Jean-Paul BOUTTES

NUCLEAR WASTE: A COMPREHENSIVE APPROACH (3)

THINKING ABOUT FUTURE GENERATIONS

FONDATION POUR L'INNOVATION POLITIQUE
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SUMMARY

The time horizon of risks associated with nuclear waste requires us to think about our responsibilities to future generations, even over the very long term (centuries, millennia and beyond). Approaches based on "public economics" help inform choices between geological disposal and long-term storage, depending on the economic status of future societies. Looking at the risks and opportunities passed down to future generations through a more extensive analysis grid, one that ranks degrees of risk and geographical scales, and takes into account levels of reversibility, allows for a better understanding of the challenges posed by nuclear waste relative to local risks such as those resulting from toxic industrial waste, and relative to major global risks like biodiversity loss and climate change. We can use this same analysis grid to compare the advantages of nuclear power relative to other energy technologies (fossil fuels and renewables) for present and future generations. Lastly, we will turn to ethical philosophies to help us think more clearly about how to strike the right balance between the responsibilities of present generations and those of future generations, and to better determine what the most important legacy is to pass down: scientific knowledge, democratic institutions, or practical wisdom?

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IV. ECONOMY, PROSPECTIVE AND ETHICS

The focus of this section will be our responsibilities vis-à-vis distant future generations when it comes to nuclear waste. Our first order of business is to look at the choices to be made between, on the one hand, long-term storage (surface or subsurface), which, in some ways, is the "business as usual[1]" strategy requiring the least effort for present generations, though it assumes sustained action on the part of future generations; and on the other hand, geological disposal, a solution that entails greater investments by present generations. This initial overview highlights the necessity of asking what the needs and capabilities of future generations will be, and why we should apply an open-ended interpretation of public economics tools to be used when examining the issues around intergenerational ethics.

Being attentive to the expectations and capacities of future societies requires looking at risk through a broader lens, not just at nuclear waste, but also similar risks (toxic industrial waste), and especially global and major risks (climate, biodiversity, pandemics…). The goal is to ensure that in preparing for the future, we are planning our efforts wisely and choosing the investments that will provide the greatest benefits to future societies, knowing that our capacities are limited.

1. The "baseline option" is the term used in the socioeconomic analysis of investments.

In other words, we must look at nuclear waste within a broader analytical framework, considering all the risks and opportunities passed down to future generations. Using such a framework requires that, before considering nuclear waste management, we compare the benefits of nuclear power relative to other energy technologies (fossil fuels and renewables), not just for present generations, but also based on what they allow us to transmit to future generations in terms of the environment, knowledge capital and savoir-faire.

Expanding the scope of analysis in this way allows us to bring in ethical philosophies that can help us strike a balance between protecting future generations and recognising their capacities and freedoms, and thus balancing "solidarity and complementarity" in weighing our responsibilities against theirs. While much should be required of us, our responsibilities must first and foremost, as the Greeks said, be "measured and defined". In planning the legacy we will leave to future generations, should we not begin by ensuring the quality of our factual and ethical inquiries regarding risks and ways to protect against them, as well as the quality of the institutions through which we organise our choices and actions?

1. Geological disposal as opposed to long-term storage: an approach based on public economics[2]

An exploration of the pros and cons of geological disposal and long-term storage, starting with a relatively intuitive analysis, relies on a comparison of different evolution scenarios for societies. These scenarios are constructed based on the characteristics of these respective systems and simplified hypotheses about growth rates in future societies and related discount rates. This initial approach will be followed by a more in-depth look at the elements of economic theory underpinning the calculations. Lastly, an additional element of complexity will be included by taking into account the uncertainty surrounding future scenarios, as some uncertainty will inevitably remain as we make decisions today that will impact future generations.

a) A (simplified) comparison of the discounted costs of geological disposal and long-term storage in three types of possible scenarios for future generations, French example (Cigeo project)

The cost of building and maintaining long-term storage facilities and renewing them once a century (or every two to three centuries) is estimated at 10 billion euros per century, or 100 million euros a year (half of this for capital expenditure). If we assume that the societies of future generations will be at

2. To read more about this topic, see Andra, "Socioeconomic assessment of the Cigeo project", August 2020 (www.andra.fr), and Jean-Paul Bouttes, Christian Gollier, Anne-Laure Mascle Allemand, Aude Pommeret and Éric Preud'homme, "Counter-expertise of the socioeconomic assessment of the Cigeo project", report to the General Secretary for Investment, SGPI, 5 February 2021 (www.andra.fr/sites/default/files/2021-03/Rapport Contre expertise independante CIGEO VF.pdf).

least as wealthy as ours and have the same level of scientific and technological expertise as us, then we can assume that the active monitoring of long-term storage will ensure the same level of safety as with disposal. A comparison of discounted costs over a very long period, between the 25 billion euros invested in Cigeo over 120 years on the one hand, and the 10 billion euros per century long-term storage would require, starting around 100 years from now and recurring for as long as humanity exists, shows an advantage for long-term storage if the discount rate is above 0.3-0.4%, implying an annual growth rate of at least 0.2-0.3% (see below). Conversely, in a second scenario where discount rates and underlying per capita production (and consumption) growth rates are close to zero, then spending 10 billion per century over millennia is of course much costlier collectively than investing 25 billion euros now then nothing more going forward.

A third scenario involves projecting a strong decline followed by a long period of stagnation, such that for centuries, societies would no longer be able to maintain or renew long-term storage facilities and thus would abandon them. The concrete buildings and then the steel containers and glass matrices would gradually be worn down by water and severe weather. Over the very long term, traces of radionuclides could end up in the water tables, potentially impacting the health of nearby communities over many generations. In this case, the costs factored into the socioeconomic analysis must integrate these health impacts, applying the social value of human life loss. Cumulative health costs over a long period, furthermore discounted at negative rates, would exceed the cost of Cigeo, even if those costs may be low at the scale of only one generation.

This extremely simplified approach, based on three possible scenarios for future societies, leads us to the following conclusions:

– Sustained, robust growth scenario: future generations will be wealthier and more scientifically advanced than ours, and long-term storage will in this case be preferable to geological disposal as these future generations will have the means to manage the storage facilities and might have access to technological innovations that will make it easier to transmute-use this waste than today.

The high discount rate, consistent with the growth rate applying the Ramsey Rule (see below), is the technical translation of the moral need to redistribute a portion of the wealth of future generations to today's less prosperous generations;

– No or very low growth and secular stagnation with GDP per capita and scientific and industrial knowledge remaining at least at the current level: Cigeo is in this scenario a better solution than long-term storage as the sum of long-term storage maintenance and renewal costs, discounted at a rate close to zero over many generations, justifies the investment in geological disposal;

– Sharp economic decline until per capita GDP and scientific development fall back to the same level as before the nuclear reaction was first mastered (1930 in France): GDP per capita would in this case be close to a tenth of what it is today and would remain there for the span of a civilisation, say 1,000 or 2,000 years, before the trend could be reversed. Long-term storage facilities would no longer be maintained due to a lack of know-how. Waste packages would be damaged by water, and traces of nuclear waste would find their way into the water tables, resulting in health consequences only for those living near the long-term storage facility and a small number of persons, but over many, much less wealthy generations. Here again, Cigeo is preferable to long-term storage in the interest of fairness to future generations with fewer resources than us: the discount rate is indeed negative, consistent with growth rates, giving much greater weighting to economic costs and, especially, to the health costs borne by future generations.

b) A few comments on health impacts and related costs under the scenario with economic decline and the abandonment of long-term storage facilities

The third scenario, involving an economic decline going forward, is thus the only one in which health consequences appear for future generations in the case of long-term storage. This important issue is worth discussing in more detail to estimate the potential extent of the impacts.

Designing matrices, containers and storage systems (sites and buildings) to resist a variety of aggressions over the very long term will lessen these health impacts proportionately; possible examples include subsurface storage with particularly resilient structures and, more importantly, highly effective matrices such as glass. Research and innovation will also continue in these areas, and sites will be chosen based on their being protected from natural disasters (earthquakes, flooding, etc.).

If we look at the possible effects of the abandonment on HLW packages more than 300 years after the waste leaves the reactor, i.e. once the activity of short-lived fission products has dropped dramatically, the risks of external irradiation are low and practically non-existent if people remain more than a few hundred metres from the site and more than around ten metres from an isolated package that may have been removed accidentally by humans. Contamination by ingestion in nearby water tables would in theory be very slow, due to the low mobility-solubility of the actinides in many environments and given the resistance of glass over the long term, especially if it remains at the site, even if the surrounding structures are damaged by severe weather over a long period. The impacts should be limited to the small number of individuals residing directly next to the sites. Lastly, the risk of contamination by inhalation, the most dangerous type if actinides are concentrated in the lungs, relates more to the risk of packages exploding or

catching fire, especially in a confined space (dispersion into the atmosphere we breathe), events that are a priori not consistent with this type of society or this type of waste (glass packages).

In other words, we would not face a large-scale catastrophe at any point in time. Rather, the health impacts would be limited, local but significant for the persons affected, the number of which could be high over a large number of generations. If we assume that annual health-related costs would be of the same order of magnitude as annual operation-renewal costs of 100 million euros (the amount, in theory, if the costs were calculated to reflect the balance of benefits and risks), it would imply, based on the social value of human life of 3 million euros currently applied in public decision-making, the loss of 30 human lives a year. Such orders of magnitude, which must be backed up by more in-depth studies, combined with negative or null growth rates and therefore discount rates, naturally make Cigeo the more advantageous solution for protecting future generations.

The analyses presented here are mere outlines, drawn up notably based on the characteristics of HLW in France and the qualities of glass matrices. We nonetheless believe it is indispensable to have a direct and frank discussion about the resulting health impacts if a long-term storage facility is abandoned, in a society much less developed than ours and which, by definition, would apply neither the ASN regulations in effect today, nor existing rules governing evacuations and indemnification of local residents. Such analyses have not been explicitly conducted or shared as of today. They deserve to be developed.

c) Looking at a risk-free discount rate in terms of intergenerational redistributive justice, through the lens of public economics

An approach that includes different scenarios gives an initial idea of what the key issues will be depending on how future societies evolve. This approach is underpinned by socioeconomic analysis tools, and particularly the discount rate applied, which must be consistent with assumptions about growth rates and the attitudes of communities with regard to risk and inequality.

The public economics criterion requires identifying a decision that minimises discounted costs over a long period, internalising non-economic external costs associated with health or environmental impacts, and assigning "monetary values" for instance to CO_2 and human life. The costs borne by present generations, living at $t = 0$, are thus added to the costs borne by future generations, living at time t, divided by $(1/1+r)t$, where r is the discount rate. This discount rate is expressed using the Ramsey Rule: $r = \delta + \Upsilon g$, where δ is the pure rate of time preference for the present, g the rate of growth of consumption (or production) per capita, and Υ the elasticity of marginal utility of consumption. This formula can be formally derived from traditional

neoclassical economics, but here it may be qualitatively interpreted in a much broader yet simpler way if we consider that γ reflects collective aversion to intergenerational inequality[3].

Indeed, the higher the discount rate, the less importance is given to the costs borne by future generations relative to present generations: r increases as growth rate g rises, i.e. as future generations become wealthier than us, and as coefficient γ of g rises, translating a desire to redistribute wealth on the part of the wealthy, in this case future generations if the growth rate is positive, toward the poor, in this example present generations. Reports authored by Gollier and Quinet suggest a value of 2 for γ[4], The pure time preference for the present can be set at 0 to avoid penalising future generations, with their level of wealth equal to that of present generations. This is the choice made in both these Gollier and Quinet reports, and in the Counter-expertise of the socioeconomic assessment of the Cigeo project[5].

The pure time preference for the present can also be set at a level that reflects the probability that humanity will disappear, due to a large meteorite crashing into Earth as happened 66 million years ago, with estimated force of several billion Hiroshima bombs, or a volcanic eruption like the Siberian Traps for instance. This is what Nick Stern decided to do in the climate report he led for the British government but with a value of 0.1%, corresponding to a life expectancy of just 1,000 years for humanity, which seems overly pessimistic. Other researchers suggest an annual probability of human extinction due to natural causes of between 1/14,000 and 1/87,000[6], which would imply a very low δ value, of the order of 0.005%, sufficient to factor in the finiteness of humankind.

With the Ramsey Rule, which places the growth rate at the heart of the discount rate, applying a high γ value of 2, which increases the weighting of growth, and a very low δ value, which practically eliminates any "acausal" asymmetry between generations, the redistributive role of this rate in our choices becomes clear:

– In the scenario with sustained robust growth, the goal is to lighten the burden for present generations by limiting the amounts they have to invest

3. See Christian Gollier, "Actualisation et développement durable : en faisons-nous assez pour les générations futures ?", *Annales d'économie et de statistiques*, Special Issue No. 1, 30 January 2012 (www.tse-fr.eu/sites/default/files/medias/doc/by/gollier/annales%20en%20faisons-nous%20assez.pdf).

4. See Christian Gollier (ed.), "The calculation of risk in public investment", July 2011 (www.vie-publique.fr/sites/default/files/rapport/pdf/114000605.pdf), and Émile Quinet (ed.), "Socioeconomic evaluation of public investment", French General Commission for Strategy and Forecasting, September 2013 (www.vie-publique.fr/sites/default/files/rapport/pdf/134000626.pdf).

5. See Jean-Paul Bouttes, Christian Gollier, Anne-Laure Mascle Allemand, Aude Pommeret and Éric Preud'homme, *op.cit*.

6. See Andrew E. Snyder-Beattie, Toby Ord and Michael B. Bonsall, "An upper bound for the background rate of human extinction", nature.com, 30 July 2019 (www.nature.com/articles/s41598-019-47540-7.pdf).

in the future (including in geological disposal) and leaving it up to more prosperous future generations to implement the best solutions;

– Conversely, in the economic contraction-stagnation scenario, the growth rate, and thus the discount rate, is negative, and present generations are encouraged to invest more for the benefit of future generations, in this instance by developing geological disposal starting now.

d) Making decisions amidst uncertainty about what future societies will be

Until now, our reasoning has relied on simplified hypotheses about the evolution of societies. We have assumed that growth rates would remain stable over time and that the future scenario is known. Yet, as the history of societies reminds us, reality is of course much more complex: we must take into account the uncertainty surrounding our scenarios and consider the possibility that successive time periods will be very different, alternating between growth, contraction and stagnation, with equally great differences in transition times between periods.

To make a decision that takes into account the uncertainty surrounding the future and possible future worlds, we can assign probabilities to these scenarios and then select the solution (disposal or long-term storage) that presents the best expected value across all scenarios.

Since the discount rate is also assumed to factor in this uncertainty about possible worlds and collective risk aversion, choices in fact take into account two additional effects:

– The first is an effect of precaution or prudence related to how uncertainty grows over time due to the increasing gap in per capita GDP between the secular growth scenario and the secular contraction and stagnation scenario. This prudential effect leads to a lower long-term discount rate, which is the same as assigning a higher weighting to the pessimistic scenario than the weighting based on its probability alone;

– The second effect relates to insurance and the differentiated correlation between the costs of alternative projects and the scenarios: long-term storage entails recurring health-related costs only in the pessimistic scenario ("procyclical"), and geological disposal precisely offers future generations assurance against this risk ("counter-cyclical").

These two effects, linked to collective aversion to long-term risk, help explain why geological disposal may be preferred over long-term storage, even if the probability of the contraction-stagnation scenario playing out is moderate relative to the growth scenario, and if the very long-term growth expectation remains significantly positive.

We also need to deepen this analysis by introducing different generations' capacity to act, meaning their ability to conduct individual and collective projects and exercise their free will, as described by Amartya Sen and Paul Ricœur. Future societies' ability to respond to crises may cause a shift from one scenario to another: possibility of emerging from a contraction-stagnation scenario thanks to a "renaissance" that puts society back on a growth path or, on the contrary, "collective malevolence and/or negligence" causing a move away from an expansion scenario toward one of contraction. A brief analysis of this type was included in "Counter-expertise of the socioeconomic assessment of the Cigeo project", drawing on work done by economists over the past decades and in the area of discount rates and risks[7]. We thus observe that, with a simple model and maintaining optimistic long-term expectations (average growth of around 1% over the very long term), and with a bit more realism for the scenarios, an average expansion rate being maintained for 1,000 or 2,000 years (that of a civilisation like the Greco-Roman world) and an average duration of 100 to 500 years for the contraction scenario (from the fall of Rome to the "renaissance" of the 11th and 12th centuries), the Cigeo geological disposal solution may be preferred to long-term storage if we work within a plausible range of parameters and the cost levels referred to above[8].

It is therefore possible to propose an argument and related hypotheses that lead to the ethical choice of geological disposal as the reference solution. Given the uncertainty around future worlds, sustainable growth, secular stagnation or contraction, geological disposal entails additional costs for present generations, but prevents recurring health impacts during periods of contraction and lasting institutional fragility and significant recurring maintenance and renewal costs during periods of secular stagnation. The decision to opt for geological disposal, and to commit to it today, depends (above and beyond the cost compared with long-term storage) on three categories of key parameters alluded to above:

– Factors relating to the main characteristics of possible worlds, their capacities based on growth rates and scientific and technological capabilities, the quality of their institutions and shared values, and the probabilities of shifting between these worlds, corresponding to the average duration of periods of growth, stagnation or contraction, in other words to their fragility-resilience;

7. See, in particular, Christian Gollier (ed.), *op. cit.*, as well as the authoritative book on this subject by the same author: *Pricing the Planet's Future, The Economics of Discounting in an Uncertain World*, Princeton University Press, 2013.

8. This is a Markov process with two regimes (growth and contraction), with probabilities of regime switching that reflect their average duration. On this subject, see Jean-Paul Bouttes, Christian Gollier, Anne-Laure Mascle Allemand, Aude Pommeret and Éric Preud'homme, *op. cit.*

– Those relating to the risks and opportunities we pass down to future generations through our actions in the present and their potential long-term health, environmental, cultural, institutional and economic impacts;

– Those relating to our responsibilities and moral attitudes, factors reflected in the discount rate, aversion to intergenerational inequality, aversion to risk and pure time preference for the present (acknowledging the finiteness of humankind).

This simplified and stylised overview serves to illustrate certain important points:

– Including within the range of possibilities a contraction scenario, even with a low probability of occurrence and duration, combined with risk aversion, gives rise to a plausible range of parameter values within which geological disposal becomes a relevant choice, without requiring the consideration of hypotheses that involve catastrophes resulting from nuclear waste;

– It is therefore necessary to have a forward-looking vision (even a very simplified one) of future societies and to realistically estimate the economic, health and environmental consequences in relation to the capacities and vulnerabilities of these possible worlds;

– We must place the issue of nuclear waste within the broader context of all risks we will pass down to future generations, which are not by any means limited to nuclear waste alone: toxic industrial waste, local pollution, pandemics, climate change, biodiversity, impacts of nanotechnologies and artificial intelligence (nanorobots), nuclear war… Since the just savings available to help us pass down to our successors a satisfactory legacy are limited, we will need to prioritise and ensure that our choices are coherent and effective;

– The different scenarios, and their conclusions, correspond to moral intuitions that must be backed up by an ethical interpretation of the questions raised by all decisions taken.

2. Prospective studies of possible worlds over the very long term

a) The evolution of societies: prospective studies covering the very long term

Thinking about the consequences of our choices for distant future generations implies considering the expectations and needs of others who are not unimportant or totally foreign to us. Others who, like us, are complex and full of contradictions, are capable of innovating for the good or for malevolent reasons… others who we could understand, and who might surprise us. Gaston Berger, a philosopher specialising in phenomenology and

one of the people who launched the "prospective" (study of possible futures) discipline in France after the Second World War, made this a key element of a new discipline geared to collective action over the long term: factor into prospective studies of possible futures the behaviours and motivations of humans, their expectations and their ability to act. Use our imagination and take risks, but cautiously. As Gaston Berger said, "Living is always a risk, but at least let us avoid taking absurd risks[9]", adding this quote from Paul Valéry: "What we have to do first is imagine the man of our time, and situate this idea of man in the probable surroundings in which he will live[10]".

To ensure that the scenarios drawn up as part of these prospective studies are credible and relevant, it is important to take into consideration elements learned from long-term history that help us understand humankind, as well as how societies evolve and their ability to respond to major events.

Drawing on long-term history to think about the expansion and decline of civilisations

Thinking about possible futures beyond a few centuries requires looking back at the history of societies over a long period, considering what different historians have said about the conditions that lead to the expansion and prosperity or else the decline of civilisations. Efforts to put into perspective the historiography and progress made in recent decades, thanks to work done to revisit archaeological and epigraphic sources and expand the scope to include new aspects of the lives of those societies (rural sites or small towns, coastal areas and seabeds, deserts…), have lent more dimension and complexity to images that are too often constructed based on the preoccupations of the period during which historian live. A few brief examples below illustrate how long-term history can inform debates about possible futures:

– Civilisations communicate with one another through time and space, sketching an outline of the overall history of human societies and their exchanges: Egypt left the Greco-Roman world a cultural and material legacy (consider the role of Alexandria in the Roman Empire, a source of intellectual knowledge and key link in the grain supply chain for Rome then Constantinople), and Rome, Persia, India and even China came into contact through commercial exchanges and wars;

9. Gaston Berger, "The Prospective Attitude" [1958 version], *in* Bibliothèque de prospective, *Étapes de la prospective*, PUF, 1967 (www.laprospective.fr/dyn/francais/memoire/texte_fondamentaux/cahier_prospective/cahier-3-les-etapes-de-la-prospective.pdf).

10. Cited *in* Gaston Berger, "The Prospective Attitude" [1959 version], cited in Gaston Berger, Jacques de Bourbon-Busset and Pierre Massé, *De la prospective. Textes fondamentaux de la prospective française. 1955-1966*, L'Harmattan, 2nd ed., 2017, p. 92 (www.laprospective.fr/dyn/francais/memoire/texte_fondamentaux/attitude-prospective-g-berger-1959.pdf).

– Quite often, civilisations are thought to have been at a standstill only due to an absence of sources or because of a bias in understanding: this is the lost history of the "vanquished", the dominated classes, the societies that did not leave behind writing or objects made of durable materials. The revisiting of Ancient Egypt by contemporary historiography reveals as much[11]. Rome also appears to have gone through different phases. First came the period of conquests by the Roman Republic, during the three centuries before our era, when per capita GDP doubled; then came four centuries of the Empire, characterised by economic stagnation and broadly flat per capita GDP with a geographic footprint that was relatively stable, though at the same time, significant changes were seen in political institutions, religions, lifestyles, and technical innovations. Then, starting in the 5th century and through the 9th century, Europe was in a period of economic decline, with per capita GDP contracting before rebounding in the 11th-12th centuries to levels seen under Augustus, with a sharp decline in urbanisation and trade[12];

– We must stop dividing societies into two camps: hierarchised and archaic societies on the one hand, all seen through the lens of the same model and with cultural and technical innovations considered to be fixed, and on the other, rapidly expanding societies that appear to emerge only at the turn of the 18th and 19th centuries[13]. Conversely, it may be anachronistic to project the structures of our industrial societies onto Rome or the Middle Ages. Yet a complex web of interrelations between these periods exists through the transmission of potentialities that were outlined but unexplored. The watermill existed under the Roman Empire but only began to be widely used in the Middle Ages. Monasteries were drivers of technical and "managerial" progress while acting as the guardians of Greco-Roman manuscripts, which were resources for the renaissance of the arts and humanities in the 14th and 15th centuries and for the scientific and technological advances of the 16th and 17th centuries. Members of the Republic of Letters could only trade missives through the post offices and routes developed in the Middle Ages, sometimes inherited from Roman roads[14].

11. See Damien Agut and Juan Carlos Moreno-Garcia, *L'Égypte des pharaons. De Narmer à Dioclétien, 3150 av. J.-C.-284 apr. J.-C.*, Belin, 2016.

12. See Angus Maddison, *Contours of the World Economy, I-2030 AD*, Oxford University Press, 2007; Claire Sotinel, *Rome, la fin d'un empire. De Caracalla à Théodoric, 212-fin du v^e siècle*, Belin, 2019; Bryan Ward-Perkins, *The Fall of Rome and the End of Civilization*, Oxford University Press, 2005; Peter Brown, *Genèse de l'Antiquité tardive*, Gallimard, 1983; Joël Chandelier, *L'Occident médiéval. D'Alaric à Léonard, 400-1450*, Belin, 2021.

13. See analyses by Moses I. Finley vs Michael I. Rostovtzeff and the "Bücher-Meyer" controversy. For more information on this topic, see Jean Andreau, *L'Économie du monde romain*, Ellipses, 2010; Claude Nicolet, *Rendre à César. Économie et société dans la Rome antique*, Gallimard, 1988; Moses I. Finley, *The Ancient Economy*, Éditions de Minuit, 1975; Karl Polanyi, *The Great Transformation. The Political and Economic Origins of Our Time* [1944], Gallimard, 1983; Michael I. Rostovtzeff, *Histoire économique et sociale de l'Empire romain* [1926], Robert Laffont, "Bouquins" collection, 1988.

14. See Joël Mokyr, *A Culture of Growth. The Origins of the Modern Economy*, Gallimard, 2020.

The history of humankind is not stationary. The past 200 years of exceptionally robust and sustained technological advances have been totally unprecedented. Of course we cannot predict possible futures based on the past. And yet a look back at long-term history does illustrate the complex articulation of causalities between different areas of human action, economics and technological innovations, lifestyles and cultures, social structures and political institutions, religions and wisdom, conflicts between societies and geopolitics, human actions undertaken through inherited legacies or initiative, and in response to the opportunities and risks associated with ecosystems, pandemics, climate change, short-term changes in weather patterns and the consequences for agriculture… It is true that we have never reached a level of development like today in terms of economics, health, life expectancy, access to literacy and culture, already available to a very large number of people and with a goal of achieving "access for all" – universal service, unique in the history of civilisations. And yet a closer look at the past makes clear that the distribution of surpluses was not as unequal as previously thought. The vision of Roman fields tilled by an army of slaves and a few free men barely subsisting, with the surplus being hoarded by urban elites from "consumer cities", is thus very nuanced, and cannot be summarised as "peasants reduced to self-subsistence, and cities that were predatory, parasitic and unproductive[15]".

Even extended periods of stagnation saw an accumulation of technical innovation and scientific knowledge, meaning potentialities for possible successors, and truly remarkable cultural, artistic, spiritual and institutional inventions that, taken together, gave subsequent generations as many opportunities to bounce back. These diverse forms of wisdom of different civilisations, in some respects unsurpassable, have, for the first time, been made available to everyone on the planet. Perhaps they form the most meaningful legacy from past generations. If we agreed to bring them into our ethical and prospective thinking, it might allow the "larger body" of humanity (via scientific knowledge and the mastery of techniques) to find the "supplement of soul" to guide it, as Bergson suggested[16].

Societies' capacity for response and transmission in difficult times, when faced with crises and catastrophes

Many studies also highlight the important role played in historical trends by the reactions of those faced with large-scale or long-term difficulties: invasions, civil war, epidemics, climate change, depletion of resources or natural catastrophes[17]… These different examples are proof that neither the

15. See Jean-Michel Carrié and Aline Rousselle, *L'Empire romain en mutation. Des Sévères à Constantin, 192-337*, Seuil, "Points histoire" Collection, 1999, p. 515.

16. See Henri Bergson, *Les Deux Sources de la morale et de la religion* [1932], PUF, 2013.

17. See, among others, Jared Diamond, *Collapse. How Societies Choose to Fail or Succeed*, Gallimard, 2005; Joakim Radkau, *Nature and Power. A Global History of the Environment*, Cambridge University Press, 2008; Kyle Harper, *The Fate of Rome: Climate, Disease and the End of an Empire*, La Découverte, 2019.

best nor the worst can be taken for granted. When tackling the two biggest challenges facing humankind – the violence of humans and the violence of nature – it may be that the most vital resources stem more from the strength and resilience of values and cooperative institutions shared by groups of people than from their technical and economic resources, or even the quality of ecosystems, though the complementary and central role played by all the latter in translating goals into lasting reality cannot be overlooked.

Equally clear is the ability of societies to transmit over the long term the knowledge necessary to manage and replenish ecosystems such as forests, fishing resources, quarries and the subsoil of cities like Paris[18]. The way wisdom, knowledge and skills were safeguarded and transmitted in monasteries during the High Middle Ages is another illustration of this capacity for resilience and transmission over several generations under difficult circumstances.

Two particularly important points can be made following this overview of the resources of history:

– The societies that came before us left us resources but also problems that needed to be solved. Looking for instance at the legacy of Rome, we have a fairly good idea of how to manage the lead the Romans used in pipes and the abandoned gold and silver mines they left behind. At the same time, we are indebted to them for the roads and urban and architectural structures they built. We would not be what we are today without our Greek and Roman cultural heritage, without the law and institutions of the Roman *res publica*;

– The other remarkable observation we can make in examining major catastrophes of the past like the Plague of Justinian, the Black Death or the Wars of Religion, relates to the response capabilities of human communities. These capabilities stem from the solidity and resilience of their cultures and institutions, including in the less well-off societies that have been at the heart of the most serious crises. This is yet another reason to incorporate a long-term prospective view, inspired by the work of Gaston Berger, a systemic prospective view that fully takes on board the freedom of initiative and capacity to act of future societies.

A prospective view of possible worlds to inform our decisions about nuclear waste

Prospective thinking involves envisaging possible futures based on a set of decisions that must be informed. Yet as of today, there are virtually no studies that explore the future of human societies beyond the next 150 years, even within bodies like the IPCC, where irreversible shifts linked to climate

18. See, in particular, what some historians call "environmental reflexivity", in other words "the way societies have thought about the consequences of human actions on nature, and the feedback effects", and thus the related practices and the transmission thereof (Jean-Baptiste Fressoz, Frédéric Graber, Fabien Locher and Grégory Quenet, *Introduction à l'histoire environnementale*, La Découverte, 2014, chap. III, p. 35-54).

change should in theory justify thinking at the horizon of millennia (exploring the effects warming will have on lasting sea level rise) or multiple millennia (asking questions, for instance, about whether the next glaciation might be delayed by a few tens of thousands of years). On the other hand, interesting research has been conducted on the coming decades, for instance the scenarios drawn up by Shell, the National Intelligence Council, the WEC, the IPCC, the IEA scenarios (Energy Technology Perspectives and World Energy Outlook), and research by Vigie-Futuribles in France. These studies clearly illustrate how concerns have evolved over the past 40 years.

The Western world was fairly optimistic between 1980 and 2000, thanks to a combination of several factors: the fall of the Berlin Wall and American hegemony, the globalisation of trade and the emergence of large developing countries (China, Brazil, Turkey, India, South Africa), technological advances that promised a new industrial revolution (thanks to digital and communication technologies, biotechnologies, new materials and artificial intelligence), the oil counter-shock of 1986 and the abundance of fossil fuels with oil and shale gas, and the spread of democratic values. Overall, these years were characterised by real prospects for human development indicators to improve over the following decades.

The outlook turned pessimistic in the years 2000-2020 with regard to these different key variables, especially in OECD countries: geopolitical conflicts over global leadership pitting the United States against China, risk of regional conflicts (Taiwan, Pakistan, India…), deindustrialisation and loss of economic sovereignty of countries due to globalisation, possible stoppage of growth (secular stagnation) linked, in the near term, to excessive debt and insufficient effective demand, and in the longer term to a possible slowing of systemic technological innovations like electricity or steam engines in the past, increasing inequality within countries, fracturing of civil societies, loss of social cohesion and undermining of democracies, rise in fundamentalist values in different religions, notably Islam and resurgence of ideological battles, climate change, loss of biodiversity, emergence of pandemics… One could summarise these different elements in one question about the effectiveness and relevance of the cooperative institutions we rely on at different levels – local, state, regional and global – to resolve human conflicts, manage ecosystems and support sustainable development, and whether they can foster reasonable dialogue between our value systems in order to give rise to collective projects.

In sum, our pace of development today still corresponds to the sustained growth scenario, but we are increasingly worried about the consequences of climate change, biodiversity loss, the slowing of technical innovation, possible geopolitical conflicts, and the loss of legitimacy and effectiveness of our political institutions. Such thinking about key trends in expectations for

the future of our societies may not measure up to real prospective studies covering the very long term, but it does reveal the emergence of more pessimistic views. As long-term history has taught us, periods of decline cannot be ruled out.

The unfavourable developments alluded to above have reminded us of this in recent years. Our probability of moving from a sustained growth to a contraction or stagnation scenario tend to increase during these years, which, all other things being equal, should strengthen the case for geological disposal over long-term storage and its rapid implementation.

Beyond the intertemporal consistency of our choices based on the information we have to work with and our perceptions, we must also ensure the coherency of the exact characteristics of our solutions, in this case whether geological disposal is open (reversible for a very long time) or closed (ultimately irreversible), and the needs of future societies depending on their response capabilities. There is no question that if we base our decisions on the reasoning above, it would not only be useless, but also dangerous, to leave a cell open once it has been filled. If a society can deliver technical innovations that allow it to do better than us, then that more prosperous society can opt for the best solution available, retrieving the buried waste at what will be a low cost for it, even if the repository is "closed". But if we are talking about a society that is in a period of contraction, and is not delivering technical innovations, then leaving the repository open is irresponsible since the waste will no longer be prevented from spreading into the water tables and, that future society being less wealthy, it deserves to be helped. In sum, opting for closed disposal barely limits a future prosperous society's choices compared with open storage, but by making this waste harmless for less developed societies, we expand their choice space and ability to conduct their own projects.

b) A risk analysis grid for future generations

Analytical framework for analysing the risks and legacy to be passed on

The higher the probability of future worlds being unfavourable, the more we see the benefits of stepping up investments in order to limit the impact of risks for future generations confronted with even more dangers. We would need to increase the share of the "just savings" set aside for distant future generations. The paradox is that our responsibility to do so is rising as we, present generations, face more dangers and new constraints that weigh on our resources. This makes it that much more important to count our points and focus our investments as efficiently as possible: the first step is to do what we can to reduce the probability of tipping into these unfavourable worlds by concentrating our efforts on limiting adverse changes in the climate and on the quality of the cultural and institutional heritage we will leave behind.

The goal, therefore, is to present a grid for analysing risks over the very long term that allows us to identify degrees in the magnitude of the dangers, the geographic scale, and the level of reversibility: a geopolitical conflict leading to a full-blown nuclear war, global temperatures increasing by four of five degrees, or a massive loss of biodiversity would clearly be major global risks, with irreversible consequences. They would bring the loss of our environmental ecosystems, which are non-substitutable and essential goods. By the same token, if major ideological or religious conflicts lead to totalitarian regimes or chaotic societies, it would destroy the bulk of our legacy of practical wisdom, values, culture and the institutions through which we cooperate and manage conflicts. That would represent a major risk that could be global and irreversible over the long term, in our globalised world. By contrast, long-lived nuclear waste, like toxic industrial waste that is chemically stable over long periods (heavy metals for instance), is particularly hazardous for human health and the environment if it becomes concentrated in the food chain but does not represent a significant danger insofar as the impact is a priori local and can be partially reversible if the right technical and scientific capabilities are available. It would be helpful to go further by integrating into these analyses the comparative studies conducted on the consequences of serious accidents in the different industrial energy sectors[19], and then to compare these consequences to those of wars and civil conflicts, and to those of natural catastrophes[20]. It would make sense to then integrate these analyses of risks, based on their magnitude, scale and irreversibility into debates about weak or strong sustainable development, depending on the importance of the resources impacted and their degree of substitutability (and, therefore, depending on the role of technical innovation and the resources available on our planet).

Such a grid analysis, together with the teachings of long-term history, could thus help us do a better job thinking about and hierarchising what we should pass down to future generations:

– The list should undoubtedly start with values, practical wisdom, theoretical knowledge and savoir-faire (articulations between science and technique, between scholarship and artisanship; savoir-faire incorporated into a dynamic industrial base), institutions where differing viewpoints can be expressed and where cooperation and conflict management are organised with the goal of preventing major and global conflicts;

19. See Stefan Hirschberg, Gerard Spiekerman and Roberto Dones, "Project GaBE: Comparative Assessment of Energy System. Severe Accidents in the Energy Sector", Paul Scherrer Institut (PSI), 1st ed., November 1998 (www.psi.ch/sites/default/files/import/ta/RiskEN/ENSAD98.pdf), and "New Elements for the Assessment of External Costs from Energy Technologies", Final Report to the European Commission, DG Research, Technological Development and Demonstration (RTD), September 2004 (www.psi.ch/sites/default/files/import/ta/NewExtEN/newext_final.pdf).

20. See Andrew E. Snyder-Beattie, Toby Ord and Michael B. Bonsall, *op. cit.*; Richard A. Posner, *Catastrophe. Risk and Response*, Oxford University Press, 2004.

– Next come global public goods like the climate, biodiversity and landscapes, the aim here being to reduce the likelihood and impacts of scenarios that involve major, global and irreversible risks, including over the long term;

– Third on the list would be suitable, coherent solutions to problems that are important, local and in part reversible, once society has the right scientific and technical expertise and effective institutions: toxic industrial waste, waste from the different parts of the nuclear, fossil fuel and renewable energy industries.

The first priority is clearly to invest most of the "just savings" reserved for future generations in a way that minimises the probability of occurrence of unfavourable scenarios (contraction and stagnation) which, as we have seen, ties in with the partial loss, irreversible over the long term, of global public goods such as the climate and biodiversity, increasing risk of major geopolitical and/or ideological conflicts, or loss of the ability to transform scientific and technical innovations into an industrial base that produces goods and services useful to humanity.

Nuclear waste versus toxic industrial waste and waste from other parts of the energy sector

The first way our analysis grid can be used is to compare the dangers of and solutions adopted for toxic industrial waste and nuclear waste. Where the former is concerned, it is undoubtedly important to divide the waste into different categories, not just based on dangerousness but also on how long it remains toxic: complex molecules such as organophosphates and dioxins decompose over time, whereas heavy metals are stable. A significant portion of toxic industrial waste is stable and comparable in terms of potential danger to HLW and ILW-LL. These kinds of waste require the same recycling and confinement via storage, and the right matrices and packaging must be chosen, though some of this waste has low concentration levels and is released into the environment. As of today, the 15 regional centres where the most hazardous industrial waste is stored in France are designed to be used for about 30 years. There was talk at one time of placing some of this waste in geological disposal in old potash mines (StocaMine in Alsace), following Germany's example for managing this type of waste, but specific and serious problems arose at the site, and for now this solution is on hold. The ultimate fate of this waste deserves to be discussed. It exists in quantities far greater (in mass and volume terms) than HLW and ILW-LL but can in some cases be easier to recycle and, a priori, is often less concentrated. From this standpoint, the most appropriate solution could be long-term reversible storage, which is less costly for large volumes, enables opening for recycling, and, if ever abandoned, would release less concentrated products.

A second application for our analysis grid is to compare waste, in the broad sense of the term, from the different key segments of the energy sector, notably electricity generation. The processes involved in fossil fuel electricity generation (coal, oil, gas) produce three categories of waste. First, solid and liquid waste, some of which is comparable to nuclear waste; a significant share of this waste is the toxic industrial waste alluded to above. Generating electricity from fossil fuels also produces a kind of waste that is partly released into the atmosphere (after varying degrees of filtration); these are the local pollutants (SO_2, NOx, ozone, particulates) that cause significant health problems for present generations and those in the near future. Lastly, burning fossil fuels to produce electricity of course also creates a "waste" that is particularly worrisome for future generations, since fossil fuel energy is the main source of CO_2 emissions in the world, accounting for nearly a quarter of greenhouse gas emissions and 40% of energy-related CO_2 emissions, with coal emitting close to 1t of CO_2/MWh and gas half that. The share of this "waste" that remains in the atmosphere has a lifespan of about 100 years. It thus contributes directly to global warming over the coming centuries with the quantity present in the atmosphere being halved every 100 years. Yet it also has very long-term effects. Most of the heat produced today due to the greenhouse effect is stored in the oceans, and the resulting rise in ocean temperatures will have very significant impacts over the very long term, notably on sea levels. Similarly, a significant share of current CO_2 emissions is stored in greenhouse gas sinks – the oceans and biosphere – and could be partially released on a distant time horizon. This would have delayed effects on the planet, possibly even affecting the next glaciation- deglaciation cycle[21].

Like nuclear power, renewable energy sources, wind and solar power, are very low-carbon emitting and, as with nuclear, production of local pollutants is limited. On the other hand, renewable energy sources produce large volumes of industrial waste, as do fossil fuel energies. Indeed, wind turbines and solar panels generate energy from a fuel source – the wind and sun – that is free, but the "density" of which is low. These energies thus require significant quantities of materials that must be extracted from mines and transformed via chemical processes, which is why they produce large quantities of waste and take up much more space. Equally important is the fact that these energy sources are intermittent and that their siting depends on the best locations for wind and sun, rather than on human geography.

These two characteristics make it necessary to build much more expansive transmission and distribution networks and to have storage systems (batteries or other) in place. Another important issue to bear in mind is that with intermittent energy comes the requirement to have dispatchable

21. See IPCC, "Climate Change 2021. The Physical Science Basis", 7 August 2021 (www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf).

power plants ready to generate electricity during the days or weeks when there is no wind and overnight and on cloudy days when there is no sun. Without nuclear, the solution adopted could be to keep gas- and coal-fired power plants in service for too many more years (factoring in the likely limitations of gases from biomass, and until the hydrogen industry is fully in place). Lastly, the space required for a massive rollout of these low-density energy sources will put them into competition with the land needed for food production and the "breathing room" biodiversity requires.

We can thus see that, based on the same level of development of humanity, and thus the same level of energy production, greater use of nuclear energy going forward would help reduce the waste produced by other technologies, such as toxic industrial waste. It would also help reduce the significant amounts of local pollutants that seriously impact the health of communities, as well as the considerable quantities of CO_2 emitted by fossil energy sources (and, perhaps for a non-negligible portion, by intermittent renewable energies due to the need for backup generation). Nuclear energy could thus make a potentially significant contribution to resolving global issues around biodiversity and land use, notably when compared to renewable energy sources.

Beyond the interesting work done by the European Union around the ExternE[22] project, these major questions have not been addressed within the context of a global and coherent vision. There is no public or private entity in charge of tracking the waste produced by these different segments of industry at a national scale and then overseeing its management based on an approach that is precise, rigorous and systemic, as is the case for the nuclear industry. And in a world of waste-producing societies, there is no international coordination of action comparable to what is done for nuclear waste through the IAEA and NEA[23].

3. Marshalling the resources of ethical philosophies

What should be done about the risks we might pass on to future generations? This is the common thread of our survey, which initially focused on nuclear waste but must now be expanded to include waste from all electricity production activities and, beyond that, to global risks, such as an unfavourable change in the climate or a loss of biodiversity. Here, the question is formulated in its ethical dimension, our foremost concern. Our task now is to invoke ethical resources to look at our responsibility vis-à-vis future generations. This requires first taking a detour, to get in touch with the real meaning of these approaches. Indeed, the latter are often caricaturised to the point that their true purpose is lost. One can speak about the future

22. The so-called "ExternE" methodology is an approach that involves calculating environmental external costs. It was developed over the course of the "ExternE project-series" called the "Impact Pathway Approach".

23. The other international institutions only address some of the subjects periodically.

generations' inalienable right to a world without risk, the need to make steep investments to benefit future generations that will live in the least advantaged of possible worlds, applying John Rawls's difference principle[24], or our obligation to do all we can to preserve the sustainability (the immortality?) of humankind, to borrow expressions inspired by Hans Jonas's "principle of responsibility"[25]. The ethical requirement is thus presented as an absolute obligation, needed to counter a risk that is presented as an absolute evil.

In our view, this goes directly against ethical philosophy approaches, the objective of which is to apply human reasoning to the real world, not the world of the Olympian Gods, to measure and understand the risks and responsibilities (relationship between actions-consequences and imputability), to ultimately better identify different generations' capacity to act on these risks. Such an approach, which requires ethical reasoning (or practical reasoning), leads us to learn, and continue to relearn, how to set aside our interests, our convictions and our prejudices. We are also forced to acknowledge our limitations – bounded rationality, resource constraints, impulses and malevolent behaviours. The result is that we are able to work together on doing better here and now, and to lessen these limitations, even if we cannot eliminate them.

To develop this discussion, we will begin with an overview of some of the key current trends in thinking about future generations ("rights" approach, utilitarianism, John Rawls and contractualism, Hans Jonas and the "principle of responsibility"), highlighting their historical context, their primary ethical intuitions, what they say about future generations, and the strengths and weaknesses of their approaches. But first, we needed to resituate the two key sources who inspired all these approaches, Aristotle and Kant, and recognise already in their work practical reason in situation, seeking a path toward the good and the just within a determinate world and time.

In view of all the collective risks outlined above, from nuclear waste to pandemics to climate change, we cannot afford to adopt an attitude of indifference, but nor can we sink into despair and powerlessness. Ethical approaches, very different in many regards, offer avenues leading to meaningful collective action and a way to control our destiny in a lucid and measured way based on a few simple ideas:

– Rigorous inquiry regarding risks, dangers, and possible solutions;

– Careful crafting of a framework for analysing the risks and hierarchising these risks as well as the actions to be taken;

24. Concept developed in *A Theory of Justice*, which explains that certain differences can be tolerated in a just society as long as two conditions are met: the positions and functions that enable advantages must be equally accessible to all members of society, and inequalities are justified if they allow the situation of the least advantaged to be ameliorated (see John Rawls, *A Theory of Justice*, Seuil, 1987).

25. See Hans Jonas, *The Imperative of Responsibility* [1979], trad. J. Greish, Flammarion, coll. "Champs essais", 2013.

– Rigour and standards in effective implementation of solutions;

– Invention and transmission of practical wisdom and the democratic institutions involved in risk management processes.

a) The Aristotelian and Kantian traditions: demands, scope and limitations of practical reason

The discussion developed above about history and prospective analysis shows that it is necessary to address some key questions before choosing collective actions to manage the waste produced by our societies:

– What are our responsibilities and obligations vis-à-vis distant future generations, and what are their responsibilities and rights?

– On the basis of what arguments (values, finalities, rational imperatives…) should we determine the scope of our efforts and allocate them between different issues, prioritising our actions and investments?

In sum, this is an invitation to leverage the resources of ethical reflection which, for the most part, are inspired by the two major traditions of Western philosophy: Aristotle's "teleological" theory and Kant's "deontological" theory. In both of these moral philosophies, reason plays a central, two-fold role: for Aristotle, it is an access pathway, a means of defining good, happiness and the finality of human action, while for Kant, it opens the door to a sense of justness and duty, what is a categorical imperative or in other words, the "universalizable" rule that governs our actions. And yet in both cases, reason is in a way much more than that.

For Aristotle, it is the divine part of man, and man finds his practical purpose, his telos, in exercising this reason in the political life of the city as well as in friendship. For Kant, it is one's capacity to set aside one's own interests and desires through rational moral reflection, the necessity of coherence, of an explanation for the action based on a universal rule, that, by making man autonomous and free, commands respect, and requires that every man be treated not as a means but as an end.

Both approaches are interesting and appealing because of the importance they place on this ability to explain the reasons for choices and the limitations thereof. Aristotle's definition of the good life speaks to us even today thanks to the intimate understanding the philosopher had of man's varying expectations and the overall potentialities to be developed by each individual: from the theoretical reasoning of the philosopher or scientist, to man's involvement in public life guided by practical and political wisdom, not to mention the wellbeing and health necessary to consider oneself happy. Aristotle also underscores man's fragility and vulnerability when confronted

with his possible lack of good luck and the vagaries of chance[26]. And if Nicomachean Ethics still speaks to us today, it is also because it is rooted in the reality of the Greek world, also revealing its shortcomings, including the lack of regard for the poor, the condition of women, and slavery.

Kant, on the other hand, influenced by Christian and Jewish tradition and by the Enlightenment ideal of emancipation, goes straight to a position of universality and regard for each individual, regardless of condition. Yet his requirement of arriving at a universalizable rule of action (moral law), applicable to all men, all societies, has difficulty moving beyond formalism and taking into account the constraints of everyday life: conflicting norms in real situations, conflicts between individuals even though each incarnates humanity, natural constraints – scarcity of resources, natural catastrophes, epidemics… This formalism is of course the result of the very construct of the concept of practical reason, which is right away established in the "intelligible" world of what should be, far from the phenomena and consequences of the real world. Like Aristotle's, his intention still touches us today, and it is because it too is rooted in historical context. It incorporates the Enlightenment ideal of emancipation, the hope embodied in democracy, and faith in the idea that science and technology will be able to overcome the constraints of late 18th century Europe and make it possible for all to have access to more health, culture and wellbeing.

Today, we too must think in a way that articulates the desire for universal rational principles and moral intuitions in real situations. This reflection must take into account two differences from the cultural worlds of the Greeks and the Enlightenment: first, axiological pluralism, which complicates convergence toward a single concept of the "good life"; and second, consciousness of the limitations of science and technology, as well as democratic institutions, limitations that make it more difficult to forge a shared concept of what is just and that affect our confidence in our ability to reduce risks.

We outline below a few of the main approaches based on ethical philosophy that have looked at this issue of intergenerational justice over the past five decades: rights of and obligations toward future generations, utilitarianism and economic approaches (more Aristotelian and consequentialist), the contractualist and procedural approach proposed by John Rawls, and Hans Jonas's "principle of responsibility". This gives us the opportunity to listen to their "moral intuitions" and, more importantly, to better understand and measure the difficulties they faced in seeking to describe an intergenerational justice that would be coherent, grounded in reason, and realistic in practice.

26. See Aristotle, *Nicomachean Ethics*, I, 1099 a32-1103 a19.

b) Problems associated with defining the rights of future generations

Clearly, there are many reasons for us to feel concern, solidarity, and responsibility toward distant future generations and, beyond them, to the future of humanity and its environment[27]. Talking about the rights of future generations over present generations requires going even further. The issue has been the subject of many controversies seen from different angles[28].

The first challenge is to define the rights of persons who do not yet exist vis-à-vis others who will have disappeared long before the former come into existence. How can we know enough about the interests and preferences of future generations that do not yet exist to define rights for them in a sufficiently precise way, and how will those generations be able to exercise their rights vis-à-vis past generations that have disappeared? The non-coexistence of the generations (in the sense of distant "cohorts") makes it difficult to talk about a social contract that lays out these rights and obligations, even asymmetrical, due to the arrow of time.

The second challenge relates to what we call the problem of non-identity[29]: can I blame the leaders of the 18th century Enlightenment and members of the Republic of Letters for their enthusiasm for the sciences and technologies that had consequences in terms of air pollution in 21st century France, which damaged my health and shortened my lifespan? The issue here is that I would probably not exist with the personality I have today if distant past generations had not made the choices that shaped my identity. As Olivier Godard puts it: "In reality, for the long period separating non-contemporaneous generations, selecting a different intertemporal profile of costs and benefits also means choosing to bring other persons into the world[30]". And yet, "if the goal is to add up the losses and advantages attributable to the actions of past generations, the analysis should look at future persons with a defined and unvarying identity for the comparisons used[31]" – a defined and unvarying identity that does not hold up.

The third challenge is common to all ethical approaches, including those that sidestep the notion of "personal rights" to instead focus on the objectives of wellbeing or the "capacities" of future societies (aggregating all the individuals

27. On this subject, see the range of moral intuitions underlying what Anglo-Saxons call "lifetime-transcending interests" (in particular, read Samuel Scheffler, *Why Worry About Future Generations?*, Oxford University Press, 2018).

28. See Janna Thompson, *Intergenerational Justice. Rights and Responsibilities in an Intergenerational Polity*, Routledge, 2009; Dieter Birnbacher, *Responsibility for Future Generations*, PUF, 1994; Axel Gosseries and Lukas H. Meyer, *Intergenerational Justice*, Oxford University Press, 2009; Axel Gosseries, *Penser la justice entre les générations. De l'affaire Perruche à la réforme des retraites*, Aubier, 2004; Hendrik Ph. Visser't Hooft, *Justice to Future Generations and the Environment*, Springer, 1999.

29. See Derek Parfit, *Reasons and Persons*, Oxford University Press, 1984.

30. Olivier Godard, *Environment and Sustainable Development. A meta-economic approach*, De Boeck, 2015, p. 223.

31. *Ibid.*

that comprise them): it is a delicate matter to compare the very long-term positive and negative consequences of our actions given the uncertainty that exists on that time horizon about the sequencing and intersection of natural causal chains ("butterfly effect") and how intermediate generations will exercise their free will[32]. Imputation only holds up if "directed at a subject that is capable of acknowledging being the author of the acts[33]" and can thus connect these acts to their consequences. As Paul Ricœur suggested, invoking the practical wisdom of the Greeks: "Between fleeing responsibility for the consequences and inflating it to infinite responsibility, we must strike the right balance and join R. Spämann in quoting the Greek precept: nothing in excess[34]". And we can delve even deeper into these questions about the extension of our responsibilities: should we take actions today to guarantee equitable distribution or protection against malevolent acts between person who will live together in 1,000 or 10,000 years? Or should we consider that it is mostly up to these distant future generations to exercise their freedom of choice and assume the responsibilities? We could take a nuanced position and say that our responsibility and that of intermediate generations is to transmit examples of collective solidarity, traditions of practical wisdom and institutions of cooperation. The same questions arise with nuclear waste, the dangers of which can, over time, as in many other areas, be a function of acts of malevolence or human-caused errors in the management of its confinement.

When controversies arise, these different aspects have often been illustrated through parables that allow for thought experiment as a way to measure ethical reasoning against our moral intuitions in delicate situations. One such approach that is interesting and illustrative is proposed by Olivier Godard: "After a war, for instance World War I, unexploded shells remain buried under the sand at a beach; a century later, children find the shells and play with them, setting them off, and are injured or killed. Let us assume that those who fired the shells died on the battlefield before the war ended. Should we conclude that they acted immorally because they infringed the rights of the children who were injured a century later? Who was responsible for the children's safety? The soldiers from a century earlier? Or the State that had sovereignty over the beaches, which are public property, when the accident occurred? Or the parents who did not properly supervise the children?[35]:" Beyond issues relating to non-existence or the capacities of

32. See Hilary Greaves, "Cluelessness", *Proceedings of the Aristotelian Society*, vol. 116, No. 3, October 2016, p. 311-339.

33. Paul Ricœur, "The Concept of Responsibility: An Essay in Semantic Analysis" [1994], quoted *in Le Juste 1*, Éditions Esprit, 1995, p. 69.

34. *Ibid,* p. 68.

35. Olivier Godard, *op. cit.*, p. 221. For an evocative summary of these issues, see, from the same author: *Global Climate Justice. Proposals, Arguments and Justification*, Edward Elgar Publishing, 2017, chap. 5 ("The puzzle of intergenerational equity").

present generations to act and control the long-term consequences of their actions, this parable clearly illustrates the complementarity and solidarity of responsibilities between different generations – present, intermediate and future – underscoring the need to take into account each's capacity to react.

Regarding the management of nuclear waste in a declining society that abandons storage facilities, there can either be a quick return to a society that is scientifically and technologically capable of decontaminating the area and re-confining the waste, or the society will remain without technological mastery over a long period, in which case we can imagine that local communities would protect themselves by relocating away from contaminated water tables, as they would if they lived near an active volcano. This would very likely be the case, as the real danger is a priori local and observable after a period of time. In both instances, future generations will have taken advantage of their response capacity; they will have found different yet relevant solutions to the problems posed by the abandoned storage facility. This illustrates the advantages of looking both at ethical reflection and a risk analysis grid "in real situations", depending on the possible society considered.

c) Utilitarianism: an Aristotelian and consequentialist approach serving as the source of public economics

Utilitarianism focuses on undertaking all collective actions that maximise the sum of wellbeing for all individuals and all generations. It measures the benefits of these actions and public policies with regard to their real impacts on happiness in the broadest sense (from artistic emotion to health, from material wellbeing to the ability to take part in political life), taking into account constraints imposed by resource scarcity. This moral philosophy is rooted in the preoccupations of the 19th century, particularly those of its founders, Jeremy Bentham and John Stuart Mill: how to allow citizens real access to formal rights (right to vote, right of expression, which implies education, health…) and to a portion of the wealth created by nascent industry. The aim of universality, formal in Kant's case, thus becomes attentive to the concrete expectations of the era, particularly those of the exploited working class.

Two major questions arise from the outset. First, adding up the levels of wellbeing of individuals implies that we know how to compare them, and second, these individuals must also be capable, by becoming citizens who participate in public choices, of setting aside their own interests and personal goals to focus instead on the general interest, which factors in the wellbeing of all their fellow citizens (comparability of levels of wellbeing and aggregation of preferences, altruism).

Another virtue of utilitarianism is that, in adding together all individuals by construction, it poses difficult well-known questions related to population ethics: should we prefer a decision that leads to a society with a very large number of individuals with a low standard of living, or one that leads to society with a small number of individuals who are prosperous? John Harsanyi (and others), seeking to neutralise the "large number" effect, proposed maximising the level of wellbeing per individual, with this maximisation potentially posing other problems. When it comes to intergenerational justice, the "population" effect is usually neutralised at the level of each generation by maximising the intergenerational sum of "utilities-wellbeing" per capita of an agent representative of each generation. Yet excessively large numbers reappear via the very large number of future generations potentially affected relative to the present generation, of which there is only one. This is the source of the debate about pure time preference for a present δ, between those who argue that it should be set at zero (notably Ramsey and Rawls), to avoid "sacrificing" distant future generations, and those who want to assign a positive value to prevent, in the event of low or no growth over a very long time, the tyranny of the future over the present generation as a result of the very large number of successive generations[36].

We have seen the importance of two other parameters: aversion to risk and aversion to inequality. While we may be able to get an idea of the value of these parameters on a near-term horizon for the individuals comprising our generation or those of recent past generations, based on whether they invest in assets that are more or less high risk, or their willingness to redistribute to the least advantaged, it seems difficult to deduce values that are meaningful for the long term and for future generations. This leads us to examine procedures that would allow present generations (in the absence of future generations) to clearly lay out, via prospective reflection and collective deliberation, their vision of these parameters.

d) Between guaranteeing individual liberties and regard for the most vulnerable (Rawls) and the survival of humanity (Hans Jonas)

We will bring this overview to a close by looking at two important figures from recent history inspired by very different visions: John Rawls, who belonged to the contractualist and Kantian tradition of just institutions, and Hans Jonas, who followed the Aristotelian traditions aiming for the good, in alignment with his own life philosophy.

John Rawls

John Rawls took a stand against utilitarianism which, from his viewpoint,

36. See Tjalling C. Koopmans, "Stationary ordinal utility and impatience", *Econometrica*, vol. 28, No. 2, April 1960, p. 287-309 (http://mikael.cozic.free.fr/koopmans60.pdf), and Kenneth J. Arrow, "Inter-Generational Equity and the Rate of Discount in Long-Term Social Investment", *in Contemporary Economic Issues*, vol. 4 ("Economic Behavior and Design"), 1999, Palgrave Macmillan, p. 89-102.

did not focus enough on preserving each individual's liberties relative to other material and cultural goods, and did not concern itself enough with the poor and most vulnerable. His theory of justice is based on three ordered principles that are the foundation of just institutions for our societies (principles in which are reflected the three parts of France's motto, Liberty, Equality, Fraternity):

– Equal right to the most extensive total scheme of equal basic liberties, this being the primary objective of just institutions;

– Equal opportunity to access roles and offices in society;

– Inequality in the allocation of goods acceptable only if it brings greater benefits to the least advantaged members of society. This third principle, called the "difference principle", implies accepting inequality if it maximises the wellbeing of the most disadvantaged.

John Rawls constructs the "circumstances of justice" in which individuals comprising a society could agree on these principles; it is thus, in part, a procedural and contractualist approach that depends on a thought experiment, a thoughtful balance struck between reasonable and disinterested individuals placed under a "veil of ignorance" as to their preferences and place in society but with a desire to cooperate.

These "circumstances of justice", together with the "veil of ignorance", assume a sort of benevolence informed by reason, the ability to set aside one's own interests, and thus a level of material, cultural and institutional development equivalent to that of today's industrial and democratic societies, accessible to all.

This is about ethics "in a historical situation". John Rawls always had reservations about applying his principles to issues of intergenerational justice as he was aware of the difficulties that resulted, for contractual approaches, from the non-coexistence of generations and the need for a high level of economic and social development, particularly so the society can match its redistribution capacities to its principles. As he expresses at the beginning of the paragraph devoted to this subject in *A Theory of Justice*: "We must now consider the problem of justice between generations. There is no need to stress the difficulties that this problem raises. It subjects any ethical theory to severe if not impossible tests[37]". He thus opts not to think about an intergenerational contract that could generalise the difference principle by seeking to promote the wellbeing of the least advantaged generations or the least advantaged persons over all generations. The non-coexistence of generations and the impossibility of compensating for the

37. John Rawls, *A Theory of Justice*, Seuil, 1987, p. 324.

more unfavourable fate of past generations seem unacceptable to him. He falls back instead on a principle of just savings once just institutions are in place, with a vision of the future that is free from uncertainty, enabling a stationary world, and where the goal would simply be to transmit to the next generations the world we inherited: net savings of zero would suffice, and meet Rawls's ideal of frugality (based on the living standards of our developed societies). As for the means of achieving this level of economic, cultural and institutional development starting from a deteriorated situation, the question explicitly posed remains unanswered:

"How the burden of capital accumulation and of raising the standard of civilisation and culture is to be shared between generations seems to admit of no definite answer[38]".

Hans Jonas

Contrary to John Rawls, Hans Jonas is inhabited by the fragility of man and his environment: "The promises of modern technology have turned into a threat […]. The subjugation of nature for the purposes of human happiness has brought about, by the disproportion of its success, which has spread to the very nature of man, the greatest challenge for the human that his own needs have ever entailed[39]". For Jonas, the threat is clearly one of total catastrophe, the possible disappearance of humanity and its environment due to excessive use of man's technological power: global nuclear war, genetic engineering radically transforming humankind, etc. His philosophy, valuing the being, life and the preservation of humanity in a "world from which God is absent", as he describes it in a beautiful book with poetic overtones[40], leads him to a new categorical imperative addressed to man, now solely responsible and required to do everything possible to keep humanity alive: "Act so that the effects of your actions are compatible with the permanence of genuine human life[41]". The quite dramatic tone of this statement reflects the pervasiveness of the tragedies of the Second World War and concerns about the dangers of military nuclear use, biological warfare, and genetic engineering of humans: "What can act as a compass? The anticipation of the threat itself! It is only when man catches the first glimpses of its storm arriving from the future, when he sees its planetary scale and the depth of what it means for humans, that ethical principles can be discovered […]. It is what I call the "heuristics of fear[42]".

It is undoubtedly important to recall that, like civilisations, humanity is mortal. First because of the laws of nature, incomparably more powerful than those of man, as illustrated by the consequences of a meteorite strike,

38. *Ibid.*, p. 326.
39. Hans Jonas, *op. cit.*, p. 15.
40. Hans Jonas, *Le Concept de Dieu après Auschwitz* [1984], Payot & Rivages, 1994.
41. Hans Jonas, *Le Principe responsabilité*, *op. cit.*, p. 40.
42. *Ibid.*, p. 16.

powerful volcanic explosions, and, on a larger scale, the evolution of the Sun. Changes in the climate and biodiversity, while irreversible and very worrisome global evolutions, do not a priori threaten the existence of mankind, but rather the living conditions of future generations. Moreover, there is a paradox in denouncing, however rightly, the Promethean ambition of having blind faith in scientific and technological progress, while at the same time calling for man to have unlimited, quasi demiurgic responsibility for the fate of humanity and the preservation of its ecosystems. In sum, man is expected to take the place of a God that is no longer present to keep watch over and preserve life: "Creating the world, God emptied himself entirely into the world and no longer has anything left to give: it is now man's turn to give[43]".

And yet, the emphasis placed on this new, unprecedented situation, stemming from our scientific and technological power, in which the latter could turn against us and place us on a path to decline and suffering for humanity and its environment, is profoundly just. We must therefore find ways to articulate this core concern with a risk analysis grid that is realistic and grounded, as well as with an approach to our responsibility that is demanding yet measured and genuinely "prudent". This responsibility assigned despite uncertainty about the future and with regard to distant future generations should not overshadow our responsibility vis-à-vis the most vulnerable in present and near-future generations, nor should it cause us to forget the protection of just institutions, still fragile and imperfect, that were so dear to John Rawls.

e) "Practical wisdom" for the present day

As eloquently stated on several occasions by Paul Ricœur[44], the ethical goal of achieving the good and working toward shared happiness (Aristotle) and the need for a universal moral law (Kant)[45]meet their referee and their completion when measured against action, against the reasonable choice made after deliberation (Aristotelean prohairesis) pursuant to practical wisdom in a concrete situation.

Beyond any debates about the potential rights of future generations, which remain unresolved, it is clear that many of our behaviours reflect the value we place on the existence and wellbeing of those future generations[46]: from the maintenance of forests to the writing of books, from the development of legal

43. Hans Jonas, *Le Concept de Dieu…, op. cit.,* p. 38.

44. See Paul Ricœur, *Soi-même comme un autre*, Seuil, 1990; *Le Juste*, vols. 1 and 2, Éditions Esprit, 1995 and 2001; *Lectures 1. Autour du politique*, Seuil, 1991.

45. Referring to the categorical imperative in Kant, "Act only in accordance with that maxim through which you can at the same time will that it become a universal law" (Emmanuel Kant, *Metaphysics of Morals*, Section 2, IV, 421, trad. V. Delbos and F. Alquié, *in Œuvres philosophiques*, t. II, Gallimard, "Bibliothèque de la Pléiade", 1985, p. 285).

46. See, in particular, Samuel Scheffler, *op. cit.*

codes to the construction of cathedrals, from Roman roads to the irrigation systems of the great "hydraulic empires". A core part of our preferences relates to the meaning we attach to belonging to communities in space and time. These behaviours and preferences must be translated into collective ethics terms. And yet future generations are absent, and we cannot speak for them or to them; on the other hand, we can imagine their expectations and desires, seeing them as persons who are as free and capable as us, and think collectively about our relationship with past generations while working to meet the main challenges of our time.

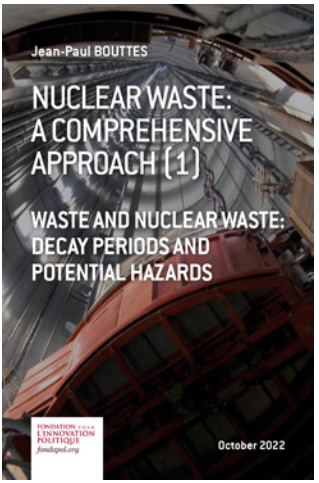
Our historic moment is of course marked by our unprecedented scientific and technological power, and even more so by our consciousness of a world that is expanded in space and time: from the origin of the galaxies and planet Earth to the explosion of our solar system, from the first signs of life to the appearance of Homo sapiens. We are aware that we belong not just to our family, our country or our thought traditions, but also to a common humanity, a common universe.

This knowledge of the histories of mankind, and this ability to imagine possible futures, to think about the possible long-term consequences of our actions, to consider together the ethical philosophies of different traditions, are much stronger today. These abilities of course resonate with today's challenges: risk of global geopolitical conflicts, climate change and biodiversity loss, ideological battles, uncertain demographic transition, etc. We cannot guarantee that these challenges will be successfully managed, but we must leverage our collective capabilities to try to tackle those that are transversal, from the most significant ones alluded to above to more moderate ones, such as managing nuclear or toxic industrial waste. Each of these examples shows, to varying degrees, the importance of using all the competences developed across multiple disciplines to assess the risks and develop solutions, of studying all the lessons from mankind's long history, of working together to create possible futures and consider different ethical traditions. And once policy decisions have been collectively made through the appropriate political institutions, we will need to bring all those competences together to successfully translate (in some industrial cases) and implement those decisions. This will require inventing new forms of cooperation on transversal subjects and demonstrating an ability to practice this principle of disinterestedness, of setting aside our individual interests.

Yet, as John Rawls accurately predicted, having this ability to set aside one's interests to collaboratively develop a just constitution implies working within "circumstances of justice", meaning a sufficient level of development to allow for the establishment of cooperative institutions and organisations that are reasonable, just and effective. The same is required to share an analysis grid and a meaningful ranking of risk for future generations, and

to successfully develop safe geological disposal facilities. In sum, we must begin by being more just, and more effective, in serving present generations, if we are to better protect the interests of future generations, by enhancing our ability to roll out these new cooperative institutions that will also be able to improve our legacy. Rather than talking at length about rights, redistribution or categorical imperative, perhaps we should be seeking to reasonably improve the fate of our own generation and to do a better job assessing and finding the right remedies for the risks and consequences of our activities, which would allow us to effectively leave a better world to future generations.

Human beings value (in a sense of strong ethical evaluation) collective projects with a distant horizon in space and time that give meaning to their actions. Yet they are first and foremost responsible for themselves, for those close to them (in time and space), and for what they understand and can accomplish. This journey through ethical philosophies is an invitation to find paths that give concrete meaning to this responsibility that seeks a universal perspective vis-à-vis future generations, but must be commensurate with a mankind that is finite, as is our collective humanity.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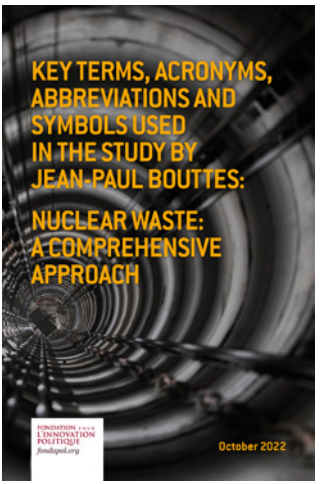
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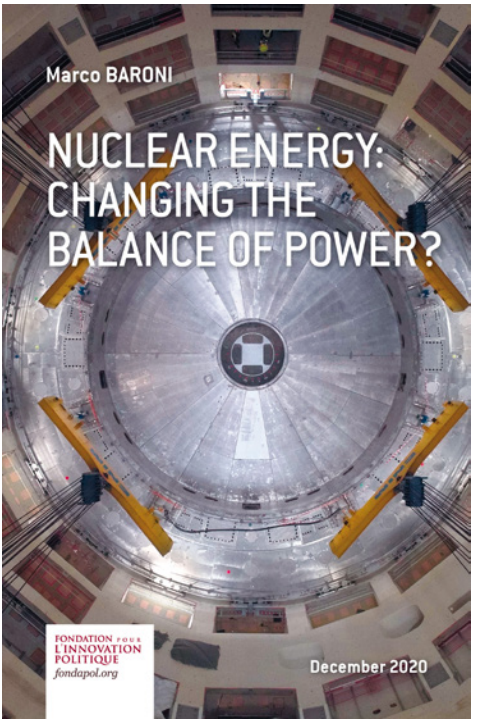
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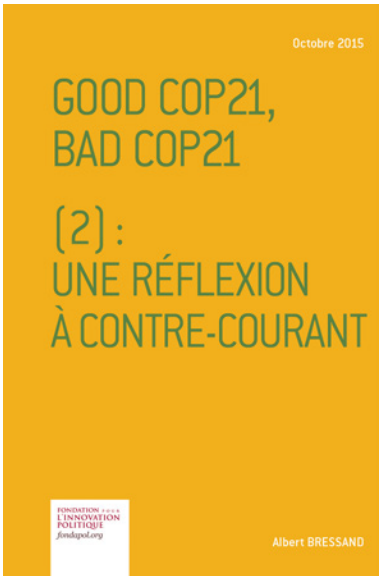
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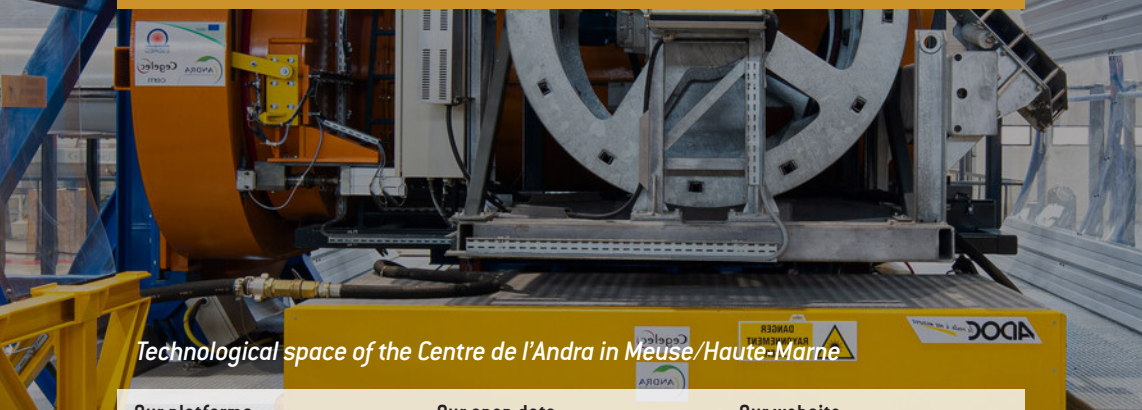
NUCLEAR WASTE: A COMPREHENSIVE APPROACH (3)

THINKING ABOUT FUTURE GENERATIONS

By Jean-Paul BOUTTES

The time horizon of risks associated with nuclear waste requires us to think about our responsibilities to future generations, even over the very long term (centuries, millennia and beyond). Approaches based on "public economics" help inform choices between geological disposal and long-term storage, depending on the economic status of future societies. Looking at the risks and opportunities passed down to future generations through a more extensive analysis grid, one that ranks degrees of risk and geographical scales, and takes into account levels of reversibility, allows for a better understanding of the challenges posed by nuclear waste relative to local risks such as those resulting from toxic industrial waste, and relative to major global risks like biodiversity loss and climate change. We can use this same analysis grid to compare the advantages of nuclear power relative to other energy technologies (fossil fuels and renewables) for present and future generations. Lastly, we will turn to ethical philosophies to help us think more clearly about how to strike the right balance between the responsibilities of present generations and those of future generations, and to better determine what the most important legacy is to pass down: scientific knowledge, democratic institutions, or practical wisdom?



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