March 6, 2000

MEMORANDUM TO: C.W. Reamer, Chief
High-Level Waste and Performance Assessment Branch

FROM: James R. Firth, Lead ***/RA/***
Key Technical Issue Team
Total System Performance Assessment and Integration
High-Level Waste and Performance Assessment Branch

SUBJECT: ACTION PLAN FOR RESPONDING TO EXTERNAL REVIEW OF TOTAL-SYSTEM PERFORMANCE ASSESSMENT VERSION 3.2

The Center for Nuclear Waste Regulatory Analyses (CNWRA) conducted an external review of the Total System Performance Assessment Code, Version 3.2 (TPA 3.2) and documented the results in a report. The external review report includes the findings of eight reviewers. Numerous comments and recommendations are contained in these findings. The comments and recommendations address conceptual models, simplifying assumptions, and data used in TPA 3.2; documentation, confirmatory testing, and quality assurance for the code; and other issues. This memorandum sets forth our plan for actions to address the comments and recommendations of the reviewers. The objective is to consider and respond to comments and recommendations through our ongoing activities, to the greatest extent possible, and to document our responses. Consistent with this objective, we will follow an approach that will track the consideration of each comment or recommendation and consolidate the means used to address them, without creating a significant new initiative.

Our strategy involves identifying individual comments and recommendations. Once identified, they can be addressed through relevant ongoing activities (e.g., code development, code documentation, sensitivity studies) consistent with pre-established schedules. The action plan — beginning with the first revision — will catalog each comment or recommendation, its location within the CNWRA report, the lead(s) for tracking the response, the status of resolution — including the proposed means and schedule for resolving it, and a summary of how it was finally addressed. The action plan will be updated as a coordinated effort, with the lead for maintaining the action plan assigned to the Total System Performance Assessment and Integration Key Technical Issue team. The action plan and the external review will be made publicly available concurrently, after the action plan is approved.

The action plan is proposed to be updated on the following schedule:

Complete initial catalog of action plan items, including documentation of comments and recommendations, leads, status of resolution, relevant activities, and preliminary schedule for response.	March 24, 2000
Issue action plan (revision 1)	April 24, 2000

Revision 1 of the action plan will establish schedules for addressing the comments and recommendations of the external reviewers. Although the intent is for the action plan to be updated continually, the action plan will be formally updated on a bimonthly basis, beginning on May 31, 2000, to facilitate oversight by management.

Attachment: Draft Catalog of Action Plan Items

Revision 1 of the action plan will establish schedules for addressing the comments and recommendations of the external reviewers. Although the intent is for the action plan to be updated continually, the action plan will be formally updated on a bimonthly basis, beginning on May 31, 2000, to facilitate oversight by management.

Attachment: Draft Catalog of Action Plan Items

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Draft Catalog of Action Plan Items[1]

ID	Reviewer	Comment	Contact/Status	Resolution
1	Brady	Further study is required to show that the lack of coupling is consistent with the intention to conduct bounding calculations in the sensitivity studies. (p. A-2) The consequences of specific assumptions (particularly in terms of de-coupling of processes) need to be tested. (p. A-11)		
	de Marsily	The TPA code does not address a number of potential couplings of the various processes active in the repository. The coupling between the thermal loading, the mechanical behavior, and finally the hydrology of the infiltration (e.g., role of potential additional fracturing) is not addressed. The rationale for not considering these couplings is not presented. The "cold wall" effect could significantly change the flux of liquid water reaching some canisters. (p. C-3)		
	Kelly	Several modules need more extensive coupling of processes between them. (p. D-4) Coupling amongst modules is sometimes missing. In some cases, this coupling could be expected to have significant effects as the results are cascaded. (p. D-8)		
2	Brady	A more comprehensive model described during the review will permit a more thorough assessment of seismic effects on WP rupture. (p. A-2) Seismic rupture of WPs is not expected to represent a major source of radionuclide release. (p. A-11)		
3	Brady	The unfilled drift model may not be conservative for FAULTO. However, the result may not be important as only a very small number of waste packages are at risk of rupture under aseismic fault slip. (p. A-2)		

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4	Brady	Thermal stresses are not taken into account and may have an important bearing on mountain-scale seismic effects and fault slip, and on the repository scale hydrology, by reducing vertical permeability at the repository horizon. (p. A-2) An effect that may be of consequence in the evaluation of seismic factors is the possibility that thermal stresses may lead to conditions sufficient to cause slip on existing faults, which may be co-seismic, within the repository domain. (p. A-5)		
5	Brady	A weakness is the possible lack of versatility in analysis of repository layouts different from the standard drift-and-pillar planar design. (p. A-2)		
6	Brady	Decoupling of many FEPs raises questions about the extent to which all the possible modes of repository response will be captured in the performance simulations. A qualification study on a repository analogue could provide strong support for an inference of an acceptable level of completeness of the formulation. (p. A-2)		
7	Brady	It is doubtful if the code is sufficiently flexible to handle possible radical changes in repository layout. One objective of further development on the TPA code should be to ensure that generic repository designs — other than drift and pillar layouts — can be simulated. (p. A-3)		
8	Brady	A more convincing analysis of the consequences of seismic loading would take account of the history of motion during a seismic event of both the WP and the local rock. This would require a more comprehensive representation of the WP and the drift near-field rock in terms of both structural detail and time history of motion. (p. A-5)		
9	Brady	The relatively simple formulation of seismic effects may be sufficient as a first pass, but the more comprehensive analysis is required to assess seismic effects thoroughly. (p. A-5)		
10	Brady	The possibility of mountain-scale, thermally induced seismic events points to the need for comprehensive seismic monitoring of the repository during construction, to establish seismic baseline parameters, and in the pre-closure phase, to characterize seismic response which may bear some relation to the temperature field. (p. A-5)		

11	Brady	While the current displacement threshold figure for rupture (i.e., 25 mm) seems conservative, at some stage some hard data derived from experimentation would be useful in determining how corrosion and other modes of damage affect WP resistance to rupture under various types of imposed deformation. (p. A-6)		
12	Brady	Because the objective is to conduct a bounding calculation on TEDE, the possibility of thermally induced fault slip and associated seismicity (even though the slip may indeed be aseismic) is worthy of further consideration. (p. A-7)		
13	Brady	Concerns about the effectiveness of shedding as a method of controlling WP exposure to percolating and refluxing groundwater could conceivably lead to changes in repository layout more radical than those expressed in the EDA-II design. (p. A-8)		
14	Brady	The documentation of the code would be improved considerably if the interaction or coupling between the FEPs was mapped as an influence diagram or a matrix, and the strength of each interaction was evaluated explicitly. (p. A-9)		
15	Brady	This reviewer was left with the impression that the design change (i.e., EDA-II) was not accommodated readily by the current TPA code functionality. (p. A-10)		
16	Brady	Flexibility in application is a feature that must be provided intrinsically in further development of the code. (p. A-10)		
17	Delaney	Although the basis for and the implementation of the empirical ash-dispersal model proposed by Suzuki (1983) was extremely well defended by CNWRA staff, it is imperative that the underlying physical processes be better understood thorough focused field and theoretical studies. (p. B-1) Although better models may be obtained, at great cost to computer time, I expect the improvement would have a marginal effect, at best, on the total population of outcome8. (p. B-1)		
18	Delaney	Increased confidence in the parameterization will probably be crucial to the eventual acceptance of the results by both scientists and the general public. (p. B-1).		

19	Delaney	My primary concern with the present TPA code is its failure to estimate dosages due to fluvial dispersal from the vicinity of a volcanic vent to the critical population. (p. B-1)		
20	Delaney	The possibility of a combined seismic and volcanic event may be judged rather high as one might be though capable of triggering the other. I see this as very unlikely, especially in view of the great depth from which magma must ascend before it is capable of eruption. (p. B-3)		
21	Delaney	I doubt that continued development of probabilistic models will be so beneficial as focused study of geologic analogs of the expected Yucca Mountain magmatic system. (p. B-3)		
22	Delaney	While this model (Suzuki (1983)) can be defended by its numerous successful applications at volcanoes worldwide, the underpinning of the dosage calculation is nonetheless weakened by its empirical nature. I suggest that a research program to develop more sophisticated models be undertaken to document more fully the viability of the Suzuki model. (p. B-3)		
23	Delaney	If data (e.g., wind direction and speed, along with atmospheric structure to the expected heights of the ash clouds) were available, it may be found worthwhile to properly integrate the ash-fragment paths temporally and spatially through changing wind conditions. (p. B-3)		
24	Delaney	The fine-grained components of these deposits (i.e., thicker deposits near the vents) would, inevitably, be washed during rainstorms into the drainages, where debris flows and flash floods would carry it to the Amargosa Valley. Some assessment needs to be undertaken of doses caused by fluvial transport to the critical group of radioactive volcanic debris. (p. B-4)		

25	de Marsily	The conceptual model of the saturated zone hydrology at Yucca Mountain is at present so uncertain, with so many alternatives and unknown transport properties, that it is not at this stage possible to derive a representative model to be included in the TPA code, even with a range of uncertainties for its parameters. The conceptual models in the TPA code are based at present on a series of unproved assumptions, not supported by the available data, and therefore underestimate the uncertainty. The only viable alternative at this stage and with the present level of data seems to me to be the use of a much more conservative saturated zone model. (p. C-3) The major issues are: (i) role of the paleozoic carbonate, (ii) horizontal anisotropy of the fractured volcanics, (iii) connectivity of the fracture network, (iv) relation between the volcanics and the alluvium, and (v) exact geometry of the alluvium in the area. (p. C-4)		
26	de Marsily	Once fracture flow has started at a given stratum, all fractures below it could also have fracture flow. (p. C-5) This can be addressed through changes to parameters. The net effect to the overall results will not be large. (p. C-3)		
27	de Marsily	Spatially variable infiltration rates with possibly higher values should be considered by incorporating neglected phenomena in the infiltration model. Neglected phenomena include: (i) relationship of shorter periods of the Milankovitch theory representing tilt and precession to climate change, (ii) a different pattern of precipitation could produce higher Average Annual Infiltration, (iii) runoff can increase localized infiltration rates, and (iv) vegetation may increase the permeability of soil cover. (p. C-6)		
28	de Marsily	It is very difficult to justify the assumptions mad and the values of the parameter used for the models of the thermal pulse. It will be very difficult for NRC to justify these choices. (p. C-3)		

29	de Marsily Kelly Ouzounian	It is not clear which FEPs were excluded and based on what reasons. A more rigorous classification of the FEPs, of their roles and of the consistency of their introduction in the Process System or the Scenarios would be desirable. (p. C-3) Documentation of the origins of many of the modules, data, and side analyses needs to be more traceable. The methodologies used for the selection and rejection of different FEPs are not clearly outlined in the documentation. (p. D-8) The scenario development methodology must be explained and documented. Sensitivity studies may also be used to focus some of the scenarios. QA and traceability are important in order to recorded how decisions were made at each step, to include or not an event or process. For those scenarios which have not been analyzed, justification must be given. In order to allow NRC to independently review DOE's approach, NRC needs to have its own capability to generate a set of FEPs and scenarios. For each of the scenarios, definition of the range and boundaries of the given set of models and data is requested in order to prove that computation was not performed out of the valid domain. (p. E-5)		
30	de Marsily	It is not defensible to assume isotropy and determine that way the flow lines and flow tubes. (p. C-4)		
31	de Marsily	The fraction of the pathway, which is situated in the volcanics, cannot be treated as a continuous equivalent porous medium, particularly if abstraction wells may be drilled directly in the volcanics. (p. C-4)		
32	de Marsily	The potential layering in the alluvium must be determined, its exact geometry, and the manner in which the flux leaving the volcanics is distributed over the vertical when it enters the alluvium must be known before defensible dilution calculations can be made. (pp. C-4 - C-5)		
33	de Marsily	The thickness over which matrix diffusion can occur, either as the half distance between two fractures, or by an *a priori* defined length, assuming the porosity to be "closed" at larger distances. Such a limitation of matrix diffusion should be included in the TPA, if the matrix diffusion option is used. (p. C-5)		

34	de Marsily	Replace the present models of the TPA Version 3.2 code for saturated zone flow and transport with the following model: assume the entire flux of water and of radionuclides which seeps into each on of the infiltration subareas of the repository can be transported with little or no retardation into one single community well, without any additional dilution. (p. C-5)		
35	de Marsily	Thermal loading of the repository will induce dilation of the rock and create new fractures that could affect the infiltration rate. (p. C-5 - C-6)		
36	de Marsily	Derive conservative estimates for the results of thermal calculations using simplified models or develop more complex three-dimensional models. (p. C-7)		
37	de Marsily Kelly	The potential effect of rock debris or dust on the surface of the canister, or even rock blocks if the drifts are partially backfilled with fallen rock could influence the corrosion rate of the metal beneath it. [Raised as a question, tempered by declared lack of expertise.] (p. C-7) Another area of coupling that must be considered is that of rockfall-induced defects/stresses to corrosion via the possibility of SCC. In addition the possibility of either rockfall-induced capillarity should be considered. If areas of the waste package are in contact with either rockfall or backfill, those areas will be more susceptible to corrosion attack via crevice corrosion. (p. D-6)		
38	de Marsily	A concern is whether the amount of early release of radionuclides from those fission products that accumulate at the fuel grain boundaries is well accounted for. (p. C-7)		
39	de Marsily	Couplings between the thermal loading and the resulting effects is not considered. (p. C-8)		
40	de Marsily	Cooler waste packages could serve as condensation surfaces and may be dripping with water. (p. C-8)		
41	de Marsily	Coupling between climate change and saturated flow, which could increase the hydraulic gradient and increase the saturated thickness, is ignored. (p. C-8)		

42	de Marsily	Fault movements may induce increased infiltration on top of the breached waste packages. (p. C-8)		
43	de Marsily	Volcanic disruption on canisters not included in the explosion are not considered. Open drifts might be used as conduits for gases and/or magma, since they are not backfilled. (p. C-8)		
44	de Marsily	It would be useful to build an “influence diagram” in which all the FEPs taken into account both as internal and external are linked to all the relevant processes on which they may have an effect. An additional document then describes, for each link, the reason why this link is not considered important in the TPA, or — on the contrary — how it is incorporated in the process system. (p. C-8)		
45	de Marsily	The level of QA for the TPA code appears to be less than the level DOE prescribes for its contractors. Should NRC use a different level of QA than DOE? (p. C-9)		
46	de Marsily	The test cases and comparisons for each of the modules of the TPA code made during the course of code development should be better documented to provide evidence of the confidence that can be placed on the TPA code. (p. C-9)		
47	de Marsily	The TPA code should be verified against the DOE TSPA code using a test case where the two codes could be given parameters and assumptions as close as possible to each other. (p. C-9)		
48	de Marsily	The decision not to include couplings, heterogeneities, and complexities into the PA models needs to be reevaluated periodically. (p. C-9)		
49	de Marsily	Consumption of two liters/day may not be reasonable for an arid climate. Another pathway that should be considered is a swamp cooler using contaminated water. (p. C-10)		
50	de Marsily	Another method to be considered for the sensitivity studies is to fix one parameter at selected values and perform a full stochastic analysis for all other parameters. (p. C-10)		

51	de Marsily	In alluvial deposits, there is very strong heterogeneity both vertically and horizontally. The analytical calculations to estimate the capture zone, depth, and width of a well depend really very strongly on the homogeneity assumption. (p. C-17)		
52	de Marsily	The lumping of the water from all four SZ streamtubes is inadequate, since they represent different zones of the repository that may have different waste package failure rates, etc. (p. C-17)		
53	de Marsily	It is not defensible to use an equivalent continuous medium approach in a fractured aquifer to calculate dilution. (p. C-17)		
54	Kelly	There is a pressing need for a more realistic abstraction of the development of the environment on the WP surface. (p. D-2)		
55	Kelly	Documentation that allows a full analysis of the entire structure of the code needs to be assembled. (p. D-2) The User's Guide is inadequate for a comprehensive review of the approach being taken by NRC to analyze the eventual DOE license application. It is recommended that a document that provides a traceable overview of all aspects of the TPA code be developed and maintained. (p. D-4)		
56	Kelly	The corrosion of the waste package canisters will be directly coupled to the nature and evolution of the environment present around them. There is a pressing need for an improved estimate for the container-surface environment. (p. D-4) It does not appear that either MULTIFLO or REFLUX3 can capture the concentration of solute that would appear in the flow of water to the waste package. (p. D-5) Experimental work would be required to determine the connections between the near-field environment, conditions on the waste package surface, and corrosion. (p. D-5)		
57	Kelly	The coupling of dripping to fracture flow should be considered. At present, the "F" factors in the dripping abstraction are better than ignoring the effects, but are not defensible in any scientific way. The dripping abstraction is a good place holder, but it represents an area where substantial effort needs to be applied. (p. D-5)		
58	Kelly	More work needs to be done in the abstraction of localized corrosion rates due to the sensitivity of the predictions of dose to the corrosion rate. (p. D-5)		

59	Kelly	It is important to keep the option to evaluate the production of peroxide via radiolysis to allow for the assessment of alternative designs. (p. D-6)		
60	Kelly	The code should be able to handle a change from the expected localized corrosion to a rapid, more uniform corrosion in the presence of elemental sulfur or reduced sulfur species. Data needed to address the corrosion rates must be developed in the proper environment. (p. D-6)		
61	Kelly	It seems that there is no direct connection between pit area density and the important parameter in EBSREL of q_{in}. The release rate is dependent on the total area of perforation, so a means to estimate this area based on the localized corrosion characteristics of the material is needed in the TPA. (p. D-6)		
62	Kelly	The effects of welds on the corrosion behavior of the materials should be studied and given high priority. The possibility of dissimilar metal crevice corrosion between the construction materials should also be studied. For some corrosion resistant alloys, dissimilar crevice corrosion can be far worse than the deformable crevice corrosion. (pp. D-6 - D-7)		
63	Kelly	Considering only the fraction of SNF below the water line would seem to be non-conservative. Within the canister above the water line, the relative humidity would be expected to be that in equilibrium with a saturated solution of SNF dissolution products. The effects of constituents from the container materials might also need to be considered. (p. D-7)		
64	Kelly	As the corrosion of SNF is electrochemical in nature, the local cathodic reactions may lead to alkalinization of the solution within the waste package. The effects of this rise in pH on the dissolution rate and nature of the SNF should be considered. For example, equilibrium may be achieved for one component of the SNF that dominates the local pH. Incongruent dissolution of the other components may follow. (p. D-7)		

65	Kelly	Although the accuracy of the temperatures in the magma is unknown, and the interplay between the stresses during an eruption and the creep rates are unknown, some study of the possibilities is warranted. (p. D-7)		
66	Kelly	The reflux effects need increased attention. The current abstraction must be compared to experimental results that need to be generated. (p. D-8)		
67	Kelly	Some of the models rely on extremely limited data and/or experience (e.g., corrosion rates over millennia for modern alloys). As indicated above, there are aspects of some conceptual models that require more effort to make them more defensible. (p. D-9)		
68	Kelly	The documentation system needs substantial improvement to allow newcomers to the code to efficiently develop a grasp of what factors are and are not being considered, the process by which the selections were made, and the influence of the selection of the various parameters.		
69	Ouzounian	This documentation can be improved, specially by adding a logical flow-chart for each module, as given for some during the EPR meeting. (p. E-3)		
70	Ouzounian	The underlying work, models, data, and assumptions should be more traceable. The links between the phenomenological or process level and the performance assessment level should be described in a comprehensive and accessible way. (p. E-4)		
71	Ouzounian	Having teams in charge of describing the processes and mirror teams performing sensitivity analyses gives certainly all chances for an efficient work. (p. E-4)		
72	Ouzounian	A methodology through which chemical pathways of water are analyzed and described all along its hydrodynamic path from infiltration in Yucca Mountain to the alluvium should be developed [strong recommendation]. (p. E-4)		

73	Ouzounian	Each iteration between a new selection and calculated dose to man will lead to a new ranking of radionuclides, and selection as to be reconsidered for each step. Thus, exercises performed with TPA 3.2 would have benefitted from previous results. (p. E-)		
74	Ouzounian	A specific methodology, starting from the total inventory of radionuclides to be disposed of must be defined and described. It can lead to the same selection as the one used, but will be justified. (p. E-)		
75	Ouzounian	Chemical composition of water is difficult to predict during the reflux cycle, and except a sludge recovered during laboratory experiments, no data is available (care must be taken about early results, which in such a context are difficult to understand; as the system is complicated, processes need to be analyzed separately before being considered as coupled. (p. E-)		
76	Whicker	It seems that NRC and DOE should agree on reference biospheres and human exposure scenarios up-front, so that cross-comparisons of performance assessment (PA) results can be directly compared at the appropriate time. However, I believe strongly that the conduct of the PAs by NRC and DOE should be quite independent from one another. (p. H-3)		
77	Whicker	Develop an appendix to the TPA 3.2 Code document which: a) provides a structural (box & arrow) diagram of the GENII-S Code which shows all compartments and pathways treated; b) provides the entire set of equations (differential and analytic); c) provides a table describing all equation parameters (names, symbols, units, and single or distributional values assumed for the TPA 3.2 application); and d) describes how the GENII-S Code works (e.g. algorithms used to solve differential equation sets, time steps used, how it performs uncertainty/sensitivity analyses, etc.). (p. H-4)		

78	Whicker	I gained the impression at the review that build up of radionuclides in the soil after years of irrigation with contaminated ground water was not accounted for in the TEDE computations. This could be particularly troublesome for radionuclides that are in relatively soluble form in deep groundwater but which become much less so in the oxidizing surface soil environment. This potential decrease in solubility of course could reduce plant uptake, but the external gamma field could certainly increase over time as a result of radionuclide buildup in surface soil. In a similar vein, it would be important to account for return, year after year, of radionuclides in vegetation and animal wastes to the soil surface. I am not certain whether GENII-S keeps track of these sorts of phenomena. (pp. H-4- H-5)		
79	Whicker	Two things which would have added to the value of the report "CNWRA (1997). *Information and Analyses to Support Selection of Critical Groups and Reference Biospheres for Yucca Mountain Exposure Scenarios.* CNWRA 97-009" are a listing of the equations used in GENII-S (and relevant to Fig. 3-2) and uncertainty expressions for the radionuclide-specific parameters in Table 2-5. (p. H-5)		
80	Whicker	It appears that retardation of radionuclides in fractures is not taken into account. While this is conservative, it would seem that at least some fine materials would be present in most of the fractures and that substantial retardation would occur there. (p. H-5)		
81	Whicker	It is indicated on p. 2-9 that lateral dispersion from streamtubes is neglected. I would like to see more rationale for this assumption because at first glance, this seems counter-intuitive. (p. H-5)		
82	Whicker	On p. 2-10, the residential community is indicated to be < 20 km from the repository. Is it possible to be more specific about the location? (p. H-5)		

83	Whicker	I question why the values were not treated as stochastic variables. There may be a reasonable rationale for this, but I believe that the overall TPA 3.2 Code output uncertainty may be less that it would be if the considerable uncertainty in the DCF values were accounted for. (p. H-7) On p. 2-11, it is implied that the mean values of the DCFs are used in the overall TPA 3.2 Code. Does this mean that they are used as single value parameters rather than being treated a distributions? If this is the case, then I think it would be more defendable, since the TPA 3.2 Code is billed as probabilistic, to treat the DCF values as distributions subject to Monte Carlo sampling. The report CNWRA 97-009 has summarized stochastic runs to show the uncertainties in the DCFs (e.g. Tables 3-1 and 3-2). The flow diagram on p. 3-3 certainly has the dose conversion steps in the correct sequence, but I'm bothered some if this step is no more than a single-value multiplication at the last step, which I think would lead to an overall underestimate of the uncertainty in the TPA 3.2 Code output. (pp. H- 3 - H-4)		
84	Whicker	Because of reliance on the GENII-S Code, I believe it would add credibility to the ultimate PA conducted by NRC/CNWRA to show some sort of results comparison for a given scenario between GENII-S and other "mainstream" codes such as RESRAD, DnD, ECOSYS etc., and even more importantly, blind comparisons with real data such as has been done in the BIOMOVS project using data sets from Chernobyl fallout. (p. H-4)		
85	Whicker	Having a table of acronyms in the document is very helpful to its review. (p. H-5)		
86	Whicker	On p. 2-10, last bullet, does "direct contact" mean external gamma exposure from radionuclides in the soil? This term could have other connotations. (p. H-6)		
87	Whicker	On p. 2-10, the pathways for the farming community receptor group are listed, but the list does not seem complete. For example, what about soil ingestion by farm animals and people? (p. H-6)		

88	Whicker	On p. 2-11, it is indicated that the residential receptor group is exposed only through drinking of contaminated well water and direct exposure from radionuclides in ash following igneous activity. It seems that this may not be conservative or realistic, because such people might purchase food products from farms in Amargosa Valley, or they may well have small vegetable gardens that are irrigated with contaminated well water. (p. H-6)		
89	Whicker	Furthermore, has anyone considered the buildup of solid deposits on swamp coolers or humidifiers? (p. H-6)		
90	Whicker	Given the extremely large variations with soil type and water chemistry, I am surprised that some of this sort of site-specific work (develop plant/soil concentration ratios) has not been carried out. At the very least, I would expect that one could narrow the range of reasonable assumptions based on soil characteristics in Amargosa Valley. (p. H-6)		
91	Whicker	It would help to describe the type of resuspension model, since many exist. (p. H-6)		
92	Whicker	I would challenge, perhaps naively, that the entire radionuclide plume from the repository would be captured by wells (paragraph 5, p. 4-95). Is this a reasonable assumption? (p. H-6)		
93	Whicker	The first bullet on p. 4-96 indicates that food consumption rates are based on national averages. The Desert Research Institute in Las Vegas did a very large survey for areas near the Nevada Test Site in the late '80s. I recall some rather large differences from national surveys. Maybe it would be worth trying to get some of this information. (p, H-6)		
94	Whicker	Table 4-7, p. 4-123 lists a K_d of 550 for ^{241}Pu. I have never seen such a low value for Pu in a natural environment. Is this a typo? Referring to Table 5-1, p. 5-7, the quantity and units for the EPA limit (last column heading) should be given. (p. H-7)		
95	Whicker	I would strongly second the notion on p. 9-1 that colloid transport should be added to TPA 3.2. (p. H-7)		

96	Whicker	In Appendix A, p. A-47, a matrix K_d for Cm of 0 is assumed. I would expect Cm to have a K_d similar to that of Am. This would also seem inconsistent with the matrix retardation factor for Cm of 1.8e4 on p. A-80. (p. H-7)		
97	Whicker	The fourth column in Appendix A often gives two values. Do these represent the range, the 5^{th} and 95^{th} quantiles, or what? For lognormal distributions (e.g. p. A-48), why not give the GM and GSD? (p. H-7)		
98	Whicker	Also, many parameters in Appendix A appear to be treated as constants, yet many of these must be somewhat uncertain. Is it clear anywhere why these are treated as constants? (p. H-7)		
99	Whicker	I do not find anything to give me confidence in the accuracy of the DCF values. (p. H-4) I suspect that the values (for DCFs) are generally reasonable, but I did not find specific evidence to make one feel entirely comfortable with them. (p. H-8)		
100	Whicker	I believe it would help if the GENII-S Code output could be compared with real data from various scenarios and with other commonly used codes. If this has already been done, then something could be said about the outcomes of such efforts. (p. H-8)		
101	Whicker	Not considering the potential use of agricultural products from the Amargosa Valley and home gardening by the non-farmer resident may not be reasonable. (p. H-8)		
102	Whicker	I do not think there is sufficient justification for the radionuclide-specific parameters (plant/soil concentration ratios and feed transfer coefficients to animal products). These parameters can vary a lot, depending on soil characteristics and chemical forms of the radionuclides. To do better in this regard, it would require site-specific experiments, which would be fairly expensive, or at least a more in-depth analysis of soil properties and expected chemical forms. On the other hand, if the current code comes up with doses and risks that are many orders of magnitude below current limits, then this kind of improvement may not be warranted. (p. H-8)		

103	Thompson	A 'Knowledge Management' system to coordinate all data, models, simulations etc…, together with records of decisions, assumptions and omissions that led to a particular PA result, should be implemented. If such a system is not already being set up by NRC then the most important recommendation that results from the present review is that NRC management should have the courage to pause the apparently continual process of PA development and refinement in order to consolidate a well defined release of TPA and all related assessment tools, techniques and datasets. Then to spend substantial time and resources designing and implementing this support system and all the resulting linked documentation in order to reveal the strength of their achievements to the scientific and technical world beyond the Yucca Mountain program. (p. F-1). The justification quantitatively for these model abstractions and the reference data is not clear as written and requires the new documents to provide traceable, transparent and defensible support for each module. This should be done in combination with the aggregation of data and compatible accounting of uncertainty. (p. F-10)		
104	Thompson	If the time period of interest is 10,000 years, then extensive enhancement in TPA may be unnecessary. If the time period of interest is extended beyond about 100,000 years (say), then considerable further development in TPA is likely to be needed. (p. F-1) Substantially longer time periods of interest will require consideration of futures with two or more volcanic events and somewhat larger seismic magnitudes. The complexity of the sampling scheme explained during the ERG Meeting may then approach that of the WIPP Compliance Certification Application, Helton (1998). (p. F-9)		
105	Thompson Van Dorp	There is no link, at present, between faulting, seismicity and volcanism, or indeed between these phenomena and the regional groundwater system. (p. F-3) Example of coupling which does not appear to be accounted for in the TPA Code: Faulting, seismicity, igneous activity, and hydrogeological processes are treated as not correlated. (p. G-8)		

106	Thompson Van Dorp	The reasons for including the present combination of features, events and processes in the TPA system model are not stated nor the procedure followed to decide what should be left out. Therefore, it is not possible to be sure that the representation is sufficiently comprehensive for purpose. (p. F-3) Nowhere is this process of conceptualisation and reduction described and justified, whether using FEP analysis or by some other method. There is no visualisation of the results of this process, for instance using influence diagrams as in the regulatory assessments undertaken in Sweden, SITE'94, SKI (1996), and in the UK, Dry Run 3, Thorne (1993) (p. F-9) Formal elicitation and documentation of all steps from raw data and FEP catalogues, for instance, to the conceptual model of the integrated system used in TPA is needed. (p. F-10) How all potential relevant "features, events and processes" (FEPs) and in particular the Key Technical Issues (KTIs) have been selected, including detailed reasons for this selection and for the omission of others should be documented. This should include all potential interactions between FEPs (e.g. coupled processes) and the reasons why they are in- or excluded. How the included FEPs and their interactions are treated in the different scenarios as well as in the different process level models and in the modules of the Total-system Performance Assessment Code should be documented. (p. G-3)		
107	Thompson Van Dorp	The effect of climate change upon the regional groundwater system is ignored but not justified. (p. F-3) Example of coupling which does not appear to be accounted for in the TPA Code: Effect of climate on water table, exfiltration of water and biosphere. (p. G-8)		
108	Thompson	There is no coupling between the volcanic deposits and soil characteristics for the groundwater exposure pathway. (p. F-3)		
109	Thompson	There appears to be no overall mass or activity balance maintained throughout the entire system. (p. F-3)		

110	Thompson	The three methods of abstraction outlined in Section 3.1 are all acceptable, in principle, but it is impossible to say from the present documentation if they have resulted in sufficiently precise approximations to observation and/or the results of calculations at a more detailed level. Evidence of quantitative verification/calibration is required, under conditions that lead to the higher dose realisations in TPA simulations, rather than for realisations based upon expected values of the independent variables. (p. F-3)		
111	Thompson	In order to independently reproduce the models (and their associated data) from fundamental source information the entire chain of reasoning needs to be recorded, together with the uncertainties and biases accumulated at each stage, and the evidence used, for instance in expert elicitations. Such a record typically may be distributed over several supporting documents and a 'roadmap' diagram, see Sumerling (1992), provided in each section of Chapter 4 would then enable the reader to recover the abstraction process. (p. F-3)		
112	Thompson	Appealing to a Bibliography indexed solely by author's names is inadequate and does not satisfy fundamental requirements of traceability or transparency. (p. F-3)		
113	Thompson	High-risk reanalysis should be performed and documented to provide confidence in the modules of TPA and hence give a better idea of their domain of applicability. (p. F-4)		
114	Thompson	The extensive and honest comments show that at least 230 of the approximately 830 items listed in Appendix A seem not to be justified by a clear, traceable, record back to reliable sources. (p. F-4) Have the items 'assumed' as quoted in the references been independently reviewed and justified or are they open to further challenge because they may not be traceable to relevant sources? (p. F-4)		
115	Thompson	The need to distinguish clearly where proponent's data and assumptions are adopted and if these have been done only after independent review? (p. F-4)		

116	Thompson	Data from design studies and site specific investigations, including the ESF, should be highlighted, as opposed to information from other sites or of a general nature. (p. F-4)		
117	Thompson	When data or judgements are 'expected' or are to be further 'evaluated', the references to explicit work packages in NRC or DOE(YM) forward programmes should be given (p. F-4)		
118	Thompson	Many 'constants' could misrepresent the true level of uncertainty. Elicitation of Maximum Entropy pdf's over ranges bounded by physical fundamentals (say) would be much better (p. F-4)		
119	Thompson	Unbounded Gaussian pdf's are unjustified surely as the truncation is open to endless discussion. (p. F-4)		
120	Thompson	Biosphere data could not be found for any climate state applicable to the critical group behaviour for the groundwater pathways compatible with the extensive (e.g. soil) data listed for the volcanic pathway. (p. F-4)		
121	Thompson	Much is made of correlations - but in hardly anywhere are they to be found or elicited (especially if not multivariate Normal?) (p. F-4)		
122	Thompson	Uncertainty is not well expressed by point estimators such as means, medians, etc… but rather by showing how the percentiles of dose, and other output of interest, vary over time and depend upon assumptions. Comparisons of design options (as in NUREG- 1668) could be compromised by not showing (say) the 95- to 5-percentile range as well as sample estimates of the mean. (p. F-5)		
123	Thompson	Displaying only indications of high doses does not give a balanced 'reasonable' account of estimated behaviour when a large proportion of realisations show values that are much lower than regulatory limits and may satisfy targets for acceptable or negligible levels of risk. (p. F-5)		

124	Thompson	Uncertainty needs to be logically and defensibly determined at the level of basic information from site studies, design and research in terms of scales appropriate to the quantities concerned. Then it needs to be translated into estimates for the various modelling levels of detail, used as the assessment proceeds, ending in the pdf's and bias evaluation for the aggregated quantities used in TPA models. This reasoning, including questions posed to elicitation groups operating at a system or at a process level, was not readily apparent from information supplied. (p. F-5)		
125	Thompson	Importance Sampling was clearly shown to have considerably greater efficiency than either random or LHS sampling and should be considered seriously for the NRC program in future developments of TPA. (p. F-6) Further examination of sampling methods and of statistical convergence is required. (p. F-10)		
126	Thompson	Without confidence intervals on results, such as those in NUREG-1668, however, the conclusions from sensitivity analysis, and the comparison of different PA, cannot be entirely credible. (p. F-6)		
127	Thompson	Sophisticated statistical methods appear broadly to support the general conclusions reached in this study but they appear to this reviewer to rely upon non-intuitive assumptions of monotonicity and Normality. They seem to have been overruled by engineering *ceteris paribus* methods when planning future DOE work. (p. F-7)		
128	Thompson	Elicitation of pdf ranges and shapes may not achieve confident consensus. The implications of differing opinions about inputs to PA should be explored. (p. F-7)		
129	Thompson	Overuse of bounding or conservative reasoning can be a serious concern if it leads to estimates for mean values that are so biassed that they nullify the entire logic of a risk-informed simulation approach using Monte Carlo sampling to account for uncertainty. (p. F-7)		

130	Thompson	The assessment 'Toolkit' needs to be explained clearly and not only from the analyst point of view, but also from a software engineering standpoint. A full structured documentation system seems invisible as yet (from the material supplied) and should be stated well in advance of licensing reviews. (p. F-7)		
131	Thompson	The TPA manual and all related documents should show the document structure and give references to standards etc. separately from general scientific references. Data flows could be illustrated graphically and could, in principle, be obtained from CASE tools. Configuration management is understood to apply to everything consistently, including program versions, simulation cases, data sets, control files, output files and post processing results, all co-ordinated and recorded to avoid mismatches etc… and, of course, all related documentation. (p. F-7)		
132	Thompson	it is somewhat disturbing that no documentation was referenced for the following TPA Modules: UZFLOW, NFENV, EBSFAIL, EBSREL (are these in EBSPAC?), UZFT, SEISMO, VOLCANO, ASHPLUMO, ASHRMOVO (are these in ASHPLUME?), DCAGW, DCAGS. (p. F-8)		
133	Thompson	There is no clear reference to EXEC in the User Guide and there appears to be no separate document showing how best to design and implement new modules for incorporation into TPA. It is not clear if EXEC permits loops in the call sequence of modules. (p. F-9)		
134	Thompson Van Dorp	No attempt seems to have been made to explore the sensitivity of the results to the shape and range of parameter pdf's. (p. F-9) Further sensitivity studies might usefully explore the influence of uncertainty over such pdf elicitation. (p. F-10) Has the influence of the choice of parameter distribution function on the result been evaluated? (p. G-7)		

135	Thompson	The present implementation of TPA seems somewhat dated and the user interface requires too much knowledge about and interest in FORTRAN and in file handling from the user, who should be allowed to concentrate upon the regulatory tasks without distraction of computing considerations. There is a confusion between 'Auxiliary Codes and 'Auxiliary Files', which are unrelated. There is no general purpose Post-Processing Module as seems standard for other PA codes. (p. F-10)		
136	Thompson	'Conservatism' is claimed but not demonstrated for the assumptions underlying many models, data values and distributions. No formal decision logic records seem to have been kept nor is the subsequent evaluation of cumulative bias undertaken as proposed under the HMIP programme, Thompson and Williams (1997) for instance. (p. F-10). Conservatism needs to be evaluated by a bias evaluation procedure at all stages of model development. If consistent levels of conservatism are not achieved, comparisons between performance assessments may be misleading and the present data and results using TPA 3.2 should be evaluated to see if significant further development is really necessary to meet 10CFR63 requirements. (p. F-10)		
137	Thompson	Model + data + uncertainty must be handled at each stage in a comprehensive and compatible manner. (p. F-10)		
138	Van Dorp	Detailed documentation can show whether the developed code fulfils the requirements implied by the assessment context. The document does not contain sufficient information. Scenario development can be a tool to demonstrate, in a structured manner, sufficient completeness or comprehensiveness of an assessment. It can be used to identify interactions between different features, events and processes (FEPs). (p. G-2)		
139	Van Dorp	It is not clear what the position of this document is within a documentation system. Such a documentation system could show the past and future phases and the different tasks and results of a series of performance assessments. (p. G-3)		

140	Van Dorp	The flow of information from field and laboratory observations, measurements, and experiments, through system understanding, the development of conceptual models, the development of process level models, to the development of the Total-system Performance Assessment code should be documented. This should include the source of the information, e.g. general, DOE, or NRC/CNWRA. (p. G-4)		
141	Van Dorp	Although scenario development techniques are being applied, they seem not to be used for demonstrating "comprehensiveness." (p. G-5)		
142	Van Dorp	The Document concentrates, as the title suggests, on the description of the code. However, in a review, the evaluation and assessment of the actual system understanding and the conceptual models behind the codes is more important. (p. G-6)		
143	Van Dorp	Imposing too many restrictions and/or simplifications, to assure short runtimes for inclusion into a probabilistic code, can reduce transparency and the code might, under certain conditions, not behave as expected. (p. G-6)		
144	Van Dorp	Uncertainty in parameters might dilute the calculated risk (as discussed at the External Review Meeting of 27 - 29 July 1999)(D. Hodgkinson in "D. Savage (editor) The scientific and regulatory basis for the geological disposal of radioactive waste, Wiley and Sons Chichester 1995", Section 10.1.6 Risk dilution in PSA, page 364). (p. G-6)		
145	Van Dorp	The transition from field and laboratory observations, measurements, experiments and general knowledge through conceptual models to computer code or modules should be demonstrated, otherwise how is it assured that a consistent "picture" or system understanding is the basis for the different assumptions? (p. G-7)		
146	Van Dorp	What will be the effects of uncertainty in knowledge of processes, in conceptual models etc. on the application of the code? (p. G-7)		

147	Van Dorp	The documentation should show which information has been used for the development if the models and codes and which for validation or confidence building and benchmarking (benchmarking can be both verification (check on correctness of the calculations) and validation (check on "fit for purpose")). (p. G-4) Which information and data have been used for the development of the models and codes and which for validation or confidence building? Validation should be discussed mainly in relation with the conceptual models and verification in relation with the codes. Have codes been benchmarked against independent data? (p. G-7)		
148	Van Dorp	Although the document deals with a code, a major part is devoted to input data. In general both the code or modules of the code and the input data are insufficiently justified. (p. G-7)		
149	Van Dorp	It might be useful to document the source of the data and information: e.g. (1) generic literature, NRC/CNWRA, DOE, (2) site specific, generic, (3) peer reviewed, other quality assurance, no quality assurance. (p. G-7)		
150	Van Dorp	Example of coupling which does not appear to be accounted for in the TPA Code: correlation of dripping model (EBSREL) and corrosion model; reflux would cause dripping => increased corrosion although relative humidity is still low. (p. G-7)		
151	Van Dorp	Example of coupling which does not appear to be accounted for in the TPA Code: increased ventilation will increase salt content of solution which might enter drift during or after ventilation => increased corrosion. (p. G-7)		
152	Van Dorp	Example of coupling which does not appear to be accounted for in the TPA Code: correlation of corrosion and mechanical failure model. (p. G-8)		
153	Van Dorp	Example of coupling which does not appear to be accounted for in the TPA Code: reactivation of faults by thermal stresses. (p. G-8)		
154	Van Dorp	Example of coupling which does not appear to be accounted for in the TPA Code: correlation of water fluxes with thermal, chemical and mechanical processes. (p. G-8)		

155	Van Dorp	Example of coupling which does not appear to be accounted for in the TPA Code: correlation of seismicity and rockfall. (p. G-8) Why has a combination of container thickness reduced by corrosion and rockfall has not been considered in the seismic failure criterion? (p. G-13)		
156	Van Dorp	Example of coupling which does not appear to be accounted for in the TPA Code: interaction between materials on corrosion potentials, (re)passivation potentials and localised corrosion. (p. G-8)		
157	Van Dorp	Example of coupling which does not appear to be accounted for in the TPA Code: correlation of Kd's in the different environments (engineered barrier system, unsaturated zone, saturated fractured zone, saturated alluvium, biosphere), because of the chemical properties of elements in chemically different environments. (p. G-8)		
158	Van Dorp	Example of coupling which does not appear to be accounted for in the TPA Code: igneous release: correlation of the assumption that ash might be transported in different directions (not only towards the critical group as is assumed at present) and that the waste might not be homogeneously distributed in the ash (giving thinner layers with higher concentrations). (p. G-8)		
159	Van Dorp	Not clear whether transport of colloids formed when radionuclides are released form the waste or during radionuclide transport in the engineered barrier system, through the unsaturated zone and through the saturated zone in included in the TPA Code (p. G-8)		
160	Van Dorp	Not clear whether effects of collapsed drifts on the infiltration into the drifts and into the waste packages are included in the TPA Code (p. G-8)		
161	Van Dorp	Not clear whether effects of welds in waste packages on corrosion and mechanical stability. (p. G-8)		

162	Van Dorp	The code should be able to evaluate the consequences of the maximum radionuclide release by groundwater beyond 10,000 years (p. G-8) Many of the results depend strongly on the time of interest. Regulators and regulations in other countries require that consequences are calculated until the peak(s) have been reached. Experience shows that peaks often appear long after 50,000 years, in particular in the more realistic scenarios and calculations. (p. G-18)		
163	Van Dorp	I would recommend to calculate also consequences of other release scenarios, both natural and "human induced", e.g. (1) for a release by groundwater in Death Valley, which is the location for release if the water is not abstracted by wells, and (2) for a release by free flowing wells in Amargosa Valley, if the groundwater table is higher than at present due to a climate with more rainfall. (p. G-9)		
164	Van Dorp	It is important to have rigorous and documented criteria for the selection of radionuclides to be included in an assessment. (p. G-11)		
165	Van Dorp	Why does the Cm-244 chain stop at Th-232? (p. G-11)		
166	Van Dorp	Justification why conceptualisations were chosen should be documented. (p. G-12) It is very important that reasons and evidence for the choice of the conceptual models are given. (p. G-14)		
167	Van Dorp	Runoff might tend to reduce infiltration if the water leaves the considered area. However local runoff might concentrate the water in small depressions where it then might infiltrate into a fracture; evapotranspiration might in such a case be less than expected. (p. G-12)		
168	Van Dorp	Several geological units are discussed. To judge the whether the assumptions for deeper infiltration are justified, one needs more information about these geological units than is given in the geological description of the site. (p. G-12)		

169	Van Dorp	What would be the effect of backfill? This conceptual model differs considerably from the conceptual model(s) in section 4.2.3.1; has it been shown that these differences do not cause inconsistencies? (p. G-12)		
170	Van Dorp	Page 4-48 and 49: Bullet points: other approaches might be possible: e.g. (1) determine a minimal thickness required for mechanical stability or integrity of the canister, (2) calculate corrosion rates, (3) assume that a canister fails if the minimal thickness required for mechanical integrity is reached. (p. G-13)		
171	Van Dorp	The assumption that the seismic acceleration at the repository level is half that at ground surface seems, for non specialists, a rough assumption in view of the many other seemingly more refined assumptions. (p. G-13)		
172	Van Dorp	An increased release rate for the "gap inventory" is not mentioned. (p. G-13)		
173	Van Dorp	The statement that doses form gaseous releases are negligible should be documented here or in a reference. (p. G-14)		
174	Van Dorp	That chain decay can be neglected for transport in the invert should be demonstrated and documented. (p. G-14)		
175	Van Dorp	Has the fracture flow model been benchmarked against other fracture flow models (with and without matrix diffusion)? (p. G-14)		
176	Van Dorp	Another potential model for UZ transport is fractures with infill might exist, radionuclides could sorb on the infill material. Radionuclides could move by diffusion between the solute flowing through the fracture and the more or less stagnant flow in the matrix ("matrix diffusion"), (see also section on NEFTRAN II). The flow through the fractures might be so fast that matrix diffusion would be negligible. (p. G-14)		
177	Van Dorp	If no retardation is assumed in the fracture flow systems, colloids would not enhance the radionuclide transport.		

178	Van Dorp	Porosity and travel times: although the determination of porosity seems to be straight forward, the determination of the relevant flow porosity is very uncertain, and may depend on the water velocity. Therefore the calculation of travel times is subject to large uncertainties. (p. G-14)		
179	Van Dorp	Have fracture flow models been considered for the flow path before the alluvium? (p. G-14)		
180	Van Dorp	Paragraph beginning with NEFTRAN II: if matrix diffusion is taken into account, the choice of parameters need to be carefully discussed and justified based on the/a conceptual model of the aquifer or stream tube. Has the model been validated or benchmarked, for matrix diffusion. (p. G-15)		
181	Van Dorp	Dilution of the radionuclide concentration as well as the fraction of the total radioactivity in the groundwater extracted by the wells depends strongly on the definition of the critical group, which is given by the proposed 10 CFR PART 63. Has a sensitivity analysis been carried out, although given 10 CFR PART 63 this would not be required? (p. G-15)		
182	Van Dorp	What period is assumed for accumulation of radionuclides in soil by irrigation? One of the aims of irrigation, besides providing sufficient water for crop growth, is to enable long-term irrigation without the accumulation of salts in the root zone in a sustainable agricultural system. (p. G-15)		
183	Van Dorp	Page 4-93, Figure 4-17: the inhalation dose might also depend on the duration. (p. G-15)		
184	Van Dorp	Children and infants are not considered. I agree because uncertainties are larger than the effect of including children and infants, however, reasons should be given in the report. (p. G-16)		
185	Van Dorp	Why so much weight on what is permitted by local authorities. These rules might change, people might not obey the rules, and anyhow releases would take place, when the rules will have been forgotten. (p. G-16)		
186	Van Dorp	Ingestion of soil or dust is neglected? (p. G-16)		

187	Van Dorp	How is Quality Assurance documented? (p. G-17)		
188	Van Dorp	How is it assured that the interaction of the KTIs and the TPA does not cause potentially relevant Features, Events and Processes to be omitted or forgotten. (p. G-18)		

[1] Catalog of action plan items is still under development. This table represents the status as of February 29, 2000.