Comparative Ethical Issues Entailed in the Geological Disposal of Radioactive Waste and Carbon Dioxide in the Light of Climate Change

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Abstract Many governments are at various stages of planning to dispose of radioactive waste (RW) in geological formations. Many governments expressly expect to use geological formations to dispose of the carbon dioxide (CO_2) produced in fossil fuel combustion. This chapter compares, in the light of climate change, the ethical issues involved in disposing of RW and CO_2 in geological formations, given their potential to cause harm and given the risks involved in the deployment of these disposal technologies. It highlights the ethical issues triggered by the need for a high level of scientific certainty regarding the ability of potential disposal sites to counteract the migration of substances of concern away from disposal areas. However, the ethical issues entailed in geological disposal of RW and CO_2 may need to be re-evaluated in light of the fact that disposal contributes to climate change mitigation. It is concluded, however, that as long as alternative methods for mitigating climate change are available that do not involve geological disposal of CO_2 and as long as scientific uncertainty remains about the efficacy of disposal sites to contain RW and CO_2, such alternative methods are ethically preferable. The chapter identifies another ethical issue, namely that the development and deployment of alternative technologies to reduce greenhouse gas emissions could be delayed by reliance on geological disposal of CO_2.

Keywords Ethics • Geological disposal of radioactive waste • Geological disposal of CO_2 • Climate change mitigation • Geological site characterization • Nuclear waste disposal

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1 Introduction

This chapter compares the main ethical issues entailed in two approaches to climate change mitigation: (1) the geological disposal of radioactive waste (RW), and (2) the geological disposal of carbon dioxide (CO_2). As all approaches to climate change mitigation can cause harm, and climate change itself is a threat to human health and the environment, the ethical issues raised by potential climate change mitigation options, such as the two considered in this chapter, must be evaluated in the light of the risks from human-induced climate change. Thus, more specifically, this chapter compares (1) the ethical issues entailed in geological disposal of RW and CO_2 with (2) the ethical issues created by climate change.

The use of nuclear technology to produce electricity raises ethical questions because of the potential risk to human health and the environment arising from, say, a nuclear power plant meltdown or the release of radiation into the environment. So too does the expansion of nuclear power expertise around the world, which could facilitate production of fissionable material by individuals or nations for use in nuclear weapons. This chapter considers neither of these ethical questions. The only ethical question discussed here is that related to the need to dispose of RW that will remain hazardous for millennia. Nor does the chapter discuss all the ethical issues that could arise from greater and more widespread use of coal due to the increased feasibility of geological CO_2 disposal.

A proper ethical analysis of the geological disposal of nuclear waste and of CO_2 must begin with a description of the known environmental, economic and social impacts and risks of the technologies involved, based on the current scientific and economic understanding of their potential harmfulness, risks and benefits. If this scientific understanding changes, then the ethical conclusions reached in this chapter may also change, for which reason they must be considered as provisional.

The term 'ethics' in this chapter means the domain of inquiry that examines claims about what is right or wrong, obligatory or non-obligatory, or the circumstances under which responsibility attaches to human actions (Brown et al. 2006). An ethical analysis of the geological disposal of nuclear waste examines claims made about whether and under what circumstances geological disposal of nuclear waste should be pursued. In a similar way, an ethical analysis of geological disposal of CO_2 is concerned with claims made about whether CO_2 disposal is ethically justified.

The ethical issues entailed in any potential environmental problem, including those discussed here, are often dependent on the nature of the harmfulness of related human activities. Identifying ethical issues arising from potential technological harm does not necessarily lead to agreement about what ethics requires—ethical theories themselves often differ in this respect. To guide ethical conclusions, one may, for instance, look to utilitarian, rights-based, biocentric, or ecocentric theories, or theories of ethical relationships, to name just a few. (For a general discussion of environmental ethics, see Hargrove 1996). However, these theories may reach different conclusions about what is ethical under the same facts. Therefore, ethical issue spotting does not necessarily lead to ethical consensus.

For some projects or problems there is an overlapping consensus among ethical theories about what ethics requires, even though ethical theories might differ (Brown et al. 2006). For other matters, although there is no ethical consensus about what ethics requires, most ethical theories would agree that certain proposals are ethically problematic. In other words, ethical criticism of proposed projects is possible, even if there is no consensus on what ethics requires under those circumstances. Thus, identification of ethical issues may lead to: (1) conflict about what ethics requires; (2) consensus about what ethics requires; and (3) consensus that a proposed activity is ethically problematic despite there being no consensus as to what ethics requires. It is the goal of this chapter to identify ethical issues entailed in the geological disposal of RW and CO_2 rather than to draw absolute ethical conclusions about all the issues identified here.

It will nonetheless be assumed in this chapter that ethics requires those who are the proponents of a project to protect others from serious harm caused by the project, particularly those who have not consented to be put at risk, and especially in cases where the harm is potentially significant and irreversible (Shrader-Frechette 2002). This ethical duty is a matter about which there is large overlapping consensus among ethical theories, particularly if the harm affecting others involves death or serious adverse health effects. However, some ethical theories, including some forms of utilitarianism, would allow a balancing of harm and benefits. Even so, most utilitarians would require those who are harmed by the actions of others to, at a minimum, be compensated for the harm done to them. In addition, most philosophers believe that those who are potentially at harm from the actions of others have a right to exercise fully informed consent to being put at risk of harm (Shrader-Frechette 2002). Thus, even utilitarians often recognize the right to exercise fully informed consent to be harmed by others. (See Shrader-Frechette (2002) for an example.) The duty to protect others from harm is usually considered to be in proportion to the harm that may be inflicted upon them. For a discussion of how ethical duties increase in relationship to the magnitude of harm, see Jonas (1984).

This chapter covers: (1) ethical issues entailed in the geological disposal of RW; (2) ethical issues raised by the geological disposal of CO_2; and (3) a comparative ethical analysis of these technologies in light of climate change. The findings are then summarized in the conclusions.

2 Ethical Issues Entailed in the Geological Disposal of Nuclear Waste

2.1 Potential Harm from High-Level Nuclear Waste Disposal

Geological disposal of RW is one of several disposal methods that has been considered and pursued at the global level, including, for example, sub-seabed disposal and reprocessing. Geological disposal has been recommended by most scientists as a preferred way of disposing of nuclear waste, although some advocate the reprocessing of fuel for use in breeder reactors (US DOE 2008a). Any complete ethical analysis of RW disposal should take into account the disposal methods that potentially create the least harm.

Most countries that generate electricity in nuclear power plants support geological disposal of nuclear waste. Belgium, Canada, China, Finland, France, Germany, Japan, Russia, Spain, Sweden, Switzerland, the UK and the USA all support deep geological disposal as the best method of isolating highly radioactive, long-lived waste (US DOE 2008a). Many of these countries have performed detailed geological studies, or characterizations, by drilling numerous boreholes and exploratory shafts and ramps in underground research laboratories. These data, it is believed, will be useful in determining the predicted safety performance of future nuclear waste repository sites (US DOE 2008a). There are currently no final disposal facilities in any country for high-level and long-lived RW produced during the generation of nuclear energy. That not a single final disposal site has been established in the nuclear industry's more than 50 years of existence and that RW is currently provisionally held in interim storage facilities (EU 2008) would imply lack of public acceptance, and thus possible ethical significance, regarding the siting of future RW disposal facilities.

Other chapters in this book discuss the potential risks and adverse effects of RW disposal. Of particular significance from an ethical perspective is the very long length of time that RW remains hazardous to human health. The risk of highest concern regarding long-term disposal of RW in geological formations is migration of radionuclides from the disposal site into the environment over the millennia during which waste remains hazardous.

As RW will remain hazardous for longer than the history of modern human civilisation (over 10,000 years), its safe disposal raises a number of ethical issues, which are discussed below. Driving these ethical concerns is the need to assume responsibility for such hazardous substances for such a long period of time to ensure that existing and future populations will not be exposed to them while they remain hazardous. This is the core ethical imperative.

2.2 *Preventing Release of Radioactive Substances from Disposal Sites*

The purpose of a deep geological repository is to provide future generations, especially those in the far future, with passive protection against any harmful release of radioactive material. This concept must prevail, even in the event of the repository's existence being forgotten and irrespective of what the technical knowledge of the future generations may or may not be (Allègre 1999).

Common elements of repository systems include RW, the containers enclosing the waste, the tunnels housing the containers, and the geological make-up, including rock types, of the surrounding area (US DOE 2008b). All elements of site design must do their part in preventing RW from escaping into the environment. Critical to the design of the facility is the ability of the geological structure to isolate the waste during the entire period for which the radioactive material is hazardous. The most likely route of leakage from a disposal facility is through water that penetrates the disposal facility and transports radionuclides to the environment, with subsequent possible exposure of people and water resources to ionizing radiation.

The 'ideal repository' would be located in a stable area and would be deep enough to be protected against surface erosion, major climatic changes (such as a new ice age), earthquakes (much less severe at depth) and human intrusion. It would be located in an impermeable formation, with sedimentary salt or clay layers being the most suitable. A continuing challenge to repository design is to find geological formations that are not vulnerable to water intrusion over the life of the facility and/or rock fracturing caused by tectonic events. Ethics, which requires protection of others from exposure to hazardous wastes, also requires proponents of geological disposal sites for RW to select repositories that will counteract any threat to others posed by the waste.

The basic idea behind this is the need to find stable geological environments that have retained their integrity for millions of years and are therefore likely to provide a suitable isolation capacity for a long time to come. Yet, it must be said that even geological sites that have been stable for long periods of time may not be stable over future periods of concern extending to thousands of years. The key to the acceptability of any geological disposal site is to find stable geological formations that are impermeable to water, impermeable in this case meaning that no water, or only a very small volume of water, can circulate in the geological formation.

A key element of disposal site design is the creation of barriers that further isolate the waste from the environment. Possible barriers, frequently considered in repository design, are glass, copper, ceramic, additional zirconium, stainless steel, nickel and titanium. Most RW disposal sites are designed to incorporate barrier methods that supplement the environmental isolation that can be expected from the site's geology. Although in some sites under certain conditions RW can be successfully isolated from the environment, at other locations, it may create unacceptable risks. Thus a key element in terms of understanding the risk of exposure to radioactive materials is the level of confidence that can be achieved about the geological properties and long-term stability of any disposal site under consideration.

For a variety of reasons, one of the important questions regarding repository design is whether the waste should be retrievable after being placed in the disposal site, so that new information about the waste or disposal site can be accommodated in the future (NEA 2001). In the design of waste repositories, many organizations with a need to dispose of nuclear waste have considered the concept of reversibility and retrievability.

The geological structures investigated to date throughout the world for possible nuclear waste disposal have included salt, granite, volcanic tuff and basalt (Warf and Plotkin 1996). Every site has been selected after much consideration of its geological and scientific suitability, and all have proven to be flawed in some way, making irretrievable burial problematic. In some instances fractures in the structure have occurred or have been discovered that would have allowed the nuclear waste to eventually escape its confines. Other problems have included the build-up and then outflow of water (Warf and Plotkin 1996). Earthquake susceptibility is always of concern and automatically precludes the use of some sites.

Reasons for incorporating reversibility and retrievability into disposal site design include the ability of such sites to:

- Deal with safety concerns that are recognized only after waste placement or when new safety standards have been introduced;
- Recover resources from the repository (e.g. where the waste has been discovered to contain a new and valuable component or where the site has been found to have an unforeseen amenity value);
- Use alternative waste treatment technology that is developed in the future;
- Respond to changes in social perceptions of risk or changes in policy requirements (NEA 2001).

As long as there is uncertainty about the long-term stability of a site, and thus its ability to isolate the waste from the biosphere for the entire time for which it is hazardous, the building of that site for potentially retrievable waste is of ethical significance. Ethics would require whoever builds a site to protect others from exposure to potential hazardous substances from that site. Thus a site that allows RW to be removed would be ethically preferable, if experience with that site demonstrates that assumptions of long-term stability were unfounded.

Reasons against incorporating reversibility and retrievability into disposal site design include:

- Uncertainty about negative effects, including conventional radiological exposure of workers, radiological exposure of workers engaged in extended operations or monitoring, and marginal increases in worker exposure;
- The difficulties involved in sealing a repository properly because of the implementation of longer-lasting or more complex operational plans designed to assure retrievability;
- Irresponsible attempts to retrieve or interfere with waste during times of political and/or social turmoil when safeguards or monitoring procedures are no longer in place;
- A possible need for enhanced nuclear safeguards (NEA 2001).

In addition, the decision to incorporate reversibility and retrievability into the design of disposal sites may greatly increase the costs of disposal.

If the risks from building a disposal site with retrievability of RW would put people at significant risk, then ethics might require that repositories should not include retrievability as part of their design.

The high costs of including reversibility and retrievability in a design could be ethically relevant if the costs of adding this feature to a disposal site were so great as to make the site unfeasible and if there were no other ways of safely disposing of the RW. However, as there is little evidence that the cost of building retrievability into storage design is prohibitive, the additional costs of including retrievability in a disposal facility design are not likely to be ethically justifiable as a basis for not including it. However, some utilitarians would modify the duty to build retrievability into site design if the costs were excessively disproportionate to the harm avoided.

It is possible to build retrievability into the early stages of the life of a repository while planning a decision for permanent waste isolation that would virtually eliminate irretrievability options at some time in the future. Even after the closure, mining techniques could allow containers to be retrieved as long as their integrity was maintained. Every decision about retrievability of waste has costs and benefits that need to be considered during the design of the disposal site along with the ethical duty to protect others from exposure to hazardous waste.

Fulfilling a campaign promise, US President Obama has proposed a budget for 2009 that cuts off most money for the Yucca Mountain nuclear waste project in Nevada, which has been under consideration by the USA as its first high-level RW disposal site. The decision could cost the Federal Government additional billions in payments to the utility industry, and if the cuts go ahead, it would mean that most of the US$10.4 billion spent since 1983 to find a place to put nuclear waste has been wasted. The Yucca Mountain project has been hotly debated and widely opposed, partly because of concerns about the adequacy of the site geology to retard water migration through the site during the life of the repository, and partly because of potential tectonic activity. Whether these issues should be a basis for denying operating permits for the Yucca Mountain site are matters of considerable controversy in the USA. Assuming the Yucca Mountain site is abandoned, new ethical concerns arise about the safety of the growing amounts of high-level nuclear waste currently being stored at nuclear power plants around the USA.

As a matter of ethics, it can be argued that the Obama decision is the right one, if one assumes that proponents of Yucca Mountain had not demonstrated that the site was sufficiently geologically stable to isolate the waste for 10,000 years, as required by US regulations.

Proponents of geological disposal of RW often argue that although risks of harm from the release of ionizing radiation into the environment exist, the benefits of nuclear energy outweigh the potential harm. At the centre of this debate are the difficulties in reaching a high level of confidence about any site's adequacy in terms of nuclear waste disposal.

The purpose of disposal of RW in geological formations is to isolate the waste from the environment during the period for which the waste is dangerous. Given that this period is millennial, the ability to know, with a high level of confidence, whether the site may leak ionizing radiation in the long term is extremely challenging scientifically. One author has identified numerous irreducible scientific uncertainties that limit the ability to predict with a high level of confidence the future performance of geological disposal sites. These uncertainties are related, among other things, to geological conditions very far in the future and to climate conditions (Shrader-Frechette 1993).

To perform adequate site characterization for geological disposal of RW, the geological structure of the site needs to be determined with a high level of precision. This includes all potential pathways of water movement throughout the site for thousands of years into the future. Predictions of groundwater flow rates and direction for some sites where nuclear waste has been stored have often proved to be wrong in the past in just a few decades. In the USA, for instance, predictions about groundwater transmission rates at Department of Energy facilities at Maxey Flats, Fernald, Savannah River, Hanford, Idaho Falls and Rocky Flats have led to problems (Shrader-Frechette 1993). Given the enormous time that RW repositories must isolate the waste, risk assessments about site safety must necessarily make unprovable assumptions—and therefore methodological value judgments—about future geological variability and climate conditions (Shrader-Frechette 1993). If these assumptions are wrong, the interests of future generations will be most affected, while the benefits of nuclear-produced electricity will be highest for present generations.

Decision making in the face of scientific uncertainty about the environmental impacts of human activities raises three types of ethical question:

1. On whom should the burden of proof rest regarding a project's safety or danger: the proponent(s) of the project, the government, or those who might be harmed by the project?
2. What quantity of proof should satisfy the burden of proof? Should a 95% confidence level—a norm followed by many scientific disciplines, the balance of the evidence, or other level of proof determine when a project is deemed to be safe or dangerous? (For a discussion of ethics and uncertainty, see Jonas 1984). A strong ethical argument can be made that the quantity of proof needed to satisfy the burden of proof should be in proportion to how dangerous or potentially catastrophic the project is. Given (1) the difficulty of reaching a high level of certainty about the safety of a proposed RW disposal site, and (2) the potentially great harm if people are exposed to waste that migrates from a disposal facility, there is a strong ethical argument that the burden of proof should rest with the proponents of the use of geological sites to show, with a high level of proof, that the site will isolate the RW for the entire period of concern.
3. Decision making in the face of scientific uncertainty raises questions of procedural justice about the rights of those who are put at risk by decisions under uncertainty and/or the rights of potentially affected parties to participate in the decisions.

2.3 Ethical Duties to Existing Local Populations

Risks from geological disposal of RW include serious threats to local populations near the disposal site if radioactive materials migrate either from the disposal site or are released during transportation of the waste to the site into the air or into water resources, thereby exposing populations. As discussed in West et al. (2011), such releases could be lethal or cause a variety of diseases to exposed populations.

Risks of harm to local populations from doses of ionizing substances can be minimized by facility design, engineering controls, monitoring of site performance, adaptive management techniques and careful site selection.

A number of ethical issues are particularly important as far as local populations are concerned because of the scientific challenges of site characterization.

- As methodological assumptions made in the course of on-site characterization projects cannot predict future long-term geological site conditions, they should err on the side of preventing harm because of the duty to protect local populations and future generations.
- To the maximum extent that is economically feasible, and for reasons stated above, site design and operational procedures should include the potential for reversibility and retrievability if very high levels of scientific certainty cannot be achieved about a site's ability to fully contain the radioactive materials.
- Among the practices related to the disposal of nuclear waste in geological repositories, there should be obligatory financial insurance which would be used to compensate local populations and future generations in the event of a disposal site failure.
- Proponents of the disposal of RW in geological formations (hereafter, proponents) and governments with authority to approve such projects (hereafter, governments) have an ethical duty to protect local populations from exposure to ionizing radiation through adequate site selection, site design, operational procedures, and engineering and monitoring controls.
- Proponents and governments must assure adequate representation of local populations in site approval, site design and site operations, before giving final approval to RW disposal projects.
- Proponents and governments must assure adequate education of local populations about potential risks to local populations.
- Approval procedures for geological disposal sites for RW must place the burden of proof on the proponents to demonstrate that a proposed site does not create risks to local populations from exposure to ionizing radiation.

2.4 Ethical Duties to Future Generations

Because of the extraordinarily serious long-term risks from ionizing radiation, and given the millennial time spans over which nuclear waste remains hazardous, the responsibility to protect future generations from radioactive exposure is an important ethical consideration that needs to be evaluated in the course of decision making. (For a discussion of ethical duties to future generations, see Partridge 1981.) Those ethical considerations include the following:

- It is the duty of proponents to demonstrate that the site will not incur exposure to ionizing radiation during the millennia for which the waste will be hazardous.
- Disposal of RW in geological sites should be limited to those sites for which it can be demonstrated, with a high level of confidence, that either the site will isolate the ionizing radiation at millennial scales or that the waste can be removed if a site's stability becomes questionable. If these conditions cannot be met, other technologies for generating the energy needed are ethically preferable. However, as we will see, other energy generation technologies create serious risks to human health and the environment in that they intensify climate change. Thus all energy-related technologies must be compared in terms of the harm they might cause.

- The generation producing the waste is responsible for the safety of the waste disposal site on behalf of future generations. This is a particular ethical challenge because of the propensity of existing generations to consider only their ethical obligations to contemporaries. The duty to protect future generations from exposure to high-level nuclear waste is not covered by normal economic methods for calculating cost-benefit analyses, which rely on discounting future benefits. (For a discussion of ethical limits of discounting future benefits in cost-benefit analysis, see Brown et al. 2006).

3 Ethical Issues Raised by the Geological Disposal of CO_2

3.1 Potential Harm from the Geological Disposal of CO_2

As described in other chapters of this book, there are a number of CO_2 capture and storage technologies for removing (capturing) CO_2 from fuel combustion emissions, and then injecting it into geological formations for long-term storage, instead of releasing it to the atmosphere. This section focuses on ethical issues arising from CO_2 storage in geological reservoirs and does not consider the risks of capturing CO_2 from combustion processes.

Risks of harm from geological disposal of CO_2 have been described in other chapters. These risks can be grouped into the following categories: (a) risks to local populations living near the site, and (b) risks of long-term leakage (Brown 2008).

3.1.1 Risks to Local Populations

Risks from geological disposal of CO_2, described in other chapters of this book, include serious risks to local populations near the injection site or along feeder pipelines, should CO_2 above certain concentrations leak from injection wells, pipelines and other elements of a storage system. Particularly vulnerable to such releases are people who live in the proximity of injection wells. However, this risk can be virtually eliminated by locating injection wells in unpopulated areas. In addition, if sites selected for geological disposal of CO_2 do not provide adequate caprock isolation of injected gases from groundwater systems, contamination of groundwater in the site vicinity is also a potential risk.

3.1.2 Risks from Long-Term Leakage of CO_2 into the Environment

As the purpose of geological disposal of CO_2 is to keep CO_2 out of the atmosphere in order to mitigate climate change, long-term leakage from storage sites could constitute failure of this technique. In addition, if CO_2 eventually leaks into the atmosphere from geological storage sites in sufficient quantities, it could make climate change impacts worse than they would have been if CO_2 emissions had been reduced by other methods.

The amount of potential leakage from CO_2 storage sites will determine the magnitude of the risks. Very small amounts of long-term leakage may have trivial impacts on climate change, while large leakage rates could exacerbate the adverse impacts. For this reason, it is important to be able to predict with sufficient accuracy the long-term fate of the CO_2 at each proposed geological storage site. Yet, as was the case in characterizing nuclear waste disposal sites, describing all potential leakage pathways over the area that might be the zone of impact for CO_2 storage is scientifically challenging for many potential sites. However, the time period of concern regarding site integrity is shorter in the case of geological CO_2 disposal (a few hundred years) than in the case of nuclear waste disposal (tens of millennia).

There is considerable experience of CO_2 injection over several decades in petroleum and gas recovery operations and considerable experience of, and understanding about, the natural storage of CO_2 and natural gas. However, there is little experience of long-term leakage from sites expressly chosen for the purpose of long-term CO_2 storage in places where petroleum or gas has not been naturally stored. Leakage of CO_2 from gas and petroleum production sites where CO_2 has been injected to enhance fossil fuel recovery is believed to be almost zero in the short term, but adequate long-term performance in terms of CO_2 leakage has not been demonstrated. Experience with leakage of CO_2 injected as part of petroleum and gas recovery operations may not be applicable to sites that do not have geological confining layers to the extent of those present in petroleum and gas fields.

To prevent threats from long-term leakage of CO_2, it is critically important that any potential site be properly characterized to determine not only the presence of an adequate caprock that will trap injected CO_2 but also the absence of other pathways through which CO_2 could leak into the environment. Whereas in the case of RW disposal there is a need to assure that the disposal site is stable for tens of thousands of years, for geological carbon storage it is usually assumed that after a hundred years or so from final CO_2 injection, the CO_2 will no longer pose a threat of leaking into the environment. This difference has ethical significance because it is technically more challenging to predict geological structure performance over very long periods.

To perform adequate site characterization, it is necessary to determine the geological structure of the site and all potential pathways of leakage from it, including leakage that could come from caprock dissolution. For this reason, most of the scientific challenges entailed in characterizing a site for RW disposal are also relevant to CO_2 disposal, with geological CO_2 disposal areas probably having the added problem of being much larger than RW storage spaces. As is the case in geological disposal of RW, significant ethical questions arise in the characterization of geological sites for CO_2 disposal about who the burden of proof should rest with, what quantity of proof is satisfactory, and the role in decision making of those who may be susceptible to harm from leaking CO_2.

The injection of CO_2 captured from the emissions of large coal-fired power plants will have a large area of impacts. Thus it may be particularly challenging to determine the variability of the geology over the entire impact area of a proposed site, particularly in parts of the world that have a highly variable geological structure. A site's zone of impact will increase with time as CO_2 injection continues, and it is thus necessary to understand the site geology over the entire zone of impact throughout the life of the project.

Risks of long-term leakage can be minimized by adaptive management techniques that are based on adequate monitoring of injection pressures and storage rates, which will limit further injections of CO_2 if leakage potential is identified. For this reason, regulatory controls of storage operations are necessary to assure adequate performance of the site in storage terms.

It may be necessary to install institutional controls over the site to prevent the creation of new leakage pathways in the course of time. For this reason, it could be necessary to restrict some aspects of future land use over the entire zone of impact.

3.1.3 Earthquake Risks

Underground injection of CO_2 or other fluids into porous rocks at pressures substantially higher than formation pressures can induce fracturing and movements along faults (IPCC 2005). Induced fracturing and fault movement activation can both increase pathways of leakage and induce earthquakes large enough to cause damage. Reduction of the risk of earthquakes can be accomplished by keeping injection pressures below pressures that will induce seismic activity and by not locating storage sites in seismically active zones. It is believed that risks of earthquake induction can be greatly minimized by regulatory controls over injection pressures and site selection (IPCC 2005).

3.2 Ethical Issues Entailed in the Geological Disposal of CO_2

For the reasons given above, proponents of geological storage of CO_2 have an ethical duty to demonstrate that a proposed disposal site will not harm others. As discussed in the chapter on environmental issues (West et al. 2011), in addition to adverse potential impacts on human life and health from geological disposal of CO_2, there are potential impacts on plants, animals and ecological systems. While there is a duty to protect people from harmful levels of exposure to CO_2 that is recognized by most ethical theories, different ethical theories would reach different conclusions about duties to plants, animals and ecological systems. Some utilitarians would find no absolute duty to protect plants, animals or ecological systems that could not be modified based on cost-benefit considerations. Other ethical theories such as biocentric and ecocentric ethical theories would demand their protection. Thus, one of the ethical issues raised by geological disposal of CO_2 is what are the ethical duties to prevent harm to plants, animals and ecosystems in cases where there are no risks to human life or health.

3.2.1 Ethical Issues Concerning Risks to Local Populations and Ecosystems from Geological Carbon Storage

Ethical issues raised by risks to local populations and ecological systems from geological CO_2 storage include:

- Proponents of geological CO_2 disposal projects (hereafter, proponents) have ethical duties to protect local populations from toxic doses of CO_2 through adequate site selection, design, engineering, and monitoring controls. For this reason, approval procedures for geological disposal of CO_2 must place the burden of proof on proponents to demonstrate that a proposed CO_2 storage project does not create unacceptable toxic risks to local populations or ecological system through leakage of CO_2.
- Proponents must ensure adequate representation of local populations in site approval and design.
- Proponents should ensure adequate education of local populations about the potential risks they face to assure fully informed consent about being put at risk.
- Governments responsible for approval of CO_2 disposal sites must insist upon adequate regulatory controls over project design and site selection criteria.
- Proponents must acknowledge their ethical duties to compensate local populations or insure them from harm caused by leakage of CO_2, should this occur.

3.2.2 Ethical Issues Entailed by Potential Earthquake Triggering

Ethical issues raised by risks of potential earthquake triggering by injected substances include the following:

- Proponents must demonstrate that injection of CO_2 and associated liquids or gases will not trigger earthquakes. This will involve demonstrating that injection rates will not be sufficient to induce seismic movement and that the site is not located in a seismically active zone for as long as earthquakes threaten human health or the environment.
- Governments responsible for approval of CO_2 disposal sites must make site approval conditional upon compliance with regulatory controls to guard against seismic movement.
- To assure the absence of potential triggering of earthquake by CO_2 injection, the burden of proof must rest with proponents to show that they have adequately characterized the geology of a proposed injection site to determine potential seismic response from CO_2 injection.

4 The Comparative Ethical Issues Involved in Geological Disposal of Nuclear Waste and CO_2 and Human-Induced Climate Change

Enormous and unprecedented challenges and threats to the human race are raised by climate change (Brown et al. 2006). Among the challenges are numerous profound ethical questions that emerge on at least four grounds:

1. The nations and people who are the main contributors to climate change are often not those who are most vulnerable to its impacts.
2. The impacts of climate change are potentially catastrophic. That is, climate change threatens people and ecosystems around the world with, inter alia, droughts and floods, rising seas, vector-borne disease, killer heat waves, and reductions in agricultural productivity (see Brown et al. 2006).
3. To address the threats posed by climate change, those who cause the problem need to consider the adverse impacts of climate change on people and their environment separated from them in time and space.
4. Most of the options for mitigating climate change carry potential harm and risks that must be considered through an ethical lens. That is, although most approaches to climate change mitigation, including geological disposal of RW and CO_2, raise ethical issues that need to be considered before the technologies are deployed, the ethical issues raised by these solutions must always be evaluated in the light of ethical issues raised by the threats posed by climate change itself. In particular, the ethical dimensions of each approach must be compared both with ethical issues entailed in harm arising from business-as-usual use of fossil fuels and with ethical issues raised by specific efforts to mitigate climate change.

Climate change raises many different civilisation-challenging ethical issues, some of which are relevant to the choice of climate change mitigation options, including nuclear power and the geological disposal of CO_2 (Brown et al. 2006). Among other ethical issues, climate change creates an immediate duty for nations to reduce their share of global greenhouse gas emissions to a level that is fair. This duty in turn creates a responsibility on the part of those nations currently exceeding their fair share of safe global emissions to consider approaches to climate change mitigation, including nuclear power and the geological disposal of CO_2. Climate change also raises many other ethical issues such as what atmospheric stabilization level should be the goal of all nations and who should pay for damage caused by climate change (Brown et al. 2006).

There follows an evaluation of ethical issues arising from human-induced climate change compared with ethical issues arising from the two potential approaches to mitigating climate change considered in this chapter, namely nuclear power and the geological disposal of CO_2.

4.1 The Ethics of Climate Change and of High-Level Nuclear Waste Disposal

As seen above, high-level nuclear waste disposal creates potential risks to local populations and future generations because of the millennia during which the RW must be isolated from the biosphere. If geological disposal facilities for nuclear waste fail, resulting in contamination of the surrounding environment, those who live in the vicinity of the disposal site are at highest risk, with the contamination likely to be local or regional, rather than global. There are numerous ethical issues arising from these risks.

The potential harm from RW and associated ethical questions, as serious as they are, must be reconsidered in the light of the potential harm of climate change and related ethical issues. From this, a number of things follow:

- Climate change creates an ethical duty for nations exceeding their fair share of greenhouse gas emissions to reduce their emissions. These nations must seriously consider alternatives to conventional fossil fuel technologies, including nuclear power and the geological disposal of CO_2. Ethically speaking, proponents of climate change mitigation options have a duty to deploy technologies that minimize potential adverse effects on human health and the environment. For this reason, technologies such as nuclear power or geological disposal of CO_2 may be ethically superior to fossil fuel technologies, although not necessarily superior to other technologies that can meet energy demand while reducing the threat of climate change.
- Those with greatest interest in the potential harm resulting from RW disposal are the current and future generations that could be adversely impacted by release of ionizing radiation. Given the nature and danger of these risks, a strong case can be made that as long as there are other ways of generating energy, then, as a matter of ethics, methods that are less risky should be chosen for generating energy until technologies are invented that allow radioactive geological waste disposal without generating contamination threats for future generations at a millennial scale.
- As fossil fuel technologies like carbon capture and storage also create potentially catastrophic impacts for existing and future generations, as well as for plants and animals and ecosystems around the world, there is a strong ethical imperative to move away from current methods of generating energy from fossil fuels.
- Given the ability of nuclear energy to produce power with minimum greenhouse gas emissions, there is a need to re-evaluate ethical issues associated with RW disposal.
- To the extent that alternatives to fossil fuel and nuclear energy can meet energy needs, a strong case can be made that these energy generation technologies should be given priority over both nuclear energy and fossil fuel-derived energy that releases large amounts of greenhouse gases. In fact, until problems associated with long-term isolation of ionizing radiation can be resolved, other approaches to climate change need to be considered before the use of nuclear power is extended.

4.2 The Ethics of Climate Change and of Geological Disposal of CO_2

Geological disposal of CO_2 raises ethical issues that need to be considered before the technology is deployed. However, this disposal technology also represents a way of mitigating climate change by not releasing into the atmosphere greenhouse gases currently being generated by coal combustion. Given that climate change-related threats are enormous, the ethical issues raised by the geological disposal of CO_2 must be evaluated in the context of climate change-related ethical problems that it could help to mitigate if the technology were deployed. Because of climate change concerns, the ethics of geological disposal of CO_2 must consider: (a) short-term risks from geological disposal of CO_2, (b) ethical issues entailed in the risk of long-term leakage of CO_2 back into the environment, and (c) ethical issues created by inappropriate reliance on geological disposal of CO_2.

4.2.1 Ethical Issues Entailed in Short-Term Risks from Geological CO_2 Disposal in the Context of Climate Change

As seen, geological disposal of CO_2 creates ethical issues regarding the need to protect people living near a CO_2 disposal site from leakage and the need to prevent the triggering of earthquakes. Yet these risks, comparatively speaking, are less serious and more local than the potentially catastrophic risks of climate change. Therefore, although there are continuing duties and responsibilities related to the geological disposal of CO_2, an ethical argument can be made regarding the short-term risks from geological disposal of CO_2, namely that this technology should be deployed for as long as there is no viable alternative to fossil fuel energy production and for as long as there is a reasonable prospect that the technology will meet design criteria and is economically feasible.

4.2.2 Ethical Issues Entailed in Risks of Long-Term Leakage of CO_2 Back into the Environment

If geological sites for CO_2 disposal leak CO_2 into the atmosphere in sufficient quantities, the requisite reductions in greenhouse gases cannot be provided and financial resources that could have been used for more effective greenhouse gas reduction technologies will have been wasted. Therefore, ethical duties with regard to long-term leakage of greenhouse gases from geological CO_2 disposal sites include the following:

- Proponents of geological CO_2 disposal sites have an ethical duty to demonstrate that there will be no long-term leakage of CO_2. This will be a difficult duty to meet because of the scientific challenges involved in characterizing the geology of a large site in parts of the world where the geology may be highly variable or fractured.
- As long-term leakage of CO_2 from a geological CO_2 disposal site could harm people at great distances from the disposal site, there is a global interest in assuring that geological CO_2 disposal sites do not contribute to climate change. Given the potential international climate change impacts from geological CO_2 disposal sites, those responsible have the ethical duty to ensure that siting criteria satisfy international standards.

4.2.3 Ethical Issues Entailed in Delays in Reducing CO_2 Emissions Because of the Potential for Geological Carbon Storage

Most observers agree that significant research is needed before geological storage of CO_2 can be widely deployed at coal-fired power plants around the world. There needs to be a high level of confidence that they will not leak CO_2 into the atmosphere; they should not pose short-term risks to persons and ecosystems near the site; and they must be economically feasible. A recent report of the Intergovernmental Panel on Climate Change (IPCC 2005) on geological storage identified the following knowledge gaps that need to be filled before this technology, although very promising, can be extensively used:

- There are major gaps regarding storage capacity at global, national and regional scales.
- There are significant knowledge gaps regarding storage capacity in those parts of the world that are likely to experience the greatest energy growth, such as China, South-East Asia, India, Russia, other successor states of the former Soviet Union, Eastern Europe, parts of South America, and southern Africa.
- There is a need for greater knowledge about some storage mechanisms including: (a) the kinetics of geochemical trapping and the long-term impact of CO_2 on reservoir fluids and rocks; and (b) the fundamental processes of CO_2 adsorption and methane (CH_4) desorption on coal during storage operations.
- There is some need to improve knowledge about: (a) risks of leakage from abandoned wells caused by material and cement degradation; (b) temporal variability and spatial distribution of leaks that might arise from inadequate storage sites; (c) microbial impacts in the deep subsurface; (d) environmental impact of CO_2 on the marine sea floor; and (e) methods to conduct end-to-end quantitative assessment of the risks to human health and the environment.
- There is a need to improve knowledge about the quantification of potential leakage rates from a greater number of storage sites.
- There is a need to improve reliable coupled hydrological–geochemical–geomechanical simulation models to predict long-term storage performance;
- There is a need for better monitoring technology at the surface and subsurface for: (a) location of CO_2 in the subsurface; (b) detection of sub-aquatic CO_2 see page; (c) leak detection at the surface; (d) fracture detection and characterization of leakage potential; and (e) long-term monitoring techniques (Benson et al. 2005).
- This research will be quite expensive. The highest-profile cancellation of geological sequestration research involved a project known as FutureGen, which President Bush announced in 2003. The project had been funded by a utility consortium with subsidies from the US Government, which intended to build a plant in Mattoon, Illinois, that tested the most advanced techniques for coal gasification, capturing pollutants, and burning the gas for power (Wald 2008). The project design called for CO_2 from coal combustion to be compressed and pumped underground, with monitoring devices determining whether gases would escape into the atmosphere. According to a New York Times article (Wald 2008),

about US$50 million had been spent on FutureGen before the Government pulled out of the project in January 2008 when the projected costs more than doubled to US$1.8 billion accompanied by fears that costs would go even higher. In addition, electricity utilities have also been cancelling their commitments to coal gasification plants that would make geological sequestration more affordable because they would produce less CO_2 per kWh of electricity generated.

Because of these research needs, it has been predicted that CO_2 from geological CO_2 disposal technology may not be technically feasible at the scale for which it is needed until 2030 (WBCSD 2006). Thus, the efficacy and magnitude of geological CO_2 disposal as an effective method of mitigating the effects of climate change may not be ascertained for perhaps decades.

Some observers of the development of geological CO_2 disposal technology are concerned about the potential for scarce research finance to be consumed on costly geological carbon storage research that could be more effectively used to research other climate change mitigation options, such as wind, solar power and advanced biofuels. For these reasons, waiting perhaps several decades for preliminary geological carbon storage research to be concluded may delay the introduction of other technologies that could reduce the threats from climate change.

Moreover, the additional costs of geological CO_2 disposal may make this technology economically undesirable compared to other climate change solutions. Thus, even if geological disposal of CO_2 is proven to be an effective means of keeping greenhouse gases from entering the atmosphere, it may not be economically viable.

Given the urgency of reducing greenhouse gas emissions in large quantities over the next several decades, using the potential of geological carbon storage as an excuse to delay deployment of other greenhouse gas emission technologies and strategies could exacerbate the impacts of climate change still further. Geological disposal of CO_2 therefore raises the following ethical issues.

- Given that greenhouse gas emissions are already causing harm to populations and ecosystems at a global scale, no nation that is already exceeding its fair share of safe global emissions may delay taking steps to reduce its emissions on the basis that new less costly technologies, including geological disposal of CO_2, may be invented in the future (Brown et al. 2006).
- For these reasons, nations that are already exceeding their fair share of safe global emissions need to use all currently available means to reduce greenhouse gas emissions, for example by using renewable energy and energy demand side management to reduce emissions to their fair share of safe global emissions while other technologies such as geological CO_2 disposal are being tested and developed.
- A nation that delays deploying available technologies to reduce greenhouse gas emissions on the basis that new less costly technologies such as geological CO_2 disposal may be available in the future should be liable for any damage caused by the delay.
- The promise of geological CO_2 disposal should not be used as an excuse for not implementing other available greenhouse gas emissions reduction strategies in those countries that are already exceeding their fair share of safe global emissions.

5 Conclusions

As we have seen from the above, the geological disposal of both nuclear waste and CO_2 creates several different types of potential risk which trigger ethical issues and concerns. Common to both types of disposal is the need to achieve an appropriately high level of confidence that the geological structures will contain the substances of concern during the period for which the substances could cause harm.

Ethically speaking, the higher the degree of seriousness of the potential adverse impacts, the higher the level of care that needs to be provided. Making a comparison of the ethical obligations triggered by the use of these two technologies is useful for contrasting the nature of the potential harm that could be caused if the geological structures fail to contain the substance disposed of. As geological disposal of RW and that of CO_2 entail different time periods of potential concern and different threats to human health and the environment if, once disposed of, they leak into the environment, ethics requires that different levels of scientific scrutiny be achieved about the suitability of the geological structures that are relied upon to contain each.

Without doubt, safe geological disposal of RW requires the geological structure in which the RW is disposed of to isolate the nuclear waste for the millennia during which the nuclear waste is hazardous, unless the disposal facility allows for retrieval of the waste where there may be evidence that the site is not performing as designed. The period of concern for geological sites for CO_2 disposal is considerably less (several hundred years) than that for nuclear waste disposal.

As the period of concern is so long for RW, and as ethics requires care in proportion to the degree of potential harm, a strong case can be made that as a matter of ethics, extreme care about the long-term suitability of any given nuclear waste disposal site is required. Because of the scientific challenges involved in reaching a high level of confidence that any geological structure will prevent radioactive substances from migrating into the environment during such a long period of concern, the duty of care regarding the suitability of geological disposal sites for RW is a particular technical challenge. Although the period of concern regarding CO_2 containment is significantly shorter than that for RW, there are nevertheless significant technical challenges in meeting relevant ethical obligations to prevent CO_2 leakage, given the large areas that will be needed to dispose of the CO_2 generated by large coal-fired power plants.

As we have seen, ethics requires care in proportion to the degree of potential harm from the proposed activity under consideration. As the radioactive substances that will be disposed of in geological sites will be extremely toxic, high levels of care are warranted regarding the ability of such sites to prevent exposure. Exposure to CO_2 is not, under most circumstances, likely to be a threat to human health except in cases where very high concentrations of CO_2 could leak from injection wells or other large leakage pathways, potentially harming local populations or reversing climate change mitigation efforts.

If it can be shown that the risks from the geological disposal of RW and CO_2 are less problematic than the threat of climate change and that there were no reasonable alternatives to the geological disposal of RW and CO_2 as a way of mitigating the threat of climate change, an ethical justification for the use of these technologies, despite their risks, can be made; however, ethical duties remain to deploy these technologies in a consistent way with other ethical obligations to the maximum degree feasible. If, however, there are reasonable alternatives to nuclear power and the use of fossil fuels with geological disposal of CO_2 as methods of mitigating the threat of climate change, and an appropriate level of confidence cannot be attained that the geological structures can prevent radioactive substances or CO_2 from harming human health or the environment, then an ethical argument can be made that other alternatives should be preferred.

References

Allègre M (1999) The deep geological repository: an unavoidable and ethically correct solution. In: Proceedings of the 24th Annual International Symposium, The Uranium Institute. http://www.world-nuclear.org/sym/1999/allegre.htm. Accessed 17 Nov 2008

Benson S, Cook P et al (2005) Underground geological storage. In: Metz B, Davidson O, de Coninck HC, Loos M, Meyer LA (eds) IPCC Special Report on Carbon Dioxide Capture and Storage. Cambridge University Press, Cambridge, pp 195–276, http://www.ipcc.ch/pdf/special-reports/srccs/srccs_summaryforpolicymakers.pdf. Accessed 17 Nov 2008

Brown D (2008) The ethics of allocating public research funds for carbon capture and storage. Rock Ethics Institute, Penn State University. http://climateethics.org/?p=48. Accessed 24 Nov 2008

Brown D, Tuana N, Averill M, Bear P, Born R, Lessa Brandão CE et al (2006) White paper on the ethical dimensions of climate change. In: The Collaborative Program on the Ethical Dimensions of Climate Change, Rock Ethics Institute, Penn State University. http://php.scripts.psu.edu/dept/rockethics/climate/whitepaper/whitepaper-intro.shtml. Accessed 17 Nov 2008

EU (European Union) (2008) Management of spent nuclear fuel and radioactive waste. http://europa.eu/legislation_summaries/energy/nuclear_energy/l27048_en.htm. Accessed 17 Nov 2008

Hargrove EC (1996) Foundations of Environmental Ethics. Environmental Ethics Books, Denton

IPCC (Intergovernmental Panel on Climate Change) (2005) IPCC Special Report on Carbon Dioxide Capture and Storage. Metz B, Davidson O, de Coninck HC, Loos M, Meyer LA (eds). Cambridge University Press, Cambridge/New York, Available in full at www.ipcc.ch. Accessed 12 July 2009

Jonas H (1984) The Imperative of Responsibility: In Search of an Ethics for a Technological Age. University of Chicago Press, Chicago/London

NEA (Nuclear Energy Agency) (2001) Reversibility and retrievability in geologic disposal of radioactive waste. Reflections at the international level. NEA Report 3140. http://www.nea.fr/html/rwm/reports/2001/nea3140.pdf. Accessed 17 Nov 2008

Partridge E (ed) (1981) Responsibilities to Future Generations. Prometheus Books, Amherst

Shrader-Frechette KS (1993) Burying Uncertainty: Risk and the Case Against Geological Disposal of Nuclear Waste. University of California Press, Berkeley

Shrader-Frechette KS (2002) Environmental Justice: Creating Equality, Reclaiming Democracy. Oxford University Press, New York

US DOE (US Department of Energy) (2008a) Radioactive waste: an international concern. http://www.ocrwm.doe.gov/factsheets/doeymp0405.shtml. Accessed 17 Nov 2008

US DOE (US Department of Energy) (2008b) Managing nuclear waste: options considered. http://www.ocrwm.doe.gov/factsheets/doeymp0017.shtml. Accessed 17 Nov 2008

Wald ML (2008) Mounting costs slow the push for clean coal. The New York Times. http://www.nytimes.com/2008/05/30/business/30coal.html. 30 May 2008

Warf JC, Plotkin SC (1996) Disposal of high-level nuclear waste. Nuclear Age Peace Foundation. http://www.wagingpeace.org/articles/1996/09/00_warf_disposal.htm. Accessed 17 Nov 2008

WBCSD (World Business Council for Sustainable Development) (2006) Facts and trends: carbon capture and storage. http://www.wbcsd.org/web/publications/facts&trends-ccs.pdf. Accessed 17 Nov 2008

West JM, Shaw RP, Pearce JM (2011) Environmental issues in the geological disposal of carbon dioxide and radioactive waste. In this volume