from all lifecycle phases to all impact indicators (closed cycle)

Scientific evaluation:
The source specified for this Figure refers to a publication [4–2] Ch. Poinssot et al.: Assessment of the environmental footprint of nuclear energy systems. Comparison between closed and open fuel cycles, Energy 69 (2014), 199–211. This is an analysis and a comparison of the situation in France (closed fuel cycle). The report does not mention that the Figure specifically illustrates the French circumstances. This raises the question as to whether it can be transferred to the situation in other countries.

It should also be noted from an editorial point of view that the Figure is hard to read (font size, colour).

Source:
[4–2] (Poinssot et al., 2014)

A 4.3: Main conclusions of the analyses outlined in Chapter 3.4 and 3.5

No. 138

Source:
A 4.3, p. 186
Reference text:
Severe accidents with core melt did happen in nuclear power plants and the public is well aware of the consequences of the three major accidents, namely Three Mile Island (1979, USA), Chernobyl (1986, Soviet Union) and Fukushima (2011, Japan). The NPPs involved in these accidents were of various types (PWR, RBMK and BWR) and the circumstances leading to these events were also very different. Severe accidents are events with extremely low probability but with potentially serious consequences and they cannot be ruled out with 100% certainty. After the Chernobyl accident, there were focused international and national efforts to develop Gen III nuclear power plants. These plants were designed according to extended requirements related to severe accident prevention and mitigation, for example they ensure the capability to mitigate the consequences of a severe degradation of the reactor core, if such an event ever happens. The main design objective was to ensure that even in the worst case, the impact of any radioactive releases to the environment would be limited to within a few kilometres of the site boundary.
The deployment of various Gen III plant designs started in the last 15 years worldwide and now practically only Gen III reactors are constructed and commissioned.

Scientific evaluation:
Current nuclear power plant series (e.g. EPR), as described, have an extended design which covers core meltdown accidents. From a design point of view, therefore, the discharge figures applying to these NPPs should not be exceeded, even during major meltdown accidents, and the radiological effects of these accidents should therefore be significantly lower than with reactors of an older design. Core meltdown accidents are not part of the design features at these older plants, but, as beyond-design accidents, their effects can only be restricted by means of emergency protection measures within the plant within certain limits. The “worst case” statement is, however, restricted to accident sequences related to this extended design and does not form a statement for accident scenarios that are highly improbable, but cannot be completely ruled out – and go beyond the design of such reactors. Even if the possibility of a beyond-design accident occurring is improbable, the consequences of this should be considered.

The study does not mention that the nuclear power plants with older designs, which continue to operate, do not achieve the safety level of a new plant, despite refitting measures that may have taken place.

No. 139

Source:

Part A, Chapter 4.3, p. 186

Reference text:

- The average annual exposure to a member of the public, due to effects attributable to nuclear energy-based electricity production is about 0.2 Sv, which is four orders of magnitude less than the average annual dose due to the natural background radiation (see Figure 3.4–1).

Scientific evaluation:

Specifying the average effective doses per head of the population does not match the latest standard in radiation protection 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, i. e. a member of the public, who is exposed to higher levels of radiation because of their lifestyle.

Sources:

(ICRP, 2006), (ICRP, 2007)

No. 140

Source:

Part A, chapter 4.3, p. 186

Reference text:

- The average annual exposure to a member of the public, due to effects attributable to nuclear energy-based electricity production is about 0.2 Sv, which is four orders of magnitude less than the average annual dose due to the natural background radiation (see Figure 3.4–1).

Scientific evaluation:

These studies were only briefly mentioned in Part A 3.4, but not analysed in any detail.

A 4.4: Evaluation and conclusion

No. 141

Source:

A 4.4, p. 187

Reference text:

- NPP operation
  - Prevention of thermal pollution related to water withdrawal
  - Limitation of water consumption
  - Limitation of conventional releases with focus on toxic materials
  - Ensuring adequate radioprotection of workers and the public
  - Limitation of gaseous and liquid releases
  - Limitation of solid radioactive waste production (mainly VLLW and LILW-SL)

Scientific evaluation:

It is not clear here whether "NPP operation" includes decommissioning (cf. no. 76).

A 4.5: Recommendations

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A 5: Illustrative Technical Screening Criteria for selected lifecycle phases of nuclear energy

/

A 5.1: Background and general considerations

No. 142

Source:
A 5.1, p. 190
Reference text:
In order to be in line with the TSC listed in the TEG reports [5–1] and [5–2], kept rather qualitative than quantitative, usually it was not necessary to give precise limit values in the TSC tables developed for the selected LC phases of nuclear energy. Therefore, often fulfilment of regulatory requirements and/or regulatory limits are provided as proof of not doing harm to the environment. It was supposed that this approach is accepted also in the case of nuclear energy.

Scientific evaluation:
This statement presumes that there are internationally valid regulatory requirements and/or regulatory thresholds as evidence that there are no problems for the environment during the life cycle phases. However, no appropriate sources are specified for deriving the TSCs (criteria) or information that international experience exists, which has led to a reassessment of the disposal issue, e.g. in Germany, or USA. No detailed grounds are provided for fundamentally transferring the TSCs to the topic of nuclear energy.
The methodical process here is unclear.

No. 143

Source:
A 5.1, p. 191
Reference text:
Note that no TSC were prepared for the climate change adaptation objective, because the nuclear energy was primarily considered as a potential contributor to climate change mitigation.

Scientific evaluation:
This information is misleading, as “climate change adaptation” is explicitly mentioned previously as a desirable environmental objective – cf. section (2) “Adaptation”, cf. p. 190.
It would be better to indicate here that nuclear energy may have been primarily viewed as a potential contributor to climate change mitigation, but this assumption has been modified. It is also unclear whether there will be an independent TSC table, which deals with the environmental objectives mentioned in chapter 5.1.
No reference is made to Appendix E.

A 5.2: Correspondence to the NACE codes

No. 144

Source:
A 5.2, p. 191
Reference text:
The NACE codes used in the TSC tables were determined according to the above considerations.

Scientific evaluation:
This statement and the description or list of the various NACE codes suggest that they have been fully included and used in the life cycle phases. It would have been desirable to have information that the codes "[...] can be adapted and further specified, if required."

A 5.3: Development of Technical Screening Criteria

No. 145

Source:
A 5.3, p. 192
Reference text:
The relevant EU directives and regulations – together with the national laws and regulations in effect – are considered as legal obligations to be compulsorily satisfied in the EU and their fulfilment is a minimum condition for eligibility.

Scientific evaluation:
This statement is incomplete. It would have been good to have some direct information that the conditions in the relevant EU directives, orders, national laws etc. relate to the promotion of the peaceful use of nuclear energy – i. e. a clear distinction with the military use of radioactive waste etc.

A 5.4: Development of TSC for the NPP operation phase

No. 146

Source:
A 5.4.2, pp. 193–194
Reference text:
Considering nuclear safety requirements for existing NPPs, the compliance with the WENRA Safety Reference Levels (RLs) for Existing Reactors (see Ref. [5–4]) is required as a minimum. The Western European Nuclear Regulators' Association (WENRA) develops a harmonized approach to nuclear safety since 2006, when the first set of RLs for operating NPPs was published. The RLs reflect expected practices to be implemented in the WENRA countries and they primarily focus on safety of the reactor core and spent nuclear fuel. The RLs are regularly revised when new knowledge and experience are available, for example, the current version of the RLs takes into account the lessons learned from the Fukushima accident and the insights from the EU stress tests.

Compliance with the Euratom Nuclear Safety Directive (NSD) [5–5] is also

required. The nuclear safety objective specified in article 8a of the NSD requires that nuclear installations are designed, sited, constructed, commissioned and operated with the objective of preventing accidents and, should an accident occur, mitigating its consequences and avoiding:
- Early radioactive releases that would require off-site emergency measures but with insufficient time to implement them;
- Large radioactive releases that would require protective measures that could not be limited in area or time.

New nuclear power plants must at least meet the WENRA Safety Objectives for New Nuclear Power Plants [5–6]. WENRA expects new NPPs to be designed, sited, constructed, commissioned and operated in line with these objectives. The [5–6] objectives promote the defence-in-depth approach at all levels of plant protection and require that multiple failure events and core melt accidents should be considered in the design of new NPPs. WENRA requires that accidents with core melt which would lead to early or large radioactive releases have to be practically eliminated. For those accidents with core melt that have not been practically eliminated, design provisions have to be taken so that only limited protective measures in area and time are needed for the public and the environment, and that sufficient time is available to implement these measures (see [5–6] for more details). These requirements are meant to ensure that even accidents with core melt have limited consequences on the public, even in the vicinity of the NPP.

Scientific evaluation:
Even if various regulations (including the German nuclear regulations at various points) talk about the “exclusion” or the “practical exclusion” of particular events or accident scenarios or consequences of accidents (e.g. no radiological consequences outside the unit site, preventing any major or early discharge, etc.) (WENRA, 2010), this technical terminology does not mean that these events are categorically ruled out.

In a probabilistic sense, this kind of “exclusion” means that the probability of the event being considered is sufficiently low because of the measures that have been adopted.

The use of this regulation terminology in the report suggests, however, that “exclusion” should be understood in a categorical sense (cf. no. 248 below).

Example: IAEA SSR-3 (Safety of Research Reactors):

“6.8. The design shall ensure that facility states that could lead to high radiation doses or large radioactive releases are practically eliminated and that there are no, or only minor, potential radiological consequences for facility states with a significant likelihood of occurrence.”
It continues:
“The possibility of certain conditions occurring is considered to have been practically eliminated (i. e. eliminated from further consideration) if it is physically impossible for the conditions to occur or if the conditions can be considered with a high level of confidence to be extremely unlikely to arise.”

That is to say, “exclusion” means that measures have been adopted so that the relevant event can be excluded from any further consideration.

Source:
(WENRA, 2010)

A 5.5: Development of Technical Screening Criteria for the uranium mining and milling phase

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A 5.6: Development of TSC for the reprocessing of spent nuclear fuel

/

A 5.7: Development of TSC for the interim storage and final disposal of spent fuel and high-level radioactive waste

No. 147

Source:
A 5.7, p. 196
Reference text:
Development of TSC for the interim storage and final disposal of spent fuel and high-level radioactive waste

Scientific evaluation:
When drawing up the technical screening criteria, the JRC follows the screening criteria defined by the TEG for other activities. The list covers all the activities. As has already been mentioned with regard to Part A 3.3.8.3, the framework for the events being considered is restricted to those that must be assessed in the associated licensing procedures. In particular, the severe accidents addressed in Part A 3.5 are not considered here (cf. the comments on Part A 3.5).

No. 148

Source:
A 5.7, p. 196
Reference text:
Disposal of low level and short-lived intermediate level waste is less challenging than disposal of high level waste, and thus it is considered that the Technical Screening Criteria as developed for interim storage and disposal of high level waste and spent fuel cover as well the disposal of low level and short-lived intermediate level waste.

Scientific evaluation:
The statement quoted here contains the assumption that the TSCs developed for the interim storage and disposal of HLW and spent fuel elements cover the disposal of LLW and short-lived ILW.

This raises the question about which TSCs apply to the other radioactive waste, which is not included in the aforementioned waste classes, or should apply. This involves, for example, VLLW and long-lived LLW and ILW.

The short-lived LLW and ILW only have small amounts of long-lived radionuclides. To be called short-lived, the waste must meet the following criteria (IAEA, 2009; GRS, 2004):

- the waste’s half-life is less than 30 years,
- the specific activity of the α emitters from the waste in the complete repository is lower than 400 Bq/g,

- the specific activity of the α emitters in individual containers is lower than 4,000 Bq/g.

The long-lived LLW and ILW include waste that exceeds the aforementioned criteria and does not produce any significant heat.

We assume that the design and concept for deep geological repositories will have a different quality in terms of its robustness than for near-surface repositories, which are normal for LLW, according to the JRC Report (cf. JRC Report, Part B 5.1). As a result, facilities for LLW, which are designed to be near the surface, are estimated to be more prone to extreme external events and processes, e.g. natural phenomena, accidents, anthropogenic effects and HI (IAEA, 2012).

Another difference relates to greater proximity to layers feeding groundwater as opposed to deep geological disposal, which could have unfavourable effects if a leak occurred. Separate consideration of the specific TSCs for radioactive waste or near-surface disposal and deep geological disposal therefore seems urgently required.

Sources:
(IAEA, 2012), (IAEA, 2009), (GRS, 2004)

No. 149

Source:
A 5.7, p. 196
Reference text:
Therefore we used them only as “skeletons” and developed the required TSC from scratch. Formally the “disposal of HLW” was considered as enabling activity, because the safe management and adequate final disposal of radioactive waste – among other conditions – contribute to the long-term sustainability of nuclear energy.

Scientific evaluation:
The authors of the study rightly comment that deriving the necessary screening criteria from the instructions provided is very difficult or even impossible. They suggest the possibility of considering additional screening standards, but, in the end, do not use them.

The focus on this “enabling activity” is not critically viewed to any greater extent in the report. The report only contains some information at this point on how the assessment of the DNSH criteria might have looked if a different approach had been adopted. This creates the impression that the procedure is “without an alternative”.

No. 150

Source:
A 5.7, p. 197 and Part B, Annex 4(4)
Reference text:
Development of TSC for the interim storage and final disposal of spent fuel and high-level radioactive waste
Criteria defined in the TSC table focus on ensuring the fulfilment of the following requirements:
- Ensuring nuclear safety during the operations, including transport manoeuvres (in particular subcriticality, cooling and containment of radioactive materials);
- Ensuring adequate radioprotection of workers during the operations;
- Limitation of gaseous and liquid releases during operation and post-closure;
- Limitation of conventional waste generation (e.g. during excavation,

manufacturing, decommissioning and dismantling of encapsulation plant and auxiliary facilities);
- Limitation of migration of radionuclides from the repository to the accessible biosphere;
- Ensuring the fulfilment of Taxonomy-specific requirements.

Scientific evaluation:
Given the role of the Technical Screening Criteria (TSC) in the proposed methodology, the TSC presented in this section (in particular in the table in Annex 4 point 4) are overly general. Greater specification is required (e.g. dose criteria for radiological assessment).
In their current form, the TSC are a "work-in-progress" as admitted in the Executive summary (Key Conclusions): "The TSC published here are preliminary proposals illustrating that adequate criteria can be compiled." Therefore, further elaboration is needed before they can be applied, and the assessment finalised. For example, with regard to radiological effects, the Technical Screening Criteria focus on maintaining dose contributions below regulatory limits through the deployment of the multiple-barrier system. There is no explanation why the requirement is limited in this particular manner. For example, no mention is made regarding other potentially important safety indicators such as risk or radioactivity fluxes. There is no discussion about how the different regulatory limits in different countries should be handled (in a standardised manner) either.

Annex 1, Appendix E, page 369ff cites further requirements for the DNSH criteria, particularly aspects of funding. They are not addressed here. This is consistent with the internal logic in the JRC Report, but this aspect is missing in any general discussion about sustainability.

Part B: Specific assessment on the current status and perspectives of long-term management and disposal of radioactive waste

B 1: Radioactive waste management: main principles and legal framework

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B 1.1: Main principles of radioactive waste management

No. 151

Source:
B 1.1, p. 200, 2nd paragraph
Reference text:
No radionuclides are released from the waste and no radiological pollution and/or harm to the biodiversity and ecosystems (including marine environment) occur during the operational lifecycle stages.

Scientific evaluation:
When operating nuclear facilities, exposure below the thresholds is allowed, cf. Section 80 of the Radiation Protection Act. The fundamental statement that no discharge is allowed should be adapted.

Nr. 152

Source:
B 1.1, p. 200
Reference text:
For the final disposal of radioactive waste, the objective has to be fulfilled until the radiotoxicity level of the waste has decayed sufficiently to ensure that the maximum allowed dose contribution set by the relevant regulation is not exceeded. For the waste containing long-lived radionuclides, in particular for the spent nuclear fuel and the vitrified waste from reprocessing (High-Level Waste, or HLW), which are characterized by high concentration of long-lived radionuclides and the most intense radioactivity level, the decay time required to reduce the radiotoxicity down to the relevant threshold can be of the order of a hundred thousand years. Ensuring the safe containment and isolation of the waste for very long timespans cannot rely upon active human monitoring and intervention.

Scientific evaluation:
The statement indicates a period of roughly hundreds of thousands of years as the time required for isolation or containment of HLW. This timescale is already difficult to imagine, but does not match the real isolation period required for the waste to protect people and the environment. A number of long-lived, relevant radionuclides (e.g. Ra 226, Th 229, Np 237 and Cs 135) still have overall activities greater than 1010 Bq, even after a period of 1,000,000 years, if the materials are assumed to include 10,000 spent fuel elements (0.534 Mg HM/BE) (AkEnd, 2002).

An assessment period of one million years is being used for the safety analyses in a number of countries. It is often wrongly assumed that, after this time, the radioactive waste put into storage is viewed as harmless for people and the environment. Any consideration of one million years (at least in Germany) can be traced back to the work performed by AkEnd. It states the following:
“AkEnd believes that fairly reasonable forecasts about the geological development of sites in favourable areas, such as they exist in Germany, can be drawn up over a period of roughly one million years, according to scientific findings. They are essential if it is going to be possible to prove the long-term safety of a disposal site during the later licensing procedure.
AkEnd has discovered that the isolation period for the repositories being sought should be in the order of 1,000,000 years in order to develop the quantitative criteria for searching for repositories with generally favourable geological situations.” (AkEnd, 2002)

This statement reveals that even the one million years refers to the ability to make forecasts about favourable geological areas. This is the reason why the isolation period has been set at 1,000,000 years. This is not the time, after which the disposed waste can then be classified as non-hazardous.

Source:
(AkEnd, 2002)

No. 153

Source:
B 1.1, p. 200
Reference text:
The safety demonstration addresses both the “normal” long-term behaviour of

the repository and the behaviour in case of "perturbations", such as glaciation, seismic events, and human intrusion, and it is assessed independently by the competent regulatory authority.

Scientific evaluation:
This raises the issue of the distinction between "intended operations" and "non-intended operations" or "situations that go beyond design features". However, it is not included in the assessment (cf. comments on Part A 3.3.8.5 p. 162).

No. 154

Source:
B 1.1, p. 200
Reference text:
The fundamental safety objective applicable to all facilities and activities handling radioactive materials is to protect the people and the environment from the harmful effects of ionizing radiation [1–7]. Thus, the basic and foremost goal of radioactive waste management is to ensure that the radioactive waste materials are contained and sequestered from the biosphere throughout all stages of waste management.

Scientific evaluation:
Part B chapter 1 describes the necessary conditions for fulfilling the DNSH criteria. The report relies on the international regulations and the positive experience gained by individual member states in implementing the DNSH criteria. However to deduce adequate criteria that are also required, there is no assessment of other international experience, which has led to a reassessment of the disposal issue. Examples here would be Germany, the USA or Australia.
The analysis also only includes the perspective of EU member states, which are in a position to implement their own disposal programmes. The viewpoint of smaller member states, which may require support for their disposal plans, is not mentioned.

No. 155

Source:
B 1.1, p. 200
Reference text:
Direct monitoring and intervention by the operators ensures maintaining the safe functions of all the shielding and containment barriers isolating the radioactive waste. No radionuclides are released from the waste and no radiological pollution and/or harm to the biodiversity and ecosystems (including marine environment) occur during the operational lifecycle stages.

Scientific evaluation:
The absolute statement made in this paragraph is not quite correct. The national and international regulations correctly cited in the report do not assume a "zero criterion", but a "negligibility criterion" with regard to the effects of the disposal activities caused by disposing of HLW.

No. 156

Source:
B 1.1, pp. 200 ff
Reference text:
The safety demonstration addresses both the "normal" long-term behaviour of the repository and the behaviour in case of "perturbations", such as glaciation, seismic events, and human intrusion, and it is assessed independently by the competent regulatory authority.

Scientific evaluation:
Human intrusion (HI) is placed on a par with the formation of glaciers, earthquakes etc. here and this suggests that the same safety standard would be employed for all events (i. e. human activities and non-anthropogenic events) and would particularly relate to the dose thresholds listed on p. 201. However, this is not the case. HI scenarios have been fundamentally exempted from the need to create dose thresholds (*2) in some countries (*1)
It is therefore correct to state that "the safety demonstration addresses HI", but it would be wrong to view this as a "safety demonstration" for HI in the sense of the dose thresholds emphasised in this chapter. As a result, the ideal "expected radiation dose" for a deep geological repository (Fig. 1-1, p. 203) is not suitable for HI scenarios.

Sources:
*1: in Germany, for example: cf. safety requirements

*2: As a result, these countries follow the recommendations made in the IAEA's HIDRA Project and the OECD/NEA in its scenario working group

No. 157

Source:
B 1.1, p. 201
Reference text:
The above-mentioned regulations set the maximum allowed levels of radioactivity and dose, below which no significant harm is caused to the human population and to the environment (biosphere) also for the radioactive waste management activities. For instance, the nuclear law and regulations in Finland [1-3], [1-27] states that a final repository for spent nuclear fuel under normal operations may not cause a dose to the most exposed member of the public higher than 0.1 mSv/y. In Sweden, the maximum allowed dose contribution due to the final repository for a person that would live in its vicinity is 0.014 mSv/y [1-4], [1-5], and [1-6]. These limits are very low.

Scientific evaluation:
The information provided in this statement is not fundamentally incorrect, but the details need to be relativised. The dose threshold in Finland, for example, has been set at 0.1 mSv/y for the expected development of a repository. However, this threshold applies to an assessment period of several thousand years. This is a much shorter period of time compared with an assessment period of a million years, which is being used in some countries. No thresholds for an effective annual dose are being prescribed after several thousands of years. These figures are geared towards average discharge thresholds. There is a need to quantify the resulting exposure for improbable events, if possible. The expected figures from this should then be compared with the aforementioned dose threshold or the discharge thresholds for specific radionuclides. The possibility that radiological exposure could occur (of at least approx. 0.5 Sv) is assumed to be very low.

There is no underlying dose criterion in Sweden, but a radiological risk of 10-6 for the individuals most seriously affected (SSM, 2009). The risk can then be converted into a dose that is the same as the information provided.

Sources:
(STUK, 2014), (SSM, 2009)

No. 158

Source:
B 1.1, p. 201

Reference text:
The basic and foremost objective of radioactive waste management is to ensure that the radioactive waste materials are contained and sequestered from the biosphere throughout all stages of waste management.

Scientific evaluation:
According to the statements in Part A 3.3.8.2, p. 155, it is impossible to provide any guaranteed safeguards when containing the radioactive waste from the biosphere at the repository, as future human activities, including HI in the post-closure phase, which impair the safety of the disposal site, cannot be ruled out (ICRP, 2013).

Source:
(ICRP, 2013)

No. 159

Source:
B 1.1, p. 202 and graphic p. 203
Reference text:
Figure 1–1 shows an example of the expected dose caused by the geological repository to the most exposed individual living in its vicinity as a function of time. The actual dose will be two orders of magnitude lower than the maximum level allowed by the regulation, which, in turn, is one order of magnitude lower than the dose from natural sources.

Scientific evaluation:
The graph does not include any uncertainty indication. As a result, the statement made in the text cannot be assessed. No classification is provided in the text. This is not the only figure to which this remark applies.

No. 160

Source:
B 1.1, p. 204
Reference text:
The avoidance of significant harm to humans and to the environment is ultimately ensured by the compliance with the regulatory limits set for the radioactivity dose contribution to the non-professionally exposed population, which is a pre-condition for the authorization and licensing of any radioactive waste management facility.

Scientific evaluation:
This portion of text says the “avoidance of significant harm” is therefore “ultimately ensured” because it is based on compliance with dose thresholds. However, as the anthropogenic scenarios like inadvertent human intrusion are not prevented by compliance with dose thresholds, the evidence for the statement of “avoidance of significant harm” is incomplete.

This also applies to the key conclusions nos. 15 and 17 (third-to-last and last), where compliance with “no significant harm to human health” is proven by compliance with dose thresholds.

No. 161

Source:
B 1.1, p. 204
Reference text:
Due to the high radiological hazard potential of radioactive waste forms,

especially in the case of spent fuel and HLW, and as required by the relevant regulations, all steps of radioactive waste management fulfil the requirements and are designed to ensure that the waste remains fully contained and isolated from the environment at all times.

Scientific evaluation:
This statement must be contradicted in its current absolute form. Cf. reasons in Part A 3.3.8.2, p. 155 and Part B 1.1, p. 201.

It is necessary to refer again to the quotation from the OECD/NEA (OECD, 1995) on the comment in Part A 3.3.8.5, p. 162. Another quotation (ICRP, 2013) is specified in the following text to emphasise the contradiction:

"Eventually, loss of memory and consequently loss of oversight may take place, either progressively or following major unpredictable events such as war or loss of records. Therefore, inadvertent human intrusion in the disposal facility cannot be ruled out during this time period. The intrinsic hazard of the waste decreases with time, but it may continue to pose a significant hazard for a considerable time."

Regardless of the possibility of humans intruding into a repository, the question of the safety of the repository is associated with a large number of uncertainties and it is impossible to rule out or completely prevent all of them (GRS, 2018).

There are no doubts that the permanent elimination of radioactive waste is viewed as essential and requires safe disposal to protect people and the environment. In the light of this, however, the fact should not be forgotten or overlooked that no geological repository is being sought, because we believe that we have found an absolutely safe method of disposal, but because we are convinced that geological disposal in comparison to all the other alternatives is the best possible option for disposing of radioactive waste and protecting from its dangers. This conviction, however, should not be misunderstood or taken as a reason for declaring that geological disposal is a safe disposal option without any reservations.

Sources:
(OECD, 1995), (ICRP, 2013), (GRS, 2018)

B 1.2: Legal framework for long-term management of radioactive waste and spent fuel

No. 162

Source:
B 1.2, p. 206
Reference text:
Whole section

Scientific evaluation:
No reference to the ICRP (2013). Cf. no. 255 on the importance of the ICRP in this table. One of the central references is therefore missing from the subsection entitled "Long term management in international recommendations". Publications from the OECD/NEA listed on the right are barely mentioned in the whole Part B 1.2. The only reference to the OECD/NEA in Part B. 1.2 is a "collective opinion" from 1995. However, the status of discussions has made considerable progress since that time, particularly in terms of ethical principles. In addition to

a reference to the ICRP (2013), OECD (1995) should be complemented by OECD (2014).
Cf. no. 161 in this table on the importance of the ICRP (2013) for the long-term management with reference to ethical principles and the long-term preservation of information.
Cf. no. 255 in this table on the importance of the ICRP (2013) for the long-term management with reference to radiation protection principles.

Sources:
(ICRP 2013), (OECD, 1995), (OECD, 2014)

No. 163

Source:
B 1.2, pp. 205–206 and Annex 5.4
Reference text:
Sub-section "Main provisions and principles addressing long term management" und "Long term management in international recommendations"

Scientific evaluation:
This outlines the importance of the ICRP (2013) for the long-term management with reference to ethical principles and preserving information.
The importance of preserving information and knowledge in the long term is not considered or recognised in the JRC Report. Even if the preservation of records is mentioned in the report (Part B 1.2) as a quotation from article 17 of the Joint Convention, the topic is largely ignored in other respects. It is particularly missing in the chapters on the basic principles of deep geological disposal.
The core element in largely ignoring this topic involves failing to or not taking note of three key documents:

- ICRP (2013): the document is only used in the JRC Report as a reference (among many others) for definitions of "safety case" and "stakeholders". The key statements in ICRP (2013) are not mentioned. The ICRP recommendations in ICRP (2013) are therefore missing in the JRC Report, even if the document itself is quoted.
- OECD (2014) is not considered.
- OECD (2019) is not considered.

The ICRP recommendations in 2013 (ICRP, 2013) are an addition to the recommendations in 2007 (ICRP, 2007), particularly when applying these principles to deep geological disposal and very long periods of time. As a result, the ICRP recommendations in 2013 should have been listed in Annex 5.4 "General principles of radiation protection" – and also in Part B 1.2, in the subsection entitled "Main provisions and principles addressing long term management" and "Long term management in international recommendations". Their absence is probably one of the reasons for omitting the topic of "preserving information and knowledge in the long term" in the complete JRC Report.

Re. the content and relevance of the ICRP recommendations (ICRP, 2013) for the long-term basic principles and the long-term preservation of information and knowledge:
The ICRP deals with the problem in ICRP (2013) that one of the cornerstones of radiation protection – "control" (control of the radiation source and/or a geographical area) – is only available to a limited extent with deep geological disposal, because controls cannot be guaranteed over very long periods of time. The ICRP therefore recommends that the concept of "oversight" should be added for radiation protection principles over very long periods of time. "Oversight" means both "monitoring" and "watchful care" and "keeping an eye on things". Here are the key statements:
"[...] this publication introduces the concept of oversight or 'watchful care' during different phases of waste management and disposal. This is a crucial factor,

influencing how the system of radiological protection is applied over long periods of time, and referring not only to monitoring but also to decisions on actions and implementation of plans. […]
The level of oversight affects the capability to control the source, i. e. the waste and the repository, and to avoid or reduce potential exposures." (ICRP, 2013, p. 6f)
Preserving information and knowledge in the long term, including long-term documentation, is one of several oversight measures in the post-closure phase of a repository and, overall, forms the basis for maintaining oversight over fairly long periods of time.
The Radioactive Waste Management Committee (RWMC) of the OECD/NEA has confirmed the ICRP's oversight concept in a consensus paper (OECD, 2014), relating it to the long-term preservation of information and knowledge ("RK&M preservation") and has therefore formulated an ethical standard.

Key formulations from the Collective Statement (OECD, 2014):
"There is no intention to abandon repositories for geological disposal of radioactive waste, either before or after closure. The RWMC accepts and adopts the ICRP [2013] position on the relevance of maintaining oversight over the geological disposal of radioactive waste for as long as practicable.
Maintaining Records, Knowledge and Memory for a radioactive waste repository after its closure will allow future members of society to take informed decisions regarding the repository and its contents and to prevent inadvertent human intrusion. Enabling future members of society to make informed decisions is part of responsible, ethically sound, sustainable radioactive waste management, and is in line with a prudent approach regarding safety."

As these statements have not been included in the JRC Report and are particularly missing from the subsection entitled "Long term management in international recommendations" (chapter B 1.2, p. 206), the JRC Report is not based on the latest international recommendations from the ICRP and the OECD/NEA in 2013 and 2014 as regards "preserving information and knowledge in the long term" – including its inclusion in radiation protection principles and ethical principles for disposal.
The OECD/NEA launched the so-called RK&M Initiative ("Initiative on the Preservation of Records, Knowledge and Memory Across Generations") in 2011 to thoroughly deal with this topic; its final report (OECD, 2019) must be viewed as a compendium of principles and guidelines for preserving information and knowledge in the long term in the context of disposal. The absence of this reference in the JRC Report underlines the fact that no significant importance is attributed to this topic in the document.
From the point of view of the OECD/NEA, the importance of preserving information and knowledge in the long term is significant and its objectives are formulated as follows: 1.) To enable future generations to make informed decisions and 2.) To enable future generations to prevent inadvertent human intrusion. Any waiver of preserving information and knowledge in the long term would therefore affect the basic principles of "avoiding imposing undue burdens on future generations" (on account of 1.) and "causing no significant harm to humans" (on account of 2.).

Cf. no. 255 in this table re. the importance of the ICRP (2013) regarding long-term management with reference to radiation protection principles.

Sources:
(ICRP, 2013), (OECD, 2014), (OECD, 2019)

B 2: Inventory of radioactive waste and spent fuel in the European Union

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B 2.1: Generation of radioactive waste and spent fuel

No. 164

Source:

B 2.1, p. 210

Reference text:

Table 2.1–1. Typical annual radioactive waste generation rates from the nuclear fuel cycle (excluding mining and milling)

Scientific evaluation:

An IAEA TECDOC from 2017 is mentioned as the source for the table presented in 2.1–1. The JRC Report in Part B 2.1, p. 210 takes over a table (Table 2.1–1) from the IAEA document entitled TECDOC 1817 (IAEA, 2017), which illustrates typical annual waste generation rates. The figure quoted for decommissioning power plants has a footnote in the JRC Report, which does not exist in the IAEA source. The footnote in the JRC Report states that the unit is [m^3 per plant (1 GW)], while in the IAEA source it is specified as [m^3/GW x year], i. e. an annual waste generation rate. While the JRC Report mentions a waste volume arising from the decommissioning of a nuclear power plant of "375 m^3 per plant (1 GW)" in Part B 2.1, the associated IAEA source refers to an annual waste generation rate. The volume of waste arising from decommissioning a power plant would therefore be significantly higher than specified in the JRC Report in Part B 2.1, depending on the time required to dismantle it.

Source:

(IAEA, 2017)

No. 165

Source:

B 2.1, p. 210, Table 2.1–1

Reference text:

The largest fraction of the radioactive waste comes from operation and decommissioning of nuclear power plants and associated nuclear fuel cycle activities (see Chapter 3.3. of part A of this report). Table 2.1–1 shows the typical annual waste generation per unit energy broken down to the different stages of the nuclear fuel cycle. The table does not include waste from uranium mining and milling activities. In terms of activity, most of the radioactive waste is generated during operation of nuclear power plants, in particular by the fuel irradiation. However, in terms of volume, most of the waste comes from decommissioning of nuclear power plants and other nuclear facilities at the end of their operational lifetime, mainly as low level waste.

Scientific evaluation:

Decommissioning and dismantling place huge challenges on the life cycle of nuclear fuel supply units. A more detailed presentation is necessary.

No. 166

Source:

B 2.1, p. 211

Reference text:

Most of the radioactive waste resulting from non-power generating activities consists of short-lived radionuclides. Management of this type of waste usually involves storage for a time span allowing radioactive decay and subsequent disposal as conventional waste.

Scientific evaluation:
This ignores the fact that most of the radioactive waste (L/S or liquid/solid) from medical diagnostics comes from Tc-99m. Patients excrete the extremely long-lived Tc-99 (t1/2 = 211,000 yrs) via stool and urine. More than 30 million examinations are conducted around the world every year. About 60,000 examinations using Tc-99 are performed every week in Germany alone. The average, injected activity amounts to about 100 MBq. This creates wastewater with an activity of approx. 6 TBq of TC-99 in Germany alone every year. Because of its complex forming capability, its long half-life and its capacity as a soft beta emitter, proving that the nuclide exists in waste water is a metrological problem and a containment problem when designing a repository. This problem is only dealt with later and in a different context on p. 221: “These radionuclides will govern the long-term radiotoxicity in the case of HLW not containing actinides”.

Source:
(OECD 2011a), (Bockisch et. al., 2009), https://www.nuklearmedizin.de/leistungen/leitlinien/html/neben_schild.php?navId=

B 2.2: Classification of radioactive waste

No. 167
Fundstelle:
B 2.2, pp. 211–216, specifically p. 214
Bezugstext:
Whole section

Scientific evaluation:
The classification of radioactive waste in Germany in waste that develops heat and waste that does not develop heat is presented correctly.
However, the fact that safe containment is required in Germany for at least 1,000,000 years for the safety case for HLW is not mentioned.

The general conditions explicitly mentioned in the report of 300 years for LLW (“radioactivity of such waste types will decay to background levels within about 300 years”) would not be adequate in Germany in such a general manner today. No minimum term for the safe containment of ILW is provided in the report.

By setting the requirement for retaining a disposal site for LLW and ILW at a very low level or frequently restricting discussions to short-lived waste (LLW-SL & LILW-SL), the potential effects of any discharge are systematically underestimated to a huge degree; as a result, nuclear energy when compared to other forms of generating energy is presented in very favourable terms in relation to waste that does not generate any heat.

Source:
(Site Selection Act), (cf. also Rübel, 2019)

B 2.3: Amounts of radioactive waste and spent fuel in nuclear fuel cycle

No. 168

Source:
B 2.3, p. 216
Reference text:
The estimated total inventory of radioactive waste in the EU territory at the end of 2016 was 3 466 000 m^3. It is important to note, that 71.6% of this volume has been already disposed of. The amount of radioactive waste in storage was 983 000 m^3.

Scientific evaluation:
Unfortunately, the report does not provide any more details about the way of disposing of 12,000 m^3 of intermediate-level waste, for example. A greater breakdown would be desirable, because it is not clear whether the report is talking about material reuse in the sense of recycling or a definition issue. This suggests that waste, e.g. from uranium enrichment, was redesignated and therefore deemed to have been "disposed of".

No. 169

Source:
B 2.3, p. 216
Reference text:
The inventory data includes all radioactive waste present on the EU territory originating from various civil activities.

Scientific evaluation:
Unclear statement. Individual information about civil research/military research into radioactive waste would be desirable here.

No. 170

Source:
B 2.3, p.217 and B 5.2.4, pp. 260–273
Reference text:
2.3. Amounts of radioactive waste and spent fuel in nuclear fuel cycle [...]
The first deep geological repository for spent fuel disposal will start its operation within the present decade in Finland. Corresponding repositories are in advanced licensing stages in Sweden and France as well.

5.2.4. Implementation of national projects
Crystalline Rock: KBS-3 project in Finland & Sweden (S. 260ff)
Argillaceous formation: France (S. 268ff).

Scientific evaluation:
The scientific, technical progress for disposal projects for the three repository projects in Sweden, Finland and France is outlined on pages 260–273. The report states that the repository in Finland will start operating this decade (p. 217).

However, the development status of these projects in terms of public participation and transparency is largely ignored. The requirements for participation formulated in the report (e.g. forming a consensus between all the stakeholders, cf. above as a requirement in Teil B 5.2.3.1) are not applied to the three country examples.

No. 171

Source:

B 2.3, p. 217

Reference text:

The first deep geological repository for spent fuel disposal will start its operation within the present decade in Finland.

Scientific evaluation:

One-sided statement. “[...] is scheduled to start [...] ” would be more neutral wording here.

No. 172

Source:

B 2.3, p. 217

Reference text:

At the end of 2016 approximately 58 000 tHM of spent fuel was stored in the EU and around 900 tHM of spent fuel (about 1.5 %) was sent for reprocessing outside the EU with the resulting radioactive waste from reprocessing expected to return as specified in the relevant agreements.

Scientific evaluation:

Firstly, the source(s) of the figures for spent fuel elements should be mentioned at this point and, secondly, example sources for “relevant agreements” should also be cited here as specifically as possible.

No. 173

Source:

B 2.3, p. 220

Reference text:

In addition to the solid radioactive wastes some countries (i. e. the United States of America and the Russian Federation) have accumulated large volumes of liquid wastes (around 62 million m^3) that will require specific management approaches. As most of this waste originates from defence activities it is not discussed in this report.

Scientific evaluation:

This ignores the fact that Poland completely exports its fuel elements from the “MARIA” research reactor to the reprocessing facility in Russia (cf. p. 217). As a result, some of the Russian waste water must be entered on the balance sheet as the residue from the reprocessing of European fuel elements. The last HEU (highly enriched uranium) was transferred to Russia in September 2016.

Sources:

https://www.iaea.org/newscenter/news/
sensitive-nuclear-material-removed-poland

https://nucleus.iaea.org/RRDB/RR/HeaderInfo.aspx?RId=291

B 2.4: Main radionuclides affecting the properties of high level waste

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B 3: Strategies and technologies for radioactive waste management

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No. 174

Source:
B 3, p. 224
Bezugstext:
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.

Scientific evaluation:
Any deliberate dilution of radioactive waste is according to German law forbidden, cf. Section 61 Para. 3 of the Radiation Protection Act.

B 4: Storage of radioactive waste

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B 4.1: Storage of low and intermediate wastes

No. 175

Source:
B 4.1, p. 229
Reference text:
Short-term storage is typical for short-lived radioactive waste classified as VLLW or LLW, as many countries already have operational near-surface or surface disposal facilities.

Scientific evaluation:
All types of radioactive waste in Germany (including low- and intermediate-level waste) must be taken to deep, geological disposal sites. Cf. nos. 114 and 201.

B 4.2: Storage of spent fuel and high level waste

No. 176

Source:
B 4.2, p. 233
Reference text:
Figure 4.2–1. Radioactive waste locations in Germany, including spent fuel storage facilities.

Scientific evaluation:
The Figure (map of Germany) is not up-to-date in terms of the existing storage sites for low- and intermediate-level waste (therefore incomplete). The source quoted, www.cleanenergywire.org (a network of journalists) demonstrates that it contains the figures for 2015. This is not specified in the report.

Source:
(CLEW, 2015)

No. 177

Source:
B 4.2, p. 234
Reference text:
Several technologies are available for dry storage. Spent fuel assemblies are placed in baskets inside canisters.

Scientific evaluation:
The JRC's presentation is correct in terms of content, but does not use the normal international description for the different storage systems. Generally, a distinction is made between the canisters in the canister-based systems and the casks, as they are used in Germany ("dual-purpose casks"). The containers referred to later are not subdivided into those containers that serve as pure transport containers and those that serve as a surrounding shield for storage.

No. 178

Source:
B 4.2, p. 238
Reference text:
Entire section "Wet storage"

Scientific evaluation:
The remarks on wet storage are restricted to a very short section. This is unsatisfactory, particularly because of the link with reprocessing.

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.

Source:
(IAEA, 1999)

No. 179

Source:
B 4.2, p. 239
Reference text:
Entire section "Implications of extended storage"

Scientific evaluation:
The report addresses the principle challenges for extended interim storage, but draws no conclusions in relation to potential effects.
It would have been desirable to have a more precise description of the possible courses of action here.

B 5: Disposal of radioactive waste

No. 180

Source:
B 5, (cf. A 3.3.8.8, p.165 too)
Reference text:
Entire section

Scientific evaluation:
The disposal path depends on the national regulations. All radioactive waste, which has not been released from supervision under the Atomic Energy Act, will be disposed of at deep geological repositories (> 300 m deep). Germany does not envisage any near-surface repositories.

Source:
(BMU, 2020)

No. 181

Source:
B 5, p. 336
Reference text:
The Taxonomy Expert Group therefore considers that the challenges of safe long-term disposal of CO_2 in geological facilities, which are similar to the challenges facing disposal of high level radioactive waste, can be adequately managed.

Scientific evaluation:
The comparison between CCS and disposal of radioactive waste is inappropriate, as CO_2 is not a harmful substance for humans in comparison with high-level radioactive waste. The safety rules for the two types of disposal are therefore different.

No. 182

Source:
B 5, p. 241
Reference text:
Thus the radionuclides of the radioactive waste must be contained in a disposal facility designed so that they will not reach the accessible biosphere in significant amounts, and will never exceed the limit below which they can cause no harm.

Scientific evaluation:
The following statement "and will never exceed the limit below which they can cause no harm" is contradictory, as even doses lower than 0.3 mS/y can cause health problems (e.g. Section 99 (1) of the Radiation Protection Ordinance). According to the BfS:
"Dose thresholds do not serve as a dividing line between hazardous and non-hazardous exposure to radiation. Exceeding a threshold means that the probability that health consequences will occur (particularly cancer) is higher than a figure that is set as being acceptable. Parliament or regulators define the thresholds.
As there is no dose below which ionising radiation certainly does not involve any health risk, a certain if slight risk exists even below the thresholds and this increases as the dose rises. Any exposure to radiation must therefore be prevented even below the set thresholds, if possible, and, if this is not feasible, be kept as low as possible (principle of optimisation)."

Source:
https://www.bfs.de/DE/themen/ion/strahlenschutz/grenzwerte/grenzwerte_node.html

No. 183

Source:

B 5, p. 241

Reference text:

Disposal is the last step in the process of radioactive waste management, and consists of the emplacement of radioactive waste in an appropriate facility without the intention of retrieval. Disposal facilities are designed to contain the radioactive waste and to isolate it from the accessible biosphere and from the public for as long as its radioactivity remains hazardous. More specifically, the disposal facilities aim at reducing the likelihood (and consequences) of human intrusion, and at inhibiting, reducing and delaying the migration of radionuclides from the waste to the accessible biosphere; in case radionuclides are released and eventually reach the biosphere their amounts are sufficiently low that the potential radiological consequences are negligible.

[...]

Thus the radionuclides of the radioactive waste must be contained in a disposal facility designed so that they will not reach the accessible biosphere in significant amounts, and will never exceed the limit below which they can cause no harm.

Scientific evaluation:

Attention is drawn to the quotation already listed in the remarks on Part A 3.3.8.5, p. 162 by the OECD/NEA with regard to this statement (OECD, 1995), as it seems particularly relevant in this context and really does not require any other comments.

“It must be acknowledged that the most robust and passively safe system that can be devised by current generations may ultimately be compromised by the actions of a future society, through inadvertent intrusion.”

In the case of HI, there are no grounds for ruling out that discharge may occur in association with this and exceed the prescribed thresholds. However, it is not helpful either to speculate about possible doses. Instead, a review should take place to what degree measures can be adopted to reduce the possibilities of HI and/or the consequences associated with HI. Relevant measures have been identified and discussed as part of the IAEA’s HIDRA project.

Quotation:

“As part of the HIDRA project, Member States developed an approach for identifying and selecting scenarios to be assessed, and protective measures to reduce the potential for and consequences of inadvertent human intrusions. The project also fostered information sharing and communication about potential inadvertent intrusion.”

Sources:

(OECD, 1995), (IAEA/HIDRA, Phase I 2013–2015),
(IAEA/HIDRA, Phase II 2016– 2018)

No. 184

Source:

B 5, p. 241

Reference text:

Disposal facilities are designed to contain the radioactive waste and to isolate it from the accessible biosphere and from the public for as long as its radioactivity remains hazardous.

Scientific evaluation:

The evidence of safety for a repository is continued for a period of time that has been set by parliament. The period in Germany amounts to one million years. The statement that the waste is no longer dangerous after the expiry of this period cannot be supported. The radiotoxicity of highly active waste is evident in Figure

2.4–1 (Part B) of the JRC Report. This describes a radiotoxicity level of 105 Sv per tonne of spent fuel for a period of one million years.

Source:
JRC Report, Figure B 2- 4.1

No. 185

Source:
B 5, p. 242
Reference text:
Low level waste is disposed of in surface or near-surface facilities (up to a depth of a few tens of meters – typically up to 30 m) with passive engineered and natural barriers aimed to last a few hundred years. The same route can be used for intermediate level waste with half-lives below ~30 years. Longer-lived intermediate level waste is disposed of at facilities a few tens, to a few hundred meters deep – typically up to 300 m. Spent fuel and high level waste, which in addition to high levels of radioactivity also generate nonnegligible decay heat, are to be disposed of in deeper geological disposal facilities several hundred – typically more than 300 – meters below ground level, with engineered barriers and embedded in stable geological formations whose characteristics and evolution in the long term are predictable.

Scientific evaluation:
The presentation gives the impression that disposing of LLW at facilities on or near the surface is the standard option. However, there are a number of countries that have envisaged deep geological disposal for LLW and every other kind of radioactive waste (e.g. Switzerland, Finland, Sweden and Germany) (KOM, 2015).

Source:
(KOM, 2015)

No. 186

Source:
B 5, p. 243
Reference text:
The disposal of radioactive waste is implemented through a stepwise approach. Each step is taken based on a documented decisionmaking process, in which all relevant, scientific and technical advances, operational experience, social aspects and updates in the legal and regulatory framework can be incorporated. This process allows making decisions that are flexible and do not oblige sticking to a rigid roadmap for the entire lifecycle of the facility, and that involve all the relevant stakeholders in the process. This makes it possible to incorporate new knowledge, decide among different options that are available, or go back to a previous step if necessary.

Scientific evaluation:
The report mentions at this point the requirement for a learning procedure in the search for a repository. This requirement is not specified or operationalised at any point during the ongoing course of the report. There is no presentation/assessment/ evaluation in the presentation in chapter 5.4 about the three country examples of Finland, Sweden and France, which, according to the report, have made great progress in this matter; however, the report does not state whether these three countries meet the requirement for a learning process formulated in Part B 5.
This gap in the report is particularly evident through the fact that the scientific and technical requirements for a repository are certainly operationalised in Part B 5.2.3.2 (in contrast to the requirement for a learning process) and the scientific

and technical status/progress in the projects in the three countries of Finland, Sweden and France are outlined and assessed in Part B 5.2.4 in terms of these requirements.

No. 187

Source:
B 5, p. 243
Reference text:
With the partial exception of the so-called natural analogues (i. e. sites where natural nuclear reactors occurred billions of years ago (see Chapter 6.4.3 of part B of this report), there is no empirical evidence generated by a radioactive waste disposal facility that has gone through all the three stages (pre-operational, operational, and post-closure) for the entire timeframe foreseen (up to a hundred thousand years for a deep geological repository).

Scientific evaluation:
The time-frame needing to be considered for a deep geological repository is as much as one million years, depending on the national regulations.

Sources:
(BMU, 2020), (OECD und IAEA, 2020)

No. 188

Source:
B 5, p. 243
Reference text:
For this reason 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.

Scientific evaluation:
General comment: as no disposal site has yet been operational for HLW, the verb "is" here is incorrect.

No. 189

Source:
B 5, p. 243
Reference text:
The safety demonstration includes a description of the site and features of the disposal facility, the characteristics and amount of waste that can be emplaced (waste acceptance criteria), and a description of a relevant series of scenarios including [...]

Scientific evaluation:
Imprecise/incomplete. The so-called safety case is described here.

Source:
(IAEA, 2012)

No. 190

Source:
B 5, p. 243
Reference text:
Post-closure institutional controls are limited in time and depend on the nature of the disposal facility. As an example, institutional monitoring and control is limited

to a few decades for very low level disposal, and a few hundred years (typically 300) for surface or near-surface facilities for low level waste disposal.

Scientific evaluation:
Maintaining institutional controls over a period of several hundreds of years cannot be guaranteed. Any loss of knowledge about the site and the radiological risk emanating from the site cannot be ruled out (ICRP, 2013; IAEA HIDRA Phase I and II). As a result, the potential for inadvertent intrusion into the disposal site exists. The intrusion opportunities near the surface are greater than with a deep geological repository, as the intrusion opportunities at greater depths involve only some of those relevant to intrusion near the surface (IAEA, 2012; IAEA HIDRA Phase I and II).

Beyond this, there are no plans for institutional controls for deep geological repositories from passive safety and ethical points of view, which aim to relieve future generations of any excess burdens (OECD, 1995). An institutional control period of 300 years is normal for near-surface repositories, as stated in the JRC Report. However, the issue of reasonable burdens for future generations needs to be raised here too.

Sources:
(IAEA, 2012), (OECD, 1995), (ICRP, 2013), (IAEA/HIDRA, Phase I 2013–2015), (IAEA/HIDRA, Phase II 2016–2018)

No. 191

Source:
B 5, p. 243
Reference text:
With the partial exception of the so-called natural analogues (i. e. sites where natural nuclear reactors occurred billions of years ago (see Chapter 6.4.3 of part B of this report), there is no empirical evidence generated by a radioactive waste disposal facility that has gone through all the three stages (pre-operational, operational, and post-closure) for the entire timeframe foreseen (up to a hundred thousand years for a deep geological repository).

Scientific evaluation:
The statement that no experience exists with handling deep geological repositories, which have already passed through the pre-operational, operational and post-closure phases, can only be agreed with. However, it should be noted that only one licensed repository for HLW is being constructed at this time globally. With regard to the specified time period of up to hundreds of thousands of years, however, this time-frame is believed to be inadequate for dealing with or having contact with the high-level radioactive waste in a non-hazardous manner. Cf. also the remarks on Part B, Chapter 1.1, p. 200. AkEnd has set the assessment period for isolating the waste at one million years, for example. However, this period does not describe the non-hazardous dealings with the waste, but represents a qualitative end mark for forecasting favourable areas (AkEnd, 2002).

Source:
(AkEnd, 2002)

No. 192

Source:
B 5, p. 243
Reference text:
The long timeframes of the disposal of spent fuel and high level waste also raise concerns about how the conditions of the site might evolve in the remote

future, including the impact of the facility and the waste emplaced therein on the surrounding media (e.g. due to heat generation), and how society and human behaviour would be tens or hundreds of thousands of years from now.

Scientific evaluation:
The doubts mentioned here about developing a repository for HLW are justified. Deriving and reviewing scenarios, which take into account relevant repository developments, are subject to a number of uncertainties. These uncertainties include, for example, the occasional occurrence of events and processes, their interaction and ultimately their nature. Any estimate of these uncertainties with regard to their effect on a repository system cannot be even partially resolved or only with great difficulty.
There is therefore agreement that the development of society and human behaviour beyond the underlying periods of time cannot be forecast (NAS, 1995). As a result, there remains an unknown factor, which cannot be resolved, even if researchers make enormous efforts. This also means that even an extremely robust disposal system cannot completely rule out any effects by people in future, even by using further optimisation measures (OECD, 1995).

Sources:
(NAS, 1995), (OECD, 1995)

No. 193

Source:
B 5, p. 243
Reference text:
For this reason 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. The safety demonstration includes a description of the site and features of the disposal facility, the characteristics and amount of waste that can be emplaced (waste acceptance criteria), and a description of a relevant series of scenarios including potential and extreme events that could lead to the release of radionuclides from the waste and to subsequent exposure of the public to radiation. The safety demonstration includes calculations and models of the behaviour of the engineered barriers under different circumstances, of the migration of the radioisotopes through the natural barriers, of the effects of climate events, hydrogeological, seismic and other phenomena, and of the impacts and consequences of potential releases of radionuclides from the waste to the public and/or to the environment.

Scientific evaluation:
(Cf. the previous remarks on Part B 5, p. 243, no. 192 on this matter).

B 5.1: Disposal low level waste

No. 194

Source:
B 5.1, p. 244
Reference text:
[…] Germany will use mines at depths of several hundred meters to dispose of radioactive waste regardless of its classification.

Scientific evaluation:
(Geological) disposal in deep geological formations is the intended destination

for any radioactive waste that cannot be released from monitoring procedures in Germany.

Source:
(BMU, 2020)

No. 195

Source:
B 5.1, p. 244
Reference text:
The objective of a near surface disposal facility is the isolation of the low level radioactive waste from the accessible biosphere and the public for a period of a few hundred years, typically 300.

Scientific evaluation:
Comprehensibility: Information about sources should be provided here.

No. 196

Source:
B 5.1, p. 244
Reference text:
The objective of a near surface disposal facility is the isolation of the low level radioactive waste from the accessible biosphere and the public for a period of a few hundred years, typically 300. It is considered that after that period of time there are no more radioactivity hazards. On such a timescale, the behaviour of the materials that constitute the engineered barriers is well known and predictable, and the barriers are considered sufficiently reliable. Therefore, there is no need for deep geological repositories for the disposal of low level waste. Although the waste acceptance criteria are specific for each facility, near surface disposal facilities establish radionuclide content limits associated with half-lives and specific activities: higher concentrations are allowed for beta/gamma emitters with half-lives shorter than some 30 years; and lower concentrations are accepted for alpha emitters and other longer-lived nuclides.

Near surface disposal facilities encompass a variety of designs for the emplacement of solid radioactive waste: earthen trenches, above ground engineered structures, engineered structures just below the ground surface, and rock caverns, silos and tunnels excavated at depths of up to a few tens of metres underground.

Scientific evaluation:
The statement indicates that the typical time for isolating LLW in near-surface repositories is 300 years. It also states that the material behaviour of the technical barriers is well-known during this time and can be forecast and the barriers should be viewed as sufficiently reliable.
There is no further information to back up this statement and/or prove it with references. Near-surface repositories cover, as the next paragraph in the JRC Report indicates, a number of different disposal concepts and different technical facilities and components. The requirements placed on the materials must be adapted by taking account of, e.g. the specific conditions at the site, the range of waste needing disposal, the climatic circumstances and other general conditions. Transferring the aforementioned generalising statement to all near-surface repositories must first be described and confirmed.
We cannot share the statement that there is no need to place LLW in deep geological repositories. When compared to deep geological repositories, any near-surface sites represent a greater potential risk. Aspects such as robustness, accessibility, protection, loss of knowledge etc. must be considered in the

safety assessment. Typical institutional controls of 300 years cannot in principle be guaranteed for near-surface repositories either.
The conclusion drawn by the “Storage of High-Level Radioactive Waste” committee on or near the surface can in principle be transferred to near-surface repositories too.

This indicates that the uncertain forecasts about social and political developments and the risk of accidents (for example, through a lack of maintenance) and attacks caused by war or terrorism, the risk of proliferation, the huge organisational and financial expenditure for future generations and climatic uncertainties when storing waste on or near the surface do not represent an acceptable option for the verifiably safe, long-term handling of radioactive waste.

Source:
(KOM, 2016)

No. 197
Source:
B 5.1, p. 244
Reference text:
Therefore, there is no need for deep geological repositories for the disposal of low level waste.

Scientific evaluation:
This statement is incorrect as an absolute assertion. The issue can also be answered differently. Low- and intermediate-level radioactive wastes are planned to be disposed of in deep geological repositories in Germany.

No. 198
Source:
B 5.1, p. 244
Reference text:
Although there is no need for deep geological repositories for the disposal of low level waste, some countries such as Sweden and Finland are disposing their low level radioactive waste in low and intermediate level waste disposal facilities located between 60 and 100 m below ground level, and Germany will use mines at depths of several hundred meters to dispose of radioactive waste regardless of its classification. There are other countries that operate disposal facilities at different depths.

Scientific evaluation:
As already explained with regard to Part B 5, p. 242, there are a number of countries that envisage geological disposal for LLW and some of them for all kinds of radioactive waste. It is therefore impossible to understand that near-surface disposal is presented as the standard option for disposing of LLW.
Geological disposal offers a number of benefits compared to near-surface disposal. Some passive protection exists, for example, which is not available at near-surface repositories (KOM, 2016).

Source:
(KOM, 2016)

No. 199
Source:
B 5.1, p. 246
Reference text:
Some modular designs account for the partial installation of covers over disposal

cells that have been already filled with waste packages. The design and characteristics of the cover must consider the erosion due to inclement weather, and prevent or strongly hamper human intrusion.

Scientific evaluation:
Deriving measures against HI must be considered as part of optimising the facility and should be a firm part of planning work and providing evidence of safety. Although institutional controls and design measures reduce the possibility of human intrusion, it cannot be completely ruled out. Other human activities at the site must also be included in addition to HI. These activities are different from HI in that no direct intrusion is associated with them, but a possible indirect effect, for example, by changing the groundwater situation at the repository site. A large number of measures have been established and discussed as part of the IAEA's HIDRA Project.

Sources:
(IAEA/HIDRA, Phase I 2013–2015), (IAEA/HIDRA, Phase II 2016–2018)

No. 200

Source:
B 5.1, p. 246
Reference text:
After the facility closure, a period of institutional control begins. Institutional control includes an active phase for knowledge preservation, prevention of human intrusion, and monitoring and surveillance to detect any potential degradation of the engineered barriers. During this phase implementing corrective measures, up to and including retrieval of the radioactive waste if necessary, is possible. A passive phase of institutional control is also implemented: it includes the archiving of the relevant information, and the installation of durable markings to try and prevent human intrusion. Institutional control monitoring and surveillance proactively supports the confidence in the effectiveness of the disposal facility to contain the waste and isolate it from the biosphere.

Scientific evaluation:
In principle, the same applies here as has already been stated. Maintaining institutional controls cannot be guaranteed. As part of optimisation, measures must be adopted to reduce the possibilities of HI and/or the possible consequences if somebody does intrude. Ultimately, no statements can be made either about whether the envisaged measures against HI or messages can be correctly detected and understood if knowledge about the disposal site is lost. The markings mentioned here in particular are the subject of heated discussion. This also includes the risk that future generations might tend to be attracted to the site and encouraged to make their way into it. Reference is also made at this point to the IAEA's HIDRA Project, which, among other things, also discusses the issue of markings for repositories.

Sources:
(IAEA/HIDRA, Phase I 2013–2015), (IAEA/HIDRA, Phase II 2016–2018)

No. 201

Source:
B 5.1, p. 248
Reference text:
Disposal of low level waste in near surface facilities is an industrial reality. Disposal facilities for radioactive waste generated in the nuclear fuel cycle have been constructed and have been operating for many years in many countries such as (list is not exhaustive) Bulgaria, Czech Republic, Finland, France,

Germany, Hungary, Japan, Norway, Russian Federation, Romania, Slovakia (see figure 5.1–3), Spain (see Figure 5.1–5), Sweden, the USA and the UK.

Scientific evaluation:
As far as Germany is concerned, all kinds of radioactive waste (including low- and intermediate-level radioactive waste) are to be taken to deep geological repositories. Cf. nos. 114 and 175. The context creates the false impression that near-surface repositories have already been built in Germany. However, Germany is not correctly classified in this list.

No. 202

Source:
B 5.1, p. p. 249, Para. 3
Reference text:
There are some cases in which the safety (re)assessment of disposal facilities indicated challenging conditions and resulted in the decision to recondition part of their radioactive waste and dispose of it in the same or in another facility. An example of this is the Asse II, a rock salt mine in Germany that was used to dispose of low and intermediate level waste between 1967 and 1978. Since the mine revealed safety issues, it was decided to retrieve the waste and dispose of it in a different facility [5–5].

Scientific evaluation:
Asse II was formally never a repository site and should definitely not be included in the list here. The incorrect classification of the Asse II mine as a repository for radioactive waste gives rise to the fear that research has not been sufficiently adequate at other points too. The context of the Asse example implies that there is no problem in retrieving waste either, if new findings require this. No mention is made of the overall problems or the difficulties, costs and new potential risks associated with any planned retrieval.

No. 203

Source:
B 5.1, p. 249
Reference text:
There are some cases in which the safety (re)assessment of disposal facilities indicated challenging conditions and resulted in the decision to recondition part of their radioactive waste and dispose of it in the same or in another facility. An example of this is the Asse II, a rock salt mine in Germany that was used to dispose of low and intermediate level waste between 1967 and 1978. Since the mine revealed safety issues, it was decided to retrieve the waste and dispose of it in a different facility [5–5].

Scientific evaluation:
Additional comments to no 202:
To be strictly accurate, it is necessary to state that the Asse II mine was not a repository in the sense of the Atomic Energy Act during the period when items were disposed of there (and in the decades after this). It could not have been, because disposal was not legally defined or regulated until the 4th amendment of the Atomic Energy Act in 1976.

As part of the German government's environmental programme in 1971, however, there was an unmistakable declaration that "a repository had been created at the Asse salt mine […], which […] could safely accommodate about 250,000 cubic metres of radioactive waste until the year 2000".

As the report correctly states, Asse II can be used as an example that a renewed safety review has led to the decision that the waste disposed of there must be reconditioned and disposed of at a different facility.

From an historical point of view, however, the highly simplified formulation in the last sentence of the reference text requires some commentary and additional information. The statement that a decision has been made to retrieve the waste because safety problems have come to light in the mine is misleading and it also suggests a close temporal connection between the recognition of the problems and the decision to retrieve the waste. In fact, at least 30 years have passed between these two stages.

It would be better to state that the weaknesses of the old mine had already been clearly seen during the 1960s, even in the responsible ministry, and had become clear to a broader circle of state authorities by the end of the 1970s/beginning of the 1980s.

Besides, the example of Asse II implies that there would be no problem retrieving waste from the mine if this would be necessary according to new findings in the future. The overall problem as well as the expectable difficulties, costs and risk potentials are not considered within the report.

Sources:
(Möller, 2009), (Möller, 2016)

No. 204

Source:
B 5.1.3, p. 337
Reference text:
There is an advanced regulatory framework in place in the Community for both carbon dioxide storage and radioactive waste management. In terms of practical implementation, there is currently no operational geological disposal for carbon dioxide or for radioactive waste.

Scientific evaluation:
There are currently two CCS projects in operation, the Snovhit and Sleipner gas fields in Norway, in which CO_2 has been stored for more than 20 years. Other CCS projects are planned by 2024 (the Acorn Project (GB) and the Northern Lights Project (Norway).

Source:
https://www.norway.no/de/germany/norwegen-germany/aktuelles-veranstaltungen/aktuelles/weltweit-erste-co2-lagerstatte-feiert-jubilaum--und-weist-in-die-zukunft/

B 5.2: Deep geological disposal of spent fuel and high level waste

No. 205

Source:
B 5.2, pp. 249–273
Reference text:
Entire section

Scientific evaluation:
Part B 5.2 provides an overview of basic principles and common industrial

practices as well as selected information about national implementation projects for deep geological disposal of HLW in Europe.

Importantly, in the context of the entire report, this chapter is not an evaluation of deep geological disposal per se – rather, it serves as a knowledge base for the assessment of the eco-balance sheet found in Part A and identifying potential threats (Part A 3.3.8.5).

In view of this, Part B 5.2 cannot be assessed against the relevant taxonomy criteria. What BASE can however evaluate is the extent to which Part B 5.2 is fit-for-purpose (e.g. whether the descriptions are factually true, correspond to the state-of-the-art developments in the field, and if they are sufficiently complete) for the analysis performed in Part A of the JRC Report.

No. 206

Source:

B 5.2, in relation to A 3.3.8, p. 249–273

Reference text:

Entire text

Scientific evaluation:

The role of Part B 5.2 is to provide a knowledge base for the assessments performed in Part A 3.3.8. However, this knowledge base is presented in an isolated, stand-alone manner. There are few actual references from Part A to Part B. It is therefore not clear which statements in Part A are meant to be supported by which elements of knowledge presented in Part B.

No. 207

Source:

B 5.2.1, p. 249

Reference text:

[…] the intergenerational equity entails:

- choosing technologies and strategies which minimise the resource requirements, cost and risk burdens passed on to future generations
- not unduly restricting the freedom of choice of future generations

Scientific evaluation:

The development and implementation of a geological disposal programme takes decades. Monitoring the disposal site after closure will also continue for at least another 100 years. During this long period, following generations have to deal with problems that were caused by their predecessors. The long-term burdens caused by geological disposal for several generations are not adequately considered. In light of the requirement “to minimize the resource requirements, cost and risks burdens passed on to future generations,” it can be assumed that the challenges associated with deep geological disposal have already violated the principle of intergenerational justice. In particular, the development and implementation costs of a deep geological repository are generally high and hard to predict over the long time frames involved (BMU 2015). Will future generations be willing to share in these costs? How should spending be prioritised in times of crisis (e.g. during a global health or environmental crisis)? What if funding is interrupted? The discussion presented does not consider these kinds of questions.

Source:

(BMU, 2015)

No. 208

Source:

B 5.2.1, p. 250

Reference text:
There is consensus in the scientific and regulatory communities that geological disposal is the preferred solution for the long term management of spent nuclear fuel and other high-level long-lived radioactive waste forms, including high-level waste resulting from closed fuel cycle scenarios [5–14, 5–15, 5–17 5–22]

Scientific evaluation:
There is a broad consensus concerning the need for deep geological disposal of high-level radioactive waste. However, it is necessary to note that the safety of a geological repository has not yet been practically demonstrated and no operational experience exists. This underlines the role of a safety case when building trust and acceptance.

No. 209

Source:
B, 5.2.2, p. 250
Reference text:
Disposal facilities are designed to ensure both operational safety and post-closure safety. The operational safety of geological disposal facilities is provided by means of engineered systems and operational controls; the post-closure safety is provided by means of multiple engineered and natural barriers.

Scientific evaluation:
Part B 5.2.2 discusses the safety of repositories by providing a selection of results from radiological safety assessments performed in the Finnish, Swedish and French programmes. These discussions are restricted to (i) the post-closure safety, and (ii) the radiological aspects of safety. Although repository safety during the operational period is mentioned, it is done to a very limited degree by stating that operational safety will be “guaranteed by technical systems and operational controls”. There is no more detailed discussion of these measures or a presentation and assessment of the risks during the operational period.

No. 210

Source:
B 5.2.2, p. 250
Reference text:
Chemical and mechanical interactions between natural and engineered barriers will occur [5–69]

Scientific evaluation:
Viewed in isolation, this is an understatement that may be viewed as misleading. The chemical and mechanical interactions mentioned between the barriers will not only occur, but also inevitably lead to barrier degradation and impairment of their safety functions over time. It is important to stress that these processes are unavoidable and hard to quantitatively predict over the very long period of time when their performance must be assessed. If empirical data is not available, simplifying and enveloping assumptions must be made in order to assess the functioning of these barriers over the relevant time-frames. It is one of the main hurdles of the safety case to convincingly show that these simplifications and assumptions can be defended.

No. 211

Source:
B 5.2.1, p. 250
Reference text:
Fulfilling this requirement includes providing reasonable assurance that any risk

from inadvertent human intrusion would be very small [5–16]

Scientific evaluation:
There is general agreement that human behaviour and actions, including any intrusion into a repository, cannot be predicted (National Academy of Science, 1995; Roger Seitz et al., 2016). On the basis of this statement, unintentional human intrusion into a repository, if knowledge about the facility is lost, cannot be ruled out (ICRP, 2013).
As a consequence of this, it is impossible to exclude contamination of the environment if human intrusion takes place during the post-closure phase of a repository (ICRP, 2013). International discussions are taking place (the IAEA HIDRA Project) that any comparison of possible contamination with predefined thresholds makes limited sense. Instead, measures against HI should be identified as part of repository optimisation and investigations should take place to see whether they are harmful or not with regard to operational and long-term safety and they should be implemented if the findings are positive. These measures should either reduce the possibilities of HI or, if it occurs, the consequences resulting from it.
Despite these measures, the risk of unintentional human intrusion cannot be completely ruled out and a certain risk, which is hard to reduce, will always exist. The report does not deal with this important aspect.

Sources:
(NAS, 1995), (Seitz et al., 2016), (ICRP, 2013), (ICRP-122),
(IAEA/HIDRA, Phase I 2013–2015), (IAEA/HIDRA, Phase II 2016–2018)

No. 212

Source:
B 5.2.2, p. 250–251
Reference text:
Fulfilling this requirement includes providing reasonable assurance that any risk from inadvertent human intrusion would be very small [5–16] [...]
In clay there are no fractures and the diffusivity is extremely low [...]

Scientific evaluation:
The reference here is to “clay” (unconsolidated) and not as commonly used with regard to “consolidated clay” or “clay formations”. This is misleading, as consolidated clay should be mentioned as a host rock in the context of this paragraph and not unconsolidated clay. There may well be fractures in consolidated clay-rock or they may form during the assessment period.

A brief treatment of fractures in consolidated clay-rock can be found in the BGR clay study (2007) on p. 13.

Source:
(Hoth et al., 2007)

No. 213

Source:
B 5.2.3, p. 252
Reference text:
Figure 5.2.3–1 outlines the different phases of a national DGR project in chronological order from the first planning to its closure. R&D and the build-up of the safety case, technical activities, and decision stages are illustrated in green, blue and red respectively. The process in all phases also involves interaction between the waste management organizations, the regulators and the general public, in line with the intragenerational equity principles, and as stipulated in the Radioactive Waste Directive [5–13]

Scientific evaluation:
The report paints a simplified and overly optimistic picture of the process of implementation for a national deep geological repository (DGR). No mention is made of the examples of failed/halted programmes in the past (e.g. in the UK and USA) – typically due to a lack of public acceptance. Admittedly, there are also some examples of geological disposal that are making headway towards successful implementation (notably in Finland and Sweden). Moreover, there are examples of national disposal programmes being restarted based on a traceable and transparent basis with a focus on public involvement (such as in Germany). In any case, discussions should take place about the inherent risk that a disposal programme may fail completely or be significantly delayed (even if the programme implements what is today considered to be best practice) due to social, technological, political or economic problems. Although these risks are difficult to assess, they are nonetheless real and should be mentioned.

No. 214

Source:
B 5.2.3, p. 253, Figure 5.2.3–2
Reference text:
/

Scientific evaluation:
It is not clear why the Federal Ministry of Economics and Technology is listed here instead of the Federal Ministry for the Environment.

No. 215

Source:
B 5.2.3.1, p. 253–254
Reference text:
Key stakeholders, and their roles include [5–31]:
– […]

Scientific evaluation:
The list of bullet points does not mention NGOs. They would involve e.g. BUND or ausgestrahlt in Germany. As a result, the stakeholders that are traditionally particularly critical are omitted from the list.

No. 216

Source:
B 5.2.3.1, p. 254
Reference text:
The role and interactions of the different stakeholders must be clearly defined, in particular between policymakers, regulator and waste management organization. All the stakeholders need to be involved during the entire process, which must be characterized by transparency, trust and confidence building through open dialogue among the stakeholders, and in particular with the general public and the decision-makers. The documentation, observations and the field and laboratory studies that support a repository safety case are likely to be both massive and unintelligible to a non-expert stakeholder, and to the average member of the public. Yet it is only through a broad consensus of all stakeholders and the public that proposed repository will be accepted. The challenge is to communicate the case for safety in plain language, which accurately reflects the outcome of the scientific and technical studies, analyses and calculations [Communication on the Safety Case for a Deep Geological Repository, © OECD 2017, NEA No. 7336]

Scientific evaluation:
The report cites various requirements for the participation process in the search for a repository at this point (clarity of roles for those involved, transparent and trustworthy involvement of all the relevant stakeholders through a process of open dialogue, a broad consensus of all the stakeholders and the general public etc.). As the report continues, however, these requirements for the participation process are not specified or operationalised at any point.

There is no assessment/evaluation about whether the requirements for the participation process formulated here in the search for a repository are met by the three country examples of Finland, Sweden and France, which are far advanced in searching for a repository site, according to the report.

This gap in the report is particularly evident because (in contrast to the requirements for the participation process) the scientific/technical requirements for a repository in Part B 5.2.3.2 are definitely further operationalised and the scientific/technical status/progress in the projects in the three countries of Finland, Sweden and France is described and assessed in Part B 5.2.4.

No. 217

Source:
B 5.2.3.1, p. 254
Reference text:
Yet it is only through a broad consensus of all stakeholders and the public that proposed repository will be accepted. The challenge is to communicate the case for safety in plain language, which accurately reflects the outcome of the scientific and technical studies, analyses and calculations [5–29].

Scientific evaluation:
There is no mention at this point that it is possible that there may be no consensus among all the stakeholders. The problems of searching for a site are therefore simplified and presented in a one-sided manner.

No. 218

Source:
B 5.2.3.2, p. 254
Reference text:
[…] the waste packages ensure containment for these “early” stages […]

Scientific evaluation:
“ensure containment” → safe containment is presented as a fact. This presentation is misleading, as no country in the world has got beyond concepts yet.

No. 219

Source:
B 5.2.3.3, p. 257–258
Reference text:
A common denominator for any European national programme is that it complies with the international conventions and the Radioactive Waste Directive, it is adaptive and stepwise, and it includes public engagement.
[…]
Following these stages should ensure inter- and intra-generational equity, and should achieve the main objective that the final disposal does not result in any significant harm for present or future generations.
[…]
As stated above the involvement of the different stakeholders, in particular the

independent regulator, is important; the local community and region must also be supportive.

Scientific evaluation:
The process stages for building, operating and decommissioning a disposal site are described in Teil B 5.2.3.3. However, there is no mention of participation stages during the relevant process stages or how intergenerational justice can be created. Individual requirements are formulated at the start of the chapter, e.g. that there should be justice within and between the generations or that there must be support for the repository project for the local community affected by it. These requirements are, however, not mentioned in any greater detail. It remains unclear how these requirements can be achieved/handled, if there is no support for the local community involved, for example.

No. 220

Source:
B 5.2.3.3, p. 258
Reference text:
This depends on the size of the nuclear programme and whether a closed or open fuel cycle has been adopted.

Scientific evaluation:
It is not clear whether a "partially" or "fully closed fuel cycle" is meant here. Due to this lack of precision, the impression may be given that a fully closed fuel cycle is already possible.

No. 221

Source:
B 5.2.3.3, p.258
Reference text:
Stage 2: Selection of site; the research and development and data collection become site specific and design options are reduced. Note that site selection is not only based on the best geological formation; local acceptance and absence of highly valuable natural resources, (..)

Scientific evaluation:
Some reference to the need for public participation for local acceptance would be desirable here.

No. 222

Source:
B 5.2.3.3, p. 259
Reference text:
The radioactive waste needs to be kept isolated from the biosphere for very long times. Pursuant the intergenerational equity principle it must be a requirement that Records, Knowledge and Memory (RK&M) prepared as part of the DGR project are maintained after its closure in order to allow future generations to make informed decisions regarding the repository and its content, including to prevent inadvertent human intrusion [5-30]. The solutions depend on the time-frame and become more challenging the further we look into the future. In the short term, detailed records can be preserved essentially using today's technology, whereas for much longer time frames less detailed information can be kept, but using very stable methods [5-30]. Figure 5.2.3-6 illustrates such a hierarchical RK&M system.

Scientific evaluation:
It makes greater sense to list the cited passage including Figure 5.2.3-6 directly

below the heading “5 Disposal of radioactive waste” at the end of the text. In its current position, only nuclear fuels and high-level radioactive waste, which are to be disposed of in deep geological repositories, are explicitly considered, according to the statements in the JRC Report. The OECD’s RK&M project may have considered deep geological repositories, but makes no distinction between the level of activity in the waste needing being disposed of, so that even low- and intermediate-level radioactive waste are considered. However, in chapter 5.1 “Disposal of low-level waste” on p. 244, the JRC Report explicitly points out that “Germany will use mines at depths of several hundred meters to dispose of radioactive waste regardless of its classification” and facilities at various depths are earmarked for disposing of low- and intermediate-level radioactive waste in other countries too.

By repositioning the text passage that is being mentioned and the Figure in the suggested manner, any reference to classifying radioactive waste is irrelevant and increases the general significance of long-term documentation for disposal.

Source:
(OECD, 2019)

No. 223

Source:
B 5.2.4, p. 264
Reference text:
The diagrams show that the dose caused by the repository will be well below the maximum allowed limit and hence will cause no significant harm to humans.

Scientific evaluation:
The report makes a deterministic statement about future developments here. Safety analyses/diagrams, however, cannot make such absolute statements and they do not claim to do so either. The statement pretends to provide certainty, but this does not correspond to reality.

No. 224

Source:
B 5.2.5, p. 273
Reference text:
Entire section

Scientific evaluation:
Numerous aspects are omitted here which represent complex problems when disposing of high-level radioactive waste. For example, the high costs of the complete project, acceptance of the project, which is hard to achieve (acceptance not only at the time of selecting the site, but during the complete procedure, i. e. throughout many generations), “intergenerational equity”, which is already showing cracks and therefore cannot be achieved, the usage conflicts with other geological resources at the repository for current and future generations.

No. 225

Source:
B 5.2.5, p. 275
Reference text:
There is broad consensus in the scientific community that deep geological disposal is the safest long-term solution for spent nuclear fuel and high level radioactive waste. The deep geological repositories (DGR) are based on a multi barrier combination including both engineered and natural barriers. The

operational safety of geological disposal facilities is provided by means of engineered systems and active operational controls. Disposal facilities are designed to be passively safe after closure. The DGR are designed so that potential radioactive release from them occurring in the remote future are well below the maximum allowed dose limit set by the relevant regulation, which, in turn are orders of magnitude below natural background dose levels, and which ensure that no significant harm will be caused to humans by the repository. There are presently no deep geological repositories in operation, but after four decades of research and technology development the construction and operation of several repositories is expected in the present decade. The process for the design, licensing, construction, operation and final closure of deep geological repositories is regulated by national law, based on international conventions and European directives; this means that there is a common ground shared by all programmes based on the best available principles and concepts. The very long process to build a DGR is stepwise and reversible to various extents to ensure that the best available technology is used and that the radiological effects are and will be as low as reasonably achievable.

Scientific evaluation:
The conclusion in chapter 5 emphasises the scientific and technical status of developments for disposal, which has taken place during four decades. In the light of these developments, the construction and operation of repositories is expected to start in various European countries during this decade. As far as the development status of public participation in disposal in the European countries overall and in these countries in particular, no assessment is made of the requirements for participation that are listed at the beginning in the conclusion. Has consensus been achieved among all the stakeholders in these countries? Has it been possible to achieve a long-term, open dialogue to involve all the stakeholders in the countries in a transparent and trustworthy manner?
It is clear here that the JRC Report heavily depends on an understanding of sustainability, which largely focuses on various ecological criteria for sustainability. A broader understanding of sustainability, as has been defined by the United Nations, for example (UN, 2015), which considers participative decision-making as an integral part of sustainability, cannot be found in the JRC Report.

Source:
(UN, 2015)

No. 226

Source:
B 5.2.5, p. 273
Reference text:
There is broad consensus in the scientific community that deep geological disposal is the safest long-term solution for spent nuclear fuel and high level radioactive waste. The deep geological repositories (DGR) are based on a multi barrier combination including both engineered and natural barriers. The operational safety of geological disposal facilities is provided by means of engineered systems and active operational controls.
Disposal facilities are designed to be passively safe after closure. The DGR are designed so that potential radioactive release from them occurring in the remote future are well below the maximum allowed dose limit set by the relevant regulation, which, in turn are orders of magnitude below natural background dose levels, and which ensure that no significant harm will be caused to humans by the repository. There are presently no deep geological repositories in operation, but after four decades of research and technology development the construction and operation of several repositories is expected in the present decade. The process for the design, licensing, construction, operation and final closure of deep geological repositories is regulated by national law, based on international

conventions and European directives; this means that there is a common ground shared by all programmes based on the best available principles and concepts. The very long process to build a DGR is stepwise and reversible to various extents to ensure that the best available technology is used and that the radiological effects are and will be as low as reasonably achievable.

Scientific evaluation:
The report adopts one-sided perspectives at various points. It only explicitly considers, firstly, the experience of member states, which have continued to rely on nuclear power as a central pillar of their energy supplies, and, secondly, countries that are in a position to implement their own disposal programmes. Thirdly, all the arguments in the report are solely based on “intended operations”. This fails to consider the systematic question of which assessment would have been reached if “non-intended operations” or beyond-design plant conditions had been included in the assessment too. This creates an impression that only conditions necessary to achieve the DNSH criteria have been used in the report, but not adequate conditions. The deduction method is therefore hard to understand and not sufficiently transparent.

B 5.3: References for Chapter 5

No. 227

Source:
B 5.3, S. 273
Reference text:
Entire section (References)

Scientific evaluation:
The report uses a broad knowledge base as outlined in the IAEA and OECD/NEA documents. Laws, directives, but also research strategies (EURAD) are listed. A large number of reports from operators is used to underpin and illustrate the latest science and technology which is complemented by statements by regulators and governments. Only very few peer-reviewed journals are used. Arguments from critics or NGOs are not mentioned at all, let alone discussed.
The knowledge base from the operators’ side is very broad and suitable to illustrate the technical feasibility. However, it is only subject to a very limited independent review. The possibility of complementing this by independent publications (journals, monographs) has not been sufficiently used. As critics have not been included either, the knowledge base seems unbalanced and overall possibly unsuitable for supporting a neutral position.

B 6: Research and development for radioactive waste management

No. 228

Source:
B 6, p. 277–290
Reference text:
Entire section

Scientific evaluation:
The enormous expenditure on research, which has been conducted in the past, is still being performed and will also continue in future, clearly illustrates the

complexity of the issues associated with the safety of a repository system. A number of questions and detailed aspects still have to be clarified. It is possible that some issues will not be fully resolved and remain tainted by uncertainties. In any comparison of potential sustainable technologies for the resources that are used and are still required for research, the technology for using nuclear energy is probably easily the top-ranking item. In this connection and considering the overall environmental criteria, the question needs to be asked about whether the sustainability of the technology exists to the fullest extent.

B 6.1: Introduction

No. 229

Source:
B 6, pp. 277–290
Reference text:
Entire section

Scientific evaluation:
One important aspect is completely omitted and it plays an important role in research today: the connection between interim storage, the operating phase and the “long-term phase” (integrated safety case) and the relevance of the connection for safety on the relevant time scale.

Sources:
(IAEA, 2016a), (IAEA, 2016b), (IGSC, 2008), (OECD/NEA, 2016), (GRS, 2020)

No. 230

Source:
B 6, pp. 277–290 or B 6.5, p. 289
Reference text:
Entire section

Scientific evaluation:
The topic of uncertainties is only mentioned in a subordinate clause here. However, it makes sense to at least mention here that the impression is created that there are no uncertainties because this topic has not been dealt with in the previous chapters. The issue of uncertainties is playing a key role in research today.

B 6.2: Scope of R&D activities

Nr. 231

Source:
B 6.2, p. 277–278
Reference text:
In the case of HLW and spent fuel, the long term evolution of the wasteform during extended interim storage and after disposal in a geological repository is studied, with particular attention to solid state ageing effects during the pre-disposal stages and to mechanisms that may affect corrosion resistance, and release of radionuclides in groundwater in the final repository. Similar studies are performed on the waste package and containment barriers ensuring that the safety function is maintained. There is a large body of knowledge collected over

the years through numerous scientific projects and collaborations, which provides a solid basis for implementation of final disposal options; this is reflected in the safety case demonstration and in the documentation supporting the disposal licence application submitted to the relevant national regulatory authorities.
[…]
The deep geological repository for spent fuel and high level waste is designed to contain and isolate radioactive waste for a very long time. Engineered barriers and natural conditions will contribute to delay the occurrence of direct reaction between radioactive waste and groundwater, and radionuclide release from the wasteform for thousands of years or more. Moreover, the properties of the selected geologic media in the far field will ensure very slow migration of released radionuclides. R&D efforts include determining the timeframe of interest for eventual radionuclides mobilization, and extrapolating the safety functions to the set of conditions expected at that time, to ensure that the potential exposure of the public does not reach the limits established by the relevant regulations.

Scientific evaluation:
A multi-barrier concept forms the basis for disposal in most safety concepts. This concept is built on a number of technical, geotechnical and geological barriers, which are more or less intertwined with each other. The functionality of the individual barriers has to be demonstrated and proven for the envisaged periods of time in each case. Overall, the effectiveness of the complete system has to be proven, even if one or several individual barriers fail. The evidence of the functionality of the technical (e.g. casks) and geotechnical barriers and the ability to transfer this to long periods of time represent an enormous challenge.

No. 232

Source:
B 6.2, p. 277
Reference text:
In particular, the scope of research programmes includes:
Basic knowledge
Acquiring basic knowledge on physical and chemical properties of radioactive species and compounds allows optimizing their immobilization in corrosion resistant wasteforms for final disposal, and allows understanding mechanisms and processes affecting the long term behaviour of the wasteforms after disposal. As such, research is a necessary component informing safe management of radioactive waste. In the case of HLW and spent fuel, the long term evolution of the wasteform during extended interim storage and after disposal in a geological repository is studied, with particular attention to solid state ageing effects during the pre-disposal stages and to mechanisms that may affect corrosion resistance, and release of radionuclides in groundwater in the final repository. Similar studies are performed on the waste package and containment barriers ensuring that the safety function is maintained. There is a large body of knowledge collected over the years through numerous scientific projects and collaborations, which provides a solid basis for implementation of final disposal options; this is reflected in the safety case demonstration and in the documentation supporting the disposal licence application submitted to the relevant national regulatory authorities.
The current focus of basic research is to extend the body of knowledge to cover special cases, e.g. new or unconventional wasteforms, and to reduce uncertainties associated with the very long timeframe of final disposal, e.g. the accurate determination of the inventory of radionuclides relevant to the waste repository evaluations and/or the properties of “hard to characterize” radionuclides [6–29]

Scientific evaluation:
1. At this point in the text, there should be a list of the research topics that are important at this time. Under the heading “Basic knowledge”, only a few examples are mentioned, which relate to the inventory. The aspect of basic

research, which deals with host rocks, is completely missing at this point. However, it is impossible to mention all aspects of basic research here. Due to the brief outline, scientifically controversial topics are therefore not mentioned (for example, human intrusion (IAEA/HIDRA)).

2. Only one source is mentioned in this paragraph; other sources are missing. A summary from one source, which is quoted one paragraph earlier (IGD-TP, 2020), would have been very suitable at this point. It describes the challenges and current aspects of future research into repositories.
3. Generally, it is necessary to ask why research and research programmes with a focus on Europe are treated in chapter 6. At least in "6.1 Introduction", there should be some more detailed critical estimation of activities related to this outside Europe with the major emphasis on what is happening there. Simply naming some countries (e.g. p. 286, end of the third paragraph "Such global partnerships with, e.g. with USA and Japan have been in existence for a long time") without mentioning other sources seems inadequate.

Sources:
(IAEA/HIDRA, Phase I 2013–2015), (IAEA/HIDRA, Phase II 2016–2018),
(IGD-TP, 2020), (US, 2011)

No. 233

Source:
B 6.2, p. 277
Reference text:
The current focus of basic research is to extend the body of knowledge to cover special cases, e.g. new or unconventional wasteforms, and to reduce uncertainties associated with the very long timeframe of final disposal, e.g. the accurate determination of the inventory of radionuclides relevant to the waste repository evaluations and/or the properties of "hard to characterize" radionuclides [6–29]

Scientific evaluation:
This deals with uncertainties, among other things. It should be pointed out in this connection that a number of uncertainties, which cannot be further reduced or resolved, still remain at the end (GRS, 2018). R&D must be used at an early stage on how to deal with these uncertainties or how these uncertainties can be taken into account.

Source:
(GRS, 2018)

No. 234

Source:
B 6.2, p. 278
Reference text:
Disposal in geological repository
[…] (see Chapter 6.3.1 below).
The outcome of the research is peer reviewed and, especially the components directly used for safety and licensing applications, subjected to independent critical assessment and review by the regulators, including comparisons and cross-referencing among different programmes.

Scientific evaluation:
1. The reference to Part B 6.3.1 is incorrect and must probably mean 6.4.1.

2. The peer review in the field of repositories must be distinguished from a scientific peer review, as is performed for scientific publications in scientific journals.

3. The aspect of “components” is unclear. It is not clear what is meant by this term. If technical components are meant, which are developed as part of R&D, a review can take place from a purely scientific point of view. If, however, components are meant, which are to be used as the latest technology, a review cannot take place from a scientific point of view, but as an assessment as part of a licensing procedure.

No. 235

Source:
B 6.2, p. 278 up to B 6.2, p. 279 top
Reference text:
Over the decades, in the case of final disposal in geological repository, the R&D contributions have been deployed along two main dimensions: space and time.
[…]
the safety functions to the set of conditions expected at that time, to ensure that the potential exposure of the public does not reach the limits established by the relevant regulations.

Scientific evaluation:
Only very general statements are made here. There is only one source for a specific aspect going back to 1980. Providing sources is the basis for scientific work.

Source:
(DFG, 2019)

No. 236

Source:
B 6.2, p. 278
Reference text:
R&D (or, in this case, RD&D: research, development and demonstration) provides the knowledge and the technical and scientific assessment basis for system design, siting and optimisation as well as contributions to fundamental understanding of the underlying processes affecting the behaviour of the repository (see Figure 6.2–1). Experimental and modelling activities provide an important input to the safety case and the performance assessment of the radioactive disposal, and consequently contribute to the licensing process.
RD&D activities stretch from the initial decision to build a disposal for radioactive waste through all implementation and operation stages until disposal closure and possibly through post-closure monitoring (see Chapter 5.2 of part B of this report).

Scientific evaluation:
At this point in the text it is clear that no consistent distinction is made between
a. research and development
b. the state of the art of science and technology.
The latter is crucial for disposal (e.g. Section 19 of the Site Selection Act). Research and development can move these findings forward.

No. 237

Source:
B 6.2, p. 279
Reference text:
- The deep geological repository for spent fuel and high level waste is designed to contain and isolate radioactive waste for a very long time. Engineered barriers and natural conditions will contribute to delay the occurrence of direct reaction between radioactive waste and groundwater, and radionuclide release from the wasteform for thousands of years or more.

Scientific evaluation:
Technical barriers ("engineered barriers") should delay the spread of radionuclides which has to be demonstrated and proven for the envisaged period of time. The term used in the text ("thousands of years or more") should be formulated in more precise terms.
Section 1 of the Site Selection Act applies in Germany:
The best possible safety is the site that will be determined as part of a comparative procedure arising from the sites that are suitable in each phase according to the crucial requirements in this Act and guarantees the best possible safety for the permanent protection of people and the environment from ionising radiation and other damaging effects of this waste for a period of one million years. This also includes preventing unreasonable burdens and obligations for future generations.

B 6.3: Innovative options for the back-end of the nuclear fuel cycle

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No. 238
Source:
B 6.3, p. 280
Reference text:
Due to the fact that fast reactors allow multiple (re)cycling of the fractions of fuel/waste not consumed/burned, the final result of iterating this process would be an almost complete use of the fuel and an increasingly reduced fraction of long-lived species (mostly in terms of minor actinides fraction) in the irradiated fuel.

Scientific evaluation:
Minor actinides have not yet been added to the fuel. In this sense, this is simply a forecast. It is unclear to what degree minor actinides can be added to the fuel, as they have a negative effect on the safety properties of the fuel.

No. 239
Source:
B 6.3, p. 280
Reference text:
Another potential benefit from the adoption of a closed nuclear fuel cycle would be the significant reduction of the footprint of the geologic repository for HLW (see Figure 3.3.8–11 of part A of this report).

Scientific evaluation:
Relevant factors for the size of the repository are not only the volume, but also the decay heat at the time when the materials are put into the site ("Storage of High-Level Radioactive Waste" committee according to Section 3 of the Site Selection Act 2016, p. 227).

Source:
(KOM, 2016)

No. 240
Source:
B 6.3, p. 280
Reference text:
Implementing partitioning and transmutation would reduce the time necessary

for the HLW to decay down to the natural reference level to some centuries instead of some hundred thousand years.

Scientific evaluation:

1. It is unclear here what “natural reference level” means. The decay periods mentioned are generally (far) too short. For example, Np-237: 2.14 million years.

2. As far as the debate about partitioning and transmutation is concerned, the results of the BASE research report recently published on the BASE home page entitled “Technical safety analysis and risk assessment of concepts for partitioning and transmutation facilities for high-level radioactive waste” should be used. BASE draws the following conclusion:
   “The expert report concluded that partitioning and transmutation will tend to provide negative effects for the two goals mentioned in the Site Selection Act – the best possible protection for people and the environment from the effects of ionising radiation and preventing unreasonable burdens for future generations”. [Source of this with other BASE assessments of the report at: https://www.base.bund.de/DE/themen/kt/kta-deutschland/p_und_t/partitionierung-transmutation.html]

Source:
(BASE, 2021)

No. 241

Source:
B 6.3, p. 281
Reference text:
Abbildung 6.3–1

Scientific evaluation:
The Figure shows that transmutation of Pu and Am would lead to a significant reduction of the radiotoxicity (through inhalation). The diagram does not show the fission products, which initially dominate the radiation, at least at thermal reactors (Schwenk-Ferrero 2013). Studies in Switzerland also showed that long-lived fission products have extremely high mobility in soil and therefore account for the lion’s share of the dose released into the biosphere (NAGRA – National Cooperative for the Disposal of Radioactive Waste 2002, p. 203).

Sources:
(NAGRA, 2002), (Schwenk-Ferrero, 2013)

No. 242

Source:
B 6.3, p. 281
Reference text:
Significant R&D effort at national, European and international level, has been dedicated to investigating options aimed at implementing a closed fuel cycle which includes P&T. Table 6.3–1 lists Euratom Research and Training programmes dedicated to P&T since the 5th Framework Programme (FP) of the European Commission ([6–14]; see also e.g. [6–13]. Although essentially all steps of P&T have been demonstrated at laboratory scale, the Technology Readiness Level is not yet corresponding to industrial maturity. Therefore, the input required from research activities includes a broad spectrum of applications, to fill some remaining knowledge gaps and to support implementing prototype level demonstrations to increase the TRL of these concepts. The progress in this area is associated also with the development of new irradiation facilities. R&D programmes involving Member States, the EC and international partners and organizations are continuing the effort.

Scientific evaluation:
P&T is neither developed nor operational on the industrial level. A technical feasibility is currently uncertain, however it would require at least a decade for it to be operational. A hypothetical delaying of disposal and placing the waste in long-term near-surface interim stores would lead to further risks. This option has been the subject of work performed by the German “Storage of High-Level Radioactive Waste” committee for example. It has concluded that any permanent storage of waste for an indefinite period in the storage facility on or near the surface would require long-term social controls. In this context, the uncertain forecast about social and political developments and the risk of accidents (for example, caused by a lack of maintenance) and attacks caused by war or terrorism, the risk of proliferation, the huge organisational and financial effort and expenditure for future generations and climatic uncertainties play a major role. The committee also reached the following conclusion with regard to the topic of long-term storage on or near the earth’s surface:

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

Source:
(KOM, 2016), quotation p. 218

No. 243

Source:
B 6.4, p. 282–288
Reference text:
Entire seciton

Scientific evaluation:
The JRC Report particularly focuses on the funding provided by the EU for joint projects. This however raises the question about independent, varied research in many directions. As all the relevant European WMOs and TSOs are combined in joint projects, any critical diversity seems doubtful. In this context, reference should be made to the German procedure with a regulatory authority conducting research.

Sources:
(BASE, 2019a), (BASE, 2019b)

No. 244

Source:
B 6.4.3, p. 288
Reference text:
Table 6.4.3–1 describes the main features characterizing the two types of URL [6–26].

Scientific evaluation:
The literature in [6–26] is simply quoted with reference to the distinction between a “generic URL” and a “site-specific URL”, but it should be noted that the OECD/NEA literature from 2013 no longer represents the current reality in Germany, particularly with the BfS as the responsible authority and Gorleben as the URL. In the OECD/NEA report, ‘URL’ refers to both an ‘underground research laboratory’ and an ‘underground rock laboratory’. In this context, it is necessary to ask to what degree the facilities at Morsleben and Konrad actually meet the requirements for being called an ‘URL’.

Source:
Literatur [6–26] ist einsehbar unter folgender Internetadresse:
https://www.oecd-nea.org/jcms/pl_48874/underground-research-laboratories-url

B 6.4: European research in radioactive waste management: who does it and how it is structured

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No. 245

Source:
B 6.4.1, p. 283

Reference text:
As described in the preceding section, research organizations or entities (national or supra-nationals as in the case of the JRC) supply scientific data addressing basic and/or applied open issues, and perform validation modelling and experimental campaigns, often providing input to the performance assessment of a geological repository or waste disposal concept.

Scientific evaluation:
At various points in the text, it is clear that no consistent distinction is made between
a. research and development
b. the state of the art of science and technology.
Cf. no. 236.

ANNEX 1: Legal and regulatory background of nuclear energy

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ANNEX 2: Summary of LCA results for all lifecycle phases of nuclear energy

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ANNEX 3: NACE codes corresponding to main lifecycle phases of nuclear energy

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No. 246

Source:
Annex 3, p. 355

Reference text:
D – Electricity, gas, steam and air conditioning supply
E – Water supply; sewerage, waste management and remediation activities

Scientific evaluation:
It would have been desirable to have some information about how the environmental objectives of the Technical Expert Group in chapter 5.1., e.g. on preventing

air and water pollution (cf. Table A.3-1 points D and E) and in the phases of the life cycle of nuclear energy, are considered. Which NACE codes or TSCs are used to implement them?

ANNEX 4: Illustrative TSC tables

No. 247

Source:
Annex 4.1, p. 358
Reference text:
(DNSH) (3) Sustainable use and protection of water and marine resources

Scientific evaluation:
The statements and activities for protecting water and marine resources purely relate to the effective increases in temperature. When discharging cooling water away from a nuclear power plant to a river/the sea, checks must also be performed on the radionuclides, similar to those for temperature measurements.

No. 248

Source:
Annex 4, pp. 357–358
Reference text:
2. Construction and operation of new nuclear power plants:

The activity complies with the criteria set out in Appendix E to this Annex.

1. Extension of the service time of existing nuclear power plants Compliance with the WENRA Safety Reference Levels for Existing Reactors and the Euratom NSD ensures that the existing facility is able to cope with extreme natural hazards (such as floods and extreme weather conditions) potentially resulting from future climate change. The resilience of the EU nuclear power plants against extreme natural hazards (including earthquakes) was demonstrated in the EU stress-tests exercise.

2. Construction and operation of new nuclear power plants Fulfilling the WENRA Safety Objectives for New Nuclear Power Plants and compliance with the Euratom NSD guarantees that the new facility will be able to cope with extreme natural hazards (such as floods and extreme weather conditions) potentially resulting from future climate change.
(DNSH2) (6) Protection and restoration of biodiversity and ecosystems

Scientific evaluation:
Cf. no. 146: even if the plants (new and old ones) satisfy the rules mentioned, accidents with serious radiological consequences may be improbable, but cannot be categorically ruled out. This should be assessed and discussed with regard to the “Do No Significant Harm” goal. The report has a significant gap here.

No. 249

Source:
Annex 4.1, p. 359
Reference text:
(DNSH) (6) Protection and restoration of biodiversity and ecosystems

Scientific evaluation:
It would be desirable to mention specific examples and sources about how to

protect natural and cultural assets of the first order in Natura 2000 or the UNESCO World Cultural Heritage. How will these “necessary mitigation measures [...] [be] implemented”?

No. 250

Source:
Annex 4, p. 367
Reference text:
Regarding (4) Transition to a circular economy:
The largest need for materials that are neither recyclable nor reusable results from the encapsulation and backfilling, but their amount is very small.

Scientific evaluation:
Although the amount of bentonite[1] used in deep geological repositories may be small relative to global bentonite production, it should be noted that the specific material (e.g. in terms of its mineralogical composition, and particularly the content of undesirable components) used in the repository will probably be subject to strict technical specifications. This might make it significantly more challenging to obtain the type of bentonite that meets such requirements and poses a potential risk of restricted availability.

[1] Bentonite is the material that is often used as a buffer and backfill product in the construction of repositories in crystalline or clay host rocks.

No. 251

Source:
Annex 4, S. 366
Reference text:
Do no significant harm (’DNSH’):
(2) climate change adaption
The design and construction of the facilities applied for the interim storage and disposal of high level radioactive waste shall ensure the containment of the waste and its isolation from the accessible biosphere also during the occurrence of extreme natural hazards, such as earthquakes, tornados, flooding, etc.

Scientific evaluation:
This annex shows, that the JRC, against their omission of incidents and accidents in Part A 3.3.8.3, is including these kind of events for their development of technical screening criteria.
Thereby the definition of technical screening criteria becomes plausible on the basis of European or rather national law, directives and regulatory framework. However, the regulations do not categorally rule out accidents. This should be considered in an assesment of nuclear energy, cf. no. 146.

No. 252

Source:
Annex 4, p. 361–362, TSC Table 2 “Mining and processing of uranium ore”
Reference text:
An Environmental Impact assessment (EIA) or screening has been completed, for activities within the Union, in accordance with Directive 2011/92/EU. For activities in third countries an EIA has been completed in accordance with equivalent national provisions or international standards.

Scientific evaluation:
The uranium mine at Crucea in Romania has been the only uranium mine on EU soil since 2017. Prior to this date, the Czech Republic (2017), France (2001) and

Portugal (also 2001!) had closed their uranium mines. A current EIA on uranium mining activities in the EU is therefore very straightforward.
If the environmental law in other uranium mining countries is used to draw up EIAs, this is often a dubious and fruitless project. It is true that most modern industrial countries in the northern hemisphere have appropriate regulations (e.g. the "Surface Mining Controlling and Reclamation Act" in the USA (1977)), but most of the African countries, which perform uranium mining, do not have these kinds of legal bases – and even in Australia, the rules are very incomplete.
It would therefore have been desirable if EIAs for countries outside the EU had provided support for EU taxonomy and the EU environmental criteria too.

Source:
(Le Monde diplomatique et al., 2019)

No. 253

Source:
Annex 4 (3), p. 364
Reference text:
The ALARA (as low as reasonably achievable) principle should be applied during the control of radioactive discharges consistently.

Scientific evaluation:
It is fundamentally doubtful whether any assessment of discharging radioactive process waste water from the reprocessing facility should take place simply on whether it meets the ALARA principle and the statutory thresholds according to the DNSH criterion of "Sustainable use and protection of water and marine resources". Discharging no radioactivity would provide the most sustainable protection for the marine ecosystem.

No. 254

Source:
Annex 4, p. 366, Point 4, (already inserted here, as related to the previous point in the TSCs)
Reference text:
Entire Annex

Scientific evaluation:
The criteria listed in Annex 4 of the JRC Report contain the following requirements apart from the aspect of "Transition to a circular economy":

"Climate change adaptation":
"The design and construction of the facilities applied for the interim storage and disposal of high-level radioactive waste shall also ensure the containment of the waste and its isolation from the accessible biosphere during the occurrence of extreme natural hazards, such as earthquakes, tornados, flooding, etc."

And for all the other "Sustainable use and protection of water and marine resources",
"Pollution prevention and control" and "Protection and restoration of biodiversity and ecosystems":
"The safety case demonstration shall address the long-term evolution of the reference case and shall also include consideration of extreme scenarios (e.g. loss of functionality by the engineered barriers, external events)."

The TSCs mentioned should be extensive and apply both to LLW and short-lived ILW as well as HLW and spent fuel elements.

Any consideration of these requirements (e.g. considering external events, the loss of safety functions) will lead to a different assessment or different effects in relation to near-surface repositories when compared to deep geological ones.

Source:
(Cf. statements on Part A, Chapter 5.7, p. 196)

ANNEX 5: Ionising radiation: definitions, units, biological effects and radiation protection

No. 255

Source:
Annex 5.4, p. 376 ff, “General principles of radiation protection”
Reference text:
Entire Annex

Scientific evaluation:
The general principles of radiation protection, among other things, in relation to the ICRP publication 103 (ICRP 2007) are mentioned in this chapter/Annex.
The ICRP, however, has specially complemented its recommendations for using these principles for geological disposal with ICRP publication 122 (ICRP 2013). The ICRP uses this to stress the need to complement any use of the principles of radiation protection for very long periods of time with the concept of “oversight”. “In particular, the crucial factor that influences the application of the protection system over the different phases in the life time of a disposal facility is the level of oversight or ‘watchful care’ that is present. The level of oversight affects the capability to control the source, i. e. the waste and the repository, and to avoid or reduce potential exposures.”

The word “oversight” only appears in the report as a secondary quotation – there is no consideration or reference to the concept of “oversight”. The ICRP (2013) document is quoted as a reference “[5–15] in the JRC Report in other contexts. Failing to consider the oversight concept in the ICRP (2013) is therefore no less serious, because the fundamental status of oversight measures (e.g. inspections, monitoring, preserving documents, knowledge, memory in society [...]) is not mentioned in the JRC Report.
Whether the main statements in the JRC Report might have been different, if ICRP (2013) had been fully considered, cannot be judged at this stage.

Please note: the IAEA has not paid much attention to the ICRP concept so far either; the general IAEA safety requirements were drawn up before 2013. The OECD/NEA, on the other hand, has explicitly supported the ICRP principles in its own consensus papers, in connection with preserving knowledge and information in the long term too (“RK&M preservation”) (OECD, 2014).

Source:
(ICRP, 2013)

ANNEX 6: Characteristics of radioactive waste

Nr. 256

Source:
Annex 6(1), p. 378
Reference text:
Entire Annex

Scientific evaluation:
When describing the three types of decay or their ionising capability, the neutron dose is not discussed. However, this forms part of the radiation protection that must not be neglected in the case of transuranes and actinides (sf or spontaneous fission) as well as their criticality safety. Reference should also be made to the interdependence between high-energy α radiation (> 4 MeV) and materials with a high (α,n) cross-section effect, such as Be-9 (compound core formation), which leads to the formation of high-energy, free neutrons.

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