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ORIGINAL PAPER

# Specifying the Concept of Future Generations for Addressing Issues Related to High-Level Radioactive Waste

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**Abstract** The nuclear community frequently refers to the concept of "future generations" when discussing the management of high-level radioactive waste. However, this notion is generally not defined. In this context, we have to assume a wide definition of the concept of future generations, conceived as people who will live after the contemporary people are dead. This definition embraces thus each generation following ours, without any restriction in time. The aim of this paper is to show that, in the debate about nuclear waste, this broad notion should be further specified and to clarify the related implications for nuclear waste management policies. Therefore, we provide an ethical analysis of different management strategies for high-level waste in the light of two principles, protection of future generations—based on safety and security—and respect for their choice. This analysis shows that high-level waste management options have different ethical impacts across future generations, depending on whether the memory of the waste and its location is lost, or not. We suggest taking this distinction into account by introducing the notions of "close future generations" and "remote future generations", which has important implications on nuclear waste management policies insofar as it stresses that a retrievable disposal has fewer benefits than usually assumed.

**Keywords** Future generations · Geological disposal · Nuclear power · Radioactive waste · Safety · Security

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## Introduction

The nuclear community frequently refers to the concept of "future generations" when discussing the management of high-level radioactive waste. This can be widely illustrated in documents issued by international and national nuclear agencies as well as in the scientific literature. For example, the International Atomic Energy Agency (IAEA) states that "arrangements have to be made to be able to pass on information about the disposal facility and its contents to future generations to enable any future decisions on the disposal facility and its safety to be made" (IAEA 2011, p. 43). In the same perspective, the Nuclear Energy Agency (NEA) considers the "policy of reversibility and retrievability in order to respond to the guiding principle of preserving options for future generations" (NEA 2012, p. 19). The International Commission on Radiological Protection (ICRP) is also considering future generations when establishing radiation protection criteria. A recent publication dedicates even an entire chapter to "basic values, principles and strategies for protecting future generations" (ICRP 2013, pp. 23–35).

However, this notion is generally not defined. Even though the concept is often referred to, it is defined neither in the glossary of key terms associated with stakeholder confidence in radioactive waste management from the (NEA 2013a), nor in the glossary of the ICRP publication on radiological protection in geological disposal of long lived solid radioactive waste (ICRP 2013), for example. The notion of future generations remains basically implicit in the technical literature on high-level waste management.

This gap requires assuming a wide definition of the concept of future generations. In his book *Why posterity matters*, De-Shalit gives such a definition. He defines a generation as "a set of people who are more or less the same age and who live in the same period in history, usually regarded as having a span of 30 years", and future generations as "people who by definition will live after the contemporary people are dead" (De-Shalit 1995, p. 138). This definition embraces thus each generation following ours, without any restriction in time. This monolithic conception of future generations stands, even though many scientific works are taking into account different time frames at an operational level, when comparing nuclear waste management options. For example, the Belgian *Strategic environmental assessment* is making a distinction between short-term (up to 100 years) and long-term (after 100 years) potential incidences of nuclear waste management options (ONDRAF 2010, pp. 31, 129 and ff.). On the other hand, when analysing the means for preserving records, knowledge and memory of the waste at an international level, the NEA is distinguishing between very short term, short term, medium term and long term (NEA 2013b, p. 18). Furthermore, works in the field of scenario analysis are also relevant in this respect. Indeed, these works are considering time as a continuum, and are introducing distinctions whenever meaningful events are following from the analysis (Weetjens et al. 2012).

The aim of this paper is to show that, in the debate about high-level long lived nuclear waste, the concept of future generations should be further specified and to clarify the related implications for nuclear waste management policies. Therefore we will analyse the ethical impacts of different management strategies for high-level long lived waste in the light of two principles, namely protection of future generations and respect for their choice. We will try to identify whether there are some differences across future generations, more specifically between "close future generations" and "remote future generations". We define "close future generations" as generations who still have memory of the waste and its location, and "remote future generations" as generations who have lost its memory. Our concept of "remote future generations" is thus distinguished from the concept of "distant future", which sometimes refers to the "the future with which people alive today will make no direct contact (…)" (Routley and Routley 1981, p. 281), even though these categories might be overlapping.

The paper is structured as follows. First, the methodology is presented (section "Methodology"). In a second part, three management strategies for high-level waste that will be scrutinized are briefly described: long-term surface storage, non-retrievable geological disposal and retrievable geological disposal (section "Three Management Strategies for High-Level Waste"). Then these three management strategies are studied and compared with regard to protection of future generations and respect for their choice (section "High-Level Waste Management Strategies in the Light of Protection of Future Generations and Respect for Their Choice"). A discussion follows, where we compare the ethical impacts associated with the three options both for close future generations and for remote future generations, before drawing the practical implications of these results for nuclear management policies (section "Discussion and Conclusion").

## Methodology

It should straightforwardly be noted that the question at stake in this paper is not the normative question of the duties we have towards future generations. There has been a tremendous amount of high-quality literature about the moral status of future persons, about the type of moral categories that apply to our relationship with future people, or about the use of cost-benefit analysis and the issues of discounting future costs and benefits[1] (see for example Barry 1978; Lind 2007; Parfit 1984; Partridge 1981, 2001). Neither do we intend to assess policy options with regard to future generations—neither at the global level of energy nor at the more specific level of radioactive waste management. Again, some very thoughtful papers have been written on these subjects (see for example Andrianov et al. 2015; Brown 2011; Chapman and McCombie 2003; Hillerbrand 2015; Shrader-Frechette 1993; Taebi and Kloosterman 2008; Taebi 2011; van de Poel 2011). Rather, our goal here is more modest: we intend to study how high-level waste management options are affecting future generations in order to see if the concept of future generation should be further specified and if such a distinction adds input for policy-making.

We will focus on long-term surface storage, non-retrievable geological disposal and retrievable geological disposal. These three options are studied and compared in

[1] For a clear presentation of discounting applied to radiation protection, see (Hansson 2007).

the light of protection of future generations and respect for their choice, which have been identified as valuable principles to highlight the fact that some ethical impacts are not the same across future generations without restriction in time.

From a methodological perspective, the principles of protection of future generations and of respect for their choice are briefly defined. Some criteria are derived from these definitions, which are used to study the impacts, on future generations, of long-term surface storage, of non-retrievable geological disposal, and of retrievable geological disposal (section "Defining the Principles of Protection of Future Generations and of Respect for Their Choice"). Then each of the three management strategies is analysed with respect to each of these criteria, on the basis of an interdisciplinary literature review (sections "Safety Impacts", "Security Impacts", "Impacts Associated with the Possibility to Adopt Other Waste Management Strategies"). This analysis is specifically focusing on future generations and on the differences that might occur between close future generations and remote future generations. In the discussion, the three management strategies are ranked according to each of these criteria both for close and remote future generations and scorecards are used to summarize the distinctions observed between close and remote future generations (section "Impacts for Close Future Generations Versus Impacts for Remote Future Generations"), which allows highlighting the implications of our results for radioactive management policies (section "Implications for Radioactive Waste Management Policies").

An important assumption underlying this paper is that the memory of the waste and its locations will be lost at some point. Indeed, high-level long lived waste is harmful for a period ranging from 100,000 to 1,000,000 years. Even though there is some research about the preservation of information,[2] no one can currently ensure that people will be able to keep the memory of the waste for such a long time. Hence humility requires assuming the possibility of such a memory loss. Practically it is of course impossible to know today when the memory of the waste will be lost. It seems however reasonable to share the position of the French nuclear safety authority (the Autorité de Sûreté Nucléaire, ASN) stating that it will not occur before 500 years: "This memory is depending on the permanence of the measures that will be implemented during the filing of information, on the institutional papers resulting from regulations… Under these circumstances, the loss of memory of the existence of the disposal can reasonably be estimated beyond 500 years" (ASN 2008, p. 30).

Another assumption that is made for the purpose of our analysis is that as long as the memory of the waste is kept, the knowledge of its location and of the way to manage it are preserved as well. This is an important issue as long as, without this knowledge, issues related to the monitoring of the waste or to the implementation of other management strategies become irrelevant.

[2] For example, the project "Memory for future generations" (Andra), the project "Preservation of records, knowledge and memory (RK&M) across generations" (NEA 2013b), etc.

## Three Management Strategies for High-Level Waste

Three management strategies for high-level waste are scrutinized in this paper: long-term surface storage, non-retrievable geological disposal, and retrievable geological disposal.

### Long-Term Surface Storage

Long-term surface storage is involving the storage of conditioned packages of high-level waste in surface buildings. For safety reasons associated with the permanence of the packages and the buildings, such storages are not supposed to exceed a period ranging from 100–300 years. During that time frame, it is necessary to monitor the waste packages and the surface buildings and to proceed to their maintenance. After such a period, if no alternative management strategy is adopted, the waste needs to be reconditioned and a new surface storage needs to be rebuilt. Long-term surface storage can be implemented either in a perspective of "eternal storage"—it is then supposed to become the theoretical repetition of storage and reconditioning over hundreds of millennia (ONDRAF 2011, pp. 84–85)—or it can be implemented in an interim perspective, pending the choice of a definitive management option or pending the industrial availability of advanced nuclear technologies (ONDRAF 2011, pp. 88–90).

Surface storage of high-level waste is thus an active waste management strategy, which means that it "provides protection of man and the environment indefinitely, i.e. as long as it must be ensured [for several hundreds of millennia for B&C waste (high-level and/or long lived radioactive waste)], through human actions" (ONDRAF 2011, p. 84).

### "Non-retrievable" Geological Disposal

The basic principle of a "non-retrievable" geological disposal[3] differs drastically from the principle of a surface storage, as it is a solution intrinsically designed to be definitive. Indeed, in that case, the idea is to isolate the waste in man-made packages and to dispose these packages deep underground—generally at a depth of a few hundreds meters—in a stable geological host formation. Once the waste is properly disposed, all the galleries and shafts are backfilled, and the repository is sealed. Regarding sealing procedures, it has to be noted that the situation is highly complex. Indeed, different countries have established/are establishing different types of sealing procedures for their geological disposal (IAEA 2009, p. 10). When speaking about non-retrievable geological disposals, we are referring to disposals that we

[3] We have to remind that, "even without special provisions and design enhancements to facilitate waste retrieval, it would be possible, at least in principle, to recover waste from closed geological repositories (e.g. using specific mining techniques)" (IAEA 2009, p. 11). The question of retrievability is thus always a question of means, as we will see it further on. Hence, strictly speaking a disposal is never completely "non-retrievable". However, for clarity purposes, we are adopting this terminology to designate a disposal where special provisions to ease retrievability have not been added, in order to oppose it to a "retrievable disposal" defined in section "Retrievable Geological Disposal".

intend to seal soon after the waste emplacement (like in Switzerland, for example). In that case, retrievability of the waste is only possible during the operational phase. After closure, both the engineered barriers and the natural barrier—the host formation—are ensuring the safety of human beings and the environment, as they contribute together to the isolation of the waste from the surface (ONDRAF 2011, p. 86).

Geological disposal is hence a passive safety management option—meaning that it provides "protection of man and the environment without human interventions being necessary once the management facility is closed" (ONDRAF 2011, p. 84).

## Retrievable Geological Disposal

First of all, let us define the notion of retrievability in its relationship to reversibility. On the one hand, "reversibility is the ability to reverse one or a series of steps in repository development at any stage of the programme. This implies the review and, if necessary, re-evaluation of earlier decisions, as well as the technical means to reverse previous steps. A disposal programme planned to facilitate reversibility needs to include provisions for review of the programme at discrete steps, as well as measures to facilitate reversal of actions taken at each step of implementation. In the early stages of a programme, reversal of a decision regarding site selection, or the adoption of a particular design option, may be considered. At later stages, during construction and operation, or following placement of the wastes, reversal may involve measures, such as modifications of one or more components of the disposal system, or retrieval of waste packages" (IAEA 2009, p. 4). On the other hand, "retrievability is a special case of reversibility, being the ability to reverse the action of waste emplacement" (IAEA 2009, p. 4).

Insofar as we are interested in the comparison between different management options for high-level waste, my focus is on retrievability rather than on reversibility—the latter being more related to the decision process than to the chosen option itself.

Briefly put, a retrievable geological disposal—or a disposal with retrievability provisions—is a geological disposal including provisions allowing the possibility of waste retrieval. However, the situation is complex because there is not one single concept of retrievability. Rather, retrievability of the waste depends on a variety of factors such as the selection of host rock, the implementation of measures enhancing the waste confinement (use of long lived materials or of additional structural components, for example), or the choice of sealing procedures. Some countries are planning a stepwise approach for sealing the repository, including specific design provisions in order to ease the retrievability of the waste—it is the case of France or the UK for example (IAEA 2009, pp. 40–44). In these cases, the sealing procedures could actually be implemented after a very long period—for example the UK is considering a period up to several hundreds of years (IAEA 2009, p. 60).

Ideally, a specific ethical analysis should be provided for each different concept of repository integrating retrievability measures and for different time frames—namely before and after closure. However, the purpose of this paper is not to provide an exhaustive analysis of this type of strategy, but rather to highlight some potential differences between different management options, with regard to ethical consequences for future generations. Hence, when studying this third option, we choose to consider a repository with structural provisions to enhance retrievability that is still open. Indeed, after closure, the situation will be very similar to the case of a non-retrievable geological disposal. On the other hand, when the repository is still open, important differences can be noticed, linked to the fact that, even though the disposal galleries are backfilled, the shafts and the access galleries are kept open. Therefore, we decided to focus on the specific time frame during which the repository is kept/left open—without prejudging the length of that period.

## High-Level Waste Management Strategies in the Light of Protection of Future Generations and Respect for Their Choice

In this section, we compare the impacts of long-term surface storage, non-retrievable geological disposal and retrievable geological disposal in the light of protection of future generations and respect for their choice. Let us first define these principles and describe the criteria that will be used to analyse the three management strategies.

### Defining the Principles of Protection of Future Generations and of Respect for Their Choice

The fundamental principle of protection of future generations is stressed both by the IAEA, and by the NEA (IAEA 1995; AEN 1995). In the IAEA's principles of radioactive waste management, the fourth principle is precisely dedicated to this issue. It states that "radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today" (IAEA 1995, p. 6). Safety is thus at stake here, understood as "the achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards" (IAEA 2007, p. 133). However, as Taebi and Kadak put it, the protection of future generations not only refers to safety issues, but also to security concerns (Taebi and Kadak 2010, p. 1346). The latter designates "the prevention and detection of, and response to, theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear material, other radioactive substances or their associated facilities" (IAEA 2007, p. 133). Hence, safety and security are identified as relevant criteria for assessing the way each management option contributes to satisfy or to infringe the principle of protection of future generations.

In the specific context of high-level nuclear waste, the ethical stakes associated with respect for the choice of future generations are linked to the possibility for them to adopt other waste management strategies if they wish to do so. Other management strategies may refer to safer management options, to the implementation of advanced technologies that could make the waste less harmful, or to the recovery of the waste for example. In other words what is at stake here is the flexibility left by the different management strategies. Practically, the possibility to adopt another waste management strategy is identified as the relevant criterion for assessing each management option with regard to respect for the choice of future generations.

## Safety Impacts

Safety of a radioactive waste facility can be assessed in many different ways. Our goal here is not to provide a quantitative assessment of the different options, which would be anyway highly unrealistic without reference to a specific project. Rather, we intend to provide a qualitative comparison between surface storage and geological disposal integrating retrievability provisions or not. Therefore, we will focus on the health impact of the waste management options, and more specifically on the notion of potential exposure of individuals, determined by four dimensions (ONDRAF 2010, pp. 238–245):

- the distance between the radiation source and the receiver,
- the power of the source, linked to its volume, its composition and its activity,
- the presence of protection barriers and their characterization,
- the probability of contact of receivers, associated with periods where individuals—workers, visitors, etc.—can be or have to be close to the source.

A fifth component can be added in order to give a more exhaustive picture of the stakes at the safety level: the *possibility* to monitor the facility and the waste and to proceed with maintenance if necessary.

Let us examine each of these components with respect to surface storage, non-retrievable geological disposal, and retrievable geological disposal.

The distance between the radiation source and the receiver constitutes an advantage for geological disposal, either with or without retrievability provisions. Indeed, the distance is greater because, besides the distance between the facility and the potential receivers, we have to take into account the distance associated with the depth of the disposal—generally a few hundred meters.

The power of the source is another factor that favours geological disposal—both with and without retrievability provisions: in the case of a surface storage, every 100–300 years, the waste needs to be reconditioned and stored in new facilities, and the old facility needs to be dismantled, thereby increasing the volume of the waste and hence, the power of the source.

Concerning safety barriers, a geological disposal without retrievability provisions is advantaged compared to a surface storage and to a geological disposal with retrievability provisions, which would still be open.[4] Indeed, the protection barriers are twofold in the case of a non-retrievable geological disposal, because in that case,

[4] It is important to note here that if a geological disposal with retrievability provisions is sealed, it is perfectly plausible that the barriers are in fact enhanced compared to a non-retrievable geological disposal because of the necessity to enhance the confinement of the waste in case people would be retrieving the waste. However, as a reminder, we are not considering this case here, as we are focusing only on geological disposal with retrievability provisions, which would still be kept/left open.

a natural barrier is added to the man-made barriers—which are the only type of barriers used in the case of surface storage. On the other hand, a retrievable disposal is favoured compared to a surface storage, even if it is kept open. Indeed, in such a case, the disposal galleries would be backfilled, which gives an advantage to this option in terms of isolation compared to surface storage. The advantage stands even though a retrievable geological disposal could possibly suffer from structural damage if it is kept open over a long period: man-made barriers could corrode if not adequately protected, hydrological perturbations are likely to increase, etc. (Chapman and McCombie 2003, p. 65; IAEA 2009, pp. 17–18).

The probability of contact is another factor that constitutes an advantage for non-retrievable geological disposal, insofar as monitoring and maintenance procedures are inherent to the introduction of retrievability provisions. This observation is even more relevant for surface storage, where the whole facility has to be dismantled and rebuild every few centuries. Moreover, in that case, the probability of contact of receivers is also possibly higher because of the number of transports associated with the potential storage of the waste in another location. On the contrary, the fifth factor, the possibility to control the facility and to proceed to its maintenance if necessary, favours clearly a surface storage option and, to a lesser extent, a retrievable geological disposal. It is even partially because of the difficulty to control a non-retrievable geological disposal and to react in case of problem that some authors are favouring surface storage in the name of safety (Andren 2012; Shrader-Frechette 1993).

It is important to have in mind that this fifth dimension, associated with the possibility to control the facility and to proceed to its maintenance, is a factor that is only relevant as long as future generations still have the memory of the waste, as well as the knowledge of its location and of the way to manage it. When the memory and the knowledge are lost, these advantages are of course lost at the same time. This observation leads to introduce the distinction between close future generations—having the memory of the waste—and remote future generations—having lost the memory of the waste—, and it highlights the fact that the impacts of management strategies differ across future generations: there is a significant advantage associated with surface storage and retrievability provisions for close future generations in terms of monitoring and maintenance, whereas this advantage is lost for remote future generations[5].

The objection that could be made against this argument is that we currently do not know whether memory will be lost at all. However, as a reminder, humility leads us to make the assumption it might be lost at some point, probably some time after a period of 500 years (ASN 2008, p. 30), but before the waste becomes harmless. Moreover, it is also important to note that the memory loss could potentially occur at different times, according to the management option that is chosen. Indeed, it is likely that the memory will much more actively be kept in the case of a surface storage or of a retrievable geological disposal, than in the case of a non-retrievable geological disposal. Hence, in the latter case, we could possibly be dealing with remote future

[5] We have to bear in mind that the advantadges at the safety level for close future generations can of course lead to indirect advantages for remote future generations.

generations much earlier. However, if the memory loss is due to a major societal instability for example, this comment becomes irrelevant. It is thus very difficult to argue firmly that the memory loss will—or will not—occur at different times according to the chosen option, insofar as we currently do not know at all the type of scenario leading to such a memory loss. Nevertheless, the distinction between close and remote future generations remains relevant in any case.

Let us now proceed to the analysis of surface storage, non-retrievable geological disposal, and retrievable geological disposal with reference to security and to the possibility to adopt other waste management strategies—with a specific focus on the identification of other discrepancies between close and remote future generations.

### Security Impacts

Whereas the previous section was dedicated to unintentional effects of ionising radiation, this section is about security, which refers to intentional adverse effects of ionising radiation.

For close future generations, a non-retrievable geological disposal is clearly favoured compared to a surface storage because an underground location makes the access to the waste and its theft even more difficult. The same remark is relevant for attacks against the facilities. Moreover, the consequences of an attack against an underground facility are likely to cause less damage insofar as the waste is better isolated in that case. The introduction of retrievability provisions in a geological disposal is intrinsically problematic with regard to security. Indeed, the implementation of any provision designed to ease the retrievability of the waste is by definition opposed to the aim of avoiding the possibility to access these radioactive materials (IAEA 2009, p. 15). Retrievability provisions weaken thus a geological disposal at the security level. The IAEA even assumes that the waste could be diverted from such a facility in a few days, whereas several years would be needed in the case of a sealed geological disposal (IAEA 2009, p. 15). However, due to the underground location of the waste, the situation is still better off in the case of a geological disposal kept open than in the case of a surface storage.

For remote future generations who have lost the memory of the waste, the question of security becomes irrelevant. Indeed, security issues imply necessarily malevolent intentions, which are of course not at stake anymore if the memory of the waste is lost.

### Impacts Associated with the Possibility to Adopt Other Waste Management Strategies

Respect for the choice of future generations is analysed in terms of possibilities left by an option to adopt other waste management strategies.

A geological disposal without retrievability provisions hinders the possibility for future generations to choose another option—except if they decide to implement specific mining techniques in order to retrieve the waste. However, the latter operation would possibly be very expensive, time-consuming, as well as potentially hazardous for the workers.

The introduction of retrievability provisions is a way of preserving a choice for future generations insofar as it eases the access to the waste and thereby leaves the possibility, for future generations, to choose the management strategy that seems the most appropriate to them at a specific moment in time. It is even one of the arguments invoked by philosophers and by the public in favour of retrievability (Andren 2012; Fondation Roi Baudouin 2010; Shrader-Frechette 1993). With retrievability provisions, future generations could for example opt for a safer management option, implement advanced technologies that could make the waste less harmful, or decide to recover the waste. The latter remark is highly relevant for fissile materials such as uranium or plutonium, which are still in the spent fuel when the waste is not reprocessed (Chapman and McCombie 2003; IAEA 2009), but also for other resources that are not currently recognized as such—for example if future generations wanted to rehabilitate the site of the facility or if they came to realise that other components in the waste could be valued (Brown 2011).

In the same perspective, a surface storage would allow future generations to adopt another waste management strategy even more easily.

However, these advantages associated with surface storage and retrievability measures are only relevant for close future generations. On the contrary, it is of course not interesting to be able to implement another strategy if the memory of the waste and its knowledge are lost. For remote future generations, the previous argument does not hold anymore.

Two remarks are needed. First, the possibility, for future generations, to adopt other management strategies associated with surface storage and retrievability measures is coming together with the burden of solving eventually the radioactive waste issue by themselves (Barthe and Mays 2001; ONDRAF 2011, pp. 100–104). This is particularly the case with surface storage. Secondly, several conditions need to be fulfilled in order for future generations to be actually able to choose another management option. Besides the duty of memory and knowledge of the waste and of the type of facility implemented, there is a need to transfer certain kinds of skills and therefore to organise continuous trainings in order to be able to manipulate the waste. Moreover, there is a need to develop alternative research paths if future people are to be able to actually choose between several options. Without research on alternative options, the introduction of retrievability provisions would in fact only be relevant in the light of control and monitoring, as well as in the light of the production of further knowledge about this precise option. However it would not promote the possibility, for future generations, to make choices because it would not allow them to adopt a radically different management strategy if they wanted to (Barthe and Mays 2001).

## Discussion and Conclusion

### Impacts for Close Future Generations Versus Impacts for Remote Future Generations

In the previous section, we have shown that high-level waste management strategies are having different ethical impacts for close future generations on the one hand,

and for remote future generations on the other. These results are summarized here below, using scorecards, which are tools that "enables one to rank different alternatives according to a single criterion (…) Each column in such a table represents one alternative and each row a certain criterion's impacts on all the alternatives" (Taebi and Kadak 2010, p. 1355).

Here, our scorecards include the criteria associated with the principles of protection of future generations and of respect for their choice, namely safety, security, and the possibility to adopt other waste management strategies. The scorecards summarize how each of the three alternatives—surface storage, non-retrievable geological disposal and retrievable geological disposal—is assessed according to these criteria, by ranking the impacts of these criteria, with "*" corresponding to the least favourable option, "**" to the intermediate option and "***" to the most favourable one. A first scorecard is dedicated to close future generations (Table 1) and a second one to remote future generations (Table 2).

Three differences appear between close future generations and remote future generations. First, whereas the security criterion is highly relevant for close future generations and favours non-retrievable geological disposal, it becomes irrelevant for remote future generations. Indeed, security implies malevolence, which cannot be at stake anymore if the memory of the waste is lost. Then, the possibility to monitor the facility and to proceed to its maintenance is a criterion which favours surface storage and the introduction of retrievability provisions, but only for close future generations. For remote future generations, it is not the case anymore, as this criterion is intrinsically linked to the memory of the waste, and to its knowledge. Finally, the same goes for the possibility to adopt other management strategies.

It appears thus clearly that the ethical impacts of surface storage and geological disposal—with or without retrievability provisions—are different, both in connection with protection of future generations and with respect for their choice, depending on whether the memory and the knowledge of the waste is lost or not. This justifies the introduction of a distinction between close and remote future generations.

**Table 1** Impacts for close future generations

| Alternatives<br>Criteria | Surface storage | Non-retrievable geological disposal | Retrievable geological disposal |
|---|---|---|---|
| Distance source/receiver | * | *** | *** |
| Power of the source | * | *** | *** |
| Safety barriers | * | *** | ** |
| Probability of contact | * | *** | ** |
| Possibility to monitor/maintain the facility | *** | * | ** |
| Security | * | *** | ** |
| Possibility to adopt other waste management strategies | *** | * | ** |

**Table 2** Impacts for remote future generations

| Alternatives<br>Criteria | Surface storage | Non-retrievable geological disposal | Retrievable geological disposal |
|---|---|---|---|
| Distance source/receiver | * | *** | *** |
| Power of the source | * | *** | *** |
| Safety barriers | * | *** | ** |
| Probability of contact | * | *** | ** |
| Possibility to monitor/maintain the facility | / | / | / |
| Security | / | / | / |
| Possibility to adopt other waste management strategies | / | / | / |

It has to be observed that, even though this conceptual distinction is not explicitly mentioned in the technical literature, researchers from the nuclear community are assuming that a loss of memory is possible and hence are implicitly making such a distinction. It is indeed partially because of a potential long-term societal instability associated with a probable memory loss that surface storage has been banned (ONDRAF 2010, annex C; 2011, p. 95). In the same perspective, the introduction of retrievability provisions is generally coming along with procedures for sealing the repository at some point, in order to avoid problems associated with memory loss.

## Implications for Radioactive Waste Management Policies

The introduction of a distinction between close and remote future generations has important implications for high-level long lived radioactive waste management policies.

Indeed, usually surface storage and retrievability provisions are justified in the name of the possibilities they leave for future generations (NEA 2012; IAEA 2009). However stressing the distinction between close and remote future generations draws the attention to the fact that all the advantages of surface storage and retrievability provisions are only at stake for close future generations. More specifically, the introduction of such a distinction highlights the fact that if we look at a far-distant future, surface storage is getting the worst scores for each criterion. It emphasizes also that the scope of the introduction of retrievability provisions is limited and that, if we look at remote future generations, retrievability provisions have fewer benefits that is usually assumed—specially given the fact that these provisions are precisely presented as a way to manage high-level waste ethically, leaving opportunities to future generations. In the end, the non-retrievable geological disposal appears to be the most favourable option for remote future generations. This is an important finding, which needs to be taken into account in the establishment of nuclear waste management policies, when assessing intergenerational and value trade-offs. In this respect, it could be used as an added input in multi-criteria analysis for example (Xu et al. 2008).

## Conclusion

In this paper, we have shown that surface storage, non-retrievable geological disposal and retrievable geological disposal have different ethical impacts along the future time scale and hence, that a global concept of future generations is not sufficient to grasp the entire picture. Therefore, we have introduced a distinction between close future generations—who still have the memory of the waste—and remote future generations—who have lost it. This distinction allows taking ethical impacts associated with different management options properly into account, and highlights the advantages of non-retrievable disposal when considering remote future generations.

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