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Ethics of Nuclear Power: How to Understand Sustainability in the Nuclear Debate

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1. Introduction

With the nuclear accidents in Fukushima Daiichi in Japan, the global public and political debate on nuclear power is rapidly reaching boiling point. On the one hand, it seems that nuclear power is losing public support. Japan intends to review its nuclear policy – one in every eight nuclear reactors is currently in that country – and China have planned one-year moratoriums on new nuclear power constructions. China's position is relevant since the country is set to become a world leader in the next decades: China currently has 13 operational nuclear power reactors, 27 reactors under construction, 50 planned and 110 that are proposed (WNA, 2011). More concretely, pro nuclear stances have led to a loss of political power in Angela Merkel's party in different regions in the recent German elections; Merkel's administration recently decided to phase out all German nuclear reactors (Dempsey & Ewing, 2011). Furthermore, the Swiss government abandoned plans to build new reactors and Italians rejected nuclear energy in a referendum. On the other hand, the extent of our dependency on nuclear power makes one wonder whether we are witnessing the end of the nuclear era; approximately 16% of the world's electricity is currently being produced in nuclear power plants. Perhaps it is more likely that a certain pragmatism with regard to securing domestic energy supplies and curbing carbon dioxide emissions will eventually dominate the debate; see in this connection president Barak Obama's recent plan to cut American oil import and diversify, indeed, in the direction of renewable energy, but to also include nuclear power (Wynn & Doyle, 2011).

Now, more than ever before, there is a need to reflect on the desirability of nuclear power. In such analysis proponents stress the abundant availability of nuclear resources, 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 conventional energy sources that mainly have to be imported from other parts of the world. The detractors, on the other hand, would emphasize the accident risks of reactors – the unfolding disaster in Japan speaks for itself – the waste transport risks, the proliferation concerns or worries about the possibility that such technology can always be deployed for destructive purposes and, indeed, the matter of what to do with the long-lived radiotoxic waste.

In this paper, I do not intend to get involved in the general desirability debate. I assert that when carefully reflecting on the desirable *energy mix* for the future one needs to consider

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 effects that long-lived waste could have upon 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. This paper presents this comparison by focusing on the notion of sustainability and its philosophical origins in justice between generations, alternatively known as *intergenerational justice*.

Some people might object that *sustainable nuclear power* is a *contradictio in terminis*. Their objections probably arise from the fact that nuclear power leaves behind highly dangerous toxic waste with tremendous long life-times. This correctly relates to one interpretation of sustainability, but in a comprehensive analysis we need to include all the relevant interpretations. Sustainability could, for instance, also be seen as the endurance of energy resources for future generations. New technology in nuclear power production (i.e. nuclear breeders and multiple recycling of the waste) could facilitate the latter for a very long time. So, nuclear might be unsustainable in one interpretation and sustainable in another; precisely which one should be given priority might emerge after thorough moral analysis. Rather than using *sustainability* as an adjective, this paper sets out to clarify the notion by focusing on how nuclear power production affects the distribution of burdens and benefits over the different generations. Such an analysis can help decision-makers in the making of technically and ethically informed choices, when opting for a certain nuclear fuel cycle. It could also help when comparing nuclear power or, more to the point, a certain nuclear fuel cycle with other energy systems on the basis of the notion of how they affect the interests of people living now and in the future.

The paper consists of seven sections. In Section 2, I will elaborate on the ethical aspects of the notion of sustainable development, arguing that sustainability and intergenerational justice are closely intertwined. This section further elaborates on the question of what we should sustain for posterity. Section 3 focuses on a set of moral values which, together, encompass the value of sustainable development. These moral values will then be operationalized and connected to different steps of nuclear fuel cycles in Section 4. The latter Section further elaborates on the intergenerational conflicts between the values. The role of new technologies will be addressed in Section 5 and Section 6 reviews three challenges when assessing the social and political desirability of nuclear power. The final section concludes the paper with the findings in brief.

2. Sustainability and ethics

In the second half of the last century there was growing public awareness of the fact that the earth is a *living space* that we not only share with our ancestors but also with our children and grandchildren and with their offspring. The natural resources upon which our economies heavily depend seem to be running out as a result of the ever-rising world population and industrialization. In addition, the accompanying pollution presents a serious problem; we have been urged by the Club of Rome to consider 'The Limits to Growth' (Meadows et al., 1972). So, the technological progress that had once brought wealth and prosperity has come to create concerns for people living now and in the future. These genuine concerns eventually culminated in an Environment and Development report published by a United Nations' commission with the very telling title 'Our Common Future'. The first systematic definition of sustainable development emerged as an attempt to

balance economic growth and industrialization on the one hand with environmental damage on the other. Sustainable development as a kind of development that “meets the need of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987, 43) was named after the commission’s chairwoman, the then Norwegian Prime Minister, Gro Harlem Brundtland.

Many of the analyses regarding the desirability of nuclear power seem to revolve around this notion of sustainable development and the specific interpretations made by different scholars and organizations (Elliott, 2007; IAEA, 2006; Turkenburg, 2004). The implicit assumption seems to be that sustainability is synonymous with social and political desirability. Proponents find nuclear energy sustainable as it can produce clean, secure and reliable electricity that does not put the earth’s climate in jeopardy (Bonser, 2002); other enthusiasts have more reservations but maintain that nuclear power can contribute to sustainable development in a “transitional role towards establishing sustainable [renewable] energy systems” (Bruggink & Van der Zwaan, 2002, p.151). The latter endorse the popular opinion that we are facing an “energy gap” in the coming decades which can only be filled with nuclear power (Connor, 2005; Pagnamenta, 2009). The detractors, on the other hand, are utterly resolute in their view that nuclear power is inherently “unsustainable, uneconomic, dirty and dangerous” (GreenPeace, 2006).

Even though Brundtland’s definition has been very influential in the academic and public domain, it requires further clarification, particularly from an ethical point of view. In other words, sustainability is not only a *descriptive* notion, merely stating the facts about the subject of a matter, but also one that should express *normative* opinions about what it is that we *should* sustain, why and how we *should* sustain it and for whom and how long we *should* sustain it (Raffaella et al., 2010). In this paper I will focus on these normative aspects in the case of nuclear power deployment. In the next section, sustainability will be presented as an overarching moral value encompassing certain other values.

Before getting into detailed discussion about what exactly sustainability should protect, let us pause for a moment to elaborate on the philosophical roots of the notion of sustainability. Brundtland’s sustainability is founded on principles of social justice viewed from two main angles: 1) the distribution of wealth among contemporaries or the *spatial* dimension and 2) the distribution of burdens and benefits between generations or the *temporal* dimension. Sustainability also has a third main theme, namely that of the relationship that human beings have with their natural environment which, again, has both a spatial and a temporal dimension. The question of how to value the environment in a moral discussion will be addressed in Section 3.

The two social justice notions that underlie sustainability are referred to as *intragenerational* and *intergenerational* justice. Obviously, in nuclear energy discussions intragenerational justice is relevant, for instance when addressing the question of where to build a nuclear reactor or in connection with issues concerning the distribution of the burdens and benefits between contemporaries; see for instance (Kasperson, 1983; Kasperson & Dow, 2005; Kasperson & Rubin, 1983). In this paper I will mainly focus on the long-term consequences of nuclear power and on the complex questions of intergenerational justice to which that gives rise; in Section 6 I will briefly discuss the issues of intragenerational justice.

2.1 Intergenerational justice and nuclear power production

Let me present and briefly discuss the central claim that underlies my analysis, namely that the production of nuclear power creates a problem of intergenerational justice. There are

two intergenerational aspects in nuclear power production that support this claim. Firstly, nuclear energy is produced from a non-renewable resource (uranium) that will eventually be less available to future generations. Stephen Gardiner (2003, 5) refers to this problem as “The Pure Intergenerational Problem” (PIP), which is in fact an exacerbated form of the Tragedy of the Commons, extended over generations. The Tragedy of the Commons is a situation in which various rational agents might be inclined to deplete limited resources on the basis of their own self-interest, while the same action will negatively affect the collective interest. The dilemma was first illustrated in an article compiled by Garrett Hardin, in which he pictured a pasture open to many herdsmen (Hardin, 1968). It is in individual interest of each herder to keep as much cattle as possible on the common ground while in collective terms such a strategy would culminate in the fast depletion of the common. Gardiner extends this argument to include different 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. It is in the individual interest of each generation to use as many as possible of these commodities, but it is in the collective interest of all temporally diffused generations if earlier generations would avoid depletion. Hence, engaging in activity with these goods poses the problem of justice between generations.

A second intergenerational aspect is the long-term consequences (e.g. pollution) that could be created for future generations, while benefits mainly accrue to the current (and immediately following) generations (Gardiner, 2003). A typical example of this intergenerational problem is the fossil fuel energy consumption situation, which is characterized by predominantly good immediate effects but deferred bad effects in terms of the anthropogenic greenhouse gas emissions that cause climate change. Intergenerational justice and climate change have received increasing attention in the literature in recent years (Athanasidou & Baer, 2002; Gardiner, 2001; Meyer & Roser, 2006; Page, 1999; Shue, 2003). The main rationale behind these discussions is that a change in a climate system that threatens the interests of future generations raises questions concerning justice and posterity.

Alongside the first (depletion) analogy that nuclear power production has with non-replaceable fossil fuel resources, both energy generation methods have potential long-term negative consequences in common. In the case of fossil fuel combustion, it is the emitting of greenhouse gases that can trigger long-term climatic change for posterity, while with nuclear power deployment, it is the creation of long-lived radiotoxic waste that could potentially pose safety and security problems to future generations. What exacerbates this problem is the fact that we – the present generation – are in a beneficial temporal position 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” (Gardiner, 2006).

Intergenerational justice has already been an influential notion in discussions related to nuclear energy, particularly in relation to nuclear waste issues. The International Atomic and Energy Agency (IAEA) has laid down several principles on Radioactive Waste Management, in which concerns about the future were expressed in terms of the “achievement of intergenerational equity”¹ (IAEA, 1995). It was asserted that nuclear waste

¹ It should be mentioned that equity entails a narrower notion than justice. However in this paper I do not make a distinction between the two notions.

should be managed in such a way that it “will not impose undue burdens on future generations” (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 (NEA-OECD, 1995). I will defer further discussion on this issue to Section 6.

2.2 What is it that we should sustain?

The notion of sustainable development implies that there is a certain good that we need to sustain for future generations. I will follow here Brian Barry (1999) in his discussions on the normative aspects of the notion of *sustainable development* and how that relates to the principle of intergenerational justice. Barry argues that there is an entity X which, as we enjoy it, should be *sustained* into the future so that future generations do not fall below our level of X. He then presents principles for the theorems of *fundamental equality*, two of which are the principle of responsibility – “[a] bad outcome for which somebody is not responsible provides a prima-facie case for compensation” – and the principle of vital interests: “locations 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” (Barry, 1999, p 97-99).

The ensuing question is what this valuable entity of X should be. Barry proposes *opportunity* as a metric of justice: one requirement of justice is that above all else “the overall range of opportunities open to successor generations should not be narrowed” (Barry, 1978, p 243). So, whilst adhering to the guiding principle that we should not narrow the total range of opportunities, I will develop two other sustainability principles that will lead to the matter of how this main principle relates to nuclear power generation, the main rationale being that whenever we find ourselves in a position to *negatively influence the opportunities open to future generations* we should be careful not to narrow these opportunities.

We should recall the two intergenerational aspects of nuclear power production and how they could affect posterity’s equal opportunity. Firstly, we leave behind radiotoxic waste with tremendously long life-time spans. If not properly disposed of, this waste can influence the *vital interests* of future generations and thus also, their equality of opportunity. Hence, the first moral principle I am defending urges us to sustain posterity’s vital interests. Secondly, we are depleting a non-renewable resource, to which posterity has less access. If we assume that well-being significantly relies on the availability of energy resources then we are in a position to influence future opportunity for well-being. From the latter I derive the moral principle that we should sustain future generations’ opportunity for well-being insofar as that can be achieved through the availability of such energy resources. In the following section I will discuss these principles in detail.

3. The moral values at stake

So far I have argued that the notion of sustainable development needs further ethical clarification which has been provided in terms of the two moral principles that we have with regard to posterity, namely 1) to sustain future generation’s vital interest and 2) to sustain human well-being in the future. In this section I will elaborate on how to understand these principles in terms of the moral values at stake. But let me first say something about the meaning of *value* and why I intend to approach sustainability from the angle of moral values.

Questions about rightness and wrongness are generally subsumed under the heading of *values*. In everyday life, there are many things we uphold such as honesty and integrity; those things are referred to as values and they inspire social norms in human interaction. Outside this common sense meaning of the term, values are also relevant to many of the choices that we make, also with regard to technology; they reflect our understanding of the rightness and wrongness of those choices. The term value indeed has definitions that extend beyond philosophy and ethics. We find many things such as art and music valuable without making any reference to their moral goodness or rightness; these are indeed non-moral values. The focus of this paper is confined to the moral values that deal with how we want the world to be. In other words, moral values are things worth striving for in order to achieve a good life (Scanlon, 1998, p 78-79). However, we should not confuse values with the personal interests of individuals; values are the general convictions and beliefs that people should hold paramount if society is to be good. Those values in relation to the notion of sustainable development will be reviewed here; what are the things that we find valuable when we refer to sustainability and why do we find them valuable? More importantly, which value should be given priority if different values contradict or cannot be complied with simultaneously?

3.1 Sustaining human safety and security and the environment

Let us remind ourselves that one interpretation of sustainable development is that we should sustain the vital interests of future generations. Let us then explore for a moment what exactly is meant by Barry's principle of vital interest and how that relates to the principle that I am defending here. Barry (1999, 105) argues that taking equal opportunity seriously means that "the condition must be such as to sustain a range of possible conceptions of the good life"; such a good life will, in any case, include "adequate nutrition, clean drinking-water, clothing and housing, health care and education". Here my understanding of vital interest is applied to a very specific sense. I argued earlier in this paper that whenever we are in a position to negatively influence future opportunities we should be careful not to narrow those opportunities. One clear way in which we can negatively affect future interest is by inappropriately disposing of nuclear waste. My account of future generation's vital interest relates to the status of the environment and to the safety and security of future generations in so far as they depend on the actions of present generations and how we dispose of our nuclear waste.

Something first has to be said about how to approach issues relating to the environment in a moral discussion. One important issue when addressing 'values' is to determine whether a thing is worth striving for for its own sake or because it serves a greater good. To put this in philosophical terms, we must establish whether something has an *intrinsic* value or whether it has an *instrumental* value, thus requiring reference to an intrinsic value. This discussion is particularly relevant to the way in which we value nature and address human beings' relationships with the natural world. Generally, we can distinguish between two schools of thought: 1) anthropocentrism that situates human beings in the center of ethics; this is alternatively known as human supremacy or human-based ethics and 2) non-anthropocentrism that ascribes an intrinsic value to nature. These discussions relate to one of the central questions in the field of environmental philosophy and it is not my intention to get involved in that debate here. But let me just make one remark.

When it comes to the relationship between humans and non-humans, it is probably uncontroversial to ascribe designations such as moral wrongness; torturing animals is, for

instance, morally wrong. However, our focus in this paper is upon justice to future generations and I follow Barry (1999, p 95) in his suggestion that “justice and injustice can be predicated only of relations among creatures who are regarded as moral equals in the sense that they weigh equally in the moral scales”. Hence, in addressing intergenerational justice in this paper, we refer to the environment with regard to what it means in conjunction with safeguarding the vital interests of human beings. Such considerations would emanate from radiation hazards resulting from possible seepage of radiotoxic material into the environment, which in turn could affect human health and safety. Thus, in the anthropocentric approach adopted in this paper, the moral value of *environmental friendliness* basically relates to the issues that the value of *public health and safety* will raise and so it will be subsumed under the latter value. Indeed, one could defend a non-anthropocentric account of intergenerational justice and separate these two values. However, in discussing the sustainability issues of nuclear power deployment, these environmental concerns relate to exactly the same radiation levels that are relevant when assessing public health and safety issues. The only difference would thus be that an intrinsic value has been ascribed to the environment. In other words, the consequences of radiation in the environment should then be addressed without making reference to what these means for human beings.

Public health & safety (environmental friendliness)

Sustainability could be taken to relate to human health and safety and to the status of the environment. In its Fundamental Safety Principles, IAEA (2006, p 5) takes safety to “mean the protection of people and the environment against radiation risks”; this definition implies that the IAEA is defending a non-anthropocentric viewpoint. The latter is reiterated in IAEA’s Principles of Radioactive Waste Management, in which one of the key principles relates exclusively to the environment: “[r]adioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment” (IAEA, 1995, p 5). However, in a temporal sense and when it comes to protecting the future, the principles 5 (the protecting of future generations) and 6 (the burdens on future generations) in the latter IAEA document leave no room for misunderstanding, making it clear that the IAEA’s approach is anthropocentric and solely refers to future generations of human beings who should be protected (IAEA, 1995). The environment thus has here an instrumental value. Safety issues in nuclear power technology include “the safety of nuclear installations, radiation safety, the safety of radioactive waste management and safety in the transport of radioactive material” (IAEA et al., 2006, p 5). The value we link to these concerns is *public health & safety*, which pertains to the exposure of the human body to radiation and the subsequent health effects of radiation.

Security

Security is the next value that will be addressed in this analysis. In the IAEA’s Safety Glossary, nuclear security 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” (IAEA, 2007, p.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. Security also refers to extremely relevant proliferation considerations such as the using and dispersing 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.

3.2 Sustaining future well-being

So far we have presented three values for sustaining the environment and humankind's safety and security. Another aspect of sustainability links up with the sustaining of human well-being, insofar as it relates to the resources. I will discuss the two values of resource durability and economic viability.

Resource durability

Sustainability could be thought to refer to the availability of natural resources and their continuation. Obviously, in discussions on energy production and consumption, the value of *resource durability* plays an important role. Brian Barry presents the theory of intergenerational justice as the appropriate consumption of non-renewable natural resources across time; "later generations should be left no worse off [...] than they would have been without depletion" (Barry, 1989a, p.519) Since it would be irrational to expect the present generation to leave all non-renewable resources to its successors and since replicating such resources is not an option either, Barry (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". We should remember that this reasoning has been presented by Barry in order to keep the range of opportunities open to posterity; "[t]he minimal claim of equal opportunity is an equal claim on the earth's natural resources" (Barry, 1989b, 490). I narrowed down this argument to include only those resources that we might have depleted in the process of nuclear power production. If we now look back on the period of industrial revolution up until the present it would be fairly straightforward to conclude that the availability of energy resources has played a key role in achieving well-being. So I argue that that we should compensate for a reduction in the opportunities for well-being as that can be brought about by energy resources. The value of resource durability is therefore defined as the availability of natural resources for the future or the providing of an equivalent alternative for the same function.

Economic viability

Some economists claim that "a development is sustainable if total welfare does not decline along the path" (Hamilton, 2003, p.419) and that "achieving sustainable development necessarily entails creating and maintaining wealth" (Hamilton, 2003, p 419-420).² The next value that I shall discuss in relation to sustainability is that of *economic viability*. One might wonder whether economic issues have an inherent moral relevance and whether it is justified to present economic durability as a moral value. On the one hand, one could argue that the safeguarding of the general well-being of society (also, for instance, including issues of health care) has undeniable moral relevance. On the other hand, our understanding of economic viability in this chapter solely relates to the issues that we have presented in relation to nuclear energy production and consumption. With this approach economic aspects do not therefore have any inherent moral relevance; it is what can be achieved with this economic potential that makes it morally relevant. This is why I present the value of economic durability in conjunction with other value. First and foremost, economic viability should be considered in conjunction with resource durability. In that way it relates to the economic potential for the initiation and continuation of an activity that helps in the providing of an alternative for the depleted resources. We will see in the next section that

² In this paper I do not make a distinction between welfare, well-being and wealth.

economic viability also becomes a relevant notion when we aim to safeguard posterity's safety and security by introducing new technology. In general, economic viability is defined here as the economic potential to embark on a new technology and to safeguard its continuation for the maintaining of the other discussed values.

4. Operationalizing moral values: Assessing existing fuel cycles

Let us first recapitulate the moral values discussed in the preceding section. I argued that above all else, we should sustain *equal opportunity* for future generations. More to the point, we should safeguard posterity's vital interests and the well-being of posterity. To that end, five different interpretations of sustainable development have been presented in terms of five different moral values; the definitions of these values have been summarized in Table 1. In other words, in order to address the sustainability aspects of a certain technology (in our case the sustainability aspects of a certain nuclear fuel cycle), we need to first assess to what extent these values are safeguarded or compromised. To that end, the values should first be *operationalized*, meaning that we should assess the impacts of different stages in the production of nuclear power according to how these values are affected. In this operationalization process, we should take into consideration the fact that the values could relate to the interests of different groups of people belonging to different generations. In the remainder of this section I will first discuss different fuel cycles before going on to elaborate on how to assess the impacts of the fuel cycles according to such values.

Value	Explanation
Environmental friendliness	Preserving the status of nature to safeguard human health and safety
Public health & safety	Protecting people from the accidental and <i>unintentional</i> harmful effects of ionizing radiation
Security	Protecting people from the <i>intentional</i> harmful effects of ionizing radiation arising from sabotage or proliferation
Resource durability	The availability of natural resources for the future or the providing of suitable alternatives
Economic viability	Embarking on a new technology and continuing that activity to safeguard one of the above values

Table 1. Five moral values that together constitute the overarching value of sustainability

4.1 Existing nuclear fuel cycles: open and closed

Generally, there are two main methods, or nuclear fuel cycles, used for the production of nuclear power; namely open and closed fuel cycles. Both fuel cycles have a front-end phase, involving the mining and milling of uranium, enrichment and fuel fabrication, and a back-end phase involving the steps taken after irradiation in the reactor. Both cycles are more or less the same until the moment of initial irradiation in the reactor. I shall start by discussing these fuel cycles from the cutting point of the front-end and the back-end of the cycles, namely from the moment of irradiation in the reactor. What comes out of the nuclear reactor

is not necessarily *waste*; it would be better to refer to it as *spent fuel*. This is because precisely how we deal with this spent fuel determines the type of fuel cycle required. In the open fuel cycle, spent fuel is considered as waste. After irradiation the fuel in the reactor, the spent fuel, will be kept in interim storage on the surface for a couple of decades (basically to let it cool down) and it will then be disposed of in deep underground repositories. Since the fuel will be irradiated only once, this cycle is referred to as a once-through or an open fuel cycle. The disposed of waste should be isolated from the biosphere for the period that it constitutes a radiation risk; for an open fuel cycle this is about 200,000 years. This kind of fuel cycle is sometimes known as the American method, but it is also employed in certain other countries as well, like Sweden. The (black) solid arrows in Fig. 1 represent the open fuel cycle.

In the second method, spent fuel will be *reprocessed*. Reprocessing is a chemical process in which spent fuel can be recycled for two main purposes. Firstly, the still deployable materials in spent fuel (namely uranium and plutonium) will be separated in order to be reinserted into the cycle. That is why this method is called the closed fuel cycle; see in this connection the (red) dotted lines in Fig. 1. Separated uranium can be added at different front-end phases in the open fuel cycle; plutonium can be used to manufacture MOX (Mixed Oxide Fuel), which is a fuel based on a mixture of plutonium and uranium. The second reason for reprocessing is to substantially reduce the volume of the most long-lived type of waste; i.e. the most long-lived materials (again uranium and plutonium) will have been removed. The waste life-time in the closed fuel cycle amounts to about 10,000 years. The closed fuel cycle is more commonly known as the European method, but is also applied in some other countries like Japan. Both fuel cycle types are illustrated in Fig. 1.

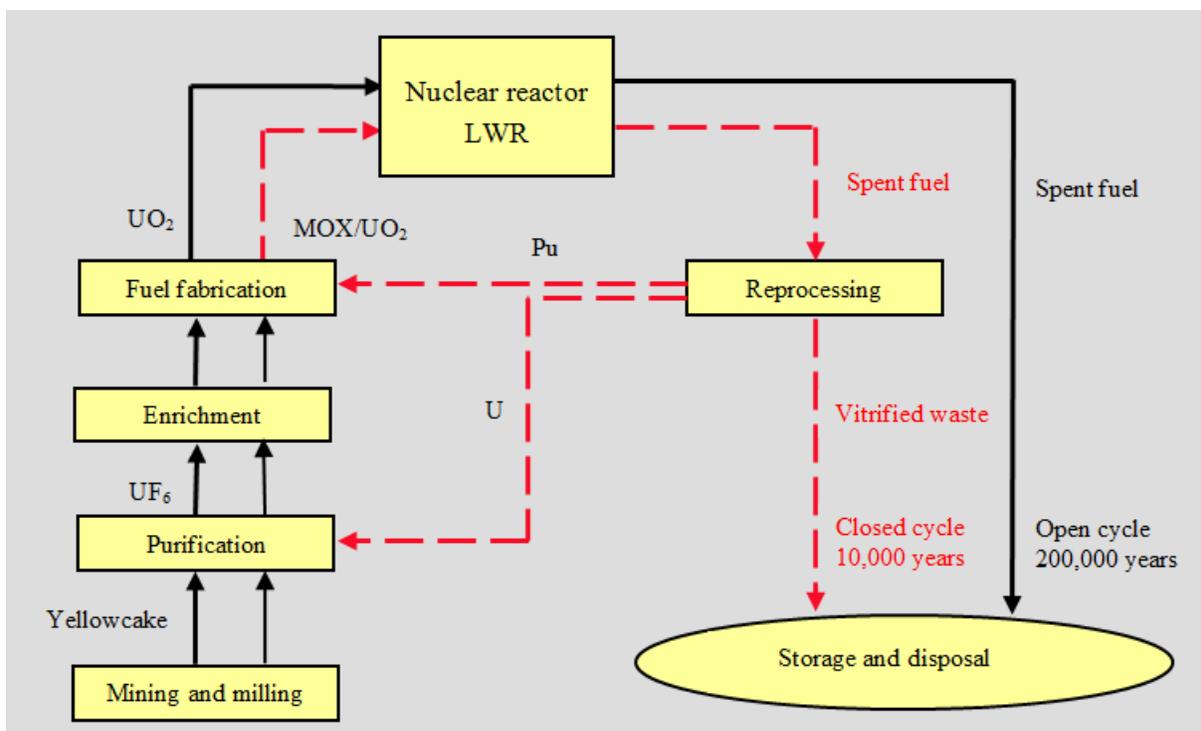


Fig. 1. Schematic representation of open and closed fuel cycles, together with the forecast waste life-times. The black solid lines represent the open fuel cycle and the red dotted lines illustrate the additional steps taken in the closed fuel cycle.

4.2 Operationalization of values: Intergenerational assessment of fuel cycles

It would extend beyond the scope of this work to discuss in detail how the fuel cycles should be assessed according to the values presented, but I will briefly discuss the steps that we need to take in order to operationalize these values. First, we must link the impact of different steps in the fuel cycle to the values presented and evaluate to what extent those impacts are for present and future generations. Let me illustrate this with an example in which we shall operationalize the value 'public health & safety'.

First, when assessing safety issues in an open fuel cycle, we should at least address the following steps that relate in one way or another to the safety issues: 1) mining, milling, enrichment and fuel fabrication, 2) transport of (unused) fuel and spent fuel, 3) reactor operation and decommissioning period, 4) interim storage of spent fuel and 5) final disposal of spent fuel in geological repositories. These impacts have been mapped in Fig. 2.³ In this figure, it has been assumed that nuclear power production will last for one generation, this is referred to as the Period for which the Activity Lasts (PAL). The first four steps particularly create risks in the short-term, which is slightly longer than the PAL. Especially the decommissioning period and the interim storage of spent fuel will last several decades longer. From the perspective of long-term safety concerns (issue number 5 above), there will be potential burdens after spent fuel has been situated in the geological repositories; these concerns will potentially last for the life-time of the spent fuel, or approximately 200,000 years. So the horizontal black arrow represents these long-term concerns extending into 'Generation n' in the future. Please note that here the value of 'environmental friendliness' is discussed in conjunction with the value of 'public health & safety'.

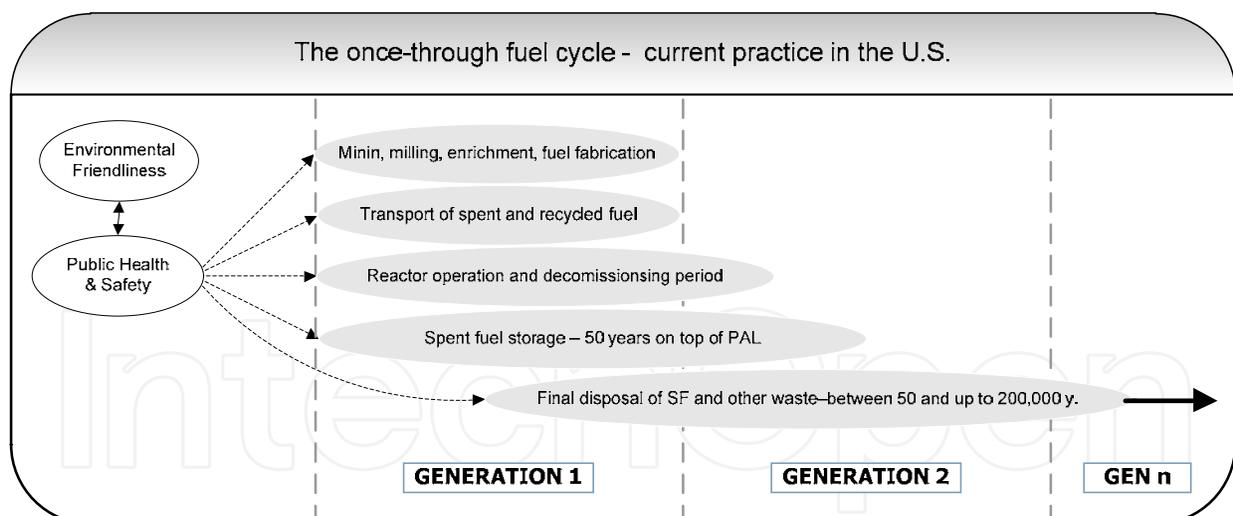


Fig. 2. Relating moral values to concrete fuel cycle steps. PAL stands for the Period for which the Activity Lasts and SF stands for spent fuel. This is a partial representation and a slightly modified version of Figure 3 in (Taebi & Kadak, 2010).

³ This is a partial representation of a detailed analysis I have made elsewhere together with Andrew Kadak. Readers who are interested could consult this publication for a detailed operationalization of these values in relation to the two existing and the two future nuclear fuel cycles; see (Taebi & Kadak, 2010).

4.3 Intergenerational conflicts

Like in the example above, we can operationalize all the values and relate them to the concrete steps in the two fuel cycle. If we now draw a comparable burden-benefit chart for the closed fuel cycle, it should show that the safety concerns for remote future generations will substantially decrease; this is because the waste life-time of the closed cycle will be a factor of 20 less (approximately 10,000 year). From the perspective of future generations, the closed fuel cycle will thus score better on the issue of safety. However, in the short-term and from the perspective of Generation 1, more safety risks will be created since reprocessing is a chemical process that creates different types of nuclear waste that subsequently has to be disposed of (these are mainly different types of waste with shorter lifetimes). Reprocessing plants are furthermore situated in only a few countries, which means that countries that endorse the closed fuel cycle but have no reprocessing plants will be forced to go back and forth with their waste to the country that can do the reprocessing; this creates additional safety risks in relation to transportation. In Europe, the two commercial reprocessing plants are situated in the UK and France. Other European countries that endorse the closed fuel cycle have their waste reprocessed in one of these countries. Another short-term safety concern has to do with the using of plutonium as MOX in fuel. Plutonium is a very dangerous substance when inhaled. See in this connection the concerns that reactor 3 has been raising in the Fukushima Daiichi accident where MOX is being used as fuel in that reactor.

A similar analysis could be presented for the security concerns. Security relates to both *sabotage* and *proliferation* and it could be linked to the following steps in any open fuel cycle: 1) uranium enrichment, 2) reactor operation and the decommissioning period, 3) spent fuel storage and 4) the final disposal of spent fuel. All four issues have to do with the risk of sabotage. Issue number 1 has, in addition, a proliferation aspect as well. The naturally occurring uranium contains different *isotopes*. Since the isotope that is deployable in the conventional reactors (^{235}U) is present in less than 1%, that uranium is enriched in order to make sure that more of that isotope will be present in the fuel. Enriched uranium to 3 (up to 10) percent is usually used for civil energy production purposes. However, the further enriching of uranium (up to 70% and higher) makes it a suitable material for weapon production. The Hiroshima bomb contained about 65 kilogram of 80% enriched uranium.

If we now assess the security concerns of the closed fuel cycle, one important issue will appear in relation to proliferation, namely the issue of the separation of plutonium during reprocessing. In addition to highly enriched uranium, plutonium is also deployable in nuclear weapons; the Nagasaki bomb contained 8 kilograms of weapon-grade plutonium. Plutonium, which usually emanates from civil reactors, is usually of a much lower quality for weapon production, but it does carry serious proliferation risks.⁴

Let us continue with the value of resource durability in our two fuel cycles. If the 2008 uranium consumption rate were continued, there would be enough *reasonably priced uranium* available for approximately 100 years (IAEA-NEA, 2010). Obviously, if many more countries join the nuclear club in the next couple of decades this availability will substantially decrease. It is, however, important to note that this uranium availability constitutes a reference to geological certainty and production costs. If we include estimations of all the available resources (in seawater and in phosphates), this will rise

⁴ For a more technical discussion on the different isotopes of plutonium and the risk of proliferation, please consult (Taebi, Forthcoming).

significantly (IAEA-NEA, 2010). Yet, the open fuel cycle depletes the resources of reasonably priced uranium much faster. The closed fuel cycle, on the other hand, extends the period of availability of uranium, since reprocessed uranium and plutonium is reused. The conclusion thus seems straightforward. Closed fuel cycles should be preferred from the perspective of resource durability for future generations.

The last issue is the one of economic viability. As stated earlier, reprocessing plants are situated in a very limited number of countries. That is partly because of security concerns in conjunction with proliferation, but what is at least of equal importance, is the fact that reprocessing plants are very expensive. So, for countries with a small number of nuclear reactors, it is not worth while building their own reprocessing plant. Purely from the economic perspective, the open fuel cycle would then be preferred.

Let us now make an overall comparison between the two fuel cycles from the justice angle. From the perspective of the present generation, the open fuel cycle would be preferred, since it creates less safety and security risks and is less costly. The closed fuel cycle is, on the hand, more beneficial from the point of view of future generations, because it reduces the long-term safety concerns of waste disposal and because it helps extend non-renewable resources farther into the future. At the same time, the closed cycle creates more short-term safety and security concerns and economic burdens. This cuts right to the heart of the central issue of this paper, namely that of intergenerational justice. The questions that need to be answered are the following. Does intergenerational justice require that we reduce the waste life-time and enhance the resource availability into the future? If so, are the additional current burdens of the closed fuel cycle sufficiently justified?⁵

5. Sustainability as an ethical field of tension: The progress of technology

When opting for a certain fuel cycle, we first need to express opinions with regard to the moral relevance of the values presented for different generations. After the accidents in Japan, we could for instance conclude that if we want to continue on the nuclear path, we will have to reduce the safety burdens for the present generations as much as possible. So, in terms of our values, we rank the moral relevance of the value of 'public health & safety' in the short-term higher than all of the other values. In such an example, the open fuel cycle with its fewer nuclear activities must be favored. On the other hand, if we now conclude that as producers of nuclear power we are the main ones responsible for reducing its future burdens, we give the same value of 'public health & safety' for future generations higher moral priority; the closed fuel cycle would then become an attractive option.

Then discussion concerning the prioritizing of moral values will gain particular relevance when we come to address technological advancement. Even though technology has no inherent moral value as such, it does enable us to comply better with other moral values. Also in questions regarding the development of new technologies for the future, it is important to be clear on the purpose of this technology, or to put it in philosophical terms, to be clear about which values this technology should improve for which group of people or which generation. Before moving on to discuss new technologies and how they could affect values, let me first say something about the interdependency of these values. Rather than contemplating them in isolation, it is actually the combination of these values which goes towards forming the overarching value of sustainability. We could liken our set of values to

⁵ See for a detailed discussion of this issue (Taebi & Kloosterman, 2008).

several American football balls held tightly together with springs; see in this connection Fig. 3.⁶ Hitting any one of these *balls* will inevitably affect the others in the construction. In other words, by presenting new technology, we might be able to comply better with any one of these values, but we should at the same time evaluate how that would affect the remaining values. This is why I am presenting our set of values as an *ethical field of tension*. Let me explain this by giving an example.

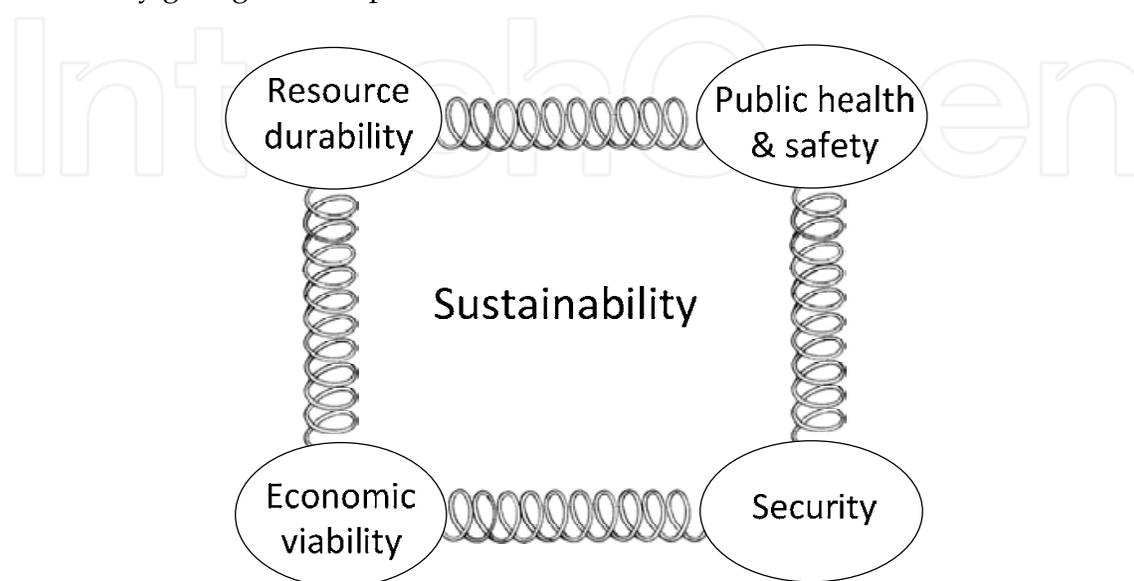


Fig. 3. Schematic representation of sustainability in an ethical field of tension

Due to its radiotoxic nature and extremely long lifetime, nuclear waste is perceived to be the Achilles heel of nuclear energy production. Serious attempts have been made to further reduce its lifetime. A new technology for the latter purpose is that of Partitioning and Transmutation (P&T). This is a complementary method to the closed fuel cycle that involves separating and dividing (partitioning) the materials remaining after reprocessing so that they can afterwards be eliminated (transmuted) in Fast Reactors; these reactors can irradiate the radionuclides that the currently operational thermal reactors cannot irradiate. If completely successful P&T will, it is expected, make the waste lifetime five to ten times shorter when compared to closed fuel cycle waste. After P&T, waste radiotoxicity can decay to a non-hazardous level within the space of hundreds of years, i.e. 500 to 1000 years (KASAM, 2005, Ch 8).

However, P&T is 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 (NEA-OECD, 2002). Furthermore, the industrialization of P&T requires the building of many more facilities, both nuclear reactors and new reprocessing facilities. All these additional safety, security and economic burdens will have to be borne by contemporaries or at least by those nations that are capable of developing the technology; due to the inherent technological implications and complexity, not all countries will be capable of developing or deploying this technology (IAEA, 2004). To conclude, while P&T is capable of improving the value of 'public health & safety' in the long run, it is

⁶Please note that the value of 'environmental friendliness' has been subsumed under the value of 'public health and safety'.

compromising short-term 'public health & safety' and 'security'. In addition, the economic burdens will mainly be borne by the present and the immediately following generation. In other words, P&T (as an extension to reprocessing) presents an exacerbated form of the intergenerational dilemmas of the closed fuel cycle.⁷

Similarly, we could present fast reactors in the configuration of nuclear breeders in order to breed (make) more fuel than they consume. Breeders are capable of *consuming* the major isotope of uranium (^{238}U) that is present for more than 99% in natural uranium. From the point of view of 'resource durability' such a breeder fuel cycle (with multiple recycling) could be very beneficial; we would then use the same natural uranium far more efficiently, all of which would extend the period of its durability. However, from the perspective of short-term concerns such a fuel cycle will bring comparable safety, security and economic burdens to P&T. It is particularly in conjunction with the abundant presence of plutonium and the ensuing proliferation concerns that this cycle method has never attracted serious attention. The term 'plutonium economy' usually refers to the using of plutonium as MOX in a closed fuel cycle and also to a fuel cycle with nuclear breeders.

In short, new technology can contribute to an improvement in moral values. It is therefore important that we include the progress of technology in our moral analysis. For one thing, in a discussion focused on what we *ought to* do for future generations, it is important to first be aware of what we *can* do, technologically speaking. This is the added value of this type of applied ethics in which solutions can be proposed within the realm of *technological realities* and in the light of the progress of technology. For another thing, we should then bring this *solution* back in the ethical field of tension proposed earlier in this chapter. How would the other values be affected by the introduction of this technology? Again, the question of how these values should be ranked in terms of their moral relevance should be determined during public and political discourse.

6. Challenges of assessing social and political desirability of nuclear power

In the preceding sections I approached the notion of sustainability as a moral value consisting of several other values. Different nuclear fuel cycles can now be assessed in terms of how well they safeguard or jeopardize these moral values for present and future generations; this gives rise to issues of intergenerational justice. What is now the relationship between these moral discussions and policies? How influential could and should these justice principles be when policy-makers need to deal with serious choices and trade-offs?

I shall elaborate on this issue by giving an example of where tangible nuclear waste management policy and fundamental philosophical discussions on justice to posterity are closely intertwined. The IAEA's principle of avoiding "undue burdens" on future generations is one that has been endorsed by all members of IAEA and it forms part of the current national policies on nuclear waste management. However, what this "undue burdens" clause precisely entails remains a moot point. 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. It has been argued that

⁷ 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 (Taebi & Kadak, 2010). The breeder fuel cycle was also assessed in this paper.

this principle is best complied with when we dispose of nuclear waste in geological repositories that are situated a couple of hundred meters underground (NEA-OECD, 1995); the possible harmful consequences of a geological repository in the long run is then tacitly taken to mean *due harm*.

It is the combination of the engineered barrier (i.e. canisters stored in concrete containers) and the natural barrier (i.e. geologic formations) that makes repositories favorable from the point of view of long-term safety (Chapman & McCombie, 2003, 27-31). However, the tremendous long-term uncertainties that repositories bring (Macfarlane & Ewing, 2006) make it difficult to guarantee equal safety for distant future generations (Shrader-Frechette, 1993, 1994; Taebi, Forthcoming). In the case of the Yucca Mountains repositories, once the location had been designated for the permanent disposal of American spent fuel for a million years, an interesting distinction was made 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” (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 conceivably be exposed to a much higher radiation limit. The underlying argument for this distinction is sought in the low degree of predictability for 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.

As a matter of fact, this issue relates to another intergenerational aspect of the notion of sustainability that I was merely hinting at in Section 2, namely that of for whom (and for how long) we should sustain the valuable entity of X? If we now agree that through the inappropriate disposal of nuclear waste, we can affect the vital interests of future generations, and if we again agree that location in time and space does not provide sufficient moral ground for treating people differently (in accordance with Barry’s (1999) principles of fundamental equality), we can now argue that this distinction between different people of the future is ethically problematic. The arguments provided for proposing this distinction are more pragmatic reasons for why we cannot act otherwise than solid moral justifications. The discussions on tangible policies should, therefore, be preceded by the more fundamental discussions on what our relationship with posterity should be.⁸

When addressing the desirability of a certain fuel cycle for the future we should incorporate the social and economic context within which policies are articulated. One possible conclusion to a moral analysis could be that if we decide to continue on the nuclear path, the P&T method as an addition to the closed fuel cycle should be favored, since it has many advantages in terms of substantially reducing the waste lifetime and the potential future burdens.⁹ However, as argued in Section 5, the further developing of this method as well as its industrialization will create substantial safety and security burdens for present generations; how can the policy-maker justify these additional burdens? Last but certainly not least, in policy-making there is the question of the legitimacy of the financial efforts that

⁸ For a detailed discussion on Yucca Mountains Radiation Standards, please see (Vandenbosch & Vandenbosch, 2007). Elsewhere I argue that the proposed distinction must urge us to reconsider other waste management possibilities that could be used to help reduce waste lifetime and potential future burdens (Taebi, Forthcoming).

⁹ This argument is extensively defended elsewhere (Taebi, 2011).

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 lion's 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. One important aspect would, for instance, be that of the distribution of these additional burdens among the currently living generations.

A highly relevant question in policy-making is that of whether nuclear power should be considered to be a viable option in the future of energy provision. I started this paper by circumventing this general desirability discussion surrounding nuclear energy. It is, however, worthwhile considering what this analysis can contribute to that public and political discourse. As stated earlier, we should not consider nuclear power in isolation but address its desirability in the broader perspective of the desirable *energy mix*; the moral insights offered here could help one distinguish between different fuel cycles, all of which can facilitate a comparison between a certain nuclear fuel cycle and another specific energy system. We can, for instance, compare the P&T cycle with the waste that remains radiotoxic for a couple of hundred years with a certain fossil fuel system that contributes to a change in the climate system. Such comparisons could be made based on considerations of intergenerational justice, or on how they affect the interests of *both* the present and future generations.

When one compares two non-renewable energy systems, focusing on the intergenerational aspects of sustainability would help us to facilitate a comparison based on moral grounds. We should then distinguish between the nature and longevity of those long-term effects; the latter is, for instance, different for oil and nuclear power both in terms of the type of the consequences and the period for which those consequences will be present. These intergenerational arguments lose, however, relevance when we assess a renewable energy system; there is no depletion of a non-replaceable resource and there are often far fewer, or virtually no more, long-term consequences. Even though renewability is an important aspect of sustainability and – we want to eventually move towards these renewable systems – we should also be aware of the societal and ethical consequences of such energy systems. When addressing the desirability of renewable energy resources, we should instead focus on the spatial aspects of sustainability and on the questions of intragenerational justice that are raised for the generations currently alive. For instance, when assessing the desirability of biofuel there are the issues of land use, water consumption and the possible effects of producing biofuel from food crops that could potentially exacerbate the problem of hunger.¹⁰

When it comes to comparing different energy systems, we encounter at least two types of implications, namely 1) how to compare different types of burdens and benefits and 2) how to value future burdens and benefits in relation to present burdens and benefits. In economic studies and investment decisions with potential benefits for the future, these issues have been dealt with in *cost-benefit analyses* (CBA) that can be used to identify and quantify different costs and benefits over the course of time. CBA is grounded in the ethical

¹⁰ The British Royal Society has represented a comprehensive analysis of how to assess the sustainability of biofuel; see (Pickett et al., 2008).

theory of *utilitarianism* which asserts that the moral worth of any action should be assessed in terms of how it maximizes overall utility (alternatively referred to as well-being or happiness). For the sake of calculation, economists argue that we could express all the costs and benefits in terms of their monetary value. Since the value of different commodities declines over the course of time, the future value of these benefits will be determined on the basis of their present value *discounted* for time.

While CBA and discounting are undisputed¹¹ and sometimes desirable for certain short-term decisions in policy-making, 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 the detrimental effects and benefits of 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 are essentially incomparable. The second issue, accounting for harm and benefit in the distant future, raises questions about the moral legitimacy of discounting (Cowen & 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 in the way advocated in this paper (see for an overview (Portney & Weyant, 1999)).

There are many philosophical objections to the applications of a CBA (see for an overview (Hansson, 2007)), but at least two of these objections are worth mentioning here. Firstly, CBAs fail to address the distribution issue between generations and, secondly, if we are to discount risks in the remote future, the policies for mitigating climate change and disposing of nuclear waste will be seriously undermined. The following example may serve to illustrate this: 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 assessment 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 (Parfit, 1983).

To conclude, policy-making on nuclear power production and nuclear waste management needs to include fundamental discussions on our relationship with posterity and to address issues surrounding the distribution of burdens and benefits between generations and also among the present generation. Since economic instruments such as CBA offer no solace, policy-making in nuclear technology should go hand in hand with more fundamental moral discussions.

7. Conclusion

Nuclear power production and consumption gives rise to the problem of intergenerational justice as we are using uranium, which is a non-replaceable resource, and as the remaining radiotoxic waste creates potential burdens extending into the very distant future. Since future interest is subject to present action, we have every reason to include posterity's interests in our decision-making in the area of nuclear power production. In my arguments,

¹¹ There are at least two issues that can make short-term CBA problematic. Firstly, the question of how to express the value of goods in terms of money; e.g. what is the economic value of rainforests? Secondly, there is disagreement on the interest rate of discounting when considering future effects; the rate can seriously influence the outcome.

I presented the notion of sustainable development as a moral value and elaborated on its relationship with intergenerational justice. Following Barry, I argued that we should sustain future generation's opportunity for well-being insofar as that can be accomplished with the available energy resources and their vital interests. I then introduced a set of moral values which, in combination with each other, comprise the overarching value of sustainability. The values 'environmental friendliness', 'public health & safety' and 'security' together safeguard the vital interests of future generation; the values 'resource durability' and 'economic viability' help to sustain future well-being.

The impacts of different nuclear fuel cycles were then assessed according to how they affect the values presented. In this operationalization process, we took into consideration the fact that the values could relate to the interests of different groups of people belonging to different generations. The two existing fuel cycles were then compared according to their values; the open fuel cycle could best be associated with short-term benefits and the closed fuel cycle with long-term benefits and the accompanying short-term costs. All of this gives rise to an intergenerational conflict of interests between those alive today and future generations.

The ranking of these values with regard to their moral relevance requires thorough public and political discourse. This is particularly relevant when assessing the desirability of new technology. Even though technology has no inherent moral relevance, it does help improve other values. In a moral discussion on what we *ought to do* for future generations, it is important to first be aware of what we *can do*, technologically speaking. This is the added value of this type of applied ethics in which solutions can be proposed within the realm of *technological realities* and in the light of technological progress. Indeed, the impacts of these new technologies should then be assessed in the ethical field of tension of sustainability, as has been proposed here. It is then worthwhile considering how other values will be affected by the introduction of this technology?

When it comes to policy-making for nuclear power deployment, we need to address several ethical issues regarding our relationship with posterity and the intergenerational distribution of benefits and burdens. Therefore, policies on nuclear power should be accompanied by thorough moral analysis. One possible conclusion arising from such analysis could be that we, the present generations who are enjoying the lion's share of the benefits of nuclear power, should remain responsible for dealing with its waste. This supports the application of P&T that reduces the waste lifetime and therefore also the potential future burdens. 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 surmounted and the development and ultimate deployment of P&T will create considerable burdens (including certain economic burdens) for contemporaries. So, if the result of the moral discussion is that we want to be able to apply P&T, then this technology 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 technology, desirable or not, creates for the present generation. This paper aims to contribute to that awareness.

8. References

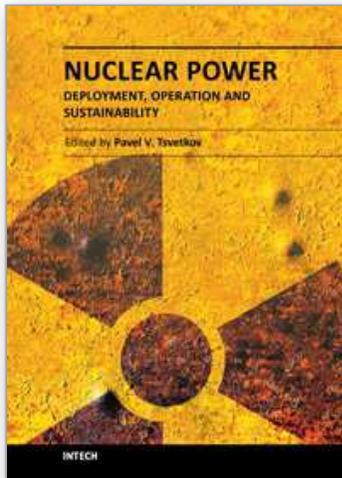
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We are fortunate to live in incredibly exciting and incredibly challenging time. Energy demands due to economic growth and increasing population must be satisfied in a sustainable manner assuring inherent safety, efficiency and no or minimized environmental impact. These considerations are among the reasons that lead to serious interest in deploying nuclear power as a sustainable energy source. At the same time, catastrophic earthquake and tsunami events in Japan resulted in the nuclear accident that forced us to rethink our approach to nuclear safety, design requirements and facilitated growing interests in advanced nuclear energy systems. This book is one in a series of books on nuclear power published by InTech. It consists of six major sections housing twenty chapters on topics from the key subject areas pertinent to successful development, deployment and operation of nuclear power systems worldwide. The book targets everyone as its potential readership groups - students, researchers and practitioners - who are interested to learn about nuclear power.

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