Miljöorganisationernas kärnavfallsgranskning, MKG

Underlag för kompletteringskrav rörande alternativa metoden djupa borrhål

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SKB'S ASSESSMENT OF DEEP BOREHOLE DISPOSAL COMPARED TO KBS-3

The comments below are based on MKG's translation of the relevant parts of SKB Report R-10-13 and on selected excerpts from SKB's licence application that deal with deep borehole disposal (DBD). These comments focus on flaws and weaknesses in the arguments against DBD arising from errors, inaccuracies and subjective judgements. No comment is made regarding the KBS-3 mined repository. While the comments do not specify what further work SKB should carry out to enable a more appropriate comparison to be made between the two disposal methods, they do identify areas and issues where SKB's assertions are incorrect or unsubstantiated and should be withdrawn or further work undertaken to justify them.

R-10-13. Comparison of the KBS-3 method and deposition in deep boreholes for the final disposition of spent nuclear fuel.

General Comments

There are a number of serious weaknesses in the comparison made in this report and these are summarised in this section. They are underpinned by the comments on specific passages from the report set out in more detail in the next section.

1. The main weakness of this report is the choice of SKB's own (PASS) version of DBD on which to base the comparison. Dating back to the late 1980's, it is out of date, un-necessarily large, over-engineered and expensive (e.g., the use of Ti canisters) and requires borehole diameters that stretch even current drilling technologies to the limit. The PASS concept has effectively been rejected by the international DBD community and does not represent the current state of DBD.

   It is claimed in the report and elsewhere (e.g., P-10-47) that this report is "an up to date summary of the state of knowledge within the area of deep boreholes". Even allowing for its publication date of 2010, it is not. Almost all of the works referred to are other WMO reports and there is little recognition of research published in the scientific literature and elsewhere (a common failing of WMO reports). However, it is quite clear that the authors are aware of developments well beyond PASS and for a valid comparison they should have used a range of versions representing modern DBD concepts for spent fuel (SNF) (Arnold et al. 2010). These would extend from a "basic economy" version (e.g., Brady et al. 2009) to more sophisticated SNF concepts (e.g., Gibb et al., 2008a, 2008b).

   The erroneous claim that KBS-3 is being compared with the state of the art DBD notwithstanding, almost all the arguments are based on comparisons with the details, components and parameters of the PASS concept (see examples below). Most of the unfavourable (to DBD) conclusions arising from this would be negated or even reversed if the optimum relevant alternatives from the range of modern DBD concepts were used. The effects of using some of these alternatives are even acknowledged in the text but apparently ignored in arriving at the conclusions.

   There are suggestions in the report that PASS is the best version of DBD because other (pre-2004) reviews have referred to it as the "most comprehensive". It is true that it is the one that has been described in most detail but it has been overtaken by developments and, while it is understandable that SKB would choose the DBD concept about which they know most, it is difficult to avoid the impression that they selected the PASS concept to produce as unfavourable a comparison as possible.

2. Typical of the arguments made against DBD is the number of boreholes (60) and the area they would occupy (15 km^2) for the Swedish reference scenario for spent fuel. This is based on the PASS concept of disposing of complete fuel assemblies at one PWR assembly per canister, PASS parameters and a borehole spacing of 500 m. Had fuel pin consolidation and a realistic spacing of boreholes been used, the Swedish reference scenario would have required 15 boreholes and an area of 0.04 km^2 (i.e. around 3 soccer pitches) – [*Contrast Fig. 2-5in R-10-13*]. Closer spacing and the option of consolidation are indeed mentioned in the report but seemingly ignored in deriving the case for comparison with KBS-3 and the conclusion.

3. It is acknowledged in several places (e.g., p.4, §.6) that the most important safety factor in KBS-3 is the containment of the SNF in the copper canister for hundreds of thousands of years whereas in DBD it is containment by the geological barrier. The comparison is thus not of like with like (e.g., between two mined repository concepts) making the whole exercise difficult and raising questions about the validity of such a comparison. For example, how meaningful is it to compare the details and performance of the various components of the engineered barrier systems (EBS) when the EBS is all but irrelevant in DBD after the hole is sealed? Nevertheless, the report goes to great lengths to present such arguments.

4. The contention that DBD is less safe than KBS-3 is contrary to the view expressed by most research works and reports on deep boreholes and is counter to the intuitive understanding that a geological barrier an order of magnitude greater would make DBD safer. It is based mainly on the assertion that very little is known about the actual geological, hydrological and geochemical conditions at depths of a few km and that what is known comes from a small number of deep holes, including two in Sweden. Apart from the fact that there are now many more deep holes than mentioned in the report (especially geothermal energy wells that give encouraging (for DBD) information on conditions at depth), both are irrelevant and ignore the basic principle of DBD: a disposal borehole would only be drilled after one or more smaller pilot holes had been sunk and proved that the conditions at depth were suitable for DBD.

5. The suggestion that the primary, if not only significant, safety function of DBD comes from the "stagnant groundwater" retarding return of escaped radionuclides to the biosphere is perpetuated throughout the report (e.g. p.16, §. 3; p.18, §.3; p.21, §.1). This is completely misleading. While density stratified brines above the disposal zone are a major contribution to safety, so too are factors like the very low bulk hydraulic conductivities, long return paths and extremely long groundwater residence times found at DBD depths.

6. The main arguments presented against the powerful isolation DBD provides because of the density stratification of groundwaters are that we can not be sure this exists at the disposal site and if it does we can not be sure it will survive future geological processes. In the first place, determining the existence of such a deep groundwater structure would be a pre-requisite to selection of the DBD site, as would be the determination of appropriate residence times of the intra-rock fluids. The latter can be 10's to 100's of millions of years, giving confidence that the system will survive well beyond the hundreds of thousands of years required.

7. Among the processes alleged in the report to affect the isolation provided by the groundwater stratification are glaciations and earthquakes. The geochemistry of deep groundwater demonstrates that past glaciation effects have failed to penetrate to such depths and earthquake shear waves do not disrupt density layered fluid systems. Despite this the report claims that the safety of KBS-3 is <u>less</u> likely to be compromised than that of DBD by future earthquakes and glaciations. This appears to be completely the reverse of reality and, if this claim is to be sustained, considerable further work is needed to present evidence to substantiate it.

8. The report develops the historical (and fallacious) arguments that DBD is inherently unsafe because large diameter boreholes create problems for drilling circular holes, the casing could become stuck and containers could become jammed and damaged during deployment. The first is true but irrelevant: the hole does not need to be circular as long as the casing retains its shape until filling is complete. Modern steel casings will do so in all but the most extreme anisotropic stress fields (in

which DBD would not be contemplated anyway). The second is highly unlikely even at the depths and casing weights involved and if the borehole could not be properly cased it would not be used - posing no threat to safety. The possibility that waste packages could become stuck and damaged in a fully cased borehole can be almost completely engineered out. Even if a package became temporarily stuck it could be safely recovered without any threat to its contents (as explained below). This is an old and outdated argument that has little basis in fact.

9. The report states incorrectly that DBD is not a multi-barrier disposal concept. It is true that the EBS (wasteform, container, casing and any buffer/support matrix used) has only to ensure containment until the borehole is sealed (usually a few years). However, the reality is that containers such as stainless steel and buffers/support matrices such as cement or metal alloys (Gibb et al., 2008b) would almost certainly retain their integrity for a thousand years or more, i.e., long enough for the radioactivity in SF to have decayed significantly. DBD is a genuine multi barrier concept with an EBS and stronger geological barriers than a mined repository.

10. The discussion of deep drilling technologies presented in section 4.1 is reasonably accurate and fair for the purposes of the comparison. Perhaps unsurprisingly [*see comment 1*], it seems unaware of the upward revision to achievable diameter/depth combinations given by Beswick (2009). However, its conclusion that the largest borehole feasible with current drilling technology is too small to allow DBD of a PWR fuel assembly is incorrect and, again, comes mainly from the PASS concept. It has been overtaken by developments (e.g., Brady et al., 2009) and later publications (Travis et al., 2011).

11. The report states that SKB has rejected the alternative of DBD, as it has done repeatedly, because the maturity of the concept is not at the same level as KBS-3 and much work, time and expense would be required to remedy this. They are almost certainly over-estimating what is required because they do not appear to fully appreciate how close advances in deep drilling technologies have brought us to being able to drill the necessary boreholes and deploy (and recover) waste packages in them. Similarly, there is no recognition of how similar waste package handling and transport requirements would be to existing practices in the nuclear industry. Nevertheless, they are right in that nobody has yet drilled a hole of the necessary size, produced a precise engineering design or developed a specific safety case for regulatory approval.

    However, does the need for such work really constitute a valid reason for not doing it if all the evidence points to the potential benefits being likely to justify it? The Swedish regulators appear to have rejected this reasoning in 1992 and, unless SKB can demonstrate more convincingly than they do in this report that DBD is not potentially safer and better than KBS-3, it does not stand up any better now.

Specific Comments

12. The historical argument against DBD of the canister becoming stuck and damaged during deployment is brought up again (e.g., p.5, §. 2; p.28, §.4). As most modern concepts point out, this risk can be almost entirely engineered out in a fully cased borehole to be no greater than the risk of damage during deployment in repository deposition holes and tunnels. The report seems oblivious to the fact that emplacement of a waste package through the borehole fluid may actually require downward pressure if deployment is to be achieved in a reasonable time (unless the clearance between the container and casing is excessively large, which would further reduce any risk of jamming). If it was possible for a container to become stuck, the downward pressure leading to this could easily be exceeded by the upward (releasing) pull generated by any drill rig powerful enough to have drilled the hole and emplaced the casing.

    Further, the waste packages have to be designed to withstand normal deployment, including the load stresses generated at the bottom of the stack, and so would be robust (e.g. thick stainless steel) possibly with protective over-packs. Consequently, the possibility of damage that would threaten the containment of the radionuclides as a result of temporary jamming is almost non-existent.

    If SKB wish to use this argument they need to substantiate it in the context of a modern DBD concept.

13. The contention (p.5, §.3) that KBS-3 is "resilient" to earthquakes but DBD is not is both disingenuous and almost certainly wrong. The shear waves generated by even a moderate earthquake could destroy the integrity of the copper canisters on which KBS-3 relies, despite claims the bentonite buffer would protect it [*For how big a shear displacement has SKB demonstrated this*?], so releasing radionuclides prematurely. On the other hand, it has repeatedly been pointed out that the isolation provided by the density-stratified groundwaters in DBD would not be disrupted by tectonic events. Unless SKB can provide evidence that (a) KBS-3 containers can survive more than the smallest of earthquakes and (b) the isolation provided by the geological barrier in DBD can not, this suggestion should be withdrawn.

14. The statement (p.5, §. 6) that it would take 30 years of research and cost 30 B kronor to bring DBD to the level where it can be evaluated "at an equal level" against KBS-3 can not be substantiated without a great deal of work, if at all. It is based on a historic belief that DBD is an "immature technology" but it is now widely acknowledged that much of the technology for drilling the boreholes and deploying materials therein already exists, or can readily be developed from current technologies, in the oil & gas or geothermal energy industries.

    Also, most of the necessary waste package handling and transport methodologies are already well developed in the nuclear industry and would require only modification or adapting for DBD. The only completely new requirement would be a shielded well-head facility for rotation and insertion of the waste packages into the borehole, which should not prove beyond existing engineering capabilities.

15. The claim (p.7) that DBD is likely to be more expensive to implement than KBS-3 contradicts all published estimates of the cost of drilling deep boreholes and ignores the modular, flexibility and "pay as you go" aspects of DBD whereby a small disposal programme can easily be extended or a large one terminated early with no further cost (contrast a mined repository where most of the cost is incurred before the first waste package can be emplaced). If SKB are to use this argument it will require much more realistic quantified estimates of the costs of a DBD programme, based on concepts other than PASS, for disposal of the Swedish inventory of SNF.

16. The statement (p.11, §.1) that foreign studies of deep boreholes rely heavily on PASS is misleading. Such studies fall into two categories: those that simply review other deep borehole studies (e.g., Nirex, 2004) and those that look to develop better DBD concepts (e.g., Brady et al., 2009; Gibb et al., 2008b). The former may describe the PASS concept as one of the "most completely documented" but the latter are axiomatically rejecting it as out of date and unsatisfactory, although they may retain/modify some aspects of its technical detail.

17. Disposing of one intact PWR assembly per canister using the PASS concept (p.12, §.2) may well require 60 holes for the Swedish reference scenario but if one of the versions of DBD based on fuel pin consolidation was employed this would become ~15 holes.

18. The discussion on DBD canister materials (p.13, §. 1; Table 2.1; p.16, §.3) is far from comprehensive, referring only to SKB's PASS-related studies. Moreover, it pre-supposes the canister is required to provide long-term containment. It is not [*see comment 3*]. It is only necessary for the container to retain its integrity until the borehole is sealed and the geological barrier is in place. Normally this would be less than 10 years from deployment, although in reality containers such as stainless steel are likely to remain intact for thousands of years, i.e., over-kill in terms of an already strong safety case (Brady et al., 2009) [*see also comment 9*]. SKB are well aware of this (see bottom of table 2.*1*) but imply that DBD is inferior because "it has not been possible to demonstrate that any one of them would provide long-term isolation". This indicates either disingenuity or confused thinking.

19. The statement (p.13, §. 2) that the minimum interval between holes has not been determined is wrong and the suggestion that holes would need to be 500 m [*where did this come from*?] apart is not correct. Our published work (Gibb et al., 2008a) shows holes for SNF DBD can be less than 50 m apart and this limit is imposed by drilling accuracy (J. Beswick, pers. comm..) rather than thermal constraints. Their 60 holes - also wrong [*see comment17*] - would require an area of ~ 0.15 km^2 and the 15 holes

actually needed would require only ~ 0.04 km^2. If such arguments are to be presented against DBD, SKB need to get the figures right, but they will almost certainly turn out in favour of DBD.

20. P.15, §.1 & Fig. 2-5 – This is very misleading. Firstly, the number of holes would be much less than this [*see above*] and the area required would be about that of 3 soccer pitches. Secondly, the comment about having to dispose of the cuttings is wrong or exaggerated: for most modern DBD schemes most of the cuttings would be recovered and used as backfill, especially where the hole is sealed by rock welding (as we propose (Gibb et al, 2008a)).

21. The option of fuel pin consolidation is acknowledged (p.15, §.2-3) but then dismissed because it introduces an extra step in the process with an increased risk. The fact it was discarded for KBS-3 is not a valid argument for doing so for DBD where the cost, time and other benefits could far outweigh any disadvantage, especially as the additional risk is small. Consolidation could be done in reactor fuel ponds using existing technologies, or in the Swedish case in CLAB with relatively small additional investment.

22. Of the 4 conclusions summarised in 2.3 (p.17) all those under deep boreholes are wrong to varying degrees. The surface area is greatly exaggerated and the volume of debris to be disposed of is wrong [*see comments 17, 19 & 20*]; emplacement can be monitored by down-hole CCTV and other techniques and the depth does not prevent investigation of the environment in which the canisters would be emplaced (by existing logging and other technologies used for hydrocarbon, geothermal and scientific investigations). This seems largely to negate the contents of the table and, by inference, the summary case against DBD.

23. The report lists (p.18, §.4) requirements of the host rock for DBD that are quite wrong. It states that it must withstand changes in groundwater flow as a result of future glaciations. As far as I am aware there is no evidence from the geological record of glaciations affecting groundwater flows at depths > 3 km. On the contrary, groundwaters with residence ages of millions of years have been found at such depths in areas that suffered Quaternary glaciations. This contrasts with depths of a few hundred metres where KBS-3 would be sited.

    It is also suggested that stresses in the host rock must be more or less isotropic or the hole will deform and collapse. Not so. Although an anisotropic stress regime could result in an elliptical hole being drilled, the steel casing is circular and strong enough to resist deformation in all but the most extreme stress regimes (which would not be selected in any case) until long after the borehole is filled and sealed, when it would not matter.

    If the authors wish to use these lines of argument it is incumbent on them to present evidence that (a) glaciations are likely to significantly affect groundwater flows at depths of several km and (b) steel drill casing will deform at inappropriate rates under the moderate anisotropic stresses that could exist in the sort of geological environments that would be selected for DBD.

24. It is asserted (p.18, §.5; p.20, §.4) that a conceptual model of conditions at DBD depths will have to be developed and would demand considerable resources. This is contentious. It will probably prove better to <u>*determine*</u> the relevant conditions in small diameter pilot boreholes before proceeding. Actual conditions determined from an array of pilot holes would reduce uncertainty more than any modelling programme.

25. The list of deep holes providing knowledge of conditions at depth is helpful but far from comprehensive or up to date. There are several recent geothermal energy wells drilled into the continental crust that could have provided useful data, some helpful to DBD. It is unfortunate, and surprising, that SKB was unable to obtain at least preliminary results from the Swedish Deep Drilling Programme!

26. It is stated (p.21, §.1) that it must be demonstrated (presumably by the advocates of DBD) that the groundwater will remain stagnant despite the influence of glaciations and earthquakes. Since there is evidence in the form of intra-rock fluid residence times deep in the crust that it does and, to the best of my knowledge, none that it does not, surely it is the responsibility of those making the argument

against DBD to prove their case by citing instances where deep crustal salinity stratifications have been disrupted by glaciations and/or earthquakes.

27. Some of the summary points on DBD (p.21, 3.3) are misleading. The argument that knowledge of the bedrock for DBD is poor because there are too few deep holes and many are in inappropriate rock types is largely irrelevant. It is not a general knowledge of conditions at depth that matters – these are well enough known on a generic basis – but the knowledge of a particular target rock volume. Just as with a mined repository, this can only be determined by site-specific investigations which, in the case of DBD can be done relatively quickly using geophysical techniques and exploratory boreholes.

    The assertion that these exploration methods need to be "developed from scratch" is incorrect. While a few new ones may have to be, most already exist in the hydrocarbon, geothermal energy and scientific drilling fields and would in some cases involve only application in, or adaptation to, different geological settings.

28. The use of a bentonite slurry as a buffer around the canisters (p.26, §.1 & elsewhere) is not a feature of all DBD concepts. In fact many schemes reject it for a number of reasons, including emplacement difficulties (although it is a component of the PASS concept). Problems arising from the use of bentonite may constitute an argument against PASS but *not* against DBD as such.

29. It is stated (p.26, §.4) that the emplacement mechanism has to "allow remote-control steering of the canisters". While this may be inherent in the PASS concept, it is considered un-necessary in others. The goal of ensuring the packages are centred in the borehole can be achieved much more simply by fitting the containers with sacrificial centring fins. Many of the other specifications in this bulleted section are also questionable.

30. All the negative comparisons in section 4.2.2 relating to emplacement times and rates and problems with bentonite buffers are again based on the PASS concept and are of little relevance to other DBD concepts. Indeed, a similar exercise using revised numbers for the Swedish reference scenario [*see comments 2, 17 & 19*] and a concept that does not require a bentonite buffer would probably reverse the outcome of the comparison – SKB need to demonstrate this is not so.

31. Section 4.3.2 deals with the closure of deep boreholes but again only considers the PASS concept and identifies possible problems with sealing that have not yet been resolved. While some more modern DBD concepts involve similar sealing methods (e.g., Brady et al., 2009) others do not (e.g. Gibb et al., 2008a). However, the alternatives also remain to be proved, although they could eliminate some of the problems with the PASS approach, e.g., the need to "grind out" the engineering disturbed zone (EDZ). This section is more an indictment of the PASS concept than DBD generically.

32. A claim is made (p.30, §.7) that no technology exists for sealing deep boreholes from the surface or checking its success. Since oil, gas and geothermal wells are frequently sealed (even under pressure) for various reasons this is clearly incorrect.

33. Section 5.3 raises two "scenarios" that infer greater radiation risks than KBS-3. The first is damage to the container as a result of "dropping" it down the hole with a high enough descent speed, although it is admitted that no calculations have been made as to what this speed might be. Such calculations are very easy to do and show that for any realistic clearance between package and casing, the upward displacement of borehole fluid is too slow to allow terminal velocities high enough to damage a robust canister of the type likely to be used [*see comment 12*]. If SKB wish to use this argument they need to (a) do the calculations and (b) show that the risk of damage is greater than dropping a container into a disposal hole in KBS-3. The second scenario repeats the notion of damage as a result of the package becoming stuck during deployment and has already been dealt with [*see comments 8 & 12*].

34. In 5.4 it is not explained why each borehole would constitute a separate nuclear facility. If the DBD facility is a realistic array of 15 holes within a secure area the size of 3 soccer pitches why would it not be classed as a single nuclear regulated facility?

35. In attempting to compare long-term safety (section 6.3.1), the safety analysis by Brady et al. (2009) is acknowledged then apparently ignored as the authors revert to the PASS-related work, reiterating the same misleading claims for it as before [*see comment 1*]. The remainder of this section merely repeats the same mistaken and irrelevant comparisons as previously, e.g. container survivability, difficulties in verifying the condition of the EBS and the need to meet PASS specifications.

36. Section 6.3.2 opens with the seemingly bizarre statement that "external influences in the form of climate change and climate-related processes are presumably the same for both deposition in deep boreholes and the KBS-3 method". One of the strengths of DBD is that effects arising from climate change and related processes (e.g., glaciations, sea-level rise, groundwater flow rates and directions) are unlikely to penetrate the crust to depths of several km (the same can not be said for mined repository depths of a few hundred metres). The authors appear to believe otherwise (p.41, §.3) and cite a conceptual model that seems to contradict geological evidence. It might apply to ice-loading induced earthquakes but these are generally believed to involve displacement on melt-water lubricated slip planes at relatively shallow depths.

    This section then proceeds to restate the same largely irrelevant comparisons of the performances of the EBS components and discusses closure based only on the PASS concept. There is an illuminating discussion on the role of the bedrock in the reference scenario. Accepting the basic strength of the hydrogeological containment in DBD, the report than looks for possible disruptive influences (such as drilling the borehole, corrosion effects and heat from the SF) but with little success. It then focuses on two hypothetical possibilities. First is the glaciation induced increase in groundwater circulation and downward penetration of melt-water. Why they believe fresh water could displace dense brine or why it would reach depths of several km is not made clear, although speculative modelling suggests it could depending on the parameters entered in the model [*!!!*]. Second are glacially induced earthquakes, although the authors accept that there would not be an increase in these at depths between 2 and 5 km.

    Overall, this section appears to identify more risks to the KBS-3 method than DBD, fails to recognise the capacity of a density stratified groundwater structure to withstand earthquakes [*comments 13, 23*] and struggles to a weak conclusion that DBD will be susceptible to external disturbances. If it is, it would be much less so than KBS-3!

37. In the summary table in 6.4 (p.45) all the entries under DBD are either zero or incorrect (as explained in the comments above) so the outcome of the comparison is, at best, inconclusive and could conceivably favour DBD.

38. The comparison based on security and retrievability does not merit further comment. It is almost universally accepted that the post-closure security of DBD is unbeatable for fissile materials. Retrievability is a contentious political and sociological issue (and a legal requirement in some countries, although not post-closure in Sweden?) but has little technical merit.

39. Section 8 on lead times, R&D and costs is highly speculative. The values cited for DBD are, at best, questionable and appear to have been chosen to produce the desired outcome.

    SKB concludes the lead time for DBD is 30 years. This is at variance with published estimates of 10-15 years to get to a practical demonstration of borehole construction and package emplacement suggested by those involved in developing DBD concepts.

    The figures cited for the costs of a borehole are out of date and unrealistic. The best published costing for a borehole is that by Beswick (2008) of ~ US$30M for the first hole reducing to ~ $18M for subsequent ones. If any meaningful cost comparisons are to be made, SKB (or any other interested party) should ask him, as one of the world's leading experts on deep drilling, for an updated estimate. Also, the costs of a Swedish DBD programme are based on an incorrect number of holes by a factor of 4 [*see 17, 19*] making the SEK 29-34B a gross overestimate.

    A cost of SEK 4.2B for the R&D programme also seems very high. Costs, currently being worked out by the Sandia/Sheffield/MIT based consortium developing DBD to take it through to a practical demonstration with non active waste are substantially less [*Actual figures could become available in 2012*].

40. The conclusion on p.53, §.5 that "in all these evaluations deep boreholes have been judged to have poorer prospects" does not make it clear this only applies to the evaluations by SKB – clearly others think differently.

41. The second § on p.54 opens with a sweeping statement that is no longer true, as the recent report of the US presidential Blue Ribbon Commission makes clear. The remainder of this § tells its own story [*see previous comments*] and merits no further comment!

P-10-47. Excerpts on deep boreholes from – **Choice of method – evaluation of strategies and systems for disposal of spent nuclear fuel.**

These excerpts draw heavily on R-10-13 and propagate many of its conclusions based on inappropriate lines of evidence and argument. The comments below simply highlight parts of the case against DBD that are flawed, mainly for the reasons given in the comments above. [*Page numbers refer to the excerpts provided.*]

42. A minor point but Fig. S-1 (p.11) (& repeated as Fig.3-4) is subtly biased against DBD by not having a linear depth scale.

43. The statement (p.12, §.1) that "the expected slow groundwater movements at large depths are assumed to be the most important safety feature" of deep boreholes – is misleading. The main safety feature of DBD is a *combination* of great depth (& hence travel distance/time), low hydraulic conductivity (= slow groundwater flow) and the long-lived isolation from near surface groundwaters provided by density stratified intra-rock fluids. This sort of misrepresentation gives the impression DBD depends on a single barrier, whereas it is a genuine multi-barrier concept [*see comments 5, 9*].

44. SKB concludes (p.12, §.5) "that disposal in deep boreholes is not a realistic alternative to KBS-3" and adds that "no technical breakthrough that could alter this assessment is expected in the foreseeable future". The latter may have been true at the time of writing but there could be a US-led technical demonstration of the feasibility of DBD within 10 years [*see comments 39 & 41*].

    The final sentence of §.12 that states "nor is any targeted R&D being conducted for this concept" was wrong at the time of writing, is even more so now, and reflects SKB's apparent unawareness of the scientific literature [*see comments 1 & 10*].

45. They state (p.12, §.9) "knowledge of the surrounding rock volume can never be as good with deep boreholes concept as for KBS-3". Maybe – but it does not need to be [*see 4, 25, 27*]. The point is irrelevant.

46. The familiar misleading statements about containers getting stuck and effects of future glaciations and earthquakes are reiterated on p.13. [*see comments 8, 12, 1, 23, 26 & 36.*]

47. The view expressed in R-10-13 to the effect that *there is no certainty* that further work on DBD would prove it superior to KBS-3 [*true, but unlikely*] has become (p.13, §.5) "it *is not likely* that such efforts would lead to a system ... that ..is ... substantially better than ... KBS-3. A subtle but significant change!

48. Interesting that the last 2 §.s and diagram on p.31 highlight the very geological conditions that make DBD safer than KBS-3 but, while these are used to support KBS-3, the even stronger case for DBD is ignored!

49. Many of the flawed assertions and conclusions from R-10-13 are repeated, often transformed into statements of fact, in these excerpts. Examples, with my comments in *italics,* include:

    - R-10-13 is an up to date summary of the state of knowledge on deep boreholes (p.37, §.1). [*see comments 1, 16.*]

- DBD would need 60 holes and 13 km^2 [*see comments 17, 19*].

- For BWR assemblies the borehole diameter needs to be 800 mm. (p.39, §.1). To be economical each canister must contain 4 assemblies. The drilling technology must be developed to attain this (p.39, §.4) [*Not so! This assumes use of the PASS container concept. Fuel pins from more than 4 BWR or PWR assemblies can be accommodated in one container by consolidation*].

- From a radiation protection viewpoint it is not advisable to split up the fuel assemblies (p.39, §.2). [*True, but the potential benefits of doing so far outweigh the minimal risks and costs involved. This is nowhere addressed.*]

- It is doubtful whether it is possible to drill holes of 500 mm diameter (to take a PWR assembly) with today's technology (p.36, §.3). [*While it has not actually been done, expert opinion is that it is quite possible (see comment 10). If SKB know better they must justify it.*]

- The geological barrier is "based on the assumption that the groundwater conditions at great depths are stagnant" (p.40, §.3). [*see comments 5, 6, 43*]

50. A case is made (p.39, §.7-8) against fanned arrays or branching boreholes. No need. [*This was originally suggested in 2003 by Chapman & Gibb as a potential cost-saver but has now been discarded by the advocates of DBD for the same reasons as given here.*]

51. It is stated that a number of other (than Ti) canisters have been discussed (p.40, §.1) but rejected as … less advantageous or unsafe. [*This may have been a conclusion of the PASS study but other DBD concepts consider steel perfectly suitable (see comment18).*]

52. The statement (p.41, §.3) that "no experience exists from drilling of deep holes with large diameters and in crystalline bedrock" is misleading. While it is true of the depth/diameter combinations required for DBD, there are many examples of very deep holes with large diameters in crystalline rock, e.g the Kola superdeep well, the KTB scientific boreholes and numerous geothermal energy wells, such as Soulz-3.

53. The report by Brady et al. 2009 is mentioned (p.42, §.1-3). That report was extremely positive regarding DBD but P-10-47 fails to take this into account, saying only that there is no analysis of how the waste canisters could be deposited safely and raising, yet again, the 'red herring'* of an improperly deposited canister [*see comments 8, 12, 33*].

54. This report concludes (p.54, §.3) that R-10-13 "shows clearly that disposal in deep boreholes is not a realistic alternative to KBS-3" and repeats many of the misleading and flawed arguments commented on above. It is difficult, if not impossible, to justify this conclusion without a great deal more work on the part of the report's authors and a much more objective analysis involving the full range of modern DBD concepts.

Excerpts on deep boreholes from SKB's **Environmental Impact Statement (March 2011)**

55. Fig. 3-5 is distorted [*see comment 42*].

56. The entries in Table 3-1 for DBD under "burden on future generations", "safety" and "radiation protection" indicate that DBD has disadvantages compared with KBS-3. Such claims are neither explained in the text (or underpinning report R-10-13) nor can they be justified [*see comments above*]. SKB will have to do a lot more to substantiate these claims. The correct entries, based on current knowledge (in my view) would be =, + & + in columns 1, 3 & 4 respectively and this would generate a complete reversal of the table's conclusion.

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* Irrelevant distraction

57. Section 3.6.1.1 repeats the same incorrect statements, misleading numbers and flawed arguments as highlighted above and needs no further comment.

58. Particularly interesting is the statement (p.41, last line) that for DBD "The rock is the only barrier that can be relied on in the long term". Would SKB deny that this is also true of KBS-3?

59. The claim (p.42, §.4) that "even if … resources were invested to develop the method, it is highly uncertain … deep boreholes would prove to be a better alternative" is over-stating their case, especially as much of the available evidence suggests it is likely to be so.

Excerpts on deep boreholes from SKB Top Document – **Application for Permit Under the Environmental Code**

60. Section 5.2 of this document simply states DBD has been studied by SKB but dismissed. However, they do not exactly explain why. This statement is followed by a paragraph listing a number of negative statements about DBD that SKB considers weaknesses, including:

    - DBD is based on "assumptions concerning conditions and groundwater movements at great depths which are very difficult, if at all possible, to verify";
    - There is a risk of the canisters getting stuck and breaking apart during deposition;
    - "Knowledge of conditions at such great depths is limited";
    - DBD "does not meet the requirements of multiple barriers".

    The first is simply not true! Following identification of a potential DBD site, exploratory pilot holes would actually determine, hydraulic conductivity, groundwater geochemistry, isotopic residence times, salinity gradients etc. and only if these proved appropriate would a disposal borehole be drilled.

    The second is wrong – the risk of a jam is almost non-existent and there is no threat to safety [*see comments 8, 12, 33*]

    The third is correct regarding knowledge in general but it is better than portrayed in R-10-13 and from what is known we can be sure that conditions suitable for DBD do exist in parts of the continental crust. All the statement really tells us is that suitable conditions for DBD will not be present everywhere and will have to be confirmed before proceeding. This is no different from any other form of geological disposal!

    The fourth is wrong [*see comment 9*].

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