Nuclear Power and Justice between Generations

A Moral Analysis of Fuel Cycles

Behnam Taebi

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The co-authored papers are written in conjunction with nuclear scientists at the Reactor Institute Delft (Delft University of Technology) and the Department of Nuclear Science and Engineering (Massachusetts Institute of Technology). The philosophical analysis in these papers may be ascribed to the candidate. Co-authors have given their permission for use of the papers in this dissertation.

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Glossary

FP	Fission Products, remaining products in addition to U, Pu and MA
FR	Fast Reactor
LWR	Light Water Reactor
MA	Minor Actinides, minor constituents of spent fuel; major constituents are U and Pu
MOX	Mixed Oxide Fuel; a mixture of UO_2 and plutonium-oxide that can be applied as a fuel
P&T	Partitioning and Transmutation
PAL	Period in which the Activity Lasts
Pu	Plutonium, radioactive metallic actinide and one of the major constituents of spent fuel
SF	Spent fuel
Th	Thorium
U	Uranium, radioactive metallic actinide and one of the major constituents of spent fuel

1 Introduction

Nuclear power is receiving increasing attention in public and political debates due to the growing worldwide demand for energy and the mounting climate change concerns emanating from fossil fuel combustion. On the one hand this renewed interest is understandable because – in comparison to oil and gas – nuclear energy has many advantages. One may, for instance, think of the abundant availability of resources[1], the ability to produce large amounts of energy with small amounts of fuel and the very low greenhouse gas production levels. It can also make industrialized countries less dependent on those conventional energy sources that mainly have to be imported from other parts of the world. On the other hand, there are also serious disadvantages attached to the using of nuclear energy such as accident risks in reactors, waste transport risks, proliferation concerns or worries about the possibility of deploying such technology for destructive purposes and, indeed, there is also the issue of what to do with the long-lived radiotoxic waste.

Discussion about the desirability of nuclear energy engenders much and deep public and political controversy. Many analyses regarding its desirability revolve around the notion of "sustainable development" (see WCED: 1987, 181) and its specific interpretations by different scholars and organizations; the implicit assumption seems to be that sustainability is synonymous with social and political desirability. Some proponents – such as David Bonser (see 2002) – find nuclear energy sustainable as it can produce clean, secure and reliable electricity that does not put the earth's climate in jeopardy; other proponents have more reservations but maintain that nuclear power can contribute to sustainable development in a "transitional role towards establishing sustainable [renewable] energy systems" (see Bruggink and van der Zwaan: 2002, p.151). The latter endorse the popular opinion that we are facing an "energy gap" in coming decades which can only be filled by nuclear power (see Connor: 2005;

1 The availability of uranium usually refers to its geological certainty and production costs. According to recent estimation, there will be at least enough reasonably priced uranium available for approximately 100 years when using only thermal reactors. If we include estimations of all the available resources, this will rise substantially to thousands of years (see IAEA-NEA: 2008).

Pagnamenta: 2009). The detractors, on the other hand, are utterly resolute in their view that nuclear power is inherently "unsustainable, uneconomic, dirty and dangerous" (see GreenPeace: 2006).

The ethical analyses provided in the relevant research reveal particular anxiety about all the risks and concerns associated with nuclear power. Some of the areas highlighted are the following: the proliferation risks (see Nye: 1988; Nwosu: 1991), radiological protection (see SSI: 2001; Eggermont and Feltz: 2008), the safety of power plants and nuclear accidents (see Hollyday: 1991), equity issues in radioactive waste management (see Kasperson: 1983) and, indeed, waste disposal (see Shrader-Frechette: 1993; Keeney and von Winterfeldt: 1994). It is especially in conjunction with the waste issue that concern is expressed with regard to future generations; for some it is a compelling reason for abstaining from the deployment of nuclear energy. Richard and Val Routley vividly illustrated this by presenting the analogy of a bus carrying a container of toxic waste and travelling through time. If the container breaks or if the content seeps into the bus some will be killed and others will suffer serious diseases. Their conclusion leaves no room for misunderstanding: the development of "nuclear energy on a large scale is a crime against the future" (see Routley and Routley: 1981, 297).

In this dissertation, I intend not to get involved in the general desirability debate. I assert that when thoroughly reflecting on the desirable *energy mix* for the future one needs to reflect on nuclear energy *in relation to* other energy sources. In so doing, we should first be aware of the distinctive aspects of nuclear technology such as the considerations that long-lived waste brings about for future generations. We should furthermore include different technological methods or *fuel cycles* in the production process as these methods deal differently with the distinctive aspects. Such a comparison of nuclear production methods based on how they affect the interests of people living now and in the future has not yet been made.[2] This dissertation sets out to bridge this gap by presenting a moral analysis of fuel cycles that is based on the notion of just distribution of the burdens and benefits over the different generations or, in short, on *intergenerational justice*.

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[2] There are analyses that do include a point of reference, for instance the Paul Scherrer Institute's comparative study of electricity supply technologies (see PSI: 2004) and the Dutch Social and Economic Council's advisory report on a comparison with gas and coal (see SER: 2008). However, once again, these analyses do not distinguish between different nuclear fuel cycles.

A related objective of this dissertation is to help decision-makers to better understand the ethical considerations behind different production methods. Nuclear energy currently accounts for approximately 6 percent of the global energy consumption and 16 percent of the global electricity production. A considerable growth of approximately thirty percent in the total production and consumption of nuclear energy is foreseen by 2030 (see EIA: 2008; IAEA-NEA: 2008). It would indeed constitute a naturalistic fallacy to move from this observation to the conclusion that we *ought to* deploy the nuclear option, but assuming that its deployment will continue it is worthwhile considering the differences between various fuel cycles from the perspective of the burden-benefit distribution between generations. Ultimately this can help decision-makers in the making of ethically informed choices.

I am not claiming any originality for the suggestion that we should be wary of the intergenerational distribution issue in nuclear energy related discussions. Both in legal agreement on waste management (see IAEA: 1995, 1997) and in philosophical scholarly works excellent analyses have been produced on the topic of nuclear waste disposal based on the notion of intergenerational justice. Two such examples are worth mentioning. Firstly there is, Kristin Shrader-Frechette (see 1993), one of the pioneers in the discussions on the ethics of nuclear power, who objected, for instance, to the idea of disposing of the waste in geological repositories, because of the great long-term uncertainties for future generations.[3] Secondly, there is the Swedish ethicist Lars Löfquist (see 2008) who devoted his PhD dissertation to the topic of the responsibility owed to future generations and nuclear waste management; he compared different waste management methods and concluded that "the most ethically legitimate distribution of risks" is the method that reduces the waste life-time and hence also risks to future generations (see 2008, 264). Indeed, I gratefully make use of these analyses in the present dissertation. I do however believe that we should approach the moral issues surrounding nuclear power from a broader perspective, in which waste management is certainly a relevant stage. Therefore I shall concentrate here on the whole production process, from uranium ore to the disposal of remaining waste after possible treatment has taken place.

Let us therefore focus for a moment on these production methods and on my reasons for approaching them from the perspective of intergenerational justice. Nuclear energy producing countries currently employ one of the following two

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3 See also various other works of Shrader-Frechette (see 1991b, 1994, 2005).

fuel cycles: 1) an *open fuel cycle* in which the fuel (uranium) is irradiated once in a reactor; the irradiated fuel or spent fuel then has to be disposed of underground for approximately 200,000 years and 2) a *closed fuel cycle* in which the still deployable material in the spent fuel is recycled and reused; the waste life-time of the remaining material is then substantially reduced to 10,000 years. One major disadvantage of this method is that of the separation of plutonium during reprocessing. The plutonium is supposed to be reinserted into the fuel cycle as a fuel ingredient but it also carries serious proliferation concerns as it can also be used for destructive purposes.[4] As can be concluded from this brief discussion on fuel cycles,[5] they clearly affect the interests of future generations differently. In Chapter 3, I argue that the closed fuel cycle could predominantly be associated with future benefits and present costs while the open fuel cycle is more beneficial to the present and creates more future costs and burdens. What is morally at stake in the choice of fuel cycle is therefore best approached from the perspective of justice between generations.

One central question here is this: what exactly does justice to future generations require of us? I will answer this question by focusing on theories of intergenerational justice. Assessing the nature and the strength of our moral obligation to posterity could well assist us when it comes to choosing a certain fuel cycle from a moral perspective. What is at least as important is the fact that understanding these issues can also help us reflect on future developments of this technology. In this dissertation I aim to combine philosophical discussions and technological *realities*; the state-of-the-art in the field of nuclear technology is explicitly incorporated in this analysis. In other words, what is our obligation to posterity and to what extent can existing technology help us to comply with these moral obligations and, finally, which scientifically feasible future technologies have the potential to help us to further comply with these obligations? If, for instance, we state that we should reduce possible risks to posterity, we could then opt for a recently proposed method known as Partitioning & Transmutation (P&T) which further reduces the waste life-time to several hundred years. P&T is, however, a scientifically proven method that still requires decades of development and industrialization. Having considered this technological

4 It should be noted that separated plutonium in the closed fuel cycle – also called reactor-grade or civil plutonium – contains too much contaminating isotopes for nuclear bomb creation, but it can still be used as a nuclear explosive (see DOE: 1997). Plutonium could also be deployed for *dirty* bombs due to its toxic nature. For detailed discussion on this, please see Section 2.4.2.

5 Detailed discussions on existing and future fuel cycles are presented in Chapters 3 and 4.

possibility I will then return to my philosophical analyses in order to examine how far our obligations to posterity extend, particularly whether the reducing of burdens to posterity allows the creating of additional burdens and risks to contemporaries. The intergenerational conflicts that such technologies bring about are further discussed in this dissertation.

Throughout my research I applied the analytical framework of intergenerational justice so that nuclear power production could be morally reflected upon. There are several factors that support the application of this framework. Firstly, since we are depleting a non-renewable resource (uranium) that will eventually not be available to future generations, the very production of nuclear power creates a problem of intergenerational justice. Stephen Gardiner (see 2003, 5) refers to this problem as "The Pure Intergenerational Problem" (PIP), which is in fact an exacerbated form of the prisoner's dilemma extended over generations. He imagines a world that consists of temporally distinct groups that can asymmetrically influence each other; "earlier groups have nothing to gain from the activities or attitudes of later groups". Each generation has access to a diversity of temporally diffuse commodities. Engaging in activity with such goods culminates in modest present benefits and substantial future cost and that, in turn, poses the problem of justice.

A typical example of the PIP is the general (fossil fuel) energy consumption situation characterized by predominantly good immediate effects but deferred bad effects in terms of anthropogenic greenhouse gas emissions that cause climate change.[6] Intergenerational justice and climate change have received increasing attention in the literature in recent years (see Page: 1999b; Shue: 1999; Gardiner: 2001; Athanasiou and Baer: 2002; Shue: 2003; Meyer and Roser: 2006). The main rationale in these discussions is that a change in a climate system that threatens the interest of future generations raises questions concerning justice and posterity.[7] The same rationale also applies to the production of nuclear power. In addition to the depletion of a non-renewable resource, the remaining long-lived radiotoxic waste adds another intergenerational dimension to the problem. What exacerbates this problem is the fact that we – the present generation – are in a beneficial temporal position

6 Gardiner terms such goods "front-loaded goods", in contrast to "back-loaded goods" with costs for the generation that produces them and deferred benefits for future generations (see Gardiner: 2006b, 1).

7 For a comprehensive discussion on climate change and future generations, see Edward Page's 'Climate Change, Justice and Future Generations' (see Page: 2006).

with regard to not yet existing generations and it is, therefore, quite convenient for us to visit costs on posterity, all of which makes us susceptible to "moral corruption" (see Gardiner: 2006a).[8]

What also supports the application of the framework of intergenerational justice is the fact that it has already been an influential notion in nuclear energy related discussions, particularly in relation to nuclear waste issues. In the last decades, the long-term concerns of waste have triggered a debate on how to deal with radiotoxic waste in an *equitable* way. The International Atomic and Energy Agency laid down several principles of Radioactive Waste Management, in which concerns about the future were expressed in terms of the "achievement of intergenerational equity"[9] (see IAEA: 1995). It was asserted that nuclear waste should be managed in such a way that it "will not impose undue burdens on future generations" (see IAEA: 1995: Pr. 5). Many nations agree that this undue burdens clause must be taken to mean that nuclear waste should be disposed of in geological repositories which, it is believed, will guarantee the long-term safety of future generations (see NEA-OECD: 1995). I will defer discussions on this issue to Chapter 2, where I will challenge the international consensus on geological waste disposal.

1.1. Objectives and research questions

Before turning to a general discussion about what intergenerational justice means, let me first introduce the research questions. As noted earlier, the main objective of this dissertation is to offer insight into the moral issues surrounding nuclear power production and its future technological possibilities, by applying the notion of intergenerational justice. To this end, the following research questions were formulated. 1) How can we approach the moral dilemmas attached to fuel cycles within the framework of intergenerational justice and 2) which fuel cycle is most desirable from a moral perspective? I am presenting a conceptual clarification of the concept of justice between generations in relation

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8 Gardiner puts forward this argument in the case of climate change where he addresses three related problems which he terms three storms. "These three 'storms' arise in the global, intergenerational and theoretical dimensions, and [...] their interaction helps to exacerbate and obscure a lurking problem of moral corruption" (see Gardiner: 2006a: 399). I believe that the main rationale of this argument which is based on our advantageous temporal position is not undermined.

9 It should be mentioned that equity entails a narrower notion than justice; more will be said about this issue in the next section.

to nuclear power production. This analysis is a certain type of applied ethics. Some remarks on the definition and scope of applied ethics might be appropriate here. There is a degree of skepticism about applied ethics as some believe that it is solely of secondary importance – compared to theoretical ethics – when it comes to applying a fundamental principle to a particular case. As Bernard Gert (see 1982, 51-52) puts it, applied ethics is "the application of an ethical theory to some particular moral problem". Against this skeptical view Tom Beauchamp (see 2003, 12) argues that if general moral principles are to be applied, these principles "must be made specific for context; otherwise moral guidelines will be empty and ineffectual". The specification should not be confused with the mere application of general theory, since it should take account of many complex issues such as uncertainty about risk and moral dilemmas. However, as Beauchamp (see 2003, 12) argues, this is "what philosophers have always done: they analyze concepts, examine the hidden presuppositions of moral opinions and theories, offer criticism and constructive accounts of moral phenomena in question".

In this dissertation I shall be doing applied ethics in the latter sense. According to the principles of intergenerational distributive justice involving a just distribution of burdens and benefits between generations, I will derive principles and duties with regard to future generations that could guide us when we reflect on nuclear technologies. The work does not, however, stop there, as Beauchamp has correctly argued. In order to *specify* these principles we should place them in the context of nuclear power production and take several relevant issues into consideration, such as how to deal with the long-term uncertainties of repositories and how to cope with the intergenerational moral dilemmas presented by fuel cycles. Without these specifications, the mere general principles would not be sufficient to enable moral reflection of the fuel cycles within the framework of intergenerational justice.

In answering the research question, I will first focus on the tacit assumption in the question to the effect that the notion of intergenerational justice is relevant to a moral analysis of fuel cycles. This has to some extent already been done in the foregoing paragraphs, but in the next Chapter I will elaborate on this issue and on how arguments of intergenerational equity have influenced waste management policies in nuclear energy producing countries (Chapter 2). After that I demonstrate that choosing one of the two existing fuel cycles may best be viewed as a matter of intergenerational justice (Chapter 3). On the basis of this knowledge, I present a suitable method for assessing future fuel cycles according to intergenerational justice drawn from the notion of sustainable development (Chapter 4). Based on the foregoing three chapters, I then address the normative issue of the desirability of fuel cycles and how to deal with intergenerational conflicts of interests. The particular focus is on seeking situations in which future interests can guide us in choosing certain technologies (Chapter 5). In Section 1.3, an overview of the chapters is presented in more detail.

1.2. What is intergenerational justice? Temporal duties

Let us now focus on the question of what it means to contemplate justice for posterity and on the different possible approaches. There are several features that characterize our relationship with future generations and which complicate the applying of theories of *intra*generational justice to posterity. Nevertheless, justice within the present generation is a good starting point for understanding how to address responsibilities to future generations and temporal justice.[10] The three categories of justice theories that are worth considering in the intergenerational context are: *commutative*, *aggregative* and *distributive* justice.[11] In the following paragraphs, I shall briefly discuss these theories and argue why I adhere to the distributive theory of intergenerational justice. I shall then conclude this section by explaining the different metrics of benefits in distributive justice and by showing how temporal obligations arise from this.

A common way of discussing justice for members of the same society is in terms of *reciprocity* regarding "the rightness of meeting reasonable expectations that a favour will be returned" (see Barry: 1989b, 464). Lack of reciprocity just so happens to be a distinctive feature of the relationship we have with posterity. That, however, does not necessarily render the notion of reciprocity useless

10 One might argue that we can also speak about responsibilities to future people without invoking any concept of justice, for instance when we care a lot about the welfare of our descendants. This is true when it comes to responsibilities to immediate future generations, but "if we care about the prospects of people in the remote future very much it is not on the basis of a natural sentiment but out of consideration of justice" (see Barry: 1989d, 192).

11 Here I am following and elaborating on the three theories that Gosseries (see 2008b) discusses when addressing 'Radiological Protection and Intergenerational Justice'. For an overview of different theories of intergenerational justice see 'Justice Between Generations' (see Barry: 1989c), 'What do we owe the next generation(s)?' (see Gosseries: 2001) and 'Intergenerational Justice' (see Wolf: 2003). For detailed discussions about different theories and their challenges the following two edited collections can be recommended: namely Joerg Chet Tremmel's 'Handbook of Intergenerational Justice' (see Tremmel: 2006b) and 'Intergenerational Justice' edited by Axel Gosseries and Lukas Meyer (see 2009).

when it comes to discussing intergenerational justice; one possible approach would be to conceive of justice as *indirect* reciprocity. The basic rationale behind this theory may be formulated thus: "since we have received benefits from our predecessors some notion of equity requires us to provide benefit for our successors" (see Barry: 1989b, 483). In other words, we have inherited the earth from our ancestors and should leave it in a fit state for future generations. This theory is based on exchanging (commutating) benefits; since we are expected to return these benefits to people other than our benefactors, the theory is dubbed indirect reciprocity.[12] The most important aspect of this approach that may be objected to is that of justifying the *gift*-obligation, namely why does receiving a gift creates an obligation to give it back?[13]

The second category is the aggregative theory of justice, the most prominent theory in this category being *utilitarianism*. In these people's view the morally right action is the one that produces the most good or *utility*, a phenomenon that is mostly understood to be sought in well-being or social welfare (see Driver: 2009). As a school of thought, utilitarianism must be traced back to the two eighteenth and nineteenth century British philosophers, Jeremy Bentham and John Stuart Mill. To Bentham's mind utilitarianism could be said to be founded on notions of *equality*: as everyone counts as one and no one as more than one, the interests of all (in terms of pain and pleasure) should be seen as equal. Mill (see 1859/1998b, 198) reiterates this principle by proclaiming that equality is "the first principle of morals". Utilitarians argue that the most desirable situation is achieved when the aggregation of well-being is maximized so that all are equally taken into consideration.

When considering utilitarianism in an intergenerational context so that the total utility between generations is maximized, a remarkable problem arises. If we assume that a certain capital invested properly today will create more capital, and thus more welfare, the maximization criterion will then demand huge sacrifices from contemporaries if overall utility is to be maximized.[14] Utilitarians are very well aware of this problem. One of the solutions that has been proposed is that of *discounting* the positive interest of future generations who are, as the argument goes, better off than the present generation. Discounting is however

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12 For detailed discussions on indirect reciprocity (see Barry: 1989b). See also Gosseries' (see 2001, 297-303) 'What we owe the next generation(s)?'.

13 Barry (see 1989b, 483-486) discusses this and other objections in 'Justice as Reciprocity'.

14 This objection is addressed by many scholars, including John Rawls (see 1971/1999, 253). See also Gosseries' (see 2005, 2008c) various articles on this issue.

an ad hoc solution that does not solve the problem of distribution; more about this issue will be said in Section 1.3.4.

Unlike utilitarianism, which is particularly interested in aggregation, the third category of justice focuses on the distributive aspect of justice which is why the term distributive theories of justice has been coined. John Rawls, the most prominent defender of this theory, is very well aware of the main problems of utilitarianism in the intergenerational context: "the classical principles of utility leads in the wrong direction for questions of justice between generations" as the advantages for future generations will require huge present sacrifices (see Rawls: 1971/1999, 253). In his seminal work 'A Theory of Justice', Rawls defends a *contraction* approach to justice as fairness. Contract-theory states that only free and rational agreements that are reached in social cooperation can generate moral norms (see Cudd: 2007). In the intergenerational context an ideally fair contract to distribute goods needs to be reached that cannot be rejected by any reasonable person. This is possible, Rawls (see 1971/1999, 118-123) argues, if we achieve agreement from an "original position" and from behind a "veil of ignorance" that will supposedly blind us to any preference; different parties "do not know how the various alternatives will affect their own particular case and they are obliged to evaluate principles solely on the basis of general considerations".

From behind the veil of ignorance we can now assess what justice demands that one generation should save; this is termed the *Just Saving Principle*. As the parties in the original position all know that they are contemporaries "in arriving at a just saving principle [...] the parties are to ask themselves how much they would be willing to save [...] on the assumption that all other generations have saved, or will save, in accordance with the same criterion" (see Rawls: 1971/1999, 255). According to Rawls (see 1971/1999, Ch. 44), fairness requires us to prohibit *dissaving*; in other words, we should save at least as much "real capital ... not only factories and machines ... but also the knowledge and culture, as well as the techniques and skills" for future generations.[15] One general critique on the just saving principle is that it does not account for other moral aspects like the transfer of risk to future generations. The latter is a relevant

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[15] Rawls actually proposes a two-stage approach in which an accumulation phase precedes the steady-state stage (see Rawls: 1971/1999, Ch. 44). Gosseries (see 2005, 44) argues that egalitarianism should not only prohibit dissaving but also that saving for future generations as a possible surplus "should benefit the least well off members of the current generation rather than the next generation as a whole".

aspect when we talk about nuclear power production and I will account for risk transfer in the way I relate to intergenerational justice; more about this issue will be said in Section 1.2.3.

1.2.1. Sustainability and intergenerational justice

One famous adherent to this Rawlsian framework is Brian Barry. Barry, however, criticizes the construction of the proposed original position as "the parties are to pursue their own conception of the good unconstrained by any consideration of fairness" (see Barry: 1995, 60). Barry adheres to the premise of egalitarian fundamental equality. While utilitarians incorporate this principle in their calculus by claiming that pains and pleasures of equal intensity should have the same value, regardless of who bears them, Barry (see 1999, 96-97) asserts that the application of the principle is not confined to utilitarianism: "different treatment of different people must be justified by adducing some morally relevant grounds for different treatment". He then presents principles for the theorems of fundamental equality, two of which are the principle of responsibility – "bad outcome for which somebody is not responsible provides a prima-facie case for compensation" – and the principle of vital interests (e.g. living a healthy life): "location in space and time do not in themselves affect legitimate claims ... [therefore] the vital interests of people in the future have the same priority as the vital interests of people in the present" (see Barry: 1999, 97-99).

Barry expounds his theory of intergenerational justice by spelling out the normative aspects of the notion of *sustainable development* and commenting that the value of an entity X as we enjoy it should be *sustained* into the future so that future generations do not fall below our level of X (see Barry: 1999). Regardless of what this X stands for, two questions need to be asked at this stage: 1) what is so special about the present situation that we should sustain it? and 2) should we account for population growth in our analysis?

The first issue constitutes an objection to Barry's proposal for projecting the same value of X into the future. Wilfred Beckerman (see 1999, 73) argues that taking the present situation as a point of comparison is arbitrary and has no normative significance when it comes to supporting an intergenerational duty; "past generations seem to have survived with far less". Barry argues that this objection arises from a misconception about the term 'intergenerational justice'. This notion should not be taken to refer to our connection with posterity;

"[b]ecause of time's arrow, we cannot do anything to make people in the past better off" (see Barry: 1999, 107). We are, however, in a position to influence the interests of future generations. "[U]nless people in the future can be held responsible for the situation that they find themselves in, they should not be worse off than we are" (see Barry: 1999, 106).[16]

The next issue that deserves attention is that of population growth. Passing on the same amount of X that is to be distributed over more people in the future "fails to accommodate the fact that later generations may be much more numerous" (see Wolf: 2003, 289) and is, therefore, incompatible with an egalitarian theory of justice. Barry states that we have every reason to limit future population, because a smaller population has a better chance of living satisfactory lives, but he argues at the same time that possible future growth is primarily the responsibility of future generations: "[i]f future people choose to let the population increase [...] that is to be at their own cost" (see Barry: 1999, 109).[17] The sustainability principle involving maintaining the value of X over a fixed number of people into the future is already a stringent principle; incorporating population growth would potentially render the principle inept. Questions regarding population also play a part in these discussions at a more fundamental level. Do we, as the present generation, have any obligation to bring about future generations? Even though this and other questions with regard to *population policy* deserve attention, they are not prima facie relevant to this dissertation.[18] The focus of this dissertation is on determining the kind of temporal obligations that we have in terms of what future generations inherit from us presuming that there will be future generations.

There is another difficulty attached to the notion of sustaining X over generations. If we assume that the value X is properly sustained for posterity does that necessarily guarantee a just distribution for future generations? Even though Barry (see 1999, 113) argues that "intragenerational injustice in the [near]

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16 This is a very brief discussion of Barry's extensive theory; for more information, see Barry's 'Sustainability and Intergenerational Justice' (see Barry: 1999). Lars Löfquist (see 2008, Ch. 2) presents in his dissertation – 'Ethics Beyond Finitude' – an excellent overview of Barry's theory of the responsibility we have to future generations.

17 On first inspection this argument sounds counterintuitive, as many choices concerning future population size are determined in the present. Barry is very well aware of this problem and argues that we should limit the population in near future (see Barry: 1999, 109-113). To my mind the reference should be to population growth in remote future generations.

18 Richard Sikora and Brian Barry have edited a classic volume on this issue (see Sikora and Barry: 1978).

future is the almost inevitable consequence of intragenerational injustice in the present", we can hardly influence the intragenerational distribution of X for any generation in the distant future. Figure 1 illustrates the space and time dimension of the two notions of distributive justice, namely intragenerational and intergenerational justice. By understanding how intragenerational justice within Generation A (the contemporary generation) works, I aim to relate to intergenerational justice; Intragenerational justice for Generation B extends beyond the scope of this dissertation; instead my focus will be on what we bequeath to posterity as represented by the horizontal black arrow given in Figure 1.

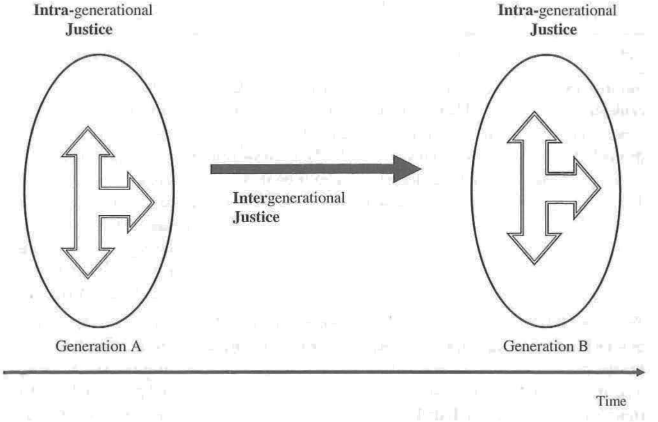

Figure 1: The temporal and spatial dimension of intergenerational and intra-generational justice. Source (see Tremmel: 2006a)

1.2.2. The currency of distributive justice

So far I have argued that in order to consider intergenerational justice there is a valuable entity of X that should be distributed equitably over generations. "Equality of What?" (see Sen: 1982) is the next question that arises: what is the "unit of benefit or advantage, on which our distributive concerns should focus" (see Page: 2006, 50). There are different ways to perceive the *currency* of justice. One possible response is that each person should enjoy the substantive freedom or a set of *capabilities* if they are to achieve valuable functioning, do what they want to do and be who they want to be. Amartya Sen and Martha Nussbaum are the founding parents of this approach.[19]

Barry proposes *opportunity* as a metric of justice: a requirement of justice is that "the overall range of opportunities open to successor generations should not be narrowed. If some openings are closed off by depletion or rather irreversible damage to the environment, others should be created (if necessary at the cost of some sacrifice) to make up" (see Barry: 1978, 243).[20] In this dissertation, by following Barry's principle that we should not narrow the total range of opportunities, I will develop two other principles that relate to nuclear power generation. Whenever we are in a position to possibly influence the opportunities of future generations we should be wary of not narrowing these opportunities.

We should recall the two intergenerational aspects of nuclear power production. Firstly, by depleting a non-replaceable resource (uranium), we are giving future generations less access to it. If we assume that welfare and well-being[21] significantly rely on the availability of energy resources we are in a position to influence future well-being. From the latter I conclude that we have a moral obligation to ensure future well-being, insofar as it can be achieved by the availability of such resources. My first *drilled-down* principle of intergenerational justice in nuclear power generation is an egalitarian one that is mainly concerned with the *opportunity for welfare* that future generations have.[22] The second intergenerational aspect in nuclear energy related discussions is the fact that we leave behind radiotoxic waste with tremendously long life-time periods. If not properly disposed of this waste can influence the safety and security of future generations and therefore also their *vital interests*. The latter is a fundamental condition if future generations are to enjoy equal opportunities. To sum up, the moral principles of equality of opportunity as proposed by Barry are

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19 In an overview article Ingrid Robeyns (see 2005) discusses the similarities and differences between the capability approach as outlined and further developed by each of these two scholars.

20 The notions of capability and opportunity do perhaps have similarities. Capability is, to my understanding, a notion that refers to individuals, while the notion of opportunity as applied here refers to a total range of opportunities for a group of people, without making reference to particular individuals.

21 In this dissertation I do not distinguish between these two notions.

22 Many scholars, such as Richard Arnesson (see 1989), defended equality of opportunity as a metrics for justice. There are also objections to this idea; see for instance Page's (see Page:

specified here by relating them to the specific context of nuclear power production and its distinctive features. This is termed specifying moral principles in order to apply them to a certain case (see Beauchamp: 2003); such specification is needed to make the general principles relevant in the context of this particular case.

There are, indeed, several philosophical challenges to be addressed in relating to these two principles, such as whether any changes in the safety levels of people of the future – caused, for instance, by radiotoxic leaking into the environment – will threaten their vital interests. It is not my intention to enter into such detailed discussion here. For the purposes of my analysis, I merely state that the opportunities of future generations are subject to our actions, in terms of what we bequeath to them. Egalitarian principles of distributive justice therefore at least require us 1) to sustain the opportunity for welfare that future generations have insofar as that can be achieved with resources and 2) to sustain the vital interests of future generations, or at least not endanger their safety and security.

Before spelling out these obligations, let me quickly address one more issue: where does the environment feature in these principles? Is this theory of egalitarianism essentially confined to human beings and should we only address considerations that relate to the environment if they serve human interests? In environmental philosophy there is a big current debate on whether we should ascribe an *intrinsic* value to the environment or an *instrumental* value so that future generations have equal opportunities to make use of it. Even though we can discuss justice to non-human animals or even all living creatures in the future[23] I shall confine the scope of this dissertation to an *anthropocentric* approach in the interests of clarity.[24] In my specified principles – or obligations, as they will be called in the remainder of this chapter – I relate to the environment form the point of view of how it affects future people's safety and security. By adopting the egalitarian principle of equal opportunities, I will now

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2006, 54-59) discussion for an overview of discussions on this ongoing issue. It is beyond the scope of this work to enter these discussions here.

23 Page (see 2006, 50) refers to this as the scope of justice. A more detailed discussion on this issue is presented in Chapter 4.

24 Such an anthropocentric approach is also in accordance with the way in which the United Nations' Framework on Climate Change (see UN: 1992b, Ar. 3) and the Brundtland definition of sustainable development (see WCED: 1987) perceives the environment.

formulate our temporal obligations or duties[25] to posterity in nuclear power production.

1.2.3. Two temporal obligations in nuclear power deployment

Let me start with the first obligation with regard to nonreplicable resources or *intergenerational resourcism*[26]. Brian Barry (see 1989a: 515) states that "[f]rom a temporal perspective, no one generation has a better or worse claim than any other to enjoy the earth's resources". It is, however, unfair to require the present generation to leave all non-renewable resources for their successors. As replicating such resources is not an option either Barry (see 1989a, 519) argues that we need to offer compensation or recompense for depleted resources "in the sense that later generations should be no worse off [...] than they would have been without depletion". Technology plays a crucial role in establishing how to comply with these duties, for instance by making combustion engines more efficient, which again contributes to making the remaining stock of non-renewable resources go further (see Barry: 1989a, 519-20).

In this dissertation, I adopt Barry's reasoning on the adequate consumption of non-renewable resources: "[t]he minimal claim of equal opportunity is an equal claim on the earth's natural resources" (see Barry: 1989b, 490). If we assume that welfare relies heavily on the availability of energy resources – a claim that could be historically underpinned by considering developments from the time of the industrial revolution until the present day – I would argue that we should compensate for the reduction of opportunities for well-being as they can be brought about by resources.[27]

For the notion of compensation to make sense, we need to assume a certain level of *substitutability* of natural resources with human-made resources (see

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25 Many moral philosophers maintain that the notion of 'obligation' should be seen as "referring to voluntary, mutually acknowledged commitment to, or between, identifiable persons" (see Partridge: 1981a, 5). This means that 'duty' is probably a more appropriate term when it comes to a temporal relationship. However, as the notions of 'obligation' and 'duty' towards people of the future are used interchangeably in the literature, I do not distinguish between the two terms in this dissertation.

26 Edward Page calls Barry's theory intergenerational resourcism (see Page: 2006, 60).

27 Another way of defending compensation is, as Barry (see 1989a) has argued, that natural resources are no one's property; so consumption creates an obligation to compensate. This *ownership* argument is valid, independent of any loss of welfare. Assuming that, above all, it is

Skagen Ekeli: 2004: 434).[28] This, however, does not pose a challenge to our egalitarian approach to intergenerational justice, because we do not ascribe any inherent value to resources; the moral relevance of resources lies in the fact that they can sustain the opportunity for welfare. I am furthermore avoiding questions regarding how these resources are to be deployed by next generations (namely the spatial distribution by generation B as illustrated in Figure 1) and whether equal access to energy resources will result in equal welfare[29].

The second obligation that I discuss in this dissertation is the obligation not to negatively influence the vital interests of future generations by safeguarding their safety and security. This is a fundamental condition if future generations are to enjoy their equal opportunities. In broader terms, this can alternatively be called the obligation not to harm posterity. Before discussing this obligation from an intergenerational angle, let me say something about the origins and the applications of this principle. One of the fundamental ethical obligations underscoring all human interaction is that of avoiding harm to others. In his seminal work 'On Liberty', John Stuart Mill (see 1859/1998a: 14) states that "[t]he only part of the conduct of anyone, for which he is amenable to society, is that which concerns others." Mill (see 1859/1998a: 14) who definitely acknowledges that an individual is sovereign when it comes to his body or mind simultaneously argues that "[t]he only purpose for which power can be rightfully exercised over any member of a civilised community, against his will, is to prevent harm to others. His own good, either physical or moral, is not sufficient warrant." This *no harm* principle is also a leading creed for health care professionals; the related maxim that is frequently invoked in health care is thus: 'to do not harm above all else' (see Beauchamp and Childress: 2009: Ch. 5). In environmental policy-making, too, this principle is becoming increasingly influential, for instance where it inspires the Precautionary Principle: namely "[w]hen an activity raises threats of harm to the environment or human health, precautionary measures should be taken even if some cause and effect

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the equal opportunity of future generations we are concerned about, I rather focus on what these resources can bring about in terms of opportunity for welfare.

28 At a more fundamental level we need to assume that the substitutability of natural capital with man-made and physical capital (see Pearce et al.: 1989, 40-43) is a fact. This assumption has many implications, such as the fact that man-made capital is, by definition, less diverse. Here I refer only to the substitutability of natural energy resources. This assumption also raises certain questions such as that of whether exhaustible energy resources should be compensated by technological progress or with renewable resources (see Pearce and Turner: 1990).

29 Edward Page further elaborates on this objection (see Page: 2006, 62-3).

relationships are not fully established scientifically", as stipulated in the Wingspread statement (see 1998).

Throughout this dissertation this concept of negative obligations is extended to include the intergenerational context and it is dubbed the principle of not harming the vital interests of future generations or, in short, the maxim of not harming future generations. The necessity to avoid causing harm to posterity is also very well acknowledged in nuclear waste management, as we are urged not to impose "undue burdens" on future generations; there is consensus that the technological solution to meeting this requirement is to dispose of long-lived radiotoxic waste underground (see IAEA: 1995). In next chapter I will discuss and challenge this view in some detail.

To conclude this section, let me emphasize that I am not offering a coherent and comprehensive account of intergenerational justice. From the egalitarian distributive principle that we should safeguard posterity's equal opportunity, as proposed by Barry, I derive two drilled-down principles or temporal duties: 1) we should safeguard their opportunity for welfare and 2) we should not endanger their vital interest which is a condition if they are to enjoy equal opportunity.

1.3. Challenges to temporal justice

Intergenerational justice primarily implies that the present generation has a certain duty or obligation to posterity. Before turning to the challenges that this notion faces, let me first devote attention to a group of scholars who categorically deny any duty to posterity (see Schwartz: 1978; Thompson: 1981). Schwartz (see 1981), for instance, argues that human beings are psychologically incapable of being concerned about and caring for future others. A possible response to this objection is offered by Partridge (see 1981b, 217-8) who states that "human beings have a basic and pervasive need to transcend themselves" without which "our lives would be confined, empty, bleak, pointless, and morally impoverished".

Among those scholars who do not disregard duties to posterity, there is dispute about the justification and extent of these obligations. At least three challenges are posed to the notion of temporal duties. Firstly, future generations do not exist and cannot have rights to justify our duties to them. Secondly, we cannot be said to harm future generations as their identity is contingent on our action. The third objection operates on a more practical level: who are these future generations to whom we owe obligations? In the following paragraphs, I will elaborate on these challenges and examine how they influence the two duties as I have formulated in the last section.

1.3.1. Do non-existent people have rights?

One of the distinctive features of future generations – if we discount the overlap with the immediately following generation – is that they do not yet exist. This plain fact brings with it objections when it comes to addressing temporal obligations, namely that these people who have not yet been born cannot be said to have rights to justify duties that correspond to them.[30] We can distinguish here between three schools of thought. The first group argues that "the ascription of rights is properly to be made to actual persons – not possible persons" (see Macklin: 1981, p. 151)[31] since the possessors of rights are inescapably active agents capable of choice (see Steiner: 1983). The second group, on the other hand, has no problems attributing *moral* rights to future individuals (see Baier: 1981a; Pletcher: 1981). The third group follows the *interest* theory of rights argumentation from the point of view that if agent X has a right then that implies that "other things being equal, as aspects of X's well-being (his interest) is sufficient reason for holding some other person(s) to be under a duty" (see Raz: 1986, 183). I follow here this interest theory, since we can safely assume that there will be future generations and that these people will have interests which will be subject to the action taken by the current generation. (see Feinberg: 1981, 148).

No matter how the dispute about future rights is settled, virtually everyone engaged in this dispute acknowledges the existence of a certain duty for contemporaries to accept constraints on any actions of theirs that might affect people living in the future. Even the cynics, such as Beckerman and Pasek (see 2001, 28) who categorically deny ascribing rights to non-existent people, acknowledge that "we have a moral obligation to take account of the interests of future generations in our policies, including those policies that affect the environment". For the two duties as formulated in the last section, the very fact that future generations have an interest that is not insensitive to our actions is sufficient reason to justify duties on the part of contemporaries; these obligations are not necessarily grounded in rights. The existence of long-term

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30 In an overview article Gosseries discusses four challenges to the meaningfulness of granting rights (including constitutional rights) to future generations (see Gosseries: 2008a).

31 See also De George (see 1981).

radiation protection policy in countries deploying nuclear technology is also an acknowledgment of such temporal obligations in the case of nuclear waste management.

1.3.2. Can we harm future people whose identity depends on us?

The second objection is whether we can *harm* future generations whose contingent identities rely on the actions and choices of contemporary people: "any event that affects the condition under which a particular conception takes place (that is any event that influences which particular sperm and egg cells come together under favorable conditions) will influence who exists" (see Kavka: 1982, 94). Therefore, practicing a policy that is presumably wrong (e.g. environmental pollution) for future generations simply leads to the existence of different future individuals; future generations can never therefore claim to be harmed as their very existence relies on those alleged wrong actions. This theoretical problem is extensively discussed by different philosophers, but Derek Parfit has offered the most comprehensive account of this problem which he dubs the *non-identity* problem (see Parfit: 1987 [1984], Ch. 16).

Let us explore whether the non-identity problem poses a challenge to our formulated obligations in the case of nuclear power production. The second duty of not harming future generations is evidently founded on a harm-based account of justice and is therefore vulnerable to the non-identity problem. This second duty also has some similarity to certain accounts of intergenerational justice and climate change that view anthropogenic climate change as unjust because it makes some people worse off;[32] this approach is also criticized as being prone to the non-identity problem (see Page: 1999b, 61).

In addition, our first duty is also based on some accounts of *disadvantaging* future people by exhausting non-renewable resources. The argument is that it is this disadvantage that is not justified and should be compensated for. If we now assume that it is the very same depletion that constitutes the conditions for existence of certain future people then the non-identity problem suddenly poses a severe challenge to this intergenerational resourcism view. Indeed, this is precisely the argument put forward by Edward Page (see 1999b, 57-58).

When it comes to the matter of to bypassing or solving the non-identity problem certain solution propositions have been made but none would prove

32 Such an approach is for instance defended by Shue (see Shue: 1995).

entirely successful. One is the notion of *impersonal* harm, according to which an action or policy (e.g. pollution) could be harmful, even if it did not harm particular individuals (see Glover: 1992). Another escape might be sought in *communitarian* theories of justice that emphasize the moral relevance of a community. Avner De-Shalit (see 1995) presents a *transgenerational* community[33] that extends into the future and argues that we directly owe them an obligation; "[s]ince the theory ties the obligations and their origins to us, the present generations, we need not ... relate the obligations to the rights of someone else who is not yet alive in order to find the moral grounds" (see De-Shalit: 1995, 127-128). Edward Page (see 1999b) proposes something similar with his notion of "collective interests" that circumvents the non-identity problem of future individuals in discussions on intergenerational resourcism and global climate change (see Page: 1999b). A final response to the non-identity problem which I would quickly like to mention is to follow a *sufficientarian* concept of justice as proposed by Meyer and Roser (see 2009). Sufficientarianism is primarily concerned about everybody's well-being above a certain *threshold* level; likewise we can establish a normative baseline in order to determine whether harm has occurred.

In short, let me reiterate that the non-identity problem is a serious theoretical problem that theories of intergenerational justice, particularly the personal and harm-based theories, are facing. Certain solutions have been proposed, but they are either not definite or have a too small scope; the relevant philosophical inquiries should certainly continue to *fix* this theoretical ineptitude. The non-identity problem, however, does not deny our moral obligations to posterity. This is a counterintuitive conclusion that is gladly supported by just a few people, Schwartz (see 1978) being one of them. It is also worth noting that Parfit (see 1987 [1984], 357) would disagree with such a conclusion as he states that the fact that we can influence the well-being of future generation creates a certain obligation towards posterity.

1.3.3. Obligations to which people of the future?

So far I have argued that we can be said to have an obligation to safeguard future generations' opportunity for welfare and not to harm future generations by

33 Note that this transgenerational community contrasts with Gardiner's temporally distinct generations as reflected in the Pure Intergenerational Problem (see Gardiner: 2003).

endangering their vital interests. A next issue pertains to the extent of this obligation. In fact it directly relates to the period for which the formulated obligations should be complied with. In other words, should we distinguish between generations of the near future and of the remote future in terms of compliance with temporal obligations? Perhaps even more importantly, how should we deal with possible conflicts of interest?

These questions date back to the early days of discussing obligations to posterity. By introducing the notion of membership within a "moral community" which should share our perceptions of what constitutes a good life, Martin Golding argues that "the more *remote* the members of this community are, the more problematic our obligations to them become" (see Golding: 1981, 147)[34] and he concludes that we should be more concerned about the more immediate generations. Daniel Callahan (see 1972) on the other hand states that ignorance does not free us of our obligations when the question is whether we might harm future generations. Evidently Callahan's notion of our negative obligations to posterity obviously extends much further that Golding's positive obligation.

Both ideas are connected together by Avner de-Shalit (see 1995: 13) who emphasizes that contemporaries have a strong *positive* obligation to close and immediate future generations to "supply them with goods, especially those goods that we believe [...] will be necessary to cope with the challenges of life", but he also advocates that we should adhere to less strong *negative* duties towards the distant future. Our two formulated obligations can also to be approached in terms of positive and negative obligations: not harming future generations is plainly a negative obligation and the duty to offer compensation to posterity is an attempt to want to positively influence their lives with the available energy resources. One can also argue that the latter obligation is derived from the fact that the exhausting of non-renewable resources disadvantages our descendants; but the obligation as formulated here is not one of not disadvantaging; it is argued (for instance by Brian Barry) that the deploying of non-replaceable resources is allowed as long as we offer compensation or recompense. The second obligation may therefore be best understood as a positive obligation to compensate posterity. Further discussions on the extent of moral stringency will be deferred to Chapter 5.

34 This is the point emphasized in the original version. It is a communitarian approach like the one mentioned in the last subsection and also defended by Avner de-Shalit (see 1995).

Let us go now return to the ideas presented above to the effect that we have a less far-reaching obligation to remote future generations when we compare that to our obligation to proximate generations. The ensuing question then becomes whether we are allowed to make a distinction between how we treat different future generations. This permissibility issue will be assessed and examined from a moral standpoint in the following chapter (Chapter 2). All I want to emphasize here is that the notion of diminishing responsibility over the course of time is the one that is currently adhered to in policy-making on environmental issues with long-term consequences. Two examples are worth mentioning.

Firstly, a Panel of the American National Academy of Public Administration, (NAPA)[35] has established four principles of intergenerational decision-making which state that we are *trustees* for future generations and that – according to the sustainability principle – we should not deprive the future of a quality of life comparable to our own (see NAPA: 1997, 7). The ethical justification of unequal treatment towards the distant future therefore has to be sought in the degree of predictability of the near future as well as in its reasonable similarity to our situation. A second attempt concerns the Swedish KASAM[36] which follows the same line of reasoning: "our responsibility diminishes on a sliding scale over the course of time", since "the uncertainties of our base of knowledge [...] of the system's technical design, increase as a function of increasing time span perspectives" (see KASAM: 1998, 27). Like NAPA, they believe that we have a more extensive duty to the immediate future (see KASAM: 2005a, 430).

The current leading notion of diminishing responsibility over the course of time has also influenced nuclear waste management policy. In legislative documents concerning the Yucca Mountains repository in the state of Nevada in the United States, the Environmental Protection Agency (EPA)[37] states that "a repository must provide reasonable protection and security for the very far future, but this may not necessarily be at levels deemed protective (and controllable) for the current or succeeding generations" (see EPA: 2005: 49036). If we appeal to the principles discussed by the NAPA and KASAM, it may be argued that people living in the next 10,000 years deserve a level of protection

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35 NAPA is a nonprofit-based organization established by the US Congress to positively influence the effectiveness and the performance of the government.

36 KASAM is the National Council for Nuclear Waste operating under the authority of the Swedish Government.

37 The Environmental Protection Agency is the United States federal agency that is responsible for protecting human health by protecting the natural environment.

equal to the current level and that the generations belonging to the period extending beyond 10,000 years could well be exposed to much higher radiation limits.[38] Extensive discussions on this issue are presented in Chapter 2.

1.3.4. Should we discount future benefits and burdens?

The values of certain commodities vary at different future times when we compare them to present monetary values. If we can spend € 1,000 now or in twenty years' time, it is probably wise to do the former as the value of money declines over the course of time. Apart from inflation, there is another reason for discounting, and that is the fact that properly invested money will probably be more productive in the future, this is referred to as the *opportunity cost of capital*. In investment decisions it is very important to assess the net economic benefit of certain investments over the course of time. For the latter purpose, *cost benefit analyses* (CBA) have been proposed to identify different costs and benefits; discounting is then the device that enables costs and benefits to be calculated over the course of time. The same rationale applies to certain investments and costs made today that will bring about benefits in the future. In energy policy, for instance, current R&D investments will start to produce benefits within a few decades. These benefits may then accrue over centuries. A standard analytical method in economic studies is to *discount* these future benefits and costs from their present values (see Lind: 1982b).[39]

While CBA and discounting are undisputed[40] and even desirable for certain short-term economic decisions, the whole matter becomes complicated and even controversial when there is more at stake than just monetary costs and benefits, or when we need to account for detrimental effects and benefits in the distant future. The first issue is the problem of incommensurability. How should we incorporate human lives, environmental damage and long-term radiation risks into a CBA? Although there are ways of expressing such concerns in terms of monetary units, all the approaches face the problem of comparing matters that

38 One difficulty here is the matter of how to define a generation. There are different definitions varying from 3 decades – such as within KASAM (see 2005a) – to longer periods of time.

39 For an extensive discussion on discounting, see an article collection edited by Lind (see 1982a).

40 There is disagreement on the interest rate against which future effects should be discounted; the rate can seriously influence the outcome.

are essentially incomparable[41]. The second issue, accounting for harms and benefit in the distant future, raises questions about the moral legitimacy of discounting (see Cowen and Parfit: 1992). Discounting is particularly controversial in the case of non-economic decisions, for example when decisions are made from an intergenerational point of view[42] in the way advocated in this thesis. It is not my intention to review all the arguments for and against discounting.[43] Instead I shall focus on the question of how to value future risks, which is very important in nuclear energy technologies.

If we are to discount risks in the remote future, policies for mitigating climate change and disposing of nuclear waste will be seriously undermined. One may, however, question whether the mere fact that a risk materializes at a later point in time (and inherent uncertainty is involved) supports the discounting of the effect of such risk. Suppose, for example, that radiation release (as a result of inappropriate nuclear waste disposal) leads to harming people, culminating in 100 fatalities 500 years from now. How should we value these deaths in relation to present lives? At a discount rate of 5 percent, one death next year becomes *equivalent* to more than a billion deaths in 500 years. It would be outrageous to include such conclusions in the valuation of future risks. In light of the fact that we are considering tremendously long periods of time, discounting – even at a very small rate – will make future catastrophes morally trivial (see Parfit: 1983b).[44] The appropriateness of CBA in long-term nuclear waste management has been questioned, in view of the serious uncertainties involved and the inability of CBA to address the distribution issue between

41 Even when we remove money from the formula, we still have to deal with incomparable entities in our decisions (see Hansson: 2007).

42 For extensive discussions, please consult the collection 'Discounting and Intergenerational Equity' edited by Portney and Weyant (see 1999).

43 Cowen and Parfit (see 1992) systematically review and defuse many arguments used to justify a positive discount rate. For more recent discussions the two following articles can be recommended: Marc Davidson (see 2006) defends a zero consumption rate for climate damage and Simon Caney (see 2009) rejects the arguments for discounting time, wealth and risk, as they violate the fundamental rights of future people.

44 For more discussion on the issue of discounting future risk, see Cowen and Parfit (see 1992, 146-147) and Caney (see 2009, 176-181). A similar argument that relates to the valuing future risk is that of whether we should compare one type future risk with another more severe one, arguing that the latter justifies the former; e.g. the more serious risks of climate change might render the risks of nuclear waste disposal less important. However, this is a slippery slope argument in which all risks could be justified as long as more severe risks are conceivable.

generations (see Berkhout: 1995). Even though discounting is more or less standard practice in short-term policy-making, I believe that only a zero discount rate is defensible when it comes to valuing possible harm to distant future generations.

It is furthermore important to consider whether we see the issue of building repositories as one that offers benefits for future generations or seeks to avoid harming them. This is not just a simple matter of semantics; the framing of these effects is highly relevant to the moral argument. I argue that disposing of nuclear waste ought to be seen as a matter of avoiding harming posterity; the present generation has enjoyed the lion's share of the benefits to be derived from nuclear power and remains responsible for dealing with its waste. In Chapter 5 I formulate two conditional duties for the present generation towards future generations, arguing that the negative duty (of avoiding harm) is more compelling and extends farther into the future than the positive duty of benefiting posterity.

1.4. Overview of the dissertation

Before introducing the main body of this dissertation, there are a few remarks that first have to be made. Firstly, there is a degree of repetition in the dissertation that should be apologized for. The following four chapters were written as four separate and independent papers that were submitted to four different journals. This means that unavoidably certain passages concerning the theory and the technology facets are presented, to a different extent, in various chapters. The claim that there is an intergenerational problem which emanates from the production of nuclear power is, for instance, one that is repeated in three chapters. The technical details regarding the fuel cycles are also slightly duplicated though different details are discussed in different papers. Chapter 4, for example, extensively discusses the fuel cycles and their various aspects while Chapter 5 merely hints, in very general terms, at these fuel cycles. These discrepancies can be explained on the basis of the target groups of the journals to which the chapters were submitted and the level and amount of technology and philosophy appreciated by these interdisciplinary journals. In order to clarify the contribution made by each chapter to the dissertation, the main arguments of the consecutive chapters are listed in a very concise schematic overview given in Section 1.4.5.

Another issue is the (seemingly) different terminologies that are applied, such as with the notion of sustainability in Chapter 3 and Chapter 4. In Chapter 3 I adopt a *narrowed-down* definition as proposed by the Nuclear Energy Agency, while my proposal in Chapter 4 is to take 'sustainable development' as the overarching moral value from which other relevant values could be derived within the intergenerational context. These apparent differences in terminology do not, however, undermine the main arguments put forward in the dissertation. In other words, applying the broader notion of sustainability in Chapter 3, does not alter the conclusion that there are trade-offs to be made between the interests of present and future generations when it comes to choosing a fuel cycle. I shall now introduce the four chapters that aim at answering the research question.

1.4.1. Is geological disposal the best option? (Chapter 2)

The challenge with regard to the extent of our obligation to the future (as discussed in Subsection 1.2.3.) is of particular relevance when it comes to the question of how to dispose of nuclear waste properly. In Chapter 2, I focus on how the notion of intergenerational equity underlies nuclear waste policies. The consensus within the nuclear community happens to be that spent fuel should be buried in geological repositories rather than kept in surface storage depots, particularly because repositories are believed to be safer in the long run. This long-term safety does, however, seem to be disputable as it relies on great long-term uncertainties which, in turn, necessitate the sanctioning of a distinction between different groups of people living in the future. The latter is borne out by the case of the Yucca Mountains repositories in the United States, where the radiation exposure limit for people living there after 10,000 years could well be almost seven times as high as it is at present. In this chapter I argue that putting distant future generations at a disadvantage lacks solid moral justification, all of which should urge us to reconsider our temporal moral obligations in the light of recent technological developments. The technological possibility of substantially reducing the waste life-time through Partitioning and Transmutation (P&T) might well challenge geological disposal and come to place long-term surface storage in a new perspective.

In Chapter 2, I will elaborate on this discussion by evaluating the intergenerational arguments that underlie policies in the light of P&T. If we acknowledge that because of nuclear power production there is a problem of intergenerational justice then we can conclude that the present generation has a moral obligation to ensure the well-being of people of the future (in terms of resources) and not harm future generations. P&T is still, however, a laboratory-scale technology which means that substantial investments will be required before it can be introduced on an industrial scale. Moreover, the deployment of this technology creates additional safety risks and economic burdens for the present generation. Nevertheless, the potential chance to diminish "undue burdens" for future generations is too relevant to be neglected in philosophical discussions on nuclear waste management policies. The question will further be explored to what extent we should rely on future technological possibilities for today's policy-making.

1.4.2. An intergenerational approach to fuel cycles (Chapter 3)

In Chapter 3, I approach the two existing fuel cycles (open and closed) by considering the moral values at stake. I apply there the three main values of 'sustainability', 'public health & safety' and 'security' and relate those values to different fuel cycles. The values of 'public health and safety' link up with any kind of health concerns that would emanate from the possible leakage of nuclear material into the environment, while security has to do with intentionally caused harm and is associated with proliferation, that is to say, the fabrication and/or the disseminating of nuclear material for destructive purposes. The notion of sustainability as adopted in this particular chapter, is an adapted version of how it was presented in a Nuclear Energy Agency study carried out for the purposes of comparing different P&T strategies (see NEA-OECD: 2002, 18). I approach sustainability by considering the three specified values of 1) Supply certainty, 2) Radiological risks to the environment and 3) Economic affordability.

In this chapter, I show that the open fuel cycle must mainly be associated with short-term advantages, as it brings about relatively fewer radiological risks, and thus public health and environmental concerns; it is furthermore less proliferation sensitive in terms of the present generation. The closed fuel cycle, on the other hand, could bring with it long-term advantages, as it would improve sustainability in terms of uranium supply certainty and it would lead to fewer long-term radiological risks and proliferation concerns; this type of fuel cycle furthermore compromises short-term public health and safety as well as security, due to the fact that it involves the separating of plutonium. By revealing the value conflicts that accompany the production of nuclear energy, I argue that it is best to see the choice between open and closed nuclear fuel cycles as a matter of intergenerational justice.

1.4.3. Intergenerational criteria to assess fuel cycle (Chapter 4)

Many nations are currently considering alternative fuel cycles in an effort to prolong uranium fuel supplies for thousands of years. They are, for instance, contemplating using breeder reactors and alternative means of managing nuclear waste, strategies that bring with them different benefits and burdens for the present generation and for future generations. In Chapter 4, a method is presented that provides insight into future fuel cycle alternatives and into the conflicts potentially arising between generations within the framework of intergenerational equity.

In that chapter, I view the notion of sustainable development as a moral value consisting of other values that contribute to it. By elaborating on the relation between sustainability and intergenerational justice, I formulate a set of intersubjective values. I distinguish there between two value categories 1) for sustaining the environment and humankind's safety and security, as a fundamental condition if future generations are to enjoy equal opportunities, and 2) for sustaining human welfare. I furthermore focus on the notion of the technological applicability of a certain technology. If we concentrate on its scientific feasibility and industrial readiness that will enable us to reflect on that new technology in terms of the effects that it may have in the future.

By operationalizing these values and mapping out their impacts, value criteria can be introduced for the purposes of assessing fuel cycles based on the distribution of burdens and benefits between generations. The once-through fuel cycle model currently deployed in the United States and the three fuel cycles projected for the future are subsequently assessed according to these criteria. The four alternatives are then compared in an integrated analysis in which the implicit trade-offs are highlighted, whenever decision makers choose a certain fuel cycle.

1.4.4. The morally desirable fuel cycle (Chapter 5)

Chapter 5 address the normative issue of the desirability of any given fuel cycle on the basis of the findings of the foregoing three chapters. In this particular chapter it is argued that the morally desirable option for nuclear power production is to safeguard the interests of future generations. I argue that the desirable option should primarily be formulated in terms of the duty that the present generation has towards posterity 1) not to harm people of the future and 2) to sustain future well-being by guaranteeing the availability of resources. If these duties are to be fulfilled then certain technologies will have to be implemented, all of which affects the burdens and benefits for different generations.

In order to be able to address these intergenerational conflicts, I treated temporal duties as *prima facie duties* and alluded to the fact that they might be overruled by morally more important duties. It is a notion borrowed from moral pluralists and in particular from William David Ross (see 1930/2002). I argue that – in all-things-equal situations – the duty not to harm future generations extends farther into the future and is more compelling; this supports the idea of introducing Partitioning and Transmutation (P&T) fuel cycles in order to substantially reduce the waste life-time periods. Such a fuel cycle creates additional safety, security and economic burdens for contemporaries. All these intergenerational conflicts are further explored. In addressing intergenerational conflicts Chapter 5 examines the extent of the moral stringency of the no harm duty by seeking out situations in which future interest could guide us in our decisions to choose a certain technology.

1.4.5. An overview of the arguments given in the various chapters

Chapter 1: Introduction

- ⇨ Intergenerational conflicts of interests in nuclear power production
- ⇨ A review of several theories of justice; an egalitarian theory chosen
- ⇨ Presenting the notion of “opportunity” as a currency of justice

Chapter 2: A challenge to geological disposal

- ⇨ A review of waste management policies & intergenerational arguments
- ⇨ Challenging the distinction between the short-term and long-term future
- ⇨ Long-term uncertainties and how they challenge geological repositories
- ⇨ P&T helps us avoid a distinction between the near and remote future
- ⇨ A discussion of three counter-arguments to P&T

Chapter 3: An intergenerational approach to fuel cycles

- ⇨ A review of open and closed fuel cycles and their waste life-times
- ⇨ Identifying the values at stake when choosing a fuel cycle
- ⇨ Operationalizing these values

- ⇨ A review of the pros and cons of the fuel cycles in the light of these values
- ⇨ Identifying intergenerational value conflicts in choosing a fuel cycle
- ⇨ Discussing the tacit assumptions behind the analysis and counter-arguments

Chapter 4: Assessing the intergenerational considerations of fuel cycles

- ⇨ A way to highlight the intergenerational aspects of fuel cycle choices
- ⇨ Deriving values from the notion of sustainability
- ⇨ Presenting criteria by relating these values to the consequences of fuel cycles
- ⇨ Reviewing the current American and three possible future fuel cycles
- ⇨ Assessing cycles on the basis of the presented criteria; a descriptive analysis

Chapter 5: Choosing the morally desirable fuel cycle; a normative analysis

- ⇨ Identifying two fundamental moral duties to future generations
- ⇨ Presenting these moral duties as conditional (prima facie) duties
- ⇨ Addressing the conflicts between these duties: which one is more persuasive?
- ⇨ Examining the stringency of conditional duties in intergenerational conflicts
- ⇨ Choosing the no harm duty as the leading notion, thus a P&T cycle

Chapter 6: Conclusions

- ⇨ General conclusions to be drawn from the dissertation
- ⇨ Reflections on how they will affect policy making
- ⇨ Assumptions and disclaimers

2 A Challenge to Geological Disposal

How Partitioning & Transmutation Changes the Outlook on Intergenerational Equity in Nuclear Waste Management Policy[45]

Abstract

The consensus within the nuclear community is to bury spent fuel in geological repositories rather than keeping it in surface storage places, particularly because repositories are believed to be safer in the long run. This long-term safety seems to be disputable as it relies on great long-term uncertainties which, in turn, necessitate sanctioning a distinction between different future people. Putting distant future generations at a disadvantage lacks, however, solid moral justifications, which should urge us to reconsider our temporal moral obligations in the light of recent technological developments. The technological possibility of substantially reducing the waste life-time through Partitioning and Transmutation (P&T) is believed to challenge geological disposal, placing long-term surface storage in a new perspective. P&T is, however, a laboratory-scale technology which means that substantial investments will be required before industrial deployment. Moreover, the deployment of this technology creates additional safety risks and economic burdens for the present generation. Nevertheless, the potential possibility to diminish "undue burdens" for future generations is too relevant to be neglected in philosophical discussions relating to nuclear waste management policies. The question that will further be explored is: to what extent should we rely on future technological possibilities for today's policy-making?

Keywords: Nuclear Waste Management, Intergenerational equity, geological disposal

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45 An earlier draft of this paper has been presented in a conference on Energy and Responsibility in Knoxville (Tennessee) in April 2008.

2.1. Introduction

The rapidly growing energy consumption level, future forecasts and climate change have prompted a new debate on alternative energy resources. Alongside green energy such as wind and solar power, a new nuclear era seems to have started. According to the World Nuclear Association, there were 439 operative nuclear reactors in January 2008. In addition, a further 34 reactors are under construction, 93 have been ordered or planned and 222 have been proposed. Nuclear energy currently accounts for almost 16% of all the electricity produced worldwide (see WNA: 2008b; IAEA: 2007b).

The main advantage of nuclear energy – when compared to fossil fuels – is that it can produce a large amount of energy from relatively small amounts of fuel while generating very small amounts of greenhouse gases. However, there are some serious drawbacks attached to nuclear energy such as the accident risk level, proliferation threats and nuclear waste. Nuclear waste remains radiotoxic for a long period of time before decaying to a non-hazardous level; the latter is defined by the radiotoxicity of the same amount of uranium ore. This period is known as the waste life-time and for spent fuel in a once-through fuel cycle that amounts to 200,000 years. Recycling technologies (reprocessing) are capable of reducing this waste life-time to 10,000 years. Recent developments in nuclear waste management – Partitioning and Transmutation (P&T) – demonstrate at laboratory level that it could be possible to reduce the waste life-time yet further, to a couple of hundred years (see NRC: 1996).

For the current and future protection of human health and the environment in dealing with radioactive waste, the International Atomic and Energy Agency (IAEA) has laid down certain principles for Radioactive Waste Management, one of which states that nuclear waste should be managed in such a way that it “will not impose undue burdens on future generations” (see IAEA: 1995, Pr. 5). This “undue burdens” clause could best be placed within the framework of intergenerational equity or equity across generations (see NEA-OECD: 1995). Current policy in nuclear energy producing countries mainly stems from intergenerational equity considerations, and from striving for an equitable distribution of risks and burdens inspired by the belief that the safety and security of future generations should not be jeopardized. Intergenerational equity also involves guaranteeing equal opportunities for future generations. In nuclear energy-related discussions, equal opportunity mainly pertains to the retrievability of waste for its potential economic value.

The consensus within the nuclear community for the ultimate disposal of waste seems to be in favor of burying spent fuel in geological repositories rather than storing it on the surface; this consensus is founded on the long-term safety (and security) assurances that host geological formations supposedly guarantee (see IAEA: 2003). However, the long-term safety depends on certain considerable uncertainties, which necessitate sanctioning a distinction between different future generations. I argue that this distinction lacks moral justification; we should best avoid these uncertainties. Implementing P&T allows for the latter, as the period of necessary care for P&T waste is substantially shorter.

This paper is organized as follows. In Section 2 I briefly discuss the production of nuclear energy and different options for the final isolation of waste. Section 3 presents a discussion on nuclear energy in terms of intergenerational equity. The philosophical foundations of policy-making derived from the three intergenerational principles are then discussed in Section 4. In addition, that section explores how these principles affect actual long-term policies in relation to nuclear waste management. In Section 5, I examine the moral legitimacy of distinguishing between future people, particularly when designing geological disposal areas. Section 6 revisits the intergenerational arguments underlying nuclear waste management policy in the light of P&T, thus presenting a challenge to the geological repository option. A number of possible counter-arguments to the application of P&T will also be reviewed in that discussion section. The concluding section briefly presents the findings.

2.2. Nuclear Waste Management: fuel cycles, storage and disposal

Nuclear energy is produced by irradiating fuel in a nuclear reactor. In this paper irradiated fuel is referred to as spent fuel rather than waste because the way in which spent fuel is dealt with represents a crucial choice in terms of nuclear waste management. Two possible scenarios are these: 1) directly isolate spent fuel as waste for a long period of time, thus creating an open fuel cycle and 2) ‘destroy’ or convert the very long-lived radionuclides to shorter lived material in accordance with closed fuel cycle guidelines.

2.2.1. Fuel cycles and waste life-times

Irradiating uranium (U) produces other materials, including plutonium (Pu), which is a very long-lived radioactive isotope. Apart from plutonium, other residual radioactive materials, minor actinides as well as fission products will be formed. Actinides are elements with similar chemical properties. Uranium and plutonium are the major constituents of spent fuel and so they are known as major actinides. Neptunium, americium and curium are produced in much smaller quantities and are thus termed minor actinides. Fission products are a mixture of radionuclides that will decay to a non-hazardous level after approximately 250 years.

The presence of major actinides in spent fuel defines the waste life-time in an open fuel cycle; neither minor actinides nor fission products have a significant effect on long-term radiotoxicity. The waste life-time of spent fuel in this fuel cycle is 200,000 years and it is dominated by plutonium. Removing plutonium from spent fuel can thus substantially diminish the waste life-time. In a closed fuel cycle, plutonium and any remaining uranium are isolated and recovered during a chemical treatment phase which is referred to as reprocessing. Reprocessed uranium could either be added to the beginning of the fuel cycle or used to produce Mixed Oxide Fuel, a combination of uranium-oxide and plutonium-oxide that can be used in nuclear reactors as a fuel (see Wilson: 1999). The closed fuel cycle waste stream is referred to as High Level Waste (HLW) or vitrified waste and it has a waste life-time of approximately 5,000 to 10,000 years.[46] Also the volume of HLW is substantially reduced after reprocessing.[47]

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46 Reprocessing is not 100% efficient and after reprocessing HLW contains some trace elements of long-lived plutonium. However, the presence of these trace elements does not mean that HLW has the same life-time as spent fuel, i.e. the waste life-time is defined as the period in which a certain nuclear material becomes as radiotoxic as the same amount of uranium ore; see Figure 5. As radiotoxicity is defined as the effect of radiation on human health, even with the presence of some trace elements of long-lived plutonium, the waste life-time of HLW is substantially less than that of spent fuel. Therefore 10,000 years is not a really distinct cut off point in Figure 5; the more plutonium there is in HLW, the longer the waste life-time of HLW will be.

47 It is important to observe that the volume of troublesome long-lived isotopes is substantially reduced through reprocessing, while at the same time more Intermediate and Low Level waste is produced that also needs to be disposed of. However, the disposal is less troublesome than in the case of HLW and spent fuel. See in this connection Wilson (see 1996); Chapter 8 and particularly Table 8.1. There are some scholars who believe that the presence of a larger

2.2.2. Partitioning and Transmutation (P&T)

As spent fuel is conceived of as the Achilles' heel of nuclear energy, serious attempts have been made to further reduce its life-time and volume. A new technology for the latter purpose is that of Partitioning and Transmutation (P&T).[48] As stated above, spent fuel contains uranium and plutonium, minor actinides and fission products. Uranium and plutonium are separated during reprocessing in order to be reused; P&T focuses on 'eliminating' minor actinides in spent fuel, as illustrated in Figure 2. P&T complements reprocessing but does not provide an alternative solution.

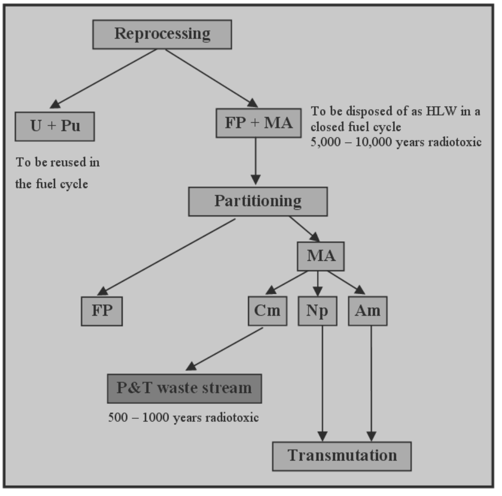

Figure 2: A schematic representation of Partitioning and Transmutation

FP fission products
MA minor actinides
Cm curium
Np neptunium
Am americium

If completely successful P&T will, it is expected, make the waste life-time five to ten times shorter when compared to closed fuel cycle waste. After P&T, waste

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volume of different types of nuclear waste constitutes a reason to argue against the reprocessing and recycling of fissionable materials (see Berkhout: 1991, 181).

48 This corresponds with the NEA's fully closed fuel cycle as illustrated in Figure 2.3 in their report 'Advanced Fuel Cycles and Radioactive Waste Management' issued in 2006; see (see NEA-OECD: 2006).

radiotoxicity can decay to a non-hazardous level within the space of 500 to 1000 years. This estimated reduction in the waste life-time is based on the assumption that all minor actinides are transmuted except for curium; the waste stream would therefore only consist of relatively short-lived fission products and curium isotopes.[49] The latter is considered to be too hazardous to be recycled at reasonable expense and without excessive risk; curium would dominate the waste life-time. At present P&T is only available in the laboratory; a considerable amount of R&D effort is required before P&T can be industrially utilized (see IAEA: 2004; NEA-OECD: 2002).

2.2.3. Interim storage, long-term storage and geological repositories

Irrespective of the fuel cycle choice, the waste remaining after optional treatment needs to be disposed of. In waste management, a distinction is made between storage and disposal: storage entails keeping the waste in purpose-built facilities above ground or at a certain depth beneath the surface, while disposal entails isolating and depositing waste at a significant depth (of several hundred meters) under the ground in engineered facilities. The latter are termed geological repositories or simply repositories.

Spent fuel is usually stored under water for a period of time – varying from a couple of years to several decades – after having been removed from the reactor core; this stage is called the interim storage stage. Water serves as a radiation shielding and cooling fluid. The interim storage of waste is also a crucial factor in the safe management of radiotoxic waste, since it is designed to allow radioactive decay to reduce the level of radiation and heat generation before the final disposal stage. It is especially heat generation that very much influences the capacity of a repository. (see Bunn et al.: 2001).

A commonly proposed alternative to geological disposal is long-term monitored surface storage. However, the technical community largely appears to disregard this option since it views surface storage as merely an interim measure pending the time when waste can be disposed of in geological repositories (see IAEA: 2003; NEA-OECD: 1999b). Up until now, all the available facilities for

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49 There is a dispute about what exactly the waste life-time will be after successful P&T. It is beyond the scope of this work to enter such discussions. However, for the sake of argument I adhere to the mentioned period, arguing that the scientific possibility of the reduction of the waste life-time to a period like 500 years urges us to revisit some intergenerational arguments relating to waste management.

spent fuel and High Level Waste tend to have been located above ground or at very shallow depths.[50] Some people are, however, concerned that this interim storage phase may well become, de facto, perpetual.

Depositing the waste in space or disposing of it in inaccessible deep-sea sediments – like for instance beneath the Antarctic ice – are the alternatives that have been proposed (see KASAM: 2005a, Ch. 3). These options are not, however, being taken seriously, due to the unacceptable safety risks involved and what amounts to the violation of international conventions.

Existing fuel cycles and their latest developments have been reviewed in this section. The two ways to dispose of waste: i.e. in geological repositories or by means of storage above ground will be further discussed. In the following section I shall elaborate on the question as to why the production of nuclear power raises the problem of fairness between generations. Precisely how considerations of equity between generations have influenced current policy in favor of geological disposal is explored in Section 4. By including P&T in this discussion and re-evaluating the underlying policy arguments, I will argue that P&T could shed new light on long-term storage above ground as a serious alternative to geological disposal.

2.3. Intergenerational equity and nuclear waste management

Widespread concerns about depleting the Earth's resources and damaging the environment have recently triggered new debate on the equitable sharing of goods over the course of generations or, on intergenerational justice.[51] This concept of equity was first introduced by John Rawls (see 1971/1999) who alluded to intergenerational distributive justice. Since then intergenerational justice has been extensively applied to various future-related discussions, mainly those concerning the environment and more specifically climate change but recently also, the allocation of emission rights (see Page: 1999b; Meyer and

50 In some countries, such as Sweden and Finland, geological repositories are currently used for the disposal of Low-Level Waste and Intermediate-Level Waste; see for more information (see KASAM: 2005a, Ch. 1).

51 For detailed discussions on intergenerational justice readers are referred to these articles (see Gosseries: 2002), (see Meyer: 2008) and the following two collections (see Gosseries and Meyer: 2009) and (see Tremmel: 2006b).

Roser: 2006). In nuclear waste management this notion of justice or equity[52] across generations has been influential, particularly in promoting geological repositories as final disposal places for nuclear waste; in Section 4 I will elaborate on this issue. Before that I would like to pause for a moment to reflect on the claim that there is a problem of intergenerational justice that emanates from nuclear power production.

I shall adhere here to Stephen Gardiner's discussions about "The Pure Intergenerational Problem" (PIP), in which he imagines a world consisting of temporally distinct groups that can asymmetrically influence each other; "earlier groups have nothing to gain from the activities or attitudes of later groups". Each generation has access to a diversity of temporally diffuse commodities. Engaging in activity with such goods culminates in modest present benefits and substantial future cost and that, in turn, poses the problem of fairness. Gardiner refers to the problem of energy consumption and anthropogenic carbon which causes climate change and has predominantly good immediate effects but deferred bad effects. Even if present benefits exceed future costs (assuming that we can compare these entities), this is a moral problem because just as with most theories of justice, distribution is independent of overall utility (see Gardiner: 2003, 483-488).

There are two ways in which PIP relates to nuclear power production and to waste management. First of all, assuming that this generation and the immediately following ones will continue depleting uranium, a non-renewable resource, there will be evident intergenerational equity considerations to bear in mind. Secondly, the production of nuclear waste, and its longevity in terms of radioactivity, signifies substantial present benefits with deferred costs, as stated in Gardiner's PIP.

Another cause for concern in nuclear energy related discussions is our beneficial temporal position with regard to successive generations: "our temporal position allows us to visit costs on future people that they ought not to bear, and to deprive them of benefits they ought to have"; Gardiner refers to this as "The Problem of Intergenerational Buck Passing" (see Gardiner: 2006b, 1). As we can reasonably expect that the incentive structure remains the same for all generations, the Problem of Intergenerational Buck Passing will be exacerbated

[52] Justice, fairness and equity are used interchangeably in the relevant literature sources. In this paper I do not intend to go into great depth on these philosophical discussions. *Intergenerational equity* or *justice* are referred to here as the equitable distributions of risks and burdens across generations.

over the course of time, all of which gives rise to moral justification for limiting the impacts of our actions that have intergenerational consequences (see Gardiner: 2006b, 2-3).

I argue that the intergenerational problem resulting from nuclear power production entails certain moral obligations and that contemporaries must not endanger the interests of future generations. These obligations can manifest themselves in two different ways. Firstly, there is the depletion of a resource, namely uranium, that will not renew itself for future generations which justifies placing certain restrictions on depleting these resources.[53] Assuming that well-being significantly relies on the availability of energy resources – a claim that could be historically underpinned by considering developments from the time of the industrial revolution up until the present – we could be said to have an obligation to ensure well-being for the future. Another, perhaps more important obligation, relates to the longevity of nuclear waste and to the fact that its inappropriate burial can harm future generations. So the next moral obligation that the intergenerational problem creates is that of not harming future people.

There are, however, certain theoretical and practical objections to this reasoning. The theoretical problem is whether rights can be ascribed to future people to justify obligations and whether we can harm future people whose very existence depends on our action and inaction. At the practical level of applying these ideas we might encounter the question of how far into the future these obligations extend and how we can deal with the uncertainties linked to such long-term predictions.[54] In this paper, I take the liberty of not extensively discussing such theoretical impediments. In the following paragraphs I shall touch on the theoretical objections and briefly argue why I do not find them

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53 Estimations of the available supplies of uranium in the world are actually much larger than is commonly realized. The availability of uranium usually constitutes a reference to its geological certainty and production costs. The availability of uranium usually refers to its geological certainty and production costs. According to recent estimation, there will be at least enough reasonably priced uranium available for approximately 100 years when using only thermal reactors. If we include estimations of all the available resources, this will rise substantially to thousands of years; see (see IAEA-NEA: 2008). This does not, however, undermine the basic rationale that the present generation is depleting a non-renewable resource, particularly the currently reasonably priced supplies.

54 There are more practical objections to the notion of obligation to future generations, such as how to incorporate the interest of future generations and whether we should discount their benefits. These questions are beyond the scope of this work. In this paper, I address instead the legitimacy of having a distinction between different future people, from a moral point of view.

persuasive enough to free us from talking about the obligation not to harm future generations. In section 5, more attention will be given to the relevance and legitimacy of a distinction between different future generations in the light of long-term uncertainties.

Future people's identity and numbers are very much contingent on the actions and policy choices we make now. As it is the moment of conception that determines which individuals will come into existence and as different policy choices result in different individuals, we can never be accused of harming future individuals since, in line with Parfit's (see 1983a) non-identity problem, it is changing policy that will change the number and identity of all these still to be born individuals. The next ensuing problem is whether we have any obligations towards these contingent people and whether these obligations are founded in rights. Some scholars argue that "the ascription of rights is properly to be made to actual persons – not possible persons" (see Macklin: 1981: 151); see also Beckerman and Pasek (see 2001). Here, I follow the interest theory of rights argumentation to the effect that if agent X has a right then that implies that "other things being equal, as aspects of X's well-being (his interest) is sufficient reason for holding some other person(s) to be under a duty" (see Raz: 1986, 183). We can safely assume that there will be future generations and that these people will have interests which will be vulnerable to harm caused by the actions of the current generation. "The identity of the owners of these interests is now necessarily obscure, but the fact of their interest-ownership is crystal clear" (see Feinberg: 1981, 148).

To conclude, the depletion of uranium and the longevity of nuclear waste cause the problem of intergenerational justice, that in turn, create moral obligations for present generations to ensure future well-being – in terms of resource availability – and not to harm future people. It should be clear that I am not intending to examine the extent of the stringency of these moral obligations[55] nor to elaborate on any theoretical impediments that may arise. In this paper, I am merely assuming that the production of nuclear power creates certain moral obligations, the extent of which remains the subject of ongoing discussion.

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55 Elsewhere I take up this challenge by focusing on the extent of these two positive and negative obligations to respectively ensure future well-being and avoid future harm, particularly when they conflict with each other and – more importantly – with the interest of present generations. See for a preliminary discussion of these issues (see Taebi: 2009).

2.4. Nuclear Waste Management; "a desire for equity"

Having discussed the moral obligations that ensue from the intergenerational problem that the production of nuclear energy creates, I shall now return to the nuclear waste management principles and to the overarching notion of intergenerational equity. The long-term concerns, as discussed above, have triggered a debate on how to deal with radiotoxic waste in an equitable way. The level of acceptance[56] of risks for present generations is proposed as a reasonable indication for the future. The International Atomic and Energy Agency (see IAEA: 1995) laid down several principles of Radioactive Waste Management, in which concerns about the future were expressed in terms of the "achievement of intergenerational equity". It was asserted that nuclear waste should be managed in such a way that it "will not impose undue burdens on future generations" (see IAEA: 1995, Pr. 5). The Nuclear Energy Agency (NEA) reiterated those principles in a Collective Opinion, which stated that geological disposal should be preferred to above ground storage on the basis of considerations of intergenerational equity: "our responsibilities to future generations are better discharged by a strategy of final disposal [underground] than by reliance on [above ground] stores which require surveillance, bequeath long-term responsibility of care, and may in due course be neglected by future societies whose structural stability should not be presumed" (see NEA-OECD: 1995, 5). All national programs have already subscribed to the concept of geological disposal as a "necessary and a feasible technology"; but some countries prefer to postpone implementation in order to first evaluate other options and alternatives (see NEA-OECD: 1999b, 11).

In the following paragraphs I will present current thinking on waste management policies in terms of the underlying philosophical and ethical considerations stemming from the principle of intergenerational equity. The basic notion is that the present generation is required to ensure that there is an equitable distribution of risks and burdens, which must ensure the safety and security of future people. In addition, equity across generations also involves the assurance of equal opportunities for future generations when dealing with nuclear waste. Three ethical values relevant to current nuclear waste policy – namely those of safety, security and equal opportunity – will be reviewed below.

56 The term 'acceptance' might be misleading here, as we are not referring to what is actually *accepted* by the public, but rather to what is taken to be a maximum allowable risk in policy-making, e.g. as in maximum exposures in setting current radiation standards.

I will furthermore focus on the issue of how these principles motivate geological disposal, as opposed to above ground storage.

2.4.1. Safety for people of the future

From the early days of nuclear energy deployment, the safety of future generations has been a primary concern, as can be concluded from the guidelines laid down in 1955 by the US National Academy Committee on the Geological Aspects of Radioactive Waste Disposal (see NRC: 1966). In spite of this early recognition, it was a long time before the nuclear community explicitly mentioned the safety of future people as a concrete concern. In 1984, the Nuclear Energy Agency first pronounced "a desire for equity" and acknowledged a need for "the same degree of protection" for people living now and in the future (see NEA-OECD: 1984). The IAEA articulates these concerns in its Safety Principles where it states that nuclear waste should be managed in such a way that "predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today" (see NEA-OECD: 1995, 6) and it refers to this as the neutrality criterion. Geological disposal is believed to ensure safety as it is seen as a "resistance to […] containment of the waste over very long time". The engineered facility, together with the natural safety barrier of the host geological formation must guarantee that "no significant radioactivity" will even return to the surface environment (see NEA-OECD: 1999b, 11).

2.4.2. Security for people of the future

"[T]he same degree of protection" as stated by the NEA (see 1984) not only refers to public health issues, but also to future security concerns. Security relates to the unauthorized possession or theft of radiotoxic waste in order to either sabotage or use these materials for the production of nuclear weapons. The main concerns relate to the threat of nuclear weapon proliferation which is extremely relevant given the current state of affairs in the world. Proliferation threats arise either from the using of Highly Enriched Uranium (HEU) which has been enriched up to 70% (and higher) or from the production or separation of plutonium.[57] Hundreds of tons of highly enriched uranium and weapon-grade plutonium derived from the dismantled nuclear weapons found in American and Russian stockpiles are the "deadly legacy" of the Cold War that give rise to so much concern (see Bunn: 2000). Apart from deriving from disarmed nuclear warheads, both highly enriched uranium and plutonium can also be produced using the technology currently available in many nuclear energy producing countries. As soon as uranium becomes more than 20% enriched the intentions are evidently for destructive ends; such action in any declared facility is immediately detected by the IAEA. Enrichment facilities are not present in all nuclear energy producing countries.

Plutonium, on the other hand, is produced during fuel irradiation and separated during reprocessing in countries favoring the closed fuel cycle approach (see Section 2). The extracted plutonium is destined for use as a fuel ingredient (as Mixed Oxide Fuel), but it also carries proliferation threats. To illustrate the seriousness of these potential risks: eight kilograms of weapon-grade plutonium (^{239}Pu) is sufficient to produce a bomb with the devastation potential of the Nagasaki bomb. The kind of plutonium which, under normal circumstances emerges from a power reactor consists of different isotopes including ^{238}Pu, ^{240}Pu and ^{239}Pu; Figure 3 shows the build-up of different plutonium isotopes during energy production or fuel irradiation. When more than 93% of ^{239}Pu is present, plutonium becomes a weapon-grade element and below 80% of this isotope it is referred to as reactor-grade or civilian plutonium. For destructive purposes plutonium must contain as much as possible ^{239}Pu in proportion to the relatively short burn up time, as can be seen in Figure 3.

To conclude, "[d]eploying reactor-grade Pu is less effective and convenient than weapon-grade in nuclear weapons", but still "[...] it would be quite possible for a potential proliferator to make a nuclear explosive from reactor-grade plutonium using a simple design that would be assured of having a yield in the range of one to a few kilotons and more, using an advanced design. Theft of separated plutonium whether weapon-grade or reactor-grade, would pose a grave security risk" (see DOE: 1997).

Let us now move on to the question of how these considerations relate to the choice of final disposal of waste methods. Geological repositories are believed to ensure security which is perceived as "resistance to malicious or accidental

57 Strictly speaking, there are also other isotopes which could be used for destructive purposes, such as 233U, which is produced by irradiating thorium (Th) in a nuclear rector. However, these are not broadly applied technologies.

disturbance [...] over very long times" better than easily accessible above ground storage facilities (see NEA-OECD: 1999b, 11). "[W]aste stores [on the surface] are vulnerable to inadvertent or deliberate intrusion by humans if not kept under close surveillance. This places obligations on future generations" (see IAEA: 2003, 5). The IAEA (see 2003, 7) further asserts that "[p]utting hazardous materials underground increases the security of the materials".

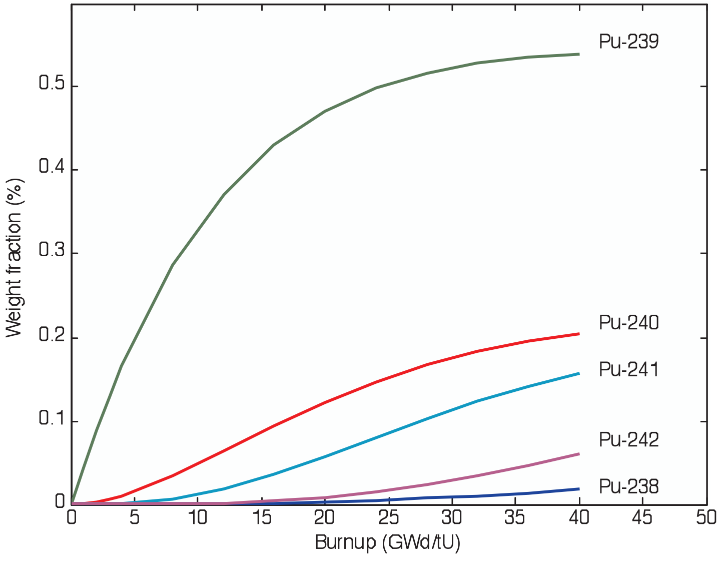

Figure 3: Weight concentration of different plutonium isotopes in a Light-Water reactor.[58]

2.4.3. Equal opportunity: retrievable disposal

The third concern is how to act in accordance with our alleged obligations in order to minimize future burdens while at the same time not depriving people of the future of their freedom of action. NEA (see 1999b, 22) states that the present generation "should not foreclose options to future generations". This is termed the equal opportunity principle: "[i]t is of equal worth that we guarantee coming generations the same rights to integrity, ethical freedom and responsibility that we ourselves enjoy" (see KASAM: 1988). In other words, we should respect their

58 I received this Figure from personal communication with Jan Leen Kloosterman, Associate Professor at the Department of Radiation, Radionuclides and Reactors at Delft University of Technology.

freedom of action – conceived of by KASAM (see 1999, 14) as a moral value – by acknowledging that "future generations must be free to use the waste as a resource"; since spent fuel contains uranium and plutonium which have a potential energy value. Two other reasons in favor of creating the option to retrieve waste from disposal facilities are these: 1) to be able to take remedial action if the repository does not perform as expected and 2) to be able to render radiotoxic waste harmless with new technology.

Retrievability, as intended here, has to do with repositories that will be kept open for an extended period of time so that future societies have the option to retrieve the waste. One might thus argue that retrievable waste could compromise the long-term safety of any repository. However, retrievability as commonly understood in the literature implies having a temporary measure based on the assumption that at a certain point a decision will be taken to either retrieve the waste (for any purpose) or to close the repository (see IAEA: 2000, 9-10). If one relates retrievability discussions to the question of final disposal, one can argue in favor of storage on the surface, as the "[r]etrieval of material is easier from surface facilities than from underground facilities, but geological disposal can be developed in stages so that the possibility of retrieval is retained for a long time" (see IAEA: 2003, 7).

The underlying intergenerational principles of nuclear waste management policies have been discussed in this section. We furthermore explored how a need for "the same degree of protection" for different generations has led to the conclusion that geological disposal is the most appropriate way to dispose of waste. In the following section I challenge this view by reflecting on the assumptions that underlie the alleged long-term safety of geological disposal, arguing that the key weakness of this technological solution lies in the great uncertainty that goes with it.

2.5. Moral legitimacy of distinguishing between future generations

In this section I will focus on the notion of reducing responsibility in the course of time while criticizing the moral legitimacy to make a distinction between future people. Elsewhere in this paper I argued that the production of nuclear power creates certain moral obligations for the present generation to ensure people's future well-being – in terms of resource availability – and not to harm future people. On the practical policy-making level one could question to whom we owe these obligations and whether we should distinguish between people of the near and remote future (see Norton: 1995). These questions date back to the early days of discussions on our obligations towards posterity. By introducing the notion of membership within a "moral community" that shares our perception of what constitutes a good life, Martin Golding (see 1981, 62) argues that we have an obligation to produce "a desirable state of affairs for the community of the future [and] to promote conditions of good living for future generations". However, "the more remote the members of this community are, the more problematic our obligations to them become", Golding (see 1981, 69) states and he concludes that we should be more concerned about the more immediate generations. Daniel Callahan (see Callahan: 1981), on the other hand, states that ignorance does not relieve us from our obligations when the issue at stake is whether we might harm future generations; Callahan's notion of our negative obligations towards posterity obviously extends much further than Golding's stated positive obligations.

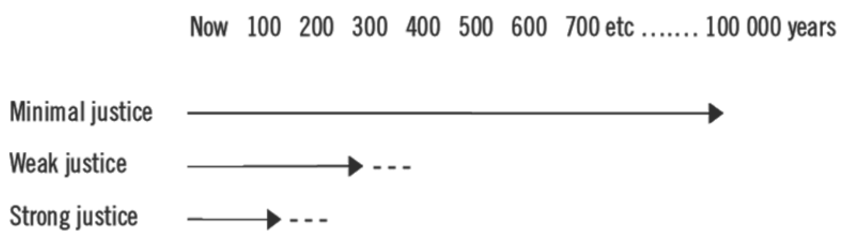

Figure 4: Three principles of justice with respect to the various time periods
Source: Chapter 9, Nuclear Waste State-of-the-art, KASAM (see 2005a, 440)

The Swedish KASAM (see 1999, 27) argues along the same lines as Golding by stating that "our responsibility diminishes on a sliding scale over the course of time", as "the uncertainties of our base of knowledge [...] of the system's technical design, increase as a function of increasing time span perspectives". So KASAM (see 2005a) contemplates a more extensive duty to the immediate future by introducing three principles of justice to distinguish between the various periods of time in the future: 1) the next five generations (150 years) deserve our greatest attention; 2) the subsequent 150 years come in second place and 3) the beyond 300 years era. These periods of time represent different concepts of justice in what is perceived as a "diminishing moral responsibility" perspective, as illustrated in Figure 4.

The KASAM's strong principle of justice states that we must ensure that our immediate descendants have "a quality of life equivalent to ours", while the weak principle says that we need to respect and protect future people's right to satisfy their basic needs. The minimal principle of justice, on the other hand, merely states that today's people should not jeopardize future generations' possibility for life. KASAM seeks justification for these proposed periods by asserting that if we define a generation as being 30 years then our imagination hardly extends beyond that of our grandchildren's grandchildren; these five generations or 150 years are believed to represent the boundary of our "moral empathy". Another reason is that "our primary relationships" can barely have any influence beyond five generations. If one were to define local communities and nations in terms of "secondary relationships", this time scale could possibly be extended to, as KASAM suggests, 300 years, beyond which predictability and positive influence "appears to be almost non-existent" (see KASAM: 2005a).

Another initiative worth mentioning is that of the American National Academy of Public Administration (see NAPA: 1997, 7) to establish four principles of intergenerational decision-making which state that we are trustees for future generations and that – according to the Brundtland's (see 1987) sustainability principle – we should not deprive the future of a quality of life comparable to our own. Since we know more precisely the needs and interests of our own generation and the immediately ensuing ones and since we are hardly in a position to predict the very distant future, a "rolling present" should "pass on to the next the resources and skills for a good quality of life"; NAPA (see 1997, 8) further states that "near-term concrete hazards have priority over long-term hazards that are less certain".

2.5.1. Geological disposal and long-term uncertainties

One of the key arguments when opting for geological disposal rather than above ground storage is the alleged long-term safety issue. In safety studies it is assumed that canisters will inevitably breach and radioactive material will leak at some time in the future; canisters are therefore enclosed in engineered facilities to avoid unnecessary seepage into the environment. In addition, host earth formations are viewed as a natural barrier impeding further leakage into the biosphere, all of which should support arguments in favor of the long-term safety of repositories. This alleged safety seems, however, to be founded on a number of serious uncertainties and has therefore triggered a whole debate on whether geological disposal should not be reconsidered for the final isolation of radiological waste;[59] more will be said about this issue in the following section.

It is curious to see how the problem of the technical unpredictability of the remote future and the associated uncertainties are addressed in long-term policy-making, particularly in relation to geological disposal. Let me illustrate this by pointing out how the radiation standards are set for the Yucca Mountains repositories in Nevada (US). According to the Energy Policy Act of 1992 the Environmental Protection Agency (EPA)[60] is charged with the task of developing health and safety radiation standards for the designing of repositories.[61] EPA's first proposed standards limit exposure to radiation to 15 millirem[62] per year, with a compliance time of 10,000 years. In objection to this it has been argued by the US National Academy of Science that "the peak risks might occur tens to thousands of years or even farther in the future" (see NRC: 1995); 10,000 years seemed both insufficient and arbitrary. In a successful lawsuit the D.C. Court of Appeal subscribed to the latter conclusion ruling that the EPA had to revise these radiation standards (see Vandenbosch and Vandenbosch: 2007, Ch. 10.). In 2005, the EPA proposed distinguishing between two future groups, i.e. the people of the next 10,000 years who could maximally be exposed to the already set 15 millirem per year standard and the period beyond 10,000 (up to one million years) for whom a radiation limit of 350 millirem per year was proposed (see EPA: 2005). This two-tiered approach was necessary, EPA (see 2005, 49035) argued, in connection with long-term uncertainties which are "problematic not only because they are challenging to quantify, but also because their impact will

59 In an edited anthology different authors address the uncertainties involved in a number of technical issues concerning the evaluation of the Yucca Mountains repository; see (see Macfarlane and Ewing: 2006). Shrader-Frechette is one of the scholars who holds a strong view on refuting geological disposal based on these uncertainties; see (see Shrader-Frechette: 1993) and (see Shrader-Frechette: 1994).

60 The Environmental Protection Agency is the United States' federal agency in charge of protecting human health by protecting the natural environment. Projects that involve affecting the natural environment – such as the disposal of nuclear waste – need to be first approved by EPA.

61 These standards must further be incorporated into licensing by the Nuclear Regulatory Commission (NRC) regulations. Compliance with these standards must then be demonstrated by the US Department of Energy (DOE). For an overview of how these organizations are connected to each other see (see Vandenbosch and Vandenbosch: 2007, Ch. 8.)

62 Rem and Sievert (Sv) indicate radiation exposure in order to determine radiation protection. 1 Sievert (Sv) = 100 Rem

differ depending on initial assumptions and the time at which peak dose is projected to occur".

By applying KASAM's Minimal Principle of Justice (of not jeopardizing the possible life of future generations) and NAPA's preference for avoiding near-term concrete hazards in contrast to the long-term hypothetical hazards of spent fuel disposal, EPA (see 2005, 49036) concludes that "a repository must provide reasonable protection and security for the very far future, but this may not necessarily be at levels deemed protective (and controllable) for the current or succeeding generations". The proposed 350 millirem is the difference between the naturally occurring radiation in an average place in the US (350 millirem per year) and that experienced in Colorado (700 millirem per year). EPA justifies this discrimination by stating that after 1 million years, people in Nevada will maximally experience the same level of radiation as people living in Colorado today.

On the one hand this discrepancy in radiation standards seems understandable if one thinks that providing equal protection levels for such periods of time is virtually impossible in view of the fact that "the uncertainties for a thousand years [...] from now are large [and] they are almost incalculable when one goes to 10,000 or 100,000 years" (see Kadak: 1997, 49). On the other hand, we can question whether changing the standards for the latter reason is appropriate. "If one were designing a bridge whose steel and concrete performance become more uncertain [over the course of] time, would one loosen or tighten the structural design standards if one realizes that the bridge was going to have to provide safe transport for a long period of time?" (see Vandenbosch and Vandenbosch: 2007, 136) The justification provided by the EPA is furthermore believed to be flawed as these policies "threaten equal protection, ignore the needs of the most vulnerable, [and] allow many fatal exposures" of the people living in the distant future (see Shrader-Frechette: 2005, 518).

In its "final rule" the EPA (see 2008) changed the radiation exposure limit for the period beyond 10,000 years to 100 millirem per year. It remains unclear what precisely motivated this change; a speculative conclusion is that that public opposition to the huge difference between the originally proposed 15 and 350 millirem for the stated periods might have triggered this adjustment in the final ruling. In June of 2008, the US Department of Energy submitted a license application to the Nuclear Regulatory Commission to build a long-term geological repository for the permanent disposal of spent fuel for a million years (see DOE: 2008).[63]

In this section I have reviewed the underlying arguments for distinguishing between different future groups based on the low degree of predictability concerning the remote future and the fact that any positive influence on such societies is meaningless. Even though these arguments are sound, I argue that at most they provide pragmatic explanations indicating why we cannot act otherwise, rather than solid moral justifications for discriminating future generations; ignorance does not relieve us from our temporal obligations when it comes to the question of harming future people (see Callahan: 1981). If my arguments to the effect that the production of nuclear power creates a problem of intergenerational equity are sound, I consider the minimal principle of justice an undesirable one as it facilitates the serious discrimination of remote future generations; that is to say, we can dramatically reduce the well-being of future generations and jeopardize their health and safety without depriving them of “the possibility for life”, even though their quality of life might be much lower than ours.[64]

The distinction that is also made in policy-making, for instance with the setting of radiation standards for Yucca mountain repositories, seem to be rather a pragmatic solution making it possible for such repositories to remain within the margins of technical predictability for the remote future. This should urge us to reconsider our temporal moral obligation and what, in the light of recent technological developments, we ought to do with regard to future generations, assuming that ‘ought to’ implies ‘can’. The following section contemplates the technological possibility of substantially reducing the waste life-time and challenging the need for geological disposal.

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63 (see DOE: 2008) This paper was written in 2008 when the Yucca Mountains repository was still considered to be the most feasible option for the geological disposal of American nuclear waste. However, following the most recent presidential elections in the US, the Obama administration has announced that the Yucca Mountains site is no longer seen as an option; see (see Obama: 2009) and (see Josef Hebert: 2009).

64 Whether the present level of well-being has sufficient moral relevance to serve as a point of reference is a claim that I leave unanalyzed; I simply assume that it does. For more information on this dispute the reader is referred to the debate between Wilfred Beckerman (see 1999) and Brian Barry (see 1999).

2.6. Intergenerational arguments revisited: a challenge to geological disposal

In the preceding section I argued that all distinctions between future generations lack solid moral justification. By including Partitioning and Transmutation (P&T), a technology than enables substantial reductions in waste life-time, I shall now examine whether geological disposal remains the best option for nuclear waste management. Some experts in the nuclear community have hailed P&T as the alternative to geological disposal in nuclear waste management but have then gone on to reject it for two reasons: 1) because it necessitates the building of new facilities and 2) because even after successful application some materials still remain radiotoxic (see IAEA: 2000; NEA-OECD: 1999b). Even though both arguments are sound, they do not provide sufficient grounds for rejecting P&T. In this kind of reasoning P&T is wrongly presented as an alternative to geological disposal. If my arguments in this paper are correct it must be asserted that P&T challenges the need for final disposal underground and places the serious alternative of repositories – for long-term storage on the surface – in a new perspective. Let me start supporting this claim by reevaluating the three main intergenerational arguments that underlie nuclear waste management policy.

In objecting to above ground storage places, the IAEA (see 2003) draws attention to "some structural degradation of the packages and their contents […] over time", which makes further transfer of the waste to other storage facilities or geological repositories inevitable. Long-term safety is therefore not well served by very long periods of time in above ground storage facilities. In its recommendations in favor of geological disposal, IAEA takes its long-term safety for granted. However, this long-term safety of geological disposal depends on certain considerable uncertainties, which necessitate sanctioning a distinction between different future generations. If we now accept the conclusion drawn in the last section to the effect that this distinction lacks moral justification, we can argue that it would be best to avoid these uncertainties. Implementing P&T allows for the latter, as the period of necessary care for P&T waste amounts to 500 years, a period in which it is presumed that reliable predictions can be made about a canisters' status.

Likewise, security concerns will change. Security has to do with the unauthorized possession or theft of radiotoxic waste for the purposes of sabotage, dispersal or proliferation. As far as sabotage is concerned, geological disposal has obvious advantages for all three above-mentioned types of radiotoxic waste: potential hazards will literally and figuratively be buried at very difficult to access distances under the ground. In the case of proliferation, however, we must distinguish between the three types of waste. For the sake of clarity, the three different types of waste, their constituents and the relevant waste life-times are all illustrated in Table 1.

Spent fuel has potential proliferation hazards, as there is still plutonium that could be separated; spent fuel might therefore best be disposed of underground (see Stoll and McCombie: 2001). High-level waste, however, has no potential proliferation threats, as the fissionable materials (i.e. uranium and plutonium) have already been extracted and the remaining waste (minor actinides and fission products) is not suitable for proliferation purposes. Similar reasoning is applicable to P&T waste: in other words P&T waste does not necessitate geological disposal from the avoidance of proliferation point of view. Any sabotage concerns associated with radiotoxic waste remain evidently less in the case of geological disposal.

	Contains	Waste life-time	Dominant
Spent Fuel	U, Pu, MA (Np, Am, Cm) + FP	± 200,000 y	Pu
HLW or Vitrified Waste	MA (Np, Am, Cm) + FP	± 10,000 y	Np + Am
P&T Waste	MA (Cm) + FP	± 500 y	Cm

Table 1: Three different states of waste, the constituents and the waste life-times

Equal opportunity is the third intergenerational consideration that underlies policy-making in nuclear waste management. Nuclear waste should always be disposed of in a retrievable manner for (i) possible future resource value of spent fuel, (ii) remedial action if the repository does not operate as expected and (iii) the need to render radiotoxic waste harmless with the help of new technology. By including P&T in these discussions as a technological option one can conclude that considerations about future resource value cease to be relevant as P&T waste comprises no potential source value in view of the fact that plutonium and all the remaining uranium are separated during reprocessing. However, retrievable disposal remains desirable to adjust repositories and render the waste harmless, whether it is necessary or desired for other purposes, even with P&T waste streams. This retrievability argument does not, however, support geological disposal; retrievability is, in principle, more feasible in above ground storage places.

2.6.1. Challenges to geological disposal

To conclude, P&T enables us to avoid all the long-term uncertainties that go with the geological disposal of long-lived spent fuel. In other words, it helps us to avoid ending up in situation in which – from a pragmatic point of view – we need to discriminate remote future generations in the way that we build and design repositories. P&T therefore puts contemporaries in a better position to fulfill the obligations arising from the intergenerational equity problem caused by uranium depletion and, just as importantly, the longevity of nuclear waste.

As stated above, P&T helps us to avoid putting distant future generations at a disadvantage as it increases the degree of predictability. Does such increased predictability imply that the risks in the coming 500 years are justifiable? Making the relevant time scales more predictable makes appropriate risk assessment possible. However, the questions about the acceptability of these risks for future generations and, more importantly, the additional risks brought about for the present generation remain unanswered. This brings us back to the issue at the heart of this matter, namely that of intergenerational equity. Kloosterman and myself have compared open and closed fuel cycles in terms of conflicting moral values and have argued that the fuel cycle choice should be presented within the framework of intergenerational equity (see Taebi and Kloosterman: 2008).[65] The closed fuel cycle improves uranium supply certainty and entails fewer long-term radiological risks and proliferation concerns. On the other hand, it compromises short-term public health and safety, and also security. The trade-offs inherent in opting for the fuel cycle are, as we have argued, reducible to a primary trade-off between the present and the future. If we view P&T as an extension of the closed fuel cycle – since without reprocessing the deployment of P&T is useless – and if we assume that P&T requires extra nuclear activities for the further irradiating of HLW so as to eliminate minor actinides, then more or less the same time-related conflicts will arise. There are conflicts of interest between the present generation and future generations; advocates of P&T need to justify why they are willing to accept additional risks as a result of P&T in order to reduce risks to people living in the distant future.

What is of minor importance in moral discussions but still relevant in the broader perspective is all the economic considerations. NEA has evaluated the viability of P&T through Fast Reactors and Accelerator-Driven Systems and has

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[65] Chapter 3 in this dissertation.

concluded that a considerable amount of R&D will be required in the coming decades before utilization at industrial level can be considered (see NEA-OECD: 2002). In addition, more nuclear facilities will possibly be needed for the further elimination of minor actinides. Why are these additional economic burdens upon the present generation permissible or even desirable? Precisely specifying the time-related dilemmas and trade-offs that need to be considered before P&T can be deployed should be the subject of future studies.

2.6.2. Is P&T a feasible and desirable option? Three counter-arguments

So far I have argued that there are good reasons to believe that P&T is a potential future possibility and that if P&T is industrially feasible we might want to reconsider geological disposal for the final isolation of nuclear waste. There are, however, unanswered questions (or objections) to applying this technology. The three main ones are 1) the reliance on industrially not yet proven technology for changing policy, 2) the continued need for final isolation and building repositories and 3) the inappropriateness of relying on future societies to deal with our waste. These three counter-arguments will be reviewed below.

The first question is whether the prospect of future technology should change current policy. Some people argue that envisaged technological progress justifies the current postponing of action as far as the building of repositories goes. KASAM (see 2005a, Ch. 8.) has evaluated the validity of postponing actions based on potential P&T possibilities as follows . On the one hand, it could be asserted from a utilitarian point of view that technologically better final disposal technology increases safety and reduces the risks for future generations. On the other hand, it is doubtful whether that provides sufficient reason to shift the burden of finding a solution for final disposal to future generations. In addition, we need to make a very explicit assumption about the progress of technology, so as to justify postponing action; this is referred to as the technological fix position, as it is for instance defended by Beckerman and Pasek (see 2001). Although there has been evident technological progress during the last few centuries and although inductive reasoning forecasts its continuation, we cannot be sure that the progress is sufficient to deal with the risks we have created (see Skagen Ekeli: 2004) and whether future societies will be able to dispose of radiotoxic waste more appropriately than we can at the present time. More importantly, there is no guarantee of whether and, if so, when and to what extent P&T, at industrial level, will live up to the expectations it has created.

In Sweden, on the basis of P&T technology as it stood in 2004, KASAM recommended that the nuclear waste program should be neither interrupted nor postponed and that the building of repositories should be continued as P&T cannot be cited as an alternative to final disposal (see KASAM: 2005a). Nevertheless, it is believed that P&T development and future possibilities seriously call for the retrievability of waste so that future people's freedom of action to deal with such waste in a more appropriate way can be respected. The Canadian Nuclear Waste Management Organization (see NWMO: 2005b) also finds P&T an interesting option as it reduces waste radiotoxicity and volume, but the organization has serious reservations about the economic and practical aspects of this technology and therefore maintains that it is not a desirable option for Canada. The UK Committee on Radioactive Waste Management (see CoRWM: 2006, 69) has similar reservations with regard to P&T, as it is not a "complete waste management option"; CoRWM further questions whether the costs outweigh the benefits.[66]

The second problem is that P&T fails to make ultimate isolation redundant which means that some materials will remain hazardous and must therefore eventually be isolated from the environment. Even after successful P&T trace elements will remain in the waste and will need to be disposed of as spent fuel (see KASAM: 2005c, 348). P&T cannot therefore entirely replace repositories. For instance, tons of highly enriched uranium and weapon-grade plutonium emanating from dismantled nuclear warheads after the Cold War raise serious proliferation concerns. The American National Academy of Sciences acknowledged these concerns and called for the urgent implementation of a program 1) to burn this plutonium in reactors of existing types as mixed oxide fuel and 2) to mix this weapon-grade plutonium with highly enriched uranium and vitrify it for final geological disposal (see NAS: 1994). Likewise, the highly enriched uranium extracted from the dismantled nuclear warheads could, to some extent, be blended down to reactor-grade uranium suitable for use in a reactor. However, for the time being, there is no realistic way to fission all these materials in reactors, in spite of all the technical possibilities we have at our disposal. If we bear in mind that uranium and plutonium are the long-lived isotopes that necessitate geological disposal and if we take for granted the fact that the nuclear community is right about the appropriateness of geological

[66] Even though no explicit time references are made in this observation, the costs undoubtedly refer to short-term costs and burdens while the benefits will probably be those seen in the long run.

repositories for the long-term disposal of long-lived isotopes, the need for geological disposal for military waste containing these materials will subsequently remain unchanged. Nonetheless, one can argue that we should consider the need for repositories that are directly related to nuclear energy production and realize that P&T will challenge this need, as fewer long-term concerns will be involved. Even though some repositories will still be needed (particularly for dismantled military material) successful P&T deployment would be suitable for reducing this need.

The third objection to surface storage (irrespective of the waste life-time) is that it forces us to rely on future societies for the possible further treatment and final disposal of waste (see NEA-OECD: 1995). It has been argued that near future geological disposal complies better with intergenerational equity, as it does not involve passing on our responsibilities to our descendants and it imposes fewer safety and security burdens on the present generation. Axel Gosseries (see 2008b), for instance, argues that from the viewpoint of intergenerational equity, the "seriousness risk of malevolent use" calls for the early disposal of spent fuel rather than for storage.

2.7. Conclusions

In this paper I have reviewed the main ethical considerations underlying nuclear waste policies and have evaluated those arguments in the light of the most recent technological progress. If we acknowledge that there is a problem of intergenerational justice caused by the production of nuclear power, we can conclude that the present generation has a moral obligation to ensure future people's well-being and not to harm future generations. Nuclear waste management policies are founded on the equitable distribution of risks and burdens between generations indicating that the safety and security of future generations is not jeopardized. Intergenerational equity also stands for the guaranteeing of equal opportunities for future generations, which mainly pertains to the retrievability of waste.

The consensus within the nuclear community seems to be that burying spent fuel in geological repositories rather than keeping it in surface storage places, as repositories are believed to be safer and more secure in the long run. This long-term safety seems to be disputable though as it relies on great long-term uncertainties which, in turn, necessitate making a distinction between different future people. The latter distinction lacks, however, solid moral justifications, which should urge us to reconsider our temporal moral obligation and what we ought to do with regard to future generations, in the light of recent technological developments. The technological possibility of substantially reducing the waste life-time through Partitioning and Transmutation (P&T) is believed to challenge geological disposal, placing long-term surface storage in a new perspective. Deploying P&T sheds new light on the social and technical predictability capacity for the future and enable contemporaries to better discharge temporal obligations, particularly the obligations not to harm those living in the distant future.

In the nuclear community P&T was wrongly presented as an alternative to geological disposal and so it was subsequently rejected as a possibility. The misunderstanding hinges on the fact that new facilities do have to be built and the need for final isolation does remain. Even though both arguments are sound, P&T challenges the need for final disposal underground, thus placing long-term surface storage in a new perspective. Before P&T can be phased in on an industrial scale in the next decades substantial investments first have to be made and there is no guarantee of success, as its future development depends on very many technical, social, political and economic factors. More importantly, the introduction of P&T creates additional risks and burdens for the present generation and serious trade-offs need to be made before acceptance and deployment can be achieved. There are also other objections to the application of P&T, such as a reliance on near future societies to deal with the waste and that it is an industrially not yet proven technology. Nonetheless, P&T helps us avoid ending up in situation in which we – from a pragmatic point of view – need to place remote future generations at a disadvantage because of the way in which we build and design repositories. Even the potential possibility to diminish "undue burden" with respect to the future is too relevant to be neglected in philosophical discussions relating to nuclear waste management and how we perceive our moral obligations towards posterity.

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3 To Recycle or Not to Recycle?

An intergenerational approach to nuclear fuel cycles[67]

Keywords: Intergenerational justice, nuclear waste management, reprocessing, recycling, future generations, value conflicts, sustainability

Abstract

This paper approaches the choice between the open and closed nuclear fuel cycles as a matter of intergenerational justice, by revealing the value conflicts in the production of nuclear energy. The closed fuel cycle improve sustainability in terms of the supply certainty of uranium and involves less long-term radiological risks and proliferation concerns. However, it compromises short-term public health and safety and security, due to the separation of plutonium. The trade-offs in nuclear energy are reducible to a chief trade-off between the present and the future. To what extent should we take care of *our* produced nuclear waste and to what extent should we accept additional risks to the present generation, in order to diminish the exposure of future generation to those risks? The advocates of the open fuel cycle should explain why they are willing to transfer all the risks for a very long period of time (200,000 years) to future generations. In addition, supporters of the closed fuel cycle should underpin their acceptance of additional risks to the present generation and make the actual reduction of risk to the future plausible.

3.1. Introduction

The worldwide need for energy is growing. The International Energy Agency foresees a 60% increase in energy need in the world between 2004 and 2030 and most of this expansion is expected to be met by fossil fuel (see IEA: 2004). Fossil fuels are not an attractive option, however, for reasons concerning the availability of resources and climate change. An increased need for alternative

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[67] This article is a part of a research project at the Delft University of Technology, department of Philosophy and department of Radiation, Radionuclides and Reactors. It was also presented at the bi-annual conference of the Society for Philosophy and Technology in Charleston (South-Carolina), July 2007

energy sources is therefore expected in the upcoming decades, e.g. wind energy, solar energy, but also nuclear energy. After being ruled out in many countries following the Chernobyl disaster in 1986, nuclear energy has recently made a serious comeback in the public and political debates about the future of energy. Many people consider nuclear energy at least as a serious alternative for the *transition period* between fossil fuels and sustainable energy sources. According to the World Nuclear Association, there were 435 operative nuclear reactors in January 2007; The United States, France, Japan and Russia together possess the vast majority of the operative reactors producing 370 GWe. As a whole, nuclear energy provides almost 16% of worldwide energy supply (see WNA: 2007; IAEA: 2007b).

The main advantage of nuclear energy – compared to fossil fuels – is its capability of producing a large amount of energy with relatively small amounts of fuel and a very small production of greenhouse gases. However, nuclear energy has serious drawbacks, such as accident risks, security concerns, proliferation threats and nuclear waste. The waste problem is perhaps the Achilles' heel of nuclear energy as it remains radiotoxic for thousands of years (see Cochran and Tsoulfanidis: 1999).

Discussions about nuclear waste management must be related to the production of nuclear energy, as the most hazardous waste is produced during energy production. The question guiding this paper is whether spent fuel[68] is to be disposed of directly or to be reused in the fuel cycle, referred to as the open and closed fuel cycle, respectively (see IAEA: 2000). This issue is still topical after more than four decades of widely deployment of nuclear energy. In an open fuel cycle, uranium is irradiated once and the spent fuel is considered as waste to be disposed of directly. This waste remains radiotoxic for approximately 200,000 years; the period in which the radiotoxicity of spent fuel will equal that of the amount of natural uranium used to produce the fuel. Radiotoxicity is defined as the biological impact of radioactive nuclides on human health, in case they are digested or inhaled; these effects are indicated in Sievert (Sv) or millisieverts (mSv). The closed fuel cycle reuses spent fuel after irradiation to produce energy and diminishes its toxicity and volume substantially. This fuel cycle has many long-term benefits, but it also creates extra short-term risks.

68 For the sake of consistency, we here refer to the irradiated fuel in a nuclear reactor as *spent fuel* rather than waste.

The question rises here how to deal with spent fuel in a proper way, taking the needs and interests of this generation and future generations into account. We should not foreclose options for future generations and should manage the waste in a such way that "will not impose undue burdens on future generations" (see IAEA: 1995; NEA-OECD: 1995). In this paper we approach "undue burdens" in the light of fuel cycles and propose *intergenerational justice* as a framework in order to choose between the fuel cycle: are we willing to transfer all risks of spent fuel to future generations, or do we find it more *just* to diminish risks and hazards of *our* waste to the maximum extent and accept, consequently, some additional risks to the present generation. In Section 2, we discuss the idea of having right towards future generation and the concept of intergenerational justice. We further present the two fuel cycles (Section 3) and identify the associated risks with these fuel cycles (Section 4). In the following Section (Section 5), we focus on conflicting values in choosing between them and reduce all trade-offs to a chief trade-off between the present and future generations. Section 6 provides a few underlying assumptions and possible counter-arguments.

Whether nuclear energy is desirable or indispensable as an energy source in the future is a controversial issue, which is beyond the scope of this paper. At the same time, applying nuclear energy through different fuel cycles raises a number of ethical concerns and moral dilemmas; on those issues we focus here. Moreover, the existing spent fuel all around the world is an urgent problem that needs to be dealt with. 280,000 tons of spent fuel had been discharged globally by the end of 2004, of which one-third has been recycled, leaving 190,000 tons of spent fuel stored; the growth rate is estimated on 10,500 tons a year (see IAEA: 2006a; McCombie and Chapman: 2002). The choice between the open and closed fuel cycle has significant influence on this growth. These intergenerational discussions are also crucial for the future of research investments on waste management issues. *Partitioning and Transmutation* (P&T) is a new technology for further diminishing the waste radiotoxicity. P&T is still in its infancy and needs serious investments to be further developed (see KASAM: 2005c; NEA-OECD: 2002); these investment are *justified* if and only if one chooses the closed fuel cycle, of which the P&T could be considered as an extension: see section 3.3.

3.2. Future rights, present obligations: intergenerational justice

Increasing concerns about depleting the Earth's resources and damaging the environment have invoked a new debate on justice across generations or *intergenerational justice*. This concept of justice was first introduced by John Rawls in 1971 as *intergenerational distributive justice*, which stands for an equal allocation of social benefits and burdens (see Rawls: 1971/1999). Justice for future implies that today's people have obligations towards their descendants (see Callahan: 1981) and these obligations entail certain rights for the future (see Baier: 1981b; De George: 1981; Feinberg: 1974). These *assumed* rights have been challenged by some philosophers: "...the ascription of rights is probably to be made to actual persons – not possible persons" (see Macklin: 1981) and non-existing future people cannot be said to have rights, as our action and inaction define their composition and identity (see Parfit: 1983a); this is referred to as the Derek Parfit's 'Non-Identity-problem'. Other objections against these alleged rights are expressed as the inability to predict future properly, the ignorance of the need and desire for future as well as the contingent nature of future. There have been a variety of arguments provided in the literature to these objections[69] (see Laslett and Fishkin: 1992; Shrader-Frechette: 2002; De-Shalit: 1995; Beckerman and Pasek: 2001): William Grey has proposed "impersonal principles subject to retroactive person-affecting constraints" (see Grey: 1996) and Wilfred Beckerman has argued that we should provide future people with the minimum opportunity for a "decent and civilised society" (see Beckerman: 1997).

Although these fundamental discussions about right and obligation towards future people are very relevant, in this paper we will focus on the application of these *assumed future* rights to environmental policy and more specifically nuclear waste. In the last decades the climate change has given rise to serious concerns for the future (see Page: 1999a; Meyer and Roser: 2006). Do we have a duty to future generations (see Shrader-Frechette: 2002, ch. 5) and if so what does this duty entail (see Gosseries: 2001) and how should we realize it (see Gardiner: 2003)?

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69 For an extensive discussion on future obligations and rights, see *Justice Between Age Groups and Generations*, ed. Laslett and Fishkin, Sharder-Frechette's *Environmental justice Creating Equality, Reclaiming Democracy* (Chapter 5), Avner de-Shalit's *Why Posterity Matters, Environmental policy and future Generations* and *Justice, Posterity and the Environment*, ed. Beckerman and Pasek (all mentioned in the bibliography).

Anticipating technological progress in a rapidly developing world and being concerned about future generations, the World Commission of Environment and Development introduced the concept of *sustainable development* in 1987. This moment designates the introduction of intergenerational concerns in environmental policy. This Brundtland definition – named after commission's chairperson - states that the key to sustainable development is an equitable sharing of benefits and burdens between generations "[...] that meets the needs of the present without compromising the ability of future generations to meet their own needs" (see WCED: 1987, 43). The United Nations Conference on Environment and Development in Rio de Janeiro in 1992 (Earth Summit) not only endorsed this concept of sustainable development formally among 178 national governments, it also explicitly included the concept of equity in its principles (see UN: 1992a, Principle 3).

The sustainability principle implies that there is a conflict of interest between the present and future generations. In an anthology edited by Andrew Dobson, the concept of sustainable development is evaluated in the light of intergenerational justice (see Dobson: 1999). Wilfred Beckerman believes that the problems future people encounter have existed for millennia and states that our main obligation towards future people is "moving towards just institution and a 'decent' society", which encompasses future generations as well (see Beckerman: 1999, 91). Brian Barry investigates whether sustainability is a "necessary or a sufficient condition of intergenerational distributive justice". Barry emphasizes the obligations we have towards future generations and says that "measures intended to improve the prospects of future generations [....] do not represent optional benevolence on our part but are demanded by elementary considerations of justice" (see Barry: 1999, 1997)[70]. Bryan Norton perceives of sustainability as "an obligation not to diminish the opportunity of future generations to achieve well-being at least equal to their predecessors." He further presents a model in order to compare well-being across time (see Norton: 1999). The "contested meaning of sustainability" in technology is comprehensively discussed by Aidan Davison (see Davison: 2001).

What does the forgoing discussion about rights and obligations entail for nuclear fuel cycles, considering the fact that spent fuel life-time concerns a

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70 First published in Theoria in 1997 and two years later in Dobson's anthology *Fairness and Futurity*.

period between 1000 up to 200,000 years? The Nuclear Energy Agency (NEA[71]) introduces sustainability in one of its studies (see NEA-OECD: 2002). In this paper we adapt this definition both conceptually and practically and introduce intergenerational justice as a framework to choose between the fuel cycles. Intergenerational concerns have already been expressed about nuclear waste (see NEA-OECD: 1999b; IAEA: 2003; KASAM: 2005b), but mainly with respect to the choice for final disposal of long living radioactive waste; see Section 5.2.

3.3. Nuclear fuel cycles: open and close

The characteristic difference in the fuel cycles is how spent fuel is dealt with after irradiation. Two main approaches to spent fuel outline the main dissimilarity between these cycles: 1) the direct isolation of the material from the environment for a long period of time in which it remains radiotoxic and 2) 'destroying' or converting the very long-lived radionuclides to shorter lived material (see IAEA: 2000). The first approach represents the open fuel cycle in the production of energy. The closed fuel cycle is in accordance with the second approach. Here below we will elaborate on these two fuel cycles.

3.3.1. Open fuel cycle (OFC): once-through option

In the OFC, the lesser isotope of uranium (^{235}U) is *fissioned* – split - in Light Water Reactors (LWR) to produce energy; 90% of all operative nuclear reactors to produce energy are LWRs. Natural uranium contains two main isotopes, which constitute ^{235}U and ^{238}U. Only the first isotope (^{235}U) is fissile and is used in LWRs as fuel, but it only constitutes 0.7% of natural uranium. This low concentration is not sufficient in nuclear reactors, the concentration of ^{235}U is therefore deliberately enhanced to a minimum of 3% through a process called uranium *enrichment* (see Cochran and Tsoulfanidis: 1999).

Irradiating uranium produces other materials, including plutonium (^{239}Pu), which is a very long-lived radioactive isotope. Apart from Plutonium-239, other fissile and non-fissile plutonium isotopes as well as *minor actinides* will be formed during irradiation. Actinides are elements with similar chemical properties: uranium and plutonium are the major constituents in spent fuel and

71 NEA is a specialized agency of the OECD (Organization for Economic Co-operation and Development).

are called *major* actinides; neptunium (Np), americium (Am) and curium (Cm) are produced in much smaller quantities and are called *minor* actinides. The presence of actinides in spent fuel defines the radiotoxicity and waste life-time. The OFC is also called the once-through strategy, as the spent fuel does not undergo any further treatment.

The spent nuclear fuel in an OFC will be disposed of underground for 200,000 years. This waste life-time in an OFC is dominated by plutonium. Neither minor actinides nor fission products have a significant influence on long-term radiotoxicity of waste in an OFC. Figure 5 illustrates these radiotoxicities. The dashed line represents spent fuel in an OFC, decaying to the ore level in approximately 200,000 years. Fission products are a mixture of various radionuclides that will decay to the uranium ore level after approximately 300 years (see NEA-OECD: 1996), indicated by the dotted line in Figure 5.

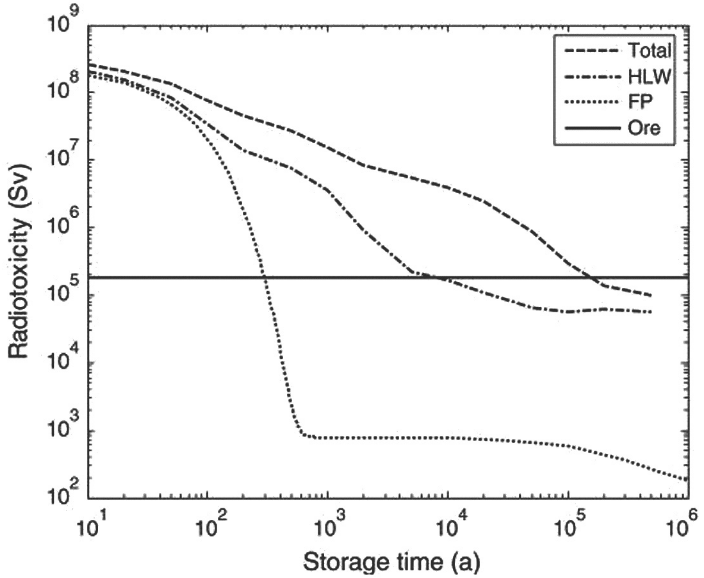


Figure 5: Radiotoxicity of spent fuel, vitrified waste (HLW) and fission products, compared with regard to the radiotoxicity of uranium ore needed to manufacture the fuel.

3.3.2. Closed fuel cycle: recycling plutonium and uranium

As stated above, less than 1% of the uranium ore consists of the fissile isotope ^{235}U. The major isotope of uranium (^{238}U) is non-fissile and needs to be converted to a fissile material for energy production: plutonium (^{239}Pu). Spent fuel could undergo a chemical treatment to separate fissionable elements including Pu, this is referred to as *reprocessing*. During reprocessing, uranium and plutonium in the spent fuel are isolated and recovered. Recycled uranium could either be added to the front-end of the fuel cycle or used to produce *Mixed Oxide Fuel* (*MOX*), a mixture of uranium-oxide and plutonium-oxide that can be applied in nuclear reactors as a fuel (see Wilson: 1996) (see Figure 6). Reprocessing is also called the "washing machine" for nuclear fuel. The irradiated fuel is "washed and cleaned" and "clean" materials (U + Pu) are reinserted into the fuel cycle to produce more energy, while the "dirt" is left behind (fission products and minor actinides) to be disposed of as High Level Waste (HLW) (see Cochran and Tsoulfanidis: 1999). HLW contains fission products and minor actinides and will be put into a glass matrix in order to immobilize it and make it suitable for transportation, storage and disposal. This process is called conditioning of waste and results in so-called *vitrified waste* (see IAEA: 1995). The ultimate radiotoxicity of vitrified waste will decrease to the uranium level in approximately 5,000 years (see NEA-OECD: 1996), as illustrated by the dashed-dotted line in Figure 5.

As uranium and plutonium are separated and reused, this fuel cycle is called the *closed* fuel cycle. The choice for a CFC is rightly associated with the choice to recycle spent fuel. Figure 6 illustrates various steps in both nuclear fuel cycles and their different interpretations of spent fuel. As can be seen in Figure 6, the thicker line representing the OFC is a once-through line. The CFC on the contrary is illustrated by separating plutonium and uranium and returning them to the fuel cycle, represented by the dashed lines. Nowadays, the main objective of reprocessing is to use uranium more efficiently and to reduce the waste volume and its toxicity considerably.

In the CFC, one can distinguish between two options with respect to nuclear reactors. In the first option, conventional LWRs are used, which are capable of using MOX as fuel. Reprocessed spent fuel is returned to the fuel cycle as MOX. Spent MOX fuel could again be reprocessed to separate uranium and plutonium. Further recycling of plutonium is only possible in another type of reactor capable of handling non-fissile plutonium: fast reactors, which constitute the second option. In the second option, the latter are basically used as energy producing reactors, in which MOX is the fuel. Due to the fast neutrons, fast reactors are capable of using the major isotope of uranium (^{238}U) to the maximum extent via conversion to ^{239}Pu (see van Rooijen: 2006).

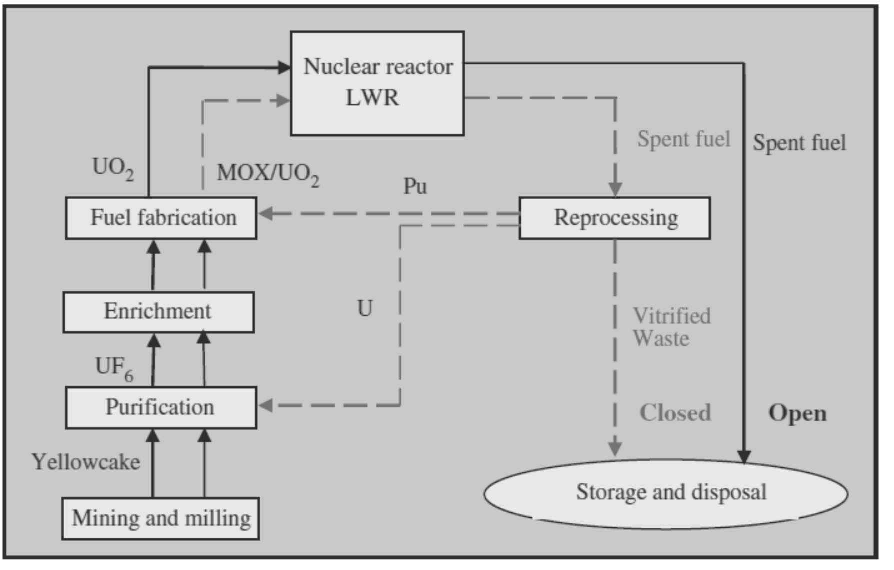


Figure 6: An overview of the open and closed nuclear fuel cycle; the thicker lines and arrows represent the OFC, the thinner ones the CFC.

3.3.3. The future of the closed fuel cycle; maximal recycling

As spent fuel is conceived of as the Achilles' heel of nuclear energy, there have been serious attempts to further reduce its radiotoxicity and volume. A new method is *Partitioning and Transmutation* (P&T), which could be considered as a recent supplementary method to reprocessing. Spent fuel comprises uranium and plutonium, minor actinides and fission products. Uranium and plutonium are separated during reprocessing in order to reuse; P&T focuses on "destroying" minor actinides in spent fuel. If completely successful, P&T is expected to reduce the volume and radiotoxicity of spent fuel one hundred times (compared to OFC). After P&T, fuel radiotoxicity would decay to a non-hazardous level in 500 to 1000 years (see KASAM: 2005c). The waste stream would then only consist of relatively short-lived fission products and curium isotopes. The latter will dominate the waste life-time and are considered to be too hazardous to be recycled at reasonable expenses and risks. P&T is merely available at the laboratory level at the moment; a considerable amount of R&D efforts is needed, before P&T could be utilized industrially (see NEA-OECD: 2002; KASAM: 2005c).

3.3.4. Waste management, interim storage, long-term storage and repositories

Irrespective of the fuel cycle choice, the remaining waste in a nuclear reactor after the (optional) treatments needs to be disposed. In waste management, a distinction is made between storage and disposal: storage means keeping the waste in engineered facilities aboveground or at some ten of meters depth underground, while disposal is the isolation and emplacement of the waste at significant depth (a few hundreds of meters) underground in engineered facilities, called 'geological repositories'.

Until now, all the available storage facilities for spent fuel and High Level Waste have typically been above ground or at very shallow depth. Spent fuel is mostly stored under water for at least 3 to 5 years after removal from the reactor core; this stage is called *interim storage*. Water serves as radiation shielding and cooling fluid (see IAEA: 2003). Bunn e.a. argued that interim storage for a period of 30–50 years has become an implicit consensus, as the world's reprocessing capacity is much less than globally spent fuel generation. In addition, there are no final repositories at our disposal yet. Interim storage of waste is also a crucial element in the safe management of radiotoxic waste since waste should be stored to allow radioactive decay to reduce the level of radiation and heat generation before final disposal. For the countries that favor reprocessing, spent fuel remains available for some decades to be reprocessed and there is no need to build up vast stockpiles of separated plutonium after reprocessing. For countries supporting direct disposal of spent fuel, interim storage allows more time to analyze and develop geological repositories appropriately (see Bunn et al.: 2001).

A commonly proposed alternative to geological disposal is the long term monitored storage on the surface. Spent fuel remains in this case retrievable in the future. However, the technical community appears largely to disregard this option and considers the surface storage only as an interim measure until the waste can be disposed of in geological repositories (see IAEA: 2000, 2003; NEA-OECD: 1999b, 1999a). Deep oceans and outer space are mentioned as possible locations for final disposal as well, but there are substantial political, ethical as well as technical impediments, mainly related to the safety of these locations (see IAEA: 2000).

3.4. Risks and associated values

In this paper we distinguish moral values at play in the production of nuclear energy. Values are what one tries to achieve and strives for, as we consider them valuable; moral values refer to a good life and a good society. However, we should not confuse them with people's personal interest; moral values are general convictions and beliefs that people consider as worth striving for, in public interest (see Royakkers et al.: 2004). We further identify dilemmas and moral problems rising from conflicting values: some trade-offs need to be made in order to choose a fuel cycle. The three main values we distinguished are as follows: sustainability, public health and safety and security. In the following sections we try to specify these values and, for the sake of comparison, relate them to risks and benefits of the open and closed fuel cycle.

We here distinguish between short-term and long-term effects, in which we consider the upcoming 50 years as short-term and after that as long-term. This period is chosen in view of comparisons in the literature between the fuel cycles: strong views about maintaining the OFC are mainly about the coming five decades (see Deutch and Moniz: 2003) and in economic comparisons, short-term is defined as 50 years (see Bunn et al.: 2003), probably based on estimations of reasonably assured uranium sources for the coming five to six decades in 2002 (see IAEA-NEA: 2002). To conclude, fifty years is the period in which supply certainty of the OFC is assured. However, as will be shown later on, this period can be extended to 85 years or more without invalidating the arguments and conclusions of this paper.

3.4.1. Sustainability: supply certainty, environmental friendliness and cost affordability

A comparative study of the Nuclear Energy Agency (NEA) on various P&T technologies introduces the following three axes in order to assess sustainability: 1) resource efficiency 2) environmental friendliness and 3) cost effectiveness (see NEA-OECD: 2002). In this paper we take these axes as a guideline for understanding sustainability with respect to nuclear energy and follow an adapted version in terms of concepts and terminology, with regard to the fuel cycles.

Supply certainty

On the first axis, sustainability refers to the continued availability of uranium: NEA uses the term *resource efficiency* for this. In this paper we apply the term *supply certainty* instead. Deploying resources *efficiently* means that we aspire to use as less as possible resources for the same purpose, while *supply certainty* refers to availability of resources in order to fulfill the needs. In energy discussion, certainty is a more significant concept than efficiency. Although this difference in designation has no consequences for the factual comparison in availability of uranium, we prefer the conceptually correct term.

As there are 50 to 60 years of reasonably assured uranium resources (see IAEA-NEA: 2002), there will be no significant short-term influences of the fuel cycle on the supply certainty. Later estimations of the NEA and the IAEA[72] present approximately 85 years of reasonably assured resources (RAR) uranium are available for a once-through option in a LWR. These institutions estimate that this amount suffices for 2500 years in a CFC, based on a pure fast reactor cycle, which is an improvement in supply certainty with a factor 30 (see IAEA-NEA: 2006). Two later reports of the IAEA in 2006 adjust this period to 5000-6000 years, assuming that fast breeders allow essentially all non-fissile ^{238}U to be bred to ^{239}Pu in order to be used as fuel (see IAEA: 2006b, 2006a). It needs to be mentioned that these estimations are made under the explicit assumptions that fast breeders will be broadly deployed in the future.

The supply certainty benefits of the CFC will be relevant in the long run. Although there are no short-term significant differences between the fuel cycles, countries without natural fossil fuel, like Japan and France, tend to opt for reprocessing and recycling (see Bertel and Wilmer: 2003).

Environmental friendliness: radiological risks to the environment

The second axis of the OECD approach in specifying sustainability concerns *environmental friendliness*. This value depends on the accompanying radiological risks to the environment. Radiological risks, as we perceive them in this paper, express the possibility or rather probability that spent fuel leaks to the biosphere and can harm both people and the environment.

The NEA proposes three stages to assess radiological risks: 1) mining & milling, 2) power production and 3) reprocessing. They compare the radiological

[72] The International Atomic and Energy Agency (IAEA) is the World's central intergovernmental forum for scientific and technical cooperation in nuclear field. IAEA is a specialized agency of the United Nations.

risks of the OFC with the (once) recycled and reused MOX fuel. In the power production phase, NEA argues, there is no difference between the cycles. The main difference lies in the two other steps: mining & milling and reprocessing. They further argue that deployment of reprocessing decreases the need for enriched uranium and, therefore, natural uranium, of which the mining and milling involve the same radiological risks as reprocessing and reusing plutonium as MOX fuel. In fact, NEA argues that under the described circumstances there are equal radiological risks for both fuel cycles (see NEA-OECD: 2000b). This argument is probably sound in the long run, for large scale reprocessing enterprises and under ideal circumstances, but one can wonder whether the factual short-term consequences are such that radiological risks of both fuel cycles are quite similar. The question remains whether we should take comparisons under ideal circumstances or factual consequences into consideration (in moral discussions). Furthermore, NEA completely neglects the distribution of benefits and burdens: building a reprocessing plant in France will increase local risks to the surrounding area and will diminish the burdens in a uranium-exporting country, such as Canada.

NEA further neglects the risks and hazards associated with the transport of waste in case of reprocessing: "..[R]adiological impacts of transportation are small compared to the total impact and to the dominant stage of the fuel cycle" (see NEA-OECD: 2000b). If we consider different aspects of public perception of risk, we cannot retain the idea that radiological risks of nuclear waste transportation are negligibly small (see Slovic et al.: 1991). Only a few reprocessing plants are currently available around the world and spent fuel needs to be transported to those plants and back to the country of origin. In Great-Britain, for instance, a serious debate is currently taking place about the possibilities to return Japanese reprocessed spent fuel to Japan.

One of the serious counter-arguments against reprocessing is the large investments needed to build the plants; small countries with a few nuclear power plants and in favor of the CFC will probably not build a reprocessing plant and will keep transporting spent fuel to those countries capable of this technology. To illustrate, the Netherlands is one of the countries with favorable reprocessing policy: Dutch spent fuel is currently transported to La Hague (France). There is no real chance that the Netherlands will build its own reprocessing plant in the coming years. To conclude, we assume that reprocessing will result in more short-term radiological risks, both to the environment and to the public health and safety, as illustrated in Figure 7.

The short-term and long-term effects mentioned above also pertain to environmental friendliness. Using the fuel to the maximum extent and maximally recycling the spent fuel could be considered as long-term 'environmentally friendly', as the environment is less exposed to potential radiological risks and radiotoxicity in the long run. One of the main arguments in favor of reprocessing – along with enhanced resource efficiency – is the vast reduction of waste volume and its toxicity and the accompanying advantages from a sustainability point of view. The volume of each ton of spent fuel containing approximately 1.5 cubic meter of HLW could be reduced through reprocessing three times (see NEA-OECD: 2001). The waste toxicity will decrease at least with a factor three (see Bertel and Wilmer: 2003).

Affordability

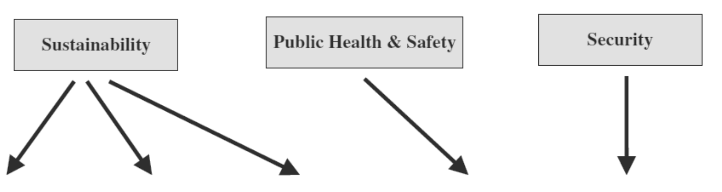
The third axis the NEA proposes in its comparison is *cost effectiveness*. We adapt this axis here into *affordability*. We acknowledge the relevance of economic aspects for initiation and continuing a technological activity. Sustainability can be conceived of as *durability*, to that purpose. However, economic effectiveness goes much further than the question whether an activity is *reasonably durable* or *affordable*. Social security is, for instance, mostly ineffective economically but we consider that as a duty of the state with respect to its citizens; nevertheless, it is supposed to be neither economically effective nor profitable.

It is also arguable whether durability should be accepted as sustainability. This is an ongoing debate about different interpretations of the notion of sustainability. In a moral discussion, it is probably more just to separate economic considerations from other aspect of sustainability. However, for the sake of our analysis we follow here NEA's analysis and accept sustainability conceived as durability.

In 1994, a NEA study determined a slight cost difference between the reprocessing option and direct disposal. Based on best estimates and the uranium prices of that time, the cost of direct disposal was approximately 10% lower, which was considered to be insignificant, taking the cost uncertainties into account (see NEA-OECD: 1994). However, considering later uranium prices and resource estimations, there is a strong economic preference for the once-through strategy, even if a considerable growth of nuclear energy production is anticipated (see Bertel and Wilmer: 2003). A MIT study in 2003 on 'The Future of Nuclear power' upholds the same view on economic aspects of reprocessing. Deutch et al. conclude in this report that – under certain assumptions and the

US conditions – the CFC will be four times as expensive as the OFC. The once-through option could only be competitive to recycling if the uranium prices increase (see Deutch and Moniz: 2003). These MIT researchers are not susceptible to the counter-arguments that disposing of reprocessed HLW will be less expensive. They furthermore present a cost model in which reprocessing remains uneconomic, even if the cost of reprocessed HLW were zero (see Deutch and Moniz: 2003). Another international study compares reprocessing with the once-through option and concludes that – even with substantial growth in nuclear power - the open LWR fuel cycle is likely to remain significantly cheaper than recycling in either LWRs (as MOX) or fast breeders for at least the next 50 years (see Bunn et al.: 2003).

In the previous reasoning we considered reprocessing as a broadly applied technology, which will create the need to build new reprocessing plants. Economic affordability appear totally different if we base our analysis on the existing reprocessing plants, as many small consumers of nuclear energy reprocess their spent fuel in France or Great-Britain. These countries do not have excessive initial expenditures for their CFC.



	Supply certainty		Radiological risks to environment		Affordability		Radiological risks to public		Proliferation	
	Short	Long	Short	Long	Short	Long	Short	Long	Short	Long
Open	+	-	+	-	+	-	+	-	+	-
Closed	+	+	-	+	-	+	-	+	-	+

Figure 7: Ethical values (first row) and their specification (second row) related to the OFC and CFC. A plus sign represent an improvement of the ethical value and has a positive connotation, a minus sign is a drawback of the value.

3.4.2. Public health and safety: short-term and long-term radiological risks

The second value is public health and safety. We again distinguish between short-term and long-term radiological risks, which cause hazards to public health and safety. Recycling of plutonium as MOX diminishes the eventual radiotoxicity of spent fuel with a factor three, assuming that spent MOX fuel is disposed of after one use (also called once-through recycling[73]). Theoretically, multiple recycling of plutonium in fast reactors can decrease the long term radiotoxicity of disposed waste by a factor ten. These scientific achievements could be brought into practice in several decades (see Bertel and Wilmer: 2003).

Recycling spent fuel includes the separation and storage of plutonium. Along with security arguments which will be discussed later, plutonium contains serious potential risks to the public health due to its exceptional toxic nature. Plutonium needs especial isolation from humans, as it contains long-lived alpha emitters, which are very radiotoxic upon inhalation (see Cooper et al.: 2003, 113). We included these risks in the short-term radiological risk for waste treatment. With respect to long-term radiological risks, the same reasoning as for the previously mentioned sustainability holds true: the short-term radiological risks associated with the CFC are significantly higher than the OFC.

3.4.3. Security and proliferation hazards

The last, but certainly not least value at play in waste management is security as a result of production of plutonium during recycling. Concerns regarding nuclear weapon proliferation are extremely relevant given the current state of world security. Proliferation threats rise either by the use of enriched uranium (up to 70%) or by the production or separation of plutonium. To illustrate, eight kilograms of weapon grade plutonium (^{239}Pu) are sufficient to produce a Nagasaki-type bomb (see Bunn: 2000).

Proliferation is also a potential hazard in countries capable of enriching uranium. One of the main tasks of the IAEA is to annually report to the United Nation's Security Council about nuclear energy possessing nations. Although both the OFC and the CFC need enriched uranium in the reactor, the short-term proliferation concerns of the CFC are considerably higher, due to the separation of plutonium during reprocessing.

The security concerns are double-edged: reprocessing increases proliferation concerns for the contemporary people, but at the same time it decreases those concerns for future generations, since the spent fuel residuals contain no plutonium any more. One can argue that the potential proliferation concerns of direct disposal of spent fuel in the OFC are negligible compared to the actual security concerns in case of reprocessing: disposed spent fuel cannot be

73 Not to be confused with the once-through option or the OFC.

retrieved unnoted, and expensive and inaccessible reprocessing plants are needed to separate plutonium from it for weapon manufacturing. Some scholars argue, on the other hand, that spent fuel in geological repositories becomes a better weapon-grade material as time goes by, due to the natural enrichment of ^{239}Pu (see KASAM: 2005c). However, this effect will take place in several thousands of years. In sum, the CFC involves more short-term proliferation and security concerns but decreases those concerns in the long run, as illustrated in Figure 7.

3.5. Value conflicts in fuel cycles and future generations

In the preceding analysis, we formulated a number of values and aimed to translate risks and benefits of the fuel cycles into these values. In decision-making about the fuel cycles we are confronted with a number of value conflicts. It should be mentioned that the plus and minus signs in Figure 7 are merely approximations which enable us to make a comparison between the OFC and CFC, these signs are neither quantitative measures nor absolute entities. It should further be mentioned that plusses represent an improvement in terms of the three basic values, illustrated in squares on top of Figure 7; minuses are drawbacks of these values.

3.5.1. Value conflicts

In choosing between options, we have to accept certain trade-offs between these basic values. The CFC enhances sustainability in terms of supply certainty and creates less radiological risks to the environment. It also diminishes public health and safety concerns, as well as security concerns in the long run. At the same time, however, the CFC involves more short-term additional risks and, therefore, compromises public health and safety as well as security of contemporary people. It also deteriorates short-term sustainability, perceived as environmental friendliness. Trading off these conflicting values in a certain way can help one choose one of the fuel cycles. To illustrate, if one holds the *cleanness* of the environment we bequeath to our descendants as most important, she should be willing to accept some additional risks to the public in the present and, therefore, the CFC would appear the obvious choice. Short-term risks are traded off against the long-term benefits in the CFC. Another example: if one considers proliferation threats in the current security state of the world highly unacceptable, she trades off long-term benefits of the CFC against the short-term benefits of the OFC; the latter will be the outcome of this trade-off.

In the literature, implicit trade-offs are made. A MIT study in 2003 concluded unambiguously that the once-through fuel cycle is the best choice for the US for at least 50 years. MIT researchers asserted that the reprocessing plants in Europe, Russia and Japan involve unwarranted proliferation risks and did not believe that benefits of the CFC outweigh the safety, environmental and security risks as well as economic costs (see Deutch and Moniz: 2003). Von Hippel upheld the same view on reprocessing: proliferation and economic costs of reprocessing are high and the environmental benefits are questionable. He maintained that direct storage of spent fuel after irradiation is cheaper, safer and more environmentally benign than reprocessing (see von Hippel: 2001).

Proliferation of nuclear weapons is one of the main concerns in the discussions about recycling nuclear waste. IAEA director El-Baradei noted in 2004: “We should consider limitations on the production of new nuclear material through enrichment and reprocessing, possibly by agreeing to restrict these operations to being exclusively under multinational control” (see El-Baradei: 2004). Proliferation concerns with respect to reprocessing are the main reason why many countries prefer the OFC. The US, Sweden, Finland and Canada have chosen the OFC to avoid plutonium separation. But unlike these countries, reprocessing occurs in many European countries such as Great-Britain and France as well as smaller nuclear energy consumers like the Netherlands, that reprocesses its nuclear waste in the French plants in La Hague. There are serious attempts to make reprocessing proliferation-resistant, including the US Global Nuclear Energy Partnership (GNEP) and the Russian Federation’s Global Nuclear Power Infrastructure Initiatives (see IAEA: 2006a).

3.5.2. Intergenerational justice and nuclear waste management

One of the key principles of Radioactive Waste Management laid down by the IAEA in 1995 is that it should be managed in such a way that it “will not impose undue burdens on future generations” (see IAEA: 1995). This principle is founded on ethical consideration that the generation enjoying the benefits of an undertaking should manage the resulting waste. The NEA supported this definition in the same year in a Collective Opinion (see NEA-OECD: 1995).

As illustrated, the CFC mostly has long-term benefits and compromises public health and safety as well as security of the contemporary people. Does the aim to avoid “undue burdens on future generations” mean that we are supposed to diminish waste radiotoxicity and its volume as much as possible? To what extent should we accept the increased risks and hazards to the present generation in order to accomplish the latter?

The questions how to interpret the “undue burden” can best be understood within the framework of intergenerational justice. Especially in fundamental policy decision-making, the question rises how one generation could equitably take the interest of future generations into account. Serious discussions about this issue started in the US (see NAPA: 1997) and are still ongoing in nuclear communities in choosing between options for final disposal of waste (see NEA-OECD: 1999b; IAEA: 2003). Some scholars interpreted the NEA collective opinion in 1995 as a confirmation for the – once and for all - sealed underground repositories. Uncertainty in long-term safety and possible future needs to recover plutonium (from spent fuel) for its potential energy value are two serious objections to permanently closed repositories (see NRC: 2001); we are after all required not to deprive future generations of any significant option (see IAEA: 1995; NEA-OECD: 1995). Inequity of risks and benefits across generations are two other reasons opposing permanent disposal (see Shrader-Frechette: 1993). In other words, scholars argue that permanent disposal forecloses options to future generations to retrieve and reverse waste. Alternatives to permanent disposal are long-term continued surface storage or phased repositories, which remain open for an extended period of time. There seems to be consensus among nuclear experts that disposal in repositories should be given preference above surface storage, as it is believed to be a passively safe solution that does not require burden of care by future generations (see NEA-OECD: 1999b).

In a recent European study, Schneider et al. argue that the main concerns in risk governance are the transfer of a whole waste management system, including a safety heritage, from the present to the future generations (see COWAM: 2006). They approach various technical and societal issues, such as long-term responsibility, justice and democracy from the perspective of generations, both across generations and within one generation.

In this paper we propose to reduce the trade-offs in choosing the fuel cycle to a chief trade-off between the present and the future. Is it legitimate and just to transfer all the risks and hazards of nuclear waste to future generations? How can we arrange an equitable transfer of the whole waste management system – as argued by Schneider et al. – to the future? Or is it more just and equitable to handle *our waste* as much as possible, in order to diminish its risks in the far future?

The OFC is to be associated with short-term benefits and the CFC primarily has long-term benefits[74]. In this reasoning, accepting the CFC means that we intend to diminish the risks and hazards to the future and accept some additional risks for the present generation. The OFC transfers the risks as much as possible to the future and avoid those risks in the present.

3.6. Underlying assumptions and possible counter-arguments

So far we have argued that decision-making on the fuel cycles could best take place within the framework of intergenerational justice. This conclusion is based on the analysis in the foregoing Section, in which we illustrated the choice between the OFC and the CFC mainly as a choice between the present and future generations. Obviously, there are a few assumptions at the basis of this analysis. Below, we will discuss some of these underlying assumptions and provide some possible counter-arguments and evaluate their validity.

3.6.1. Defining short-term as fifty years

In our analysis, we defined short-term as fifty years. Beyond half a century we considered as long-term. The question that rises here is whether fifty years constitute the real *turning point* in comparing the specified values, as we introduced in Figure 7. And more importantly, will other distinctions in time spans between short and long-term change our conclusion? As we mentioned earlier, the period of fifty years was taken from the comparisons we found in the literature. Most scholars preferring the OFC, pronounce their strong opinion for the coming five decades and economic comparisons are made for this period of time (see Deutch and Moniz: 2003; Bunn et al.: 2003). Both mentioned studies based their strong opinion on estimations of reasonably assured uranium resources at the beginning of this century; NEA and IAEA considered this amount in 2001 enough for 50 to 60 years (see IAEA-NEA: 2002). This period is, however, extended to 85 years in the 2005 estimations (of IAEA and NEA). It needs to be mentioned that the bulk of this increase is not due to discovering

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74 One exception to this trade-off is supply certainty that shows no significant difference between the fuel cycles.

more resources, but it is a result of re-evaluation of previous resources in the light of the effects of higher uranium prices (see IAEA-NEA: 2006).

Looking at the first columns in Figure 7 (supply certainty), the long-term benefits of the CFC will not change if we take 85 years as a turning point, the long-term benefits of supply certainty in the CFC will come into practice after this period. We should mention here that we founded our analysis on the identified resources. The total *Undiscovered Resources* of uranium are expected to be significantly higher (see IAEA-NEA: 2006). If we base our analysis on the latter, the long-term benefits of the CFC will probably vanish entirely, even for a much longer period of time. However, an analysis based on Undiscovered Resources comprises such an amount of uncertainty that estimations are practically meaningless.

Whether the column *affordability* will change, if we consider short-term as being 85 years, is not clear. We can state that high initial investments for the reprocessing plant might perhaps be affordable, if we consider a longer period of time. However, there have been no serious estimations based on the announced reasonably assured uranium resources in 2005.

3.6.2. All released Pu will eventually be 'destroyed'

Beneficial long-term radiological risks of the CFC are based on the assumption that all plutonium is separated from spent fuel and "*destroyed*". As plutonium is the dominant element in indicating the waste life-time in spent fuel, its extraction from waste will diminishes waste radiotoxicity substantially. The mentioned period of radiotoxicity of vitrified waste after reprocessing of 5,000 years (see NEA-OECD: 1996), includes the assumption of complete *consumption* of plutonium after separation. Less long-term proliferation hazards in the CFC are also based on the same assumption: extracted plutonium is ultimately fissioned. How realistic is this assumption if we consider the millions of kilograms weapon-grade plutonium and Highly Enriches Uranium (to above 70%) discharged as a result of dismantlement of warheads after the Cold War?

These released materials could also either be considered as waste to be disposed of directly or as potential fuel for the production of energy. These different points of view mark the divergent approaches between the two superpowers in the Cold War. Americans believe that excess plutonium has no economic value, as it costs more to use as energy source than the energy is worth. However, since the other option of dealing with this hazardous material, i.e. its disposal, is costly as well, some plutonium is supposed to be used as reactor fuel (MOX), but only in a once-through scenario. This is perfectly in line with the American concerns about (civilian) plutonium which is not recycled and reused either. Russians hold a totally different view on this issue: they consider excess weapon plutonium as fuel having "significant energy potentials". Russia also acts in accordance with their CFC perspectives. However, they believe – together with Americans – that the potential value of these plutonium stockpiles cannot be *cashed* in the near future, as it needs substantial additional costs (see Bunn: 2000).

Plutonium has already proven its benefit in the production of energy. Reprocessed plutonium from civil reactors is called *civilian plutonium*, a name that could mistakenly be understood as unfeasible weapon material (although it is very unfavorable as a weapon material). As reprocessing of plutonium has outpaced its use as fuel and due to technical and regulatory restrictions, no more than 30% of produced MOX could be fissioned in a reactor, which creates an imbalance between separated civil plutonium and reused MOX; in the beginning of this century an estimated amount of 200 tons of civilian plutonium was available in the stockpiles (see Bertel and Wilmer: 2003). This amount is vastly growing and is believed to surpass the total amount of released weapon plutonium soon. Referring to the theft concern and concerns on excessive surpluses of plutonium, mainly in former Soviet Union countries, Bunn et al. argue for an international phased-in moratorium on reprocessing (see Bunn et al.: 2002; Bunn: 2000).

Irrespective of Bunn's reasoning's validity regarding nuclear theft, we can easily state that separated plutonium for the purpose of reprocessing contains more proliferation concerns than plutonium 'embedded' in spent fuel. The latter needs advanced and very expensive technology to separate plutonium, which is not accessible outside the legal authorized and controlled way of the IAEA, which supports the argument that separated plutonium involves more security and proliferation concerns.

A similar reasoning holds true for the toxic properties of plutonium. If we extract plutonium from spent fuel, under the assumption that it will eventually be fissioned and, consequently, prevent it of being disposed of underground, we create de facto more risks for the contemporary people. These risks were already included as more short-term radiological risks in Figure 7. However, if we fail to make it plausible that extracted plutonium will eventually be fissioned in reactors as MOX, we merely create more risks - both short-term and long-term -

and that will substantially change our analysis. Considering the fact that one-third of separated plutonium is currently fissioned through reprocessing, the long-term benefits of the CFC will merely be meaningful under the assumption that MOX consumption will substantially expand.

The latter is possible under two scenarios: 1) broader deployment of MOX fuel and 2) less reprocessing, as produced MOX could first be consumed. Less deployment of reprocessing conflicts with the initial assumption. We were trying to give underpinnings for long-term benefits of the CFC, of which reprocessing is a crucial component. That leaves the first scenario open: less long-term risks of the CFC are plausible if and only if we take a wider deployment of MOX fuel for granted, either as a result of adapting existing reactors or due to a broader application of MOX in the planned reactors or reactors being built. According to the World Nuclear Association, there are 28 new reactors being built and 64 are ordered or planned worldwide. Furthermore, there are 158 reactors proposed and waiting for funding or approval (see WNA: 2007). These developments *can* give support to the long-term benefits of the CFC. Still, the protagonists need to make plausible that the stockpiles of civilian plutonium extracted through reprocessing will eventually be fissioned.

3.6.3. How long does the 'long-term' last in case of radiological risks?

Let's go back to the first assumption discussed with respect to defined time spans in order to distinguish between the short-term and long-term. So far, we argued that the CFC has less long-term radiological risks, assuming that separated plutonium in reprocessing will eventually be fissioned. However, these *radiological benefits* will be noticeable only after 5,000 years, which represents the waste life-time of reprocessed waste (vitrified waste). After 50 years the CFC creates more additional risks to both public and the environment (at that moment), the more so since reprocessing will be an ongoing business in the CFC.

The question raises here whether this challenges our analysis. The trade-offs needs still to be made between the short-term and long-term radiological risks. The CFC is rightly associated with less long-term risks: perceived from now or after 50 years, there will be less long-term risks in remote future. The analysis is still valid, but these long-term benefits will reveal after a much longer period of time than the proposed fifty years for supply certainty. To sum up, fifty years is not applicable to all comparisons, but the line of analysis will not change as a consequence.

3.6.4. The CFC and the transition period

Let's now take a look at the argument of nuclear energy being used in a *transition* period between conventional fuel resources (fossil fuel) and sustainable energy, from the perspective of the CFC. As we stated earlier, based on the 2004 nuclear energy consumption, the uranium resources are available for a period of approximately 85 years for a once-through option in a LWR (see IAEA-NEA: 2006). There is also no economic reason for deployment of the CFC in the upcoming fifty years, as it remains uneconomic for this "short" period of time and the high initial investments cannot be recovered, even if a considerable growth of nuclear energy is anticipated (see Bunn et al.: 2003; Bertel and Wilmer: 2003; Deutch and Moniz: 2003). So far we argued that the benefits of the CFC will be revealed in the long run only, certainly in no less than fifty years. If this time exceeds the transition period, should those who believe in nuclear energy to bridge the *transition period*, be consequentially in favor of the OFC?

This transition period is not accurately defined in the literature; it concerns the transition of fossil fuel to sustainable energy sources. Nuclear energy is believed to play a significant part into this transition until 2020, due to its assured supply certainty and low emissions (see Bruggink and van der Zwaan: 2002). Which role nuclear energy will play after this period depends on developments in tackling safety, waste and proliferation issues. Most advocates of the transition-period argument do not exclude nuclear energy: they believe that nuclear energy is capable of being *sustainable* in the future, if the aforementioned concerns are being taken care of (see Bruggink and van der Zwaan: 2002).

If we agree that the CFC is – under some assumptions – more environmentally benign in the long run and if the latter is the outcome of our trade-offs, we can argue that we should use the CFC for the transition period, no matter how short or how long this period is. The long-term burdens as a result of nuclear energy deployment will be there anyway, the CFC enables one to diminish those burdens to some extent. There are also no technical restrictions to deployment of the CFC in short periods of time, except the time needed to build a reprocessing plant. However, the argument we presented with respect to actually destroying plutonium holds stronger if one is in favor of applying nuclear energy to bridge a transition period: within that same period, all plutonium should then be destroyed.

3.6.5. Choosing between OFC and CFC. Isn't that a false dilemma?

In our analysis we presented two different methods in the production of nuclear energy. Prior to our analysis, we stated that the questions with respect to desirability of nuclear energy will be beyond the scope of our paper. We also listed the state-of-the-art in the production of nuclear energy, being responsible for 16% of world's energy production, and focused on existing moral conflicts. Under these assumptions, there are two methods to produce nuclear energy, namely the OFC and the CFC.

The question raises here whether there will be a third fundamentally different option, or in other words, whether the choice between the OFC and the CFC is a false dilemma? Future developments of nuclear energy mainly concern effort to reduce radiotoxicity of waste, such as the P&T presented in this paper. These options are to be considered as an extended CFC and are not essentially different. We still need to deal with the trade-offs as we described n this paper.

One can further argue that the framework of intergenerational justice can give rise to *unacceptable risks* in both scenarios. In other words, the intergenerational justice framework refutes both nuclear fuel cycles. Such reasoning challenge the assumptions we made with regard to nuclear energy rather than our analysis based on those assumptions.

3.6.6. Why don't we talk about justice among contemporaries?

In the preceding Sections we argued that the choice for a fuel cycle should be made within the framework of intergenerational justice. In other words, we should (also) take the needs and interest of future generations into consideration and make a trade-offs between the latter and the interest of contemporary people, in order to make a decision on the fuel cycle. The question rises here: is that a sufficient condition? Especially when we consider that the majority of nuclear plants is located in developed countries, while more than 30 percent of the world's uranium production is coming from developing countries (see IAEA-NEA: 2006). Kazakhstan, Uzbekistan, Namibia and Niger that are bearing the *burdens* of the front-end of the fuel cycle (i.e. milling, mining etc) do not have a power plant at all and will not be able to share the *benefits* of nuclear energy? Isn't this a relevant question, perceived from distributive justice?

The authors fully acknowledge the relevance of evaluating justice among contemporaries in this discussion, which is referred to in the literature as *intragenerational justice*. However, intragenerational considerations are not decisive in the choice for the fuel cycle, they rather follow from the choice one makes. To illustrate, when a country decides to deploy the CFC, the question rises where the country is going to reprocess its waste; is it *just* that Dutch waste - for instance - goes to La Hague in France to be reprocessed? These intergenerational justice considerations are also relevant within a country: is it *just* that the Nevadans bear the burden of the *whole* American waste which probably will be disposed off under the Yucca Mountains in Nevada. Similar considerations are to be made in case of locating a nuclear power plant: people in the direct vicinity bear the burdens, while the whole nation enjoys the benefits.

As we briefly showed here, intragenerational considerations rather challenge the assumption we made in the beginning of this paper with regard to the deployment of nuclear energy, than to help us to make a choice between the fuel cycles. *Inter*generational justice, however, offers a suitable framework for choosing the fuel cycle. Once this choice is made, intragenerational concerns are born.

3.7. Conclusions

In this paper we evaluate NEA's definition for sustainability (see NEA-OECD: 2002) and adapt that definition both conceptually and practically: it is questionable – from a moral standpoint - whether sustainability can be related to economic issues and it is more correct to use economic affordability instead of cost effectiveness. We further argue that though sustainability - as defined by NEA and adapted here - is a crucial aspect in this discussion, it does not offer a proper basis to choose a fuel cycle: public health and safety as well as security concerns are at least as important to be included. By adding a time dimension to this comparison, we propose a new framework in order to choose the nuclear fuel cycle - intergenerational justice – and specify consequences of both fuel cycles within this new framework. To that purpose, we identify values at play and value conflicts one encounters in choosing between the fuel cycles: the CFC improves sustainability in terms of the availability of fuel and involves less radiological risks to the public and the environment in the long run, but it compromises public health and safety in the present. The CFC also poses serious security threats for the contemporary people, due to the production and the separation of plutonium. However, at the same time it diminishes those threats for future generations.

These trade-offs in nuclear energy are reducible to a chief trade-off between the present and the future. To what extent should we recycle *our* produced nuclear waste in order to avoid "undue burdens" on the future and to what extent should we accept additional risks for the present generation? These questions can be answered within the proposed framework of *intergenerational justice*. This concept of justice is often used in the nuclear discussions, mainly to tackle issues with respect to final waste disposal, waste retrievability in the future and, more recently, risk governance with regard to the question how we can equitably transfer a whole waste management system to the future.

In our analysis we used lots of estimations with regard to uranium resources, waste radiotoxicity and the radiological risks of the waste. How valid are these estimations if we include the uncertainties encompassing our analysis? Estimations and predictions are the key problems in dealing with the future, especially when we talk about the remote future. These uncertainties need to be further investigated in future studies in order to test the validity of provided analysis. It is also recommendable to quantify the probabilities of these risks in order to compare them in a more appropriate way. Do the decreased risks to the public and the environment in the remote future equal the increased risks to the present generation?

In this paper, we approach the choice between the fuel cycles perceived form the perspective of intergenerational justice. Advocates of he OFC should argue why they are willing to transfer all the risks for a very long period of time (200,000 years) to future generations and accept all the accompanying uncertainties for their descendants. Supporters of the CFC should underpin their acceptance of additional risks to the present generation. More importantly, they should make it plausible that separated plutonium during reprocessing is eventually "destroyed". Proliferation remains the leitmotiv in these discussions, as it is the main objection against the CFC.

4 Intergenerational Considerations Affecting the Future of Nuclear Power

Equity as a Framework for Assessing Fuel Cycles[75]

Abstract

Alternative fuel cycles are being considered in an effort to prolong uranium fuel supplies for thousands of years to come and to manage nuclear waste. These strategies bring with them different benefits and burdens for the present generation and for future generations. In this paper we present a method that provides insight into future fuel cycle alternatives and into the conflicts arising between generations within the framework of intergenerational equity. A set of intersubjective values is drawn from the notion of sustainable development. By operationalizing these values and mapping out their impacts, value criteria are introduced for the assessment of fuel cycles which are based on the distribution of burdens and benefits between generations. The once-through fuel cycle currently deployed in the United States and three future fuel cycles are subsequently assessed according to these criteria. The four alternatives are then compared in an integrated analysis in which we shed light on the implicit trade-offs made by decision makers when they choose a certain fuel cycle. When choosing a fuel cycle, what are the societal costs and burdens accepted for each generation and how can these factors be justified? This paper presents an integrated decision making method which considers intergenerational aspects of such decisions; this method could also be applied to other technologies.

Keywords: intergenerational equity, value, nuclear fuel cycles, reprocessing, partitioning and transmutation, breeder

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[75] This paper is a contribution to an interdisciplinary MIT study about the future fuel cycle options for nuclear power production in the United States that is expected to be published in 2009. An earlier version of this paper was presented during the annual Workshop on Philosophy and Technology in November 2008, in London.

4.1. Introduction

Anthropogenic climate change caused by greenhouse gases and projected future energy demands poses serious challenges to future fossil fuel use. While some believe that we can meet this challenge by tapping renewable resources, others maintain that in future nuclear energy will be indispensable. At present nuclear energy accounts for approximately 6 percent of the global energy consumption and 16 percent of the global electricity production (see EIA: 2008, 138). A considerable growth of more than thirty percent by 2030 is foreseen.[76] Future growth predictions depend on how well nuclear plants operate, the cost of constructing of new nuclear plants, the resolving of the nuclear waste disposal issue, proliferation concerns, international agreements concerning greenhouse gas reduction and rising oil and natural gas prices. Nuclear energy also engenders controversy in public and political debates that may well prevent its expansion.

In this paper we propose a framework of *intergenerational equity* in order to assess nuclear power production practices now and in the future (see Meyer: 2008). The "achievement of intergenerational equity" is one of the cornerstones of nuclear waste management (see IAEA: 1997) and one of the reasons for choosing geological repositories for the ultimate disposal of nuclear waste (see NEA-OECD: 1995). Many nations are currently considering alternative fuel cycle possibilities in order to prolong uranium fuel supplies and manage nuclear waste. These strategies bring with them benefits and burdens for present and future generations; the choice between existing fuel cycles has already come to be seen as a matter of intergenerational equity (see Taebi and Kloosterman: 2008). This paper puts forward a way of assessing future fuel cycles in accordance with the intergenerational equity criteria presented as a broadly defined set of *moral* values built around the principle of sustainability. We characterize these values as moral values since they contribute to the environment and humankind's safety and security as well as an overall welfare of society in terms of sustainability; see in this connection Figure 8.

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76 The joint report of the NEA and the IAEA (the Red Book, 2007) foresees a low consumption and a high consumption scenario, varying from 372 GWe in 2007 to between 509 GWe (+38%) and 663 GWe (+80%) in 2030 (see IAEA-NEA: 2008). The Energy Information Administration of the US Government foresees a growth of approximately 33% going from 374 GWe in 2005 to 498 GWe in 2030 (see EIA: 2008).

We base our analysis on the future energy forecasts made primarily in the United States assuming that nuclear energy will play a part for at least another century. We do not, however, intend to make any normative claims regarding the desirability of nuclear power. We aim instead to provide a method that will allow every individual and stakeholder to be able to assess the future developments of nuclear technology on the basis of intergenerational equity criteria, i.e. according to the distribution of benefits and burdens between generations. Even though we believe that a similar analysis could be made in order to address the consequences deriving from employment of other energy systems such as those involving coal or gas, this paper presents an assessment of different nuclear fuel cycles, rather than a comparison between the nuclear option and other energy resources.

The paper consists of two main parts in which a method is introduced that is subsequently applied to a fuel cycle. The following section first discusses the notion of values and why they are of relevance to our analysis. Section 2 further discusses the relationship between sustainable development and intergenerational equity. Values stemming from sustainability are then explored in Section 3 which lead to criteria of intergenerational assessment that are derived from these values. The remainder of the paper focuses on the application of the method. In Section 4 the proposed criteria are applied to the once-through fuel cycle currently adhered to in the United States and to three possible alternatives. In Section 5, the four fuel cycles are compared on the basis of a scorecard that provides a summary of criteria and intergenerational assessments. The final section presents a number of concluding remarks.

4.2. Sustainability and intergenerational Equity

In this section we focus on the questions of what values are, of how sustainability is considered as a value and of what its relation is to the notion of equity between generations. We conclude the section by arguing why it makes sense to talk about intergenerational equity in discussions on nuclear power production.

4.2.1. Values, valuers and value systems

In conventional ethics and in discussions on human relations, terms such as "rights, justice, beneficence and malificence, social contract [etc.]" are regularly used; here the fundamental term that will help to orient us is *value*, "it will be out of value that we will derive duty" (see Rolston: 1988, 2). The first important issue is to determine whether something is worth striving for because it serves a higher good or for its own sake. To put this in philosophical terms, we must establish whether something has *instrumental* value or *intrinsic* value and thus does not require further instrumental references.[77] This discussion gains serious relevance, when it comes to the questions of how to value the environment and how to understand a human being's relationship with his natural world.[78] Generally, we can distinguish between two schools of thought: 1) those philosophers who believe that the environment only has an instrumental value to serve "human beings and the place it occupies in their lives" (see Goodin: 1992) by emphasizing that "values always occur from the viewpoint of a conscious valuer" (see Norton: 1991, 251) – this is referred to as *anthropocentric* or human-based ethics and 2) other philosophers who believe that nature has intrinsic value of its own,[79] also known as the *non-anthropocentric* view (see Barry: 1995, 20). In Section 3, we further elaborate on this issue and its relevance when identifying the values at stake.

Values are things worth striving for. However, we should not confuse values with the personal interests of individuals; values are general convictions and beliefs that people should hold paramount if society is to be good. This

77 When something has an intrinsic value it has a value in itself. Instrumental values are on the other hand ascribed to things that have no value as such or no intrinsic value; an instrumental reference is then needed here.

78 Valuing nature is a long and still ongoing subject in environmental philosophy. Rolston-III gives in his book, "Environmental Ethics" a comprehensive account of the notion of value. He distinguishes (in Ch. 1) between different categories of values such as life-support value, economic value, scientific value, aesthetic value etc. and deals with the fundamental question of whether we have obligations to the natural world. (see Rolston: 1988) See also Values and The Environment (see O'Brien and Guerrier: 1995) and Valuing Nature (see Foster: 1997).

79 Among the latter we can also distinguish between those who defend *ecocentrism* or *biocentrism* by asserting that nature's value is independent of humans and animals (see Taylor: 1986) and those who believe that non-human animal interests should be given equal consideration (see Singer: 1975; Regan and Singer: 1976). Some people argue that it is a form of "human chauvinism" to reduce environmental justice purely to human interests (see Routley and Routley: 1979). DesJardiens gives in his book "Environmental Ethics" an accessible overview of this discussion (see DesJardins: 2006, Ch. 7). These discussions have already gone beyond philosophical considerations regarding animal's right and have entered the reality of policy-making. Recently a "Party for the Animals" was established in the Netherlands and even got into the Dutch Parliament. This political party's primary concerns are "animal welfare and the respectful treatment of animals", see for more information: http://www.partyfortheanimals.nl/

highlights the central challenge of defining values or, in other words, of how we can propose any broadly accepted set of moral values designed to serve the greater good of society? The inherent difficulty is that a value system one adopts should define a perception of moral values, describing a good way of life, and society; "there is no possibility [...] to develop a single value or value system able to encompass the myriad strains of belief, commitments and attitudes that envelop people's relationship with their environment" (see O'Brien and Guerrier: 1995). With nuclear technology it has been found that stakeholders' value systems largely define their acceptance of courses of action (see Kadak: 2000).

We aim to present a set of broadly defined and *intersubjectively*[80] formulated values; by intersubjective we mean that different individuals and stakeholders could relate to these values, regardless of their subjective value systems. A stakeholder's attitude towards risk acceptance relates more to the way values are prioritized and traded off against one another, rather than to how an isolated value is perceived.

4.2.2. Sustainability and equity: a two-way road

Widespread concerns about the depletion of the earth's natural resources and environmental damage have invoked discussions on the equitable sharing of benefits and the burdens between generations so as to meet "the needs of the present without compromising the ability of future generations to meet their own needs", commonly referred to as the Brundtland definition (see WCED: 1987, 43). As this definition implies, the equitable distribution of goods across generations is what underlies the notion of sustainability. In the following section, different interpretations of sustainability will be presented in terms of moral values; the conflicts arising from the interests of different people in relation to these values will be clarified and elaborated by using the notion of equity between generations.

Equity, as a principle in environmental policy-making, was first officially incorporated into the Rio Declaration on Environment and Development of 1992 (see UN: 1992a) and it was reiterated in the same year during the UN framework convention on Climate Change when it was stated that we should protect future

80 We do not claim that moral values are *objectively* to be defined; therefore we adhere to the notion of intersubjective values.

people's interests "on the basis of equity" (see UN: 1992b). Equity has also been very influential in discussions linked to nuclear waste management: in 1984, the Nuclear Energy Agency[81] (NEA) first expressed "a desire for equity" in radioactive waste disposal (see NEA-OECD: 1984). Partly on the basis of this desire and discussions about sustainable development, the International Atomic and Energy Agency (IAEA) laid down certain principles for Radioactive Waste Management, one of which states that nuclear waste should be managed in such a way that it "will not impose undue burdens on future generations" (see IAEA: 1995, 7) in conjunction with the idea that the generation enjoying the benefits of an undertaking should manage its consequences in terms of the waste (see NEA-OECD: 1995).

Sustainability and intergenerational equity are closely intertwined. Nigel Dower argues that "the commitment to sustainability is a moral commitment to sustaining the conditions in which human well-being can be achieved, not only now and in the near future but also into the more distant future" (see Dower: 2004, 401). Dower distinguishes between two ways of understanding justice towards future generations: namely 1) sustaining justice in the way it is perceived now and 2) achieving intergenerational justice in terms of what we leave for our descendants. "If the next generation had enough resources to distribute at that time fairly but half what the current generation had, then the sustainability of justice is achieved but not intergenerational justice" (see Dower: 2004, 401). In this paper we consider intergenerational equity or justice[82] as presented in terms of Dower's second interpretation, to the effect that the present generation's primary concern should be with what it bequeaths to future generations.

The distribution of benefits and burdens between generations could be divided into three different categories: 1) future benefits versus future burdens (as in Dower's first interpretation of intergenerational equity), 2) current benefits versus current burdens and 3) current benefits and burdens versus future benefits and burdens. In this paper we will not enter into discussion about the

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81 The Nuclear Energy Agency (NEA) is the OECD agency (Organisation for Economic Co-operation and Development) that is specialized in nuclear energy.

82 Justice, fairness and equity are used interchangeably in the relevant literature sources. Many philosophers are concerned about what is *fair* with respect to the future and fairness seems to be subsumed under the heading *justice*. *Equity* relates to the equal distribution of goods. In this paper it is not my intention to go into great depth on these philosophical discussions. *Intergenerational equity* or *justice* are referred to here as the equitable distribution of risks and burdens across generations.

first category, as already stated in the preceding paragraph. The second category deals with the question of who among our contemporaries are receiving the benefits and who are bearing the burdens referred to as *intragenerational* equity.[83] Besides intergenerational equity, discussions about the distribution of wealth between contemporaries (and the problem of global poverty) remain the cornerstones of sustainable development as originally proposed by the Brundtland commission (see WCED: 1987). Even though we acknowledge the moral relevance of the discussions, our main focus in this paper has to be on *temporal equity*, or equity considerations pertaining to nuclear power production (the third category) between generations.

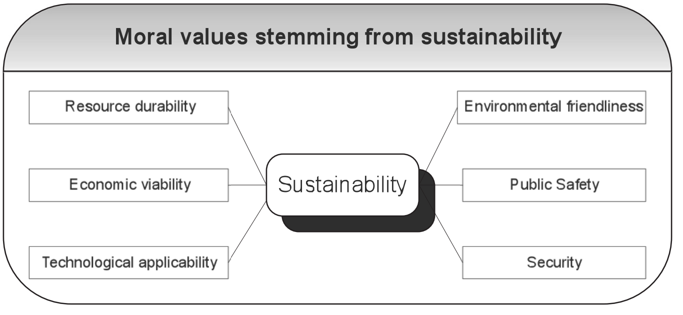

Figure 8: The values stemming from equity and interpreted as different conceptions of sustainability

4.2.3. Why do we consider intergenerational equity?

Let us focus for a while on the question of why it makes sense to view this problem in terms of generations and why it amounts to a problem of fairness? We follow here Stephen Gardiner's (see 2003) discussions of "The Pure Intergenerational Problem" (PIP) in which he imagines a world of temporally distinct groups that can asymmetrically influence each other: "earlier groups have the power to impose costs on later groups [....], whereas future groups have no causal power over them". Each generation has access to a diversity of commodities. Engaging in activity with these goods culminates in present

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83 For example questions pertaining to who are enjoying the benefits of nuclear energy production and who are bearing its burdens within a country are interesting to be examine within the framework of equity as well; see for more discussions on intragenerational equity: Duties to Future Generations, Proxy Consent, Intra and Intergenerational Equity: The Case of Nuclear Waste (see Shrader-Frechette: 2000).

benefits and potential substantial future cost, all of which poses the problem of fairness. This also holds for nuclear energy: the present generation will mainly enjoy the benefits by depleting resources. In addition, the production of nuclear waste, and its longevity in terms of radioactivity, also creates future cost and burden issues.

We relate the PIP to the production of nuclear power and follow the widest definition of future generations by defining them as "people who by definition will live after contemporary people are dead" (see De-Shalit: 1995, 138). This definition of a generation approximately corresponds to a hundred years;[84] we consider a hundred years to be the cut off point when distinguishing between Generations 1 and 2. Obviously the real-world cases are not always as temporally distinct as those presented in the PIP and a certain degree of overlap might well change a few of these arguments or make them less compelling. We do however believe that this overlap will not substantially change the intergenerational nature of this problem.[85]

In this section we elaborated on the notion of sustainable development and its philosophical relationship to intergenerational equity. We shall now continue, in the next section, by identifying the values that contribute to sustainable development.

4.3. Moral standing of sustainability: values at stake

Up until now there has been no consensus among scientists on how to apply the notion of sustainable development to nuclear power. Some perceive of sustainability as "affordable, reliable electricity" that does not put "the earth's climate in jeopardy" (see Bonser: 2002) while by referring to the same notion, the safety of plant operation as well as proliferation concerns are also addressed (see Stevens: 1997; IAEA: 2006b; NEA-OECD: 2000a; Bourdaire and Paffenbarger: 1998). Some stakeholders in these discussions believe that under certain conditions "there is a basic case for treating nuclear energy as a

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84 It should be noted that Avner de-Shalit, whose definition is cited here, abides by the common definition of generation as being a time span of 30 years. If we however adopt his definition of future generations and define the immediately following generation as everyone who is now alive, including the infants born in the last couple of moments, then it will be a much longer period of time - namely the length of people's average life expectation - before the current generation ceases to exist and we can speak of a future generation.

85 Gardiner discusses a few counter arguments and concludes that even in overlap cases the main rationale of the PIP is not undermined.(see Gardiner: 2003)

contribution to sustainable development" (see Stevens: 1997, 149) at least in a "transitional role towards establishing sustainable energy systems" (see Bruggink and van der Zwaan: 2002, 151) and others state that nuclear power is inherently "unsustainable, uneconomic, dirty and dangerous" (see GreenPeace: 2006).

In this paper we do not pretend to answer the controversial question as to whether nuclear energy is - or could possibly be - sustainable. We argue that in order to understand this question we need to interpret sustainability and address the conflict of interests between people belonging to different generations. To this end, we identify values that contribute to different interpretations of sustainability and provide an account of our intersubjective set of values.

Before spelling out these values, let us just discuss one more issue, namely that of how these values are grounded in principles of intergenerational justice. Elsewhere I have argued that a requirement of justice is that the overall range of opportunities open to future generations should not be narrowed[86], this corresponds to Barry's principle of egalitarian justice (see Barry: 1978). We should thus safeguard equal opportunities for posterity. The two temporal duties proposed to comply with this principle are these: 1) we should not endanger the vital interests of future generations which is a fundamental condition if they are to enjoy equal opportunity and 2) we should safeguard the opportunity for welfare. In other words, we should sustain the environment and humankind's safety and security and we should seek to sustain human welfare. These two principles are here below linked to the relevant contributing values.

4.3.1. Sustaining the environment and humankind's safety and security

Sustainability could be seen as the process of preserving the status of nature and leaving it no worse than we found it: the value we relate to this notion is *environmental friendliness*. Another interpretation is to perceive of sustainability as the protecting of public safety and security or, as defined by NEA, the providing of "the same degree of protection" for people living now and in the future (see NEA-OECD: 1984). The IAEA articulates these concerns in its Safety Principles when it states that nuclear waste should be managed in such a way that "predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today" (see IAEA: 1995, 6). The

86 This claim is discussed in the introduction to this dissertation; see Sections 1.2.2. and 1.2.3.

value we link to these concerns is *public safety*, which pertains to the exposure of the human body to radiation and the subsequent health effects of radiation.

Depending on which school of anthropocentric or non-anthropocentric ethics we follow, 'environmental friendliness' and 'public safety' could be merged. Some scholars argue in favor of this standpoint by stating that we should protect nature for future generations in order to respect *their* equal opportunity to make use of the environment. This is allegedly a more appropriate and convenient notion in environmental policy than that of ascribing environment an intrinsic value (see Beekman: 2004, 5). The latter also corresponds to the way in which the United Nations' Framework on Climate Change perceives of nature as it proposes protecting the climate system "for the benefit of present and future generations of humankind" (see UN: 1992b, Ar. 3).

IAEA[87] (the International Atomic and Energy Agency) seems, on the other hand, to ascribe an intrinsic value to the environment. By defining "safety" as "the protection of people and the environment against radiation risks, and the safety of facilities and activities that give rise to radiation risks" (see IAEA: 2007a, 173), IAEA implies that the environment should be spared, but not necessarily for the sake of human beings. Safety in terms of the "Fundamental Safety Objective" - introduced by a few leading organizations in nuclear technology - is referred to as the protection of "people and the environment from [the] harmful effects of ionizing radiations" (see IAEA et al.: 2006, 4). In this paper, we define 'public safety' as the protecting of people from the accidental harmful effects of ionizing radiation.

We do not find it necessary to take a stand in the discussions but we present instead in this section 'environmental friendliness' as a separate value in order to broaden our set of values and give every stakeholder in this discussion the opportunity to relate to them. In our analysis in the following sections we do, however, consider the two values of 'environmental friendliness' and 'public safety' in combination as they both refer to the same radiation hazards. The latter should not be seen as a normative statement; it is merely a way of facilitating and simplifying the analysis. Besides, stakeholders are at all times free to separate these two values and discuss the related concerns separately.

"[T]he same degree of protection", alluded to by NEA (see NEA-OECD: 1984) not only refers to the health and safety of people, but also to security concerns such as the unauthorized possession or theft of radioactive material to either

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87 The United Nation's specialized agency in nuclear technology.

cause sabotage or be used in the creation of nuclear weapons; *security* is the next value that will be addressed in this analysis. In the IAEA's Safety Glossary, sabotage is defined as "any deliberate act directed against a nuclear facility or nuclear material in use, storage or transport which could endanger the health and safety of the public or the environment" (see IAEA: 2007a, 133). One can argue that 'security' as defined here also refers to the safety considerations discussed above. We shall, however, keep the value of 'security' separate in this analysis so as to be able to distinguish between unintentional and intentional harm; the latter also relates to extremely relevant proliferation considerations such as the use and dispersal of nuclear technology for destructive purposes. We define 'security' as the protecting of people from the intentional harmful effects of ionizing radiation resulting from sabotage or proliferation.[88]

4.3.2. Sustaining human welfare

So far we have presented three values for sustaining the environment and humankind's safety and security. In other words, the right side of Figure 8 represents the sustaining of human and non-human life as well as the status of nature. Another aspect of sustainability links up with the sustaining of human welfare[89]; some economists state that "a development is sustainable if total welfare does not decline along the path" (see Hamilton: 2003, 419) and that "achieving sustainable development necessarily entails creating and maintaining wealth" (see Hamilton: 2003, 420). We argue that sustaining welfare as a minimum requirement relates to the availability of energy resources which is why we distinguish between the three values of: 1) resource durability, 2) economic viability and 3) technological applicability. These three values are

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88 The overlap between the value of safety and security allows for different interpretations. It must be noticed that some scientists would rather subsume sabotage concerns under public safety and interpret it as preventing and mitigating both accidental and sabotage release; security in this line of reasoning only refers to proliferation concerns, in which the importance of the latter is emphasized. We follow here the IAEA Safety Glossary by referring to security as "any deliberate act against a nuclear facility or nuclear material in use, storage and transport" (see IAEA: 2007a, 133) and believe that it is better to see sabotage as a security concern. Such a definition enables us to draw a distinction between unintentional harm (safety) and intentional harm (security).

89 *Welfare* and *wealth* are used interchangeably not only by this author but also elsewhere in the literature. We prefer to stick to the notion of welfare because it more relates to health and happiness; wealth has a more momentary connotation. Also the notion of *well-being* is sometimes used in this context (see Dower: 2004).

presented as moral values since they gain relevance in relation to each other and in aggregate they contribute to human welfare in terms of sustaining resources.[90]

Resource durability has to do with the availability of natural resources for the future. Brian Barry presents the theory of intergenerational justice as the appropriate consumption of non-renewable natural resources across time. In relation to non-renewable resources "[L]ater generations should be left no worse off [...] than they would have been without depletion" (see Barry: 1989a, 519). Barry proposes compensatory action or recompense for depleted natural resources such as oil and gas and for all the side-effects of this depletion, such as climate change. Edward Page suggests that the most obvious example of such compensation lies in technological improvement such as that seen in heightened energy efficiency (see Page: 1999b, 55). Following this line of reasoning, we argue that technological progress could also lead to energy efficiency or to the deployment of new natural resources for energy production.[91] We therefore present here *technological applicability* as one of the interpretations of sustainability which is defined as the *scientific feasibility* of a certain technology in combination with its *industrial availability*. In particular industrial availability depends very much upon *economic viability* and competitiveness with respect to the various alternatives.

To recapitulate, the three values are defined as follows: 'resource durability' is the availability of the natural resources required for the future or the providing of an equivalent alternative for the same function, 'technological applicability' is the scientific feasibility and industrial availability of a specific technology. Finally, 'economic viability' is the economic potential to embark on a new technology at a certain point in time and to safeguard its continuation.

Let us illustrate this with an example. As thorium (Th) is a naturally very abundant resource, its deployment as a nuclear fuel has been considered since the early days of nuclear power production (see Kazimi: 2003). Its 'scientific feasibility' was revealed in the fifties, but its 'industrial applicability' is still far

90 One can also argue that the availability of resources and technology have no independent moral relevance which means that resource durability and technological applicability are rather conditions that make it possible to achieve other values or objectives. We owe this suggestion to Frans Berkhout.

91 Here we need to make an important assumption, namely that natural energy resources can be substituted by human-made resources. So the loss of exhaustible energy resources should be compensated by technological progress or other energy resources (see Pearce and Turner: 1990); see also Skagen-Ekeli (see 2004) on this issue.

from a reality. Technological impediments as well as serious proliferation concerns – due to the production of ^{233}U – are the challenges posed to a thorium fuel cycle. The adopting of thorium as a realistic alternative will require decades of R&D investments (see WNA: 2008a) and additional nuclear facilities will have to be built once this fuel cycle is finally ready to be used at industrial level. To conclude, by the time thorium becomes technologically applicable and economically viable, we may well be able to argue that it enhances resource durability.

Table II: The presented nuclear fuel cycle values and their definitions as understood in this paper

Value	Explanation
Environmental friendliness	Preserving the status of nature Leaving it no worse than we found it
Public safety	Protecting people from the accidental and *unintentional* harmful effects of ionizing radiation
Security	Protecting people from the *intentional* harmful effects of ionizing radiation arising from sabotage or proliferation
Resource durability	The availability of natural resources for the future or the providing of an equivalent alternative for the same function
Economic viability	Embarking on a new technology at a certain stage and ensuring its continuation over the course of time
Technological applicability	The scientific feasibility of a certain technology as well as its industrial availability

4.4. Intergenerational assessment of fuel cycles

In the preceding section, we introduced six central values that contribute to sustainable development (see Table II). We shall continue in this section by looking at different nuclear power production processes in terms of fuel cycles. If we assert that the fuel cycle choice should be evaluated on the basis of the stipulated values and the impact that each fuel cycle has on different generations, we can *operationalize* the central values by relating them to their burdens and benefits for different generations. The emerging operationalized values are what we call the *value criteria* for an intergenerational assessment of fuel cycles.

The nuclear fuel cycle consists of several major elements starting with the mined uranium ore and continuing with irradiation in a reactor (front end phase) and the optional spent nuclear fuel treatment required after irradiation before finally finishing with the disposal of waste (back end phase); see Figure 9. Uranium is currently deployed in most operational energy reactors or Light Water Reactors (LWR). Naturally occurring uranium contains different constituents (isotopes) in the form of the minor fissile ^{235}U that is present in less than 1% and the major ^{238}U isotopes (>99%). The former isotope is *fissile* meaning that neutrons in a LWR can fission it; fissioning *enriched* ^{235}U (an enhanced concentration of this fissile isotope) results in energy production.[92] The major uranium isotope (^{238}U) is not fissile, but as it is a *fertile* nuclide which captures neutrons and produces other isotopes some of which can be fissile such as ^{239}Pu. Plutonium-239 provides a substantial amount of energy in a typical LWR core towards the end of the operating cycle of the fuel element.[93]

In a once-through fuel cycle, *enriched* uranium (with increased ^{235}U concentration) will be irradiated once in a reactor and the spent fuel (SF) from the reactor will then be disposed of as waste. Spent fuel contains short-lived and long-lived radioactive materials; the latter, in particular uranium, plutonium and other actinides, dominate the period of radiotoxicity demanding long-term isolation from the biosphere for up to 1 million years, a period commonly known as the waste life-time.[94]

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92 An exception to this rule is the Canadian deuterium uranium reactors or, the CANDU reactors. This type of reactor uses heavy water as a moderator and light water as a coolant; this combination makes it possible to use natural uranium (instead of enriched uranium) as fuel (see Wilson: 1999, 5).

93 It should be mentioned that fissioning of not enriched ^{235}U also results in energy production; enrichment is needed to sustain the chain reaction (when using H_2O or graphite as a moderator). It is further important to distinguish between fissile and fissionable nuclides. A fissile isotope can be fissioned by slow neutrons in a LWR. The main uranium isotope (^{238}U) is a fertile material (but not fissile in a thermal spectrum) and but it can be fissioned in a fast reactor (see Duderstadt and Hamilton: 1976, 67).

94 The 1 million year time period was established by a US National Academy of Science report(see NRC: 1995) which suggested that for Yucca Mountain, the design of the repository should be capable of handling the analyzed period of peak dose which occurs at roughly 750,000 years. Also the Environmental Protection Agency follows this period in its final rule for setting radiation protection standards for the Yucca Mountains (see EPA: 2008). Other

The once-through fuel cycle currently adhered to in the United States is the first fuel cycle we will discuss in this section. We include a variant of the once through cycle in the context of giving future generations an option to deal with whether the spent nuclear fuel is a waste or a resource. The second major option is to adopt *reprocessing*, involving the extraction of fissile material from spent fuel which can then be reused as fuel. Reprocessing therefore prolongs the supply of uranium. Plutonium and uranium can be extracted from the spent fuel and recycled in LWRs as mixed oxide fuel (MOX) which is what is currently practiced in France. The use of MOX extends the supply of uranium by approximately 15 % and reprocessed waste in a vitrified form reduces the volume of high-level nuclear waste that needs to be disposed of. The third alternative fuel cycle option is to introduce Fast Reactors (FR) in combination with the reprocessing method, which enables us to *consume* or eliminate radioactive constituents. By using fast reactors in the "burn" mode, some long-lived actinides can be fissioned (consumed) while others are transmuted into isotopes that have shorter waste life-times while also diminishing long-term radiotoxicity of waste.

The same fast reactors could also be used in *breeder* configurations (in combination with recycling) to produce (or breed) more fuel during operation. Breeders need an initial start up core of plutonium or enriched uranium. This core is surrounded by a "blanket" of fuel assemblies containing ^{238}U which is used to capture neutrons producing ^{239}Pu.[95] This plutonium isotope is then reprocessed and recycled in the core. Breeding ratios as high as 1.3 are possible which means that the reactor can produce 30% more fuel than it consumes thus extending uranium supplies for power production for thousands of years by using multiple reprocessing and recycling steps. The breeder fuel cycle is the last alternative that will be discussed.

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nations may choose different lengths of time for their periods of concern all depending on the design of their repositories. It is also noteworthy that one million years is not based on the radiotoxicity of spent fuel. This radiotoxicity decays after approximately 200,000 years to the levels below the radiotoxicity of natural uranium, which means that peak doses occurring after this period have less impact in terms of radiotoxicity; therefore the waste life-time of spent fuel is determined to be 200,000 years, compared to the uranium ore line (see Kloosterman and Li: 1995, 5).

95 Generation IV reactors are designed with homogenized cores in order tor educe the proliferation risk.

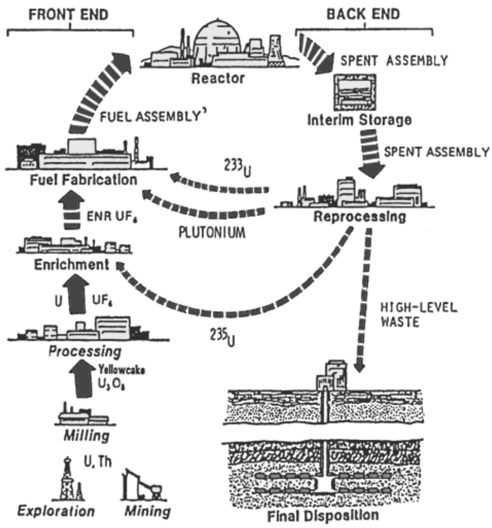

Figure 9: Nuclear Fuel Cycle, from uranium ore to final disposal
Source: Website of the US National Regulatory Commission (NRC)

In the following subsections all these fuel cycles will be assessed on the basis of the value criteria to be introduced. Precisely how the value criteria will change is mapped out in the burden/benefit charts where the once-through fuel cycle will serve as the default situation. An integral analysis of these fuel cycles is presented in the following section.

4.4.1. Current practice: the once-through cycle

In a once-through fuel cycle enriched uranium is irradiated once in an LWR and spent fuel is kept in interim storage above ground for a few decades, pending final disposal in deep geological repositories.
Figure 10 provides a chart of the operationalization of the values or value criteria in which the burdens and benefits emanating from the production process are specified and related to the different generations that experience them.

In our analysis we make the explicit assumption that nuclear power will remain in use for a period of one hundred years; we call this period the *Period in which the Activity Lasts* (PAL). Some concerns continue for the duration of the PAL, for instance the safety concerns surrounding the front-end of the once-through fuel cycle related to the mining, milling, enrichment and fuel fabrication processes. Other concerns like, for example, the power plant's decommissioning and its safety and security considerations outlive the activity period. Finally, with some activities, the period of concern starts at a later stage and ends at a time that is independent of the PAL. For instance, the spent fuel derived from a once-through fuel cycle must be disposed of underground a few decades after the operation has started and concerns will last for the duration of its radiotoxicity or its waste life-time (1 million years).

The lengths of the ellipses given in
Figure 10 are not intended to correspond to the actual durations of these periods; they merely serve to indicate the relative difference. A horizontal black arrow, like for instance the one given in front of the public safety concerns linked to final disposal, depicts a projection of these considerations extending into the future and far beyond the time frame of the charts. In our figures we can distinguish between two types of ellipses: the light-grey ones and the dark-grey ones representing all the respective burdens and benefits.

We also distinguish between generation 1 (Gen. 1) and generations 2 and beyond (Gen. 2-n). On the basis of the most recent estimations, there will be sufficient reasonably priced uranium available for at least another 100 years for the purposes of once-through fuel cycle usage (see IAEA-NEA: 2008). The benefits of uranium deployment for Gen. 1 are illustrated by means of the dark-grey ellipse given in front of the resource durability indications. We immediately see here the problem of fairness that arises between Gen. 1 that benefits from the energy production while bearing some of the burdens and future generations that will mainly bear the safety and security burdens accompanying long-term nuclear waste disposal.
Figure 10 gives a graphical illustration of the temporal behavior of burdens and benefits on current and future generations.

There is a further interesting trade-off regarding the retrievability of spent fuel. Retrievable spent fuel is designed to give future generations an equal opportunity to benefit from the potential energy advantages underlying fissionable materials in spent fuel,[96] but at the same it gives rise to additional safety and security concerns during the same period. In other words, in order to respect a next generation's freedom of action to use spent fuel for energy

[96] Besides the matter of future economic value, retrievability has other purposes too; the two most important ones are 1) to be able to take remedial action if the repository does not perform as expected and 2) to give future generations the possibility to render waste harmless with new technology. See in this connection the section entitled "Equal opportunity: retrievable disposal" in 'A Challenge to geological disposal'(see Taebi: Unpublished).

purposes, we need to impose more safety and security burdens on that generation.[97]

4.4.2. Once-through cycle with direct underground storage/disposal

This is a new option being considered for the US by researchers at Massachusetts Institute of Technology (MIT)[98] to address the dilemma of the long term storage of spent fuel at many reactor locations or in similarly vulnerable above ground open central storage sites. In this scenario, spent fuel, after 5 years of storage in spent fuel pools, will be shipped and stored underground in facilities that could be used both for storage and ultimately for disposal purposes. This fuel cycle is a derivative of the first fuel cycle in that instead of the repository closing when full it remains open as a long-term storage facility so that the next generation can determine whether the resources preserved in the form of spent fuel are used for energy production or not (see Forsberg and Dole: 2008). In this way, the next generation's freedom of action is simultaneously safeguarded. The key to this option lies in assuring that the spent fuel is retrievable which, in turn, affects the design of the repository.

This cycle considerably reduces security concerns for Gen. 1 as SF is stored underground in ventilated tunnels. The US Nuclear Waste Technology Review Board has conducted thermal analysis showing that with long term ventilation such a system is feasible (see NWTRB: 2008). With this proposal the facility would be designed as a repository but initially licensed as an underground storage place. Should it be decided that the spent fuel is indeed waste, then the disposal licensing process with the added data collected during the storage period would provide confidence in the models used to design the repository for disposal purposes. Should the site prove unsuitable for disposal, the spent fuel will be retrieved and disposed of elsewhere. However during this time, the spent fuel will have been securely stored. This option does, however, increase the transport risks because radioactive (and hot) spent fuel thus has to be transported to the storage/disposal facility. If Gen. 2 decides to leave spent fuel (because it has no economic value) the very long-term safety concerns will remain unchanged. The alterations with respect to the *conventional* once-through

97 Lars Löfquist deals in his PhD dissertation with this trade-off (see Löfquist: 2008, 254-257).

98 This is one of the fuel cycles discussed in the forthcoming MIT study on the future of nuclear power in the United States, to which this paper is a contribution; one of the authors of this paper (Kadak) is a co-editor of this study.

fuel cycle are indicated by means of the red arrows in Figure 11 pointing up and down to denote the increasing and decreasing of the burdens and benefits.

4.4.3. Transmutation of actinides: LWR-FR

In some countries (such as France and Great Britain), spent fuel is currently recycled in order to extract uranium and plutonium for reuse in LWRs and to reduce the waste life-time (see NEA-OECD: 1996). It is, however, a method that has received widespread criticism because of the proliferation risks attached to separating plutonium. A future possibility, to retain the advantages of recycling but to avoid security burdens, would be to develop an integrated fuel cycle that extracts uranium as fuel and *consumes* plutonium, together with minor actinides, in fast reactors[99]. This kind of fuel cycle *Partitions & Transmutes* (P&T) fission products and actinides (see NEA-OECD: 2006, 23). Before this type of fuel cycle can be deployed at industrial level it needs to be technologically refined and it must be economically viable (see NRC: 1996; IAEA: 2004). By using multiple reprocessing and recycling this approach would be capable of substantially reducing the long-term concerns for Gen. 2-n, as the long-lived actinides will be fissioned (or transmuted) in fast reactors.[100] However, the additional economic, safety and security burdens attached to developing the required technology and building the necessary extra facilities (i.e. reprocessing facilities and fast reactors) will mainly be borne by Gen. 1.

In our further analysis we refer to this fuel cycle as the LWR-FR (transmuter). In Figure 12 P&T approach is assessed and the differences when compared to the once-through cycle are highlighted in red.

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99 An alternative to fast reactors for the purposes of P&T is an Accelerator Driven System that is also capable of fissioning actinides (see NEA-OECD: 2002).

100 A Canadian study on nuclear waste management explicitly considers Partitioning and Transmutation (P&T) because of the possibility to reduce waste radiotoxicity and volume, but rejects it as a Canadian option for technical and economic reasons (see NWMO: 2005b, Ch.5). More will be said about this study in subsection 5.4. Another Swedish report reaches more or less the same conclusion where Sweden is concerned and states that P&T as a future possibility definitely encourages retrievable disposal so that future generations will have the chance to eliminate or further treat the waste (see KASAM: 2005a, Sec.III).

4.4.4. LWR-FR, the breeder configuration

The last fuel cycle to be considered is one in which fast reactors are used in the breeder configuration to breed (or make) more fuel than they consume. As breeders are capable of using uranium much more efficiently than LWRs, the period of resource durability and the potential benefits of resources[101] rise to thousands of years (see IAEA-NEA: 2008). On the other hand, these future benefits bring about more current burdens in terms of the technological challenges attached to developing such fuel cycles, the economic burdens arising from the additional investments that need to be made in R&D and the building of additional facilities as well as all the further safety and security concerns. To conclude, Gen. 1 will ultimately bear significant safety, security and economic burdens while facilitating adequate energy supplies and minimizing the long-term waste problems for future generations. In
Figure 13 this breeder fuel cycle is assessed and compared with the once-through fuel cycle. The dark-grey ellipse outlined in red indicates the long-terms benefits of resource durability.

The type of concerns behind the transmutation approach and this type of fuel cycle (the breeders) are similar, but all these concerns increase when fast reactors enter into the breeder configuration formula. There are two reasons for this: 1) the breeder fuel cycle system is based on the notion that eventually all the LWRs will be phased out and the whole energy production process will be based on breeders (and on the multiple recycling of waste), which will involve building more fast reactors and, thus, creating more economic burdens for this generation and 2) this fuel cycle is primarily based on plutonium, which gives rise to further security concerns.

In this section we assessed the current practice of nuclear power deployment and the three future alternatives in accordance with the criteria of intergenerational equity. The following section merges these comparisons and presents them in an integrated analysis.

4.5. Comparing fuel cycles

So far we have introduced a set of central values and we have formulated value criteria for an intergenerational assessment of fuel cycles in terms of their

101 If this benefit is to be enjoyed by future generations, we need to abandon the assumption that nuclear fission deployment will continue for 100 years. It seems fair, however, to make allowances for this as a *potential* future benefit.

impacts on different generations. The serious challenge now lies in how to compare these alternatives in accordance with the proposed value criteria. We can distinguish here between two approaches to this analysis: the aggregate and the disaggregate methods.

The aggregate method is based on synthesizing the scores of each alternative and on drawing together the numerous and diverse criteria in order to aggregate – or add together – all the individual scores to make up one overall score. The best known aggregate method is cost-benefit-analysis, which expresses (as much as possible) the values in terms of monetary values. Such approaches have attracted criticism for a couple of reasons. Firstly, they ignore the fact that the values involved are *incommensurable* or not directly comparable; (e.g. environmental values versus economic values). Secondly, different stakeholders may prioritize and trade off the relevant values in different ways, even if they uphold the same basic values.

The disaggregate approach separately presents the impacts for each alternative. It uses a method introduced by policy analysts to compare policy alternatives which is known as the *scorecard* method.[102] A scorecard enables one to rank different alternatives according to a single criterion (and its impact on the relevant alternatives). In that way considerations concerning ways of ranking and prioritizing the criteria become central to the decision process itself (see Walker: 2000). For this overall ranking which will eventually culminate in the final choice of a certain alternative the scorecard is not, however, an appropriate instrument as it only facilitates ranking for a single criterion (see Franssen: 2005). The scorecard could however assist us to clarify trade-offs when choosing an alternative; more will be said about this in Subsection 5.3.

The creation of a scorecard begins with the entering of the alternatives and their impacts on an *impact table*. Each column in such a table represents one alternative and each row a certain criterion's impacts on all the alternatives.[103] An entire column is thus a single alternative's score for different criteria and an entire row denotes the impacts that one single criterion has on all the

102 Scorecards first appeared in 1973 in a study that the Rand Corporation conducted for the US Department of Transportation (see Chesler and Goeller: 1973) and shortly after in a later RAND study for the Dutch Ministry of Transport, Public Works and Water Management (see Goeller et al.: 1977). Some, such as Hammond et al. in his book "Smart Choices: a Practical guide to Making Better Decisions" refer to the same methodology as that given in the consequence table (see Hammond et al.: 1999).

103 The scorecard proposed by many scholars gives the impacts vertically and the alternatives horizontally, but the basic idea remains the same.

alternatives. Impact tables often contain quantitative and qualitative information regarding the scores of different criteria for different alternatives. Since it might be difficult for the decision maker to decipher the patterns and trade-offs in such a detailed kind of table, a schematic representation of the impact table is proposed in the form of colored cells in order to further clarify the trade-offs. That is what is known as the scorecard.

4.5.1. The scorecard and the four fuel cycles

If we merge the alternatives into an impact table, we can evaluate the four cycles according to the proposed value criteria (expressed in terms of impacts); the alternatives are compared solely on the basis of a qualitative assessment of the single value criteria. High, Medium and Low are chosen as the ranking designations. The scorecard is completed by adding the three traffic light colors to denote the ranking of the alternatives according to one single value criterion. Red stands for the most unfavorable option, green for the most favorable and amber indicates that either there is barely a difference between the alternatives, or that the consequences are intermediate[104]; see in this connection the scorecard given in Appendix 1. When assessing burdens, high impacts are unfavorable and are thus colored red while amber and green are used consecutively. When benefits are rated (such as the benefits of energy production) high impacts are colored green.

To emphasize the intergenerational considerations (as shown in the burden/benefit charts of the last section), the demonstrated scorecard distinguishes between generation 1 and the subsequent generations. The two columns given under each alternative in the scorecard indicate Gen. 1 and Gen. 2-n. In order to make this schematic presentation convenient to use, shading is added to highlight the time dimension. When choosing one alternative, two types of comparisons can be drawn: 1) the impacts for the first generations indicated by the *brightly* colored cells and 2) the impacts on future generations, indicated by the *shaded* cells. When two different alternatives score *the best* for different generations; the conflict arising from choosing the alternative should be regarded as a matter of intergenerational equity. While this graphical

[104] Using the color green could be misleading as we are talking about a form of energy production. In choosing these colors we follow the relevant literature in policy analysis and comparable studies. The colors as applied in this analysis merely facilitate a comparison in a row without making any inference to other forms of energy.

characterization may seem complex, studying the scorecard gives the decision maker a general appreciation of all the trade-offs between and within generations that need to be made.

4.5.2. Choosing an alternative

Different alternatives score differently for different value criteria and that gives rise to conflict; trade-offs between the criteria seem inevitable. Hammond et al. propose two ways of facilitating the making of trade-offs between the various alternatives: the Even Swap method and the method of eliminating the dominated alternatives (see Hammond, Keeney, and Raiffa: 1999, Ch.6). The Even Swap method is based on ignoring a criterion when the alternatives are equally rated. Forcing us to think about one criterion in relation to other criteria renders alternatives equivalent to a given criterion while reducing the number of decisive criteria. The second method is to eliminate the dominated alternatives: i.e. when alternative A scores better than B on some objectives and no worse on all the other objectives, B is said to be dominated (see Hammond, Keeney, and Raiffa: 1999, 85).

The Even Swap method presupposes certain commensurability between the criteria, implying that they could be translated into each other which is what renders this method unfit for our purposes. However, the basic idea behind this method – if we ignore the irrelevant criteria – could help us to eliminate value criteria that do not discriminate between alternatives. For instance, under the central value of 'economic viability', the value criterion 'safety measures costs until the end of the retrievable period' is not different in the four alternatives and could therefore be ignored in the decision-making process. It is however important not to remove this criterion from the list because a future alternative fuel cycle could give rise to changing impacts for this value criterion. In our comparison, no alternative scores worse than the others on all the value criteria and so no alternative is dominated; see also the scorecard given in Appendix 1. Even though it is quite clear that the fourth alternative (breeder) scores worse on almost all the criteria, it remains the best option when we consider the central value of 'resource durability'. This alternative fuel cycle is based on applying breeder reactors that are capable of using the more abundant isotope of uranium (^{238}U) and of using uranium much more efficiently.

4.5.3. Clarifying trade-offs when choosing an alternative

As numerous incommensurable value criteria are still involved, the scorecard is not helpful for choosing the final fuel cycle alternative based on numerical ranking. However it can help the decision maker to understand a certain choice by providing information about the implicit trade-offs that this choice involves. In other words, the scorecard clarifies *the societal expense* of any choices made and the burdens that will be incurred upon different generations.

Let us illustrate this by giving an example. Suppose that the decision maker decides to continue the current practice (Alt. 1). Based on the central values of 'public safety'[105] and 'security', this alternative scores relatively high; the short-term safety burdens of spent fuel storage and the long-term safety burdens of final disposal for Gen. 2 and beyond are then implicitly accepted as a consequence of this choice. As this alternative basically involves applying existing technology (with many fewer technological challenges) it scores well for 'technological applicability' when compared with other alternatives. For this and other reasons, the alternative gives rise to less economic concern. Alt. 1 furthermore scores badly in terms of 'resource durability', as the less abundant isotope of uranium (^{235}U) is used once only in a reactor as fuel; reasonably priced uranium is available for this fuel cycle for no longer than 100 years.

What is lacking in this scorecard is a priority ranking of the values collected on this table. The priority ranking will largely depend on the value system of the decision maker and the society of the time. Will the decision maker value resource preservation more than cost or security? This is why such a scorecard can only highlight issues.

Let us also briefly consider a choice for Alt. 3 (the transmuter option) that is designed to eliminate as much as possible (long-lived) radioactive material in spent fuel. This alternative is based on utilizing fast reactors in transmuter configurations and reprocessing. The latter brings about greater safety and security concerns as reprocessing involves the separating of plutonium. The fast reactors (and their fuels) also need to be further developed, which imposes technological challenges as well as economic burdens on the present generation. An extensive discussion on the scorecard and the ranking of the alternatives based on single value criteria is presented in Appendix 1.

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105 It should not be forgotten that for ease of analysis 'public safety' is merged with 'environmental friendliness'.

While the ratings for each of the categories of the table given in Appendix 1 may be subject to some disagreement, the process for establishing the color coding should be the subject of expert solicitation and consensus in a deliberative process. Such a process can be used to clarify positions on key questions which should assist the decision maker and enhance the transparency of the decision. By studying the table one can develop an appreciation of the generational benefits and burdens when it comes to finally assessing the best course of action based on intergenerational equity principles.

4.5.4. The Canadian example

Before moving on to the concluding remarks of this paper, let us pause for a moment to discuss a case in which values have been incorporated in decision-making on nuclear energy related issues. The Canadian Nuclear Waste Management Organization launched a mission to engage Canadians in debates and decision making on the future of Canada's spent fuel. In dialogues with thousands of people the NWMO first sought to understand the values of Canadians, from which they drew their objectives, e.g. public health and safety, environmental integrity, security and economic viability (see NWMO: 2005b). Even though the NWMO acknowledges that some objectives are competing and that trade-offs are inevitable, common ground was found in two major areas, i.e. "the approach must be safe and secure – for people, communities and the environment; and it must be fair – both to current and future generations" (see NWMO: 2005a, 3). Geological disposal is believed to perform well against value-driven objectives in the very long term, due to the combination of engineered and natural barriers, despite the uncertainties involved in this time period.

We discuss this example for two reasons. Firstly, because this analysis and the method presented here share some similarities in that we both take values as the foundation of our comparison; the values presented and the objectives determined in NWMO's study coincide to a high degree with our values that are mainly drawn from the literature. The second reason for mentioning this example is because in its underlying analysis it emphasizes the fact that there are very many complicated considerations in actual decision making that have not even been addressed in our analysis. The solution proposed by NWMO is to have an Adaptive Phase Management, which is not only a technical method but also a management system capable of moving towards retrievable geological disposal.[106]

Like in the NWMO study we take sustainable development to be the main underlying notion and acknowledge the relevance of intergenerational equity in discussions related to nuclear power. Our analyses are, however, divergent from the point of view of how the latter is addressed. Intergenerational equity is referred to as one of the important objectives that needs to be taken into consideration by the NWMO while to our understanding of this notion it is the framework that enables us to address the intergenerational conflicts that arise when choosing a certain alternative.[107]

4.6. Conclusion

In this paper we have presented a method that provides insight into future fuel cycle alternatives by clarifying the complexity of choosing an appropriate fuel cycle. A set of central values is derived from the notion of sustainable development. By operationalizing these values and mapping out the impacts, value criteria are introduced for the intergenerational assessment of fuel cycles according to the distribution of burdens and benefits between generations. The current nuclear power deployment practices, together with three future fuel cycle scenarios cycles were subsequently assessed according to these value criteria.

The key questions that ultimately need to be answered prior to finally opting for a particular alternative are these. Should Gen. 1 accept significant safety, security and economic burdens for the benefit of future generations, thus in that way facilitating extended energy supplies (as proposed in Alt. 4) or minimizing the long-term waste problems (as outlined in Alt. 3)?

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106 We are not reflecting on whether this is the right conclusion to reach. We discuss this case merely because of the fact that this study – which appears to be quite influential in Canada – takes values as the basis of its analysis. The problem of ranking values – as discussed in this section – is one that has also been acknowledged and addressed here. Also the progress in technology and its influence on policy is something that the NWMO takes into considerations; we referred to this matter in discussing the notion of 'technological applicability'.

107 Another perhaps more obvious difference is that we are comparing future fuel cycles while the Canadian study focuses on future waste management options. It should further be noted that the NWMO report is focused on how to find common ground among public for 'Choosing a Way Forward', as its name suggests, while this paper merely focuses on presenting a method for understanding the intergenerational dilemmas and trade-offs in choosing a fuel cycle.

If the current analysis of the long term risk of a nuclear waste repository is correct to conclude that the risks and burdens of geological repositories to future generations are very low,[108] how can one justify placing a burden on the present generation to minimize future risk further by adopting reprocessing and transmutation? On the other hand, the question of to what extent the transferring of risk to the very distant future is acceptable and how and under what conditions this generation could consent to risks being imposed on future (still to be born) people need to be addressed.[109] These are not easy questions to answer and we do not claim that our method provides all the answers but it does illuminate the choices that need to be made and raise these questions and dilemmas in an informed manner. What this paper challenges is the notion that intergenerational equity simply means disposing of nuclear wastes in this generation since the burdens and benefits need to be carefully balanced before such a decision is made.

Quite how these questions should be dealt with and how the proposed value criteria that will lead to the choosing of one fuel cycle will be ranked, are matters that extend beyond the scope of this paper. We have merely compared four fuel cycle alternatives on the basis of the single values that we derived from the overarching value of sustainability. We have also clarified the implicit trade-offs that decision makers make when they opt for a certain alternative. When choosing a fuel cycle, what societal costs and burdens are accepted for each generation and how are these factors justified?

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108 The Environmental Protection Agency has set radiation standards that require radiation protection from disposed of nuclear waste for 1 million years (see EPA: 2008). In 2008, The US Department of Energy (DOE) filed a license application for the Yucca Mountain Repository with the US Nuclear Regulatory Commission in June 2008 (see DOE: 2008). It maintained that it could comply with the EPA's radiation protection standards for the desired period. See for a historical background, Samuel Walker's 'The Road to Yucca Mountain' (see Walker: 2009, Ch.8).

109 Shrader-Frechette (see 2000) refers to this problem as the problem of "proxy consent".

the Risk Analysis' Area Editor Warner North and two anonymous reviewers for their useful comments.

Appendix 1: Burden-benefit charts

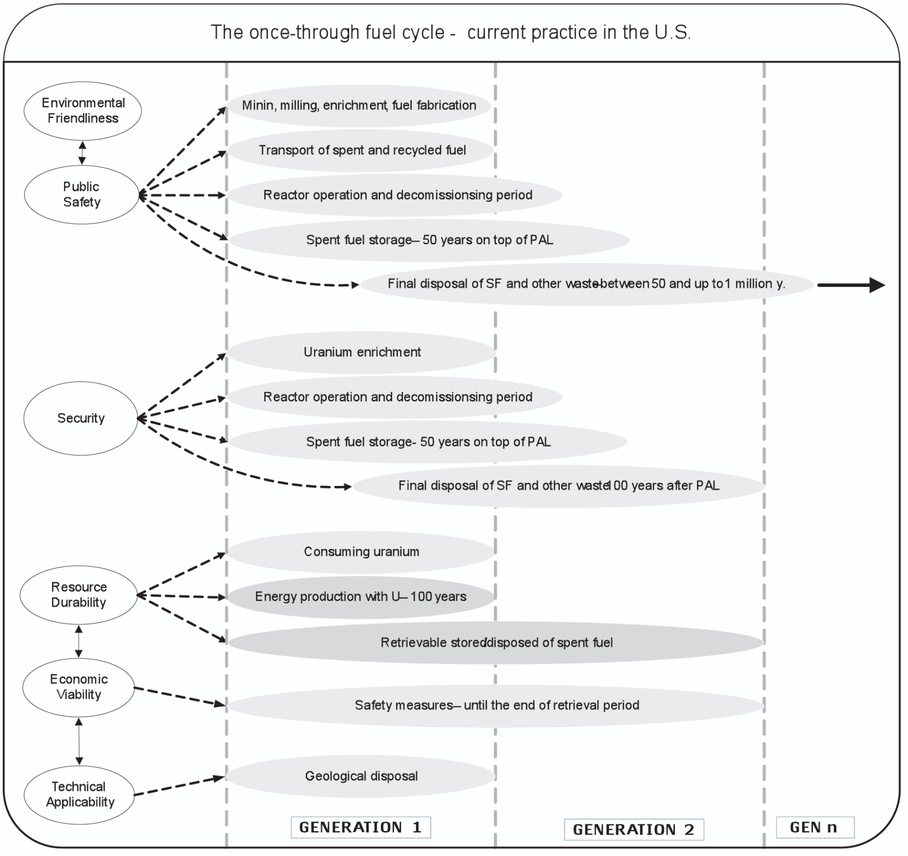

Figure 10: Relating moral values to concrete consequences and to the associated *Period in which the Activity Lasts* (PAL) as seen in a once-through fuel cycle or the current practice in the US. The light and dark gray ellipses represent the respective burdens and benefits. The horizontal black arrow depicts a projection of a certain considerations extending into the future and far beyond the time frame of the charts.

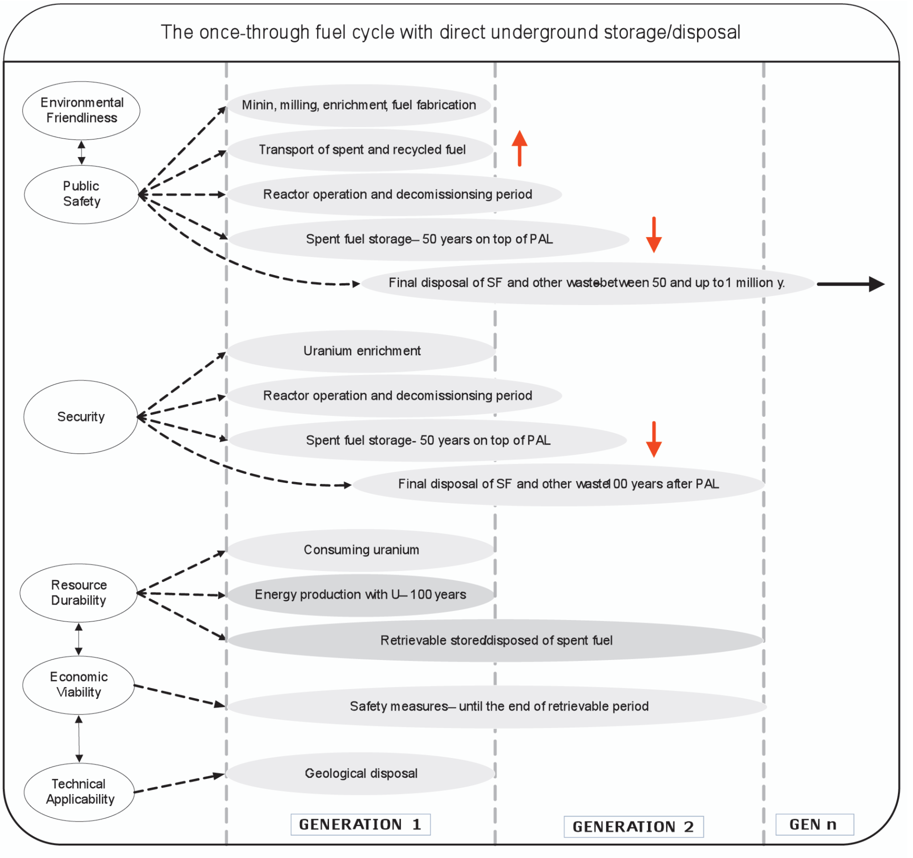

Figure 11: Relating moral values to concrete consequences on the basis of a once-through fuel cycle with direct disposal in storage/disposal facilities. The elements indicated in red represent the divergences from current practice in the US as illustrated in Figure 10. The horizontal black arrow depicts a projection of a certain considerations extending into the future and far beyond the time frame of the charts. The alterations with respect to the *conventional* once-through fuel cycle (as illustrated in Figure 10) are indicated by means of red arrows pointing up and down to denote the respective increase and decrease in the burdens and benefits.

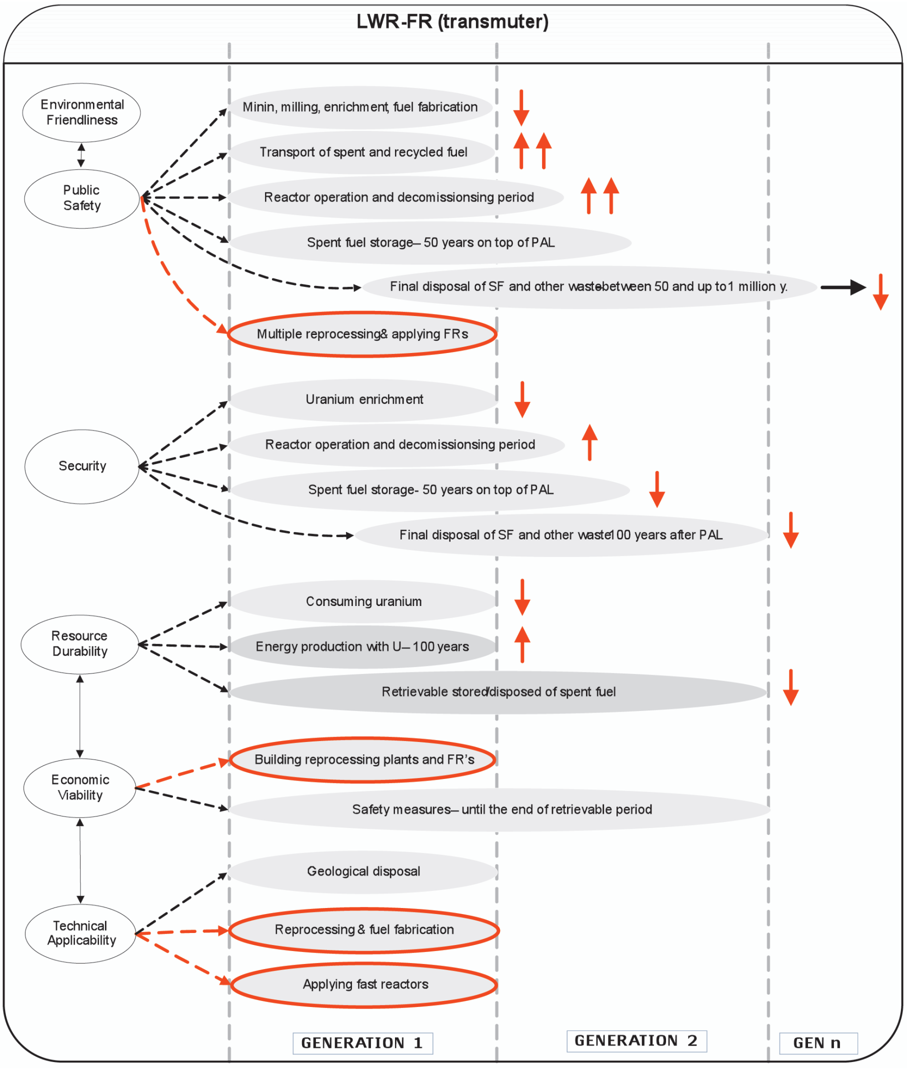

Figure 12: Relating moral values to concrete consequences in line with the transmutation approach. The elements indicated in red represent the divergence from current practice in the US as illustrated in Figure 10. The horizontal black arrow depicts a projection of a certain considerations extending into the future and far beyond the time frame of the charts. The alterations with respect to the *conventional* once-through fuel cycle (as illustrated in Figure 10) are indicated by means of red arrows pointing up and down to denote the respective increase and decrease in the burdens and benefits.

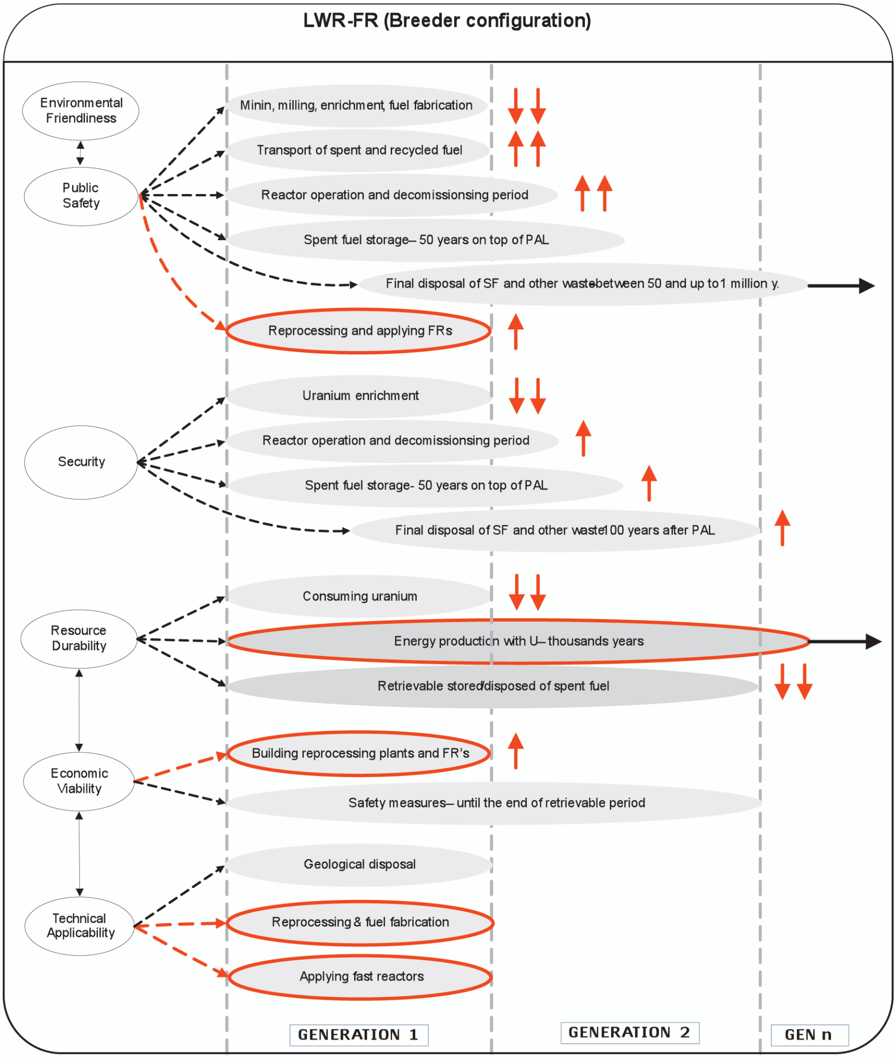

Figure 13: Relating moral values to concrete consequences and to the LWR-FR in the breeder configuration. The elements indicated in red represent the divergences from current practice in the US as illustrated in Figure 10. The horizontal black arrows depict a projection of a certain considerations extending into the future and far beyond the time frame of the charts. The alterations with respect to the *conventional* once-through fuel cycle (as illustrated in Figure 10) are indicated by means of red arrows pointing up and down to denote the respective increase and decrease in the burdens and benefits.

Appendix 2: Scorecard and explanation of impacts and rankings

IMPACTS	ALTERNATIVES							
	Current Practice		Direct Storage		Trnasmuter		LWR-FR (Breeder)	
	Gen 1	Gen 2-n	Gen 1	Gen 2-n	Gen 1	Gen 2-n	Gen 1	Gen 2-n
Environmental Friendliness/Public Safety								
Mining, milling, enrichment, fuel fabrication	High		High		Medium		Low	
Transport of spent and recycled fuel	Low		Medium		High		High	
Reactor operation and decommissioning period	Low	Low	Low	Low	High	High	High	High
Spent fuel storage	High	High	Low	Low	High	High	High	High
Final disposal of spent fuel and other waste	Indifferent	High	Indifferent	High	Indifferent	Low	Indifferent	High
Reprocessing – applying fast reactors	×		×		Indifferent		Indifferent	
Security								
Uranium enrichment	High		High		Medium		Low	
Reactor operation and decommissioning period	Low	Low	Low	Low	High	High	High	High
Spent fuel storage	Medium	Medium	Low	Low	Low	Low	High	High
Final disposal of spent fuel and other waste	Medium	Medium	Medium	Medium	Low	Low	High	High
Reprocessing – applying fast reactors	×		×		Medium		High	
Resourse Durability								
Consuming uranium	High		High		Medium		Low	
Energy production with uranium (benefit)	Low	Low	Low	Low	Medium	Medium	High	High
Retrievable stored/ disposed of spent fuel (benefit)	High	High	High	High	Medium	Medium	Low	Low
Economic Viability								
Safety measures costs until the end of retrieval	Indifferent	Indifferent	Indifferent	Indifferent	Indifferent	Indifferent	Indifferent	Indifferent
Building reprocessing plants and fast reactors	×		×		medium		High	
Technological Applicability								
Geological disposal	Indifferent		Indifferent		Indifferent		Indifferent	
Applying reprocessing and fuel fabrication	×		×		High		High	
Applying fast reactors	×		×		High		High	

Legend

Least Favorable

Intermediate/Indifferent

Most Favorable

Environmental friendliness/public safety

Mining, milling, enrichment, fuel fabrication

The two first alternatives are based on enriching uranium and they involve the highest risk. Breeders require plutonium or enriched uranium for the startup but in lower quantities than a typical LWR that continuously uses enriched uranium as fuel; a breeder fuel cycle then involves fewer steps that carry risks which is why we have assigned the lowest risk to Alt. 4. The transmuter alternative (3) is based on transmuting the actinides in SF that come out of a LWR; Alt. 3 then involves less risk than the first two and more than the breeder alternative.

Transport of spent and recycled fuel

In Alt. 1 there is no recycled fuel; spent fuel is transported to interim storage places (sometimes on-site storage facilities) and eventually to disposal facilities. In Alt. 2 there is no recycling either; however the transport risk is higher, as hot and more radioactive spent fuel that has just come out of the reactor is immediately transported to the underground storage facilities. These concerns are the highest for the two last alternatives, since recycling involves more transportation in the form of recycled fuel fabricating and returning to the reactor for irradiation.

Reactor operation and decommissioning period

There is a difference between the first two alternatives that solely use LWR and the last two that are based on FRs. The latter are generally sodium-cooled reactors, and those are relatively more difficult to decommission as the sodium needs to be disposed of and that requires storage in a cover gas shielding.

Spent fuel storage

In the last two alternatives that use sodium-cooled FRs it is difficult to store spent fuel, as we need to manage sodium which needs to be stored in a cover gas shielding. Alt. 1 stores SF above-ground and that also involves high health risks. Once SF in Alt. 2 is put underground, the safety impacts will be much reduced.

Final disposal of spent fuel and other waste

With the first generation there is no difference between the concerns related to final disposal. The designation 'indifferent' for first generation waste should not however be read as 'no concerns', but the concerns remain fairly similar and cannot be ranked internally. The difference applies to generations 2 and beyond in which Alt. 3 scores the lowest, as long-lived actinides are transmuted. Three other alternatives contain long-lived actinides that require isolation from the atmosphere for a very long time.

Reprocessing and applying fast reactors

The two first alternatives solely use LWR and do not involve reprocessing; therefore there is no such risk involved. The two last alternatives involve some but more or less the same safety concerns.

Security

Uranium enrichment

There is no difference between the two first alternatives, as the need for enriched U is the same. In Alt. 3, less enriched U is needed, as the transmuting of actinides also generates energy; Alt.3 therefore involves medium security concerns. Alt. 4 requires the lowest amount of enriched uranium, as this fuel cycle is basically based on Pu.

The reactor operation and decommissioning period:

Alts. 1 & 2 are the most favorable ones, as there is no separated Pu involved during operation; LWR work either on enriched U or Mixed Oxide fuel (MOX). Fast reactors (Alts. 3 & 4) are the least favorable due to the presence of Pu.

Spent fuel storage

Alt. 4 is the least favorable option, as it involves Pu. The best option is Alt. 3 as it gets rid of all the actinides (including Pu). Alt. 2 involves less security risks as after irradiation the SF is immediately placed underground in physically difficult to reach places. Strictly speaking, there is a difference between the types of risk related to Alts. 2 & 3, but for the sake of clarity we regard these two options as equal. In Alt. 1 we keep Pu in interim storage and therefore it scores worse than Alts. 2 & 3.

Final disposal of spent fuel and other waste:

Alt. 3 is the best option as the actinides are removed and transmuted. The two first alternatives score lower as they use enriched uranium and make Pu in the cycle. The worst option is the last one, because it is a pure Pu cycle; in the waste stream of a breeder reactor, there are still Pu isotopes that need to be disposed of.

Reprocessing and applying fast reactors

The two first alternatives solely use LWR and do not involve reprocessing; therefore there is no such security risk involved. Alt. 4 is based on the reprocessing of Pu so that it can be reused a couple of times, all of which involves the highest security burdens. In Alt. 3 actinides (including Pu) are reprocessed several times and transmuted in FRs; however the security concerns are lower than with Alt. 4.

Resource durability

Consuming uranium (as a burden)

In the two first alternatives we use the highest amount of U as there is no recycling (reusing) involved. Alt. 3 scores lower in terms of burdens energy is produced when actinides are transmuted which therefore means that we use less U. Alt. 4 uses the lowest amount of U as it is a Pu cycle.

Energy production with uranium (as a benefit)

In terms of the benefits of energy production, applying breeders (Alt. 4) is the best option for this and the next generation, as that creates more fuel (Pu) that it consumes. Alt. 3 has fewer benefits as it still involves the use of U and the transmuting of actinides in SF. The first two alternatives have the lowest benefit as they consume most U. As we are indicating here benefits, 'high' (benefit) becomes the most favorable option and it is colored green etc.

Retrievable stored and disposed of spent fuel (as a benefit)

This row involves the potential benefits of retrieving spent fuel (or waste) and reusing fissile materials as *fresh* fuel. In the two first alternatives, there is still U and Pu present that could potentially be separated and reused. The transmuter cycle (Alt. 3) is based on the transmuting of actinides, but other actinides are produced during this process which are fissile and could also be used as fuel. Breeders use up all the Pu. As we are indicating here benefits, 'high' (benefit) is the most favorable option and it is colored green etc.

Economic viability

Safety measures costs until the end of the retrieval period

There is no difference between the four alternatives, as costs need to be made in order to shield and keep SF safe before the final disposal phase. Even when we immediately put SF underground (Alt. 2), certain costs need to be incurred for monitoring and keeping it retrievable. We assume that these costs will be equal for the four alternatives.

Building reprocessing plants and fast reactors

The two first alternatives solely use LWR and do not involve reprocessing; therefore there is no such risk involved. Alt. 3 involves building reprocessing plants and fast reactors, all of which is very costly. Alt. 4 is economically speaking the worst option as inevitably all LWRs will need to be replaced by FRs.

Technological applicability

Geological disposal

It is the same for all four alternatives. Even though the design criteria for different disposal facilities differ the technological challenges remain the same.

Applying reprocessing and fuel fabrication

The two first alternatives solely use LWR and do not involve reprocessing; therefore there is no such risk involved. In the case of the last two the technological challenges are great. Even though breeder fuel has already been generated (unlike actinide fuel for transmuters as in Alt. 3), there is still a technological challenge in Alt. 4 to fabricate fuel from recycled *breeder spent fuel*; most breeder fuel has not so far been recycled. The technological challenges for Alts. 3 & 4 are ranked equally, which means that they could have been denoted as 'indifferent'. By ranking them as 'high' we aim to emphasize that these are serious challenges that need to be dealt with.

Applying fast reactors

The two first alternatives solely use LWR and do not involve reprocessing; therefore there is no such challenge. The technological challenges attached to applying fast reactors in the last two alternatives remain the same. As with the last impact, the technological challenges for Alts. 3 & 4 are ranked equally, which means that we could have termed them 'indifferent'. By ranking them as 'high' we aim to emphasize that these are serious challenges that need to be dealt with.

5 The Morally Desirable Option for Nuclear Power Production[110]

Abstract
In this paper, the morally desirable option for nuclear power production is approached as safeguarding the interests of future generations. I argue that it is particularly the duty not to harm posterity that should be the leading incentive behind nuclear power production. Recent technology has made it possible to substantially reduce the waste life-time, but it gives rise to additional burdens for contemporaries. By addressing intergenerational conflict this paper examines the extent of the moral stringency of the no harm duty, seeking for situations in which future interest could guide us in choosing a certain technology. Three rejoinders to this reasoning are further presented.

Keywords: Nuclear power production, intergenerational justice, no harm principle

Due to the growing world-wide demand for energy and the mounting concerns about climate change emanating from fossil fuel combustion, nuclear power is becoming an increasingly attractive alternative. At the same time, the controversy surrounding the desirability of nuclear power continues. I shall argue that before reflecting on the desirability of nuclear power we first need to narrow down the focus on all the potential advantages and the impediments attached to this particular technology. In this paper I introduce *the desirable option* in nuclear power production which I shall approach from a moral point of view. In other words, if we intend to continue the nuclear power production, which technology is most morally desirable? The latter will be approached from the perspective of the duties of the contemporaries if we are to safeguard the interests of future generations.[111] There are two basic reasons for focusing on the

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110 An earlier draft of this paper was presented at the IEEE International Symposium on Technology and Society, which was held in Tempe (Arizona) in May 2009 (see Taebi: 2009).

111 Addressing temporal obligations that relate to nuclear power has already been discussed in previous literature, for instance by Richard and Val Routley (see 1981, 297) who argue that "[i]f we apply the same standards of morality to the future as we acknowledge for the present" the conclusion must inevitably be that the development of "nuclear energy on a large scale is a

interest of posterity when addressing the desirability issue: 1) in producing nuclear power we are creating an intergenerational problem; namely the benefits are predominantly for this generation and the burdens will, in part, be postponed and 2) we are in a temporally beneficiary position to visit costs on our descendants and can, therefore, easily exploit this position. In Section 1, I shall elaborate on this discussion.

The desirable option is therefore primarily perceived to be that of safeguarding the interests of future generations. It is argued that in choosing a technology there are at least two duties for the present generation, namely not to harm future people and to benefit them. These duties are presented in Section 2 as pluralists' conditional duties implying, in other words, that they could be overridden by more compelling duties. In this way, moral pluralism enables us to address the conflicts; the extent of the moral stringency of the formulated duties is examined in Section 3. That section also discusses the question of which of the two duties should be decisive if they cannot be simultaneously complied with. Section 4 briefly reviews the current nuclear power production methods and discusses existing and future production methods that would comply with the duties. The application of these technologies shifts the burdens and benefits for different generations, which can potentially be conflicting. Those intergenerational conflicts are then explored in Section 5; that section furthermore presents three challenges to the idea of imposing additional burdens on the present generation in order to curtail the harm incurred upon future generations. I conclude the paper with the findings in brief.

The assumption underlying the analysis in this paper is that nuclear power deployment will continue. This is not however a normative statement regarding the societal desirability of nuclear power. This assumption is merely made in order to be able to reflect on the different nuclear power productions methods in a restricted domain. In the discussion section (Section 5) I will return to this assumption and evaluate whether it paralyses the analysis.

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crime against the future". This paper sets out to compare the technological possibilities for nuclear power production from the perspective of temporal duties, thus avoiding the general desirability issue. Shrader-Frechette (see 1993, 1994) also discusses obligations to future generations related to nuclear waste disposal, arguing that we should avoid geological repositories as they cannot guarantee future safety.

5.1. Nuclear power production and temporal duties

There are two reasons why the production of nuclear power by this generation creates a problem of intergenerational justice. First of all, assuming that all generations (ours and those that follow) have access to the same finite resources (uranium) and that *we* might be able to asymmetrically influence *their* interest, "A Pure Intergenerational Problem", as argued by Gardiner (see 2003) will emerge. It would amount to an exacerbated form of a Prisoner's Dilemma, presented over generations.[112] In addition, the longevity of the remaining waste over the course of time adds a new intergenerational dimension to the issue since the waste will mainly have created benefits for this generation and burdens for coming generations. Another salient feature of this problem is that it could be "perfectly convenient" for the present generation to "exploit its temporal position" and to visit costs on future generations, all of which could give rise to "the problem of moral corruption" (see Gardiner: 2006a, 408).[113]

Elsewhere I have argued that the production of nuclear power creates certain moral obligations[114] for the present generation not to harm future people and to ensure future well-being, in terms of resource availability (see Taebi: Unpublished). These obligations emanate from the two intergenerational aspects of nuclear power production just mentioned: 1) the longevity of nuclear waste with possible harmful consequences for future people and 2) the depletion of uranium as a non-renewable resource. In line with these two aspects, I shall formulate here two important duties for the present generation if we are to adequately safeguard the interests of future generations, namely 1) the duty not to harm future people and 2) the duty to sustain future well-being, assuming that the availability of resources can guarantee the latter.

In the remainder of this paper I shall refer to these temporal duties as conditional duties, in view of the fact they might be overruled by more compelling duties. The non-rigid character of these conditional duties enables us

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112 Elsewhere I defend this claim in more detail (see Taebi: Unpublished).

113 Stephen Gardiner puts forward this argument in the case of climate change where he addresses three problems relating to climate change which he refers to as three storms. "These three 'storms' arise in the global, intergenerational and theoretical dimensions, and [...] their interaction helps to exacerbate and obscure a lurking problem of moral corruption" (see Gardiner: 2006a: 399). Even though only two of the three "storms" relate to the problem of nuclear power production and the accompanying waste (i.e. theoretical and intergenerational), I believe that the main rationale of this argument which is based on our advantageous temporal position to impose harm on future generations is not undermined.

114 In this paper I am not distinguishing between the notions of obligation and duty.

to address the wider moral considerations of nuclear energy and to examine the weight of their moral stringency when they conflict with each other and with obligations towards the present generation. The next section introduces the notion of conditional duty and presents the two mentioned temporal duties as conditional duties. In Section 3 I shall examine the extent of the moral stringency of these duties in an internal conflict; that is when it becomes impossible to comply with both duties.

5.2. Moral pluralism and temporal prima facie duties

Pluralists believe that morality cannot be captured in one single principle or value, as is done with *monist* views such as utilitarianism. Situations in which a plurality of morally relevant features should be taken into consideration are conceivable; the emerging question of how to act then depends on which of these moral features is more compelling and that again relates to the situation context. In order to facilitate this distinction, William David Ross (see 1930/2002, 19-21) presents *prima facie duties*[115] as conditional duties that one has moral reason to follow in a certain situation. These duties hold as long as they are not overridden by any more morally compelling duties. Our *actual* duty (or 'duty proper' as Ross terms it) is then all-things-considered duties where moral conflicts have been properly addressed. By making this distinction, pluralists distance themselves from Kantians who attribute a more rigid character to moral rules. Ross (see 1930/2002, 20) distinguishes between seven basic prima facie duties, including the duties of justice, beneficence and non-maleficence.

Like moral pluralists I consider it unfeasible to capture all morally relevant features in one single principle or value. I furthermore apply Ross's notion of prima facie duties to relate to our temporal relationship with our descendants before then going on to formulate the specific duties that emanate from this

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115 "The phrase 'prima facie duty' must be apologized for", Ross states, as it "suggests that one is speaking only of an appearance which a moral situation presents at the first sight, and which may turn out to be illusory" (see Ross: 1930/2002, 20). Nevertheless Ross sticks to this notion as he believes that there is no better alternative. The phrase prima facie duty serves to highlight the conditional character of duties. "So prima facie duties should be understood as features that give us genuine (not merely apparent) moral reasons to do certain actions"; the quote is from the introduction of a later reprint of the book 'The Right and the Good', written by Phillip Stratton-Lake (see Ross: 1930/2002, xxxiv).

relationship.[116] The two prima facie duties presented in this paper do, to some extent, resemble certain basic Rossian duties. For instance, handing down resources to future generations could be a derivative of Ross' duty of justice or beneficence whilst not harming future people can evidently be subsumed under his duty of non-maleficence. However, unlike Ross (see 1930/2002, 29-30) who asserts that the basic (or fundamental) prima facie duties should be taken for granted as "mathematical axioms" or seen as "part of the fundamental nature of the universe", I derive these duties from the intergenerational nature of nuclear power production.

In other words, by using a non-renewable resource for energy production and generating long-living nuclear waste, we have created an intergenerational problem. In addition, our beneficial temporal position with regard to not yet born generations makes us vulnerable to moral corruption from the point of view that we might be tempted to exploit this position. We should therefore be wary of how adequately the interest of future generations is addressed in the choices we make concerning the applications of certain technologies. These two prima facie duties are then presented here as a *natural default* which means that if anyone disagrees that these are moral reason-giving features of our responsibilities towards future generations then the burden of proof shifts to the person who disagrees. Whether these prima facie duties even perhaps partly constitute our actual duty towards future people will emerge from our examination of these duties in the light of the intergenerational conflicts that they bring about. Let us focus now on the philosophical foundation of the proposed prima facie duties.

5.2.1. The prima facie duty not to harm future people

One of the fundamental ethical obligations underscoring all human interaction is that of avoiding harm to others. In his seminal work *On Liberty*, John Stuart Mill (see 1859/1998a, 14) states that "[t]he only part of the conduct of anyone, for which he is amenable to society, is that which concerns others." Mill (see 1859/1998a, 14) who definitely acknowledges that an individual is sovereign when it comes to his body or mind simultaneously argues that "[t]he only

[116] Shrader-Frechette (see 1994, 1991a) also refers to temporal prima facie duties in 'Risk and Rationality' and later in 'Equity and Nuclear Waste Disposal'. However, it seems that this is an allusion to the literal or common sense meaning of this phrase (indicating at first sight or apparent) rather than the Rossian interpretation of this notion.

purpose for which power can be rightfully exercised over any member of a civilised community, against his will, is to prevent harm to others. His own good, either physical or moral, is not sufficient warrant.” This *no harm* principle is a leading creed for health care professionals; the ensuing maxim that is frequently invoked in health care is then ‘above-all do not harm’ (see Beauchamp and Childress: 2009, Ch. 5). In environmental policy-making, too, this principle is becoming increasingly influential, for instance where it inspires the Precautionary Principle: namely "[w]hen an activity raises threats of harm to the environment or human health, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically", as stipulated in the Wingspread statement (see 1998). This concept of negative obligations can also be extended to the intergenerational context and dubbed the principle of not harming future generations.

As far as the nuclear discussion is concerned, there is general consensus that we should not impose “undue burdens” on future generations; this statement is taken to relate to waste management and, in particular, to final waste disposal (see IAEA: 1995). Many nations agree that this undue burdens clause should be taken to mean that nuclear waste should be disposed of in geological repositories which are believed to guarantee the long-term safety of future generations. I will defer discussions on this issue to Section 5. In short, the first prima facie duty is that of not harming future people.

5.2.2. The prima facie duty to sustain future well-being

A second fundamental issue in theories of intergenerational justice is that which relates to the appropriate consumption of non-renewable resources over the course of time. Brian Barry (see 1989a, 515 & 519) states that “[f]rom a temporal perspective, no one generation has a better or worse claim than any other to enjoy the earth’s resources”, and concludes that “depletion should be compensated for in the sense that later generations should be no worse off [...] than they would have been without depletion”. The question that then arises is why we should leave *the same* amount of goods (or resources) for our descendants. Wilfred Beckerman (see 1999: 73) argues that taking the present levels of well-being as a point of comparison is arbitrary and has no normative significance when it comes to supporting intergenerational duty; “past generations seem to have survived with far less”. Barry (see 1999: 106), on the other hand, states that “unless people in the future can be held responsible for the situation that they find themselves in, they should not be worse off than we are". To elaborate on Barry's reasoning, I would argue that we, the present generation, have a prima facie duty to compensate future generations for the resources we have depleted. In this paper I am not focusing on the question of how much we should compensate; my claim is merely that future generations should at least have access to equivalent amounts of resources that we have had access to and which necessitate compensation of some kind.[117] In Section 4, I will explore the technological possibilities of offering compensation within the boundaries of the nuclear option.

5.3. The moral stringency of temporal duties: internal conflict

So far two temporal duties have been formulated for the present generation in terms of prima facie duties, with the caveat that in possible conflicting situations they could be overridden by more compelling duties. Two types of conflicts could occur. Firstly, there could be internal conflict in situations where we are not able to accomplish both duties simultaneously; which duty should then be given priority? In complying with these temporal duties we need to implement certain technologies which, in turn, shifts the burdens and benefits for different generations. The second type of conflicts that might occur are intergenerational conflicts. The conflicts explored in this section are internal conflicts; discussions relating to intergenerational conflicts are deferred to Section 5.

An internal conflict occurs, for instance, when a certain technology complies with one duty but does not comply with the other. The question that follows from this conflict is: do we have a more important duty to benefit other people or would is it more important to avoid or at least decrease the possibility of harm? This is a long-lasting debate among contemporary philosophers. In proposing his fundamental prima facie duties, David Ross (see 1930/2002, 21)

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117 Barry (see 1989a) introduces the notion of productive potential, arguing that depletion makes future generations worse off in terms of the productive potential that needs to be compensated. My notion of compensation as it is presented here is a rather simpler one, namely that we should guarantee that future generations have access to equivalent resources. This notion poses several philosophical challenges, including how to determine what constitutes 'equivalent' when we deplete one resource and seek to substitute it with another. We furthermore need to assume that we can "substitute critical natural resources with human-made resources", as correctly stated by Skagen Ekeli (see 2004, 434). However, for the purposes of this paper I am emphasizing that we have this temporal obligation without spelling out what precisely the obligation entails in terms of compensation.

distinguished between the two duties of beneficence and non-maleficence even though he admits that "to injure others is incidentally to fail to do them good". He makes this distinction because he ascribes more stringent stipulations to the duty of non-maleficence than to beneficence. John Rawls furthermore emphasizes that negative duties that require us not to cause harm carry more weight when compared with the positive duty to do something good for others (see Rawls: 1971/1999, 98).[118] The scholars Martin Golding and Daniel Callahan added a temporal dimension to this discussion. While Golding (see 1981, 62) conceives of a positive temporal duty by stating that we should produce and promote "conditions of good living for future generations", Callahan (see 1981, 78) emphasizes the more far-reaching negative duty "to refrain from doing things which might be harmful to future generations". These two positions differ mainly in the way that they relate to future generations; Golding's positive duty is associated with close future generations, while Callahan's negative duty extends much farther into the future and also contemplates the possibility of harm caused to remote future generations. The political philosopher Avner de-Shalit (see 1995, 13) merges these two positions; he emphasizes that contemporaries have a strong positive obligation to close and immediate future generation to "supply them with goods, especially those goods that we believe [...] will be necessary to cope with the challenges of life", but he also advocates less strong negative duties towards the distant future.

Let us now return to the two prima facie duties discussed in this paper, starting with the duty of sustaining well-being and the ensuing compensation issue. One of the theoretical problems behind the notion of compensation – as argued by Shrader-Frechette (see 2002, 111) – is that future generations can never consent to an "acceptable level of compensation, even assuming it is in principle ethically acceptable". While one can argue that depleting non-renewable resources creates the obligation to compensate future generations, further justification is needed to demonstrate that these compensations are within the boundaries of the nuclear option. One can, for instance, argue that the depletion of uranium as a non-renewable resource should be compensated with the availability of other suitable resources. Nevertheless, the focus of this paper confines itself to the boundaries of nuclear technology because of certain features of this technology. There are certain features of the nuclear technology –

118 Beauchamp and Childress (see 2009, Ch. 4) also discuss the distinction between the notions of beneficence and non-maleficence.

that are alien to other non-renewable resources such as fossil fuel –, which to some extent justify exploring the possibility of compensation within the boundaries of this technology. We can, for instance, deploy nuclear fuel substantially more efficiently by recycling and reusing it. It is also possible to extract more uranium from other natural resources such as phosphate deposits and seawater and to extend the period of resource availability to thousands of years (see SER: 2008). There are even nuclear production methods that produce more fuel than they consume; more will be said about this option in the next section.

To sum up, assuming that we continue to deploy nuclear power production, we can say that technologies should then be preferred that keep more resource options open for future generations (in the form of uranium). Whether future generations will ultimately deploy the available nuclear resources is something that we cannot, and perhaps should not, even want to decide for them; we merely provide them with the opportunity to do so.

There is, however, no doubt that long-term compensation in terms of extending nuclear fuel is sound if, and only if, we assume that nuclear fission will continue for a long period of time. The latter downgrades the moral importance of this notion of compensation within the boundaries of the nuclear technology as it is defended here, especially when we have to choose between the two duties. On this basis and also on the basis of the discussion presented at the beginning of this section, I conclude that – all things being equal – the prima facie duty to avoid harm being done to future generations becomes even more compelling. This should not, however, be interpreted in absolute terms, because the ranking of moral relevance is, in principle, context dependent; also pluralists will agree with this argument. Imagine, for instance, a situation in which the harm is relatively minor compared to the possible benefits; we can conveniently argue that the obligation of beneficence would then take precedence over that of non-maleficence.[119]

5.4. Nuclear energy: a review of the technology and its future

Technology plays a crucial role in establishing how to comply with these duties. Barry (see 1989a, 519-20) for instance points out that technological development

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119 Such situations are conceivable in biomedical ethics; see for instance Beauchamp and Childress (see 2009, Ch. 5).

could be conceived as compensation, if they enable extracting more from natural resources than one could without such technology. With nuclear power production, compensation for the depleting reserves of uranium could be provided in different ways. First of all, minor changes can be made in the existing production methods or fuel cycles; for instance by extracting more uranium from other natural resources as mentioned in the last section. The focus in this paper is, however, on the entire fuel cycle. In the following paragraphs I will discuss two existing and two future fuel cycles and I shall evaluate how they score from the point of view of complying with our temporal prima facie duties.

Any nuclear fuel cycle consists of several major steps, including the mining and milling of uranium ore, enrichment, fuel fabrication, irradiation in a reactor and the optional waste treatment methods employed after irradiation and before the final disposal of the waste. Uranium is currently deployed in most operational energy reactors, which are referred to as Light Water Reactors (LWR). Naturally occurring uranium contains different constituents (isotopes) in the form of the minor fissile isotope that is capable of producing energy in existing reactors but is present in less than 1% of uranium and the major isotope (>99%) that is not fissile and therefore not deployable in existing operational reactors. In the following paragraphs, I shall distinguish between the two existing fuel cycles (open and closed) while simultaneously presenting two future fuel cycles that will help us to comply better with the presented prima facie duties towards future generations.

(i) *The open fuel cycle*: In an open or once-through fuel cycle (of the type common in the US and certain other countries like Sweden) enriched uranium is irradiated once in a reactor and spent fuel is disposed of as waste for 200,000 years. The material remaining after irradiation which is known as spent fuel contains not yet irradiated uranium and plutonium together with other radionuclides, all of which should be disposed of as waste.

(ii) *The closed fuel cycle:* An alternative option is to reprocess spent fuel so that deployable materials (uranium and plutonium) are extracted in order to be reused as fuel; the reinserting of these materials completes or closes the cycle which is why this method is dubbed the closed fuel cycle method; the life-time of the remaining waste is about 10,000 years. Closed fuel cycles are common in many European countries but some other countries, like Japan, that have access to fewer natural resources primarily see it as a way of extending their energy resources. Reprocessing and reusing deployable material considerably increases the long-term availability of uranium (see IAEA-NEA: 2008). The closed fuel cycle scores better in the fulfilling of both duties, as it decreases the waste life-time and increases the availability of resources. In the first three rows of Table 3 an internal comparison of these two fuel cycles is presented; the plus signs for the closed fuel cycle indicate its better score in terms of fulfilling the stated duties when compared to the open fuel cycle. The next two fuel cycles are proposed to explore how far we could go – technologically speaking – in fulfilling these duties. These fuel cycles are scientifically proven but years of development and industrialization are required before they can be made operational.

(i) *Partitioning and Transmutation:* In addition to reprocessing, a further deactivating of the remaining waste can be achieved by means of a new method known as *Partitioning and Transmutation* (P&T). It involves separating and dividing (partitioning) the materials remaining after reprocessing so that they can afterwards be eliminated (transmuted) in Fast Reactors;[120] these reactors can irradiate the radionuclides that the currently operational LWR cannot irradiate. This can substantially reduce the waste life-time to a period of between 500 and 1,000 years (see KASAM: 2005a, Ch. 8). It is thus a fuel cycle that scores relatively better on the no harm duty scoreboard, as is also indicated in Table 3.

(ii) *The breeder fuel cycle:* Fast Reactors could also be deployed in the configuration of a nuclear breeder for the purposes of making (breeding) more fuel than is consumed during operation. The best feasible option is to irradiate the abundant uranium isotope (which cannot be irradiated in a LWR) and breed a certain plutonium isotope, which can be extracted by reprocessing, before then reusing it as fuel. In this way the uranium consumption will become remarkably more efficient; the two plus signs in Table 3 linked to fulfilling the second duty are thus of relevance. This fuel cycle is designed to enhance the resource durability and the remaining waste

[120] Apart from Fast Reactors, Accelerator Driven Systems are also capable of the latter; see for more information NEA's report on this issue (see NEA-OECD: 2002).

contains very long-living radionuclides; therefore it does not score good on the no harm duty.

As can be seen, different fuel cycles are capable of complying with the temporal duties in different ways. I would again like to emphasize that the plus and minus signs in Table 3 merely signify relative comparisons between these four fuel cycles. Before assessing the desirability of these technologies from the point of view of safeguarding the interests of future generations, we should also remind ourselves of how they shift the burdens and benefits for contemporaries.

	No harm duty	To sustain well-being
Open Fuel Cycle	–	–
Closed Fuel Cycle	+	+
Partitioning and Transmutation	+ +	+
The Breeder Fuel Cycle	–	+ +

Table 3: four fuel cycles and their relative scores with respect to the temporal duties

5.5. Intergenerational conflicts and three challenges

So far, I have argued that we have two temporal duties with regard to posterity. These duties are presented as conditional prima facie duties in an effort to address the conflicts. In Section 3, an internal conflict was discussed. We concluded that in an all-things-being-equal situation, the no harm duty should take precedence over the duty to sustain future well-being. If we now take the no harm duty as the leading notion when choosing a fuel cycle then maximally reducing the long-term concerns for future generations through Partitioning and Transmutation (P&T) would seem to be the most desirable option, as also can be seen in Table 3. Let us dwell for a moment on how the implementation of this fuel cycle affects the interest of contemporaries.

As stated above, the P&T fuel cycle should be viewed as a complementary strategy to the closed fuel cycle. In other words, before the successful reprocessing and extraction of uranium and plutonium from spent fuel takes place it is impossible to continue eliminating the remaining radionuclides through P&T. So let us first explore how reprocessing shifts the burdens and benefits for the present generation before then continuing with the matter of P&T.

Reprocessing is as a chemical process linked to the separating of uranium and plutonium, which creates considerable safety, security and economic burdens for the present generation. To be precise, it necessitates more nuclear activities and the chemical radiotoxic residual of reprocessing subsequently has to be disposed of as well. In this case safety is connected with the unintentional release of radiotoxic material that can lead to health problems. Security, on the other hand, refers to the intentional releasing of radioactive substances; both as a result of sabotage and as meant by proliferation pertaining to the manufacturing and disseminating of nuclear weapons. Reprocessing creates additional proliferation risk for contemporaries if one considers that plutonium separated during reprocessing could be used for destructive purposes. Indeed, such separating is primarily undertaken for civil purposes (to produce nuclear fuel and reinsert it in the cycle), but security concerns will certainly mount during this process and will remain until the separated plutonium is again deployed in a nuclear reactor. Furthermore, since reprocessing plants are quite expensive only a few countries have them at their disposal. In Europe, which tends to favor the closed fuel cycle approach, there are currently two operational reprocessing plants located in Great Britain and in France. Therefore countries upholding the closed fuel cycle policy should either accept the economic burdens by constructing such a plant or transport their spent fuel back and forth to be reprocessed; such transporting further increases the safety and security burdens.[121]

During P&T, the nuclides remaining after reprocessing are separated and divided in order to be eliminated. P&T is however merely a technology that has been scientifically proven at lab level. It still requires decades of development which, in turn, will necessitate serious investments in this technology (see NEA-OECD: 2002). On top of the burdens of reprocessing, these other burdens also have to be borne by contemporaries or at least by those nations that are capable of developing the technology.[122] To conclude, the burdens of developing and eventually deploying P&T will mainly be borne by the present and immediately

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121 Together with Jan Leen Kloosterman (see 2008), I have discussed these arguments at some length elsewhere. This paper is included here in Chapter 3 of the dissertation.

122 Due to the inherent technological implications and complexity, not all countries will be capable of developing or deploying this technology; see 'Technical Implication of Partitioning and Transmutation and Radioactive Waste Management' (see IAEA: 2004).

following generation, while it is primarily designed to reduce safety burdens for remote future generations.[123]

At least three objections could be made to the idea of accepting additional burdens for contemporaries in order to reduce the likelihood of causing harm to remote future generations. The first has to do with the long-term safety that geological repositories supposedly guarantee so that there is no need to further deactivate the waste. A second rejoinder to this view is the contention that placing additional safety and security burdens upon contemporaries is highly undesirable and, therefore, unjustified. The last objection relates to the distribution of these additional burdens between contemporaries.

5.5.1. Repositories guarantee long-term safety; why should we accept more burdens?

Some people argue that current technology is quite capable of handling the waste problem. We should dispose of the waste – so the argument goes – in deep geological repositories. As a matter of fact, this enjoys broad consensus among nuclear energy producing countries. The Nuclear Energy Agency (see NEA-OECD: 1999b, 11) articulates this consensus as follows: “Potential host geologic formations are chosen for their long-term stability, their ability to accommodate the waste disposal facility, and also their ability to prevent or severely attenuate any eventual release of radioactivity. This natural safety barrier is complemented and augmented by an engineered system designed to provide primary physical and chemical containment of the waste.” Many countries are currently taking the first steps towards realizing such repositories; some countries such as Finland, France, Sweden, Spain and the United Kingdom have already set up operational repositories for less radiotoxic types of waste, for Intermediate-level and Low-level waste (see NEA-OECD: 1996). Finland and the United States have already chosen their repository sites for High-Level waste and Sweden has narrowed down its attention to two possible sites (see Rogers: 2009).

[123] The intergenerational distribution of the burdens and benefits of different fuel cycles is more precisely and extensively discussed in a joint paper written with Andrew Kadak. We have mapped out the consequences of four possible fuel cycles in terms of the moral values at stake. Both Partitioning and Transmutation and the Breeder Fuel Cycle are discussed here; see ‘Intergenerational Considerations Affecting the Future of Nuclear Power; Equity as a Framework for Assessing Fuel Cycles’ (see Taebi and Kadak: Unpublished).

In view of these considerations it seems unjustifiable to impose more risks on the present generation simply in order to deactivate nuclear waste. However, one of the problems with long-term waste disposal is the inherent uncertainty both in terms of technical predictions and regarding future societies. David Hassenzahl (see 2006) argues that in decisions about long-term US waste disposal, "uncertainty in the technical model is utterly obscured by uncertainty about human conditions". There is enough historical evidence to underpin the notion that we are hardly in a position to anticipate human behavior and the status of future societies a few hundred years from now, let alone 10,000 or 100,000 years on. The question that follows from this is whether this should have a bearing on our moral responsibility towards future generations. Kristian Skagen Ekeli argues that our ignorance with respect to future generations "reduces our responsibility in a temporal dimension because in most areas it is impossible to foresee the interests and resource needs of future generations" (see Skagen Ekeli: 2004, 442); this corresponds with how Martin Golding (see 1981, 70) views our duties to future generation as he argues that "the more distant the generation we focus upon, the less likely it is that we have an obligation to promote its good". Skagen Ekeli (see 2004, 442) argues on the other hand that there are things that we could be certain about such as the physiological needs of future people and that it is therefore immoral to impose risks upon future generations that threaten these physiological needs when risk assessment are presented that are "supported by scientifically based harm scenarios". Even though Skagen Ekeli acknowledges the difficulties that arise from scientific disagreement about harm scenarios, he does not consider this to be an insurmountable problem. Unlike Skagen Ekeli, I argue that in addressing the acceptability of a certain technology with long-term consequences, all the uncertainties and the ensuing problem of disagreement on predictions do pose intractable challenges. This is particularly the case in the foreseeing of the long-term consequences of geological repositories.

A second relevant aspect is how to deal with uncertainties regarding the technical predictions of the remote future in policy-making. Let me illustrate this by giving the example of how such uncertainties are anticipated in the case of the Yucca Mountains repositories for the permanent disposal of American spent fuel for a million years. At the same time as acknowledging the difficulties surrounding the long-term uncertainties of technical systems, it has been proposed that we should distinguish between different future people: "a repository must provide reasonable protection and security for the very far future, but this may not necessarily be at levels deemed protective (and controllable) for the current or succeeding generations" (see EPA: 2005, 49036). People living in the next 10,000 years deserve a level of protection equal to the current level and the generations belonging to the period extending beyond 10,000 years could be exposed to a much higher radiation limit. The underlying argument for this distinction is sought in the low degree of predictability of the remote future and the fact that any positive influence on such societies is meaningless, all of which is believed to diminish our responsibility towards future generations.[124]

We could now ask whether this also releases us from the duty of avoiding the possibility of imposing harm on future generations. An ensuing question might be to ask whether the present generation has a duty to reduce the waste life-time to more conceivable time periods in order to avoid ending up in a situation in which – from a pragmatic point of view – we need to discriminate against remote future generations which, in turn, increases the possibility of harming people living in the remote future. Elsewhere I argue that the distinction between future generations lacks solid moral justification, concluding that in the light of long-term uncertainties we should reconsider whether geological repositories really are the best option for final waste disposal (see Taebi: Unpublished).

5.5.2. Should we impose more safety and security burdens on contemporaries?

The next objection I would like to discuss relates to the justifiability of additional burdens for contemporaries. As argued above, developing and deploying P&T to reduce future burdens linked to nuclear waste brings with it serious additional economic, safety and security burdens for the present generation. In this paper I will leave the issue of whether it is justifiable for this generation to bear the economic burdens unanalyzed. Instead, I will focus on the morally more important question of whether the additional safety and security risks are justified. Let us just remind ourselves that more nuclear activities are involved in P&T and that during reprocessing separated plutonium (in an initial step towards P&T) involves high proliferation risks. If it is indeed true that a nuclear accident or nuclear warfare could have consequences that would be suffered far

124 The notion of diminishing responsibility over the course of time – as is referred to here – is defended by the Swedish KASAM (see 2005a, Ch. 9) and the American National Academy of Public Administration (see NAPA: 1997).

beyond the present generation, some people – such as the Belgian philosopher Axel Gosseries (see 2008b) – argue that we should avoid risks of malevolent use, particularly from the intergenerational justice point of view, defending geological disposal as the fastest and best feasible option for the disposal of waste in the near future.

It is widely accepted that since the present generation has created the waste, it should also – as far as possible – bear the responsibility of managing it (see NEA-OECD: 1995, 9). Quite how the latter point should be interpreted is, however, open to debate. Some people argue that the benefits of nuclear power enjoyed by the present generation should also be paid for by the present generation in accordance with the 'polluter pays' principle. A general consensus in nuclear waste management is the principle of equality between generations, meaning that similar levels of protection for the people now and in the future should be guaranteed (see NEA-OECD: 1984); geological repositories are believed to best comply with this principle. However, as emerged from the American example, designing such an underground disposal repository amounts to a violation of the equality principle.

I would even go one step further in my claim to argue that even the rationale of the equal treatment argument is faulty. The equal treatment principle presupposes that there is an equal temporal distribution of benefits that should justify an equal distribution of the burdens. A utilitarian would argue that nuclear power production serves the higher good of the well-being of mankind so that everyone is better off, even those who belong to future generations. Even if – for a while – we take this argument for granted, we can assert that the temporal distribution of benefit is not properly incorporated into this line of reasoning; the current benefits are unquestionably greater and that could justify accepting placing more burden on the present generation. So the default situation should be that the present generation remains responsible for the waste problem. If one then decides to transfer parts of this risk to the future and if this necessitates putting remote future generations at a disadvantage then "the burden of proof is on the person who wishes to discriminate", as by Shrader-Frechette (see 2002, 97) rightly stated.[125]

It is, however, quite reasonable to consider ways of reducing the burdens upon the present generation, particularly the security burdens. After all, the

125 Shrader-Frechette disagrees with the claim that nuclear electricity benefits future persons and presents two objections to this idea; see for more information (see Shrader-Frechette: 2002, 97-8).

additional proliferation risks are the main reasons why countries like the United States have decided to avoid reprocessing. In the first place it is the significant quantities of highly enriched uranium and weapon-grade plutonium emanating from dismantled warheads in the wake of the Cold War that need to be taken care of. As proliferation is a significant problem associated with reprocessing (and with the possible further deactivating of the waste through advanced fuel cycles such as P&T) serious attempts have been made to avoid this problem. Proliferation-resistant technologies have been proposed so that we can enjoy the benefits of reprocessing by, for instance, reducing the waste volume and its waste life-time; one of the serious alternatives worth mentioning is the Global Nuclear Energy Partnership, alternatively known as GNEP (see DOE: 2006).[126]

5.5.3. Who out of the present generation should bear the burden?

The last objection that will be explored here is that of how the additional safety and security burdens will be distributed between contemporaries and whether that should be seen as relevant when addressing the intergenerational conflicts. Some scholars argue that people who are disadvantaged in terms of income, education or occupation generally bear greater environmental and health risks; see for instance Bullard (see 1994) and Bullard and Johnson (see 2000). Issues concerning the distribution of burdens and benefits among contemporaries are referred to as *intra*generational justice or alternatively as environmental justice.[127]

If we now accept these arguments by acknowledging that the least well-off in society are indeed exposed to higher environmental risks and go on to conclude that the latter violate the norms of distributive justice – as for instance argued by Wigley and Shrader-Frechette (see 1996) in the case of a uranium enrichment facility in Louisiana – then the question as to whether the extending of these activities is justified seems legitimate. To put it bluntly, can we justify increasing the injustice among contemporaries and disadvantaging the least well-off in present-day society in order to reduce the possibility of harming remote future generations? This casts serious doubt on the extent of moral legitimacy of the

126 See for more information (see Pilat: 2006).

127 Some scholars – such as Shrader-Frechette (see 2002, Ch. 5) – see the temporal inequality that arises from the case of geological disposal of nuclear waste as an instance of environmental injustice. In this paper I distinguish between spatial and temporal justice by stressing that the former refers to environmental justice and the latter to intergenerational justice.

prima facie duty of not harming future generations. This reasoning is however dubious as it assumes that current injustice should continue. We can argue that if there is a problem surrounding the distribution of burdens and benefits among contemporaries, we need to address and solve this problem irrespective of any additional activity.

One might further argue that the dilemma presented is a false dilemma because the choice should not be between injustice done to the present generation and injustice towards the future as a result of nuclear power deployment. Perhaps it is rather the case that we should avoid nuclear power and choose instead other energy provision systems. Even though such an argument seems at first glance defensible, I shall try not to get involved in this discussion. Addressing the social desirability of nuclear power production is indeed a very legitimate discussion; however in this paper I have confined the analysis to different options for the production of nuclear power; if we produce nuclear power, which technology should we prefer and why? This question and the ability to distinguish between the different production methods comes before the general desirability issue. In other words, before being able to compare nuclear energy with other energy sources, it is advisable to be clear about the type of nuclear energy (or fuel cycle) one has in mind and to appropriately address the spatial and temporal distribution of burdens and benefits.

5.6. Conclusions

In this paper I have considered the morally desirable option for nuclear power production. In other words, assuming that we continue using nuclear energy, which technology should we deploy for its production? As nuclear power production predominantly produces present benefits with deferred costs for future generations and as we are in a temporally good position to visit costs on future generations, I argue that the desirable option should be primarily formulated in terms of the duties that present generation have towards posterity 1) not to harm people of the future and 2) to sustain future well-being by guaranteeing the availability of resources. Fulfilling these duties brings with it the implementation of certain technologies, all of which shifts the burdens and benefits for different generations. The question, as correctly formulated by Brian Barry (see 1999, 94), then becomes, if "we could provide a benefit or avoid a loss to people in the future at some cost to ourselves, are we morally required to do so?"

In order to be able to answer this question and address these intergenerational conflicts, I treated temporal duties as prima facie duties, alluding to the fact that they might be overruled by morally more important duties. I argued that – in all-things-being-equal situations – the duty not to harm future generations extends farther into the future and is more compelling; this supports the introduction of Partitioning and Transmutation (P&T) fuel cycles in order to substantially reduce waste life-time periods. Such a fuel cycle creates additional safety, security and economic burdens for contemporaries; these intergenerational conflicts were further explored.

Three objections were raised to the additional burdens that emanate from P&T. The first objections related to the possibility of disposing of the waste in geological repositories that supposedly guarantee long-term safety. It was however shown – as in the American example – that to design repositories we need to violate the equality principle with regard to remote future generations. The second objection questions the legitimacy of these additional burdens for contemporaries. This reasoning errs however as it shifts the burdens of proof. Assuming that the present generation has predominantly benefited from nuclear power, the default situation should then be that this generation remains primarily responsible for dealing with it; it is therefore the transferring of these risks to remote future generations, thus putting them at a disadvantage that requires justification. Indeed, there is every reason to reduce the burdens upon contemporaries, especially the proliferation risks as the consequences of an accident or nuclear warfare would extend far beyond the present generation. Technological solutions could be presented to such issues. The third objection relates to the distribution of additional burdens among contemporaries. Assuming that the least well-off in society are generally exposed to higher safety and health risks, one could argue that increasing such environmental injustice by applying P&T would be highly undesirable. Even though this argument mistakenly presupposes that current injustice should continue, it emphasizes the necessity of addressing the intragenerational justice issue. To conclude, the morally desirable option in nuclear power production is primarily seen here as that which safeguards the interests of future generations, after which we should explore how the latter shift the burdens and benefits for contemporaries before deciding whether that option is sufficiently justified.

6 Conclusions

The main objective of this dissertation has been to provide a moral analysis of different nuclear fuel cycle alternatives on the basis of the notion of intergenerational justice. Different fuel cycles give rise to different considerations and moral dilemmas for present and future generations. The first research question that was explored was that of how to approach the moral dilemmas attached to nuclear fuel cycles within the framework of intergenerational justice. To answer this question, I first presented what is morally at stake in nuclear power production in terms of moral values. In choosing one of the existing open or closed fuel cycle methods – these values will inevitably conflict in terms of how they relate to the interests of present and future generations. It has been demonstrated that intergenerational justice not only illuminates the choice for an existing fuel cycle but that it can also help us to understand and reflect upon future fuel cycles based on new scientifically proven technologies that have not yet been fully developed, all of which can help to set the research agenda. The second, more normative, research question was: which fuel cycle is most desirable from a moral perspective? To that end, I have further specified the notion of intergenerational justice by spelling out the obligations for the present generation to ensure that there are indeed equal opportunities for future generations. I have argued that if we continue deploying nuclear power, then Partitioning and Transmutation (P&T) is the fuel cycle that should be preferred form a moral perspective, since it substantially reduces the waste life-time and therefore also best safeguards the interests of future generations. P&T further challenges the need for geological disposal and places surface storage in a new perspective. In following paragraphs I will present these conclusions in more details and discuss some possible objections and implications for policy-making.

6.1. The moral dilemmas and technological choices underlying fuel cycles

Intergenerational justice has already been an influential consideration in nuclear energy related discussions. It has been asserted by the International Atomic and Energy Agency (see 1995: Pr. 5) that nuclear waste should be managed in such a way that it "will not impose undue burdens on future generations". Many nations agree that this 'undue burdens' clause must be taken to mean that nuclear waste should be disposed of in geological repositories rather than in long-term surface storage facilities; repositories are believed to best guarantee the safety of future generations (see NEA-OECD: 1995). This alleged long-term safety seems, however, to rely rather heavily on substantial long-term uncertainty which, in turn, necessitates distinguishing between different future generations. This discrepancy was demonstrated in legislative documents relating to the Yucca Mountains repository in the state of Nevada in the United States. The US Environmental Protection Agency (EPA) states that "a repository must provide reasonable protection and security for the very far future, but this may not necessarily be at levels deemed protective (and controllable) for the current or succeeding generations" (see EPA: 2005: 49036). The EPA argues that people living in the next 10,000 years deserve a level of protection equal to the current level but that generations of people living in the period extending beyond 10,000 years could be exposed to much higher radiation levels. In Chapter 2, I have argued that such a distinction between different future generations lacks moral justification and so challenges the consensus to dispose of the waste underground.

The framework of intergenerational justice is one that may not only be applied to waste management discussions but it could also be extended to include the whole fuel cycle from mining of uranium ore to the final disposal stage. In Chapters 3 and 4, I have explored what is morally at stake and have linked the burdens and benefits of this technology to a set of moral values that are philosophically grounded in the overarching moral value of sustainable development (see WCED: 1987). I have distinguished between the following values: resource durability (supply certainty), radiological risk to the environment (environmental friendliness), radiological risk to the public (public health and safety), economic affordability (or economic durability) and the security concerns surrounding the using of the technology for destructive purposes (or proliferation).

In choosing a fuel cycle, these values conflict in terms of how they relate to the interests of present and future generations. This has been demonstrated in Chapter 3, where the two existing fuel cycles (open and closed) are compared. These fuel cycles are similar until the first irradiation phase of uranium in the reactor. Precisely how the remaining *spent fuel* is dealt with determines the nature of the fuel cycle and therefore also the distribution of burdens and benefits. In the open fuel cycle, spent fuel is regarded as waste and is supposed to be disposed of underground and isolated from the biosphere for 200,000 years. The open fuel cycle is mainly to be associated with short-term advantages, as it brings about relatively less radiological risk and thus fewer public health and environmental concerns; more radiological risk would be transferred to the future in terms of long-term waste disposal. The closed fuel cycle, on the other hand, could be linked to the long-term advantages in view of the fact that spent fuel is seen as a resource and is reprocessed (recycled) to separate deployable materials (uranium and plutonium); the life-time of the remaining waste is further reduced with a factor 20 (10,000 years). As the uranium and plutonium are destined to be reinserted into the fuel cycle, resource durability may be said to be substantially improved in a closed fuel cycle. Additional economic, safety and security burdens that reprocessing bring about, particularly proliferation concerns emanating from plutonium, are however mainly for the present generations.

In short, the choice between the two existing fuel cycles can be reduced to a matter of justice between generations. The public and political discussions should not however be confined to the existing fuel cycles used for current deployment; it is highly relevant to look into technological innovations and to weigh up the potentials and impediments for nuclear technology in the future. At least two new proposed fuel cycles are worth considering. Both fuel cycles have emerged from progress in reactor technology and from the implementation of *Fast Reactors* which, unlike conventional thermal reactors, are capable of handling a greater range of isotopes. The first alternative fuel cycle is based on separating (partitioning) long-lived isotopes in spent fuel in order to eliminate them (have them transmuted) in fast reactors, all of which diminishes the waste life-time to several hundred years; this is called the Partitioning and Transmutation (P&T) fuel cycle.[128] The same fast reactors could also be used in *breeder* configurations; in combination with multiple recycling, a breeder fuel cycle can produce (or breed) more fuel during operation than it consumes.

In Chapter 4 a method was presented that provides insight into the intergenerational distribution of burdens and benefits in future fuel cycle alternatives. I have demonstrated that both the mentioned fuel cycles (breeder and P&T fuel cycles) positively influence the interest of future generations. The

[128] A P&T fuel cycles could also be made possible with Advanced Driven Systems (see NEA-OECD: 2002).

additional safety, security and economic burdens that accompany the developing and industrializing of these fuel cycles will, though, mainly to be borne by the present generation. The key questions that need to be answered prior to finally choosing a particular alternative are these. Should the present generation accept significant additional burdens for the benefit of future generations so that in that way extended energy supplies (with a breeder fuel cycle) will be facilitated or long-term waste problems (as with P&T cycles) will be minimized? To what extent is the transferring of risk to the very distant future acceptable? These are not easy questions to answer and I do not claim that my proposed method in Chapter 4 provides all the answers but it does address the decisions that need to be made and highlight the intergenerational dilemmas, all of which paths the way for ethically informed decision-making.

6.2. The morally desirable fuel cycle

Throughout my analysis, I have aimed to combine philosophical discussions with technological *realities*: what is our obligation to posterity and to what extent can existing technology help us to comply with such moral obligations? Finally, which scientifically feasible future technologies have the potential to help us to comply better with these obligations? The answer to these questions can help the decision-makers to reflect on the desirability of future fuel cycles, the aim being to support Research and Development paths that could culminate in the industrialization of a certain desired technology.

In Chapter 5, I have chosen the *morally desirable* fuel cycle. To that end I have first specified how to contemplate justice in relation to posterity. Brian Barry's egalitarian principles of distributive justice were followed: "the overall range of opportunities open to successor generations should not be narrowed. If some openings are closed off by depletion or rather irreversible damage to the environment, others should be created (if necessary at the cost of some sacrifice) to make up" (see Barry: 1978, 243). If we assume that welfare significantly relies on the availability of energy resources, depleting a non-replaceable resource will affect future welfare, which creates the moral obligation to offer some sort of compensation to ensure that future generations will have the opportunity to secure for themselves welfare. The second intergenerational aspect of the discussion related to nuclear energy has to do with the generation of long-lived radiotoxic waste which, if not properly disposed of, can influence the safety and security of future generations and cause them harm. The ensuing moral obligation is thus to avoid harming posterity or at least to not endanger the safety and security of people living in the future. This is a fundamental condition if future generations are to enjoy equal opportunities.

As nuclear power production predominantly produces present benefits with deferred costs for future generations, I have argued that the desirable cycle should primarily safeguard the opportunities open to future generations 1) by guaranteeing the availability of resources and 2) by not harming future generations. Technological solutions could be presented to best comply with these duties. The breeder fuel cycle, for instance, considerably extends the durability of resources and complies best with the first duty, while the P&T cycle substantially reduces the waste life-time and therefore also the possible safety and security burdening of posterity. The question has further been explored by asking which technology should be preferred when different duties are best accomplished with different technologies. I have argued that – in all-things-being-equal situations – the duty not to harm future generations extends farther into the future and is more compelling. This supports the motion to introduce P&T fuel cycles.

Adopting a morally desirable fuel cycle has further implications for the final waste disposal choice. Assuming that the arguments I have given in Chapter 2 are correct, to the effect that the proposed distinction between different future generations is morally unjustified, we should be urged to reconsider waste management options in order to avoid making this distinction. I have argued that as a method that substantially reduces the waste life-time P&T challenges the need for geological repositories while at the same time placing long-term surface storage in a totally new perspective, since such storage facilities can be used to dispose of waste with much shorter life-time.

6.3. Assumption and possible objections

The dissertation is founded on the assumption that nuclear power production and consumption create a problem of justice in relation to posterity. There are at least two factors that support this assumption. Firstly, like with fossil fuel, with the production of nuclear energy we are depleting a non-renewable resource (uranium) that will not then be available to future generations. Secondly, the retaining of long-lived radiotoxic waste brings with it possible harmful consequences for future generations. To what extent the conclusions I present are undisputed depends to a great extent on the question of whether others share this assumption. It is further thinkable that some may not shares what I find morally important in terms of the moral values presented in this dissertation. I have endeavored to avoid such problems by presenting a set of *intersubjective* values (in Chapters 3 and 4) that could, in principle, be shared by everyone. The differences are in the way values are prioritized and traded off against one another that are different, rather than to how an isolated value is perceived. Even the nuclear power opponents should be able to adopt this framework to argue why and on the basis of which considerations (or moral values) they refute this technology; considerations of justice for future generations are often implicitly referred to in opponents' arguments.

I suspect that the answer I have given to the first research question will therefore be less disputed; I expect that more contention would potentially arise from the normative analysis presented in the second question. Some people might, for instance, rank the values at stake in a different way and so reach a different set of conclusions regarding fuel cycle desirability. My conclusion with respect to the second research question also depends on my assumption that future radiation risks should not be discounted. Had this assumption not been made a different fuel cycle would probably have been more desirable. The additional current burdens that the P&T cycle creates, as I have demonstrated in Chapter 4, could be a further reason for some people to want to refute my conclusion. In Chapter 5, I have discussed three objections to these additional current burdens in order to examine whether this no harm duty holds when viewed in the context of intergenerational conflict of interests.

The first objection relates to the possibility of disposing of the waste in geological repositories; but as has been demonstrated by the American example, designing such a repository violates the equality principle with regard to remote future generations. The second objection queries the very legitimacy of these additional burdens for contemporaries. However this reasoning errs as it wrongly shifts the burdens of proof. Assuming that it is the present generation that has predominantly benefited from nuclear power, the default situation should then be that this generation remains primarily responsible for dealing with its waste; it is therefore the transferring of these risks to remote future generations, thus putting them at a disadvantage, that requires justification. The third objection relates to the distribution of these additional burdens among contemporaries. It has been argued by some scholars that the least well-off in society are generally exposed to higher safety and health risks (see Bullard: 1994; Wigley and Shrader-Frechette: 1996), one could argue that heightening such environmental injustice by introducing P&T would be highly undesirable. Even though this argument mistakenly presupposes that current injustice will necessarily continue, it emphasizes the necessity of addressing the intragenerational justice issue when opting for such a fuel cycle.

6.4. Moral norms and policy implications

In this dissertation I have applied the principles of intergenerational distributive justice to nuclear power production and its future developments. Several moral principles with regard to future generations have been presented and specified by highlighting and addressing the moral dilemmas and trade-offs that policy-makers are faced with; the framework of intergenerational justice has been adapted to moral reflection on fuel cycles.

What is now the relationship between these principles with policies? How influential could and should these principles be when policy-makers need to deal with serious choices and trade-offs? Let me explore this issue by giving an example: one major principle in international agreements is that we should avoid placing "undue burdens" on future generations. This principle has been proposed by IAEA (see 1995) and endorsed by all members of IAEA and it is a part of current national policy-making on nuclear waste management. However, what this "undue burdens" clause entails remains a subject of moral discussion. Indeed, we cannot completely prevent harm to future generations and as the principle implies, there must then be a certain degree of *due burdens* that we are allowed to impose on posterity. Many nations believe that disposing of waste underground best complies with this intergenerational principle (see NEA-OECD: 1995); the possible harmful consequences of a geological repository in the long run is then tacitly taken to be *due harm*. However, as I have argued in Chapter 2, building a repository necessitates sanctioning a distinction between different future individuals and exposing distant future generations to a much higher risk of radiotoxicity; but the latter lacks solid moral justification. Therefore it is important to take these discussions to the more fundamental level of what our relationship with posterity is and what obligations we have to it before we can address the implications for policy purposes.

In such a moral analysis we should certainly incorporate the social and economic context in which policies are articulated. I have presented the option for an open or closed fuel cycle as a matter of justice between generations. However, this has not so far been the decisive argument in choosing a fuel cycle.

The United States, for instance, does not favor the closed fuel cycle because of the problem of proliferation risk while a potential proliferator might well prefer the closed fuel cycle for exactly that reason. There are also countries with few natural resources, like Japan, that choose the closed fuel cycle in order to become less dependent on the import of resources. My conclusions might not furthermore persuade everybody because there is also the matter of the additional effort that P&T development requires: i.e. the developing and building of new reprocessing technologies, the building of fast reactors, the accepting of the additional safety and security burdens of reprocessing and P&T activities. Last but certainly not least, in policy-making there is the question of the legitimacy of the financial efforts that are required to make all of this happen. Indeed, these considerations have always been crucial to policy-making and will most probably always remain so. However, what we tend to forget is that our choices today have serious consequences for the interests of the people who happen to come after us. I am therefore endeavoring to shift the focus of the analysis on nuclear energy production and nuclear waste management policies. In other words, since we, the present generation, are enjoying the lions' share of the benefits of nuclear power; justice requires us to remain responsible for its burdens.

The challenges mentioned should not, however, be taken too lightly. Serious questions have been raised about the benefits of reprocessing as it adds, for instance, to the technical complexity of waste management while at the same time increasing the total volume of different types of waste[129] (see Berkhout: 1991, 181). The long-term advantage of less long-lived radiotoxic waste furthermore relies on the serious assumption that the separated plutonium and uranium will eventually be eliminated; the accumulation of the global stockpile of separated civilian plutonium and its associated proliferation risks does not provide compelling reasons to continue on this path (see Von Hippel: 2007)[130]. Reprocessing plants are furthermore believed to constitute an unnecessary threat to non-proliferation regimes, like for instance in South Korea which intends to build one (see Von Hippel: 2010) Some scholars argue that the current practice of one-round reprocessing and the recycling of spent fuel (by fissioning these materials in Light Water Reactors as fuel) would not reduce the long-term risks of a geological repository; in order to accomplish the substantial

129 The volume of long-lived troublesome isotopes will decrease but at the same time reprocessing produces serious amounts of Intermediate and Low Level Waste.

130 In Section 3.6.2. I discuss this argument in detail.

long-term reduction of radiotoxicity we need to deploy multiple recycling and fast reactors (see Bunn: 2006, 7). It has further been argued that the track record of developments of fast reactors is not very convincing; there are still concerns about unresolved safety and proliferation issues and fast reactors are far from economically competitive (see Cochran et al.: 2010).

My claim in this dissertation is not that all fuel cycles should be henceforth based on P&T. Before P&T can be introduced, decades of research and development still need to take place. Several technological challenges, both in the development of reprocessing technologies and in the development of fast reactors still have to be met and the development and ultimate deployment of P&T will create considerable burdens (including certain economic burdens) for contemporaries. What I argue here is that P&T should be high on the research agenda so that it can become a serious alternative in the near future; one that is both technically feasible and economically affordable. The decision-maker should be aware of the technological state-of-the-art and of the cost that the development of a certain (desirable) technology creates for the present generation; this dissertation aims to contribute to that awareness. In light of considerations concerning intergenerational justice, decision makers should eventually be able to reach decisions on future nuclear fuel cycles.

6.5. The general desirability and future research

As the demand for energy increases and hydrocarbon fuels with their gaseous by-products become less appealing, nuclear power is increasingly attracting attention as an alternative fuel. I started this dissertation by circumventing the general desirability debate surrounding nuclear energy. It is, however, worthwhile considering what this analysis can contribute to that highly relevant public and political discourse. First of all, when reflecting on the desirable *energy mix* one needs to consider nuclear energy in relation to other energy sources; the moral insights offered in this research could help one distinguish between different fuel cycles, all of which can facilitate a comparison between a certain nuclear fuel cycle with another specific energy system. A similar analysis as the one I have discussed in this dissertation could be presented to include other non-renewable energy systems such as fossil fuels. We have every reason to believe that the depletion of these conventional hydrocarbon resources and the emission of greenhouse gases with all the ensuing climate problems raise an intergenerational problem (see Page: 1999b; Shue: 1999; Gardiner: 2001). Such analysis could help us to establish the desirable energy mix in line with the burden-benefit distribution notion between different generations. We can for instance compare the P&T cycle with its waste that remains radiotoxic for a couple of hundred years with a certain fossil fuel system that contribute to a change in the climate system. Such comparison could be made based on considerations of intergenerational justice, or on how they affect the interest of *both* the present and future generations. Not only does this add more accuracy to the debate but it also enables an ethically informed discussion to take place on the future energy mix and the possible role of non-renewable energy systems (such as fossil fuel and nuclear energy) in a transition towards renewable energy systems.

Specifying what is morally at stake also has implications for future research on nuclear technology, particularly in the field of reactor design. A nuclear reactor should meet certain criteria that are potentially conflicting: it should be resistant to the risk of melt-down, generate electricity in a highly efficient way, consume as few as possible resources and produce no weapon-grade by-products or long-living nuclear waste. A *perfect* nuclear reactor should then address conflicting design criteria and the ensuing trade-offs. A pro-active ethics of technology approach could be presented through the concept of Value Sensitive Design (see Friedman et al.: 2002) which systematically accounts for human values in design in order to incorporate the relevant moral values into the design process.

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Summary

This dissertation provides a moral analysis of different nuclear fuel cycles and is based on the notion that the burdens and benefits between generations should be justly distributed or, in other words, that there should be such a thing as intergenerational justice. In producing and consuming nuclear power we are creating a problem of justice for posterity, since we are depleting a non-renewable resource (i.e. uranium) that will eventually not be available to future generations. Furthermore, the phenomenon of long-lived radiotoxic waste adds another intergenerational dimension to the problem. I argue that since we – the present generation – will enjoy the lion's share of the benefits created by nuclear power, we have a moral obligation to also deal with its burdens. Two specific research questions have been explored in this dissertation. Firstly that of how we can approach the moral dilemmas connected with nuclear fuel cycles within the framework of intergenerational justice and secondly the matter of which fuel cycle is most desirable from a moral perspective?

In Chapter 2, I review how the notion of intergenerational justice has influenced current discussions relating to nuclear energy and, in particular, to nuclear waste management. The International Atomic and Energy Agency has argued that we should avoid imposing "undue burdens" on future generations. Many nations believe that this principle is best complied with by disposing of waste in geological repositories rather than in long-term surface storage facilities; repositories are believed to best guarantee the safety of future generations. In planning repositories that are designed to isolate the waste for hundreds of thousands of years, we are confronted with substantial long-term uncertainties, all of which raise the question of what level of protection we should offer to remote future generations. In legislative documents relating to the Yucca Mountains repository in the state of Nevada in the United States, it has been argued that people living in the next 10,000 years deserve a level of protection equal to the current level but that generations of people living in the period extending beyond 10,000 years could be exposed to much higher radiation levels. I argue that such a distinction between different future generations lacks moral justification and so challenges the consensus to dispose of the waste underground.

The framework of intergenerational justice is one that may not only be applied to waste management discussions but which could also be extended to include the whole fuel cycle from the mining of uranium ore to the final disposal stage. In Chapters 3 and 4, I explore how to approach the moral dilemmas connected with the nuclear fuel cycles discussed within this framework. I first investigate what is morally at stake and identify the following moral values: resource durability (supply certainty), radiological risk to the environment (environmental friendliness), radiological risk to the public (public health and safety), economic affordability (or economic durability) and the security concerns surrounding the using of the technology for destructive purposes (that is to say for proliferation).

In Chapter 3 I compare the two existing nuclear fuel cycles which are known as open and closed cycles. These fuel cycles are similar until the first uranium irradiation phase in the reactor is reached. Precisely how the remaining *spent fuel* is dealt with determines the nature of the fuel cycle and therefore also the distribution of burdens and benefits between generations. With the open fuel cycle, spent fuel is viewed as waste and is supposed to be disposed of underground and isolated from the biosphere for 200,000 years. The open fuel cycle variant is mainly associated with short-term advantages, as it creates relatively less radiological risk and thus fewer public health and environmental concerns; larger radiological risks are thus projected into the future in the form of long-term waste disposal. On the other hand the closed fuel cycle could be linked to long-term resource durability because spent fuel is seen as a resource that can be reprocessed to extract deployable materials (uranium and plutonium), which then re-enter the fuel cycle. The closed fuel cycle is further capable of reducing the waste life-time by a factor 20 to 10,000 years. Reprocessing is, however, a very complex chemical process. It is very costly and only available in very few countries in the world. More importantly, during reprocessing plutonium is separated and that creates serious concerns in relation to the proliferation of nuclear weapons. In short, the choice between the two existing fuel cycles can be reduced to a matter of justice between generations.

In Chapter 4 a way of providing insight into the intergenerational distribution of burdens and benefits in alternative future fuel cycles is presented. Two prospective fuel cycles are explored from the point of view of the intergenerational distribution of burdens and benefits. The first alternative is an extended closed fuel cycle based on the separating (partitioning) of long-lived isotopes in spent fuel in order to eliminate them (have them transmuted) in fast reactors, all of which reduces the waste life-time to several hundred years; this is known as the Partitioning and Transmutation (P&T) fuel cycle. The same fast reactors could also be used in *breeder* configurations. In combination with multiple recycling, a breeder fuel cycle can produce (or breed) more fuel during operation than it consumes. The analysis provided in Chapter 4 shows that these fuel cycles will positively influence the interests of future generations. However, the additional safety, security and economic burdens that accompany the developing and industrializing of these fuel cycles will mainly be borne by the present generation.

In Chapter 5 I reflect upon what is seen as the *morally desirable* fuel cycle. To that end I first specify how to contemplate justice to posterity. Brian Barry's egalitarian principles of distributive justice are followed when it comes to not diminishing the opportunities of future generations (see Barry: 1978, 243). If we assume that welfare significantly relies on the availability of energy resources, depleting a non-replaceable resource will certainly affect future welfare. In addition, there is the presence of long-lived radiotoxic waste which, if not properly disposed of, can influence the safety and security of future generations. As nuclear power production predominantly meets present benefits and defers costs to future generations, I argue that the desirable cycle should primarily safeguard the opportunities open to future generations 1) by guaranteeing the availability of resources and 2) by not harming future generations; the latter could be seen as a fundamental condition if future generations are to enjoy equal opportunities. Two conditional duties have accordingly been formulated bearing in mind the fact that they might be overruled by more important duties like, for instance, those to the present generation. I argue that if we continue to deploy nuclear power, then Partitioning and Transmutation (P&T) is the fuel cycle that should be preferred from a moral perspective, since it substantially reduces the waste life-time and therefore also best safeguards the interests of future generations. P&T furthermore challenges the need for geological disposal thus placing surface storage in a new light since such storage facilities can be used to dispose of waste with a much shorter life-time (Chapter 2).

What, now, is the relationship between these principles and duties and policies? I have presented the open or closed fuel cycle choice as a matter of justice between generations. However, this has not been the decisive argument so far put forward when choosing fuel cycles. The United States, for instance, does not favor the closed fuel cycle because of the proliferation risk while a potential proliferator might prefer the closed fuel cycle for exactly that reason. There are also countries with few natural resources, like Japan, that choose the closed fuel cycle in order to become less dependent upon imported resources. My conclusions might not appeal to everybody as decades of developing new reprocessing technologies and fast reactors will be required, all of which create serious safety, security and economic burdens for the present generation, before P&T can be implemented. Indeed, the aforementioned considerations have always been, and will probably always remain, crucial to policy-making. However, what we tend to forget is that the choices we make today have serious consequences for the interests of all the other people who come after us. Hence my reasons for endeavoring to redirect the nuclear energy production and nuclear waste management policy towards the interests of posterity without downplaying the importance of the additional burdens upon contemporaries. It is in light of these intergenerational justice considerations that we should choose our policies.

Samenvatting

Dit proefschrift presenteert een morele analyse van de verschillende nucleaire brandstofcycli, gebaseerd op de notie van een rechtvaardige verdeling van de lasten en lusten tussen de generaties, oftewel intergenerationele rechtvaardigheid. Vanuit een oogpunt van rechtvaardigheid, is de productie en consumptie van kernenergie problematisch voor toekomstige generaties. We putten immers een niet-hernieuwbare bron uit, uranium, waardoor toekomstige generaties minder energiebronnen hebben. Daarnaast brengt kernafval ook nog eens langdurig een potentieel stralingsgevaar met zich mee. Aangezien wij, de huidige generatie, het meeste profijt hebben van de voordelen van kernenergie, betoog ik dat we ook voor de gevolgen en nadelen ervan verantwoordelijk zijn en blijven. Twee specifieke onderzoeksvragen zijn bestudeerd: 1) Hoe kunnen we, binnen het kader van de intergenerationele rechtvaardigheid, de morele dilemma's die de brandstofcycli met zich meebrengen, het best benaderen? En 2) welke brandstofcyclus is vanuit een moreel oogpunt de meest wenselijke?

In hoofdstuk 2 laat ik zien hoe de notie van intergenerationele rechtvaardigheid de huidige kernenergiediscussie heeft beïnvloed, hoofdzakelijk in relatie tot de eindopslag van kernafval. Het Internationaal Atoomenergie Agentschap (het IAEA) stelt dat het beheer van kernafval geen 'buitensporige lasten' mag veroorzaken voor de toekomst. De consensus in veel kernenergieproducerende landen is dat geologische opslagplaatsen het beste aan deze voorwaarde voldoen, omdat ze langdurige veiligheid kunnen waarborgen. Maar die langdurige veiligheid van honderdduizenden jaren gaat gepaard met grote onzekerheden, die het ontwerpen van geologische opslagplaatsen erg moeilijk maakt. Ik laat zien hoe de beleidsvorming reageert op deze onzekerheden aan de hand van de opslagplaats onder de Yucca Mountains in de staat Nevada van de Verenigde Staten. De officiële wetsteksten stellen dat generaties in de verre toekomst weliswaar bescherming moeten genieten, maar niet noodzakelijkerwijs op hetzelfde niveau als dat wij tegenwoordig acceptabel vinden en dat de mensen over 10,000 jaar aan een veel hoger niveau van straling blootgesteld mogen worden. Ik beargumenteer dat dit onderscheid tussen verschillende toekomstige generaties een solide morele grond ontbeert en dat de consensus om kernafval ondergronds op te slaan daarom niet onweersproken mag blijven.

Naast de rol die de notie van intergenerationele rechtvaardigheid in kernafvalbeheer speelt, is het ook een bruikbare notie voor het analyseren van de complete brandstofcycli. In hoofdstukken 3 en 4 bespreek ik de morele dilemma's die voortkomen uit diverse brandstofcycli. Allereerst bespreek ik wat er in een brandstofcyclus op het spel staat. Voorts verbind ik deze zaken met de (impliciete) morele overwegingen – of waarden – die daaraan ten grondslag liggen. De volgende waarden zijn daartoe geïdentificeerd: i) voorzieningszekerheid van de energiebronnen; ii) stralingsrisico's voor het milieu, oftewel milieuvriendelijkheid; iii) stralingsrisico's voor het publiek, oftewel volksgezondheid; iv) economische haalbaarheid; en v) de veiligheidsoverwegingen gerelateerd aan het gebruik van nucleaire technologie voor destructieve doeleinden, oftewel proliferatie.

In hoofdstuk 3 vergelijk ik de twee bestaande brandstofcycli om kernenergie te produceren: de open en gesloten cyclus. Beide cycli verlopen nagenoeg hetzelfde tot na de eerste bestraling van de splijtstof (uranium) in de reactor. In de open cyclus wordt de bestraalde splijtstof beschouwd als afval; na een relatief korte periode van tijdelijke opslag op de grond hoort dit afval dan ondergronds opgeslagen te worden voor een periode van circa 200.000 jaar. De open cyclus kent hoofdzakelijk kortetermijnvoordelen; op de lange termijn scoort deze cyclus namelijk minder goed, omdat de risico's die het langdurig opslaan van het afval met zich meebrengt op de koop toe worden genomen. De gesloten cyclus heeft daarentegen vooral langetermijnvoordelen. De reden hiervoor is dat een gesloten cyclus uitgaat van het recyclen (opwerken) van de bestraalde splijtstof en het hergebruik van de bruikbare materialen (uranium and plutonium) voor energieproductie; het reduceert verder de levensduur van het afval tot circa 10.000 jaar. Echter, de gesloten cyclus produceert meer risico's en lasten voor de huidige generatie: de opwerking is een dure onderneming die extra stralingsrisico voor mens en milieu creëert, en tijdens het opwerken komt er plutonium vrij, hetgeen bruikbaar is in een kernwapen. Ik betoog dat kiezen tussen deze cycli het beste kan worden gezien als een rechtvaardigheidskwestie tussen de generaties.

Naast het evalueren van de bestaande cycli is het ook wenselijk om de intergenerationele conflicten van toekomstige cycli in kaart te brengen; dat zal ons helpen in het bewust ontwerpen van nieuwe brandstofcycli en het onderzoeken van de wenselijkheid daarvan. In Hoofdstuk 4 is een methode ontwikkeld om inzicht te verschaffen in de intergenerationele spreiding van voor- en nadelen van alternatieve brandstofcycli. Twee toekomstige brandstofcycli zijn verder onderzocht volgens deze methode. Allereerst bestudeer ik een uitgebreide gesloten cyclus waarin de langlevende isotopen na de opwerking verder worden afgescheiden (partitie) om vervolgens te worden geëlimineerd (transmutatie) in snelle reactoren; deze methode wordt Partitie en Transmutatie (P&T) genoemd en kan in principe de levensduur van het resterende afval reduceren tot enkele honderden jaren. De andere alternatieve brandstofcyclus is ook gebaseerd op een snelle reactor, zij het in de configuratie van een kweekreactor en in combinatie met meervoudige recyclering; een kweekreactor kan in principe meer brandstof produceren dan hij consumeert. De analyse in hoofdstuk 4 laat zien dat beide alternatieve brandstofcycli de belangen van de toekomstige generaties beter respecteren, hetzij door het beter waarborgen van voorzieningszekerheid van energiebronnen, hetzij door het reduceren van de levensduur van het afval. Echter, de additionele veiligheidsrisico's en economische lasten die deze cycli creëren komen hoofdzakelijk voor rekening van de huidige generatie, die deze methode moet ontwikkelen en industrialiseren. Dit hoofdstuk beperkt zich tot een descriptieve analyse.

In het slothoofdstuk (5) reflecteer ik op de morele wenselijkheid van de bestaande en de toekomstige brandstofcycli. In navolging van Brian Barry, beargumenteer ik dat het waarborgen van intergenerationele rechtvaardigheid bovenal inhoudt dat we de kansen en mogelijkheden van toekomstige generaties niet nadelig mogen beïnvloeden. Aangezien wij het meest profijt hebben gehad van de productie van kernenergie, zou een moreel wenselijke brandstofcyclus primair benaderd moeten worden in termen van het respecteren van de gelijke kansen en mogelijkheden van toekomstige generaties. Indien we aannemen dat de aanwezigheid van energiebronnen sterk gerelateerd is aan het maatschappelijke welzijn, dan mogen we veronderstellen dat het uitputten van niet-hernieuwbare bronnen de kansen voor het toekomstige welzijn negatief zal beïnvloeden. Voorts kan het overblijven van afval – mits niet behoorlijk opgeslagen – de veiligheid van de toekomstige generatie in gevaar brengen. Twee morele plichten zijn dienovereenkomstig geformuleerd: 1) we moeten de beschikbaarheid van natuurlijke energiebronnen waarborgen en 2) we moeten voorkomen dat de mensen van later schade door ons oplopen; deze laatste is een basisvoorwaarde die vervuld moet zijn opdat de toekomstige generaties hun gelijke kansen kunnen benutten. Deze plichten zijn als *prima facie* – of voorwaardelijke – plichten geformuleerd, wat aangeeft dat ze zouden kunnen moeten wijken voor belangrijkere plichten, bijvoorbeeld bepaalde plichten jegens de huidige generatie. Ik beargumenteer dat als wij door willen gaan met de productie van kernenergie, P&T de brandstofcyclus is die de voorkeur verdient. Immers, deze cyclus reduceert de levensduur van het afval substantieel en bevordert daarmee het beste de belangen van de toekomstige generaties. Een bijkomend voordeel van deze cyclus is dat de langdurige opslag op de grond, als alternatief voor de geologische opslag, in een nieuw daglicht komt staan, wat een onderscheid tussen toekomstige mensen overbodig maakt (Hoofdstuk 2).

Hoe verhouden deze principes zich tot de beleidsvorming? De keuze tussen een open en gesloten cyclus presenteer ik hier als een kwestie van rechtvaardigheid tussen de generaties, maar de eerlijkheid gebiedt te zeggen dat deze overwegingen tot nu toe weinig invloed hebben gehad in de beleidsvorming. De Verenigde Staten mijden bijvoorbeeld een gesloten cyclus vanwege het inherente probleem van proliferatie (tengevolge van de afscheiding van plutonium), terwijl een potentiële proliferator juist om die reden een gesloten cyclus zou prefereren. Weer andere landen die weinig natuurlijke grondstoffen hebben, zoals Japan, kiezen een gesloten cyclus, vooral omdat het over een langere periode energiezekerheid en daarmee onafhankelijkheid van andere landen geeft. Mijn conclusies zouden verder overtuigingskracht kunnen verliezen omdat de werkzaamheid van P&T alleen nog op laboratoriumschaal is aangetoond. Nog decennia van ontwikkeling en investering zijn nodig voordat deze cyclus op grote schaal toegepast kan worden; de bijkomende risico's en lasten van deze ontwikkeling komen grotendeels voor rekening van de huidige generatie. Dit zijn overwegingen die altijd belangrijk zijn geweest en waarschijnlijk belangrijk zullen blijven in de toekomst. Wat wij echter geneigd zijn om te vergeten is dat onze keuzes vandaag grote gevolgen kunnen hebben voor allen die na ons zullen komen. Deze dissertatie doet een poging om de focus van de discussies rondom kernenergie en het kernafvalbeheer te verschuiven naar het waarborgen van de belangen van de toekomstige generaties, waarmee ik echter de mogelijke extra lasten voor de huidige generatie absoluut niet bagatelliseer. Wij zouden ons beleid in de toekomst moeten voeren in het licht van het intergenerationele conflict.

About the author

Behnam Taebi (1977) obtained his master's degree in Material Science and Engineering at Delft University of Technology in 2005. He also completed an additional minor in Public and Business Administration at the faculty of Technology Policy and Management. Before starting on his PhD research Taebi held a position as lecturer within the Department of Philosophy at TU Delft for one year. Whilst doing his PhD research he continued to teach on a part-time basis. In January 2007, he embarked on his PhD research into nuclear power and considerations of justice between generations, which was funded by the 3 TU Centre for Ethics and Technology. During that period he spent three months at the Massachusetts Institute of Technology (2008) as a visiting researcher and another three months, also as a visiting scholar, at the University of Washington (2009). He is currently employed by the Department of Philosophy.

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Simon Stevin (1548-1620)

'Wonder en is gheen Wonder'

This series in the philosophy and ethics of technology is named after the Dutch / Flemish natural philosopher, scientist and engineer Simon Stevin. He was an extraordinary versatile person. He published, among other things, on arithmetic, accounting, geometry, mechanics, hydrostatics, astronomy, theory of measurement, civil engineering, the theory of music, and civil citizenship. He wrote the very first treatise on logic in Dutch, which he considered to be a superior language for scientific purposes. The relation between theory and practice is a main topic in his work. In addition to his theoretical publications, he held a large number of patents, and was actively involved as an engineer in the building of windmills, harbours, and fortifications for the Dutch prince Maurits. He is famous for having constructed large sailing carriages.

Little is known about his personal life. He was probably born in 1548 in Bruges (Flanders) and went to Leiden in 1581, where he took up his studies at the university two years later. His work was published between 1581 and 1617. He was an early defender of the Copernican worldview, which did not make him popular in religious circles. He died in 1620, but the exact date and the place of his burial are unknown. Philosophically he was a pragmatic rationalist for whom every phenomenon, however mysterious, ultimately had a scientific explanation. Hence his dictum 'Wonder is no Wonder', which he used on the cover of several of his own books.

When we produce nuclear power we are depleting a non-renewable resource (uranium) that will eventually not be available to future generations. Furthermore the ensuing nuclear waste needs to be isolated from the biosphere for long periods of time to come. This gives rise to the problem of justice to posterity or inter-generational justice. Different production methods or nuclear fuel cycles address these issues differently which is why we first need to carefully scrutinize all the possibilities. This book presents just such an analysis by investigating how the various fuel cycles employed will affect the interests of future generations.
It combines philosophical discussions on justice to future generations with the technological realities of nuclear power production: what is our moral obligation to posterity and to what extent can existing technologies help us to meet such obligations? Which scientifically feasible future technologies have the potential to help us to comply with these obligations better? The answers to these questions can help decision-makers to reflect on the desirability of future fuel cycles, which again will support Research and Development paths for the final industrialization of a certain desirable technology.

'Wonder en is gheen wonder'

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