CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES
NONCONFORMANCE REPORT

Project No. 20.06002.01.112 **NCR No.** 2003-07

PART 1: DESCRIPTION OF NONCONFORMANCE:
Revision 1 of CNWRA Report 2002-05 entitled "System-level Performance Assessment of the Proposed Repository at Yucca Mountain Using the TPA Version 4.1 code" was transmitted to NRC on December 20, 2002 without having checked the review package for compliance with QAP-002.
Initiated by: Gordon Wittmeyer
Date: April 7, 2003
Action Required by: Gordon Wittmeyer and Sitakanta Mohnaty

PART 2: PROPOSED DISPOSITION AND CORRECTIVE ACTION **Response Due Date:** April 14, 2003

Response Person: Gordon Wittmeyer

Disposition: Correct review package deficiencies, verify compliance with QAP-002, re-submit report to NRC. Corrections made to Revision 1 that result from the actions to correct nonconformance will be identified to NRC for their review of Revision 2.
Basis of Disposition: NRC has requested numerous changes be made to Revision 1 of the report, which will result in a Revision 2 to CNWRA 2002-05. Review package deficiencies noted below will be corrected and compliance with QAP-002 will be verified prior to submission of Revision 2 of CNWRA 2002-005.
Action to Correct Nonconformance: The following QAP-002 deficiencies must be corrected: (i) full documentation of QAP-014 calculation over checks on the TOP-003 form for technical review conducted by G. Wittmeyer; (ii) response accepted signature required on page 34 of TOP-003 forms for technical review conducted by G. Wittmeyer; (iii) initial and date "scratch out" recorded on page 35 of TOP-003 forms for technical review conducted by G. Wittmeyer; (iv) response signature required on original copy of page 36 of TOP-003 forms for technical review conducted by G. Wittmeyer; (v) response signature required on facsimile copy of page 42 of TOP-003 for technical review conducted by G. Wittmeyer; (vi) missing pages 43 through 59 of facsimile copies of TOP-003 comment resolution forms for technical review conducted by J. Firth (note that page 42 has fax page number 13/27 and page 60 has fax page number 14/27); (viii) no QAP-014 review documented on TOP-003 comment resolution forms for technical review conducted by J. Firth; (ix) no TOP-003 comment resolutions forms from technical review conducted by T. McCartin; (x) no response accepted signature on pages 1 through 10 of TOP-003 forms for programmatic review conducted by B. Sagar; (xi) no initials from J. Firth on AP-6 form; (xii) no initials from T. McCartin on AP-6 form; (xiii) no initials from B. Sagar on AP-6 form; (xiv) no initials from J. Firth or T. McCartin under "accomplished" column on QAP-12-4 form; (xv) no initials for any of the three technical reviewers under "accomplished" column for QAP-014 review on QAP-12-4 form. (Additional information on the likely causes of these deficiencies is provided in the attached memorandum)

Target date for completion: ~~June 23, 2003~~ ~~July 28, 2003~~ WB

Proposed by: Gordon Wittmeyer **Date:** 4/7/2003

PART 3: APPROVAL

Element Manager: Gordon Wittmeyer **Date:** 4/7/2003

Director of QA: [signature] **Date:** 4/9/2003

Comments/Instructions:

8/25/2003 LBS

PART 4: CLOSE OUT	Distribution:
Comments: All actions except vi, viii, xi and xiv were completed. The exceptions require no action that is unlikely to happen. Closed based on completion of CNWRA-controllable actions	Original-CENTER QA DIRECTOR QA Records ORIGINATOR PRINCIPAL INVESTIGATORS ELEMENT MANAGERS B. Sagar, ~~H. Garcia~~ P. MACKIN, M. EHNSTROM BS 4/9/03
Verified by: KD Bull Date: 8/28/03	

MEMORANDUM

April 7, 2003

TO: Quality Assurance Records

FROM: Gordon Wittmeyer GW

SUBJECT: Causes for Deficient QAP-002 Review of CNWRA Report 2002-05

The fifteen (15) deficiencies in the QAP-002 review process for CNWRA Report 2002-05, which are identified in NCR number 2003-07, were the result of two problems.

1. The cognizant secretary for the report did not ensure that all review comment forms for the technical and programmatic reviews were properly completed. During preparation and review of this report the cognizant secretary was distracted by personal problems, which eventually led to the cognizant secretary leaving SwRI and moving to another city.

2. I, the cognizant element manager, was aware that the cognizant secretary's job performance was not acceptable, but I did not reassign the report or provide additional guidance or supervision.

These problems are not systematic; however, I now recognize that I must supervise the execution of quality assurance procedures with greater diligence whenever a key staff member is beset by personal problems.

Bruce Mabrito

From: Gordon Wittmeyer [gwitt@cnwra.swri.edu]
Sent: Monday, June 23, 2003 8:48 AM
To: 'Bruce Mabrito'
Cc: Sitakanta Mohanty
Subject: RE: QA Action Log

Bruce:

We will not complete the response to the NCR today. Several things are delaying its completion. First, we are still putting the finishing touches on the revision to the report. Second, we have not received the information from the NRC technical reviewers that we identified in the NCR. I will pursue both items ASAP. I believe that we should set a revised date of July 28, 2003 to "ensure" that we can get the information from NRC.

Gordon

-----Original Message-----
From: Bruce Mabrito [mailto:bmabrito@cnwra.swri.edu]
Sent: Monday, June 23, 2003 8:29 AM
To: Bonnie Caudle
Cc: Minerva Hernandez; Mark Ehnstrom; Gordon Wittmeyer; Robert D Brient
Subject: QA Action Log

Bonnie,
The QA Action Log has been updated.

Gordon,
We have that NCR due today on the nonconformance you wrote. Please give me an update and if you cannot finish it today, send me a request for an extension. Thanks.

Bruce

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OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS

Division of Waste Management

FAX NO: (301) 415-5397 **VERIFICATION:** (301) 415-7319

NAME/LOCATION: Gordon Wittmeyer/CNWRA
FAX NO: 210-522-5155

NAME/LOCATION:
FAX NO:

NAME/LOCATION:
FAX NO:

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COMMENTS

Gordon,
Please find the comments on the TPA 4.1 sensitivity studies report in this facsimile.
- James Firth

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NUMBER OF PAGES 18 **PLUS COVER SHEET**

FROM: James Firth
PHONE: 301-415-6628

I have reviewed the latest version of the report entitled "System-Level Performance Assessment of the Proposed Repository at Yucca Mountain Using the TPA Version 4.1 Code." Generally, the report contains some very valuable information and discussion, however, there are a number of items that still need to be addressed. Based I review I have identified concerns that I will group into the following three categories: (1) concerns that must be addressed prior to publication; (2) technical errors that should be corrected prior to publication; and (3) minor technical concerns that are left to the authors discretion for appropriate resolution.

1) Concerns that must be addressed

Page xix; First paragraph, first sentence

The sentence inappropriately over-emphasizes IA. The word "significantly" should be replaced with "increased" and "a dominant" should be replaced with "an important" to more accurately reflect the situation.

Page xix; Third paragraph, last sentence

"Process-based model for determining the number of waste packages"? - isn't this more an empirical guess? "Increased risk by one order of magnitude"? - this of course assumes the probability for the dog-leg scenario does not change! This needs to be revised to more accurately reflect the actual situation.

Page xix; Last paragraph, 2nd to last sentence

"This suggests that analyses should focus.." Why? Seems to be pure speculation - I would delete this sentence.

Page xx; Second paragraph, last sentence

"Changes in regulatory requirements" - why would we ever say this?! - unnecessary - delete.

Page 3-18; First paragraph

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The description is for the DOE model (i.e., pit, crevice, or patches) not TPA - this needs to be revised to be NRC's TPA approach. [same comment provided months ago on an earlier version]

Page 3-50; Second paragraph, first sentence

The variability in dose is "6 orders of magnitude" - this will be misunderstood and should be deleted - it does not add much to the discussion. This large variation is because we calculate dose to very small values (i.e 0.001 mrem) and should not be used as a comparison metric with the range in waste package failure times.

Page 3-54 Figure 3-26

Are we absolutely sure about this curve - we are getting next to nothing from the UZ & SZ!! There may be a better way of presenting this information such that we provide a clearer depiction of what is going on. Note: having a figure with 16 orders of magnitude on a axis may lead to an erroneous perception. Figure 3-26 does not seem to be consistent with Figure 3-38b, which shows a rather large dose increase due to not retardation? [previously raised concern over under-representation of UZ & SZ.

Page 3-55; Third paragraph

First sentence is not consistent with the first paragraph that says the Calico Hills vitric layer has significant hold-up; rather characterize this effect as "only small amount" it would be more accurate to state that a large fraction of the inventory (about 50%) are delayed by the vitric layer while the remaining are not. We could probably do without the first two words (i.e., "The conclusion").

Fifth line - states that 150-800 years is small compared to the 10,000 and 100,000 year simulations. First, we should only use 10,000 years in the comparison - the 100,000 years is not relevant. Second, the upper end of the range (i.e., 800 years) is not small compared to 10,000 years - in fact it is almost equal to the GWTT of 1,000 years of previous regulations. I would suggest we could just state the travel times and not comment on whether it is small or not - it is what it is.

Page 3-75 Second paragraph, second sentence

"Probability-weighted dose from igneous activity is approximately one to five orders of magnitude greater than the basecase groundwater dose." As I read the Figure this should be slightly more than an order of magnitude not 1 to 5!!! Also the cited figure should be Figure 3-43(b) not 3-42(b) - which doesn't exist.

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Page 5-12 last sentence

Statement is made that a log distribution should be developed correctly - delete this statement - it is true for all the distributions and the statement is not necessary.

Page 5-13 Last paragraph

Delete the last paragraph - there is no reason to politic for additional work - it is not done in other sections of the report.

Page 7-1 Third paragraph

The statement regarding the consideration of population dose is not correct - it was the integrated release of the EPA standard. I am not sure we need this paragraph in the report. The discussion on C14 seems overkill - why not just not include a simple statement somewhere that we assume C14 is not transported in the water pathway - if we need to say anything.

Page 7-3 Section 7-2, Title and first paragraph

Rather than use the phrase "Barrier Capabilities Analysis" why not use "Subsystem Analysis" here and other places such as xviii, 7-5,16,17,18,19; 8-5. I would delete the second sentence - the report is presenting analyses and is not suggesting that these analyses be used to comply with the rule, thus, we do not need to quote the rule.

Page 7-17 last sentence in Section 7.4.1.6

Delete everything after the comma - there is no reason to speculate.

Page 7-18; First Paragraph, last sentence

Delete the last sentence - no reason to editorilize.

Page 8-5; Section 8.6

Delete the first sentence - document results - no reason to comment on rule related items.

Page 8-7

The heading "Modifications to existing models and data" needs to start with the word "Potential"

Page 8-8; First paragraph in Section 8.11

Reference is made to the RMEI and being below the regulatory limit. The RMEI was not used in these analyses and we should steer clear of such a direct comparison with the limit.

Page G-13; Last sentence

Delete the last sentence - no reason to speculate in this report.

(2) Technical Errors

Page 2-12; 4th bullet

The "unsaturated zone" should be the "saturated zone"

Page 2-13; Section 2.3.2.2.1, second to last sentence

The statement is made that adjusting the WastePackageFlowMultiplicationFactor will simulate a smaller fraction of wet fuel surface area - I don't think so - this will reduce the amount of water not the surface area contacted by water. Should the parameter being adjusted be the "SFWettedFraction..."?

Page 2-13; last full sentence

The assertion all parts of a repository subarea will receive an equal quantity of water is incorrect. The subarea wet fraction controls the fraction of the subarea that receives infiltration, thus the portion of a subarea that has infiltration sees the same value but the remaining portion receives nothing. This should be clarified.

Page 3-14; Section 3.1.4.1, first line

Wouldn't it be more appropriate to use the phrase "limited knowledge" rather than "inadequate knowledge"

Page 3-19; lines 3-4

If the invert is sand or gravel, why is there a determination of flow occurring in fractures or matrix for the invert?

Page 3-29; footnote 3 & 4

This footnote is discussing the basis for the 10 km location not 20 km. I suggest deleting both of these footnotes - not necessary and potentially confusing.

Page 3-30; Third paragraph and Fourth paragraph

Cl-36 is dominant to some extent? It is 100-times less than the I129/Tc99 doses? (Same comment applies to first sentence on page 3-40)

Page 3-30; Last paragraph

The reported time of 8,100 years is not consistent with the time of 8,300 years reported on page 3-37 (paragraph 4)

Page 3-33; First paragraph

Radioactive decay is given as a reason for the drop off in release rates - I do not believe this statement is accurate - the drop off is due to inventory depletion. Conversely the other radionuclides have larger inventories and the increasing release is due to the increased water flow and has nothing to do with the half-life.

Page 3-33; Last paragraph, first sentence

Cl-36 is a dominant dose contributor? - see comment above for page 3-30.

Page 3-37; Fourth paragraph

The last part of this paragraph seems a bit confused. First, the "proportionately larger gap inventory being available" - is this a confusing way of just saying more waste packages are failed? Also, a 300 percent increase in dose at the time of waste package failure is not the best choice of words - there is no dose at the time of waste package failure unless there is instantaneous transport.

"longer impact" is used should this be "larger impact" [previously made comment]

Page 3-39; Fifth line

Figure 3-15 should be Figure 3-16. Although there is a peak at 17,000 years there is a much larger peak at 70,000 years - why is the statement made that the "release peaks at 17,000 years." Also other references to figure 3-15 in this paragraph most likely are to figure 3-16.

Page 3-39; lines 15-16

The statement is made that the decrease in the Np237 release can be attributed to higher infiltration - I certainly agree that increased infiltration can cause the source term to switch from solubility limited to dissolution rate controls, however, I find it hard to believe this will cause a decrease in the release. Similarly a few lines below the statement is made that decrease in release rates for low solubility nuclides can be attributed to high flow rates - this is very hard to believe.

Page 3-39; third paragraph

The reference to 100,000 years should be 10,000 years - the referenced figure (Figure 3-15) only presents results to 10,000 years.

Page 3-55; last paragraph

The statement is made that the TPA code does not vary the alluvium path as a function of the tuff-alluvium contact - I believe this is incorrect - are we sure this statement is correct?

Page 3-69

There seems to be some conflicting statements made on this page, such as: (1) last sentence of Section 3.5.2.1 states that the basecase dose is higher than the rapid release flow-through model - rapid release gives lower dose (hard to believe but that is the implication); (2) last

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sentence of Section 3.5.2.2 makes the same statement as item 1; (3) Section 3.5.2.5 states that a higher dose results from a higher release, which seems contradictory to items 1 and 2, and (4) Section 3.5.2.4 states the dose is higher due the much faster dissolution rate of model 1 - this is completely contradictory to item 2. What am I missing?

Page 4-27; second and third sentences

These two sentences contradict each other. Second sentence states variables that determine time of dose show less sensitivity. Third sentence states this is because the expected dose curve is sensitive to the timing of the dose. Go figure?

Page 6-8; Figure 6-1

Is this for 10,000 years or longer? Should have this information in caption.

Page 6-8; first sentence

Is the 60 percent increase for 10,000 years or longer? Would seem that it would be larger if this was a 10,000 year result and we are looking mainly at I129 and Tc99? Further explanation is needed.

Page 6-9; Unsaturated zone

This section implies that increased infiltration will increase dose, however, on page 3-39 (line 16) it is stated that higher infiltration reduces releases. This needs to be resolved.

3.) **Technical Nits**

Page 2-7; last paragraph, first sentence

"inner overpack" - this is a little confusing seeing as we only represent corrosion of the outer layer of the waste package.

Page 2-14; Section 2.3.2.2.4, last three lines

The discussion on cladding credit will be confusing to many - it could be read that full credit is being taken for cladding. A better approach would be to not get into the precise parameter values but rather provide the concept, such as: the base case assumes all cladding is ineffective in preventing release, whereas, this alternative assumes that the cladding allows release from only 1% of the waste (i.e., 99% of the cladding prevents release from occurring throughout the simulation period).

Page 3-7; Figure 3-3

The caption implies this is water hitting the waste package, however, I believe it is actually water that enters the waste package. This should be corrected.

Page 3-39; Third paragraph

The paragraph uses a release of 37 Bq/year - is there some reason for this number? seems rather odd this value is off the scale represented in the cited figures.

Page 3-40; third paragraph, first sentence

"rates are the same" - they rates can't be exactly the same suggest rewording to "rates are essentially the same"

Page 3-46; Section 3.3.1, 7th line

"ranges two orders of magnitude" - reword to "ranges approximately two orders of magnitude" - the range around a factor of 25

Page 3-59; lines 4-5

"Groundwater traveltime release is delayed until a later time." This is not very clear what is trying to be said.

Page 3-84; Figure 3-45

need values on the ordinate

Page 4-40; Section 4.4, first paragraph

"mean-mean sensitivity" - is this a real term?

Page 6-10; Section 6.4.3, first paragraph, last sentence

the 99.2 percent should be 99.3 percent per Figure 6-3

Page G-5; last paragraph, second sentence

Statement of average of 32 defective containers is not consistent with mean value reported on page 3-12 (first line) of 45 defective containers. Are both correct?

package, (vi) the well pumping rate at the 20-km [12.4-mi][1] receptor group location, (vii) alluvium sorption properties for Np-237, (viii) length of the alluvium pathway in the saturated zone, (ix) fraction of the condensate from thermal reflux moving toward the repository, and (x) fraction of waste packages that are initially defective (Chapters 4 and 7).

The significantly high risk (i.e., probability-weighted dose) from the igneous activity case compared to the basecase implies that the igneous activity model parameters play a dominant overall role in the performance assessment. The influential parameters include (i) airborne mass load above the fresh ash blanket, (ii) wind speed, (iii) diameter of volcanic conduit, (iv) volcanic event power, (v) volcanic event duration, (vi) time of next volcanic event in the region of interest, and (vii) ash mean particle diameter (Chapters 4 and 7).

Distributional sensitivity analyses were conducted to investigate the impact of distribution function shape on the dose responses. Using the 10 most influential parameters identified by the parametric sensitivity analysis, the distributional sensitivities showed that the choice of distribution function plays an important role in the performance assessment estimation. For example, a 10 percent change to the mean of the distribution function representing the uncertainty in the flow multiplication factor that modifies the flow reaching a wetted waste package results in a 150 percent change in the peak expected dose. Performance calculations also showed high sensitivity to the choice of the distribution function for the drip shield failure time parameter. The types of errors in constructing a distribution function that could lead to the improper choice of a distribution function have been highlighted (Chapter 5 and 7).

Alternative conceptual model sensitivity studies were conducted on a case-by-case basis with appropriate consideration of uncertainty in the model parameters. Analyses used peak expected dose as the performance measure. Alternative conceptual model sensitivity analyses showed that colloidal transport (if plausible, in the Yucca Mountain environment) and the spent nuclear fuel dissolution rate, in combination with the spent nuclear fuel wetting mode and the surface area over which water contacts spent nuclear fuel, could substantially influence basecase scenario risk. The process-based model for determining the number of waste packages contributing to direct release (magma-tunnel interaction model) increased risk by one order of magnitude (Chapters 2, 3, 4, and 7).

Repository component sensitivity analyses were performed for two reasons: (i) obtaining sensitivity at an easily understood subsystem level such as a physical repository component and (ii) estimating the importance of the subsystem when parametric sensitivity analysis did not lead to failure (e.g., waste package) during the compliance period or the conservativeness in the conceptual model prevented noticeable dose response to the data range. Analyses showed that repository performance is very sensitive to the waste package repository component. Also, the group of natural repository components (i.e., unsaturated zone and saturated zone together) showed approximately the same level of sensitivity as the waste package repository component. This suggests that analyses should focus on determining if any undesirable constraints in parameters and models for waste package life prediction are responsible for the long waste package life. The repository component sensitivity analysis described in this report is not intended to provide either guidance to DOE or to describe a preferred approach for

[1]The analyses presented in this report were completed before the location of the receptor group was defined to be 18 km [11.2 mi] in 10 CFR Part 63.

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demonstrating the capability of a barrier. These analyses were performed to further the staff efforts to understand the TPA Version 4.1 code and to explore where to improve understanding of the repository system (Chapter 6 and 7).

The influential parameters were traced back to the integrated subissues used by NRC to focus its high-level waste program on aspects important to repository performance (NRC, 1998). Nine out of 14 integrated subissues have at least 1 influential parameter (including the integrated subissues related to disruptive scenarios), based on the results of the TPA Version 4.1 code. The integrated subissues that showed up as important to performance are (i) volcanic disruption of waste packages (DIRECT1), (ii) airborne transport of radionuclides (DIRECT2), (iii) radionuclide transport in the saturated zone (SZ2), (iv) degradation of engineered barriers (ENG1), (v) flow paths in the unsaturated zone (UZ2), (vi) quantity and chemistry of water contacting waste packages and waste forms (ENG3), (vii) radionuclide release rates and solubility limits (ENG4), (viii) climate and infiltration (UZ1), and (ix) mechanical disruption of engineered barriers (ENG2). The integrated subissues that did not show up as important are (i) radionuclide transport in the unsaturated zone (UZ3), (ii) flow rates in the saturated zone (SZ1), (iii) representative volume (DOSE1), (iv) redistribution of radionuclides in soil (DOSE2), and (v) biosphere characteristics (DOSE3). DOSE1 has a one-to-one linear effect on estimated dose, however, this integrated subissue is moot because the pumping rate is now specified in the regulation. Note that DOSE2 and DOSE3 integrated subissues were determined to be unimportant only on the basis of parametric sensitivity. Alternative conceptual models may alter this finding (Chapter 7).

This total system performance assessment aids the NRC staff by focusing their review of DOE total system performance assessments on those models and parameters that most affect estimated system performance. It should be noted that the results presented in the following chapters are based on numerous simplifying assumptions and use only limited site-specific data. Parametric sensitivity analysis sometimes fails to show the importance of processes or parameters, especially those associated with radionuclides that never arrive at the pumping well within the regulatory period. Therefore, several analyses in this report were conducted using data outside the range (e.g., alternative conceptual model and repository component sensitivity) to identify areas where the analyst should focus.

? description ? discussion

Conclusions drawn from the analyses presented in this report may change as the models and assumptions are updated based on revised design, ongoing site characterization, recommendations from reviewers and experts, changes in regulatory requirements, and improved model conceptualization and data interpretation by staff. The analysis also contains uncertainties regarding conceptual models for consequences and scenarios. Finally, this report should be considered as an interim demonstration of some of the methods the NRC staff developed to review a performance assessment submitted by DOE as part of any potential license application. Neither the manner in which these analyses were conducted nor the assumptions and approaches used should be construed to express the views, preferences, or positions of the NRC staff regarding implementation of regulation for Yucca Mountain.

This report was prepared to document work performed by the CNWRA for NRC under Contract No. NRC–02–02–012. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards, Division of Waste Management. The report is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC.

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information obtained in these iterative performance assessment analyses was used in NRC reviews of early DOE total system performance assessments for Yucca Mountain. At the time Phase 2 analyses were completed in 1993, the overall performance measures for the geologic repository used in the iterative performance assessment were cumulative total releases of radionuclides (normalized release) to the accessible environment and radiation dose (effective dose equivalent) to the exposed population. These performance measures were consistent with regulations in 40 CFR Part 191 and 10 CFR Part 60, in effect at the time. The third NRC total system performance assessment (NRC, 1999b) was performed a few years later using the TPA Version 3.1 code to determine whether or not the NRC would be able to quantitatively evaluate the conclusions reached by DOE in its viability assessment. During this period, the focus of performance estimates emphasized radiation dose as a primary performance measure in anticipation of forthcoming U. S. Environmental Protection Agency standards for Yucca Mountain in 40 CFR Part 197 (Code Federal Regulations, 2001). Subsequent to developing and testing the TPA Version 3.1 code, detailed sensitivity and uncertainty analyses were undertaken (NRC, 1999b) that indicated the need for further refinement of the TPA code prior to its use to evaluate the DOE Total System Performance Assessment–Viability Assessment [Civilian Radioactive Waste Management System Management and Operating Contractor (CRWMS M&O), 1998]. Revisions made to the TPA code led to the TPA Version 3.2 code (Mohanty and McCartin, 1998), which was used to evaluate the Total System Performance Assessment–Viability Assessment (CRWMS M&O, 1998). This version of the TPA code was used to conduct additional sensitivity analyses documented in the fourth of the aforementioned performance assessment reports (Mohanty, et al., 1999). Analyses using the TPA Version 3.1 code and above were based on the new regulation [10 CFR Part 63 (Code Federal Regulations, 2002), which was based on the risk-informed, performance-based approach. The new regulation provides site-specific criteria (including design criteria) and eliminates detailed requirements such as quantitative subsystem performance objectives. 4r. part 60 ?

In addition, the total system performance assessment analyses are used to focus NRC activities on factors of greatest importance to repository performance. The site-specific regulations developed by NRC for the Yucca Mountain repository are risk-informed and performance-based. Therefore, the NRC review of a potential license application to build and operate a deep geologic repository at Yucca Mountain will focus on those physical aspects of the repository system of greatest importance to radiological safety. The results from this study, in part, will be used to assist development of the review strategy outlined by the NRC in its Yucca Mountain Review Plan (NRC, 2002).

1.1.2 Iterative Performance Assessment Phase 1 Sensitivity and Uncertainty Analyses

Four sensitivity or uncertainty analyses were performed for Iterative Performance Assessment Phase 1 (Codell, et al., 1992): (i) demonstration of the effect of individual parameters on the resultant complementary cumulative distribution function of cumulative release to the accessible environment, (ii) use of stepwise linear regression to estimate sensitivity of key parameters in the consequence models, (iii) determination of relative importance of individual radionuclides in the waste, and (iv) sensitivity of complementary cumulative distribution functions to the performance of the natural and engineered barriers. The sensitivity and uncertainty analyses considered only groundwater pathway releases. Gaseous release of radionuclides was not part

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infiltration reaching the waste packages will be focused or funneled by discrete fractures, which will wet some of the waste packages more heavily than others. This alternative model is invoked by increasing the range of WastePackageFlowMultiplicationFactor parameter by a factor of four (from 3.15×10^{-2} — 1.05×10^{3} to 1.26×10^{-1}— 4.20×10^{3}), while decreasing the fraction of waste packages wetted by a factor of one-fourth (from 0–1 to 0–0.25). This setting has the effect of funneling the same quantity of water for each subarea to one-fourth the number of waste packages.

2.3.2.2.4 Cladding Credit Plus Spent Nuclear Fuel-Dissolution Model 1

The basecase conceptual model assumes that once the inner and outer containers have been breached, spent nuclear fuel is exposed and available for dissolution and transport. This assumption ignores any protection afforded the fuel from intact and only partially failed cladding. In this alternative model, the effect of cladding protection is simulated by setting the cladding credit factor at a constant value of 0.01 for the entire simulation period, which is 1/100th of the cladding credit factor used in the basecase. A factor of one represents no cladding credit.

2.3.2.2.5 Grain-Size Model with Fuel-Dissolution Model 1

This conceptual model uses the grain size from the uranium dioxide fuel instead of the particle size to determine surface area, which leads to a higher dissolution rate because of the increased surface area. This alternative conceptual model combines the fuel-dissolution Model 1 for relatively fast dissolution by carbonate water, with the large surface area of the grain size.

2.3.2.3 Transport Alternatives

The transport assumptions in the basecase unsaturated zone and saturated zone conceptual models are investigated with three alternative models. These assumptions affect the releases and time of release from the engineered barrier subsystem, unsaturated zone, and saturated zone.

2.3.2.3.1 No Retardation of Plutonium, Americium, and Thorium

indicates?

This alternative conceptual model demonstrates the contribution to repository performance of retardation of plutonium, americium, and thorium in the geosphere and the effect on the groundwater doses if chemical conditions resulted in no sorption. Once released from failed waste packages, plutonium, americium, and thorium are assumed to travel at the same speed as water through the engineered barrier subsystem, unsaturated zone, and saturated zone to the receptor location. This alternative model is invoked by setting partition coefficients (K_d) to zero and retardation coefficients (R_d) to unity for these elements. This model approximates the potential effect of colloids that could move through the geosphere unretarded if filtration processes were not considered radioactive.

2.3.2.3.2 No-Solubility Limit Model indicates?

This alternative conceptual model demonstrates the contribution of the solubility limit of each radionuclide and the effect on the groundwater doses if this limit was removed for each radionuclide. Once the spent nuclear fuel is dissolved, the radionuclides are assumed to

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Time histories of radionuclide releases at the outflow boundaries of the engineered barrier subsystem, the unsaturated zone, and the saturated zone are shown in Figure 3-13. In general, the release rates from the engineered barrier subsystem in Figure 3-13(a) for the soluble radionuclides drop after the peak release is reached because of radioactive decay and because the removal of radionuclides from the waste package decreases the inventory available for release. Other radionuclides, such as U-238, U-234, Np-237, Pu-239, Nb-94, and Th-230, which are less soluble and have relatively longer half-lives, exhibit increasing release rates throughout the 10,000-year simulation period. Am-241 also has low solubility; however, with a half-life of only 432 years, the inventory decreases rapidly.

There is only a small increase {~ 1.0×10^{-5} mSv/yr [1.0×10^{-3} mrem/yr]} in the engineered barrier subsystem release rates from the instantaneous release of the gap fraction inventory. The increase in infiltration rate for the 10,000-year simulation period shown in Figure 3-1 is only marginal compared with the period beyond 10,000 years. Therefore, climatic change from current to pluvial conditions is a key event that affects release rates only beyond 10,000 years.

The similarity between engineered barrier subsystem and unsaturated zone releases shown in Figures 3-13(a) and (b) indicates the unsaturated zone as modeled apparently does not significantly delay the releases into the saturated zone for the mean value data set. One might expect the unsaturated zone to delay the transport of radionuclides because the radionuclides must be transported 300 m [984 ft] from the repository to the water table.

The unsaturated zone releases are directly related to the presence of the Calico Hills vitric layer. The groundwater travel time through the unsaturated zone is 11–21 years for subareas 2, 8, 9, and 10 (i.e., fracture flow); the remaining subareas are between 200 and 700 years (i.e., matrix flow). Subareas 2, 8, 9, and 10 show a fast path because, in the absence of the Calico Hills nonwelded vitric layer, the flow is predominately in fractures. Consequently, for subareas 2, 8, 9, and 10, which encompass almost 48.3 percent of the spent nuclear fuel inventory, the unsaturated zone does not delay radionuclide transport subsequent to release from the engineered barrier system. For the remaining 51.7 percent of the spent nuclear fuel inventory, the 200–700 years of groundwater traveltime somewhat delays the non-retarded radionuclides, however, retarded radionuclides will be effectively held up for greater than 10,000 years in those subareas where the Calico Hills vitric unit is present.

true ?

The saturated zone release illustrated in Figure 3-13(c) reveals releases of only non-retarded Tc-99, I-129, and Cl-36 in the 10,000-year simulation period. The saturated zone release rates presented in Figure 3-13(c) also can be compared with Figure 3-13(b) to evaluate the effects of flow and transport in the saturated zone. The groundwater traveltime computed using the streamtube flow rates and lengths in the saturated zone is 570 years (see Table 3-12). However, sorption in the alluvium significantly increases the traveltime for most radionuclides.

As illustrated in Figure 3-12(a), the groundwater pathway dose at 10,000 years is dominated by I-129, Tc-99, and Cl-36. These nuclides contribute the most to dose because of no retardation during transport in alluvium, a large initial inventory {1.32×10^{9}, 5.37×10^{11}, and 4.26×10^{8} Bq/MTU [0.0357, 14.5, and 0.0115 Ci/MTU]}, long half-lives compared with the 10,000-year timeframe of interest (1.57×10^{7}, 2.13×10^{5}, 3.01×10^{5} year), moderate to high dose conversion factors, and moderate to high solubilities {129, 99.3, and 36 kg/m^3 [8.05, 6.20, and 2.25 lb/ft^3]}. Tables 3-5 and 3-7 through 3-10 provide a summary of the mean values for these parameters corresponding to all radionuclides. To obtain a perspective of the magnitude

7 SYNTHESIS OF RESULTS AND RISK INSIGHTS

This chapter synthesizes information from the analyses presented in Chapters 3, 4, 5, 6, and Appendixes F and G. Chapter 3 presented trends in repository system and subsystem responses to models and data, including the effects of input uncertainty and variability on the output uncertainty. Chapters 4–6 presented parametric, distributional, and subsystem (or repository component) sensitivity analyses and their results, as well as results from alternative conceptual models. Appendixes F and G present risk calculations for stylized human intrusion and in-package criticality. This chapter (7) focuses on identifying the important parameters, alternative models, and subsystems that significantly influence performance.

The following sections discuss the system-level overall performance results including the basecase, disruptive event cases, stylized human intrusion, and in-package criticality. Barrier capability, as derived from the analysis of total system behavior calculations (Chapter 3), is presented next, followed by sensitivity analysis results from various methods (parametric, distributional, alternative conceptual model, and repository component). Parametric sensitivity analysis results from Chapter 4 are aggregated to extract the final list of the top 10 influential parameters from the basecase and the igneous activity case. These results are then verified by runs that demonstrate that most uncertainty in the dose is a result of uncertainty in the chosen parameters. Finally, the influential parameters, alternative conceptual models, and repository components are linked with integrated subissues to identify the parameters significant to performance for higher doses and maximum sensitivity to changes in parameters and conceptual models.

Although the radionuclide C-14 was included in the calculations of release, transport and dose, it will not be included in the synthesis of results. Currently, the TPA 4.1 code considers that C-14 would be in equilibrium between the water and gas phases, and would mostly partition into the gas stream, thereby being released primarily to the atmosphere (Codell and Murphy, 1992). Under 10 CFR Part 60, the staff considered that the atmospheric releases of C-14 were more important for a geologic repository than the liquid releases because of the consideration in that rule of population dose, and therefore the TPA code considered all released to be to the gas phase. The regulations in 10 CFR Part 63 consider the dose to an individual rather than a population, and places far less emphasis on doses from gaseous C-14. Conservatively, all releases of C-14 could have been included in the liquid phase, but the TPA 4.1 code does not have this provision. The staff does not believe that the omission of C-14 from the results will alter any conclusions.

Insights gained from the risk analyses produced by the TPA Version 4.1 code must be tempered by the following considerations:

- There are many assumptions, uncertainties, conservatisms, and other limitations in the analyses.
- The results of the TPA Version 4.1 code are only pertinent to those conceptual models embodied in it (e.g., there is no diffusion from the waste packages and no cladding degradation, so no pertinent results on these phenomena can come directly from the analyses).

standardized to take into account the relative change in a variable to allow more accurate ranking of sensitivities.

The regression analyses used both raw and transformed variables, including logarithmic and rank transformations. Although the transformed variables generally led to better coefficients of regression, they also distorted the meaning of the results by giving too much weight to small doses. In addition, this study added a new reliability-based method know as the Cumulative Distribution Function-Based Sensitivity Method (Appendix D).

All the nonstatistical methods used in previous total-system performance assessment sensitivity studies (Morris method, FAST, and differential analysis) were also employed in this study. In addition, this study added the fractional factorial design method.

Rankings for sensitivity took a consensus approach that determined the most sensitive variables according to the relative rank of that variable in each of the separate sensitivity analyses. The ranking of the variables for the 10,000-year simulation period is shown in Table 4-10.

Validation ~~is that~~ of whether the choice of the sensitive parameters by the various methods was correct ~~and~~ was achieved by calculating and comparing Monte Carlo runs with all 330 parameters in the basecase sampled against new Monte Carlo runs for which only the reduced set of sensitive variables were either included or eliminated. Results show that keeping only the most sensitive variables gives results similar to the basecase results. Removing the most sensitive variables from sampling reduces the uncertainty in the results. Both observations demonstrate that the correct variables have been identified as being most sensitive.

8.4.2 Distributional Sensitivity

Another new technique in this study was distributional sensitivity. It was not used directly to rank sensitive variables but to determine the effect of estimation of parameter distributions for important variables on the performance results. In this technique, the input distributions were changed either by shifting the mean of a distribution by 10 percent or changing the shape of the distribution while keeping the minimum and maximum fixed. This study used the 10 most influential variables identified in the sensitivity analyses. In summary, the distributional analyses showed that improper choice of distribution functions can significantly affect the dose response. Two parameters that appear especially important in this regard are the flow multiplication factor that determines the quantity of water entering the waste packages and the preexponential term for the spent nuclear fuel-dissolution model.

8.5 Repository Component Sensitivity Analyses

Repository component sensitivity analyses look at the whole barrier at once, either performing or not performing. In the Monte Carlo uncertainty analysis used, the performance of barriers other than the waste package often could not be seen (e.g., there were never any corrosion failures of the waste packages within 10,000 years). Repository component sensitivity analysis, which assumes failure of specific barriers, allows the exploration of barrier performance by reducing the overlapping capabilities of multiple barriers. The six repository components of the engineered and natural barriers are drip shield, waste package, spent nuclear fuel, invert, unsaturated zone, and saturated zone.

- Allow variable dispersivity for transport in the unsaturated zone.
- Include uncertainty in the saturated zone streamtube dimensions.
- Allow changes in streamtube flux after climate change.
- Improve mass loading and occupancy factors for igneous activity.
- Modify igneous activity source term to better account for physical processes of mixing fuel and magma.
- Add a short-term ash redistribution model to consider remobilization of ash by overland flow of water.
- Add effects of rockfall on drip shield.

In addition to the technical changes to the TPA Version 4.1 code to address improved model abstractions, data and models will be adjusted where necessary to accommodate changes to the current U.S. Department of Energy (DOE) repository design and thermal loading strategy.

8.11 Conclusions

The TPA Version 4.1 code has been used successfully in a structured way to provide risk insights through investigating the performance of the proposed Yucca Mountain repository and the sensitivity of this performance to repository subsystems and parameters on which they rely. The calculated risk is small within the 10,000-year simulation period, determined with the staff best estimate of models and parameters, and is well below the regulatory limit of 0.15 mSv/yr [15 mrem/yr] to the reasonably maximally exposed individual. Extrusive volcanism was the scenario that produced the maximum calculated risk, 3.5×10^{-3} mSv/yr [0.35 mrem/yr] to the reasonably maximally exposed individual, which is still well below the regulatory limit. Experimentation with a wide range of alternative conceptual models for waste form dissolution, waste package lifetime, and radionuclide transport never led to calculated risks that were close to exceeding the standard.

The NRC staff used a variety of statistical and nonstatistical methods to determine the sensitivity of dose to variations in the input parameters. Three new methods applied to the TPA Version 4.1 code proved useful in determining parametric sensitivities. Fractional factorial design provides a means of unambiguously determining the interactions among variables. Distributional sensitivity illustrates the effect of parameter estimation errors on risk. The cumulative distribution function-based method shows sensitivities in different dose ranges, particularly the high-dose responses. As in previous total-system performance assessment studies, staff relied on a consensus approach for all the parametric sensitivity methods to determine the parameters that appeared most frequently and with the highest rank among all the methods. Using this procedure, a list of the 10 most influential parameters was developed for the regulatory period of 10,000 years. This list consisted of parameters that deal with flow of water to the waste, failure of barriers to flow, retardation along transport pathways of slightly retarded Np-237, fuel-dissolution rates, and dilution at the point of use. There were no parameters in this list that dealt with waste package corrosion because the models predicted that none of the waste packages failed by this mechanism within 10,000 years. A similar list was developed for the

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100,000 year simulation period, which is not required by the regulations but serves the purpose of broadening understanding of failure modes for the repository. Parameters dealing with waste package corrosion appeared on this list, together with the retardation factor for Pu-239.

Repository component sensitivity analysis evaluated how repository components behaved in the repository system. Suppression of the performance of the repository components, singly and in combinations, provided useful informational about the sensitivity of the performance to the repository components (i.e., subsystems) although the staff never attached probabilities to these suppressions, and such results had no direct bearing on the overall risk. Repository component analysis pointed out interesting features of the repository such as (i) the redundancy of the drip shield and waste package to shed dripping water, (ii) the capabilities of the unsaturated and saturated zones independent of the waste package, and (iii) the relative unimportance of the invert as a barrier. Important components were also identified based only on their capabilities rather than their direct bearing on dose or risk. In identifying these components, the staff demonstrated that for the conceptual models included in the TPA Version 4.1 code, the drip shield, waste package, waste form, unsaturated zone, and saturated zone all contributed to waste isolation.

The NRC and CNWRA staff evaluated two stylized scenarios for human intrusion and in-package nuclear criticality. Both analyses were conditional, with no assignment of probability although these probabilities are believed to be small. Both produced maximum conditional dose values well below the 0.15 mSv/yr [15 mrem/yr] dose limit specified by the regulations.

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Robert Brient

From: Robert Brient [rbrient@cnwra.swri.edu]
Sent: Friday, July 25, 2003 9:01 AM
To: 'gwitt@cnwra.swri.edu'
Subject: RE: NCR on Missed QAP-002 review

Will do.

Bob Brient
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-----Original Message-----
From: Gordon Wittmeyer [mailto:gwitt@cnwra.swri.edu]
Sent: Friday, July 25, 2003 8:55 AM
To: rbrient@cnwra.swri.edu
Cc: Sitakanta Mohanty
Subject: RE: NCR on Missed QAP-002 review

Bob:

Yes. Lets just make it month from that date, say Friday, August 29, 2003. I believe that the document changes to the Sensitivity Studies Report are nearly complete (Sitakanta?); however, we still have not received the TOP-3 forms and AP-6 signoff sheets from J. Firth and T. McCartin at NRC.

Gordon

-----Original Message-----
From: Robert Brient [mailto:rbrient@cnwra.swri.edu]
Sent: Thursday, July 24, 2003 3:54 PM
To: Gordon Wittmeyer
Subject: NCR on Missed QAP-002 review

Reminder: This NCR is due on 7/28/03 – do you want another extension? – I don't anticipate any adverse impacts if you do.

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