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Technical Note

2012:62

Review of the MARFA Code

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SSM perspektiv

Bakgrund

Strålsäkerhetsmyndigheten (SSM) granskar Svensk Kärnbränslehantering AB:s (SKB) ansökningar enligt lagen (1984:3) om kärnteknisk verksamhet om uppförande, innehav och drift av ett slutförvar för använt kärnbränsle och av en inkapslingsanläggning. Som en del i granskningen ger SSM konsulter uppdrag för att inhämta information i avgränsade frågor. I SSM:s Technical note-serie rapporteras resultaten från dessa konsultuppdrag.

Projektets syfte

Syftet med detta uppdrag är att granska SKB: s MARFA kod och bedöma om de tekniska argument och antaganden som använts för att utveckla koden är välgrundade, lämpliga och tillräckliga för att stödja dess användning i SR-Site säkerhetsanalys.

Författarens sammanfattning

Som en del av SSM: s inledande granskningsfas av SKB: s SR-Site säkerhetsbedömning av slutförvaring av använt kärnbränsle i Forsmark har Quintessa upphandlats av SSM för att granska SKB: s MARFA kod och överväga om de tekniska argument och antaganden som används för att utveckla kod är välgrundade, lämpliga och tillräckliga för att stödja dess användning i SR-Site. Denna rapport sammanfattar resultaten av Quintessas granskning.

Den viktigaste frågan som tas upp i granskningen är den dåliga kvaliteten på dokumentationen i samband med MARFA koden, särskilt omfattningen och presentationen av kontrollfallen. Det föreslås att SSM skulle kunna genomföra en fullständig QA granskning av MARFA kodens utvecklingsprocess.

Kopplingen mellan flödes- (DFN) modelleringen och transportmodelleringen i MARFA kräver ytterligare eftertanke. Överföringen av data mellan de två modellerna bör kontrolleras. Hanteringen av variabilitet och osäkerhet mellan DFN koder och MARFA förklaras inte tydligt och skulle behöva djupare granskning.

MARFA är konstruerad för att hantera förändringar i flöden som plötsliga händelser, på motsvarande sätt har biosfärmodelleringen en liknande syn på klimatförändringar. I verkligheten sker både förändringar i vattenflöden och klimatförändringar gradvis vilket innebär att även dosnivåer under denna typ av transienta förlopp behöver bedömas.

Projektinformation

Kontaktperson på SSM: Shulan Xu
Diarienummer ramavtal: SSM2011-4246
Diarienummer avrop: SSM2012-141
Aktivitetsnummer: 3030007-4029

SSM perspective

Background

The Swedish Radiation Safety Authority (SSM) reviews the Swedish Nuclear Fuel Company's (SKB) applications under the Act on Nuclear Activities (SFS 1984:3) for the construction and operation of a repository for spent nuclear fuel and for an encapsulation facility. As part of the review, SSM commissions consultants to carry out work in order to obtain information on specific issues. The results from the consultants' tasks are reported in SSM's Technical Note series.

Objectives of the project

The objective of this assignment is to review SKB's MARFA code and consider whether the technical arguments and assumptions used for developing the code are sound, appropriate and adequate to support its use in the SR-Site safety assessment.

Summary by the author

As part of SSM's Initial Review Phase of SKB's SR-Site safety assessment of the final disposal of spent nuclear fuel at the Forsmark site, Quintessa has been requested by SSM to review SKB's MARFA code and consider whether the technical arguments and assumptions used for developing the code are sound, appropriate and adequate to support its use in SR-Site. This Technical Note summarises the findings of Quintessa's review. The main concern raised in the review is the poor quality of the documentation associated with the MARFA code, in particular the scope and presentation of the verification cases. It is suggested that SSM could carry out a full QA audit of the MARFA development process.

The linkage between the flow (DFN) modelling and the transport modelling in MARFA requires further consideration. The passing of data should be checked. The handling of variability and uncertainty between the DFN codes and MARFA is not clearly explained and would merit deeper review. MARFA is designed to handle changes in flow rates as sudden events and the biosphere modelling takes a similar view of climate change. In reality both are gradual and there is need to check whether there is a potential for higher doses during transitions.

Project information

Contact person at SSM: Shulan Xu
Framework agreement number: SSM2011-4246
Call-off request number: SSM2012-141
Activity number: 3030007-4029

Strål
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This report was commissioned by the Swedish Radiation Safety Authority (SSM). The conclusions and viewpoints presented in the report are those of the author(s) and do not necessarily coincide with those of SSM.

Content

1. Introduction

As part of SSM's Initial Review Phase of SKB's SR-Site safety assessment of the final disposal of spent nuclear fuel at the Forsmark site, Quintessa has been requested by SSM to review SKB's MARFA code and consider whether the technical arguments and assumptions used for developing the code are sound, appropriate and adequate to support its use in SR-Site. This Technical Note summarises the findings of Quintessa's review.

The primary reviewed document, where transport calculations are reported, is the Transport Report (TR-10-50). Other documents have been reviewed as indicated in Appendix 1.

MARFA (R-09-56) was reviewed in 2010 (published as part of Robinson and Watson (2011)). The version reviewed was 3.2.2 but reference was made to 3.3 (for flow fields that change direction). Version 3.2.2 has been used within SR-Site (Section 3.10 of the Model Summary Report (TR-10-51) confirms this) and this confirms that R-09-56 remains the primary reference for MARFA.

As part of that initial review, verification calculations were undertaken and a new code to calculate radionuclide transport with a small number of time-switches in parameter values was developed by Quintessa. No further calculations have been undertaken in the current review as the findings from the earlier work still apply.

The conclusions from the initial review of the MARFA code and documentation were as follows.

1. The basic algorithms employed are sound, but some aspects appear to have been implemented using overly coarse look-up tables which lead to poor approximations for simple test cases.
2. Decay chain handling has not been demonstrated for realistic chains. The code is not capable in its current form of handling short-lived daughter radionuclides correctly (e.g. Pb-210 and Po-210).
3. The descriptions of the verification tests in the User Guide are full of errors in reporting what was actually calculated. It is necessary to refer to the input files to confirm what was actually done.
4. The scope of the test cases is rather limited.
5. There are some problems with handling changes of flow rate, leading to inaccurate releases after a switch in groundwater flow conditions.
6. The Quintessa semi-analytic solutions developed during the review enable simple cases (with just a few segments) to be analysed accurately.
7. The input file syntax used by MARFA is prone to errors and hard to check because of the use of derived parameters as input and the way aspects (such as trajectories and sources) are cross-linked by number rather than name.

The reviewer considered the main strengths of MARFA to be:

- it can handle large networks in practicable run times;

- it works well for single radionuclides or short chains without rapid decay rates;
- it accurately handles advective systems where matrix diffusion effects are dominant; and
- dispersion is handled well (for high Peclet numbers).

The weaknesses identified were:

- it is unable to handle long decay chains with short-lived radionuclides;
- memory usage prevents very large numbers of samples being used (potentially leading to unconverged results);
- diffusive systems cannot be handled;
- systems where transport in the rock matrix is not dominant are not handled well;
- calculations immediately after groundwater flow rate changes can be inaccurate;
- handling short spikes is difficult (i.e. it requires careful choice of the smoothing parameters); and
- the technical aspects of the User Guide are not self-contained, with key results only presented in referenced publications.

The initial review was not able to verify MARFA for cases where it takes path information directly from the DFN model in ConnectFlow. It was not clear whether its use in a network will average away all of the inaccuracies or compound them.

A key issue for the current review is to see how MARFA has been used and whether any of the concerns expressed previously are relevant to that. Also, evidence was sought that SKB are aware of MARFA's weaknesses and have acted accordingly.

A new aspect of the use of MARFA is for modelling colloid facilitated radionuclide transport. This has not required any MARFA development, but exploits the general nature of the MARFA parameterisation. The development of effective parameters for this case was therefore reviewed.

2. Main Review Findings

The usage of MARFA within SR-Site has been quite limited. Specially, it has been used to explore:

- Varying flow conditions for the corrosion case;
- Colloid-facilitated transport for the corrosion case;
- The effect of tunnels and soil segments for the pinhole case; and
- Colloid facilitated transport for the pinhole case.

The review covers the general status of MARFA and these specific areas of application.

2.1. MARFA Verification and Documentation

A major finding of the current review is that the documentation status of the MARFA code, particularly with regard to verification, is poor. In TR-10-51, Section 3.10 asserts that "*MARFA 3.2.2 accurately represents processes that are expected to be dominant transport processes in the Forsmark geosphere, similar to the FARF31 code*". In Section 3.10.4 of TR-10-51 the QA regime under which the code was developed is described, but there is no specific reference to the QA documents for MARFA.

TR-10-51 (Section 3.10.1) states that MARFA is a category 4b code. In Section 2.3 of TR-10-51 it is stated that the QA implications are:

"*4b. Calculations performed with codes developed within the safety assessment, frequently written in languages like C++ and Fortran. These codes are in general written with the safety assessment application in mind and have a considerably smaller user base than codes in category 3. The need for verification is thus larger for these codes.*"

It is stated that "*Software [verification] tests are summarized in the MARFA user's manual*" (i.e. R-09-56), but this document contains errors as described in Robinson and Watson (2011). The process by which this document was published as an SKB report without proper checking is a cause for concern.

It may well be that the MARFA code is fit for the usage made of it during SR-Site, but there is clear lack of documented evidence that it is suitable and there is evidence of a lack of care in accepting the code for use in the assessment.

Appendix C of TR-10-50 presents a comparison between MARFA and FARF31 "*to verify that the codes produce the same results when presented with the same input*". While it is encouraging that the two sets of results are consistent, this is for a narrow range of application (e.g. without any ingrowth and covering only a small subset of MARFA's capabilities) and cannot be taken to extend the verification of MARFA to any great extent.

Most of the usage of MARFA in SR-Site is in connection with calculations from the discrete fracture network modelling. The process by which this is done is briefly explained, but no verification cases are described. Given the complexity of the linkage, this should have been subject to careful testing. It is acknowledged that such testing is difficult because of the innovative nature of what is being done (meaning that there is no direct way of undertaking the calculations with another independent code), but nonetheless some test cases should be presented.

2.2. Versions and Development Plans

The status of MARFA development is unclear to the reviewer. It is clear that version 3.2.2 was used in SR-Site. However, R-09-56 has an appendix about version 3.3 for fully transient simulations; the Main Report (TR-11-01) Section 13.4.2 says that "*MARFA development is still on-going as detailed below*" but no details are given; and the Geosphere Processes Report (TR-10-48, Section 6.1.7) says "*In a future version being developed during the SR-Site project, fully transient flow conditions will be accommodated. However, application results will be available only after completion of SR-Site.*" This seems to contradict R-09-56 which suggests that this capability was available in 2009.

2.3. Linkage to DFN Modelling

MARFA interfaces directly (via ptv files) with the DFN results from ConnectFlow. There is therefore a clear connection between uncertainties in the DFN modelling and the results calculated by MARFA. In addition, the lack of good documented verification cases for MARFA working in this mode is of concern. Further analysis of these issues would be merited.

It is unclear to the reviewer whether the stochastic rocktype option in MARFA has been used and how the transport properties for individual segments in the ptv file are determined. There is a potential confusion between genuine variable properties and uncertainty which would merit clarification.

Appendix A of the transport report (TR-10-50) discusses channelling in fractures. In earlier work (e.g. SR Can) a factor of 10 reduction in the calculated F factor was applied to account for channelling. This has been removed based on the argument given in that appendix which says that radionuclides in the flowing channels can access the entire rock matrix – either directly or via stagnant porosity within the fracture plane between the flowing channels. This may well be true (a review of this issue is part of the general radionuclide transport methodology review task) but the conceptual model that it implies differs from that assumed in MARFA where the matrix is in direct contact with the flowing water. Does it matter that only 10% of the matrix is in direct contact with the channels? Further analysis of this would be useful.

2.4. Varying Flow Conditions

Section 13.5.6 of the main report (TR-11-01) corresponds to Section 4.5.7 of the transport report (TR-10-50) and presents a case with varying groundwater flow rates for the corrosion case. Over each of 8 glacial cycles, the flow rate is changed (suddenly) 13 times, with durations between changes as little as 300 years and as long as 20 000 years. The flow factor varies up to 50 and down to 0.15 (relative to the temperate period).

The MARFA results show higher doses over short times but only by a factor of less than two (which is within the level of fluctuations that a typical MARFA result displays). The doses during high flow periods are lower due to the LDF (biosphere dose factor) being low in the high flow periods.

A key question here relates to the way that the transitions are handled. Both the biosphere and geosphere react instantaneously to changes in groundwater flow. In practice the changes will not be instantaneous. Could this lead to higher doses (e.g. from contamination brought to near the surface in a high flow period but mobilised in the biosphere after the flow, and hence dilution, has fallen back)?

It is also potentially important to note that the review of MARFA in Robinson and Watson (2011) found that its handling of short spikes was suspect with some evidence found that the initial spike release is understated with more contaminant released after the short change ends. Given that the sharp changes are unrealistic in any case, it may be that this inaccuracy is small compared to conceptual uncertainties. However, the general point is that the limitations of MARFA in this regard are not well understood or reported by SKB.

A further issue is the way that the varying flow regime is ignored in the near-field. It is argued that the near-field release is dominated by fuel dissolution rates and solubility. It would have been straightforward to show a calculation with the near-field code that demonstrates this but no such results are given.

2.5. Retention in Engineered Structures and Soils

Section 13.7.2 of main report (TR-11-01) corresponds to Section 6.4 of the transport report (TR-10-50) and presents an analysis using the pinhole release scenario. Section 6.4.4 uses MARFA to explore the effect of retention in soils and tunnels. The reference case assigns zero retention to these components. Figures 13-59 and 13-60 in the main report summarise the results. These correspond to figures 6-53 and (part of) 6-54 in the transport report.

Figure 6-53 shows the reference near-field and far-field dose results with two new results: for a case with sorption in the tunnels and soils included; and a case where transport in the tunnels and soil is neglected (which the reviewer takes to mean that the time taken for particles to travel through these zones is ignored). The result with sorption is essentially the same as the reference case – because the non-sorbing radionuclides dominate. The more surprising result is that obtained when the tunnels and soil are omitted. This increases the peak dose from the reference case by a factor of five.

There is little discussion of this result in the reports. The reviewer surmises that it is the tunnels (rather than the soil) that are important and that the result suggests that many of the pathways essentially stagnate in tunnels (many for periods in excess of the half life of C-14 and about half for more than a million years – given that the dose at a million years is dominated by I-129 and is about a factor two higher than the reference case). The implications of this strong effect of the near-field components merit more discussion in the reports. It is not clear whether the discussion in Section 6.4.3 of the transport report is relevant here – it is stated that 81% of deposition holes have no connected pathway to the biosphere but it is not stated whether this means there is absolutely no connection or just not one that is travelled in less than a million years.

The way that sorption is handled in soils gives a link to the biosphere modelling work. Has consistency been imposed here? Are there concentration mechanisms that might give higher doses?

In the main report there is a paragraph (just ahead of Figure 13-59) that discusses the effect of starting multiple paths from each deposition hole. This seems out of place (it is in the previous section on issues to do with the probabilistic nature of the calculation in the transport report). The fact that this has little effect is said to be because it is subordinate to other processes that spread the radionuclide mass in time. It seems likely that the major spreading effect is the averaging over all depositions holes – which it is not really correct to call a process.

2.6. Colloid Facilitated Transport

In TR-10-50, results using MARFA for colloid facilitated transport are presented in Sections 4.5.6, 4.5.8 and 6.4.5. Appendix I of TR-10-50 describes how the effective parameters are derived. It is noted in passing that the Main Report (TR-11-01) Section 13.4 describes MARFA as "*a separate model for ... and colloid-facilitated transport in the geosphere*". This is misleading as colloids were not part of the design for MARFA – it is just a convenience that it can be made to solve the appropriate equations.

Appendix I covers two cases: rapid reversible sorption onto colloids and irreversible sorption onto colloids. These are looked at in turn here, before returning to the application of the colloid model.

2.6.1. Rapid Reversible Sorption onto Colloids

Appendix I.1 of TR-10-50 describes how transport equations can be derived in the form solved by MARFA but including the effects of sorption onto colloids.

The derivation of equation I-8 in stages needs more explanation. With the assumption of instantaneous sorption of radionuclides onto colloids and of colloids onto fracture walls, this equation could be derived directly – the earlier equations are for a more general case. R_C does not appear to be defined – the reviewer believes it to be $1+K'_C$.

The motivation for I-9 and I-10 could be explained better – it is necessary to have the transport terms exactly as in MARFA and for the matrix diffusion term to be the same in each equation in order to relate the equations directly to MARFA. Without this insight it is tempting to try to give a physical explanation to each term – that does not work (dividing through I-9 by $R_{f,app}$ gives an equation where the terms can be understood as representing a fraction of the radionuclides being mobile in the fracture and only a (different) fraction being able to migrate to the matrix).

In summary, the derived equations appear to be correct but the explanation is too brief.

2.6.2. Irreversible Sorption onto Colloids

The discussion in Appendix I.2 of TR-10-50 is hard to follow. It is not clear to the reviewer what is being done here. Presumably this relates to concentrations at the edge of the buffer, in the fracture. There needs to be more discussion, otherwise the reader is left with a series of unanswered questions such as: what system of ODEs is being solved?; why is dividing COMP23 output by the Qeq parameter the right thing to do?; which Qeq parameter?; why 120 time steps?; and where do the 0.01 kg/m^3 and 0.07 mol/kg values come from?

There is no discussion in this section that would lead the reader to expect that different radionuclides are treated differently, however, in the application in Section 6.4.5, it is clear that Ra-226 is not treated as being irreversibility sorbed. A better explanation is needed here.

2.6.3. Application of the Colloid Facilitated Transport Model

When used in Section 4.5.6, it is stated that 10g/l is a reasonably pessimistic value for colloid concentrations. The reference is to the Buffer, Backfill and Closure Processes Report (TR-10-47) but the reviewer cannot locate the relevant discussion in that report.

It is necessary to relate K_C to K_d and it is argued that these are equal. This may be reasonable but the argument that it is because bentonite is fine-grained does not seem to be correct – it must be because the water in intact bentonite can access the same surfaces that exist on the colloidal particles – that is the intact bentonite is essentially just a set of closely packed colloids. Even if this is true, there is a philosophical objection – given that a high K_d is beneficial in the buffer but detrimental in the colloid situation, would it not be prudent to estimate them separately? There is a danger that "conservative" assumptions have been made in setting the bentonite and that these are not valid for the colloid case. This view is reinforced by the discussions in Section 5.3.6 of the Data Report (TR-10-52) where the difficulty of deriving appropriate K_d values is emphasised. The discussion of bentonite parameters in the Data Report would ideally have covered the need for K_d values for colloidal bentonite.

Ultimately, it can be seen from Figure 4-24 of TR-10-50 that the range of colloid concentrations used (10 mg/l to 10 g/l) effectively cover the range from where colloids are not significant to where they dominate and the far-field release becomes essentially equal to the near-field release.

The application of the irreversible sorption case shows no change in the far-field dose (Figures 6-61 and 6-62 in TR-10-50) but this is simply due to the dominance of I-129, C-14 and Ra-226 which are not affected by colloids. In the case of Ra-226 this is stated to be due to the way it sorbs. The K_d given for Ra in Table H-2 of TR-10-50 is small, so would there be much sorption in any case?

As an aside, the reviewer was unable to relate the data of Table H-2 with, for example, the tables in Section 5.3 of TR-10-52. They are referred to as "preliminary SR-Site median values" in TR-10-50 – what does this mean?

2.7. Relevance of Identified MARFA Weaknesses

Robinson and Watson (2011) identified a number of weaknesses in capabilities of MARFA (listed in Section 1 of this TN). There is no discussion in the SR-Site documentation of the limitations of MARFA and it is not clear whether SKB are aware of them. Here the relevance of these in SR-Site is discussed.

1. It is unable to handle long decay chains with short-lived radionuclides. The dominant radionuclides in the SR-Site calculations all pass through the geosphere unaltered. Ra-226 grows in within the near-field and passes through the geosphere too quickly to decay significantly. Thus the limitations of MARFA in handling decay chains are not likely to be relevant for SR-Site. Nonetheless, this weakness should be acknowledged by SKB and its implications explored.
2. Memory usage prevents very large numbers of samples being used. There is evidence from most of the MARFA results presented that full convergence has not been achieved (the lines are far from being smooth). This makes it hard to detect small changes for some sensitivity calculations but overall this appears unlikely to be important.
3. Diffusive systems cannot be handled. This may be relevant for the way that the tunnel transport affects the results (see Section 2.5) – further analysis would be needed to check this.
4. Systems where transport in the rock matrix is not dominant are not handled well. Again, there is potential for this to be relevant in the tunnel transport aspects.
5. Calculations immediately after groundwater flow rate changes can be inaccurate. This could be relevant for the climate cycling cases, particularly as it is the doses in the lower flow regimes that appear to dominate.
6. Handling short spikes is difficult. Again this could be relevant to the climate change cycling cases.
7. The technical aspects of the User Guide are not self-contained, with key results only presented in referenced publications. This is not a technical issue, but a self-contained document would be preferable.

2.8. Summary of Findings

SSM has suggested that all the reviewers should consider the following issues in their review of the relevant SR-Site reports as they relate to the scope of the review:

- the completeness of the documented work;
- the scientific soundness and quality of the documented work;
- the adequacy of relevant models, data and safety functions;
- the handling of uncertainties;
- the safety significance of the work; and
- the quality in terms of transparency and traceability of information in the reports.

The findings relating to these issues for the review of the MARFA code are summarised in Table 1. The points made here are essentially a summary of the points made elsewhere in this document.

Table 1: Summary Findings of the Review of the MARFA Code

Issue	Finding
Completeness	**Generally good**, in terms of the additional capabilities that MARFA offers to explore time- and spatially-varying parameters.
Scientific soundness and quality	**Generally good**, although the algorithms used will not perform well over all possible input parameters and no systematic study of the range of validity has been presented.
Adequacy of relevant models, data and safety functions	**Poor/Not Demonstrated:** The quality assurance of the MARFA code is weak, both in terms of the scope of the verification testing that is presented and the accuracy of the descriptions of these tests. Some aspects of the input file structure make verification of the data used difficult.
Handling of uncertainties	**Limited**: MARFA has been used to look at uncertainties in the central calculations but there is little consideration of the impact of uncertainties in MARFA. In particular, uncertainties associated with DFN modelling are largely unexplored.
Safety significance	**Limited**: the safety of the repository is primarily dependent on: the number of canisters that fail; the time of failure; the fuel dissolution rate; the advective travel time; and the transport resistance along the geosphere flow path. MARFA has been used to explore some details which have a limited impact on the calculated doses. The potential for higher doses during transitions between climate sates needs further study.
Quality in terms of transparency and traceability of information	**Poor**: The reasoning behind the assumptions made when undertaking MARFA calculations is not generally explained. Some problems were found with tracing data for colloid calculations. The user documentation is not self-contained but refers to published papers for some important details.

3. Recommendations to SSM

Some key QA concerns have been raised and it is recommended that these be addressed in the first instance by seeking clarification from SKB. Other technical questions for clarification have also been identified. A list of possible questions is given in Appendix 2.

The need for further review work to some extent depends on the answers to these questions, but two areas merit further work in any case – these relate to linkages to other areas, specifically to the DFN work and to biosphere work. These are described in Appendix 3.

4. References

Robinson, P.C and Watson, C.E. (2011). Handling Interfaces and Time-varying Properties in Radionuclide Transport Models. SSM Report 2011:11.

Appendix 1: Coverage of SKB reports

The SKB reports covered in this review are given in Table A1. These include all the mandatory SKB reports specified in the assignment together with the key MARFA reference.

Table A1: SKB Reports Reviewed

Reviewed report	Reviewed sections	Comments
TR-11-01 (Main Report)	13.4, 13.5, 13.7	Aspects covering MARFA only
TR-10-50 (Transport Report)	3.6, 4.5, 6.4, Appendix C, Appendix H, Appendix I	Aspects covering MARFA only
TR-10-51 (Model Summary Report)	3.10	
R-09-56 (MARFA Report)	Whole Report and supporting references	Reviewed in 2010 for SSM, published in Robinson and Watson (2011)
TR-10-47 (Buffer, Backfill and Closure Processes Report)	Searched	Pessimistic colloid density not located
TR-10-52 (Data Report)	5.3	For colloid Kd

Appendix 2: Suggested requests for additional information from SKB

Key Requests for Clarification

1. Are SKB aware of the limitations of MARFA identified in Robinson and Watson (SSM-2011:11)? Were these taken into account in deciding how to use MARFA in SR-Site?
2. Are SKB satisfied that the verification tests reported in R-09-56 are adequate? Were further (unreported) verification tests carried out?
3. How have the results for MARFA when linked to the DFN code output been verified?
4. How has the accuracy of MARFA in handling short-duration (tens of years) changes in flow rate been verified?
5. Is there a potential for higher doses during transitions between the various climate states? Are the sharp transitions used in modelling obscuring these?
6. Please give a fuller explanation of the model presented in Appendix I-2 of TR-10-50, setting out the conceptual basis for what is described and indicating how Ra-226 sorption is treated.

Other Requests for Clarification

7. Has the stochastic rocktype option in MARFA been used? How is variability and uncertainty in transport parameters communicated between ConnectFlow and MARFA?
8. Have near-field (COMP23) calculations been made to demonstrate that flow rate changes can be ignored in the near-field, to support the claim made in Section 4.5.7 of TR-10-50 that fuel dissolution is the dominant process?
9. Are tunnels the dominant factor in the effects shown in Figure 6-53 of TR-10-50 (pink versus green lines)? What is the main cause of the factor 5 change in peak dose?
10. Are the soil properties used in Section 6.4.4 of TR-10-50 consistent with those assumed in biosphere modelling?
11. Is the major cause of the lack of impact of having multiple release pathways (Figure 6-52 of TR-10-50) the averaging over all deposition holes? Would the same effect been seen with a single deposition hole calculation as presented in other scenarios?
12. Is the parameter R_C equal to $1+K_C'$ in Appendix I-1 of TR-10-50?
13. Please clarify the status of MARFA versions. What plans exist for further MARFA development – TR-11-01 Section 13.4.2 says the details are given but they do not seem to be. Why was version 3.3 not used in SR-Site?
14. Are there any implications for MARFA from the implied change in conceptual model in relation to channelling as described in Appendix A of TR-10-50?

15. Is using the same K_d for both intact and colloidal bentonite (Section 4.5.6 of TR-10-50) conservative?
16. Where in TR-10-47 (or elsewhere) is the pessimistic 10 g/l colloid figure described? It is given as the reference in the 2nd paragraph of Section 4.5.6 of TR-10-50.
17. How do the parameter values given in Table H-2 of TR-10-50 relate to those given in the Data Report (TR-10-52)?

Appendix 3: Suggested review topics for SSM

This appendix provides a preliminary list of topics that could be considered in further work by SSM and its external experts as part of the review of the MARFA code. The list has been sub-divided into:

- Topics primarily requiring further review (and maybe some limited analysis);
- Topics requiring further analysis using mathematical models; and
- Topics requiring additional competence.

Topics requiring further review

1. Conduct a full review of the QA processes adopted in the development of MARFA, the acceptance of the user guide as an SKB document, its adequacy for documenting all the information required for the QA system under which the code was developed, and the approval of MARFA for use in SR-Site. This arises because of the evident short-comings in R-09-56 as the possibility that these may be symptomatic of a wider problem with QA processes.

Topics requiring further analysis

1. Verify and/or confirm SKB's verification of the linkage between DFN models and MARFA. This could be done by checking the ptv files used in some calculations and by creating simpler ptv files for checking purposes. The aim would be to check whether the weaknesses of MARFA identified previously are exacerbated by use in the DFN mode – addressing in particular issues around changes in groundwater flow rates. This study should also look at the way property variability and uncertainty is handled between the DFN models and MARFA. This arises because there is no evidence presented of the verification and because there are clearly large uncertainties in the representation of flow as a DFN network which will have a large impact in the transport results.
2. Consider the impacts of groundwater flow rate changes on the geosphere and biosphere together, including consideration of more realistic transitions and their potential for giving higher doses. This is a wider issue than just MARFA as it links across the geosphere and biosphere. The issue arises because there is a clear time-dependence in the flow regime which has been approximated as changing in a sequence of sudden events and no evidence is presented that this is conservative compared to a more realistic representation of gradual changes.

Topics requiring additional competence

None

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The Swedish Radiation Safety Authority has a comprehensive responsibility to ensure that society is safe from the effects of radiation. The Authority works to achieve radiation safety in a number of areas: nuclear power, medical care as well as commercial products and services. The Authority also works to achieve protection from natural radiation and to increase the level of radiation safety internationally.

The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environment and has around 270 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

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