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CPD

5, S120–S128, 2009

Interactive Comment

Interactive comment on "How to treat climate evolution in the assessment of the long-term safety of disposal facilities for radioactive waste: examples from Belgium" *by* M. Van Geet et al.

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Overall Comments

This is a useful general paper that gives an overall account of proposals for the disposal of different classes of radioactive wastes in Belgium and how climate change may be taken into account in evaluating the long-term radiological safety of such disposal. The approach adopted, with disposal of short-lived low- and intermediate-level radioactive wastes in a near-surface facility and long-lived wastes in a deep disposal facility, is in accord with the approach that is being adopted in various countries. However, it is worth noting that considerable differences exist between different countries in respect of the host rock proposed for a deep geological facility. Thus, in both Sweden and Finland facilities at a depth of around 500 m in fractured hard rock are proposed, whereas in the United States a facility in unsaturated volcanic tuff at Yucca Mountain, Nevada has been proposed by the Department of Energy and a license application has been submitted. In France, as in Belgium, a facility located in argillaceous strata is proposed. Although the paper is properly focused on potential facilities in Belgium, it would have been nice to have seen these proposals framed within the context of the wide diversity of host geologies under consideration internationally.

In the 1980s and early 1990s, the potential significance of global warming in assessing the post-closure radiological safety of radioactive waste disposal facilities was scarcely appreciated. The past was considered to be an adequate model for the future, so paleoclimatic reconstructions of the last glacial-interglacial cycle (from the Eemian, Marine Isotope Stage 5e, to the present day) were imposed. This led to a heavy emphasis on cold climate conditions and, to a considerable degree this emphasis persists today in both the Scandinavian and US programmes. However, this emphasis is conditioned not only by forecasts of potential patterns of future climate evolution, but also by an evaluation of those climatic conditions that pose a threat to the long-term safety of a deep geological disposal facility. Thus, in the Scandinavian programmes, a particular concern is that the passage of an ice margin across the site could result in dilute, oxygenated groundwater being forced to considerable depth affecting both the containment properties of the bentonite buffer that is proposed and the corrosion-resistance of the waste containers. In the Yucca Mountain programme, the concern is that a future global glaciation would be associated with intense fluvial conditions and that the associated increased infiltration could enhance corrosion of the various elements of the engineered barrier system. This illustrates that in defining scenarios for assessment, consideration has to be given not only to the relative likelihood of the climate scenarios, but also to their significance for repository safety.

In the case of the proposed Belgian facility one cold region effect that could have considerable significance is the penetration of permafrost to repository depth. It is nice to see this brought out in Figure 6 of the paper. It is of particular potential significance in that the proposed host formation is the Boom Clay, which is located at a depth of only 190 m. In UK and Scandinavian conditions, permafrost depths of a few tens of metres to well over 100 m have been estimated. It would be interesting to include some comment on whether simulations have been conducted to assess the potential degree of permafrost penetration that could occur under an extended period of periglacial conditions.

Notwithstanding the above remarks, since the early 1990s there has been increasing recognition that the limited degree of variation in insolation over the next 50,000 years would lead to a much protracted interglacial episode. When anthropogenic warming is taken into account, this effect is much enhanced. The authors recognise this, but do not emphasise the underlying reasons. These include the very long-term persistence of additional carbon dioxide in the atmosphere following its release in fossil fuel combustion and positive feedback effects such as a decrease in size of the Greenland ice sheet leading to modified albedo values at high latitudes. The long-term persistence of anthropogenic warming is typically advantageous in making the safety case for a deep geological repository, but raises the question of whether reliance should be placed on this effect, which is perceived as being deleterious in a wider environmental context, resulting in a search for methods of mitigation through reductions in emissions.

The authors note the potential significance of the thermal expansion of seawater in increasing global sea levels (see Figure 8). It is not clear whether this effect is of significance at their proposed repository location. However, if it is, then consideration has to be given to other potential contributors to sea-level rise. Thermal expansion is shown as contributing up to about 2 m by 3000 ad. A simple 1D calculation for a range of global-warming scenarios suggests that the increase could be 4 m or more once equilibrium is achieved. However, in many global climate models complete or partial melting of the Greenland Ice Sheet is projected to occur over the next few thousand

CPD
5, S120–S128, 2009

years and this could contribute up to another 7 m. A similar contribution could arise from the West Antarctic Ice Sheet and a smaller contribution of about 0.5 m could come from valley glaciers and continental ice caps. Thus, overall, a sea-level rise of around 20 m on a timescale of a few thousand years cannot be ruled out.

In developing scenarios for long-term climate evolution, the authors rely on the results from the BIOCLIM project. Similar reliance is placed on these results in other deep geological disposal projects, e.g. in the work of the Nuclear Decommissioning Authority, Radioactive Waste Management Directorate (NDA RWMD) in the UK. At the time, the BIOCLIM project was highly innovative, relying on EMICs that were enhanced during the project and downscaling techniques that were developed specifically for the work. However, BIOCLIM was completed in 2004 and both EMICs and downscaling techniques have been substantially developed. There is, therefore, an argument for revisiting the types of long-term climate projections that were made in BIOCLIM. It seems likely that the overall patterns of climate change would be similar, but quantitative aspects such as the degree and persistence of warming might be significantly altered.

One aspect of the effects of climate change that has been given limited consideration is the significance of a very prolonged interglacial on ecosystems, soils and landform development. Projecting the significance of such a long, no-analogue period is compounded by the need to consider on-going human impacts on the landscape, a consideration that was not of relevance in previous interglacial periods. It is usual in post-closure safety assessments to assume human habits and behaviour continue as at the present day, either local to the site or at an analogue location for changed climatic conditions. However, present-day intensive use of the landscape has been occurring for, at most, a few centuries and it is not clear that it is sustainable for the many millennia of interglacial conditions that are forecast with or without a contribution from human-induced greenhouse warming.

Assuming that factors such as permafrost penetration and deep erosion do not signifi-

CPD

5, S120–S128, 2009

Interactive Comment

cantly affect the host formation, then disposal in a thick clay formation has substantial advantages that are not fully brought out in the paper. Specifically, any releases of radionuclides from the engineered system are likely to be transported by diffusive, as opposed to advective, processes. Transport by diffusion through a clay layer some tens of metres thick might be expected to require hundreds of thousands to millions of years (see Figure 11). If this is the case, then climate change is likely to be primarily of interest in terms of its effects on the host formation rather than on the underlying or overlying aquifers or on the biosphere.

Detailed Comments

Page 466: By achieving limitation of water flow through the disposal system, it is claimed that there will also be limitation of the gaseous transport of radionuclides. This is correct if the integrity of the host formation remains unimpaired. However, gas generation in a repository can lead to significant over-pressurisation of the host formation. In tight clay, release of this gas may be difficult to achieve and fracturing of the formation may occur. The gas is produced mainly from metal corrosion in anaerobic conditions, generating hydrogen, and from microbial degradation of organic materials, generating mainly carbon dioxide and methane. Both these processes are influenced by the availability of water, which will be limited in clay. Therefore, detailed analysis is required to estimate water availability, amount of gas generation and degree of over-pressurisation that could occur. These issues are not mentioned.

Page 467: It is clearly desirable to limit the likelihood of inadvertent human intrusion into a deep repository. This can be done by constructing the repository at great depth in an area where there is little potential for exploitable resources to be present. In this context, it is important to recognise is the potential for such resources to be present, as intrusion could occur during exploration for resources rather than their exploitation. Also, the current economics of resource exploitation need to be treated carefully in considering the potential for future exploration and exploitation, as the demand for particular resources may change very markedly, even without significant changes in

CPD

5, S120–S128, 2009

overall technology.

However, while it is clear that it is possible to limit the likelihood of inadvertent human intrusion into a deep repository, it is not clear that much can be done to mitigate its consequences, as is claimed in the paper. Intrusion would most likely be due to a borehole penetrating the repository. If this occurred without knowledge of the nature of the waste materials present, doses would arise both to the drilling crew and from the distribution of waste at the surface. Mitigation of the consequences of such intrusion would require devising techniques either to ensure that the more hazardous wastes were not accessible to penetration by such a borehole or that a consequence of intercepting the wastes would be recognition of their hazardous nature. Although not related to climate change, these are issues that need to be kept in mind.

Page 468: It is claimed that the impact on man and the environment is inversely proportional to the reduction in contaminant concentrations. It should be understood, that this statement can only be made if the primary concern is with the most exposed individuals and ecosystems or habitat patches or if there is are thresholds in the deleterious responses to releases. For humans, it is usual to assume that a linear no-threshold dose-response relationship applies at the low doses and dose rates of relevance. Thus, if contaminant concentrations are reduced, the impacts on the most exposed individuals will be reduced pro rata. However, the number of exposed individuals will be increased. Throughout the world, it has been assumed that the safety of repositories can be assessed by reference to the radiological impacts on the most exposed individuals, but this is a matter that needs to be kept under consideration. Incidentally, it is a tension in the ‘concentrate and contain’ philosophy of solid radioactive waste management that any releases of radionuclides that do occur tend to be localised in the environment, so enhancing the impacts that are considered in assessments. It is these considerations that lie behind the remark in the paper that the processes of dispersion and dilution are considered a role of the environment, as opposed to a safety function, since all efforts to maximize or optimize them would lead to a disperse and

CPD

5, S120–S128, 2009

Interactive Comment

dilute strategy.

Page 468: It would be useful to define the normalised Radiotoxicity Index. However, in general terms it is the product of radionuclide inventory and toxicity by ingestion summed over radionuclides. It is a useful overall index, but it should be kept in mind that it does not take account of the relative mobility and bioavailability of the different radionuclides and it is not a substitute for performing full radiological impact assessment calculations with results expressed in terms of dose or risk.

Page 470: The position of the FNAC is that if individual humans are protected from potential radiological hazards, then other living organisms in the environment will be sufficiently protected. This is in accord with the views expressed by the ICRP in its 1990 recommendations. However, since then there has been increasing recognition that this position was not underpinned by adequate evidence. In view of this, the ICRP has set up Committee 5 to investigate this matter further and the European Union has been exploring technical issues in the FASSET, ERICA and PROTECT projects. Although it seems likely that the FNAC position is correct, it seems inevitable that waste management organisations will have to demonstrate this through explicit calculations, rather than assuming it to be the case.

Page 472: A particular strength of the approach that is used for safety assessment is the concept of safety statements and the need to develop support for those statements. This is well illustrated in Figure 5. The approach has similarities with the use of safety indicators by SKB and it would have been of some interest to compare the two approaches. The relation of safety statements to the propagation of uncertainties (shown in Figure 6) is of particular interest, since it contributes to the demonstration that a comprehensive safety assessment has been performed.

Page 475: It is agreed that, for Europe, annual mean temperatures are likely to increase more than the global mean. However, it is relevant to consider the potential for abrupt climate changes, such as a change in the thermohaline circulation due to freshwater

CPD

5, S120–S128, 2009

inputs into the North Atlantic from melting of the Greenland Ice Sheet. These have the potential to cause cooling (or at least reduced warming) of Europe during a period of general global warming.

Bibliography

ANDRA, 2005, Dossier 2005 Argile, Tome: Evaluation du Sûreté du Stockage Géologique, ANDRA, Châtenay-Malabry, France.

Archer, D, Kheshgi, H and Maier-Reimer, E, 1997, Multiple timescales for neutralization of fossil fuel CO2, Geophysical Research Letters, 24(4), 405-408.

Archer, D, Kheshgi, H and Maier-Reimer, E, 1998, Dynamics of fossil fuel CO2 neutralization by marine CaCO3, Global Biogeochemical Cycles, 12(2), 259-276.

NAS, 2002, Abrupt Climate Change: Inevitable Surprises, National Academy Press, Washington D.C.

Schellnhuber, H J, Cramer, W, Nakicenovic, N, Wigley, T and Yohe, G (Eds), 2006, Avoiding Dangerous Climate Change, Cambridge University Press.

SKB, 2006, Long-term Safety for KBS-3 Repositories at Forsmark and Laxemar - A First Evaluation: Main Report of the SR-Can Project, SKB Technical Report TR-06-09, October 2006.

Thorne, M C and Kane, P, 2006, Development of a Series of Narratives for Climatic and Landscape Change, Mike Thorne and Associates Limited Report to United Kingdom Nirex Ltd MTA/P0011a/2005-1: Issue 2.

Thorne, M C, Watkins, S J, Goodess, C M and Palutikof, J P, 2000, The Role of the Antarctic Ice Sheets in Determining Global Sea Levels, AEA Technology Report AEAT/R/ENV/0170 to United Kingdom Nirex Limited.

US Department of Energy, 2008, Yucca Mountain Repository License Application, Safety Analysis Report: Chapter 2: Repository Safety after Permanent Closure,

CPD

5, S120–S128, 2009

Interactive Comment

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Interactive comment on Clim. Past Discuss., 5, 463, 2009.

CPD

5, S120–S128, 2009

Interactive Comment