October 9, 1999

Mr. Dwight Shelor, Acting Director
Program Management and Administration
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

SUBJECT: SUMMARY OF TOTAL SYSTEM PERFORMANCE ASSESSMENTS FOR YUCCA MOUNTAIN TECHNICAL EXCHANGE, MAY 25 - 27, 1999

Dear Mr. Shelor:

Enclosed is the summary of the Total System Performance Assessments for the Yucca Mountain Technical Exchange, held May 25 - 27, 1999, between the staff of the U.S. Nuclear Regulatory Commission (NRC) and representatives of the U.S. Department of Energy (DOE). The summary consists of the meeting minutes, the agenda (Attachment 1), the list of attendees (Attachment 2), and the presentation materials (Attachments 3-39). This interaction was a video conference between NRC headquarters in Rockville, Maryland; DOE's office in Las Vegas, Nevada; and the Center for Nuclear Waste Regulatory Analyses in San Antonio, Texas. The meeting was also attended by representatives of the State of Nevada, Nye and Clark Counties, Nevada, DOE contractors, and NRC contractors.

If you have any questions regarding this letter, please contact Christiana Lui of my staff. She can be reached at (301) 415-6200.

Sincerely,

[Original signed by:]
C. William Reamer, Chief
High-Level Waste and Performance
Assessment Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: As stated
cc: See attached list

DISTRIBUTION w/ Att. 1-39: File Center, DWM r/f, NMSSr/f, ACNW, HLWB r/f, CNWRA, OSR, OCA, OPA

DISTRIBUTION w/ Att. 1-2: JGreeves, JHolonich, NStablein, DBrooks, SWastler, JPohle, MNataraja, BLeslie, JBradbury, JDavis, JTrapp, PJustus, NColeman, JFirth, TMcCartin

DOC NAMES: S:\DWM\HLWB\CXL\te599let.wpd (letter)
S:\DWM\HLWB\CXL\Te599sum.wpd [Enclosure (minutes) & Attachments 1&2]
(Attachments 3-39 are not electronically available)

WM-11

OFC	HLWB	HLWB	HLWB			
NAME	CLui/jcg	KMcConnell	CWReamer			
DATE	9/22/99	10/8/99	10/ 9/99			

OFFICIAL RECORD COPY

NH16

ACNW: YES ✓ NO __ **Delete file after distribution: Yes ✓ No __**

1) This document should/should not be made available to the PUBLIC CL 9/22/99
(Initials) (Date)

2) This document is/is not related to the HLW program. If it is related to HLW, it should/should not be placed in the LSS. CL 9/22/99
(Initials) (Date)

99-191

PDR WASTE

MINUTES OF THE MAY 25 - 27, 1999
U.S. DEPARTMENT OF ENERGY/U.S. NUCLEAR REGULATORY COMMISSION
TECHNICAL EXCHANGE ON TOTAL SYSTEM PERFORMANCE ASSESSMENTS
FOR YUCCA MOUNTAIN, NEVADA

Introduction

On May 25 - 27, 1999, U.S. Department of Energy (DOE) and U.S. Nuclear Regulatory Commission (NRC) staff conducted a Technical Exchange (TE) to discuss NRC staff's insight on Total System Performance Assessment supporting DOE's Viability Assessment (TSPA-VA), the framework for the Yucca Mountain Review Plan (YMRP), and planned DOE approaches for Site Recommendation and beyond. The detailed agenda for this three-day meeting can be found in **Attachment 1**.

The TE was held at the Center for Nuclear Waste Regulatory Analyses (CNWRA) in San Antonio, Texas. A three-way video conference connection between CNWRA, NRC headquarters in Rockville, Maryland, and DOE's office in Las Vegas, Nevada, permitted remote participation of additional DOE and NRC staff and other interested parties. Besides staff from DOE, NRC, the CNWRA and DOE's Management and Operating (M&O) and Management and Technical Support (MTS) contractors, representatives from the State of Nevada, and Clark and Nye Counties, Nevada also attended the meeting. Members from the U.S. Nuclear Waste Technical Review Board (NWTRB) and staff from the NRC's Advisory Committee on Nuclear Waste were present, as were representatives from Electric Power Research Institute (EPRI) and Nuclear Energy Institute. **Attachment 2** contains the composite list of attendees who attended the TE at one of the three video conference locations.

TUESDAY, MAY 25, 1999

Following Wesley Patrick's (CNWRA) welcoming remarks, DOE and NRC provided opening remarks. Mark Tynan (DOE) stated that this is a critical time for the Yucca Mountain Project. DOE is now focusing on the Site Recommendation (SR), with License Application (LA) following shortly after SR. DOE was looking forward to the interaction to facilitate the preparation of TSPA-SR and a docketable LA. E. Von Tiesenhousen from Clark County stated that he found the TSPA TEs have always been very informative. Keith McConnell (NRC) in his introduction (see **Attachment 3**) clarified the objectives and limitations of this TE. He also stated that the results of analysis using NRC's Total-system Performance Assessment (TPA) version 3.2 code are preliminary, and future refinements are expected. Analyses for periods beyond 10,000 years were performed to better understand the system behavior, estimate the sensitivity of parameters, and evaluate the models in the TPA code.

NRC and CNWRA staff presented results from TPA 3.2 analyses, insights on TSPA-VA, framework for the YMRP, and a brief discussion on the defense-in-depth philosophy in the proposed 10 CFR Part 63 during the first half of this 3-day meeting. The format of NRC insights on TSPA-VA started with an overview presentation followed by discussion of selected topics in a technical area. DOE and M&O staff presented planned approaches for Site Recommendation and beyond during the second half of the 3-day meeting. The presentations are grouped by the technical areas as identified in underlined headings.

NRC Total-System Performance Assessment Code, Version 3.2 (TPA 3.2) Presentations

Attachment 4	T. McCartin (NRC), "TPA 3.2 Overview"
Attachment 5	S. Mohanty (CNWRA), "TPA 3.2 Total-System Results"
Attachment 6	R. Codell (NRC), "System-Level Sensitivity Results and Alternative Conceptual Models in TPA 3.2"

During this group of presentations, NRC provided an overview of the approaches in the TPA 3.2 code, described outputs from the TPA 3.2 code, and presented results of the sensitivity analyses. It was emphasized that use of a particular approach, model, or parameter by the NRC should not be construed as regulatory acceptance or endorsement. The results and specific numbers used in the code were just examples, and the NRC was not attempting to develop the licensing case for the DOE.

It was noted that although some of the approaches, e.g., dilution factors, used by NRC were different from those used by DOE, TPA 3.2 code is sufficiently flexible to effectively evaluate the DOE models. It was also noted that the different approaches being used by NRC, DOE, and EPRI provided similar outcomes.

Due to the minimal impacts on performance (in microrems), questions were raised regarding the need for further TPA model refinement. NRC indicated that additional work is needed to improve the rigor of analyses and implement a risk-informed and performance-based review approach. Since results of sensitivity studies pointed out the relative importance of subsystems and possible errors or weaknesses in analyses, NRC plans to use the insights gained from the sensitivity studies to concentrate on those areas that contribute most to risk.

NRC is working on documenting the results using the TPA 3.2 code. Results using the TPA 3.1.4 code have been published, and the TPA 3.1.4 code description would be published shortly in a NUREG report.

NRC Insights on Presentation of Performance Assessment (PA) Results

Attachment 7 J. Weldy (CNWRA), "NRC Insights on Presentation of PA Results"

During discussions on the topics of transparency and traceability, including areas where the VA could have been improved, it was pointed out that the ability to trace information between documents, and to know which parameters are important and require further investigation, is critical to ensure the correctness and understandability of DOE's analyses. It was also pointed out that TSPA-VA probably provides the right level of detail for a possible Yucca Mountain LA, but needs to add a discussion on what is important to performance. The presentations to follow provided an indication on whether TSPA-VA was sufficiently transparent and traceable, such that NRC was able to correctly interpret DOE's approach in its review.

NRC Insights on Design and Waste Package (WP) Failure

Attachment 8	S. Mohanty (CNWRA), "NRC Insights on Design and Waste Package Failure"
Attachment 9	N. Sridhar (CNWRA), "DOE and NRC Approaches to Model the Effects of Initial Failures of Containers"
Attachment 10	G. Cragnolino (CNWRA), "Waste Package Corrosion"

The objective of the NRC's review on WP performance was to evaluate the time of failure of WPs, the number of WPs degraded as a function of time, spatial distribution of degraded WPs in the repository, and the geometry of failure due to degradation. It was pointed out that some values presented might not have been appropriately applied in NRC's analyses (i.e., they might have been applied to stainless steel instead of Alloy C-22), and DOE offered to review NRC findings to determine how values were applied. The Issue Resolution Status Reports (IRSRs) are the appropriate documents to determine how and what values were used by NRC in the analysis. DOE indicated that it would like to have a chance to comment on NRC's findings before any significant differences become an issue in the IRSR and requested the schedule for IRSR Revision 2 production. DOE also indicated, and NRC agreed, that IRSRs and YMRP need to allow flexibility to accommodate design changes.

NRC Insights on Seepage and Release

Attachment 11	R. Codell (NRC), "NRC's Insights into Seepage and Release"
Attachment 12	T. Ahn (NRC), "Oxidative Release Models"
Attachment 13	W. Murphy (CNWRA), "Alternative Release Models"
Attachment 14	D. Hughson (CNWRA), "Near-Field Dripping and Thermal Models"

NRC compared the major differences between DOE and NRC models for seepage and release, presented selected results using the TPA code with TSPA-VA data and summarized the impact of the differences. Technical bases for the release models in TPA 3.2 were also presented. Since degradation of the drift might be an important factor for estimating dripping, the most recent work on the effect of irregularity on dripping was presented for discussion.

WEDNESDAY, MAY 26, 1999

NRC Insights on Natural System

Attachment 15	G. Wittmeyer (CNWRA), "NRC Insights on Treatment of the Natural System in TSPA-VA and Comparison with TPA 3.2"
Attachment 16	J. Winterle (CNWRA), "Groundwater Velocity in the Saturated Zone"
Attachment 17	D. Turner (CNWRA), "Geochemical Radionuclide Sorption Models for Total Performance Assessment 3.2"
Attachment 18	P. LaPlante (CNWRA), "NRC Insights on Dose Conversion Factors"

NRC compared the major differences between DOE and NRC models for infiltration and deep percolation, unsaturated zone flow and transport, saturated zone (SZ) flow and transport, and borehole dilution. Selected results using the TPA code with TSPA-VA data were presented, and the impact on performance was summarized. Technical bases for flow porosity in the SZ and geochemical sorption were discussed.

Similarities and differences in the dose conversion factors approach were described. It was noted that confirmatory calculations produce good agreements for the base case. Some differences might be due to use of default values in GENII-S. NRC noted that documentation for some important parameters and modeling choices was missing from the VA and its supporting documents and emphasized that the analyses must be adequately supported and transparent. Although it was agreed that transparency needs to be improved, the need to refine models was questioned, considering there were only microrem differences in the results. NRC stated that although doses from both the DOE and the NRC were low and the differences were small, inconsistent assumptions and data might have been used. NRC needs to understand the rationale for agreement. Bounding calculations also need to be supported by adequate technical basis.

NRC Insights on Disruptive Events and Processes

Attachment 19	J. Firth (NRC), "Disruptive Events"
Attachment 20	B. Hill (CNWRA), "Paths Forward on Igneous Activity Risk Assessments for Yucca Mountain"
Attachment 21	S. Hsiung (CNWRA), "Rockfall Abstraction Models"

NRC summarized its and DOE's modeling approach for disruptive events and processes and compared the major assumptions, parameter values and results. Current status and paths forward in igneous activity were presented for discussion. The approaches for treating rockfall were summarized and compared. NRC also pointed out a possible error in the damage level calculation in the TSPA-VA.

Yucca Mountain Review Plan and Defense-in-Depth

Attachment 22	NRC Fiscal Year (FY) 1999 IRSR Completion and Distribution Schedule (K. McConnell, NRC)
Attachment 23	C. Lui (NRC), "Framework for the Yucca Mountain Review Plan"
Attachment 24	T. McCartin (NRC), "Defense-in-Depth Philosophy in Proposed Regulations for High-Level Waste (HLW) Disposal at Yucca Mountain"

In response to some of the IRSR questions raised during the previous day, NRC clarified that insights gained from the TPA analyses would be factored into the issue resolution process as practicable, i.e., without impacting the established FY1999 IRSR production schedule. The FY1999 IRSR completion and distribution schedule was provided to the meeting participants.

NRC presented the concept behind the development of the YMRP, including the relationship of the YMRP contents to the content of 10 CFR Part 63. Portions of §63.21 will be rearranged, consolidated, or moved to Subpart E. NRC does not intend to issue a separate format and content regulatory guide for the Safety Analysis Report, and plans to give a sufficient level of information in the YMRP to address format and content. The framework of YMRP is designed to provide sufficient flexibility to accommodate uncertainties in the regulatory process. NRC also stated that all acceptance criteria and review methods currently contained in the IRSRs would be moved into the YMRP starting in FY2000. However, the status of issue resolution will continue to be documented in the IRSRs. It was noted that the risk-informed and performance-based integrated approach adopted in the YMRP would enable NRC to identify those potentially overly prescriptive acceptance criteria currently in the IRSRs. Those acceptance criteria will be appropriately modified for the YMRP. NRC would welcome feedback from DOE and any other interested parties on the IRSRs on a timely basis.

NRC discussed the definition of Defense in Depth (DID), postclosure repository performance objectives, Part 63 requirements for multiple barriers, and the use of quantitative approaches, emphasizing that NRC is not prescribing a specific approach. Barriers were not considered totally redundant, nor was there any specification of independence of barriers. Questions on the meaning of "sufficiency" of data would be judged in the context of the total system performance and specified in the YMRP. The Statement of Consideration of Part 63 will be reviewed to address the issue of potential common-mode failure of the barriers.

DOE Path Forward

Attachment 25 L. Rickertsen (M&O), "VA Results from Importance (DID) Analysis"

DOE addressed the potential issues identified by NRC previously, including: (1) potential differences in concepts for neutralization and importance analysis; (2) potential differences in how TSPA codes and models are used to represent the system; and, (3) the desirability of resolving issues with importance analysis well in advance of licensing. Key differences between the DOE and NRC codes were discussed.

Attachment 26 R. Howard (M&O), "Reference Design for Site Recommendation"

DOE reviewed the site recommendation reference design including thermal goals, rationale, design features, mass loading and footprint design, drift layout, WP design, and thermal management. Dan Bullen (NWTRB) asked whether cladding credit was taken and, if not, if any other credit was taken instead. DOE noted that many options were still being considered. DOE also indicated that once selected, the SR design is unlikely to change drastically for the LA, because of the short time span between SR and LA.

DOE Strategy for the Postclosure Safety Case

Attachment 27 A. VanLuik (DOE), "Overview of DOE's Strategy for the Postclosure Safety Case"
Attachment 28 D. Richardson (M&O), "Implementing DOE's Strategy for the Postclosure Safety Case"
Attachment 29 M. Lugo (M&O), "Process Models Reports (PMRs)"
Attachment 30 L. Rickertsen (M&O), "Implementing the DOE Strategy - the Path Forward"

DOE described the steps needed to complete the postclosure safety case. Various design options were still being considered. Because the design is changing, the principal factors for the safety case will also change, although the attributes of the Repository Safety Strategy will stay the same. Because of the long projected WP lifetime, ranking of the principal factors will mostly be based on 100,000-year calculations. DOE will use 9 PMRs to document the technical basis supporting each TSPA process model, and presented the roles and responsibilities for PMR development. Level of the technical support information will be commensurate with the level of importance to performance. NRC raised questions regarding integration of the PMRs. DOE responded that integrated teams had been assembled and that the final product would be transparent.

THURSDAY, MAY 27, 1999

DOE Presentations

Attachment 31 A. VanLuik (DOE), "Overview of Major Site Recommendations, Environmental Impact Statements, and License Application Milestones and Schedule"

DOE presented a general overview of major programmatic milestones for Site Recommendation, Environmental Impact Statement (EIS), and License Application (LA), and noted that primary information feeds to TSPA-SR Rev. 00 must take place by August 1999. DOE also indicated that the results of the drift-scale heater test will be available during performance confirmation.

Attachment 32 R. Andrews (M&O), "Overview of Total Systems Performance Assessment-Site Recommendation (TSPA-SR) and Total Systems Performance Assessment-License Application (TSPA-LA) Strategy"

DOE provided an overview of the major TSPA-SR drivers, the philosophy and scope of TSPA-SR iterations, and the TSPA-SR schedule. It was noted that PMRs would be fully qualified or would be labeled as "TBVs" (To Be Verified) for the SR.

Attachment 33 H. Dockery (SNL), "DOE Response to NRC's Total System Performance Assessment and Integration Issue Resolution Status Report"

DOE provided a brief overview of the purpose, scope, and format of Total System Performance Assessment and Integration (TSPAI) IRSR, and provided specific comments on the report. Apparent inconsistencies in language between the IRSR and Part 63, with respect to descriptions of "features, events, and processes," were discussed. NRC stated that the terms and phrases were used intentionally. DOE suggested additional explanation might be warranted in order to avoid confusion.

Attachment 34 J. McNeish (M&O), "TSPA-SR: Methods/Assumptions Overview"

DOE's TSPA-SR Methods and Assumptions document strategy was discussed, including defining the IRSR linkage, the analysis approach, and the types of results. The IRSR Acceptance Criteria Database that tracks resolution status and activities for DOE was described. NRC pointed out that DOE would need to be aware of changes in NRC 's treatment of acceptance criteria to reflect the risk-informed and performance-based approach for the YMRP. NRC also pointed out that the key technical issues (KTIs) will continue to exist, but the existing acceptance criteria and review methods under the KTI subissues in the IRSRs will be subsumed into the integrated subissue structure in the YMRP starting FY2000.

Attachment 35 G. Freeze (M&O), "Current Status of Feature, Event, and Process (FEPs) Screening and Scenario Selection for the Total System Performance Assessment-Site Recommendation"

An overview of scenario development and screening FEPs was provided, including a description of the FEPs database. The criteria for screening are on both probability and consequence, and FEPs may also be categorically excluded or screened out. NRC questioned how uncertainty is accounted for in the screening process. DOE replied that as many FEPs were being included as possible in order to have a defensible argument. J. Kessler of EPRI stressed that DOE needs to do a good job on documenting the FEP selection and screening process and consider combination of FEPs that might have an impact on performance. Regarding the issue of criticality, it is expected that the ongoing technical work would allow DOE to screen out far-field criticality based on low probability and in-package criticality based on a low consequence argument for the proposed compliance time period of 10,000 years.

Attachment 36 M. Wilson (SNL), "Natural-System Models for Total System Performance Assessment-Site Recommendation"

DOE described changes in the natural system models from TSPA-VA to TSPA-SR. In anticipation to address groundwater protection, DOE has implemented a module in the RIP code capable of outputting concentration at various locations.

Attachment 37 S. D. Sevougian (M&O), "Treatment of Engineered Barriers in TSPA-SR"

DOE described changes in the engineered barrier system models from TSPA-VA to TSPA-SR. NRC asked if DOE would model early WP failures (considering the high number of manufactured products). DOE replied that if early WP failures were modeled, this would still be a very low number. NRC indicated that DOE needs to rigorously defend its treatment of early WP failure in future TSPAs. DOE agreed and stated this is being done. DOE also indicated that testing on the drip shield is currently ongoing at Lawrence Livermore National Laboratory.

Attachment 38 V. Vallikat (M&O), "Control and Traceability of Analyses"

DOE laid out a process to keep the PA analyses transparent, traceable and manageable. The supporting information (data and models) for TSPA, including quality assurance (QA) status, will reside in the Technical Database Management System (TDMS). Improvements are being introduced to the RIP code to enhance its capabilities and facilitate a better user interface.

Attachment 39 J. McNeish (M&O), "Human Intrusion Analyses for Future TSPAs"

DOE presented 3 possible scenarios to meet the human intrusion requirements in the proposed 10 CFR Part 63 for comment. NRC encouraged DOE, and any other interested parties, to submit comments during the public comment period. Clark County commented that the three scenarios proposed by DOE are not mutually exclusive.

Feedback

After the completion of the presentations and a caucus period, the meeting resumed. The NRC provided the following comments:

1. NRC viewed DOE's institutional awareness of nuclear culture, such as devising and vigorously implementing a QA program, as a very positive step towards producing a high quality license application.

2. TSPA-VA was a significant improvement over the previous TSPAs and has made progress towards producing a transparent and traceable set of documents. Future TSPAs should continue on improving the transparency and traceability.

3. DOE's attempt to explicitly address acceptance criteria in the IRSRs would facilitate NRC's review of DOE's products.

4. DOE should reach closure on design as quickly as possible and keep NRC informed to facilitate the development of a NRC review strategy.

5. It was not clear how much information will be available at SR and LA, respectively. It was also not clear what information DOE intends to collect during the performance confirmation period.

6. NRC is moving towards an integrated approach for YMRP. DOE's approach on PMRs and AMRs seemed to be moving in the opposite direction.

7. How NRC judges sufficiency will be in the YMRP. It will be risk-informed and performance-based.

8. Regarding human intrusion, DOE and all other parties were encouraged to submit comments on all aspects of the proposed Part 63.

9. In addition to the insights highlighted during this TE, more VA comments of lesser significance would be in NRC's Rev. 2 IRSRs.

After NRC, DOE offered the following comments:

1. TSPA interactions have always been very useful. They are the most successful DOE/NRC interactions.

2. Insights gained on using the TPA code to model the TSPA-VA were helpful in understanding the similarities and differences.

3. DOE appreciated that NRC viewed TSPA-VA positively and has noted areas where improvements are needed. DOE also understood that it will need to provide a technical basis adequate to support the safety case.

4. DOE viewed the re-evaluation of acceptance criteria and IRSRs, in the context of TSPA, as a very positive development.

5. The PMRs were designed to provide traceability. DOE will make sure the use of PMRs does not lead to disintegration.

6. DOE was interested in finding out NRC's plan on the TPA results and TSPA-VA comparison. DOE thought that spending resources documenting the comparison is not productive, because DOE has moved forward and is in the process of significantly revising some of the approaches, e.g., design, taken in VA.

7. DOE's safety case will likely evolve, as more work is done for SR and LA.

8. DOE was encouraged by NRC's risk-informed and performance-based regulatory approach. However, DOE was unclear whether this approach would be applied to all issues, especially those resulting in changes in the microrem dose range.

9. Because the series of interactions led to receiving timely feedback and an efficient review of TSPA-VA, DOE proposed to hold interactions with NRC to discuss the work supporting the SR at each key stage during the preparation for the SR.

Closing Remarks

Throughout the TE, NRC stressed that VA is not a licensing document, and comments, presentations, and observations on the VA do not necessarily apply to licensing. DOE is responsible for developing a licensing case that will stand on its own merits. NRC is responsible for reviewing the licensing case and determining its acceptability. DOE emphasized that it pays attention to the IRSRs and is encouraged to see NRC moving towards a risk-informed and performance-based integrated approach. Stability of the YMRP will be beneficial to the program and provide further guidance on a potential LA in 2002.

NRC noted on several occasions that the design should be finalized as soon as possible so that NRC can focus its review and DOE can develop better technical bases. It was noted that there is still uncertainty regarding final DOE WP designs and other EBS features, as well as material selection for containers. It was also noted that better technical bases were needed for DOE's approaches to modeling the effects of initial failures of containers and NRC's evaluation. A decision on the final design is expected at the end of June 1999. DOE indicated that the NRC will receive a copy of the report documenting this decision when it becomes available.

NRC was concerned about traceability of information. Several presentations alluded to the difficulty of determining where information or values were derived or how they were used in calculations. A "road map" is needed to trace information between TSPA-related documents and to know which parameters are important and which parameters were used in calculations. This information should be a part of the TSPA documentation and should be readily available for reviewers. In particular, NRC expressed concern regarding whether the PMRs would be effectively integrated and the integration would be transparent. In addition, NRC was concerned that the use of PMRs would actually "disaggregate" rather than integrate DOE's safety case. DOE offered to discuss and clarify the content and intent of the PMRs in more detail during the planned interaction on YMRP.

It appeared that in some areas, NRC might have misinterpreted the approaches in TSPA-VA. DOE indicated that it intends to thoroughly review Revision 2 of the IRSRs and the results of the TPA calculations to ensure the correct values were used. The results of the reviews should be documented and transmitted to the NRC so that NRC can make any modifications necessary in the next iteration of IRSRs.

Regarding documenting the results of its TSPA-VA review, NRC indicated that though DOE has moved forward, it was necessary for NRC to document the basis for its comments and decisions.

In addition to the interaction on YMRP, several potential topics for future meetings were discussed, including an interaction to discuss FEPs and a demonstration of the TDMS.

The representative from Clark County offered the following comments: (1) he found the TSPA interactions have always been very informative; (2) he hoped DOE would keep up with the vigilance on QA; and (3) DOE would need to provide a detailed technical basis for juvenile failure of WPs.

The representative from Nye County offered the following comments: (1) DOE should appropriately consider and address repository ventilation in its design process; (2) DOE should include a QA person from day one in the development of PMRs; and (3) DOE needs to be more responsive to the affected units of local government. He further indicated that attending DOE/NRC interactions at CNWRA was not a burden.

There was no closing remark from the State of Nevada.

The meeting adjourned at 5:30pm.

Minutes approved by:

9/15/99

Christiana H. Lui, U.S. Nuclear Regulatory Commission, Date
High-Level Waste and Performance Assessment Branch

9/15/99

Abraham Van Luik, Department of Energy, Date
YMP Senior Policy Advisor

DOE/NRC Technical Exchange on
Total System Performance Assessments (TSPA) for Yucca Mountain

May 25 - 27, 1999
8:30am - 6:00pm (CDT)

Locations:
Center for Nuclear Waste Regulatory Analyses
6220 Culebra Road, Building 189
San Antonio, Texas

DOE Summerlin I Facility (videoconference room)
Blue Room on May 25, 1999
Atrium Room on May 26, 1999
LV625 on May 27, 1999
1551 Hillshire Drive
North Las Vegas, Nevada

NRC Headquarters - Two White Flint North
11555 Rockville Pike, Room T-2B5 (videoconference room)
Rockville, Maryland

TUESDAY, MAY 25, 1999

8:30am	Opening Remarks	DOE, NRC, NV and AUG
8:45am	Introduction	DOE, NRC
9:00am	TPA 3.2 Overview NRC Total System Results Discussion	McCartin (NRC) Mohanty (CNWRA) All
10:35am	**Break**	
10:55am	NRC Sensitivity Studies Results and Alternative Conceptual Models Discussions	Codell (NRC) All
12:15pm	**Lunch**	
1:25pm	NRC Insights on Presentation of PA Results Discussion	Weldy (CNWRA) All

Attachment 1

2:00pm	NRC Insights on Design and WP Failure	Mohanty (CNWRA)
	– Initial Failure	Sridhar (CNWRA)
	– Corrosion	Cragnolino (CNWRA)
	Discussion	All
3:40pm	**Break**	
4:00pm	NRC Insights on Seepage and Release	Codell (NRC)
	– Oxidative Release Models	Ahn (NRC)
	– Alternative Release Models	Murphy (CNWRA)
	– Near-Field Dripping and Thermal Models	Hughson (CNWRA)
	Discussion	All
5:40pm	Observer Comments	
6:00pm	End of Day One	

WEDNESDAY, MAY 26, 1999

8:15am	NRC Insights on Natural System	Wittmeyer (CNWRA)
	– Groundwater Velocity in the Saturated Zone	Winterle (CNWRA)
	– Sorption Models for TPA 3.2	Turner (CNWRA)
	– Dose Conversion Factors	LaPlante (CNWRA)
	Discussion	All
9:55am	**Break**	
10:15am	NRC Insights on Disruptive Events and Processes	Firth (NRC)
	– Igneous Activity Risk Assessments	Hill (CNWRA)
	– Rockfall Abstraction Models	Hsiung (CNWRA)
	Discussion	All
11:30am	**Lunch**	
12:40pm	Framework for the Yucca Mountain Review Plan Discussion	Lui (NRC)
1:40pm	Defense-in-Depth Philosophy in Proposed Regulations for HLW Disposal at Yucca Mountain Discussion	McCartin (NRC)
2:30pm	**Break**	
2:50pm	Results from Importance Analysis Discussion	Rickertsen (M&O)

3:50pm	Reference Design for Site Recommendation	Howard (M&O)
4:20pm	DOE Strategy	
	– Overview of the Strategy	VanLuik (DOE)
	– Implementation of the Strategy	Richardson (M&O)
	– Overview of the PMR Concept	Lugo (M&O)
	– Path Forward	Rickertsen (M&O)
5:40pm	Observer Comments	
6:00pm	End of Day Two	

THURSDAY, MAY 27, 1999

8:30am	Overview of Major SR, EIS, and LA Milestones and Schedule	VanLuik (DOE)
8:50am	Overview of TSPA-SR and TSPA-LA Strategy	Andrews (M&O)
9:35am	YMP Response to NRC's TSPAI IRSR	Dockery (SNL)
10:05am	**Break**	
10:25am	TSPA-SR: Methods/Assumptions Overview	McNeish (M&O)
11:10am	Current Status of FEP Screening and Scenario Selection for TSPA-SR	Freeze (M&O)
11:45am	**Lunch**	
12:55pm	VA Modifications/Planned Updates	
	– Natural System Models for TSPA-SR	Wilson (M&O)
	– Treatment of Engineered System in SR	Sevougian (M&O)
2:25pm	Controlled Analyses/Traceability	Vallikat (M&O)
	– RIP Code Improvements	
2:55pm	Human Intrusion	McNeish (M&O)
3:25pm	Caucus	
4:30pm	Feedback	DOE, NRC
5:00pm	Closing Remarks	DOE, NRC, NV and AUG
5:30pm	Adjourn	

LIST OF ATTENDEES
AT THE DOE/NRC TECHNICAL EXCHANGE
ON TOTAL SYSTEM PERFORMANCE ASSESSMENTS
FOR YUCCA MOUNTAIN, NEVADA

May 25 - 27, 1999

Advisory Committee on Nuclear Waste (ACNW)
A. Campbell

Center for Nuclear Waste Regulatory Analyses

S. Brossia	L. Browning	A. Chowdhury	G. Cragnolino	S. Hsiung
R. Janetzke	P. LaPlante	P. Mackin	L. McKague	M. Miklas
S. Mohanty	W. Murphy	R. Pabalan	W. Patrick	O. Pensado
B. Sagar	D. Sims	N. Sridhar	J. Weldy	J. Winterle
G. Wittmeyer				

Clark County, Nevada
E. von Tiesenhausen

Electric Power Research Institute (EPRI)
J. Kessler

Naval Reactors
J. Smyder

Nuclear Energy Institute
R. McCullum

Nye County, Nevada
N. Stellavato

Sandia National Laboratories

B. Arnold	R. Baca	H. Dockery	J. Gauthier	K. Gaither
C. Ho	M. Itamura	R. MacKinnon	R. Rechard	M. Wilson

State of Nevada

L. Lehman	S. Zimmerman

U.S. Department of Energy (DOE)

A. Gil	S. Hanauer	M. Tynan	A. Van Luik	A. Wikjord

DOE Management and Operating (M&O) Contractor

R. Andrews	G. Freeze	P. Gaillard	J. Houseworth	R. Howard
J. Lee	M. Lugo	S. Mishra	J. McNeish	D. Richardson
L. Rickertsen	W. Robinette	G. Saulnier	D. Sevougian	A. J. Smith
M. Scott	V. Vallikat			

Attachment 2

DOE Management and Technical Support (MTS) Contractor

R. Gamble	B. Mukhopadhyay	W. M. Nutt	J. York	E. Zwahlen

U.S. Nuclear Regulatory Commission

T. Ahn	J. Bradbury	D. Brooks	K. Chang	J. Ciocco
R. Codell	W. Dam	N. Eisenberg	J. Firth	C. Greene
J. Greeves	L. Hamdan	A. Ibrahim	R. Johnson	B. Leslie
C. Lui	T. McCartin	K. McConnell	M. Rahimi	C. W. Reamer
J. Trapp	S. Wastler			

U.S. Nuclear Waste Technical Review Board (NWTRB)

D. Bullen	L. Reiter	J. Wong

Winston & Strawn

S. Echols

NRC PERSPECTIVE ON THE OBJECTIVES AND LIMITATIONS FOR THE TECHNICAL EXCHANGE ON TOTAL SYSTEM PERFORMANCE ASSESSMENT

May 25-27, 1999
NRC/DOE Technical Exchange on Total System Performance Assessment
Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

Keith I. McConnell, Section Chief
301/415-7289 - KIM@nrc.gov
Division of Waste Management
High-Level Waste and Performance Assessment Branch

Attachment 3

OBJECTIVES AND LIMITATIONS OF TECHNICAL EXCHANGE

OBJECTIVES:

- Use VA review results to continue progress towards issue resolution (i.e., no more questions at this time)
  - We have used the review of the VA to evaluate our TPA code and improve our capability for resolving issues in a risk-informed manner (i.e., through focused reviews) in anticipation of our review of a possible license application.

- Compare and contrast NRC TSPA-VA review results and DOE TSPA-VA approaches to identify areas of agreement and difference
  - We have attempted to identify key performance issues
  - We have attempted to identify areas of agreement and disagreement
  - We have attempted to identify measures to reach closure (action items)

- Provide DOE and others with our proposed approach to development of the Yucca Mountain Review Plan (YMRP)
  - We hope to use the discussion at this TE to expedite and facilitate development
  - Our Approach is preliminary, focused on postclosure, and believed to be performance-based. We are seeking input on all aspects of a YMRP.

- Provide DOE and others with our approach to Defense-in-Depth (DID) as intended in the proposed 10 CFR Part 63
  - At the direction of the Commission, we are currently working on a plan to clarify DID as it relates to the repository program
  - This plan will be submitted to the Commission on June 18 and we intend to brief the ACNW on the plan at its June meeting.

- Begin the dialog on TSPA-Site Recommendation

LIMITATIONS:

- NRC recognizes the evolving nature of DOE's TSPAs
- NRC's presentations on its TPA 3.2 code, sensitivity studies, and detailed review results are preliminary and refinement is continuing (Major Issues to be transmitted to DOE via letter)
  - Detailed results provided are still under development and are preliminary in nature
  - Results presented here and in the Letter to DOE will be supplemented by information in revision 2 of the KTI IRSRs (Radionuclide Transport KTI IRSR would be Rev. 1)
- Analyses presented by NRC staff for time periods beyond 10,000 years are performed for the purposes of better defining the sensitivity of parameters and evaluating the models in the TPA 3.2 code.
- Conclusions from the review of and comments on the TSPA-VA do not constitute a staff judgment on DOE's ability to fulfill the requirements in the proposed 10 CFR Part 63

TPA 3.2 OVERVIEW

May 25, 1999
DOE/NRC Technical Exchange on
Total System Performance Assessment for Yucca Mountain

Tim McCartin
(tjm3@nrc.gov)
(301) 415-6681
Division of Waste Management
Performance Assessment and HLW Integration Branch

Attachment 4

TPA 3.2 APPROACH

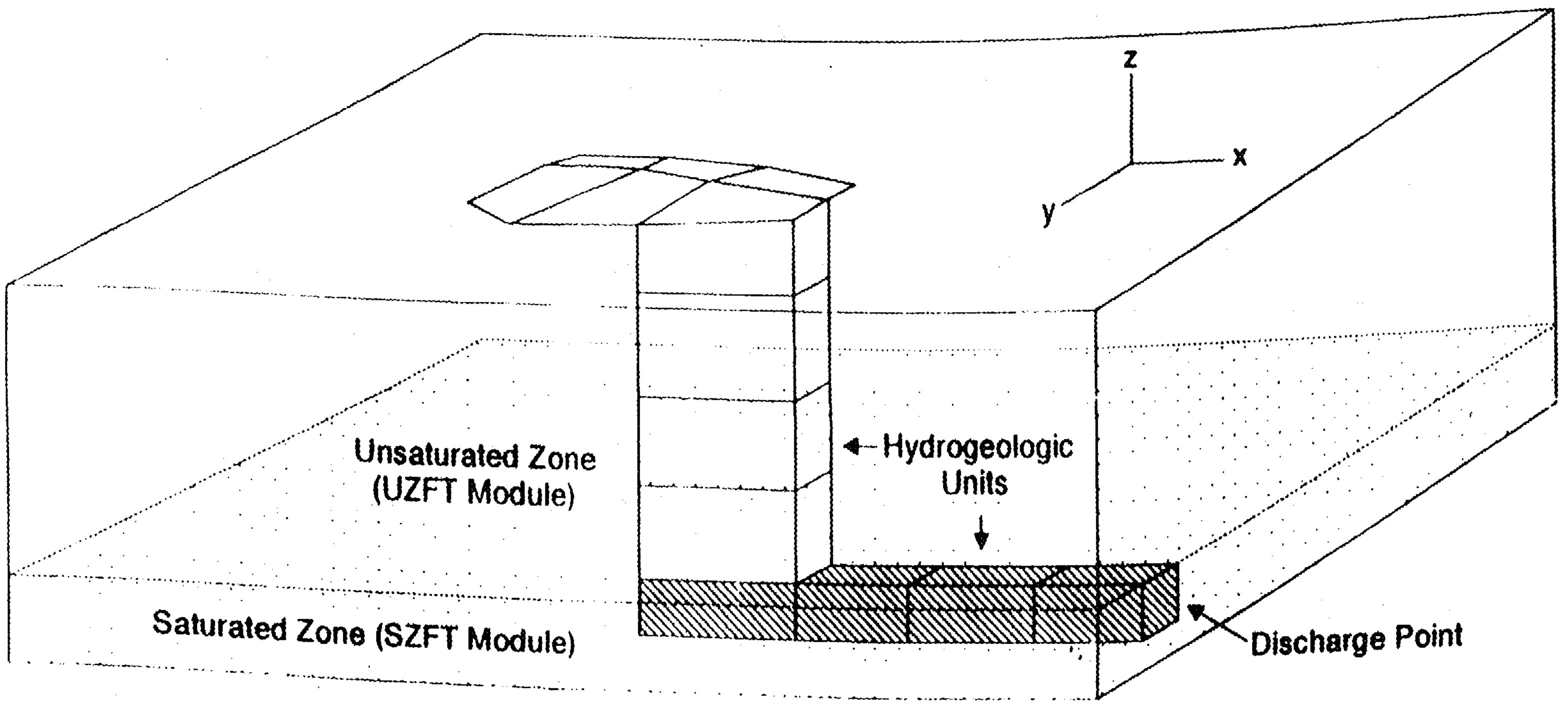
- **TPA 3.2, as part of NRC's Iterative Performance Assessment Program, was developed to provide insights on overall performance and assist reviews of DOE's TSPA**
  - provides a capability/tool with flexibility to consider a variety of concepts and models
  - use of conservative model or data range may be used, as appropriate, to limit the need for further development

- **Site information (including laboratory experiments and information from analogous environments) and results from detailed process models support PA abstractions**

NOTE: Use of a particular approach, model, or parameter in TPA 3.2 should NOT be construed as regulatory acceptance

CAUTION: INSIGHTS AND ASSERTIONS ARE PRELIMINARY
- PARAMETER AND MODEL REFINEMENT IS CONTINUING
- PRELIMINARY OUTPUTS BASED ON LIMITED ANALYSIS

Depiction of One-Dimensional Transport Paths
(Unsaturated and Saturated Zones)



PHYSICAL DESCRIPTION

- **Repository divided into 7 subareas (not limited to seven)**
  - variation in unsaturated zone stratigraphy
  - variation in deep percolation (assumes vertical flow)
  - variation in temperature and humidity

- **Representative waste packages evaluated for each subarea**
  - degradation of waste package
  - distinct failure (i.e., bathtub height) for the various failure modes (e.g., corrosion, rockfall, etc.) - TPA 3.2 improvement
  - release of radionuclides
  - inclusion of invert - TPA 3.2 improvement

- **Four saturated zone stream tubes**
  - two properties considered (fractured tuff, and alluvium)
  - correlation of Kd for chemically similar radionuclides - TPA 3.2 improvement

TPA 3.2 Code Description

1) **Amount and Distribution of Deep Percolation**
   (How much water enters repository drifts?)

2) **Waste Package Degradation**
   (When and what type)

3) **Radionuclide Release**
   (At what rate do radionuclides leave the EBS?)

4) **Unsaturated Zone Transport**
   (At what rate do radionuclides enter the saturated zone?)

5) **Saturated Zone Transport**
   (At what rate do radionuclides arrive at the receptor location?)

6) **Direct Release (volcanic event)**
   (What amount of radionuclides are released by extrusive component to the receptor location)

7) **Dose Calculation**
   (What is the dose at the receptor location?)

AMOUNT AND DISTRIBUTION OF DEEP PERCOLATION

- **Initial Infiltration Varies Between 1 and 10 mm/yr**

- **Temperature and Precipitation Affect Future Infiltration Estimates**
  - Precipitation Increase varies between 1.5 and 2.5 times present value (at glacial maximum, ~45,000 years)
  - Temperature decrease varies between 10 and 5 °C cooler than present (at glacial maximum, ~45,000 years)
  - no consideration of run-off and transpiration

- **Reflux of Water**
  - refluxing water can be sufficient to penetrate the boiling isotherm (lifetime of container minimizes effect on performance when drips do not affect corrosion rate)

- **Distribution of Deep Percolation**
  - affects number of waste packages that get wet (on average 50% of WPs are dripped on)

Waste Package Degradation

- **Waste package corrosion**
  (temperature, humidity and water chemistry at surface of waste package)
  - representative container in a subarea used in determining corrosion of container
  - average failure time of 20,000 years (range of 10,000 - 50,000 yrs)

- **Mechanical disruption of waste package**
  - fracture of the outer overpack due to thermal embrittlement
  - direct disruption due to faulting and igneous activity
  - rupture due to rock falls induced by seismicity

- **Initially Failed Packages**
  - average of 32 waste packages assumed defective

WP Failure due to Faulting and Seismicity (rockfall)

- **Fault occurs once over 10,000 years**
  - 30 WPs fail (average over 1,000 vectors)
  - annual probability 5×10^{-6}

- **Seismically induced Rockfall**
  - four distinct time periods
    (0 - 2000; 2000 - 5000; 5000 - 10,000; >10,000)
  - fractional area affected varies with magnitude of acceleration
  - WP failures in four time periods are: 0.2; 0.3; 0.7; and 1.2
    (average over 1,000 vectors)

Radionuclide Release

- **Amount of Water Contacting Waste**
  - convergence/divergence of deep percolation (0.01 - 3.0)
  - diversion of water in and around drifts and into WP pits

- **Radionuclide release rates**
  - congruent dissolution of spent fuel with surface area calculation
  - user supplied release rate
  - release rate that considers formation of secondary minerals

- **Surface area of waste form contacted by water**
  - Bath tub conceptual model
  - options for cladding credit and flow-through model

UNSATURATED ZONE TRANSPORT

- **Transport will be vertical from the repository to the water table**

- **Unit hydrologic properties and deep percolation used to determine fracture versus matrix flow**
  - Topopah Springs (welded) primarily fracture flow
  - Calico Hills (non-welded, zeolitic) primarily fracture flow
  - Calico Hills (non-welded, vitric) primarily matrix flow (Only present in 2 of 7 subareas)

- **Retardation in fractures**
  - matrix diffusion and sorption on fracture surfaces not considered significant

UNSATURATED ZONE

STRATIGRAPHIC LAYERS AND THICKNESS (m)

Subarea	TSw	CHv	CHz	PP	UCFz	BF	Distance to WT
SA #1	33	---	163	34	67	---	297
SA #2	116	---	154	39	20	---	329
SA # 3	20	---	122	40	158	---	340
SA #4	110	---	132	34	57	---	333
SA #5	20	113	---	38	158	32	361
SA #6	53	125	---	26	136	---	340
SA #7	121	---	114	43	63	---	341

SATURATED ZONE TRANSPORT

- **Four flow paths (repository footprint to receptor location)**
  - initially in fractured tuff (~13 km)
  - alluvium at receptor location (~8 km)
- Fractured Tuff
  - transport only in fractures
  - fracture velocities vary between 50 and 500 m/yr
- **Alluvium**
  - porous flow with retardation
  - alluvium velocities vary between 3 and 5 m/yr
  - Retardation Factors

    Np-237, Loguniform Distribution: [1.0, 3900.]

    Tc-99, Loguniform Distribution: [1.0, 30.]

    I-129, Loguniform Distribution: [1.0., 4.0]

DIRECT RELEASE
Volcanic Event (extrusive component)

- **Entrainment of spent fuel in ash**
  - number of containers intercepted by volcanic conduit (1 to 10 waste packages)
  - incorporation ratio of spent fuel into volcanic ash

- **Air transport of ash**
  - deposition and particle size at receptor location based on wind speed and direction, and eruption energetics

- **Time of event and time of dose**
  - dose decreases significantly with time of event (decay of relatively short-lived radionuclides; e.g., Am-241)
  - dose decreases with length of time between occurrence of event and exposure (decay of radionuclides and erosion of ash blanket)

DOSE CALCULATION

- **Dilution of radionuclides in groundwater**
  - pumping well characteristics and water use
  - pumping rate, Uniform Dist.: [4.5e6,1.3e7] gal/day

- **Dilution of radionuclides in soil**
  (direct release to surface from volcanism)
  - erosion of ash blanket (blanket remains for ~1000 years)

- **Dose conversion factors**
  - lifestyle (time spent outdoors for direct and inhalation doses)
  - diet of locally grown food
  - representative person (mean values) used in dose estimates

EXPECTED ANNUAL DOSE

- **Consequence calculation includes parameter uncertainty in dose estimate**
  - Monte Carlo sampling

- **Consequence is time dependent**
  - early disruptive events have greater impact
    (Shorter lived radionuclides have potential to cause exposure)
  - dose from direct release varies with the length between the release and the exposure

- **Expected dose combines the variation in consequence and probability**

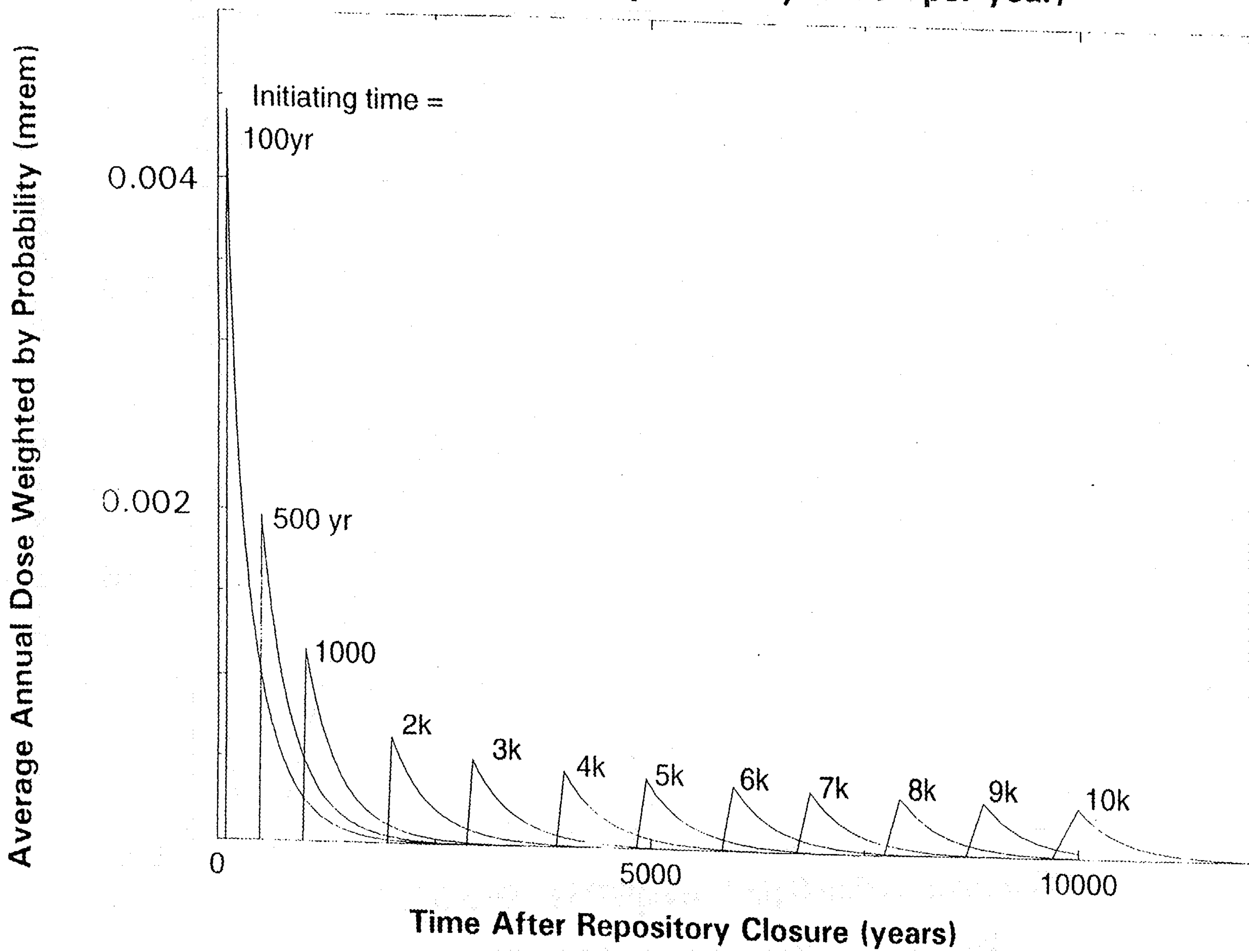
$$R(t) = \sum_{n=1}^{E} \Delta T \cdot p \cdot D_n(t)$$

where:

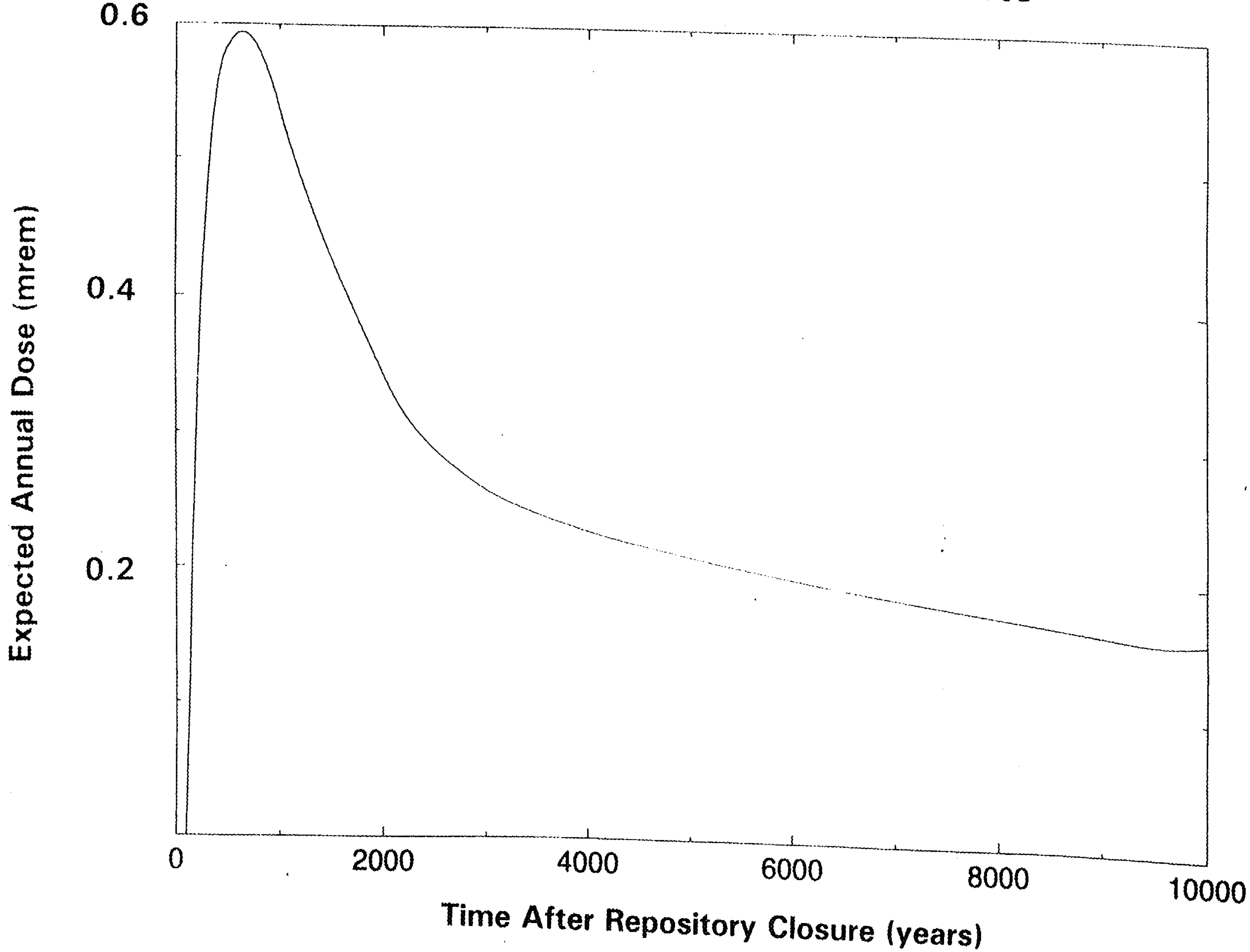
R(t)	=	**expected annual dose at time t**
ΔT	=	**increment of time associated with event n**
p	=	**annual probability for event n**
D_n	=	**average annual dose for event n at time t**
E	=	**number of events**

Average Annual Dose Weighted by Annual Probability for extrusive volcanic events at specific years

(annual event probability is 10^{-7} per year)



Expected Annual Dose for extrusive volcanic events



DOE/NRC Tech. Ex. (May 25, 1999)

COMPONENTS OF TOTAL SYSTEM ANALYSIS

SCENARIO CLASSES

- Base Case
  - Undisturbed (present day conditions) + Climate Change (precipitation history) + Seismicity (effects of rockfall on WP failure)
- Base Case + Volcanism
- Base Case + Faulting

SYSTEM LEVEL SENSITIVITY ANALYSES

- Base Case
  - Alternative Conceptual Models
  - VA Comparisons
  - parameter sensitivity
- Disruptive Scenarios
  - parameter sensitivity

Scope of Sensitivity Analyses

TPA 3.2 Provides Flexibility for UNDERSTANDING Performance in the context of different modeling approaches for representing YM

- Variety of statistical methods for examining parameter sensitivity
  - assist understanding of non-linear aspect of sensitivity

- Variety of alternative models
  - assist the understanding of conservatism in modeling approaches

- Long simulation periods (i.e., 50,000 and 100,000 years)
  - assist understanding of the sensitivity of engineered components with very slow degradation rates
  - assist understanding of the sensitivity of retardation factors that may delay doses for very long time periods
  - assist understanding of sensitivity of climatic variations
  - TSPA-VA uses long simulation periods

- All of the above used to evaluate TSPA-VA
  - assist understanding of the adequacy of TPA 3.2 for review of LA

Total System Results

- Total System Calculations in S. Mohanty Presentation
  - mean value simulation and sensitivities
  - total system results

- Sensitivity Analysis in R. Codell Presentation
  - parameter sensitivity
  - alternative models

TPA 3.2 TOTAL-SYSTEM RESULTS

Presented by

Sitakanta Mohanty

(210)522-5185 (smohanty@swri.org)

Center for Nuclear Waste Regulatory Analyses

Contributors: R. Rice, R. Janetzke, M. Muller (CNWRA)

T. McCartin, R. Codell (NRC)

May 25-27, 1999

San Antonio, Texas

DOE/NRC Technical Exchange on

Total System Performance Assessment for Yucca Mountain

Attachment 5

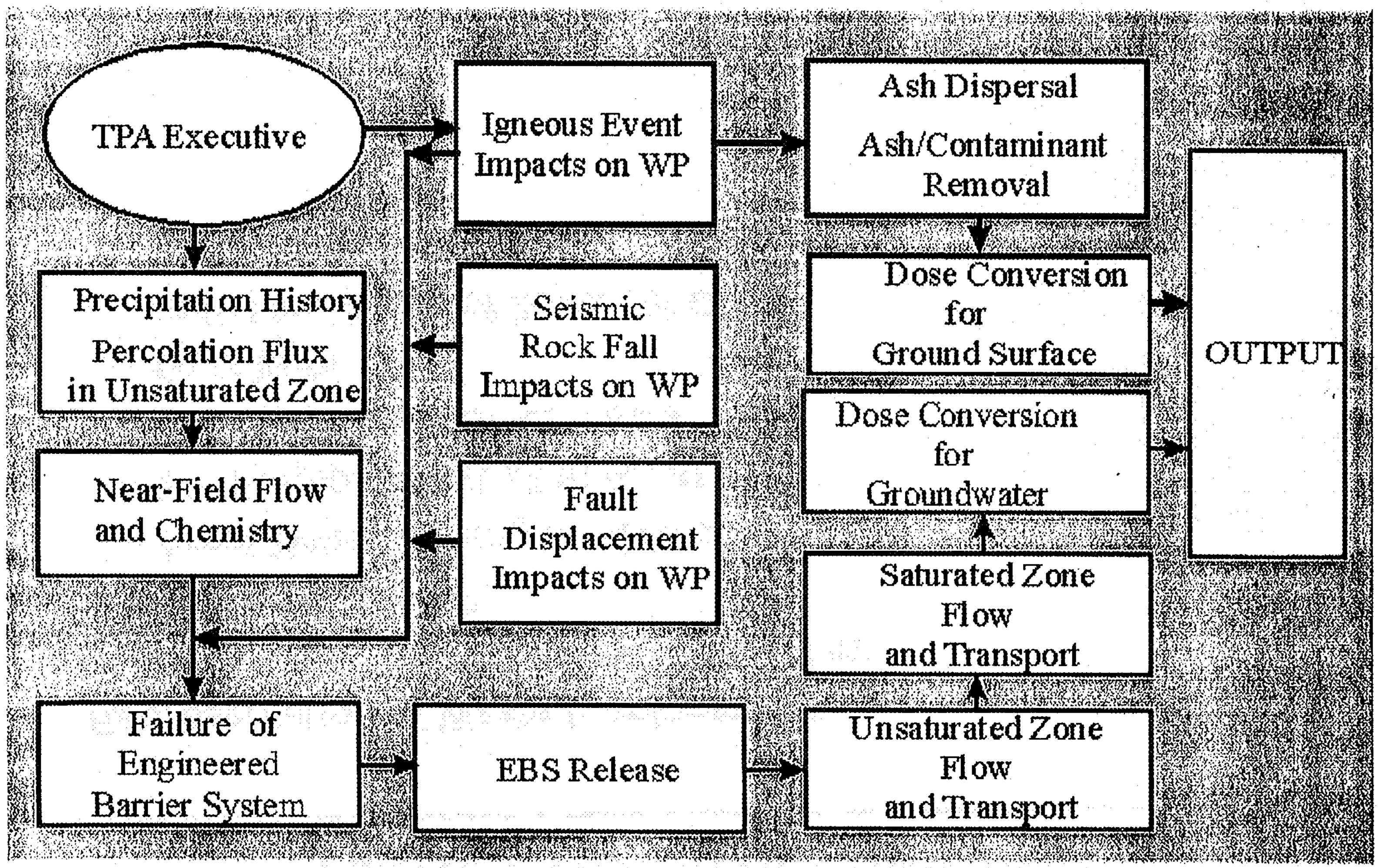
OBJECTIVES

- Outline Outputs From the TPA 3.2 Code Using NRC Reference Data Set
- Gain Insight From Intermediate Outputs

- Notes Concerning Results:
  - Mean Value Data Set to Facilitate
    - Presentation of Process-level Results
    - Comparison of TPA Results With TSPA-VA
  - Multiple Realizations for Sensitivity Analyses

- Caution: Insights and Assertions Are Preliminary
  - Parameter and Model Refinement Is Continuing
  - Preliminary Outputs Based on Limited Analysis

TOTAL-SYSTEM DESCRIPTION

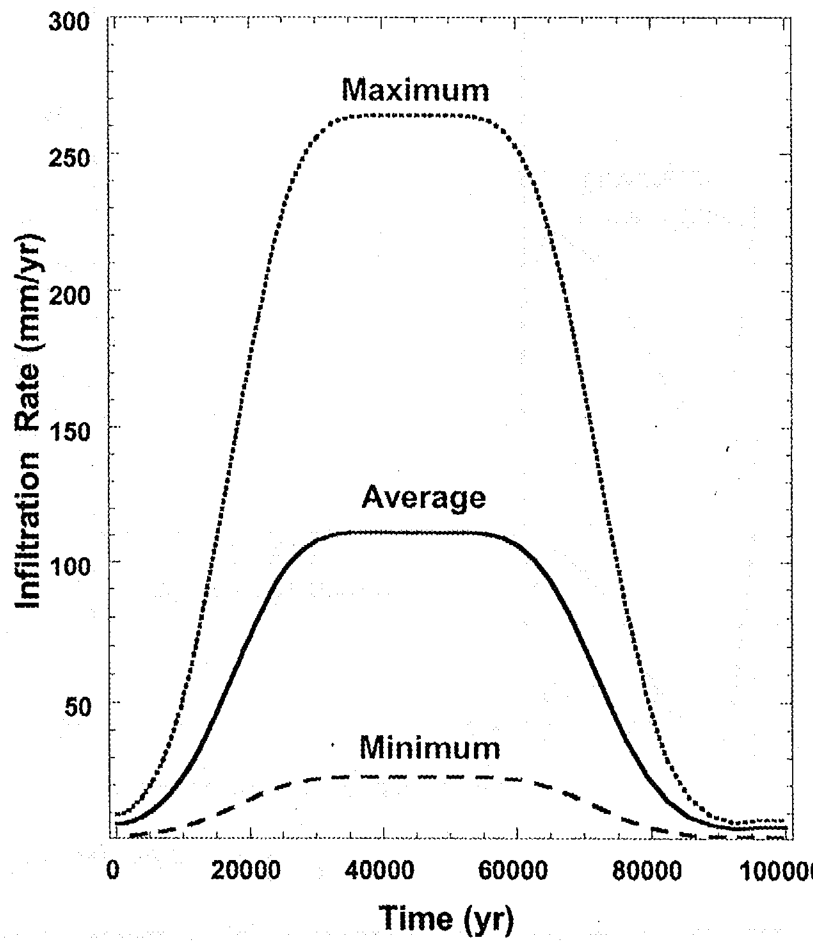


TOTAL-SYSTEM DESCRIPTION

- Representation of Waste Emplacement
  - 62,800 MTU in an Area of 3,060,000 m^2
  - 9.76 MTU Per WP
  - Areal Mass Loading 83 MTU/acre
  - WP Emplacement 22 m Apart
  - Average Age of SF 26 Years
  - 6427 WPs
  - Initial Inventory of 200×10^6 Ci

DEEP PERCOLATION

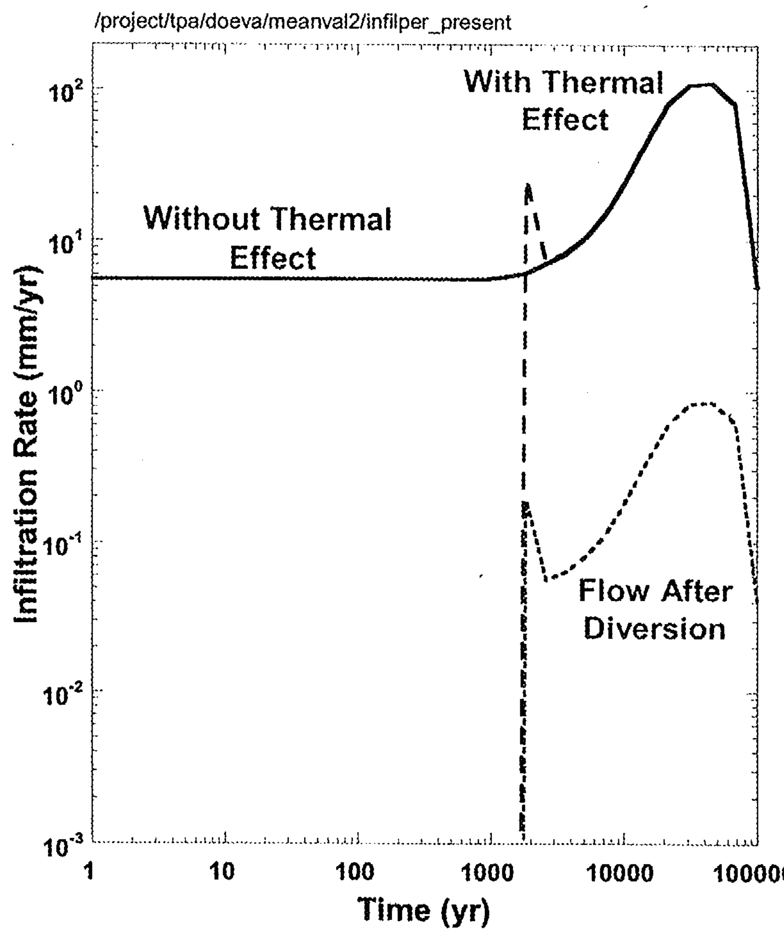
- **Infiltration As a Function of Temporal Climate Change, Soil Depth, Soil Hydraulic Properties**
- **No Surface Run off and Plant Transpiration**
- **Use As Flow Rate Above and Below the Repository**
- **Mean Parameter Values for Infiltration Calculations.**
  - **Areally Averaged Mean Annual Infiltration for the Initial (Current) Climate 5.5 mm/yr**
  - **Mean Annual Infiltration at Glacial Maximum 11.0 mm/yr**



NEAR-FIELD INFILTRATION

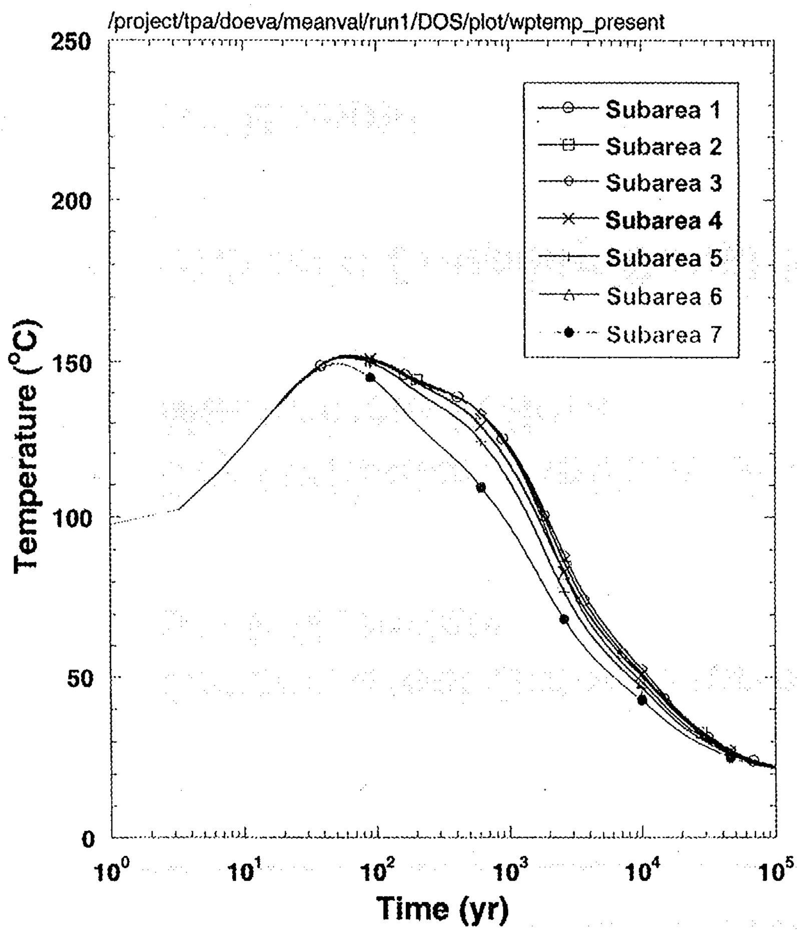
Outputs Using Mean-values Data Set

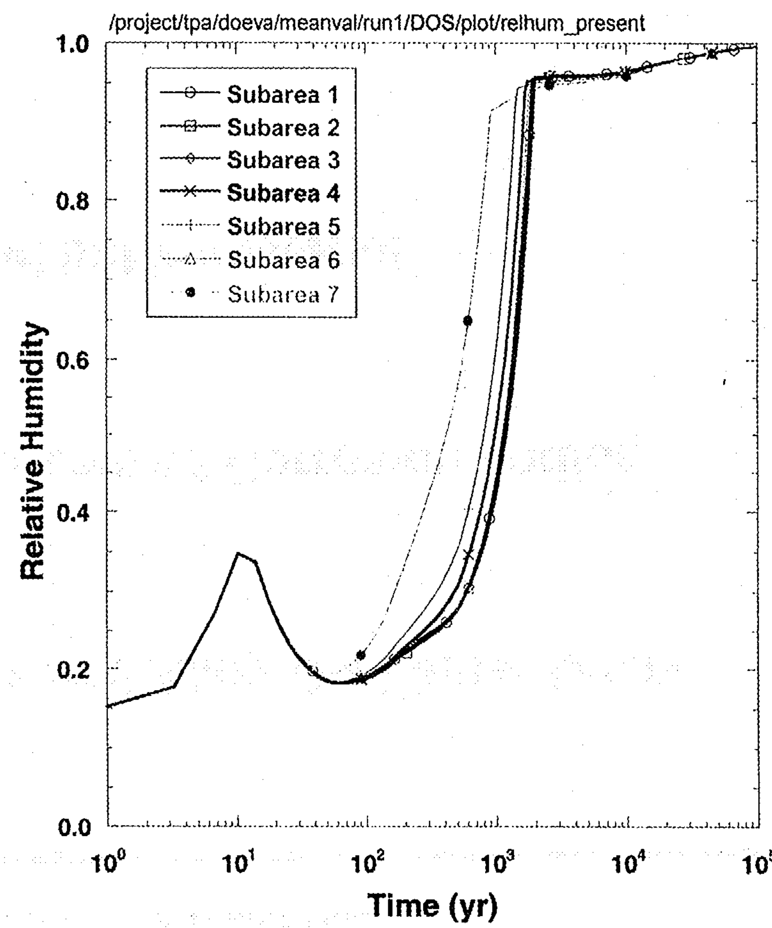
- Used Only for Radionuclide Releases, Not WP Degradation
- Phillip's Model for Reflux
- At Long Time, Reflux Augmented Infiltration Rate Approaches Isothermal Infiltration Rate
- Flow Modifications Because of Heterogeneity in the Fractured Rock, Backfill, Pits in WP Outer Inner Over-packs
- Factors Used for Wetting Area, Capture Area (WP Area), Pit Area
- Factors Do Not Change With Time



NEAR-FIELD TEMPERATURE AND RELATIVE HUMIDITY

Outputs Using Mean-values Data Set





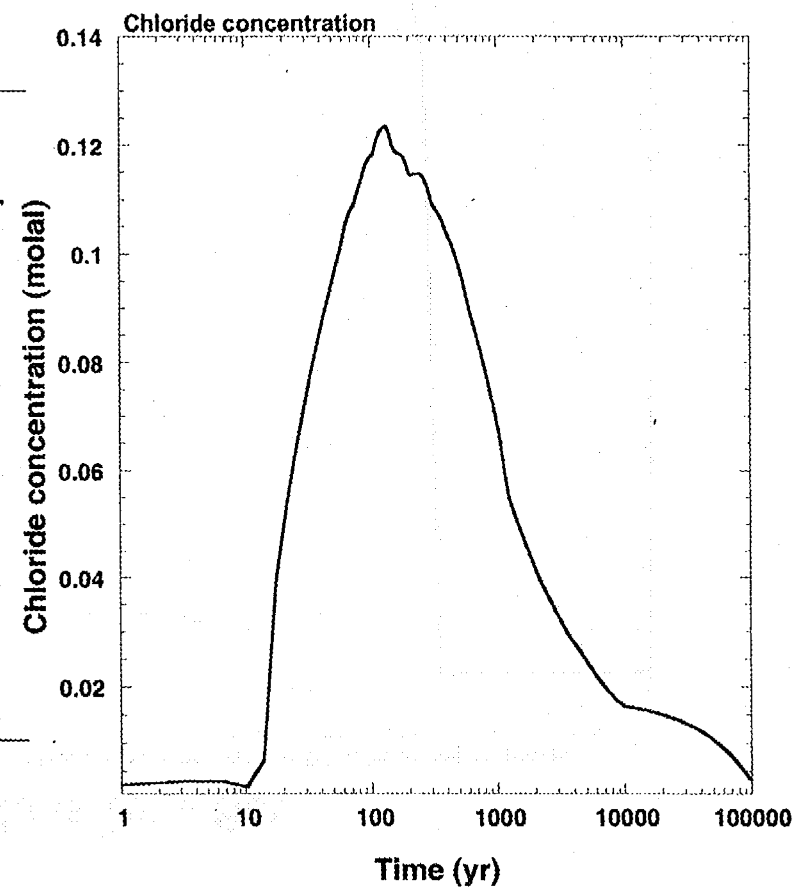
WP CORROSION FAILURE

- Carbon Steel Outer Over-pack and Alloy C-22 Inner Over-pack Materials
- Dry Oxidation, Uniform and Localized Corrosion and/or Mechanical Failure
- Galvanic Coupling Considered but Immaterial
- No Backfill
- Base Case Includes the Effects of Seismicity; Faulting and Volcanic Effects Treated Separately

WP CORROSION FAILURE

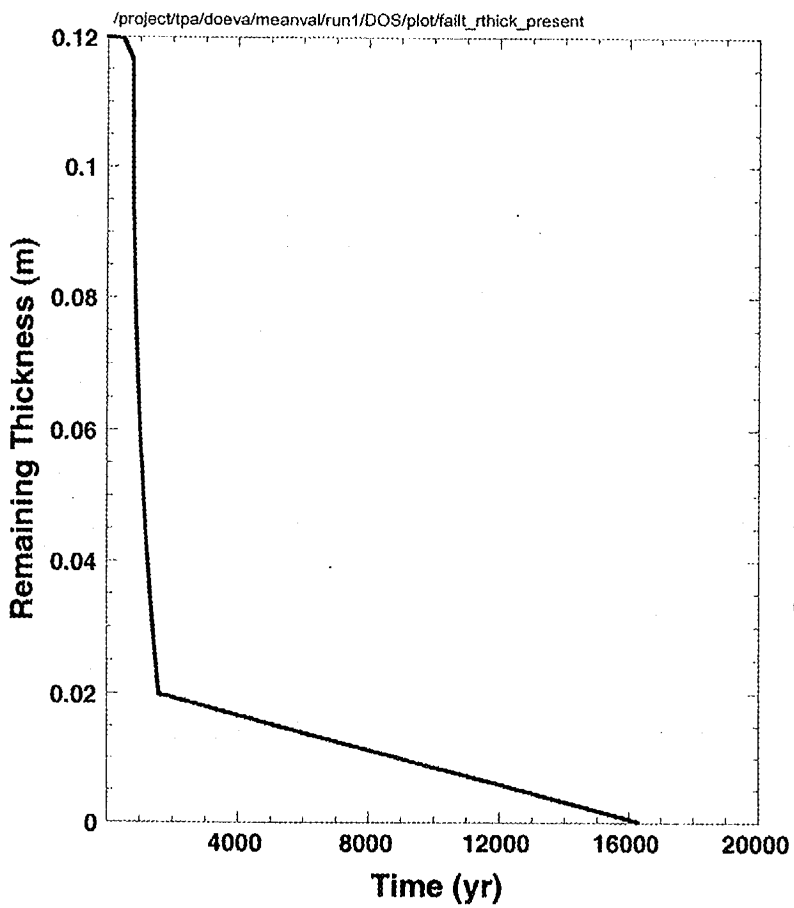
Key Mean-value Input Parameters

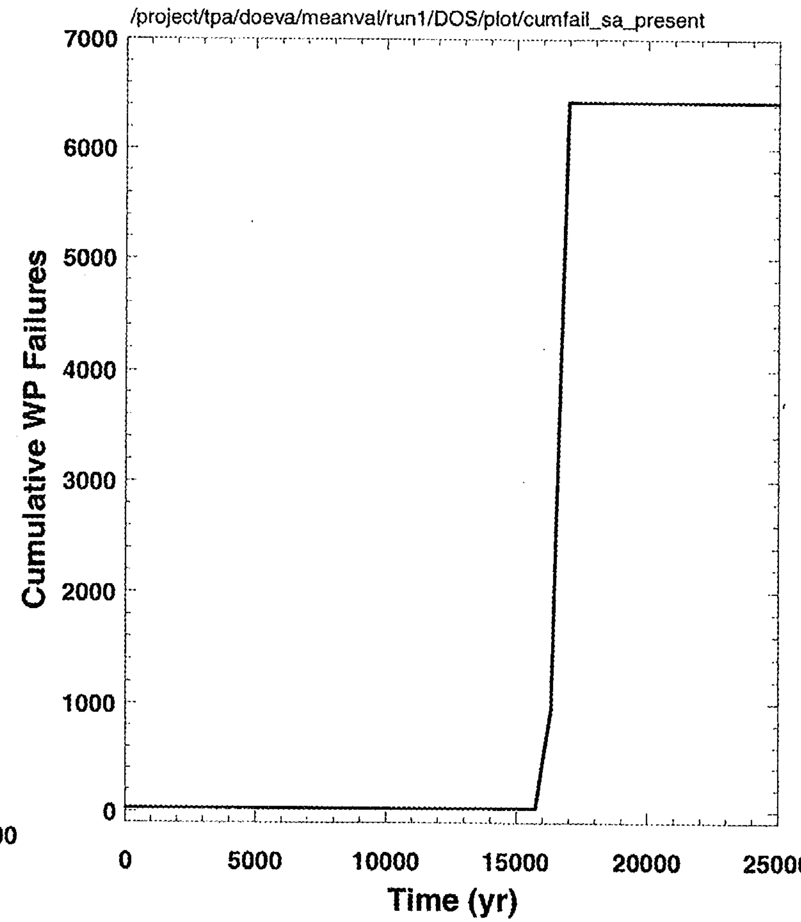
RH_c for humid air corrosion	0.55
RH_c for aqueous corrosion	0.8
Humid air corrosion rate	1.16×10^{-5} m/yr
Localized corrosion rate of inner overpack	2.5×10^{-4} m/yr
Critical chloride concentration for outer overpack	3.0×10^{-4} mol/L
Critical chloride concentration for inner overpack	1 mol/L
Chloride multiplication factor	15.5
Yield strength	205 MPa
Safety factor	1.4
Fracture toughness	250 MPa/m^2



WP CORROSION FAILURE

Outputs Using Mean-values Data Set





RELEASE FROM EBS

Base Case

- Bathtub Model
- Congruent Dissolution of SF
- Dissolution in the Presence of Ca and Si
- No Cladding Credit
- Flow and Transport Through Invert
- Radionuclide Chains:

  Cm-245 → Am-241 → Np-237
  U-234 → Th-230
  Pu-239, I-129, Tc-99, Cl-36,
  and Se-79

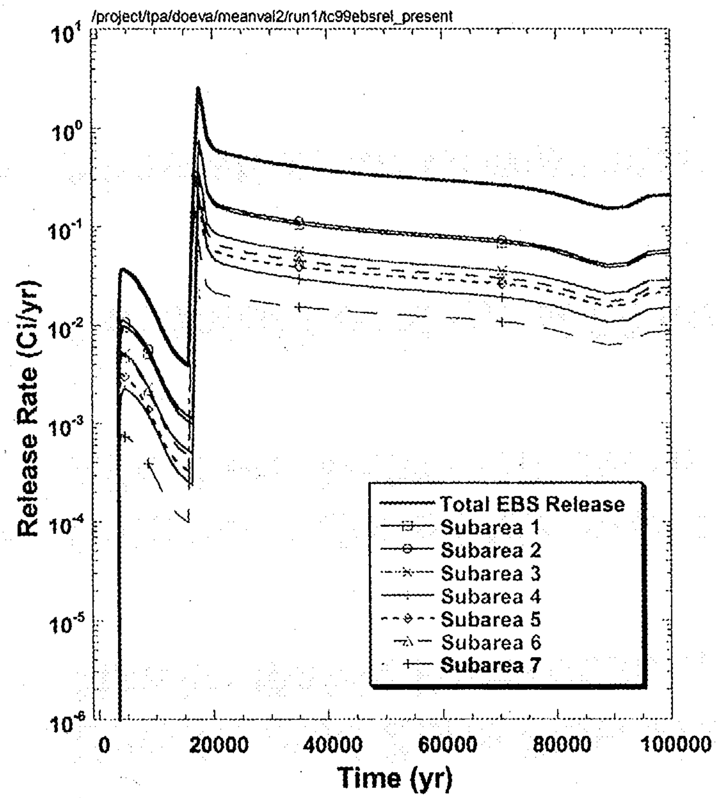
RELEASE FROM EBS

Key Mean-value Input Parameters	
Flow convergence/divergence factor	0.173
Flow multiplication factor	0.045
Subarea wet fraction	0.5
Initial failure time	0.0 yr
Defective fraction of WPs per subarea	5.05×10^{-3}
Surface area model	Particle-based
Spent fuel dissolution model	Ca/Si-based
Initial radius of spent fuel particle	1.85 mm
Cladding correction factor	No cladding
Spent fuel wetted fraction for all failure types	0.5
Invert bypass	W/ invert
Invert rock porosity	0.3
Invert thickness	75 cm
Invert diffusion coefficient	4.4×10^{-5} m^2/yr
Invert matrix permeability	2.0×10^{-17} m^2

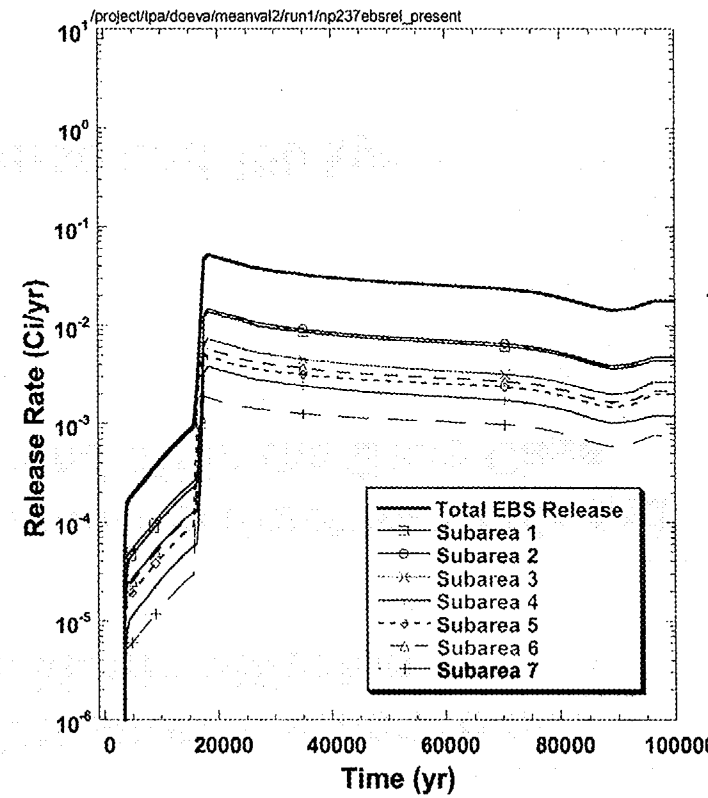
- **Wetted Spent Fuel Surface Area: 747 m^2 With 50% of Volume Immersed in Water and With Particle Size of 1.85 mm**

RELEASE FROM EBS

Outputs Using Mean-values Data Set



Tc-99



Np-237

UZ AND SZ FLOW AND TRANSPORT

- Unsaturated Zone Flow and Transport in Fracture and Matrix; Matrix Retardation; No Matrix Diffusion
- Saturated Zone Flow and Transport in Fractured Tuff and Alluvium; Matrix Diffusion Turned off in the Base Case
- Receptor Location at 20 km
- Simulation for Compliance Period and 100 kyr

UZ AND SZ FLOW AND TRANSPORT

UZ Parameters not shown here.

Key Mean-value Input Parameters:

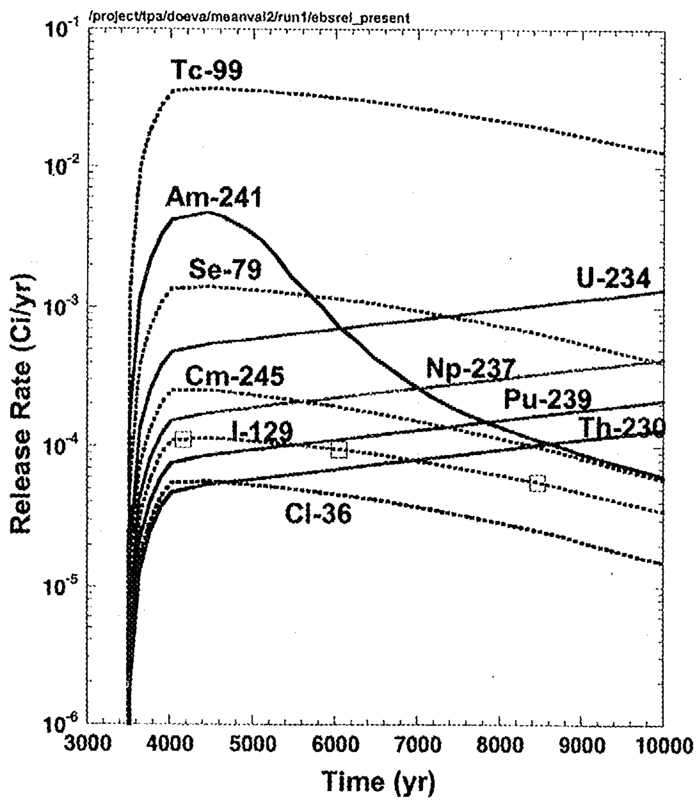
Tuff dispersion fraction	1 %
Alluvium dispersion fraction	0.1
Tuff fracture porosity	0.0032
Alluvium matrix porosity	0.125
Fracture RD for tuff (for all nuclides)	1
Minimum residence time for tuff	10 yr
Minimum residence time for alluvium	10 yr
Well pumping rate at 20 km	8.75×10^6 gpd
Mixing zone thickness at 20 km	125 m

Alluvium Matrix RD

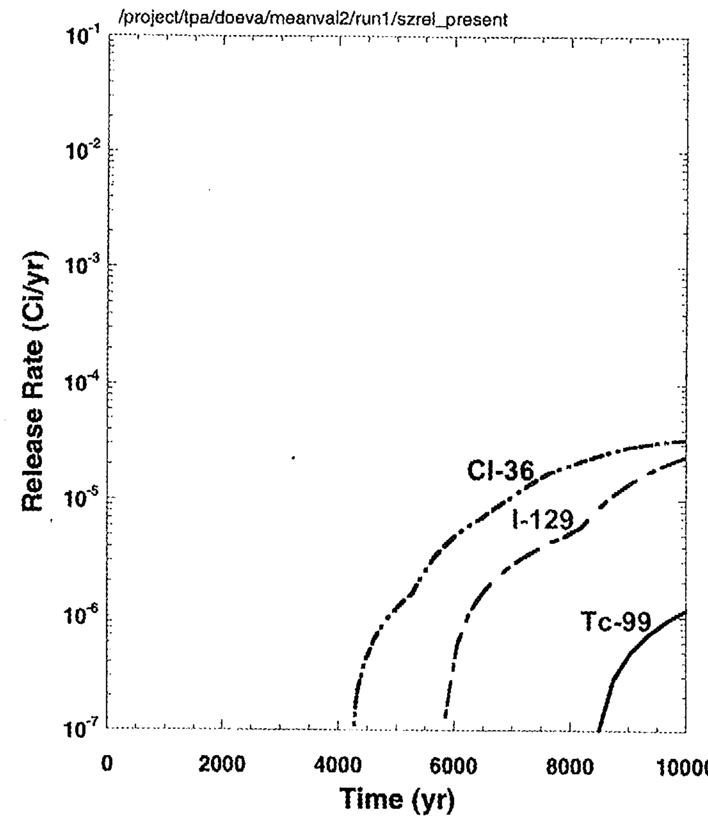
Np-237	62.5
Se-79	22.4
Tc-99	5.5
I-129	2.0
Cl-36	1.0

COMPARISON OF RELEASES FROM EBS AND SZ

Outputs Using Mean-values Data Set



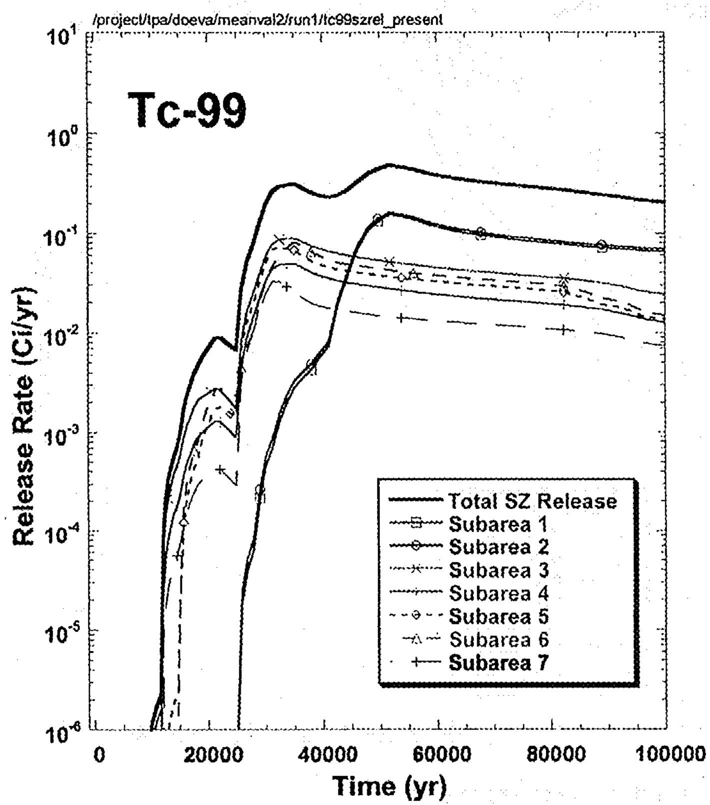
EBS



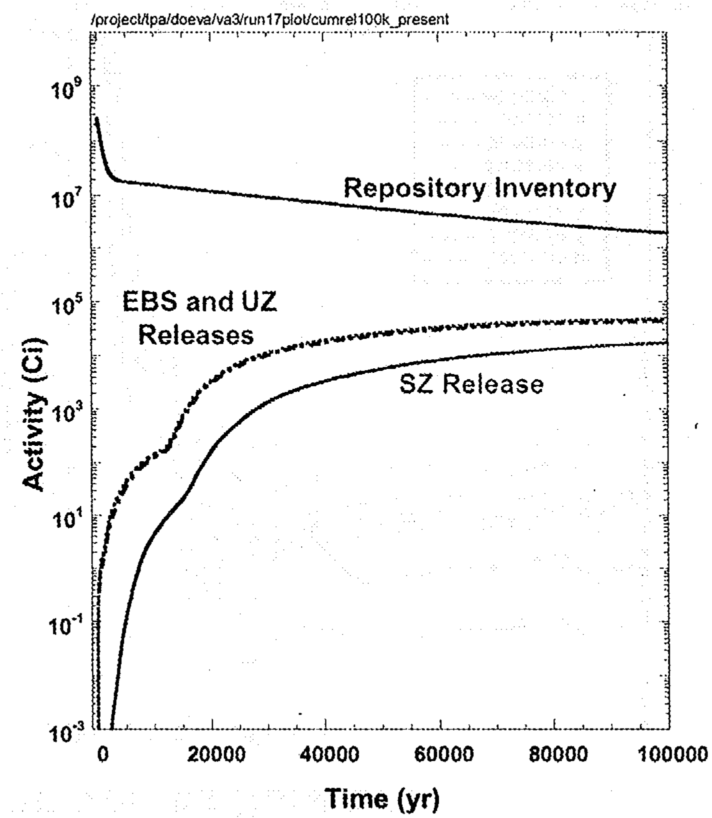
SZ

RELEASE FROM SZ

Outputs Using Mean-values Data Set



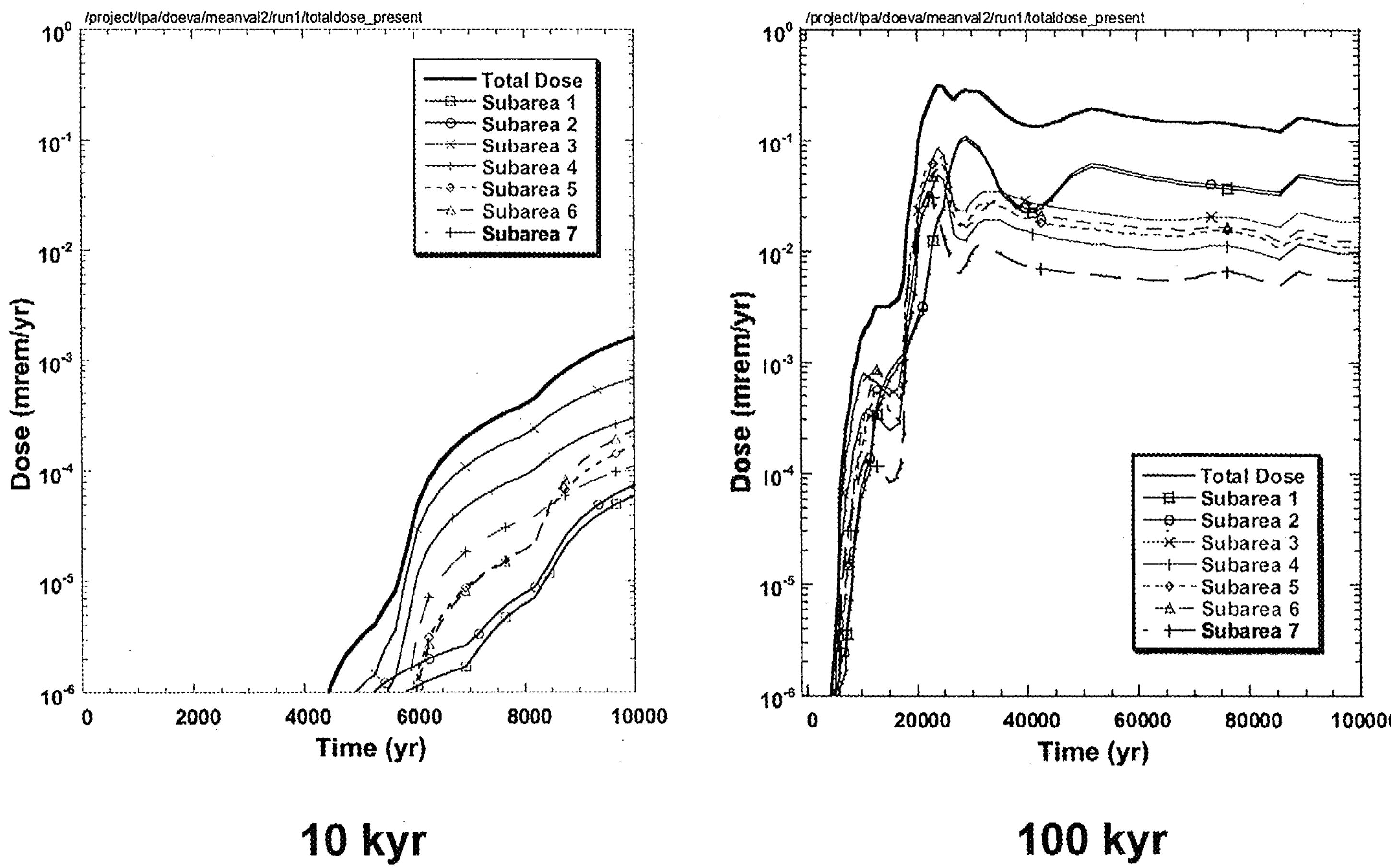
Subarea-to-subarea variability



Cumulative releases

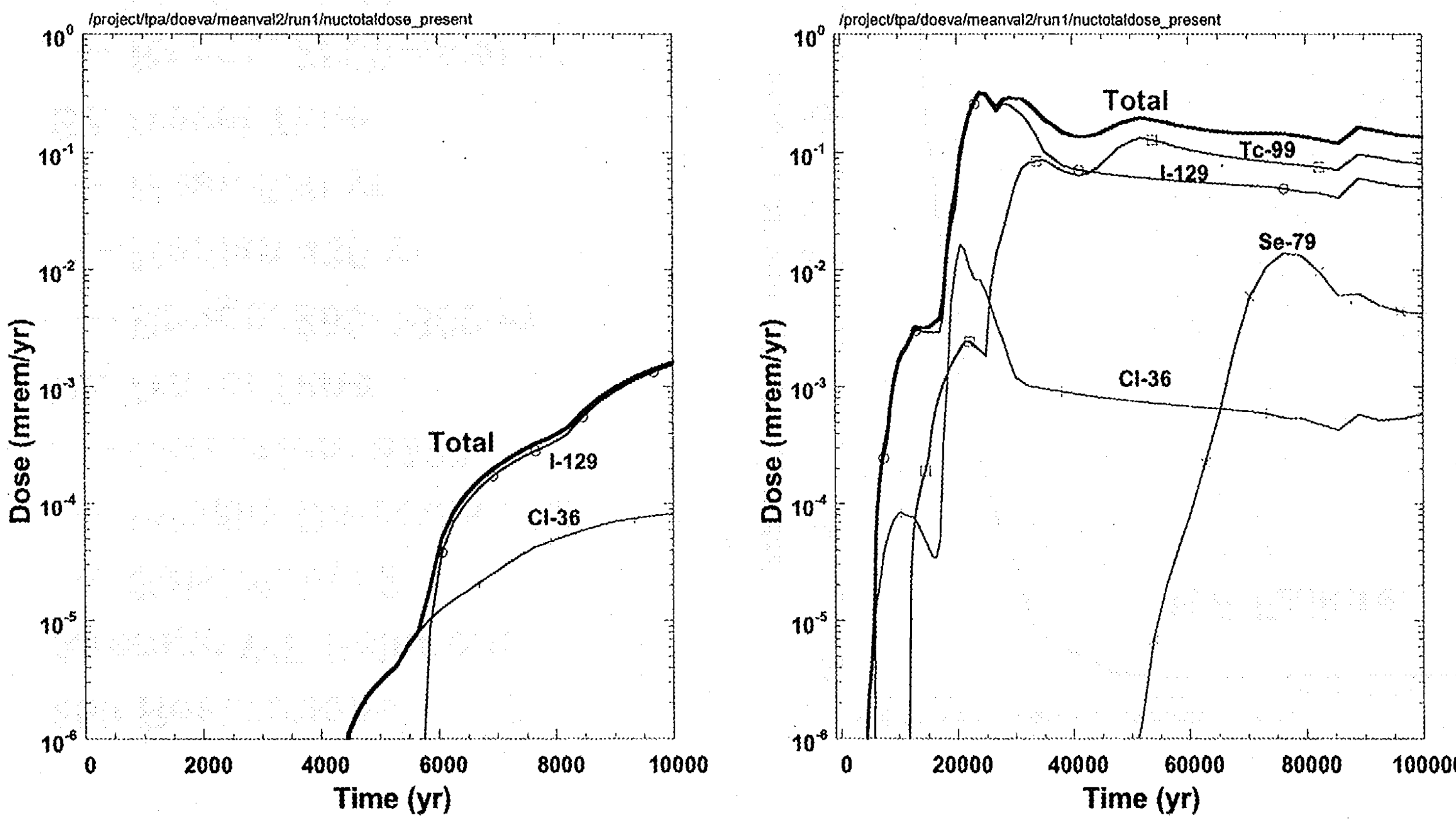
GROUNDWATER DOSE

Outputs Using Mean-values Data Set



GROUNDWATER DOSE

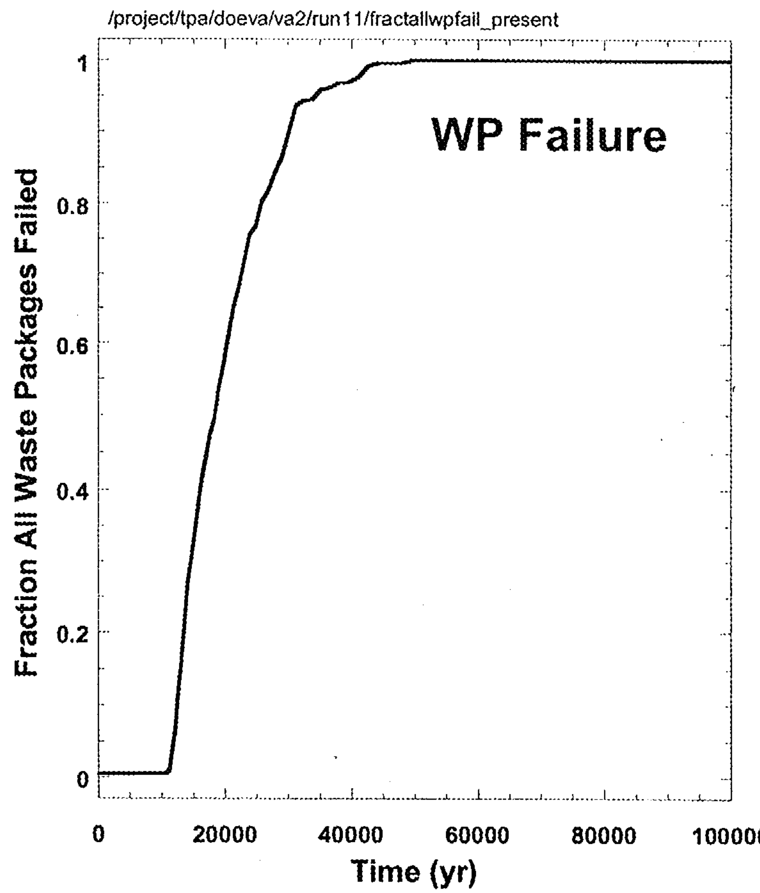
Outputs Using Mean-values Data Set



10 kyr **100 kyr**

MULTIPLE REALIZATIONS

- 250 Realizations
- Average WP Failures:
  - — Seismicity: 2
  - — Initially Defective: 32
  - — Corrosion: 6393
- UZ Travel Time
  - — Range: 250-1600 yr
  - — Median 430 yr
  - — Mean 530 yr
- SZ Travel Time
  - — Range: 2800-4400 yr
  - — Median: 3,690 yr
  - — Mean: 3,680 yr



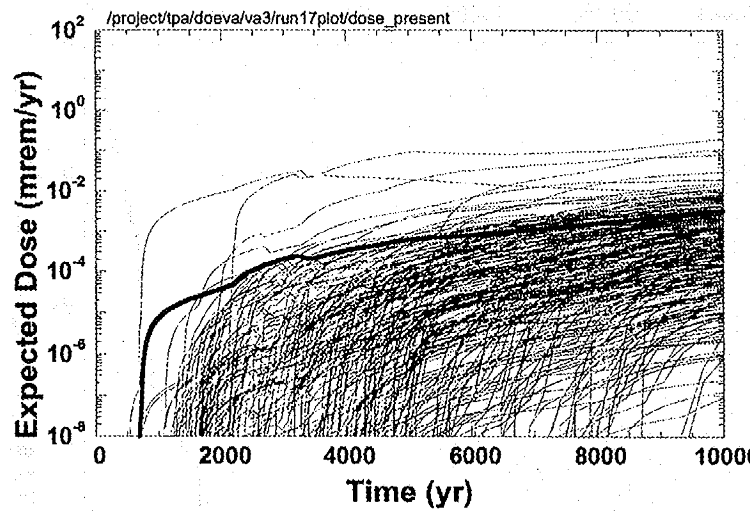
MULTIPLE REALIZATIONS: RADIONUCLIDE DOSE

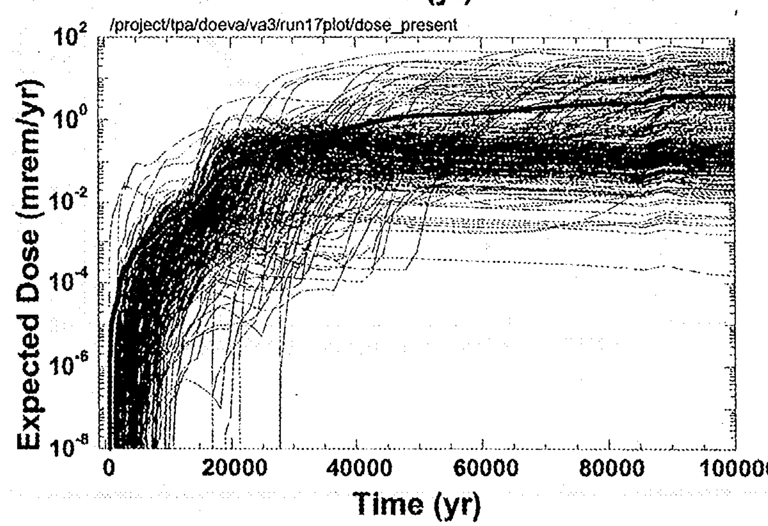
- **Primary Contributors to Peak Expected Dose**
  - 10,000 yr: 0.003 mrem/yr

Nuclide	Multiple-Realization Data set	Mean Value Data set
Np-237	38.9%	0%
I-129	34.9%	95%
Tc-99	13.8%	0.02%
U-234	10.0%	0%
Cl-36	1.4%	5%
Se-79	1.0%	0%

  - 100,000 yr: 4 mrem/yr

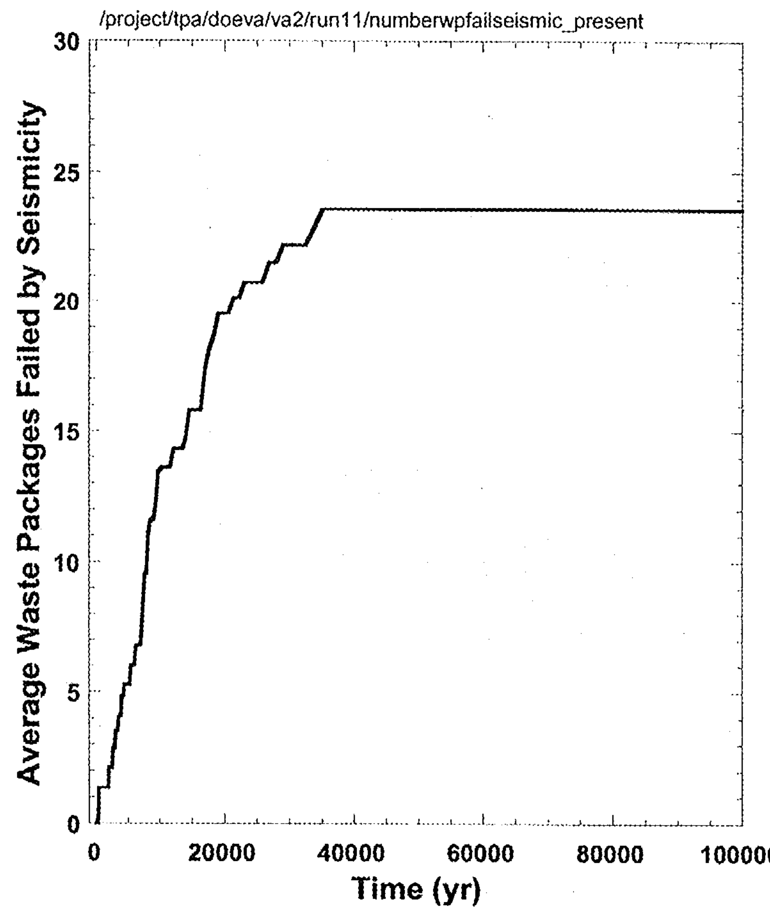
Nuclide	Multiple-Realization Data set	Mean Value Data set
Np-237	92.4%	0%
U-234	3.5%	0%
Tc-99	2.2%	59%
I-129	1.5%	38%
Se-79	-	3%
Cl-36	-	0.4%





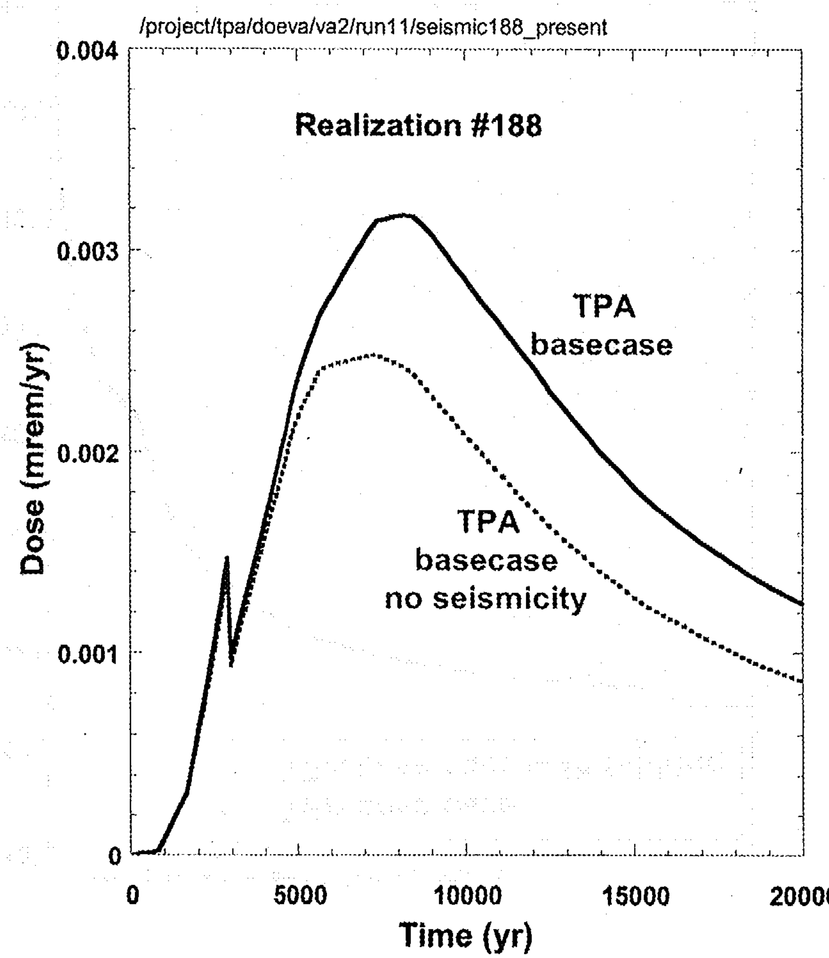
WP FAILURE FROM SEISMICITY

- Treated As a Part of Base Case
- 22/250 Realizations With Non-zero WP Failures (9%)
- 13-33 WPs Failed in the Realizations With Non-zero Seismic Failures
- Failure Time: 400-35,000 yrs
- Average Seismic Failure (All Realizations): 2



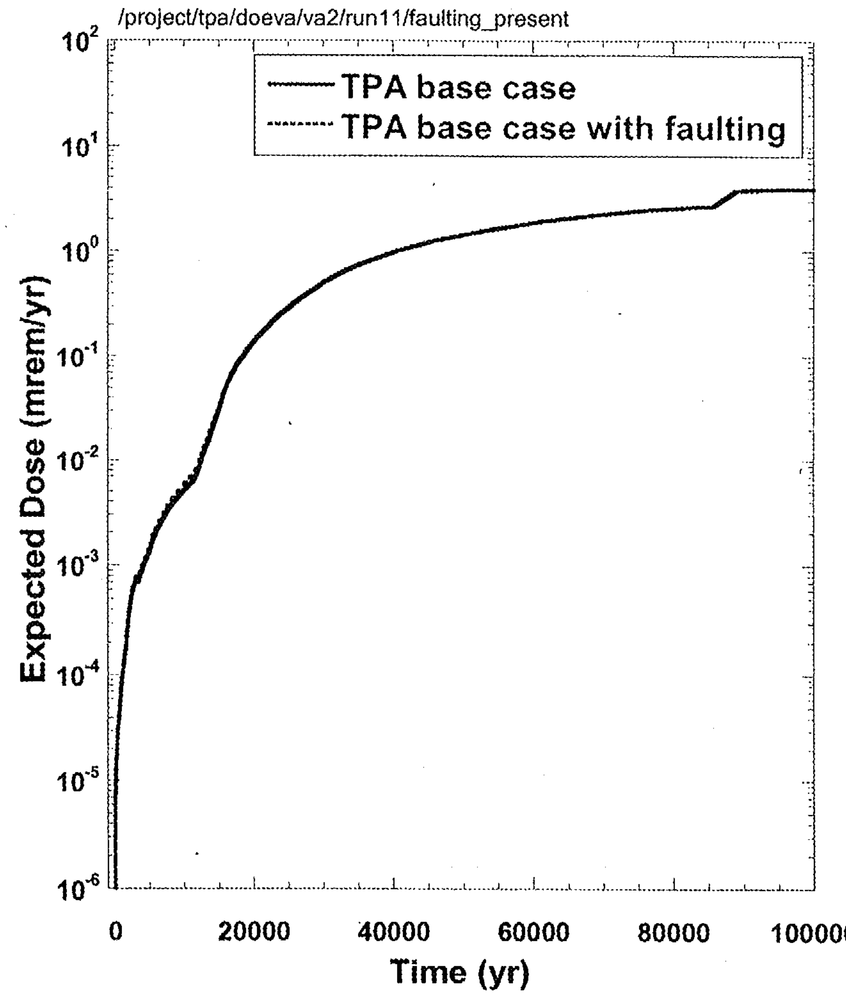
DOSE FROM SEISMICITY

- Figure Shows the Realization with the Largest Contribution From Seismic Failure to Dose in 10 kyr
- 31 WPs Failed (15 at 3,070 yr; 12 at 3,520 yr; and 4 at 8,750 yr)
- With Seismic Failure
  - Peak Dose: 3.2 micro-rem/yr at 8,180 yr
- Without Seismic Failure
  - Peak Dose: 2.5 micro-rem/yr at 7,150 yr
  - 28% Difference Compared to Basecase



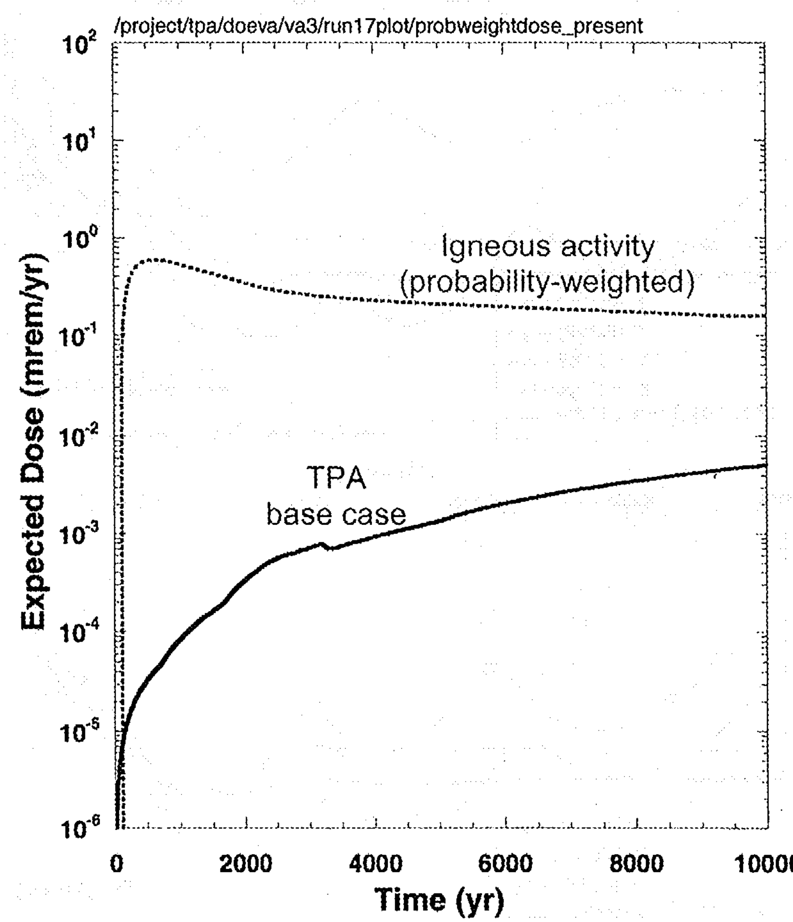
SCENARIO CASE: FAULTING ACTIVITY

- Figure Shows Expected Dose From 250 Realizations
- Recurrence probability of 5×10^{-6}/yr
- Time of Events Limited to 10 kyr
- 58/250 Non-zero WP Failures (23%)
- 4-348 Wps Failed in the Realizations With Non-zero Faulting Failures
- Average Faulting failure (all realizations): 27



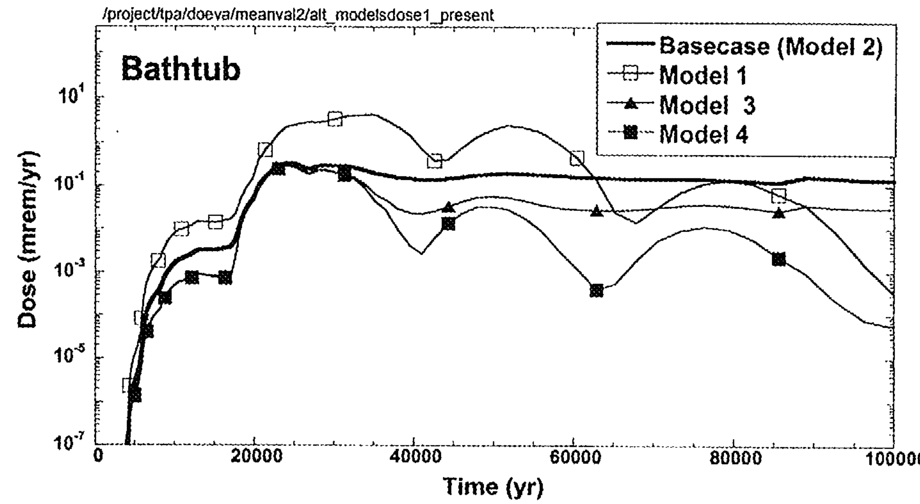
SCENARIO CASE: IGNEOUS ACTIVITY

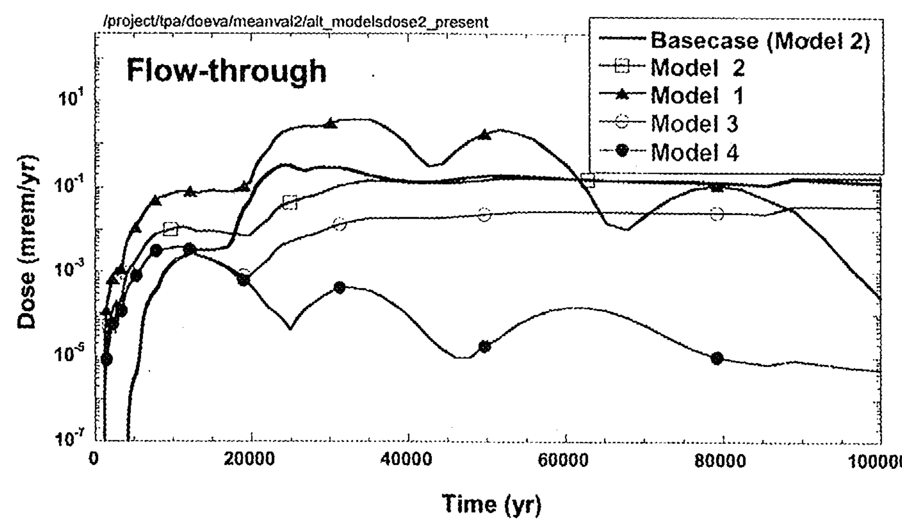
- Time of Events Limited to 10 kyr
- Recurrence probability of 1×10^{-7}/yr
- All Realizations Have Failures From Igneous Activity
- 1-10 WPs Underwent *Extrusive* Failure and 6-57 WPs *Intrusive* Failure
- Average Failure (All Realizations)
  - — Extrusive: 4.7
  - — Intrusive: 30
- Peak Expected Dose (Probability Weighted): 0.6 mrem/yr at 600 yr



ALTERNATIVE CONCEPTUAL MODELS

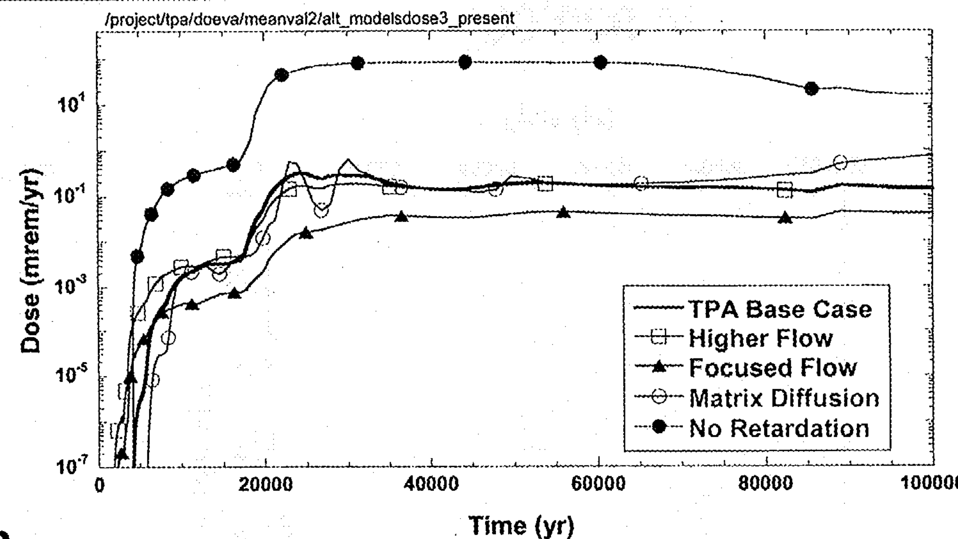
- **Bathtub vs. Flow-through**
- **Dissolution Models**
  - — pH, Carbonate, Oxygen Partial Pressure Based Model (Model 1)
  - — Dissolution in the Presence of Ca and Si (Model 2)
  - — User Supplied Release Rate (Model 3)
  - — Secondary Minerals (Schoepite) (Model 4)
- **Outputs Using Mean-values Data Set**

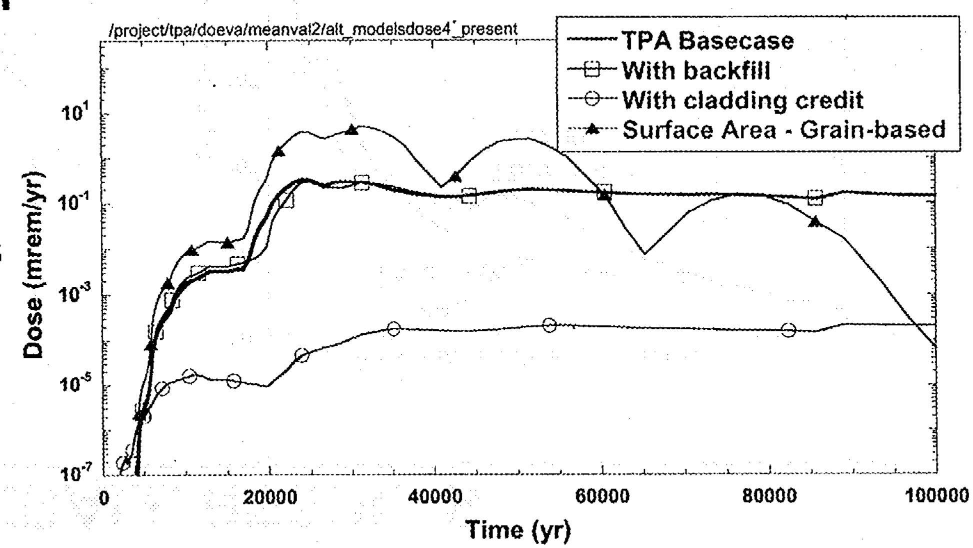




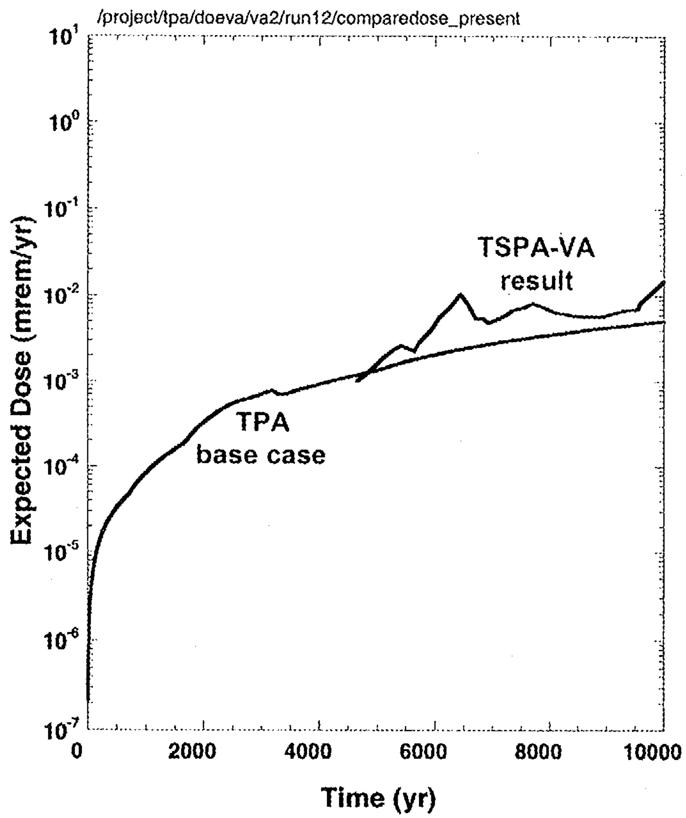
ALTERNATIVE CONCEPTUAL MODELS

- Cladding Credit
- Alternative Focused Flow
- No Retardation
- With and Without Backfill
- Increased Flow Rate
- Surface Area of Waste Form Contacted by Water
  - — Particle-based Model
  - — Grain-based Model
- Outputs Using Mean-values Data Set

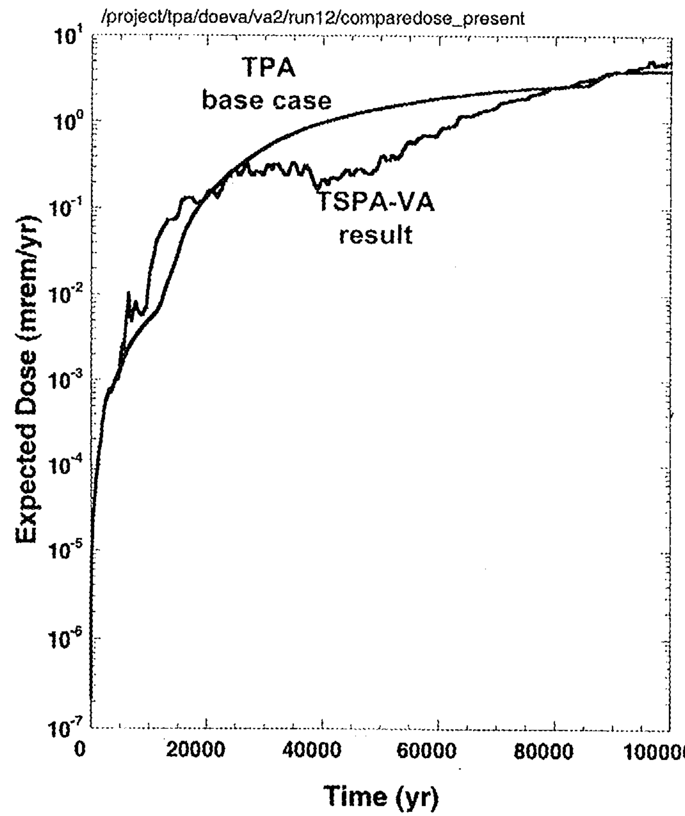




COMPARISON BETWEEN TSPA-VA AND TPA OVERALL RESULTS



10,000 yr



100,000 yr

SUMMARY

- Outputs From TPA 3.2 Code Using Base Case, Scenario Cases, and Alternative Models Are Preliminary in Nature

- Further Code Improvement and Model Refinement Are Ongoing. The Reference Data Set Will Continue to Evolve As Additional Site Characterization and Design Data Are Made Available

System-Level Sensitivity Results and Alternative Conceptual Models in TPA 3.2

Richard B. Codell
(301) 415-8167
RBC@NRC.GOV

Performance Assessment and HLW Integration Branch
Division of Waste Management
Office of Nuclear Materials Safety and Safeguards
U.S. Nuclear Regulatory Commission

Contributors: S. Mohanty (CNWRA), M. Byrne (USNRC), J. Weldy (CNWRA), R. Janetske (CNWRA), Y. Lu (SWRI)

For presentation at the NRC/DOE Technical Exchange on Total System Performance Assessment, Center for Nuclear Waste Regulatory Analyses, San Antonio Texas May 25-27, 1999

Attachment 6

Motivation for Sensitivity Analysis at Total System Level

- TPA code is complicated, and cannot be understood piecemeal.
- Sensitivity results point out the relative importance of subsystems, and possible errors or weaknesses in analyses.
- Focuses staff reviews of DOE TSPAs on those factors most significant to total system performance.
- Continues to improve staff's capability for reviewing a possible application at the Yucca Mountain site.

Purpose of Presentation

- Show sensitivities of performance measures to input parameters.
- Show sensitivities of performance measures to alternative conceptual models and scenarios.
- Determine some measure of relative importance of technical areas to the performance of the repository.

Sensitivity Analyses on Base Case and Disruptive Scenarios

- “Base case” defined here as:

  - Alloy C-22 for inner overpack
  - Carbon steel outer overpack
  - No cladding protection
  - Bathtub model for release rate
  - No matrix diffusion
  - No backfill
  - Includes effects of seismicity
  - 20 Km receptor group
  - 50,000 year maximum time
  - No volcanism or faulting

- Volcanism Scenario

- Faulting Scenario

Sensitivity Analyses on Base Case

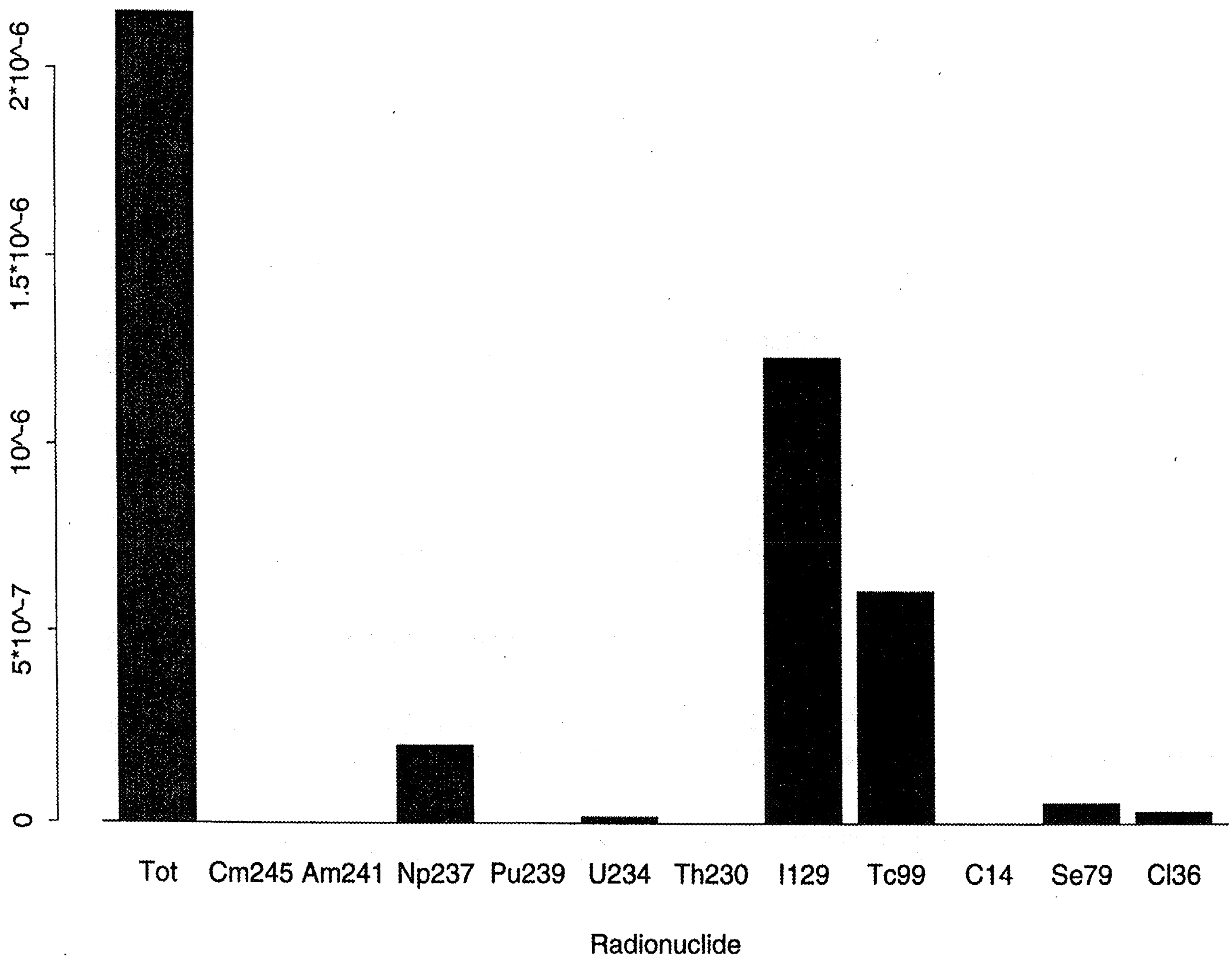
- Used a wide variety of statistically based and non-statistical methods to extract sensitivity information from the TPA results.

- Statistical Sensitivity Analysis Includes:

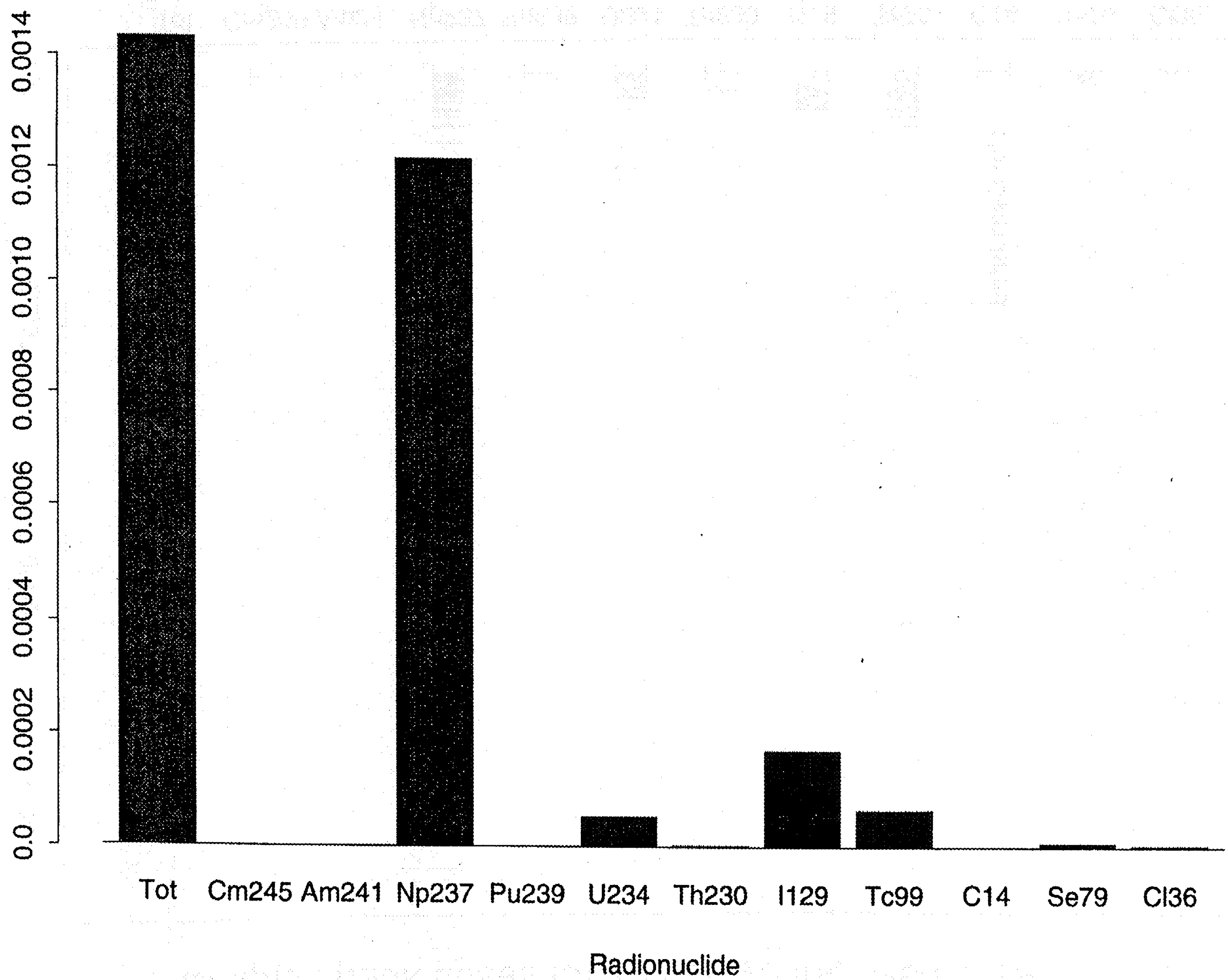
  - Compartmental analysis for most important radionuclides
  - "Classical" regression and statistical techniques
  - FAST method
  - Parameter Tree method

- Non-statistical sensitivity techniques include
  - Differential analysis
  - Morris method

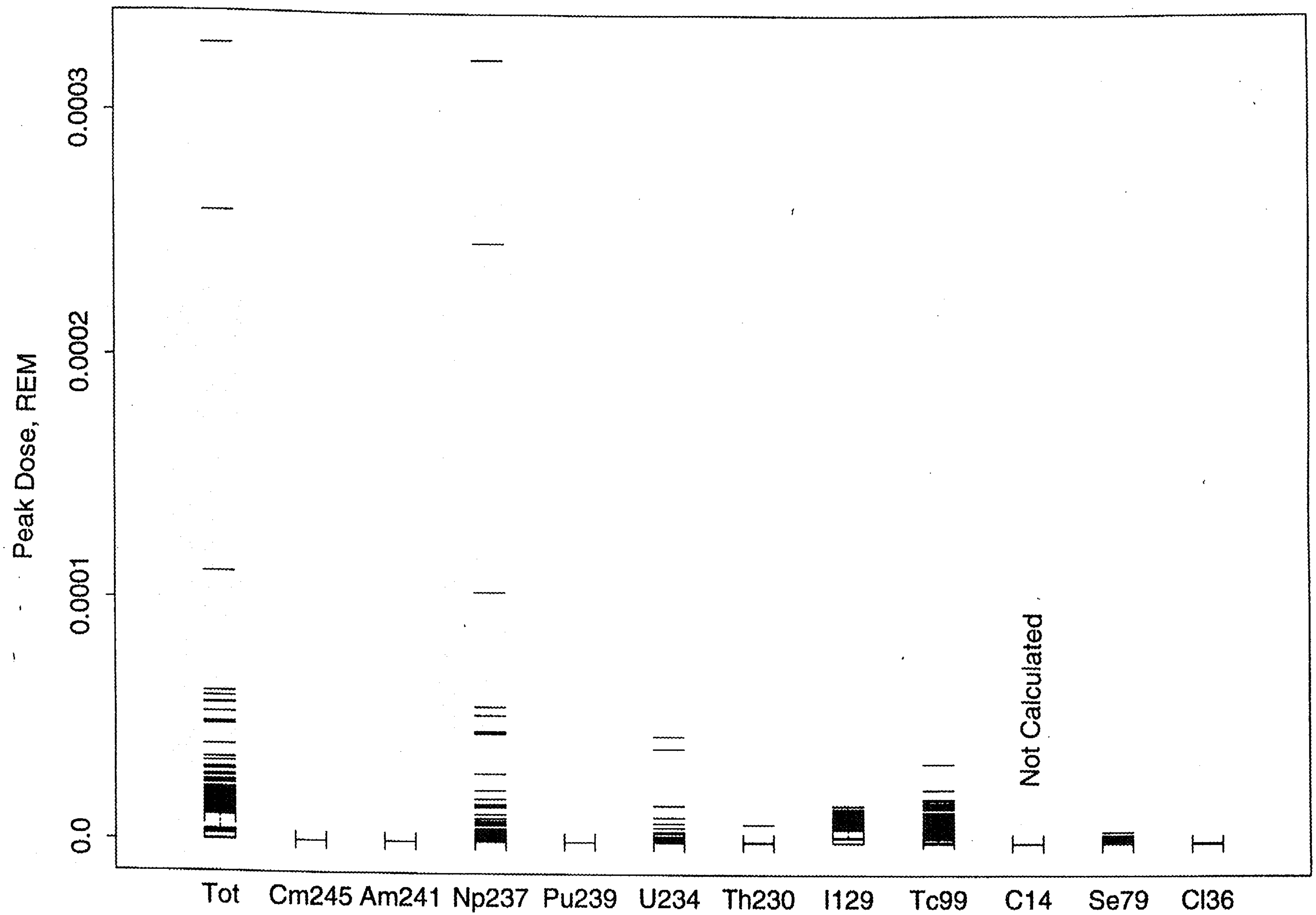
Peak Mean Dose for 10,000 Years by Radionuclide, Rem



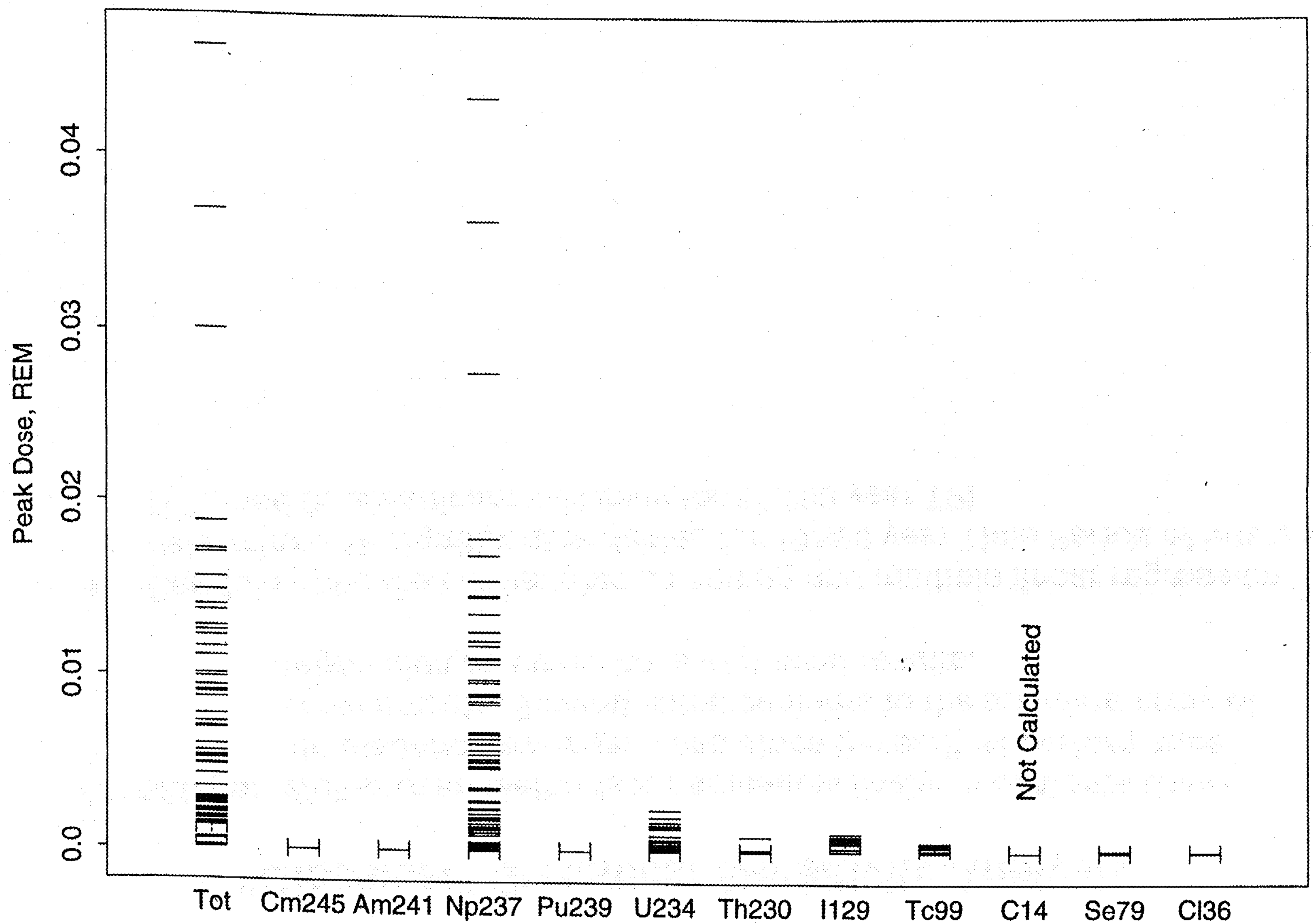
Peak Mean Dose for 50,000 Years by Radionuclide, Rem



Boxplot, peak doses for 10,000 years, base case



Dose for 50,000 years (400 vector run)



"Classical" Statistical Sensitivity Analysis

Advantage: Well-proven methods for statistical analysis of Monte Carlo simulations have been used since the earliest performance assessments. Several enhancements to the standard array of regression analyses have improved results.

- Careful application of variable screening and multiple linear regression determined 18 significant variables for 10,000 year Time Period of Interest (TPI) and 20 significant variables for 50,000 year TPI.

Preliminary Screening of Input Variables

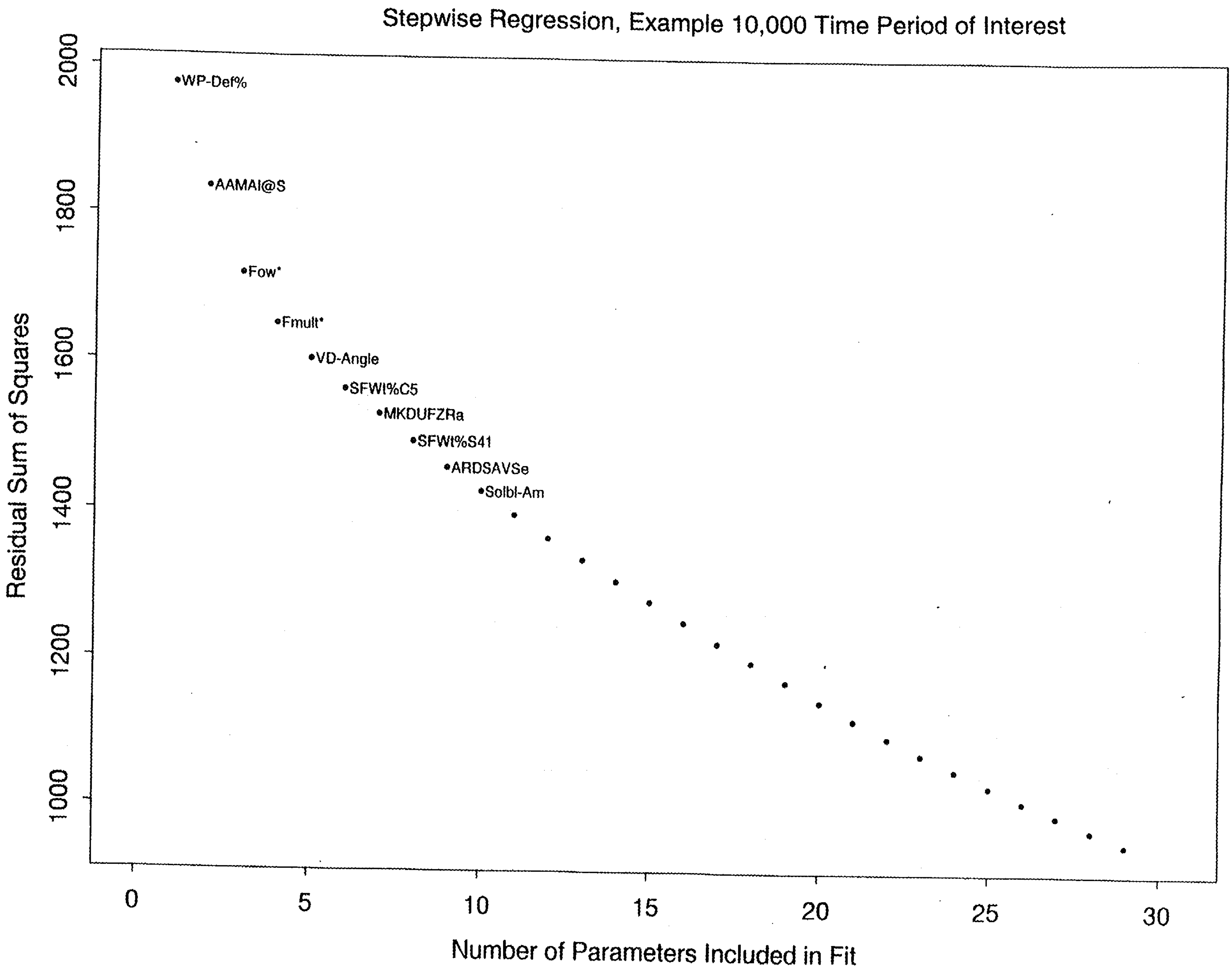
Preliminary screening of 246 input variables was used to determine a short list of likely important variables for further analysis using the following techniques:

- Single-variable regression with t-test (test that slope significantly different from zero)

- Stepwise multiple linear regression

- Tests performed on:
  - Normalized variables
  - Log of normalized variables
  - Variables normalized with scaled power law

- Non-parametric tests
  - Kolmogorov-Smirnov test
  - Sign test


Stepwise Regression, Example 10,000 Time Period of Interest
Residual Sum of Squares
Number of Parameters Included in Fit
2000
1800
1600
1400
1200
1000
0
5
10
15
20
25
30
WP-Def%
AAMAI@S
Fow*
Fmult*
VD-Angle
SFWt%C5
MKDUFZRa
SFWt%S41
ARDSAVSe
Solbl-Am

Transformation of Variables in Statistical Analysis

Variables were often transformed to improve nature of statistical analysis:

- Rank Transformation - Reduce variable to its rank in a sorted list.
- Normalization - Divide by variables by the mean of the list.
- Logarithmic transformation - Take the logarithm of the normalized variable.
- Scaled Power Transformation - Find power law transform that best reduces influence of tails of distribution.

Presentation of Sensitivities

Sensitivity results can be presented several ways to emphasize different attributes:

- Sensitivities based on normalized variables
  - Weight all results equally
  - Generally give poorer fits (i.e., R^2)
- Log-Normalized Sensitivities
  - Log transformation gives equal weights to the logs, which overestimates the smaller doses.
  - Gives better fit (R^2) because TPA model is generally multiplicative rather than additive.

Presentation of Sensitivities (Cont'd)

- **Standardized Sensitivities variables place proper emphasis on range of input variables**

$$x_i^* = \frac{x_i - \bar{x}}{\sigma_x}$$

Standardized Variables derived from Normalized or Log-Normalized Sensitivities; i.e.

$$\frac{\partial y^*}{\partial x^*} = \frac{\sigma_{x_i}}{\sigma_y}\left(\frac{\partial y}{\partial x_i}\frac{x_i}{y}\right)\frac{y}{x_i}$$

Differential Analysis

Advantage: Differential analysis gives exact values of sensitivities at local points in parameter space. However, sensitivities are local only, and require one simulation for each sensitivity coefficient.

- **Perturb independent variables one at a time around a "base point" in the parameter space (Used 7 base points in current study)**

- **Use finite difference to get sensitivity:**

$$\frac{\delta D}{\delta x_i} \approx \frac{D(x_i + \Delta x_i) - D(x_i)}{\Delta x_i}$$

Morris Method

Advantage: Economic way of conducting differential analysis for a large number of independent variables.

- **Uses a "Design Matrix" to reduce number of runs needed by half.**

Fourier Amplitude Sensitivity Test (FAST) Method

Advantage: Useful for nonlinear computational models with multiple interactions among the independent variables

- Allows influence of all input parameters at same time (unlike differential or Morris method).
- Limited to small number of independent variables.

– Used screening technique (Morris Method) to estimate 10 input parameters considered to be most influential.

Parameter Tree Method

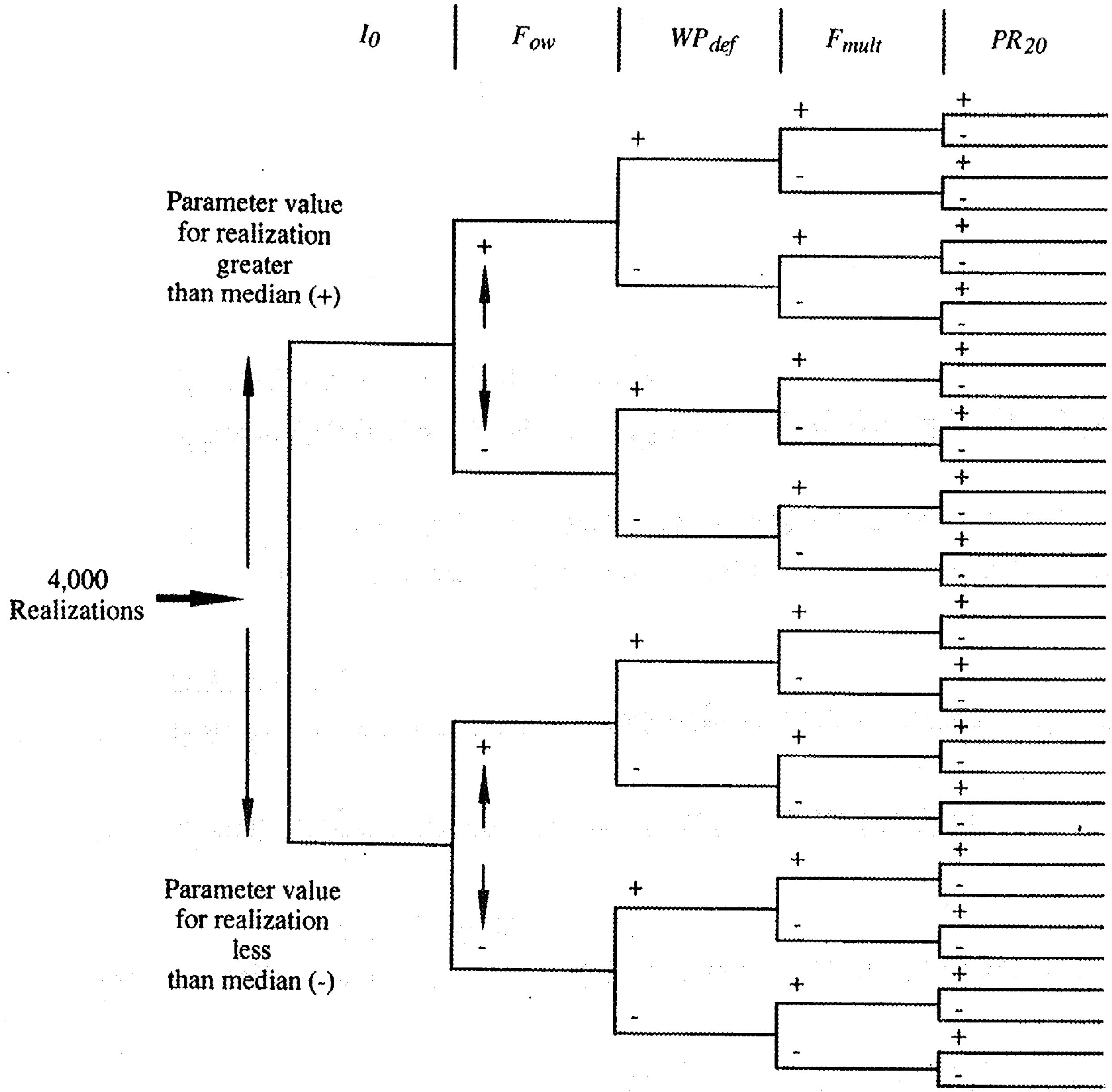
Advantage: Examines total system output relative to groups of input parameters.

- Uses large bin of Monte Carlo runs (4000)
- Parameter tree partitions input parameters into bins based on a branching criterion:

– "+" or "-" partitioning depending on whether independent variable is greater than or less than the criterion (e.g., mean)

– Procedure determines 2^M bins, where M is number of important variables determined by screening.

Parameter Tree Method



A	B	C	D
124/124	6.59E-05	0.1109	3.58
100/102	1.30E-04	0.1801	7.06
82/90	4.31E-05	0.0526	2.37
110/118	5.90E-05	0.0944	3.20
84/102	2.81E-05	0.0389	1.53
99/109	4.39E-05	0.0649	2.38
74/109	1.44E-05	0.0213	0.78
79/111	1.96E-05	0.0295	1.06
102/137	1.86E-05	0.0345	1.01
126/145	5.19E-05	0.1021	2.82
66/134	5.51E-06	0.0100	0.30
82/141	1.13E-05	0.0216	0.61
66/135	6.78E-06	0.0124	0.37
89/150	1.12E-05	0.0228	0.61
23/145	1.71E-06	0.0034	0.09
45/148	3.73E-06	0.0075	0.20
84/153	1.55E-05	0.0321	0.84
100/140	3.17E-05	0.0601	1.72
57/145	6.93E-06	0.0136	0.38
63/138	9.55E-06	0.0179	0.52
54/133	5.69E-06	0.0103	0.31
79/154	8.67E-06	0.0181	0.47
29/148	2.97E-06	0.0060	0.16
39/124	5.92E-06	0.0100	0.32
30/95	4.11E-06	0.0053	0.22
42/103	7.10E-06	0.0099	0.39
17/115	1.23E-06	0.0019	0.67
17/120	1.13E-06	0.0018	0.06
17/111	1.53E-06	0.0023	0.08
15/107	1.60E-06	0.0023	0.09
2/124	3.23E-07	0.0005	0.02
4/90	7.70E-07	0.0009	0.04

Sensitivities for Base Case, 10,000 years

Rank	Linear Model Normalized	Linear Model Log norm	Differential Analysis	Morris Method	Parameter Tree Method
1	MAPM@GM	MAPM@GM	ARDSAVTc	CritRHAC	AAMAI@S
2	MATI@GM	Aprs_SAV	FOCTR-R	YMR-TC	Fow
3	WPRRG@20	WPRRG@20	Fow	Chlorid	WP-Def%
4	WP-Def%	Fow	ARDSAV_I	SSMO-RE	Fmult
5	AAMAI@S	WP-DEF%	SFWt%I3	H2O-FThk	SbArWt%
6	Fmult	Fmult	WP-Def%	Fow	-
7	SbArWt%	SbArWt%	ARDSAVSe	Fmult	-
8	SSMOV501	AAMAI@S	SbArWt%	FOCTR-R	-
9	SFWt%46	ARDSAV_I	Fmult	FOC-R	-
10	SFWt%I1	InitRSFP	FOC-R	WPRRG@20	-

Sensitivities for Base Case, 50,000 Years

Rank	Linear Model Normalized	Linear Model Log Norm	Differential Analysis	Morris Method	Parameter Tree Method
1	SbArWt%	ARDSAVTc	ARDSAVNp	ARDSAVNp	-
2	AAMAI@S	SbArWt%	Fow	WPRRG@20	-
3	InitRSFP	WPRRG@20	OO-CofLC	AA_2_1	-
4	SbGFRATF	AAMAI@S	AA_2_1	MAPM@GM	-
5	Aprs_SAV	Aprs_SAV	SbArWt%	AAMAI@S	-
6	WPRRG@20	ARDSAVNp	ARDSAVTc	APrs_SAV	-
7	SSMOV206	InitRSFP	Fmult	Fow	-
8	SSMO-JS5	SSMO-JS5	WPRCG@20	SbArWt%	-
9	SFWt%C2	SbGFRATF	APrs-SAV	Fmult	-
10	SFWt%C3	ARDSAV_I	ARDSAVI	OO-CofLC	-

Standardized Sensitivities

Standardized sensitivities are significantly different from sensitivity coefficients.

Top 10 most-sensitive standardized variables for 10,000 Year TPI from Statistical Analysis

Normalized Variables	Log-Normalized Variables
WP-Def%	Fow
Fow	WP-Def%
SbArWt%	SbArWt%
F-Mult	F-Mult
ARDSAVTc	AAMAI@S
WPRRG@20	ARDSAV_I
AAMAI@S	ARDSAV_Tc
SFWt%S46	WPRRG@20
SFWt%I1	ARDSAVNp
Fprm_BFw	MAPM@GM

10 Most-Sensitive Standardized Variables from Statistical Analysis for 50,000 Year TPI

Normalized Variables	Log of Normalized Variables
SbArWt%	ARDSAVNp
AAMAI@S	SbArWt%
WPRRG@20	AAMAI@S
ARDSAVNp	ARDSAV_U
SSMO-RPR	ARDSAVTc
InitRSFP	InitRSFP
SSMOV206	MKDCHvNp
SbGFRATF	Aprs_SAV
SFWt%C2	ARDSAV_I
ARDSAV_U	SbGFRATF

Ranking of Standardized Sensitivities for Disruptive Events Volcanism

Rank	Regression normalized	Regression Lognorm	Differential Analysis
1	Windspd	Windspd	Ve-Power
2	ABMLFVDC	ABMLFVDC	ABMLFVDC
3	VEROI-Tn	VC-Dia	VE-Durat
4	VE-Durat	VE-Durat	VEROI-Tn
5	VE-Power	VE-Power	VC-Dia
6	VC-Dia	VEROI-Tn	Windspd
7	AshMnPLD	AshMnPLD	AshMnPLD

Faulting Scenario (Differential analysis only)

Rank	10,000 yr	50,000 yr
1	FEROI-Tn	none
2	SFWt%F0	none
3	NEFZnW	none

Insights from Sensitivity Analyses

- Several of the methods gave widely different results for sensitivity coefficients:

At the 10,000 year TPI

- Statistical, Parameter tree, and Differential analysis gave high importance to water infiltration and fuel contact parameters.

- Morris Method gave high importance to corrosion and reflux parameters.

At the 50,000 year TPI, there was more agreement among the methods on the important parameters.

- Logarithmic transformations gave better fits in terms of reduction in variance, but may distort results for higher dose categories.

- Standardized sensitivity coefficients must be used to correctly rank important variables.

Alternative Conceptual Models

- Define alternative models of performance of waste package, waste form and geosphere
- Compare alternative models to base case
- Restrict to 250 vectors per run for relative comparison
- Consider 20 Km receptor group
- Look at two TPIs :

  - Less than 10,000 years

  - Less than 50,000 years

Alternative conceptual models (Cont'd)

- Base - 250 vector base case for comparison to other conceptual models. 20 Km critical group, 50,000 year maximum time, alloy C-22 inner container, no backfill, no matrix diffusion, bathtub model, no cladding protection

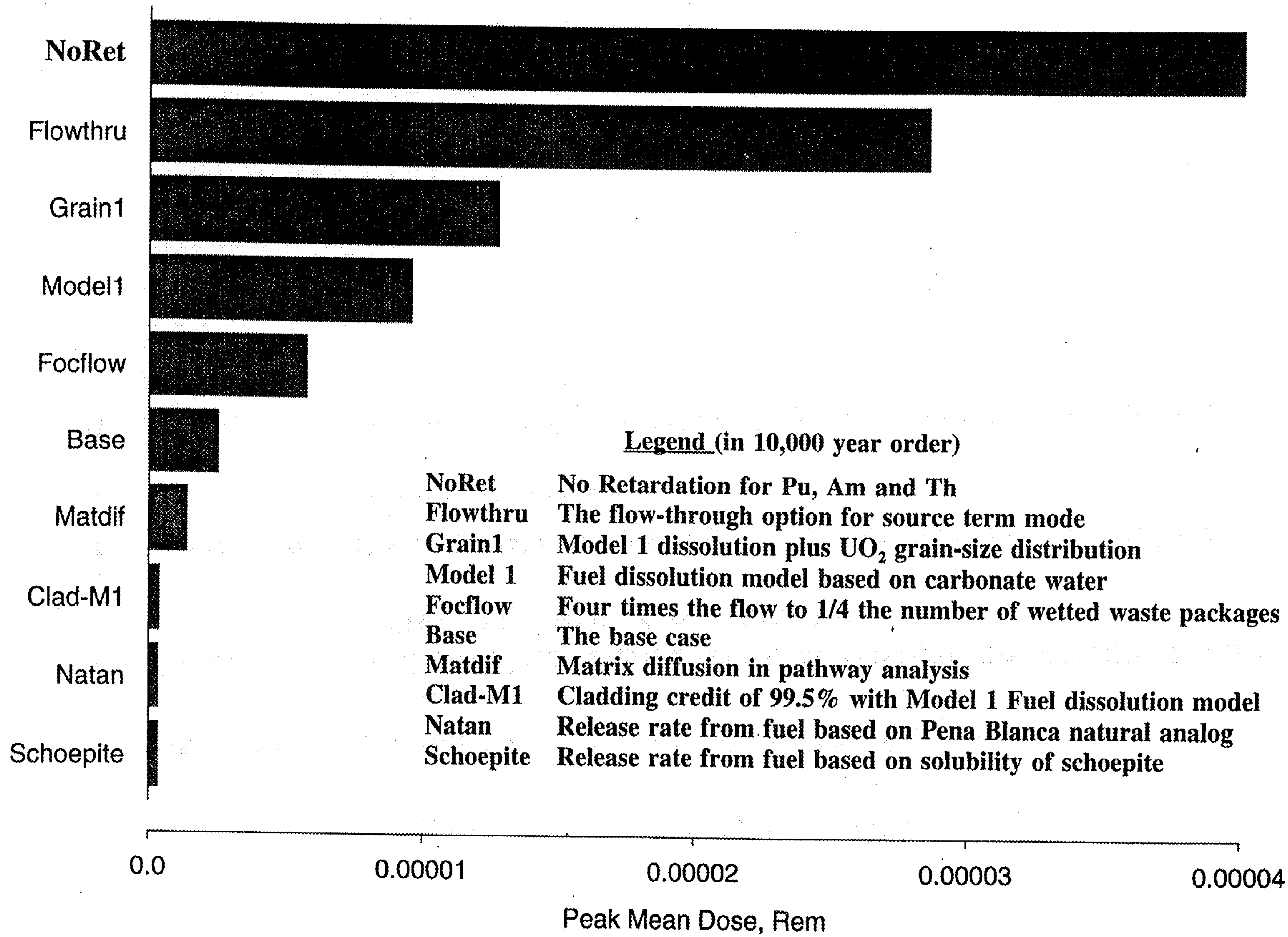
  The following runs differ from the Base Case:

- NoRet — No retardation for Pu, Am and Th
- Model 1 — Fuel dissolution model based on carbonate water
- Matdif — Matrix diffusion in legs with fracture flow
- Flowthru — The flow-though option for source term model
- Focflow — Four times the flow to 1/4 the number of wetted waste packages

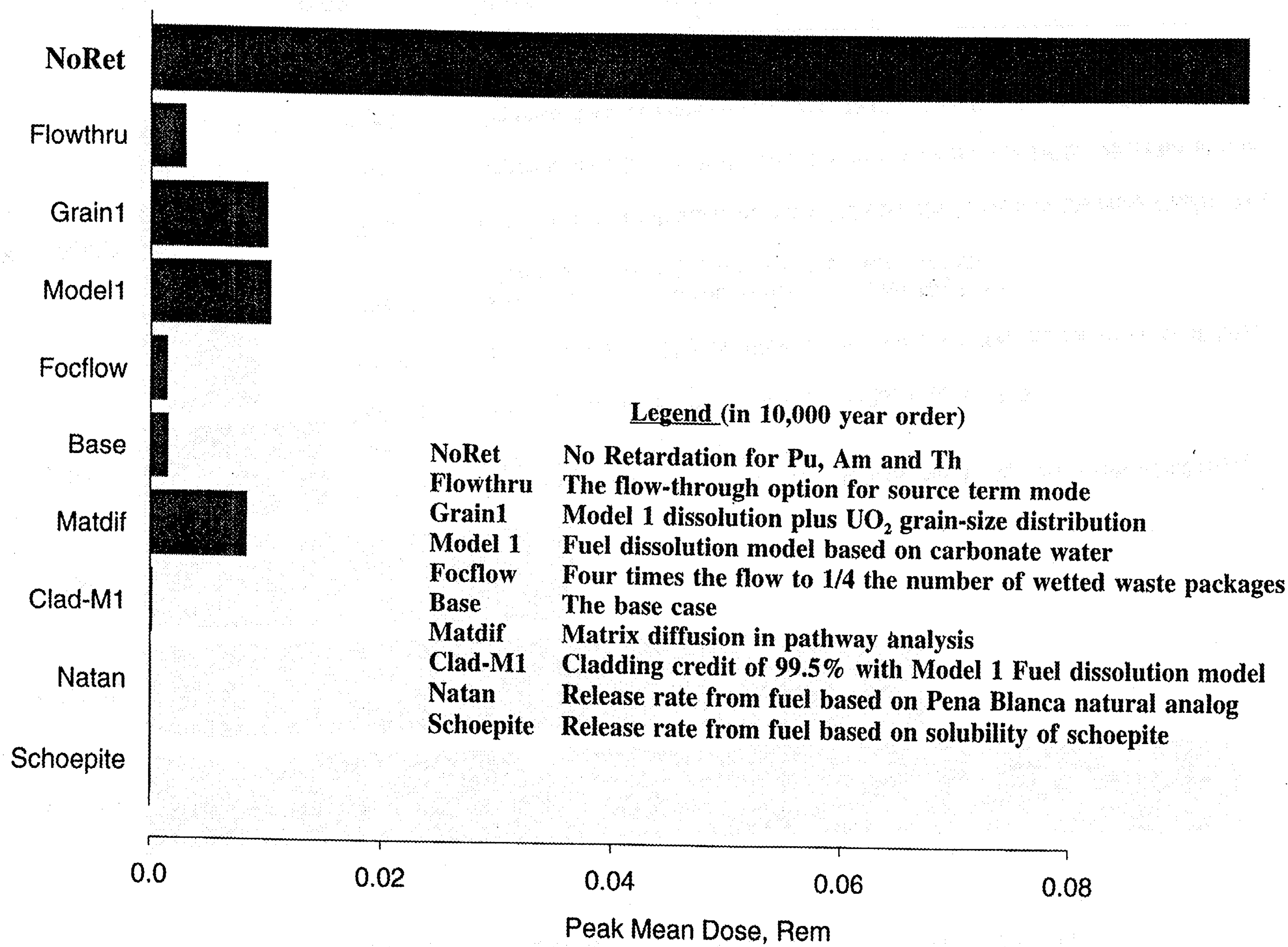
Alternative conceptual models (Cont'd)

- Clad-M1 — Cladding credit of 99.5% for Model 1 fuel dissolution
- Natan — Radionuclide release rate tied to observed release rate from natural analog at Pena Blanca site.
- Schoepite — Release rate depends on dissolution rate of secondary mineral, schoepite.
- Grain1 — Grain size UO_2 model with carbonate water dissolution

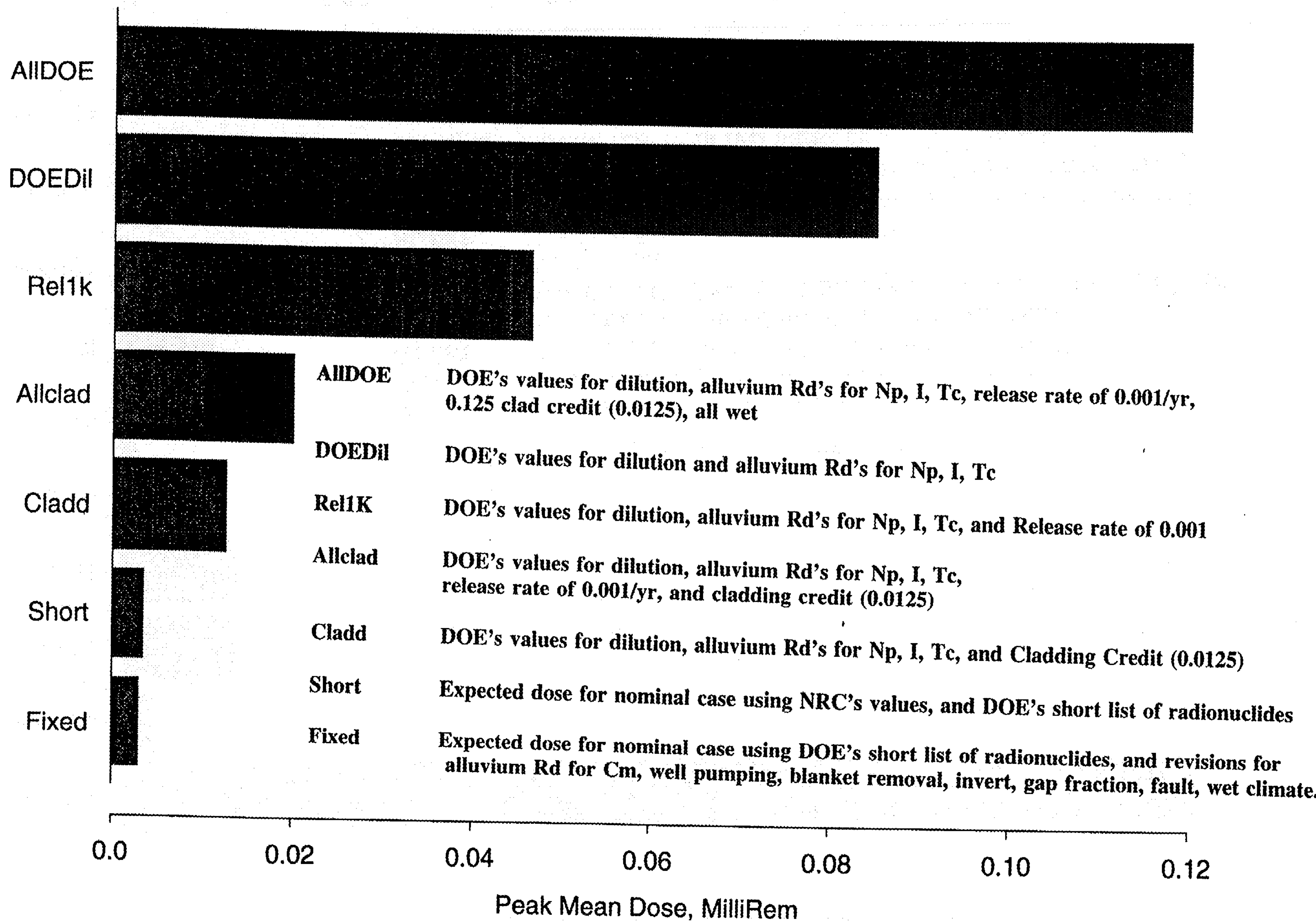
Peak Mean Dose for 10,000 Years, Rem

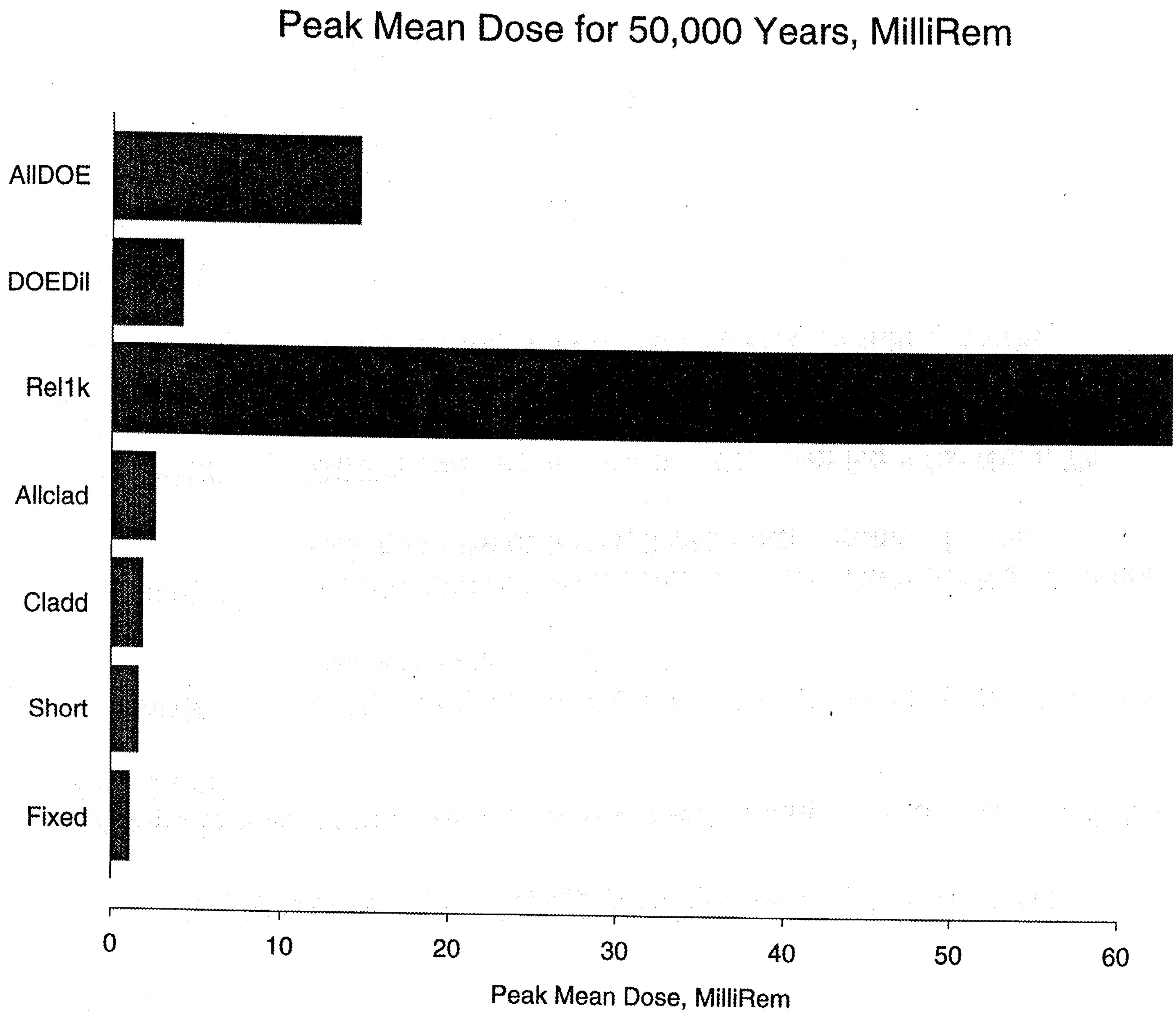


Peak Mean Dose for 50,000 Years, Rem



Peak Mean Dose for 10,000 Years, MilliRem




Peak Mean Dose for 50,000 Years, MilliRem
AllDOE
DOEDil
Rel1k
Allclad
Cladd
Short
Fixed
0
10
20
30
40
50
60
Peak Mean Dose, MilliRem

Comparison of NRC Model with DOE Inputs

Compare NRC's base case model to variants using DOE's inputs with NRC TPA3.2 code.

- **Rel1K** — DOE's values for dilution, alluvium Rd's for Np, I, Tc and Release rate of 0.001
- **AllDOE** — DOE's values for dilution, alluvium Rd's for Np, I, Tc and Release rate of 0.001, 0.0125 clad credit, all wet.
- **DOEDil** — DOE's values for dilution, alluvium Rd's for Np, I, Tc
- **Allclad** — DOE's values for dilution, alluvium Rd's for Np, I, Tc and Release rate of 0.001, and 0.0125 cladding credit

Comparison of NRC's Model with DOE inputs (Cont'd)

- **Cladd** — DOE's values for dilution, alluvium Rd's for Np, I, Tc and 0.0125 cladding credit
- **Short** — Expected dose for base case using NRC's values and DOE's shortened list of radionuclides
- **Fixed** — Expected dose for base case using DOE's short list of radionuclides and revisions for alluvium Rd for Cm, well pumping, blanket removal, invert model, gap fraction, faulting and wet climate evolution

Other Sensitivity Studies

- Models for colloids and the glass waste form absent from TPA 3.2, and may need to be added to it.

- Analyses represents *scoping* studies by NRC staff, which may be followed by a more-thorough analysis by CNWRA.

Effect of glass waste form

- Used DOE's model from TSPA-VA to adjust input parameters for TPA 3.2.

- Model assumptions include:
  - Relative dose for spent fuel and glass is proportional to the inventories of largest contributing radionuclides.
  - Relative dose is related, but not proportional to, release rate.
  - Temperature of the glass and spent-fuel waste forms is same
  - The glass waste form wetted in same way as spent fuel

Effect of Glass Waste Form (Cont'd)

- Conservatively conclude largest dose increase to be:
- 15% for 10,000 year TPI
- 5% for 50,000 year TPI

These are minor differences, but more thorough analysis may be necessary before glass source term can be ignored.

Effect of Colloids

- Simple dilution analysis
  - Used average value of 300 pCi/ml Pu from DOE laboratory data on plutonium release from spent fuel samples, assumed 100% colloidal
  - 7760 waste packages, 2.5 liter/yr/waste package at 10,000 years
  - No pathway retardation
  - Total quantity release rate enters user well at 20 km with average pumping rate of 8,750,000 gallons per day
- Dose from Pu in drinking water 1.25 millirem
- Would increase less than factor of 10 by including other radionuclides like Am and other dose pathways
- Literature survey of colloid transport shows many instances of large removal fraction by filtration.

Summary and Conclusions

Sensitivity Analysis

- Staff explored a number of sensitivity techniques to analyze the importance of variables in the TPA 3.2 code.
- There is a sometimes wide discrepancy among the results from the different sensitivity approaches, not all of which can be explained.
- The statistical regression analysis, differential analysis and parameter tree methods gave similar results, emphasizing the importance of water infiltration parameters and fuel wetting, especially at the 10,000 yr TPI.
- The Morris method emphasized the importance of corrosion and reflux parameters at 10,000 year TPI.
- Agreement among sensitivity methods was more consistent at the 50,000 yr TPI.

Summary and Conclusions (Cont'd)

Alternative Conceptual Models

- Largest impacts for both 10,000 yr and 50,000 yr TPI's came from assumption of zero retardation for Pu, Am and Th.
- No alternative conceptual models showed non-compliance with proposed standard at 10,000 yr TPI.
- Importance of assumptions about waste form dissolution, cladding protection and wetting models demonstrated.
- Doses were very small for source term models based on natural analog and reasonable alternative models for secondary minerals.
- Results of NRC models with DOE input parameters point out wide discrepancy about basic assumptions for source-term and transport parameters.

Summary and Conclusions (Cont'd)

Sensitivity analyses have directed staff into areas of model and code improvement:

- Initial indications are that colloid modeling and glass source term may not have a large impact on doses at 10,000 years.
- Most significant input variables relate to infiltration, fuel wetting, and retardation of key radionuclides (Np, I and Tc) in the alluvium.

Backup Figures

Scaled Power Transformation

- Based on principal that regression works best when tails of distributions of variables do not have undue influence

- One way of accomplishing this objective is to "scale" the distribution to make in more normal. For a variable *v* and power *p* (*p* not equal to 0), the scaled power transformation is:

$$v^{(p)} = \frac{(v^p - 1)}{p}$$

Chose value of p to make transformed distribution closest to a normal distribution. Use the Lilliefors test for normality

Use of t-Test in Regression

- **Estimate confidence level that an estimated sensitivity (slope of a regression) is different from zero:**

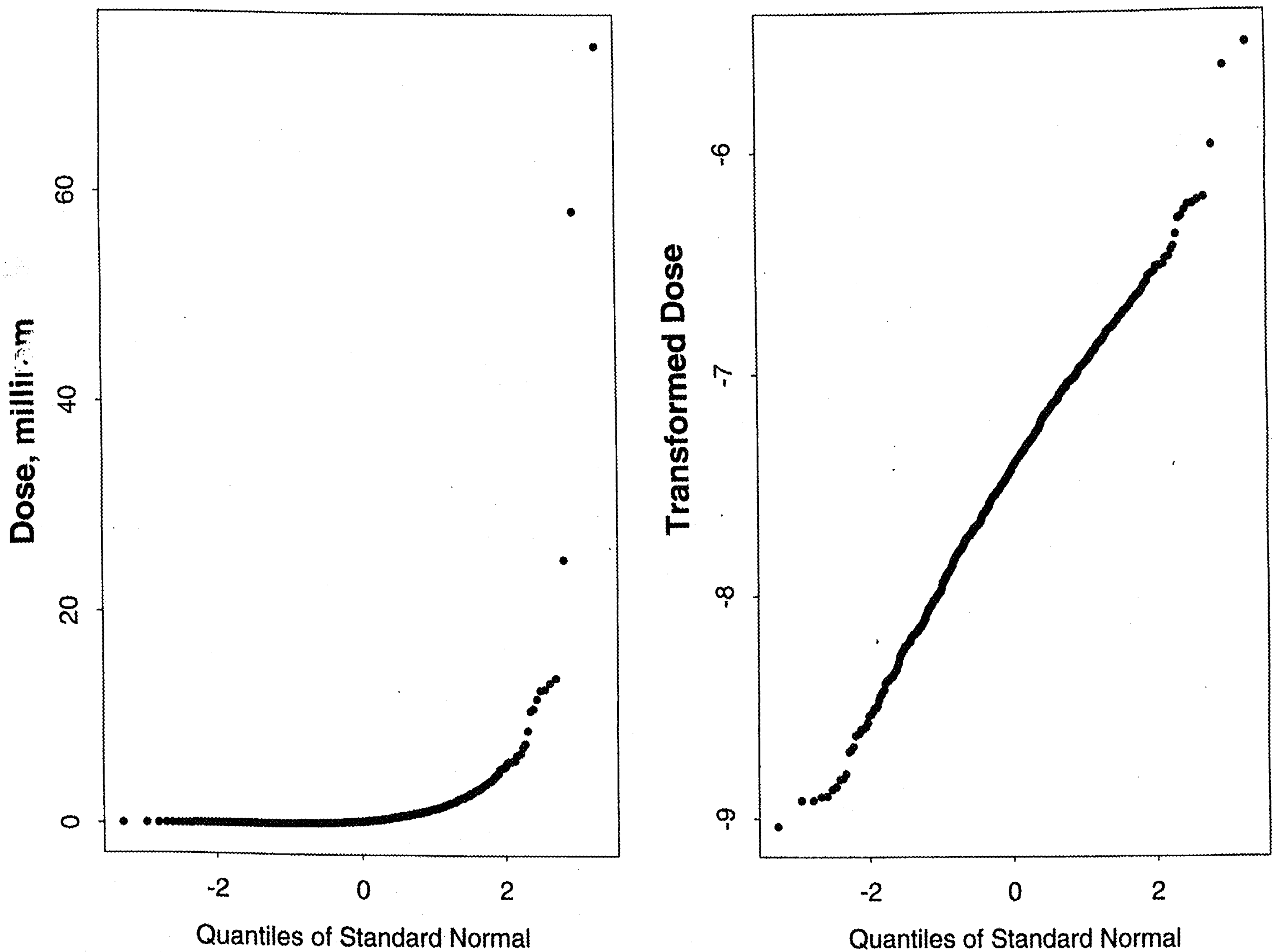
The t statistic of the slope of a single-variable regression line is defined:

$$t_i = m_i \sqrt{n \frac{S^2}{S_{i,x}^2}}$$

where

t_i	—	**t-statistic for regression coefficient *i***
m_i	—	**estimated value of regression coefficient *I* (i.e., slope of the best-fit line for dose verus the independent variable *i*)**
S	—	**estimated standard deviation of dose**
$S_{i,x}$	—	**estimated standard deviation of independent variable i**
n		**number of samples**

Scaled Power Transformation of Peak Dose at 10,000 years



Variable Names Used in TPA 3.2

1 AAMAI@S AreaIAverageMeanAnnualInfiltrationAtStart[mm/yr]
2 MAPM@GM MeanAveragePrecipitationMultiplierAtGlacialMaximum
3 MATI@GM MeanAverageTemperatureIncreaseAtGlacialMaximum[degC]
4 FOC-R FractionOfCondensateRemoved[1/yr]
5 FOCTR FractionOfCondensateTowardRepository[1/yr]
6 FOCTR-R FractionOfCondensateTowardRepositoryRemoved[1/yr]
7 TempGrBl TemperatureGradientInVicinityOfBoilingIsotherm[K/m]
8 YMR-TC ThermalConductivityofYMRock[W/(m-K)]
9 CritRHAC CriticalRelativeHumidityAqueousCorrosion
10 H2O-FThk ThicknessOfWaterFilm[m]
11 InnOvrEl InnerOverpackErpIntercept
12 AA_2_1 AA_2_1[C/m2/yr]
13 OO-CofLC CoefForLocCorrOfOuterOverpack
14 *Chlorid ChlorideMultFactor
15 SSMO-RE RockModulusOfElasticityforSEISMO[Pa]
16 SSMO-RPR RockPoissonRatioforSEISMO[]
17 SSMO-JS1 SEISMOJointSpacing1[m]
18 SSMO-JS2 SEISMOJointSpacing2[m]
19 SSMO-JS3 SEISMOJointSpacing3[m]
20 SSMO-JS4 SEISMOJointSpacing4[m]
21 SSMO-JS5 SEISMOJointSpacing5[m]
22 SSMOV201 VerticalExtentOfRockFall2_1[m]
23 SSMOV202 VerticalExtentOfRockFall2_2[m]
24 SSMOV203 VerticalExtentOfRockFall2_3[m]
25 SSMOV204 VerticalExtentOfRockFall2_4[m]
26 SSMOV205 VerticalExtentOfRockFall2_5[m]
27 SSMOV206 VerticalExtentOfRockFall2_6[m]
28 SSMOV207 VerticalExtentOfRockFall2_7[m]
29 SSMOV208 VerticalExtentOfRockFall2_8[m]
30 SSMOV209 VerticalExtentOfRockFall2_9[m]
31 SSMOV210 VerticalExtentOfRockFall2_10[m]
32 SSMOV301 VerticalExtentOfRockFall3_1[m]
33 SSMOV302 VerticalExtentOfRockFall3_2[m]
34 SSMOV303 VerticalExtentOfRockFall3_3[m]
35 SSMOV304 VerticalExtentOfRockFall3_4[m]
36 SSMOV305 VerticalExtentOfRockFall3_5[m]
37 SSMOV306 VerticalExtentOfRockFall3_6[m]
38 SSMOV307 VerticalExtentOfRockFall3_7[m]
39 SSMOV308 VerticalExtentOfRockFall3_8[m]
40 SSMOV309 VerticalExtentOfRockFall3_9[m]
41 SSMOV310 VerticalExtentOfRockFall3_10[m]
42 SSMOV401 VerticalExtentOfRockFall4_1[m]
43 SSMOV402 VerticalExtentOfRockFall4_2[m]
44 SSMOV403 VerticalExtentOfRockFall4_3[m]
45 SSMOV404 VerticalExtentOfRockFall4_4[m]
46 SSMOV405 VerticalExtentOfRockFall4_5[m]
47 SSMOV406 VerticalExtentOfRockFall4_6[m]
48 SSMOV407 VerticalExtentOfRockFall4_7[m]
49 SSMOV408 VerticalExtentOfRockFall4_8[m]
50 SSMOV409 VerticalExtentOfRockFall4_9[m]
51 SSMOV410 VerticalExtentOfRockFall4_10[m]
52 SSMOV501 VerticalExtentOfRockFall5_1[m]
53 SSMOV502 VerticalExtentOfRockFall5_2[m]
54 SSMOV503 VerticalExtentOfRockFall5_3[m]
55 SSMOV504 VerticalExtentOfRockFall5_4[m]
56 SSMOV505 VerticalExtentOfRockFall5_5[m]
57 SSMOV506 VerticalExtentOfRockFall5_6[m]
58 SSMOV507 VerticalExtentOfRockFall5_7[m]
59 SSMOV508 VerticalExtentOfRockFall5_8[m]
60 SSMOV509 VerticalExtentOfRockFall5_9[m]
61 SSMOV510 VerticalExtentOfRockFall5_10[m]
62 Fow* FowFactor
63 Fmult* FmultFactor
64 SbArWt% SubAreaWetFraction
65 WP-Def% DefectiveFractionOfWPs/cell
66 InitRSFP InitialRadiusOfSFParticle[m]
67 SbGFRATF SubGrainFragmentRadiusAfterTransFrac[m]
68 Solbl-Am SolubilityAm[kg/m3]
69 Solbl-Np SolubilityNp[kg/m3]
70 Solbl-Pu SolubilityPu[kg/m3]
71 SFWt%I1 SFWettedFraction_Initial_1
72 SFWt%I2 SFWettedFraction_Initial_2
73 SFWt%I3 SFWettedFraction_Initial_3
74 SFWt%I4 SFWettedFraction_Initial_4
75 SFWt%I5 SFWettedFraction_Initial_5
76 SFWt%I6 SFWettedFraction_Initial_6
77 SFWt%I7 SFWettedFraction_Initial_7
78 SFWt%F0 SFWettedFraction_FAULTO
79 SFWt%V0 SFWettedFraction_VOLCANO
80 SFWt%S11 SFWettedFraction_SEISMO1_1
81 SFWt%S12 SFWettedFraction_SEISMO1_2
82 SFWt%S13 SFWettedFraction_SEISMO1_3
83 SFWt%S14 SFWettedFraction_SEISMO1_4
84 SFWt%S15 SFWettedFraction_SEISMO1_5
85 SFWt%S16 SFWettedFraction_SEISMO1_6
86 SFWt%S17 SFWettedFraction_SEISMO1_7
87 SFWt%S21 SFWettedFraction_SEISMO2_1
88 SFWt%S22 SFWettedFraction_SEISMO2_2
89 SFWt%S23 SFWettedFraction_SEISMO2_3
90 SFWt%S24 SFWettedFraction_SEISMO2_4
91 SFWt%S25 SFWettedFraction_SEISMO2_5
92 SFWt%S26 SFWettedFraction_SEISMO2_6
93 SFWt%S27 SFWettedFraction_SEISMO2_7
94 SFWt%S31 SFWettedFraction_SEISMO3_1
95 SFWt%S32 SFWettedFraction_SEISMO3_2
96 SFWt%S33 SFWettedFraction_SEISMO3_3
97 SFWt%S34 SFWettedFraction_SEISMO3_4
98 SFWt%S35 SFWettedFraction_SEISMO3_5
99 SFWt%S36 SFWettedFraction_SEISMO3_6
100 SFWt%S37 SFWettedFraction_SEISMO3_7
101 SFWt%S41 SFWettedFraction_SEISMO4_1
102 SFWt%S42 SFWettedFraction_SEISMO4_2
103 SFWt%S43 SFWettedFraction_SEISMO4_3
104 SFWt%S44 SFWettedFraction_SEISMO4_4
105 SFWt%S45 SFWettedFraction_SEISMO4_5
106 SFWt%S46 SFWettedFraction_SEISMO4_6
107 SFWt%S47 SFWettedFraction_SEISMO4_7
108 SFWt%C1 SFWettedFraction_Corrosion_1
109 SFWt%C2 SFWettedFraction_Corrosion_2
110 SFWt%C3 SFWettedFraction_Corrosion_3
111 SFWt%C4 SFWettedFraction_Corrosion_4
112 SFWt%C5 SFWettedFraction_Corrosion_5
113 SFWt%C6 SFWettedFraction_Corrosion_6
114 SFWt%C7 SFWettedFraction_Corrosion_7
115 InvMPerm InvertMatrixPermeability[m^2]
116 MKDTSwAm MatrixKD_TSw_Am[m3/kg]
117 MKDCHvAm MatrixKD_CHnvAm[m3/kg]
118 MKDCHzAm MatrixKD_CHnzAm[m3/kg]
119 MKDPPwAm MatrixKD_PPw_Am[m3/kg]
120 MKDUCFAm MatrixKD_UCF_Am[m3/kg]
121 MKDBFwAm MatrixKD_BFw_Am[m3/kg]
122 MKDUFZAm MatrixKD_UFZ_Am[m3/kg]
123 MKDTSwNp MatrixKD_TSw_Np[m3/kg]
124 MKDCHvNp MatrixKD_CHnvNp[m3/kg]
125 MKDCHzNp MatrixKD_CHnzNp[m3/kg]
126 MKDPPwNp MatrixKD_PPw_Np[m3/kg]
127 MKDUCFNp MatrixKD_UCF_Np[m3/kg]
128 MKDBFwNp MatrixKD_BFw_Np[m3/kg]
129 MKDUFZNp MatrixKD_UFZ_Np[m3/kg]
130 MKD_TSwU MatrixKD_TSw_U[m3/kg]
131 MKD_CHvU MatrixKD_CHnvU[m3/kg]
132 MKD_CHzU MatrixKD_CHnzU[m3/kg]
133 MKD_PPwU MatrixKD_PPw_U[m3/kg]
134 MKD_UCFU MatrixKD_UCF_U[m3/kg]
135 MKD_BFwU MatrixKD_BFw_U[m3/kg]
136 MKDUFZ_U MatrixKD_UFZ_U[m3/kg]
137 MKDTSwPu MatrixKD_TSw_Pu[m3/kg]
138 MKDCHvPu MatrixKD_CHnvPu[m3/kg]
139 MKDCHzPu MatrixKD_CHnzPu[m3/kg]
140 MKDPPwPu MatrixKD_PPw_Pu[m3/kg]
141 MKDUCFPu MatrixKD_UCF_Pu[m3/kg]
142 MKDBFwPu MatrixKD_BFw_Pu[m3/kg]
143 MKDUFZPu MatrixKD_UFZ_Pu[m3/kg]
144 MKDTSwTh MatrixKD_TSw_Th[m3/kg]
145 MKDCHvTh MatrixKD_CHnvTh[m3/kg]
146 MKDCHzTh MatrixKD_CHnzTh[m3/kg]
147 MKDPPwTh MatrixKD_PPw_Th[m3/kg]
148 MKDUCFTh MatrixKD_UCF_Th[m3/kg]
149 MKDBFwTh MatrixKD_BFw_Th[m3/kg]
150 MKDUFZTh MatrixKD_UFZ_Th[m3/kg]
151 MKDTSwSe MatrixKD_TSw_Se[m3/kg]

152 MKDCHvSe MatrixKD_CHnvSe[m3/kg]
153 MKDCHzSe MatrixKD_CHnzSe[m3/kg]
154 MKDPPwSe MatrixKD_PPw_Se[m3/kg]
155 MKDUCFSe MatrixKD_UCF_Se[m3/kg]
156 MKDBFwSe MatrixKD_BFw_Se[m3/kg]
157 MKDUFZSe MatrixKD_UFZ_Se[m3/kg]
158 MPrm_TSw MatrixPermeability_TSw_[m2]
159 MPrm_CHv MatrixPermeability_CHnv[m2]
160 MPrm_CHz MatrixPermeability_CHnz[m2]
161 MPrm_PPw MatrixPermeability_PPw_[m2]
162 MPrm_UCF MatrixPermeability_UCF_[m2]
163 MPrm_BFw MatrixPermeability_BFw_[m2]
164 MPrm_UFZ MatrixPermeability_UFZ_[m2]
165 FPrm_TSw FracturePermeability_TSw_[m2]
166 FPrm_CHv FracturePermeability_CHnv[m2]
167 FPrm_CHz FracturePermeability_CHnz[m2]
168 FPrm_PPw FracturePermeability_PPw_[m2]
169 FPrm_UCF FracturePermeability_UCF_[m2]
170 FPrm_BFw FracturePermeability_BFw_[m2]
171 FPrm_UFZ FracturePermeability_UFZ_[m2]
172 FPrs_TSw FracturePorosity_TSw_
173 FPrs_CHv FracturePorosity_CHnv
174 FPrs_CHz FracturePorosity_CHnz
175 FPrs_PPw FracturePorosity_PPw_
176 FPrs_UCF FracturePorosity_UCF_
177 FPrs_BFw FracturePorosity_BFw_
178 FPrs_UFZ FracturePorosity_UFZ_
179 ARDSAVAm AlluviumMatrixRD_SAV_Am
180 ARDSAVNp AlluviumMatrixRD_SAV_Np
181 ARDSAV_I AlluviumMatrixRD_SAV_I
182 ARDSAVTc AlluviumMatrixRD_SAV_Tc
183 ARDSAV_U AlluviumMatrixRD_SAV_U
184 ARDSAVPu AlluviumMatrixRD_SAV_Pu
185 ARDSAVTh AlluviumMatrixRD_SAV_Th
186 ARDSAVSe AlluviumMatrixRD_SAV_Se
187 FPrs_STF FracturePorosity_STFF
188 APrs_SAV AlluviumMatrixPorosity_SAV
189 WPRRG@10 WellPumpingRateAtReceptorGroup10km[gal/day]
190 WPRRG@20 WellPumpingRateAtReceptorGroup20km[gal/day]
191 PlumeTh5 PlumeThickness5km[m]
192 AqThick5 AquiferThickness5km[m]
193 MixZnT20 MixingZoneThickness20km[m]
194 FEROI-Tn TimeOfNextFaultingEventinRegionOfInterest[yr]
195 WPFD-ThD ThresholdDisplacementforFaultDisruptionOfWP[m]
196 FEROI-X XLocationOfFaultingEventInRegionOfInterest[m]
197 FEROI-Y YLocationOfFaultingEventInRegionOfInterest[m]
198 FO-Rn#Sd RNtoDetermineFaultOrientation
199 NWFZnW NWFaultZoneWidth[m]
200 NEFZnW NEFaultZoneWidth[m]
201 NWLCDAmt NWAmountOfLargestCredibleDisplacement[m]
202 NELCDAmt NEAmountOfLargestCredibleDisplacement[m]
203 VEROI-Tn TimeOfNextVolcanicEventinRegionOfInterest[yr]
204 VEi/e-R# RNtoDetermineIfExtrusiveOrIntrusiveVolcanicEvent
205 VD-Angle AngleOfVolcanicDikeMeasuredFromNorthClockwise[degrees]
206 VD-Lengt LengthOfVolcanicDike[m]
207 VD-Width WidthOfVolcanicDike[m]
208 VC-Dia DiameterOfVolcanicCone[m]
209 WindSpd WindSpeed[cm/s]
210 VE-Durat VolcanicEventDuration[s]
211 VE-Power VolcanicEventPower[W]
212 AshMnPLD AshMeanParticleLogDiameter[d_in_cm]
213 ABMLFVDC AirborneMassLoadForVolcanismDoseCalculation[g/m3]

NRC INSIGHTS ON PRESENTATION OF PA RESULTS

Presented by

James Weldy

(210)522-6800

jweldy@swri.org

Center for Nuclear Waste Regulatory Analyses

Contributors: T. McCartin (NRC), S. Mohanty, C. Lui (NRC), R. Rice

May 25-27, 1999

San Antonio, Texas

NRC/DOE Technical Exchange on

Total System Performance Assessments for Yucca Mountain

Attachment 7

TOPICS

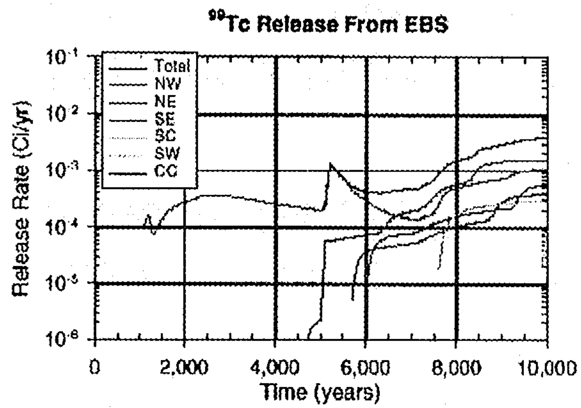
- Components of Transparency and Traceability
- What Has Helped NRC Understanding of VA
- Areas Where the VA Could Have Been More Transparent and Traceable

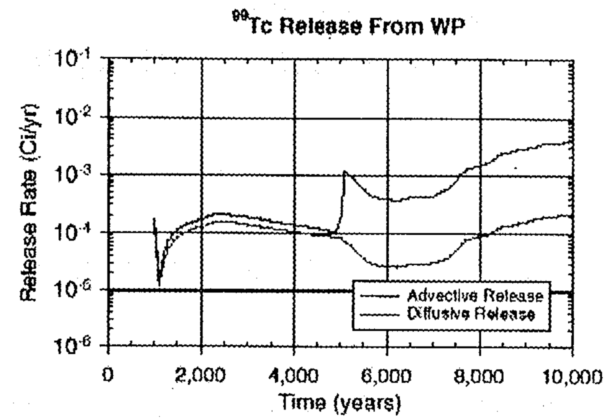
COMPONENTS OF TRANSPARENCY AND TRACEABILITY

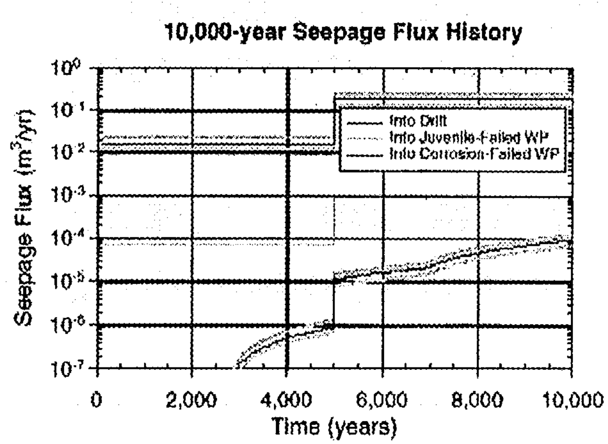
- Clear Identification of Data Transfer From One Component or Model to Another in the Description of the TSPA
- Demonstration of Consistent Treatment of Uncertain Parameters Sampled at the System and Component Levels
- Clear Description of Bases for Models of the TSPA and Data Used in the TSPA
- Clear Identification of Those Portions of the System That Have a Significant Impact on Performance of the Overall Repository

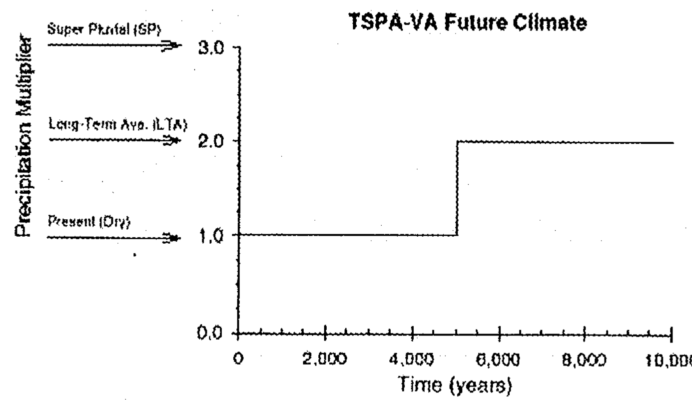
WHAT HAS HELPED NRC UNDERSTANDING OF VA

- **Extensive Plots of Intermediate Outputs**



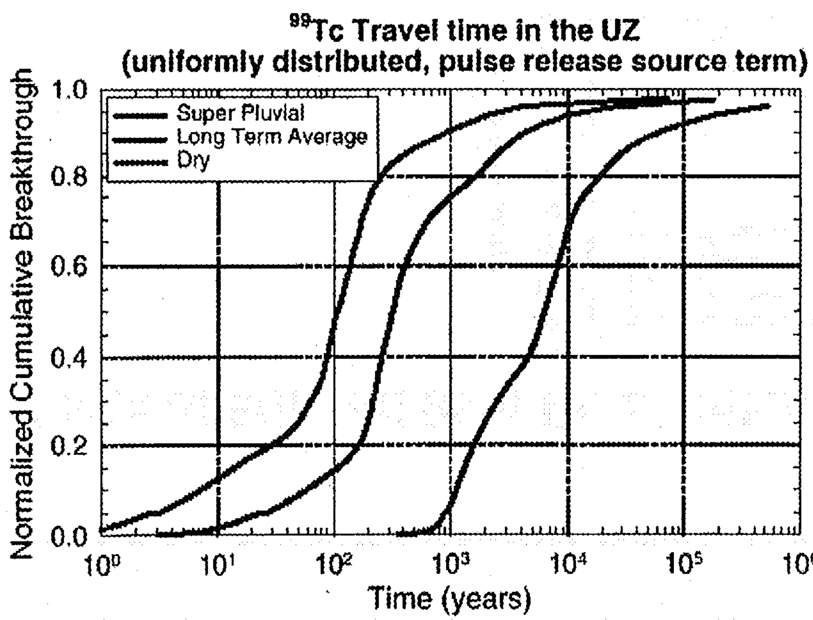


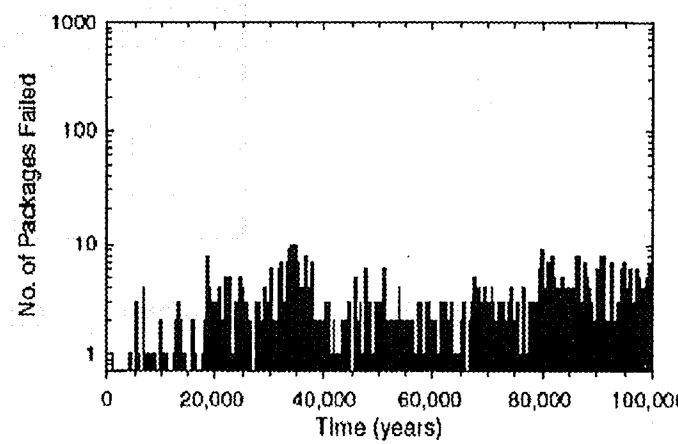




WHAT HAS HELPED NRC UNDERSTANDING OF VA

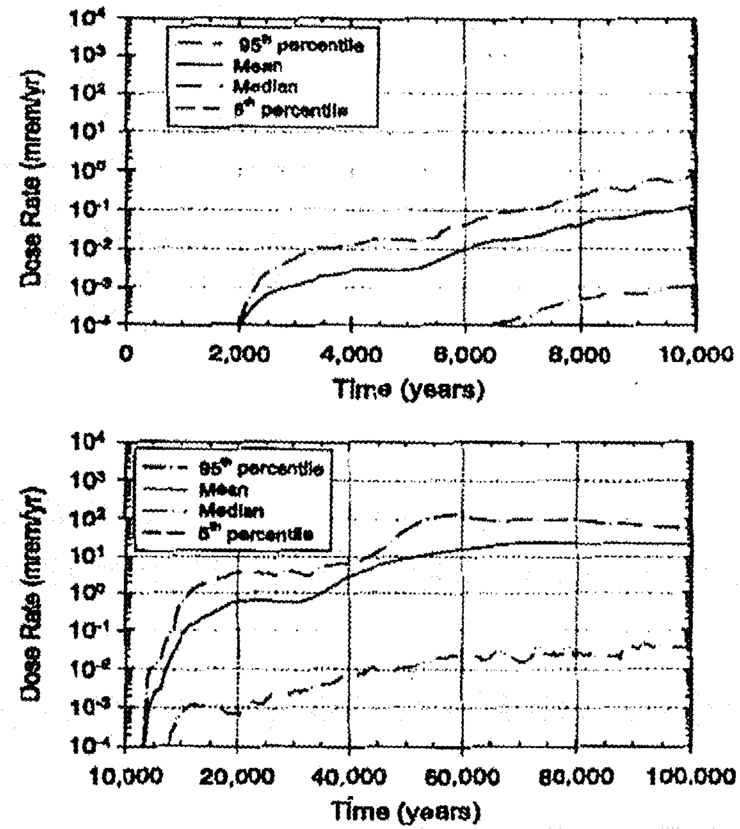
- Text Description of How the System Is Performing Over Various Time Periods
- Plots of the Performance of Subsystems Such As Travel Times and Waste Package Lifetimes





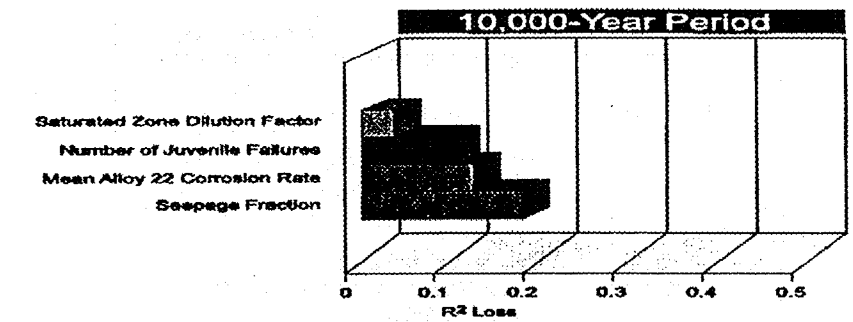
WHAT HAS HELPED NRC UNDERSTANDING OF VA

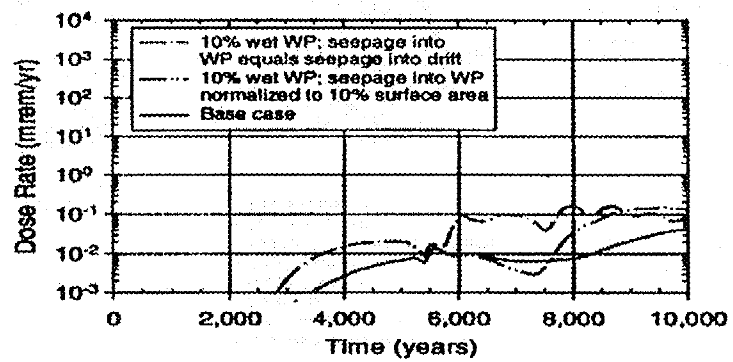
- **Plots of 5th and 95th Percentiles of the Dose-rate Distribution**

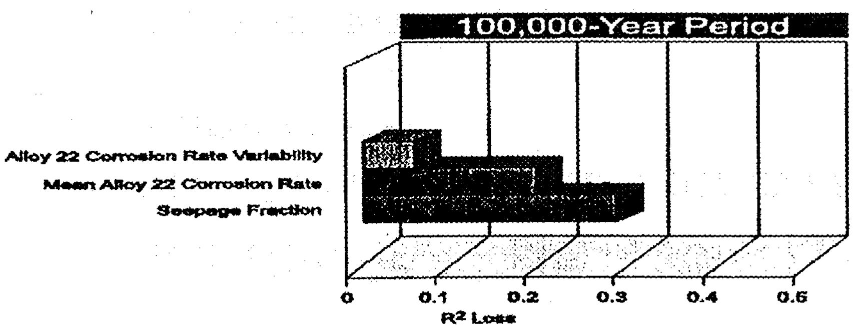


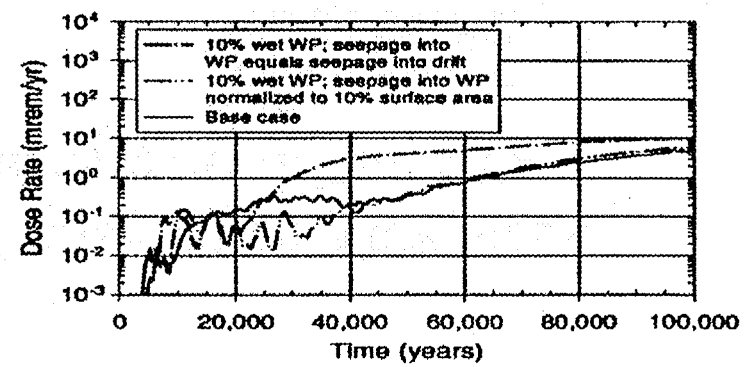
WHAT HAS HELPED NRC UNDERSTANDING OF VA

- **Plots of the Results of Sensitivity Analyses and of Alternative Conceptual Models**









WHAT HAS HELPED NRC UNDERSTANDING OF VA

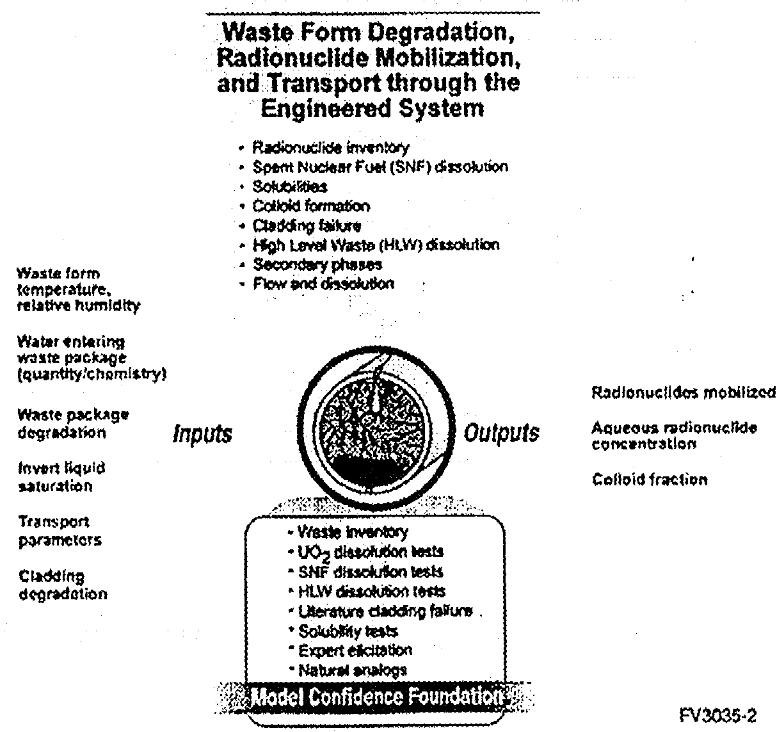
- **Tables That Provide a Summary of Abstraction Workshops**
- **Figures That Summarize Inputs and Outputs of TSPA-VA Components**

UNSATURATED ZONE FLOW ABSTRACTION/TESTING WORKSHOP
December 11–13, 1996, Albuquerque, NM
(CRWMS M&O 1997l)

PRIORITIZATION CRITERIA
- Does the issue have a strong effect on:
  - Percolation flux at the repository?
  - Seepage into the drift?
  - The partitioning of flow between the fractures and matrix?
- Will the issue be important to flow and transport below the repository?

Highest Priority Issues
- Infiltration and future climate
- Model calibration
- Lateral flow and perched water below the repository
- Flow channeling and seepage into the drift

Analysis Plans
- Sensitivity studies conducted on the site-scale model to determine abstraction methods for unsaturated zone flow
- Seepage into drifts under pre-waste-emplacement conditions
- Testing of perched-water concepts and their implications for TSPA-VA calculations
- Sub-grid-scale fractures and model calibration



FV3035-2

AREAS WHERE THE VA COULD HAVE BEEN MORE TRANSPARENT AND TRACEABLE

- Information Flow From Components to the System Code
  - The Flow of Key Information Between the RIP Code and External Process Models Is Difficult to Trace
- Sampling of Uncertain Parameters Outside of the TSPA-VA Code
  - Difficult to Determine Whether Correlations Among the Sampled Parameters Have Been Accounted for Properly
  - Inadequate Sampling of Parameters Potentially Important to Performance

AREAS WHERE THE VA COULD HAVE BEEN MORE TRANSPARENT AND TRACEABLE

- **Mathematical Basis for Lumped Parameters Used to Account for Complex Physical Processes Should Be Included, at Least in a Limited Manner, in the TSPA**
  - **Having to Refer to Technical Basis Document Exclusively to Trace the Basis for These Parameters Is Inconvenient**
- **It Would Be Useful If the VA Had Contained a Table Listing All Important Input Parameter Values and Distributions**
  - **This Would Make It Easier for NRC to Review and Easier for DOE to Check Numbers for Consistency**

AREAS WHERE THE VA COULD HAVE BEEN MORE TRANSPARENT AND TRACEABLE

- **The Depth of the Description of the Modeling Approach for a System or Process Should Be Consistent With the Importance of That System or Process With Respect to Performance**

SUMMARY

- The Transparency and Traceability of the TSPA-VA Is a Significant Improvement Over Previous Versions of the DOEs TSPAs

- Continued Dialog Between NRC and DOE Will Help to Improve the Transparency and Traceability of TSPA-LA Which Will Facilitate the NRC Review of the License Application

NRC INSIGHTS ON DESIGN AND WASTE PACKAGE FAILURE

Sitakanta Mohanty
(210)522-5185 (smohanty@swri.org)
Center for Nuclear Waste Regulatory Analyses

Contributors: G. Cragnolino, O. Pensado, S. Brossia (CNWRA)
M. Rahimi (NRC)

May 25-27, 1999
San Antonio, Texas

NRC/DOE Technical Exchange on
Total System Performance Assessments for Yucca Mountain

Attachment 8

OBJECTIVES

- Determine
  - Time of Failure of Waste Packages (WPs) Containing Spent Fuel
  - Number of WPs Degraded As a Function of Time
  - Spatial Distribution of Degraded WPs in the Repository
  - Geometry of Failure Due to Degradation That Will Dictate Quantity of Water Contacting SF

FEATURES OF DOE EBS PRELIMINARY DESIGN CONCEPT FOR VA

- WPs Based on Double Wall Over-pack Design Composed of Concentric Containers of Different Materials in a Horizontal Drift Emplacement

- ASTM A516, Grade 55 Steel for Outer Over-pack (100 mm Thick)

- Alloy 22 Material for Inner Over-pack (20 mm Thick)

- Uncanistered WP Containing 21 PWR or 40 BWR Spent Fuel Assemblies With Zircaloy Fuel Cladding

- Possible Use of Drip Shield, Ceramic Coating and Backfill Upon Closure

PRESENTATION OUTLINE

- WP Degradation Modes
  - Initially Defective Failures
  - WP Corrosion - Principal Factor Leading to WP Degradation Mechanical Disruption of Waste Package
    - Fracture of the Outer Overpack Due to Thermal Embrittlement (Treated As a Part of Mechanical Failure Model in TPA)
    - Direct Disruption Due to Faulting and Igneous Activity (Treated Only As a Part of Disruptive Event Scenarios)
    - Rupture Due to Rock Falls Induced by Seismicity in an Unbackfilled Repository
- Process-level Presentations With Technical Basis by
  - N. Sridhar (Initially Defective Failure)
  - G. Cragnolino (WP Corrosion)
  - S. Hsiung (Failure Due to Rock fall)

SYSTEM-LEVEL CONSIDERATIONS

- Implementation of the Models
  - Similar Between TPA and TSPA-VA (Both Use a Stochastic Modeling Approach Inside the PA Code)

- Spatial Distribution of Degraded WPs in the Repository
  - TSPA-VA: Divided Into 6 Subareas (SA), Considers Inter- and Intra-SA Variations
  - TPA:
    - Divided Into 7 Subareas (Not Limited to Seven);
    - Uses Only Inter SA Variations, I.E., Representative WPs Are Evaluated for Each Subarea
    - Variation in Rock Characteristics, Rock Temperature, and Humidity

SYSTEM-LEVEL CONSIDERATIONS (Cont.d)

- Geometry of Failure
  - Geometry Determines Quantity of Water Entering WPs
  - TSPA-VA Primarily Considers a Flow-through Model
  - TPA Considers Bathtub (i.e., Distinct Water Retention Capacity for Each Failure Mode
    - Corrosion: SA-to-SA Variation for Bathtub Height
    - Initially Defective Failure and Rock Fall:- Same Height for All SAs but Variation From Realization to Realization

TPA CONCEPTUAL MODEL APPROACHES

- Corrosion Modes:
  - Dry Air Oxidation (Carbon Steel)
  - Humid Air and Aqueous General Corrosion (Carbon Steel)
  - Aqueous Localized Corrosion (Carbon Steel)
  - Aqueous General and Localized Corrosion (Alloy 22)
- WP Corrosion Affected by Temperature, Humidity and Water Chemistry at Waste Package Surface and Evaluated Using a Combination of Mechanistic Modeling and Experimentally Measured Parameters
  - Temperature Based on Heat Conduction Model
  - Initiation of Humid Air Corrosion and Aqueous Corrosion Determined by Critical Values of RH
  - Chemical Composition of the Aqueous Phase With NaCl As Predominant Soluble Salt, Including pH (As Determined by [HCO^-_3]) and Assuming a Constant Value Equal to Partial Pressure of O_2 in Air
- Mechanical Failure of WP Evaluated Using a Fracture Mechanics Approach

TPA CONCEPTUAL MODEL APPROACH FOR CORROSION

- **Corrosion Potential:** $E_{corr} = f(T, pH, C_{O_2}, \ldots)$
- **Localized Corrosion:** $E_{rp} = f(T, C_{Cl^-}, material)$
- **Condition for Localized Corrosion**
  - **Outer Overpack:** $E_{corr}^{A516} > E_{rp}^{A516}$ **at pH > 9 and [Cl$^-$] > 3E-4 mol/L**
  - **Inner Overpack:** $E_{WP}^{C-22} > E_{rp}^{C-22}$ **[Cl$^-$] > 1 mol/L**
- **Maximum Pit Penetration Rate for CAM:** $\frac{dP}{dt}(mm/yr) = 3.897t^{-.55}$
- **Pit Penetration Rate for Alloy 22:** $\frac{dP}{dt}(mm/yr) = 2.5E-1$

MAJOR DIFFERENCES BETWEEN TSPA-VA AND TPA MODELING

- Corrosion in the Absence of Water
  - TSPA-VA Considers Insignificant, i.e., Appreciable Corrosion Requires Presence of Water As Either Liquid or Vapor
  - TPA Computes Dry-air Corrosion but the Effect Is Small

- Corrosion in the Presence of Water
  - In TPA, Models Are Based to a Greater Degree on Fundamentals of Electrochemical Corrosion and Experiment Data
    - TPA Model Considers Environmental Factors to a Greater Degree Such As Temperature, Oxygen Partial Pressure, pH and Chloride Ion Concentration.

MAJOR DIFFERENCES BETWEEN DOE AND NRC MODELING

- TSPA-VA Models Include Processes That Are Not Included in TPA Models Such As
  - Dripping on WP
  - Modeling of Pit and Patch Failure Modes (TPA Model Has More Simplistic Failure Modes).
- In TPA, Chemistry is Incorporated Through pH (for Aqueous Corrosion Only) and Chloride Concentration
- In TSPA-VA, for the CAM, Both Humid Air and Aqueous Corrosions Are Functions of Exposure Time and Temperature Whereas Only Aqueous Corrosion Is Modeled As a Function of RH
- In TSPA-VA, Pitting Corrosion Is Incorporated Through a Time Dependent Penetration Rate

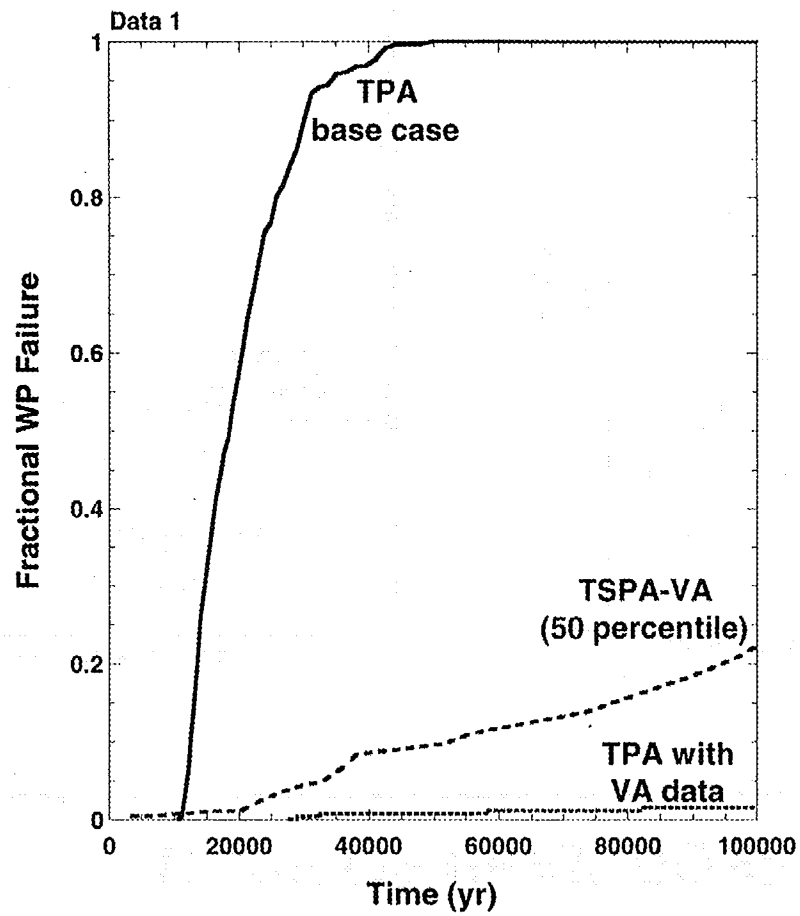
TSPA-VA PARAMETERS

- Humid Air Corrosion at 70% <= RH <= 85%
- Aqueous Corrosion at RH >= 85% (Irrespective of the Presence or Absence of the Liquid Water by Dripping or Any Other Mechanism)
- Effect of Elevated pH (>10) and Chloride Ion Not(?) Considered in the TSPA-VA Base Case
- When No Dripping, CRM Undergoes Only Generalized Corrosion
- General Corrosion of CRM Is Essentially Neglected in Humid Air Environment
- Parameter Differences Exist Between NRC and DOE for Those Aspects of Models That Are Similar
  - Corrosion Rates for Corrosion Allowance Material and Corrosion Resistant Material Are Different Than the NRC Values
  - DOE Ranges Sufficiently Wide to Include Alternate Conceptual Models.
  - DOE Relies on Expert Elicitation Based on Sparse Data for Corrosion Rates

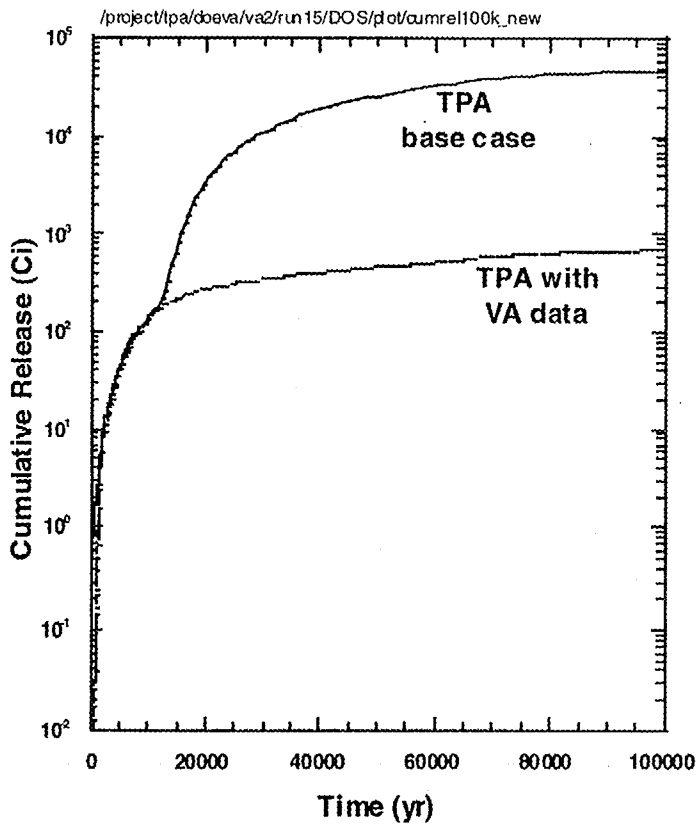
COMPARISON OF TSPA-VA AND TPA VALUES

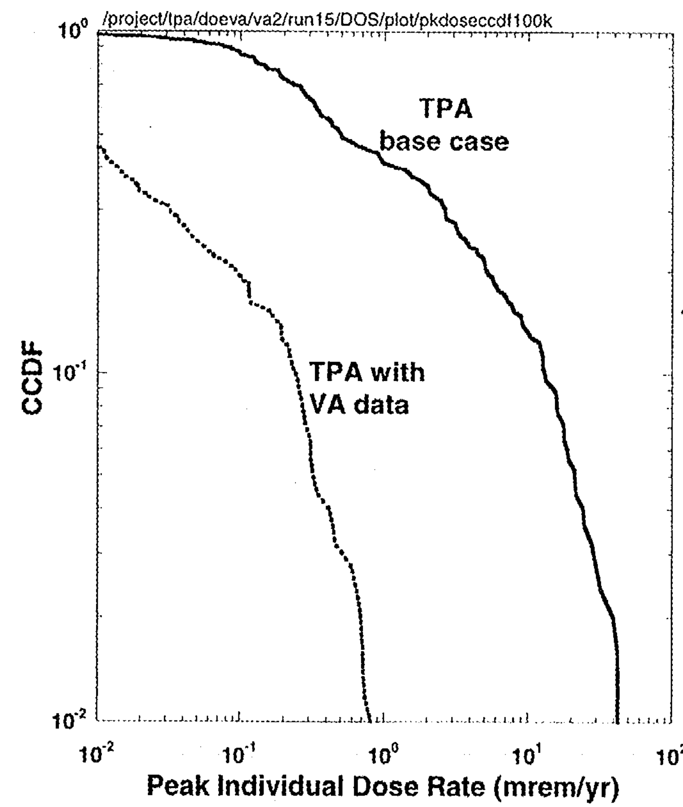
Parameters	Emulated Values to Represent TSPA-VA	TPA 3.2 Base Case
Defective Fraction of WPs/subarea	Uniform: 10^{-5} - 10^{-3} (0.06- 6.4 WPs)	Uniform: 10^{-4} - 10^{-2} (0.6 - 64 WPs)
Coefficient for localized corrosion rate of outer overpack	Lognormal: 7.9×10^{-7} - 5.6×10^{-1} (TSPA_VA, Tech. Bas. Doc. Fig. 5-20, P. F5-13)	Uniform: 8.66×10^{-4} - 8.66×10^{-3}
Corrosion rate of C-22 at 100°C and no dripping (AA_2_1)	Lognormal: 4.6 - 6.0×10^{4} $C/m^2/yr$ (1.4×10^{-7} – 1.84×10^{-3} mm/yr) (TSPA_VA, Tech. Bas. Doc. Fig. 5-23, P. F5-14)	Uniform: 2.0×10^{4} - 6.3×10^{4} $C/m^2/yr$ (6.2×10^{-4} – 2.0×10^{-3} mm/yr)

WASTE PACKAGE FAILURE



CCDF OF PEAK DOSE





SUMMARY

- For Long-lived WPs, Processes Not Included in TSPA-VA and TPA Could Accelerate Corrosion/failure (i.e., Stress Corrosion Cracking, Microbial Activity, Exposure to WP Wet/dry Cycle)

- Both NRC and DOE Acknowledge the Importance of Assessing the Propensity to Corrode the CAM by Exposing to Liquid Water

- Infiltrating Water or Re-circulating Water That Could Penetrate the Boiling Isotherm Could Be Highly Concentrated With Salt That Could Deposit on the WP Surface, Thus Leading to Higher Corrosion Rate

- Both Dripping and Temperature Between 80-100 Degree C Required for Localized Corrosion of the CRM, a Non-conservative Assumption. DOE Recognizes the Possibility of Dripping at RH Under 85%

- Negligible Aqueous Corrosion of C-22 in the Absence of Drip

DOE AND NRC APPROACHES TO MODEL THE EFFECTS OF INITIAL FAILURES OF CONTAINERS

Presented by
N. Sridhar
Center for Nuclear Waste Regulatory Analyses
(210) 522-5538 (nsridhar@swri.edu)

Technical Contributors
G. Cragnolino and T.M. Ahn

May 25, 1999
San Antonio, Texas
DOE/NRC Technical Exchange on
Total System Performance Assessment for Yucca Mountain

Attachment 9

TOPICS FOR DISCUSSION

- Definition of initial failure
- Approach used in TSPA-VA
- NRC/CNWRA approach in TPA 3.2
- Alternative considerations of initial failure

DEFINITION OF INITIAL FAILURES

- Implied in TSPA-VA and TPA 3.2
  - Failures that occur essentially instantaneously (compared to the expected period of performance) due to one or more large initial defects
  - These defects and failures are undetected during fabrication, emplacement, and performance confirmation periods
  - Account for fabrication defects and other unknown failure modes
- General definition
  - Failures that occur at times less than expected for the nominal system resulting in a decreasing hazard function with time

INITIAL FAILURES IN TSPA-VA

- Subsumes a variety of processes and model uncertainties
  - fabrication defects
  - faulty emplacement
  - faulting and seismic effects
- Assumed 1 in 10,500 waste packages (range of 1 to 10) with through-wall defect
- Assumed failure time to be 1000 years

DOE ANALYSIS OF INITIAL FAILURES

- Analysis of pressure vessels
  - $2.3x10^{-4}$ to $8.5x10^{-4}$ per vessel
- Assuming independent failure modes of dual overpack system
  - $5.8x10^{-6}$ per WP
- Preferred method (Massari, 4/1999)
  - Determine probability of various WP defect generation mechanisms
  - Adjust corrosion models accordingly

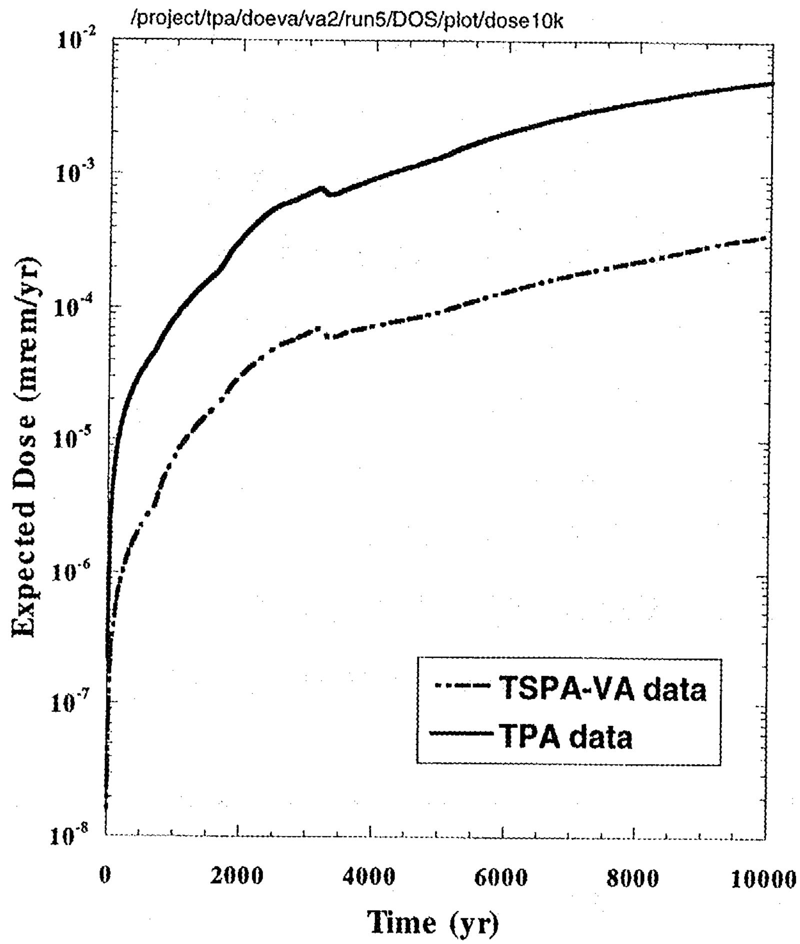
INITIAL FAILURES IN TPA 3.2

- Assumes that initial failure occurs due to
  - Fabrication defects
  - Unknown failure mechanisms
- Assumed failure probability of 10^{-2} to 10^{-4} per subarea (Average of 35 out of 7000 containers)
- Assumed failure time at t=0

NRC/CNWRA ANALYSIS OF INITIAL FAILURES

- Fuel rod failures
  - Initial defects estimated to be less than 8.2×10^{-6} to 2×10^{-6}
  - Low probability because of simple design and large experience base
- Aircraft component failures (Timmins, 1999)
  - 17 percent of failures - fabrication defects
  - 16 percent - design errors
  - 7 percent - defective material
  - Total percentage loss of aircraft: 0.4 percent in 1985
- Chemical and Offshore applications (Timmins, 1999)
  - 4 - 16 percent of failures due to poor fabrication

COMPARISON OF PERFORMANCE CALCULATIONS



- TPA 3.2 calculation using DOE and NRC initial failure rates
- Time to initial failure was at 0 years for both TSPA-VA and TPA data

ISSUES IN DETERMINING INITIAL FAILURES

- Initial failures based on experience in unrelated systems and applications
- Difficulty in separating mechanisms of initial failures
- Relationship to detectability of defects unclear
- The effect of experience on initial failure rate not considered

FACTORS AFFECTING INITIAL FAILURES

- Fabrication defects
  - Lack of fusion, penetration
  - Surface contamination (e.g., poor degreasing)
  - Laps, iron contamination
  - Improper filler metal
  - Iron dilution (bimetallic welds)
  - Inclusions/primary carbides
- Heat treatment
  - Improper temperature/time
- Material mix-up
- Material handling (dents, scrapes)
- Resolution of non-destructive examination methods

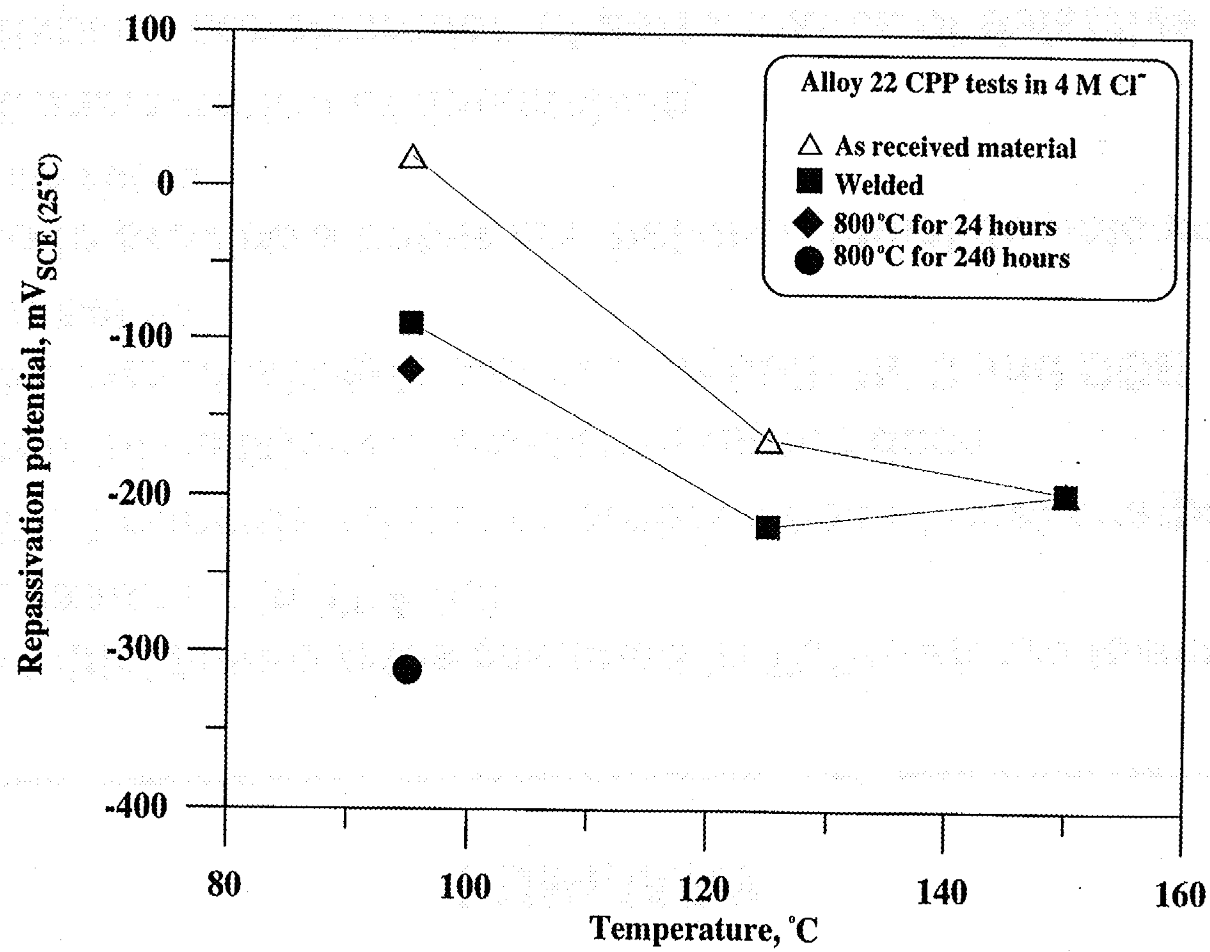
DETECTION OF DEFECTS

- Dye penetrant inspection (Timmins, 1999)
  - 90/95 percent of defects: 6 mm long
  - Longest crack missed: 3.98 mm
  - Smallest crack detected: 0.5 mm
- Ultrasonic inspection of copper canisters (Bowyer, SKI Report 97-19, 1997)
  - Smaller defects can be detected
  - Less penetration in large grained areas (welds)
- Resolution of defects in C-22 welds not known at present

EFFECT OF HEAT TREATMENT ON CORROSION RATE OF ALLOY C-22

Condition	Anodic Current Density, (A/cm^2)	Corrosion Rate (mm/y)	Life Time of 20 mm Overpack (years)
Annealed	$4x10^{-8}$	$4x10^{-4}$	50,372
Heat Treated 800 C/24 hours	$2x10^{-2}$	198	0.1

MODELING THE EFFECT OF HEAT TREATMENT IN TPA



SUMMARY

- The initial failure rates assumed in TSPA-VA are lower than that assumed in TPA 3.2
  - DOE considered failure probabilities of dual overpacks
- Higher initial failures resulted in higher dose
- Better technical basis needed for both NRC and DOE approaches
- Need to provide a better link between initial defects and failure rates
  - Consideration of detectability
  - Explicit consideration of performance of defective containers

WASTE PACKAGE CORROSION

Presented by
Gustavo A. Cragnolino
(210) 522-5539 (gcragno@swri.org)
Center for Nuclear Waste Regulatory Analyses

Technical Contributors
D.S. Dunn, C. S. Brossia, Y.-M. Pan, O. Pensado-Rodriguez,
G.A. Cragnolino, and N. Sridhar

March 25-27, 1999
San Antonio, Texas

DOE/NRC Technical Exchange on
Total System Performance Assessment for Yucca Mountain

Attachment 10

Understanding of WAPDEG as Implemented in TSPA-VA

- **Quantity and Chemistry of Water Contacting Waste Package**
  - Water as condensed layer ($RH_c^1 < RH < RH_c^2$) or dripping ($RH > RH_c^2$) on WP surface at $T < T_{bp}$; water chemistry not explicitly considered
- **Corrosion Modes of Steel Outer Container**
  - Humid air and uniform aqueous corrosion using rate equations derived from data for non-sea coastal atmospheres and lake/river waters
  - Localized aqueous corrosion using pit growth rate equation for $pH > 10$ based on expert panel assessment
- **Corrosion Modes of Alloy 22 Inner Container**
  - Uniform corrosion rate in humid air from expert panel assessment
  - Uniform aqueous corrosion rate for 3 dripping conditions ($3 < pH < 10$ and pH 2.5 at 0.34 V_{SHE}; pH 2.5 at 0.64 V_{SHE}) as assessed by expert panel
  - Localized aqueous corrosion rate using correlation from experimental data (LLNL, Haynes) and $T_{th} > 80\ ^{\circ}C$ as criterion provided by expert panel

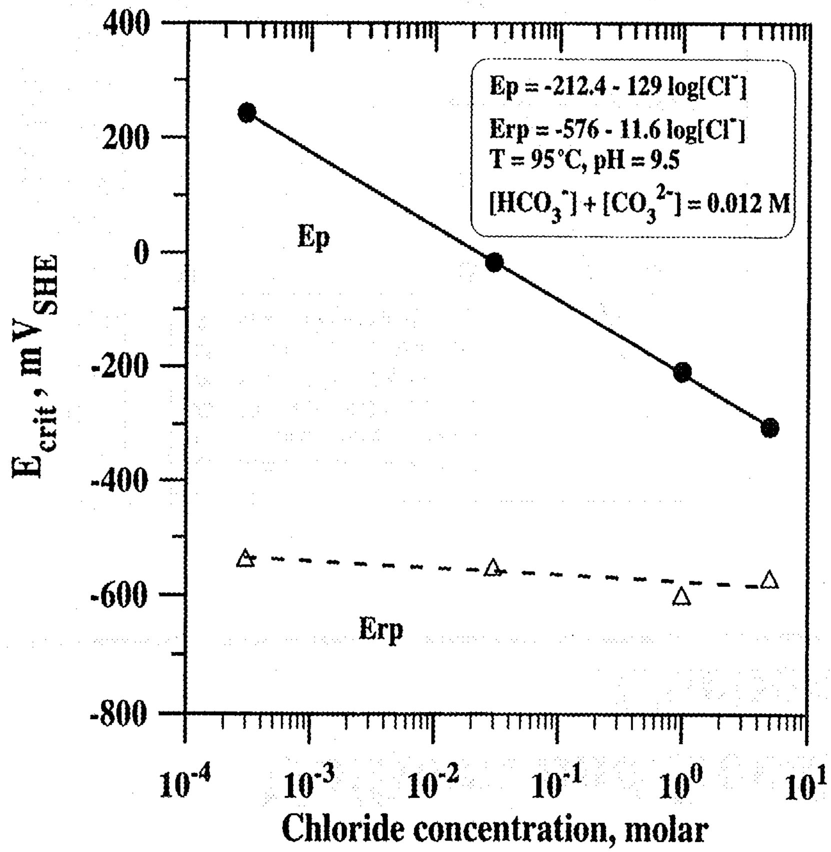
Technical Approach Adopted to Evaluate DOE WP Designs and Materials Selection

- Consider corrosion modes (general vs. localized, stress corrosion cracking) according to classes of materials (carbon and stainless steels, Ni-Cr-Mo alloys, Ti alloys)
- Evaluate a wide range of environmental conditions (i.e., anion concentrations, temperature, pH, redox potential) that can be expected for the water contacting WPs
- Develop mechanistic based models for corrosion processes that can support abstracted models for performance assessment (PA) codes
- Measure electrochemical corrosion parameters in short-term (days) laboratory tests that can be used as input parameters in the TPA code and be verified through long-term (years) corrosion tests

Methodology Applied to Evaluate Classes of Container Materials and Fabrication Effects

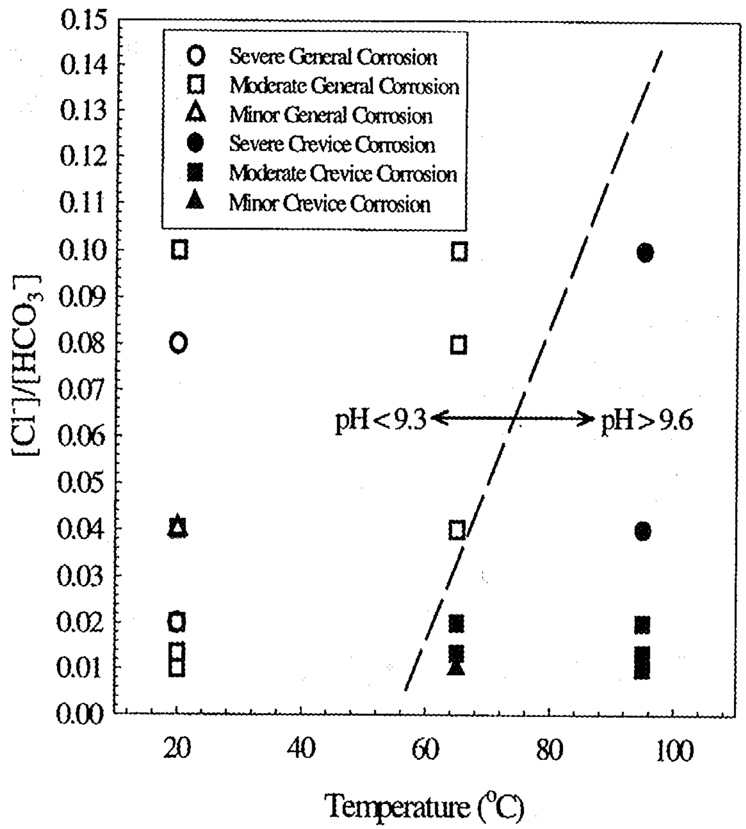
- Calculation of corrosion potential (E_{corr}) based on electrochemical kinetics laws and literature data for several physical and electrochemical parameters
- Experimental verification of E_{corr} values with and without galvanic coupling
- Experimental determination of repassivation potentials (E_{rp}) to define regimes of localized (pitting and crevice) corrosion as a function of temperature (T), pH, and $[Cl^-]$ with $[Cl^-] > [Cl^-]_{crit}$
- Experimental determination of stress corrosion cracking (SCC) susceptibility in terms of E_{rp} and critical stress intensity for SCC (K_{Iscc})
- Experimental determination or evaluation of literature data to estimate uniform corrosion rates, localized corrosion propagation rates and crack growth rates
- Experimental evaluation of the effect of welding or thermal treatments on some critical PA parameters (i.e., E_{rp}, K_{Iscc}, corrosion rates)

Localized Corrosion of Carbon Steel



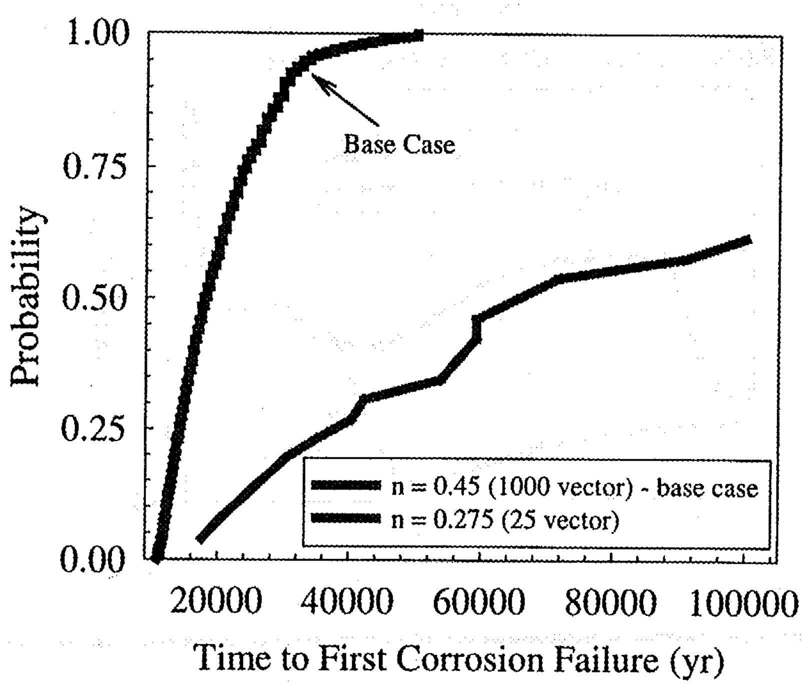
- **Localized (pitting) corrosion occurs only at pH > 9.3 (passive range)**
- **Only occurs above a minimum [Cl$^-$] (~3x10^{-4} M)**
- **Pitting potential (E_p) and repassivation potential (E_{rp}) depend on T, [Cl$^-$], and pH**
- **E_{rp} is used as the critical potential for the initiation (without induction time) of localized corrosion**
- **E_{rp} (mV$_{SHE}$) = (-620.3 + 0.47 T) + (-95.2 + 0.88 T) log [Cl$^-$] ; T in °C**

Uniform and Localized Corrosion of Carbon Steel



- **Corrosion mode of carbon steel is a complex function of environment composition**
- **Crevice corrosion is the predominant form of localized corrosion at $E > E_{rp}$, pH > 9.3, and T > 65 °C**
- **Crevice corrosion is more severe at high $[Cl^-]/[HCO_3^-]$ ratios and T close to 100 °C**
- **Uniform or general corrosion only predominates at T < 60 °C and pH < 9.3 over a relatively wide range of $[Cl^-]/[HCO_3^-]$ ratios**

Localized Corrosion Propagation Rate for Carbon Steel and TPA 3.2 Calculations

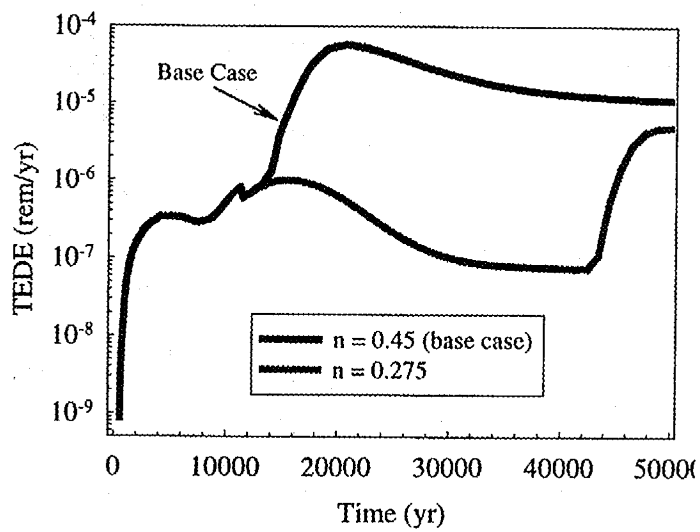


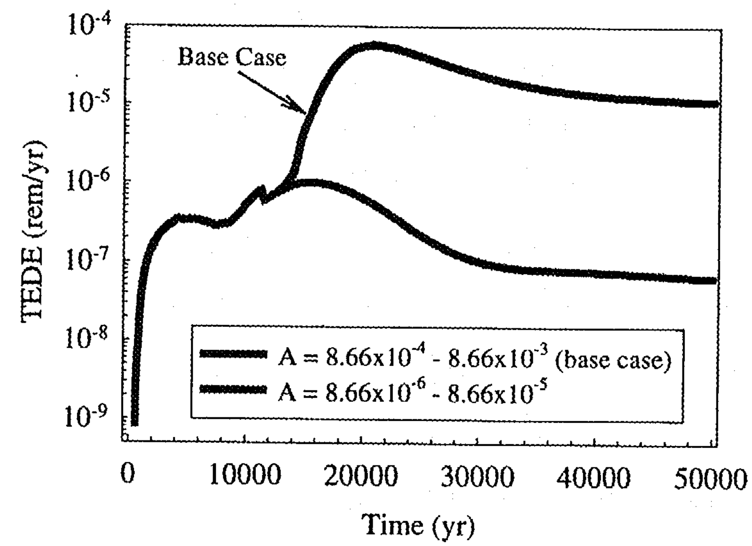
- **Penetration (Marsh et al., 1988)**

  $$P\,(mm) = A\,t(yr)^n$$

  with $A = 8.66 \times 10^{-3}$ and $n = 0.45$
- **Diffusion controlled process with penetration rate $dP/dt \propto t^{-0.5}$**
- **If pit becomes broader and shallow growth can be approximately modeled by decreasing n**
- **Carbon steel contributes significantly to WP lifetime when n = 0.275**

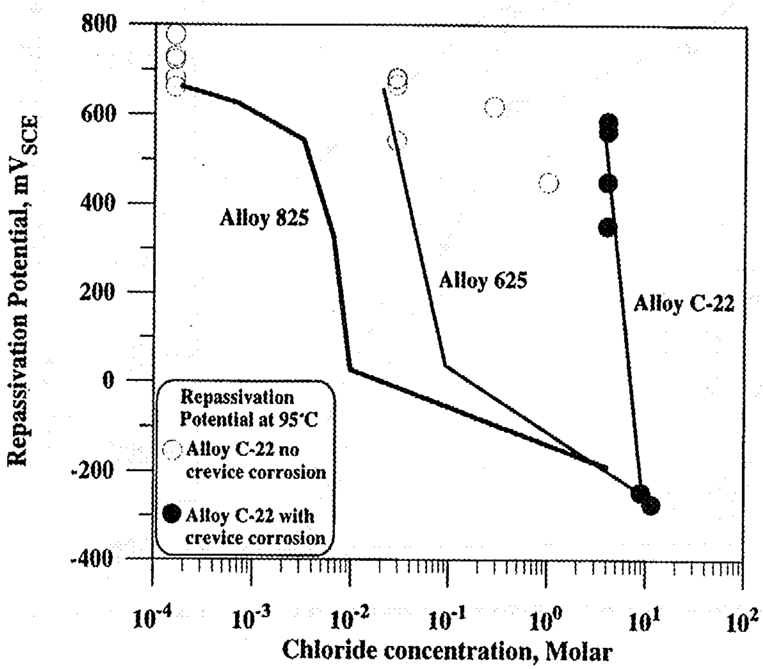
Localized Corrosion Propagation Rate for Carbon Steel and TPA 3.2 Calculations





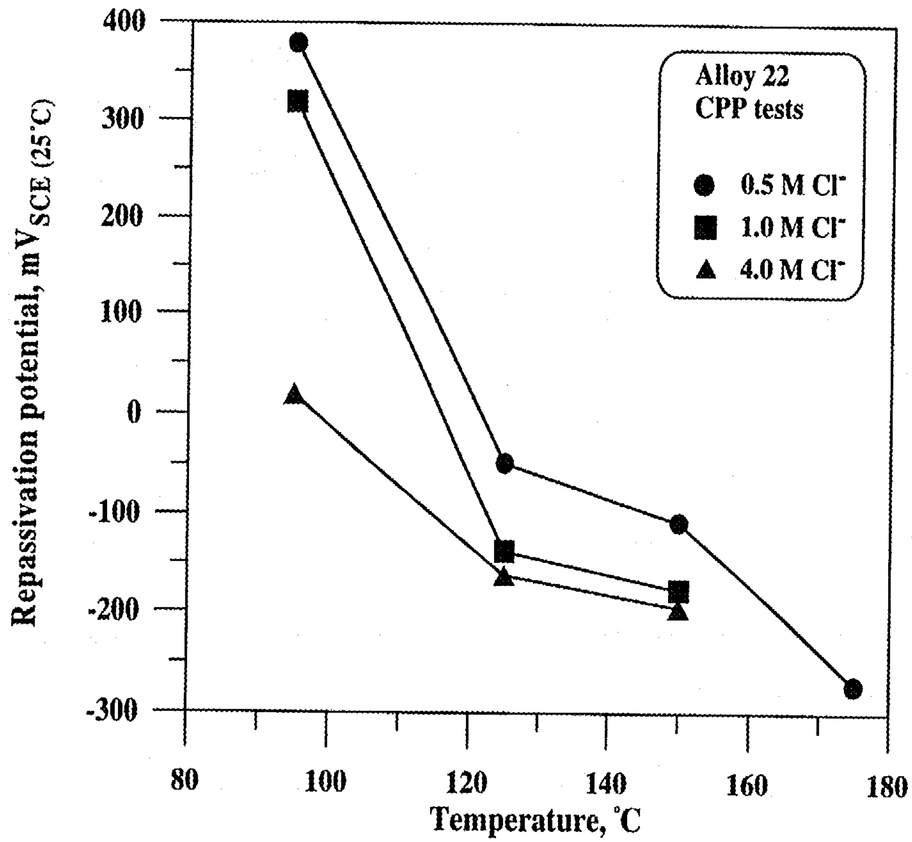
- **Decreasing A by two orders of magnitude and n to 0.275 increases the failure time of carbon steel outer container and, as a consequence, the total dose per year decreases significantly during the initial 45,000 yr**

Repassivation Potentials for Corrosion Resistant Ni-Cr-Mo Alloys at 95 °C



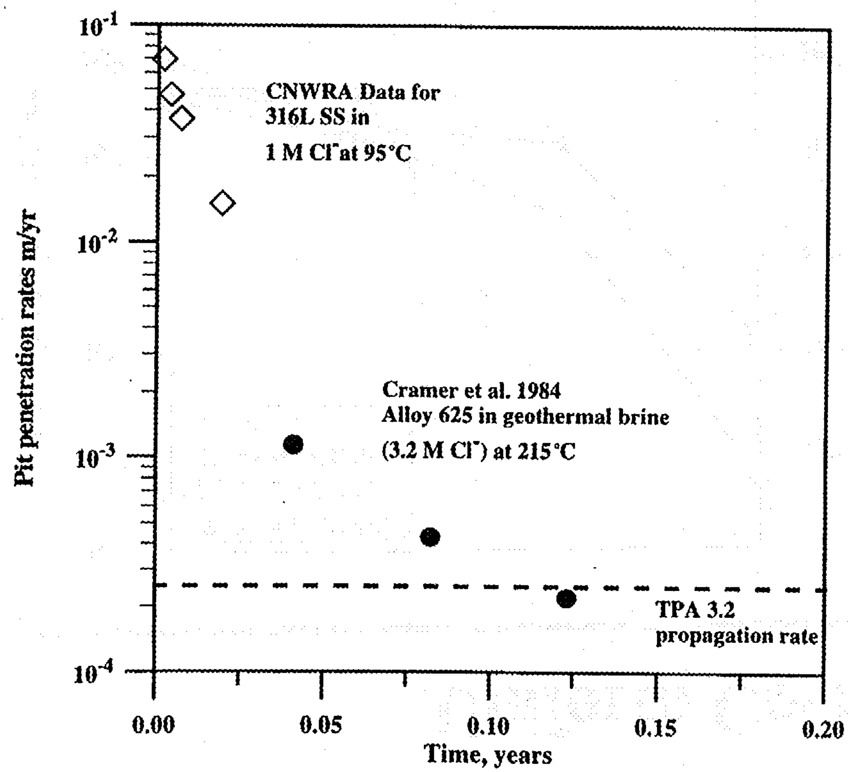
- **Repassivation potential (E_{rcrev}) used as a critical potential for the initiation of localized (crevice) corrosion in TPA 3.2 code**
- **Alloy 625 is more resistant than 825 only at intermediate [Cl^-]**
- **E_{rcrev} of Alloys 825 and 625 are almost identical at high [Cl^-]**
- **E_{rcrev} of Alloy 22 is considerably higher at [Cl^-] < 4 M, but decreases abruptly at higher [Cl^-]**
- **Effect of welding is being evaluated**

Localized Corrosion of Alloy 22



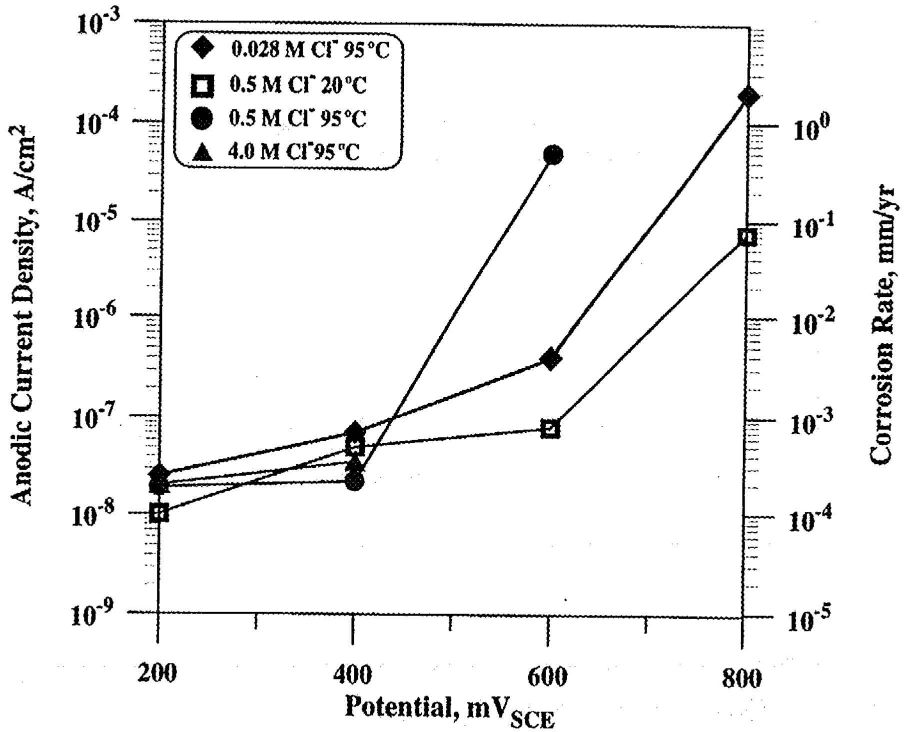
- Tests performed in deaerated NaCl solutions using autoclaves to identify ranges of susceptibility below and above boiling point
- Sharp decrease in E_{rp} above 95°C
- Crevice corrosion observed in all environmental conditions except in 0.5 M NaCl at 95°C

Localized Corrosion Propagation Rate for Corrosion Resistant Ni-Cr-Mo Alloys



- Propagation rate from laboratory and field data appears to be controlled by diffusion in solution
- A time-independent growth rate with an equivalent penetration time is currently used in TPA 3.2
- If localized corrosion initiates, a container with a 2 cm wall thickness will be penetrated in ~ 80 years
- In TSPA-VA the highest value of corrosion rate is $2x10^{-5}$ m/yr, but the median rate is $4x10^{-8}$ m/yr

Uniform Corrosion of Alloy 22

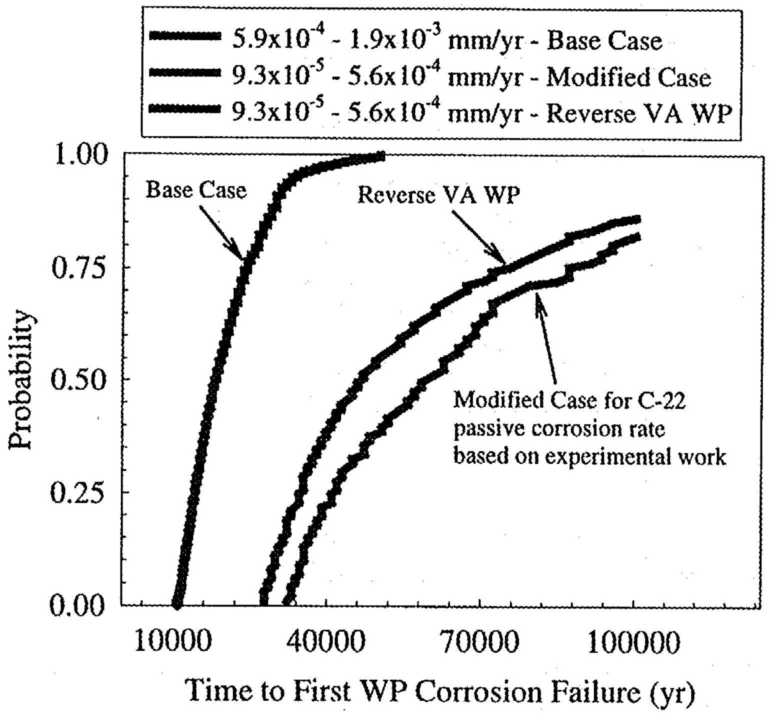


- Potentiostatic polarization to attain steady state currents in simulated groundwater environments
- Corrosion rates calculated from measured current densities
- Very low corrosion rates due to passive dissolution under conditions expected in the repository (< 400 mV_{SCE})
- Transpassive dissolution only at higher potentials
- No pitting corrosion
- Effect of welding is being evaluated

Uniform Corrosion Rate of Alloy C-22 and Values used in TPA 3.2

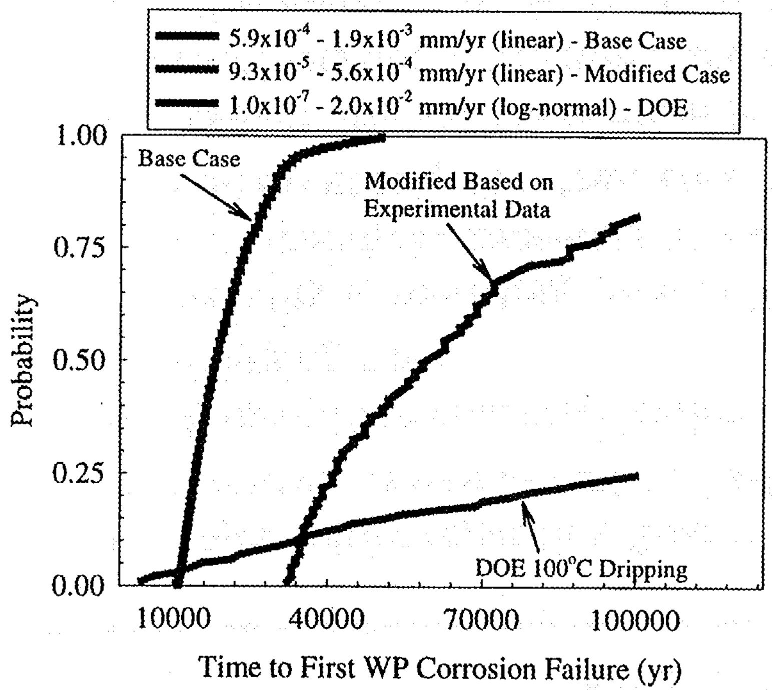
Starting Condition of Alloy C-22	[Cl-], molar	pH	Temp, °C	Potential, mV_{SCE}	Anodic Current Density, A/cm^2	Corrosion Rate, mm/yr	Lifetime of 20 mm Thick WP Barrier, Years
As-received	0.028	8	20	200	2×10^{-9}	2×10^{-5}	1,007,455
As-received	0.028	8	95	200	3×10^{-8}	3×10^{-4}	67,163
As-received	0.028	0.7	95	200	7×10^{-8}	7×10^{-4}	28,784
As-received	4	8	95	200	3×10^{-8}	3×10^{-4}	67,163
As-received	4	8	95	400	4×10^{-8}	4×10^{-4}	50,372
TPA 3.2 Calculation Low Dissolution Rate					6×10^{-8}	7×10^{-4}	33,581
TPA 3.2 Calculation High Dissolution Rate					2×10^{-7}	2×10^{-3}	10,074

Uniform Corrosion Rate of Alloy 22 and TPA 3.2 Calculations



- A median WP failure time of 17,920 yr is calculated for TPA 3.2 base case
- Using uniform corrosion rates obtained in short term electrochemical experiments the median WP failure time increases to 46,990 yr
- The reverse VA WP design exhibit a slightly higher median failure time of 59,709 yr

Uniform Corrosion Rate of Alloy 22 and TPA 3.2 Calculations



- **Uniform corrosion rates for Alloy 22 based on short term electrochemical experiments are similar to those obtained in LLNL after 1 yr testing in simulated acidified water**
- **Using those rates the median WP failure time is about 50,000 yr according to TPA 3.2 calculations**
- **Using TSPA-VA range of uniform corrosion rates for Alloy 22 TPA 3.2 calculations show 80 percent of WPs exhibiting failure times longer than 100,000 yr**

Review of the VA and Current Status of DOE WP Program

- Uncertainty regarding final DOE waste package design and other EBS features, as well as material selection for containers
- Appropriate characterization of mode of contact and chemistry of dripping water
- Validity of modeling assumptions and abstractions used for waste package performance assessment, in particular for localized corrosion processes and eventually for stress corrosion cracking
- Availability of data applicable to repository conditions taking into consideration fabrication issues (i.e., welding)
- Attendance to Waste Package Degradation Modeling and Abstraction Workshop revealed that some of these issues are being addressed

NRC's Insights into Seepage and Release

Richard B. Codell
(301) 415-8167
RBC@NRC.GOV

Performance Assessment and HLW Integration Branch
Division of Waste Management
Office of Nuclear Materials Safety and Safeguards
U.S. Nuclear Regulatory Commission

Contributors: S. Mohanty (CNWRA), T. McCartin (USNRC)

For presentation at the NRC/DOE Technical Exchange on Total System Performance Assessment, Center for Nuclear Waste Regulatory Analyses, San Antonio TX May 25-27, 1999

Attachment 11

Objectives

Determine the release rate of radionuclides entering the geosphere. This involves knowing:

- The quantity of water entering the drifts
- The fraction of this water dripping onto waste packages
- The fraction of dripping water entering failed waste packages
- The fraction of fuel wetted by the water
- The release rate of radionuclides from the spent-fuel waste form into the water
- The transport of released radionuclides from the waste package to the rock

Presentations

- Overview of NRC and DOE models for seepage and release
- Process-level presentations by:
  - Tae Ahn (Basis for NRC's choice of base-case dissolution model)
  - William Murphy (Natural analog and schoepite source term models in TPA 3.2)
  - Debora Hughson (Isothermal and coupled thermal models for infiltration to the drift)

Major Differences Between DOE and NRC Models for Seepage and Release

- Quantity and chemistry of water contacting waste packages and waste forms
  - DOE models consider temporal variation in chemistry more completely than NRC models.
  - Dripping models are different, but both are speculative.
  - DOE has mechanistic models of dripping at the drift scale (but outside of TSPA code).
  - DOE model provides more credit for water removal and diversion by capillary forces.
  - DOE model also has several likely conservatisms for dripping and chemistry.

Major Differences Between DOE and NRC Models for Seepage and Release (Cont'd)

- Colloid release and transport
  - DOE models consider colloid release and transport.
  - As an alternative conceptual model, NRC emulated transport of colloids as dissolved transport, but with zero retardation.
- Cladding - DOE takes substantial credit for cladding protection (up to 98.75% for 100,000 years). NRC takes no credit for base case.
- Water/Fuel Contact
  - DOE model assumes available water contacts fuel and saturates the fuel rind.
  - NRC assumes either a Bathtub or Flow-through model. For bathtub, water available determined by volume of water filling WP. For Flow-through model, water volume generally set to small fraction of WP volume.

Major Differences Between DOE and NRC Models for Seepage and Release (Cont'd)

- Waste-form Dissolution Model
  - DOE relies primarily on fuel-dissolution data with pure carbonate waters.
  - NRC relies on data for waters containing silica and calcium.
- Surface Area Model for Spent Fuel
  - DOE uses UO_2 grain size (about 10 micron diameter) model
  - NRC uses UO_2 particle size (about 1 millimeter diameter) model
- Solubilities
  - DOE has revised solubility of Np downward by 2 orders of magnitude
- Glass Waste Form
  - DOE takes glass waste form into account. NRC's TPA analysis did not.

Major Differences Between DOE and NRC Models for Seepage and Release (Cont'd)

- Near-field transport
  - DOE has a reactive transport model AREST-CT for off-line calculation of release behavior of spent fuel in the near-field.
  - NRC has schoepite dissolution model within TPA 3.2 code for considerations of secondary minerals of the spent-fuel waste form.
  - Both NRC and DOE have models of near-field transport through the invert. Most flow bypasses invert in NRC model because of low permeability assumed.
- Diffusional Release
  - DOE considers release of radionuclides from waste package by diffusion when advective flow is small.
  - NRC's model no longer considers diffusional releases.

Features of DOE Models of Drift-Scale Seepage and Release for the VA

- DOE model uses mechanistic (offline) simulation to estimate the fraction of percolating water flux that infiltrates the drifts.
- Seepage flux is represented in TSPA-VA as an analytic function of percolation flux.
- Waste package represented as an area 5m x 5m, approximately length of WP and width of drift. DOE did not consider potential diversion after entering drift by flow along drift wall, or runoff from waste package.
- Seepage calculated separately for each of 6 subareas, but perfectly correlated among subareas in a single realization.

Comparison of DOE and NRC Flow Rates per Waste Package

- At drift scale, seepage fraction getting into waste packages considerably higher in DOE's model.

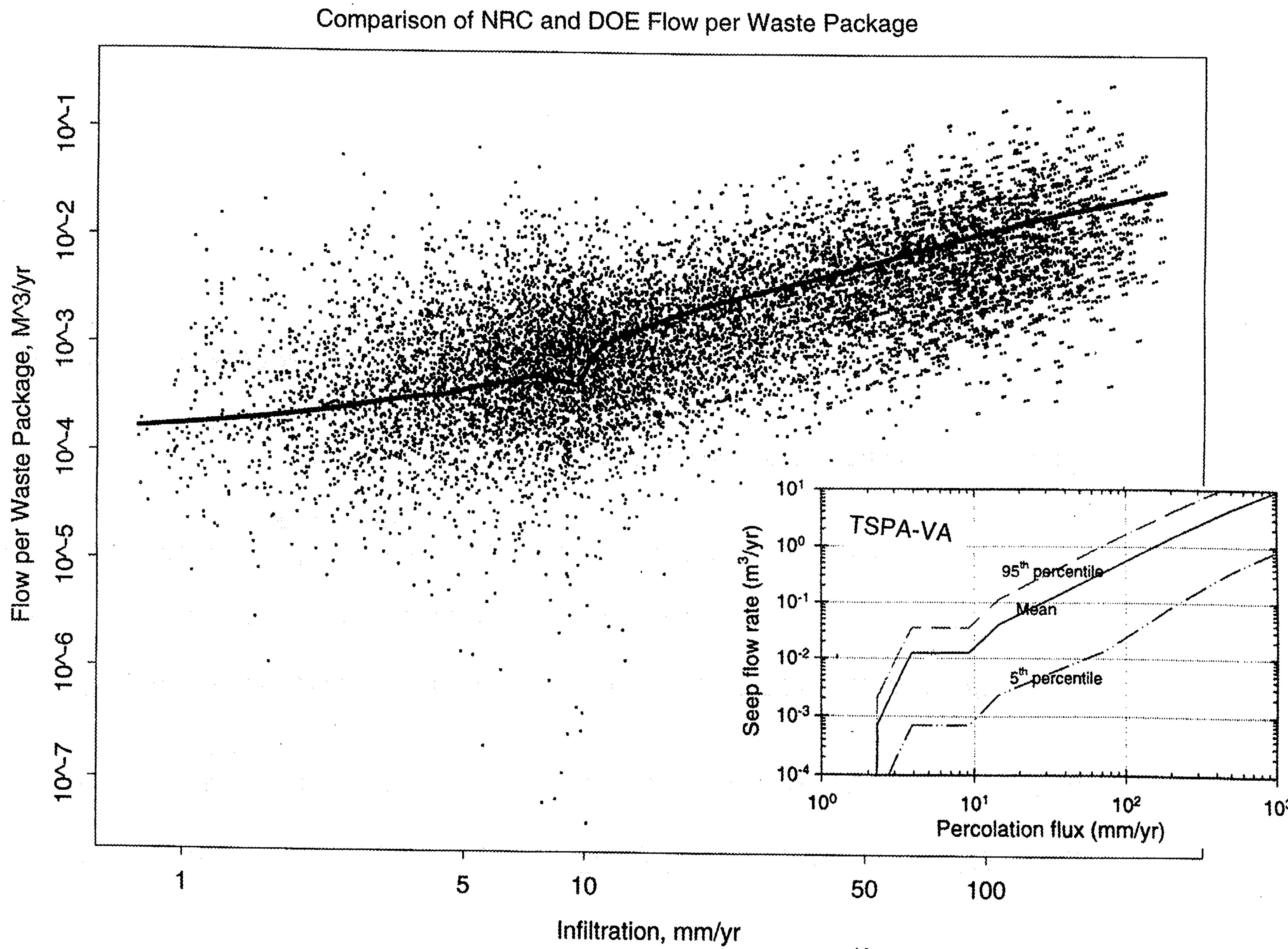
– DOE model has higher plan area per waste package (25 M^2 versus 10 M^2)

– DOE has no diversion from failed waste package.

– NRC model has diversion factor (0.01 to 0.2, lognormal) for fraction shed from waste package.

– NRC model has wetting fraction and diversion factors chosen once per run, and fixed for all time.

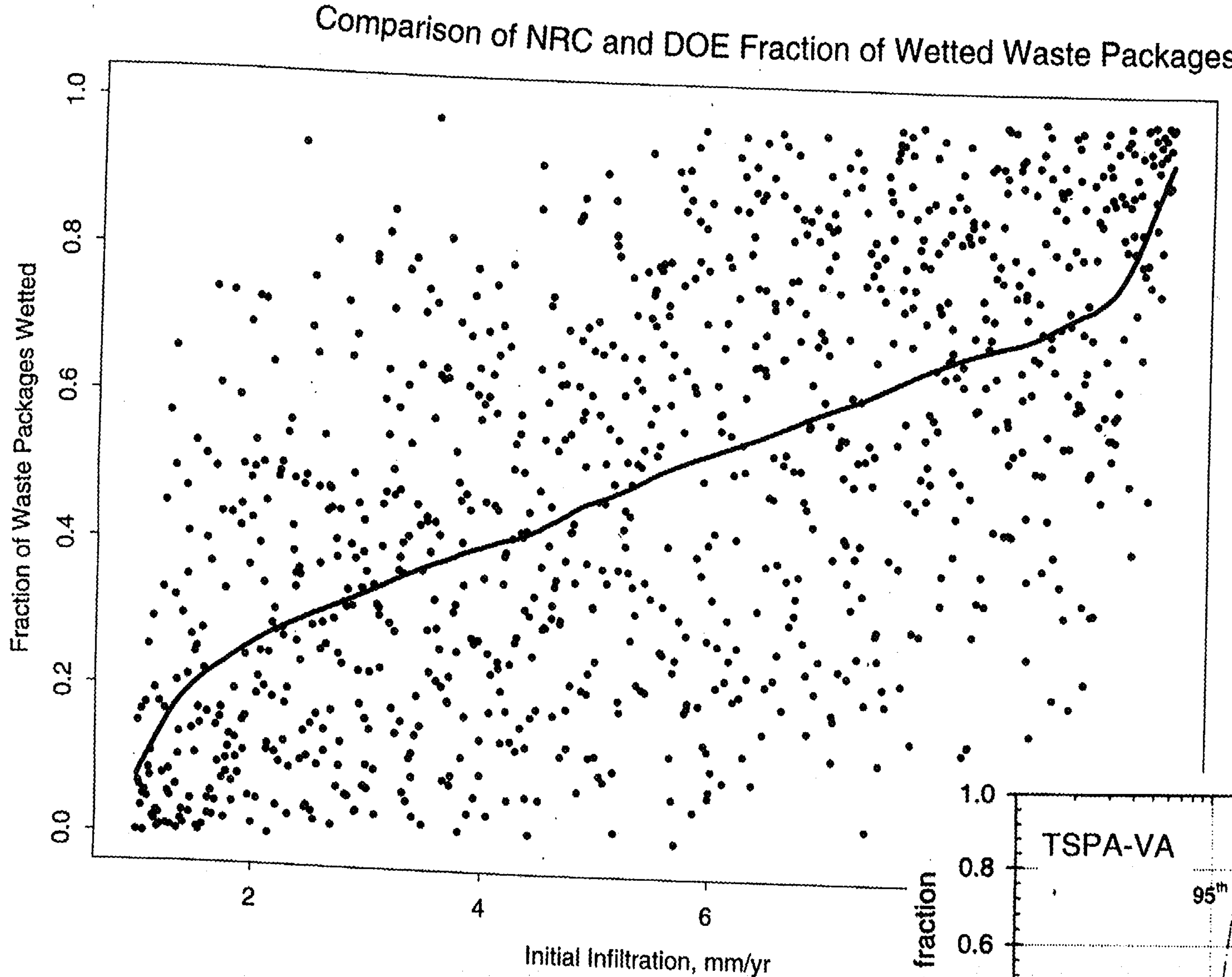
– DOE model allows number of WPs to change during run.

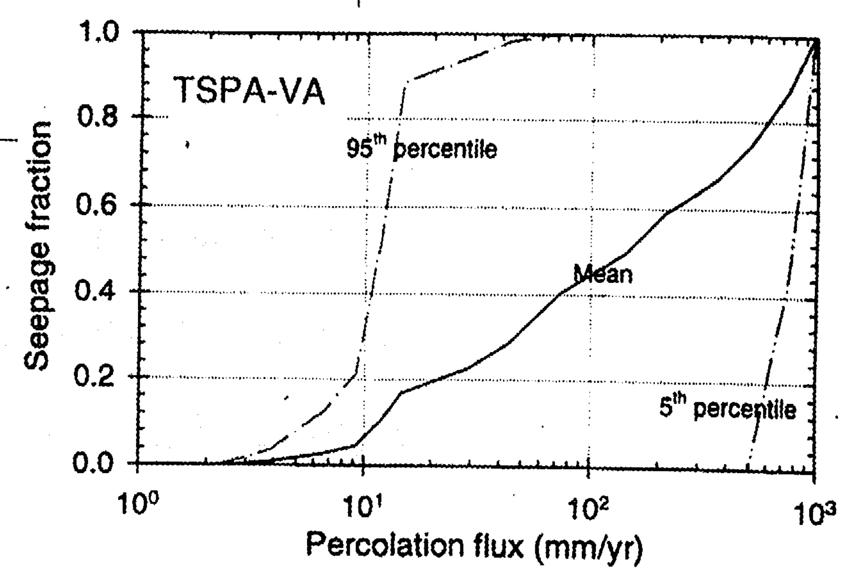

Comparison of NRC and DOE Flow per Waste Package
Flow per Waste Package, M^3/yr
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1
5
10
50
100
Infiltration, mm/yr
TSPA-VA
Seep flow rate (m^3/yr)
95th percentile
Mean
5th percentile
Percolation flux (mm/yr)

Comparison of DOE and NRC WP Wetting Fractions

- DOE wetting model has much smaller fraction of WP wet fraction than NRC.

  At 10 mm initial infiltration, DOE = 0.07, NRC = about 1.0 (Mean Values)


Comparison of NRC and DOE Fraction of Wetted Waste Packages
Fraction of Waste Packages Wetted
0.0
0.2
0.4
0.6
0.8
1.0
2
4
6
Initial Infiltration, mm/yr


TSPA-VA
95th percentile
Mean
5th percentile
Seepage fraction
0.0
0.2
0.4
0.6
0.8
1.0
10^0
10^1
10^2
10^3
Percolation flux (mm/yr)

Relationship between Seepage and WP Wetting

- DOE's model had perfect correlation between fraction of WPs wetted and seepage flux.
- NRC's model had statistical correlation between fraction of WPs wetted and seepage flux (-0.631), and TS_w matrix permeability (-0.623).
- DOE's model does not calculate thermal recirculation.
- NRC's model calculated and uses thermal recirculation for releases from early failures of WPs.

TPA CALCULATIONS WITH TSPA-VA DATA

Seepage and flow into WP

Areal avg. mean annual infiltration at start	constant: 10 [mm/yr]
FowFactor	lognormal: .054555, 0.054556
FmultFactor	lognormal: 1.0, 1.00001
SubAreaWetFraction	uniform: 0.9999, 1.0

Release rate modification

TPA dissolution model	user-specified
User leach rate	constant: 7.e-3 [kg/yr/m2]
Initial radius of SF particle	constant: 1.e-3 [m]
SF wetted fraction	uniform: 0.49, 0.51

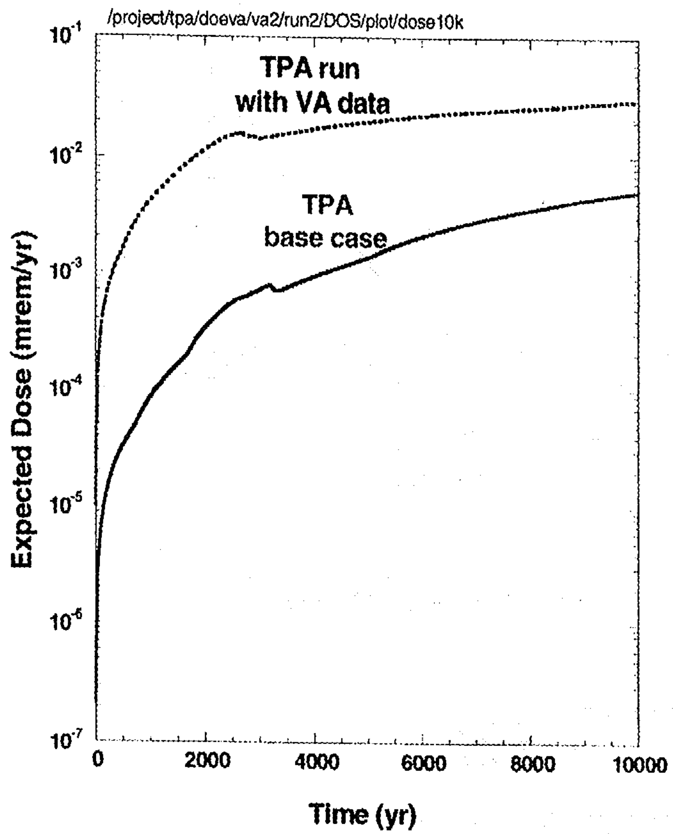
(Reflux model was turned off)
Flow into WP = 0.098 m3/yr/WP

Release rate with cladding

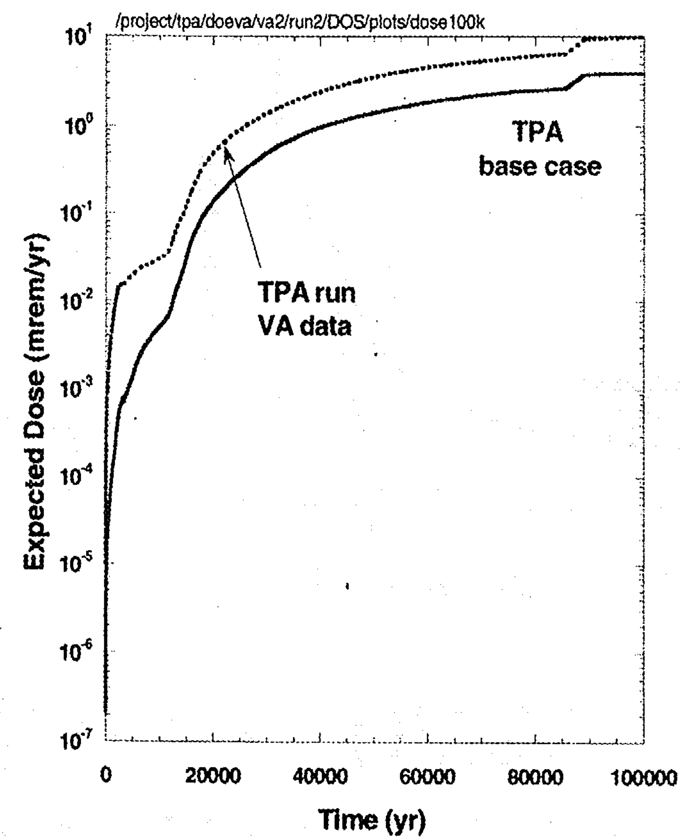
Same as release rate modifications plus

Cladding Correction Factor	constant: 0.0125

TPA RUN WITH TSPA-VA SEEPAGE DATA

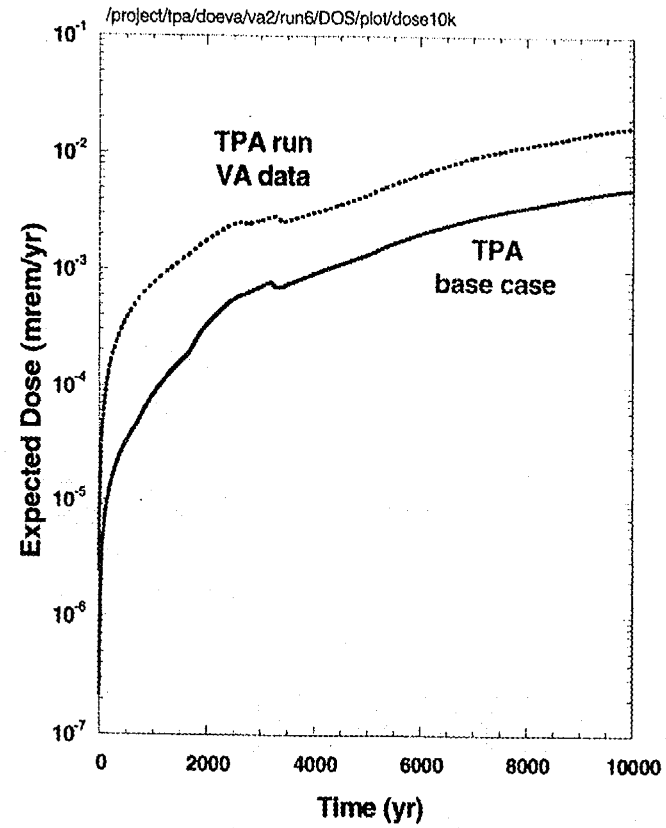


10,000 yr run

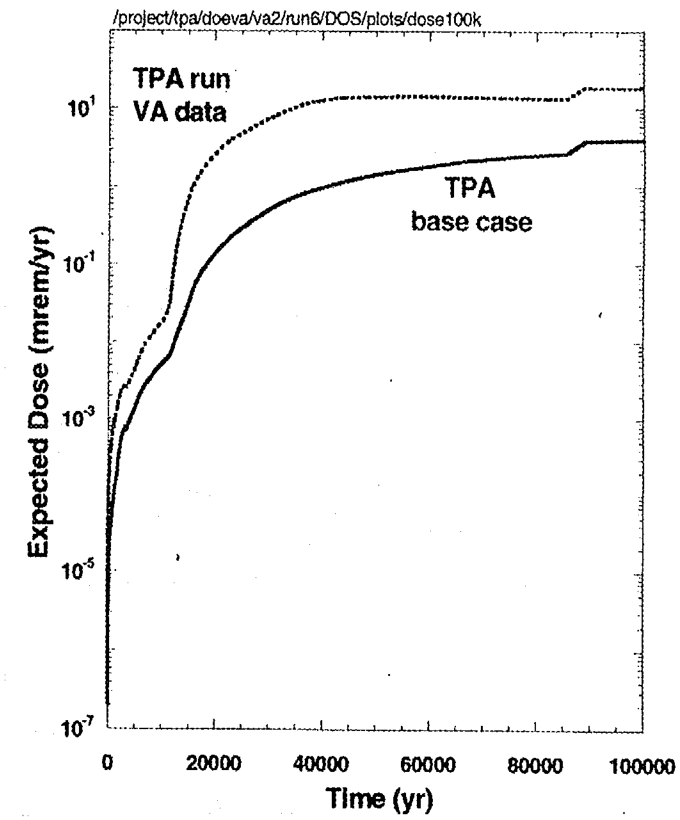


100,000 yr run

TPA RUN WITH TSPA-VA RELEASE RATE DATA

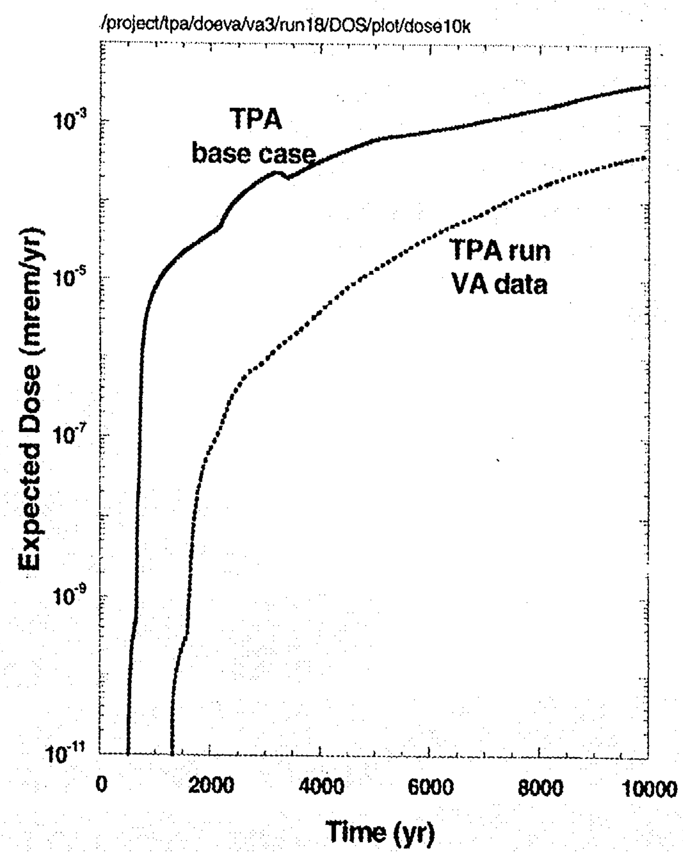


10,000 yr run

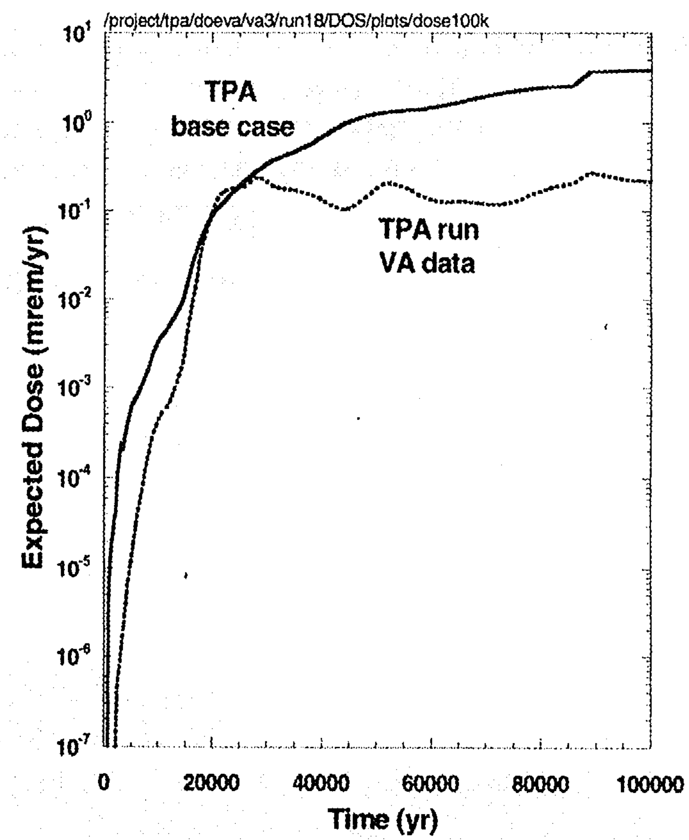


100,000 yr run

TPA RUN WITH TSPA-VA: RELEASE WITH CLADDING CREDIT

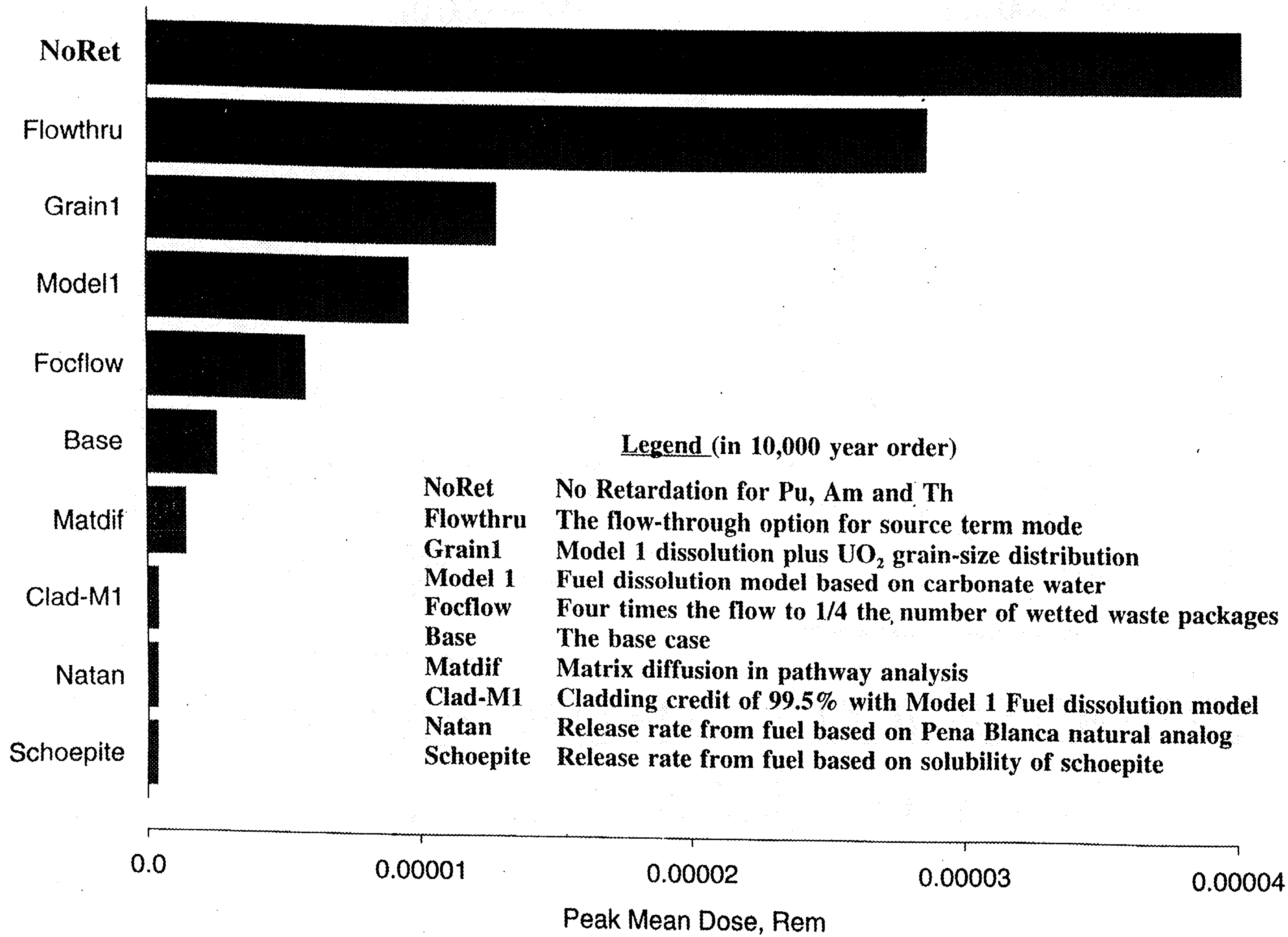


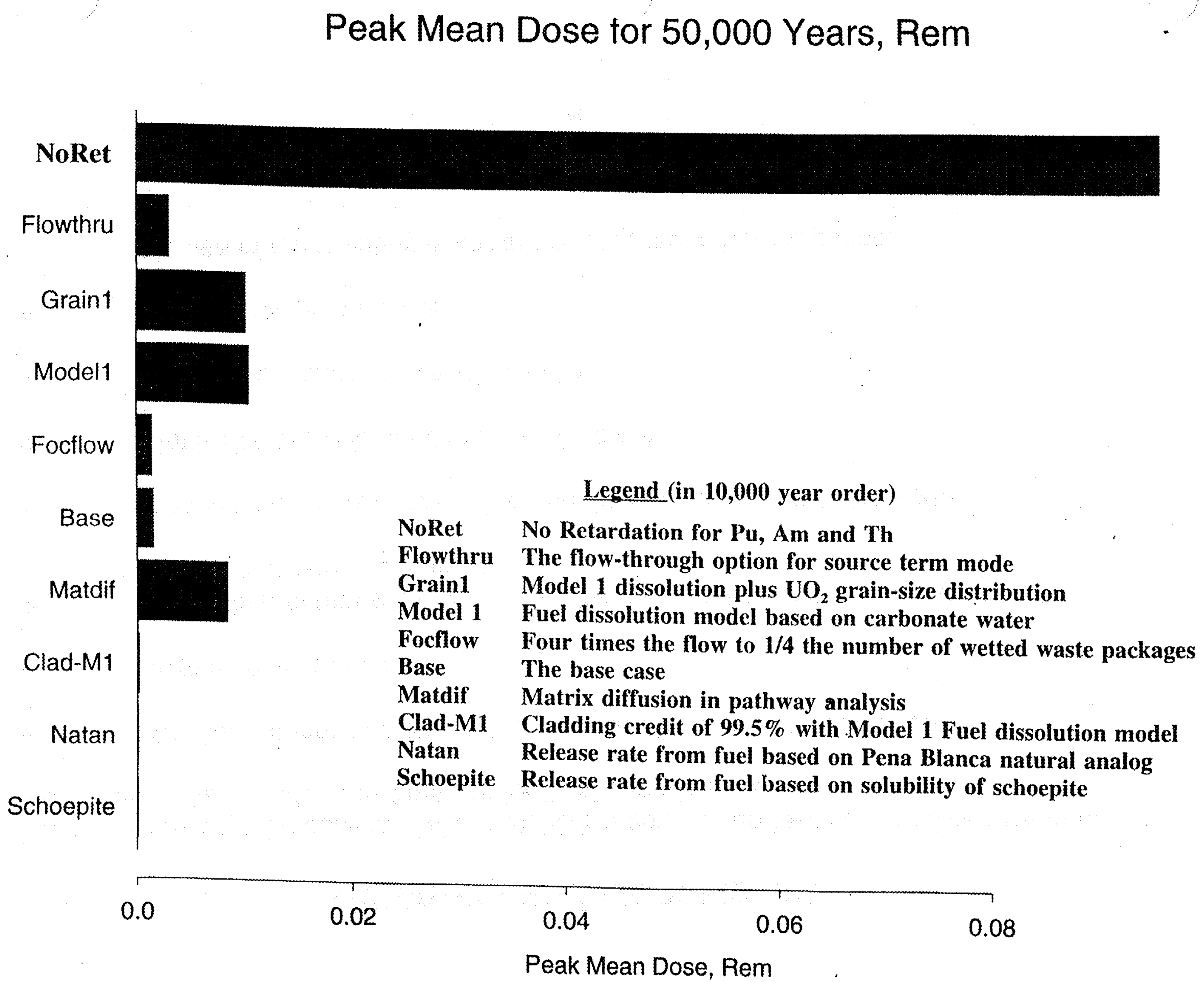
10,000 yr run



100,000 yr run

Peak Mean Dose for 10,000 Years, Rem




Peak Mean Dose for 50,000 Years, Rem
NoRet
Flowthru
Grain1
Model1
Focflow
Base
Matdif
Clad-M1
Natan
Schoepite
Legend (in 10,000 year order)
NoRet No Retardation for Pu, Am and Th
Flowthru The flow-through option for source term mode
Grain1 Model 1 dissolution plus UO_2 grain-size distribution
Model 1 Fuel dissolution model based on carbonate water
Focflow Four times the flow to 1/4 the number of wetted waste packages
Base The base case
Matdif Matrix diffusion in pathway analysis
Clad-M1 Cladding credit of 99.5% with Model 1 Fuel dissolution model
Natan Release rate from fuel based on Pena Blanca natural analog
Schoepite Release rate from fuel based on solubility of schoepite
0.0
0.02
0.04
0.06
0.08
Peak Mean Dose, Rem

Summary and Conclusions

Many differences exist between NRC and DOE models of drift seepage and release from the waste packages. Major distinctions for DOE's models are:

- Smaller number of WPs wetted, and variable number within a run.
- Less diversion in drift.
- Attempts mechanistic model for colloid release from glass waste form and transport through geosphere.
- Mechanistic models for wetting and dripping outside of TSPA code.
- Grain-size UO_2 distribution for surface area.
- Carbonate waters for fuel dissolution.
- Much lower Np solubility.
- No use of recirculating water during repository thermal period.

OXIDATIVE RELEASE MODELS

PRESENTATION IN
DOE/NRC TECHNICAL EXCHANGE ON
TOTAL SYSTEM PERFORMANCE ASSESSMENT (TSPA)
FOR YUCCA MOUNTAIN REPOSITORY
MAY 25-27, 1999, SAN ANTONIO, TX

Tae M. Ahn
Projects and Engineering Section/High-Level Waste Branch
Division of Waste Management
Office of Nuclear Material Safety and Safeguards
(301)415-5812/TMA@NRC.GOV

Attachment 12

OUTLINE OF PRESENTATION

- Model Assumptions
- Models for Oxidative Dissolution of Spent Fuel
- Comparison with Other Models
- Supporting Data Base
- Summary and Future Work

MODEL ASSUMPTIONS

- Bathtub (Immersion)
- Oxidative Reaction
- Groundwater: J-13 Well Water with Ca and Si Ions
- The release rate of highly soluble radionuclides such as ^{99}Tc and ^{129}I is proportional to the dissolution rate of uranium in the primary phase.

MODELS FOR OXIDATIVE DISSOLUTION OF SPENT FUEL (Model 2, Nominal Case)

- Data:
  (1) Immersion Test of Spent-Fuel Particles (~ 1 mm) J-13 Well Water at 25° and 90° C (Wilson, 1990)
  (2) Flow-through in J-13 Well Water at 25 ° C
  (Gray and Wilson, 1995; Gray, 1992) - Figures

- Dissolution Rate, r (mg m^{-2} d^{-1}) =
  $r_o \exp[-34.3/(R\,T)]$

  - r_o (mg m^{-2} d^{-1}) from 1.4×10^4 to 5.5×10^4, and R (kJ mol^{-1} K^{-1})
  - The release rate is with respect to the real surface area, including grain (~ 10 μm) boundary penetration. The activation energy is from the dissolution rate obtained in pure carbonate solution (modifications in later pages).

- Alternative Models:
  (1) pure carbonate solution (Model 1, user supplied)
  (2) J-13 well water drip (Model 3, user supplied)
  (3) others: W. Murphy

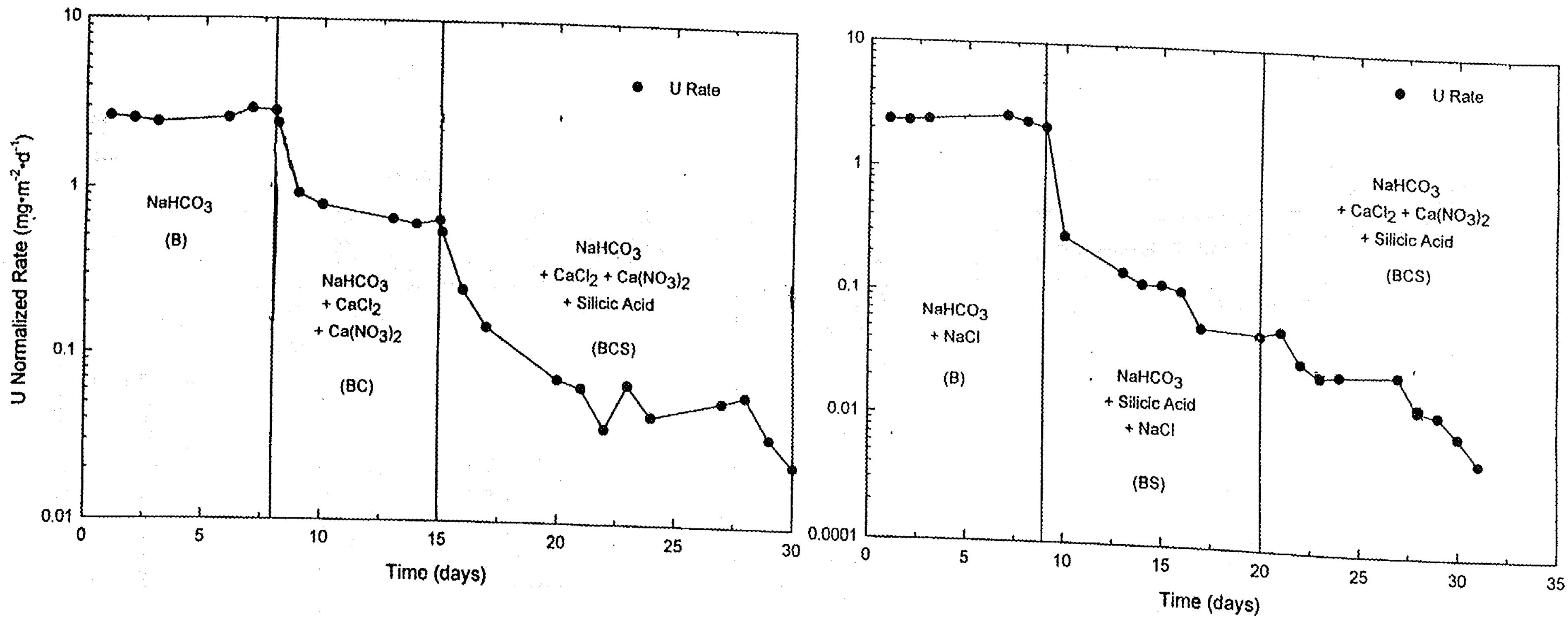


Figure. Effects of Solution Composition on Dissolution Rate, Flow-through Tests of 44 ~ 105 μm UO_2 at 25 °C (Gray and Wilson, 1995)

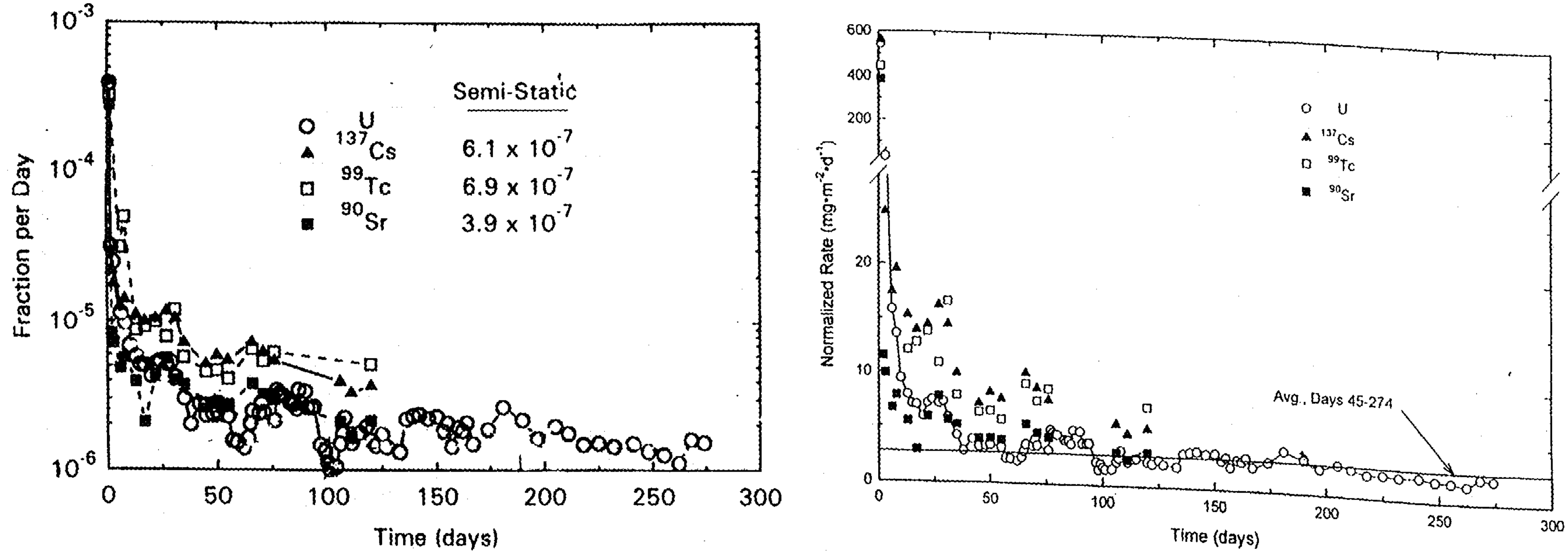


Figure. Spent-Fuel Dissolution Rates of Archived Particles, Flow-through Tests at 25 °C (Gray and Wilson, 1995; Gray, 1992; Wilson, 1990)

COMPARISON WITH OTHER MODELS

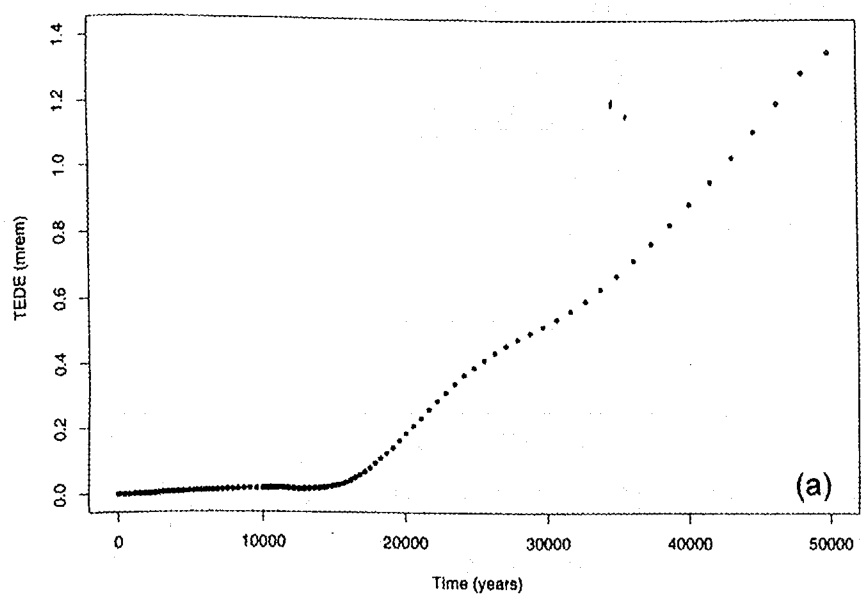
- Dissolution Rate (mg m^{-2} d^{-1}) at 25° C

This Base Model (NRC Model 2, Grain)	$(1 \sim 5)\times10^{-2}$
DOE Model (NRC Model 1, Pure Carbonate Solution, Grain, User Supplied)	~ 3 ($[CO_3]=2\times10^{-3}$M, $P_{O_2}=0.2$ atm, pH=8.4)
ANL Drip Test Model (NRC Model 3, Particle, User Supplied)	7 ~ 110

- Uncertainties

  - Grain boundary openings increase the surface area, resulting in the increased dissolution rate.
  - Grain boundary inventory could have contributed to the apparent dissolution rate. Because the PA Codes have separate inputs of the grain boundary inventory, the real dissolution rate of the matrix may be lower.

- \- TPA Code has an option of particle and grain models (Figures)



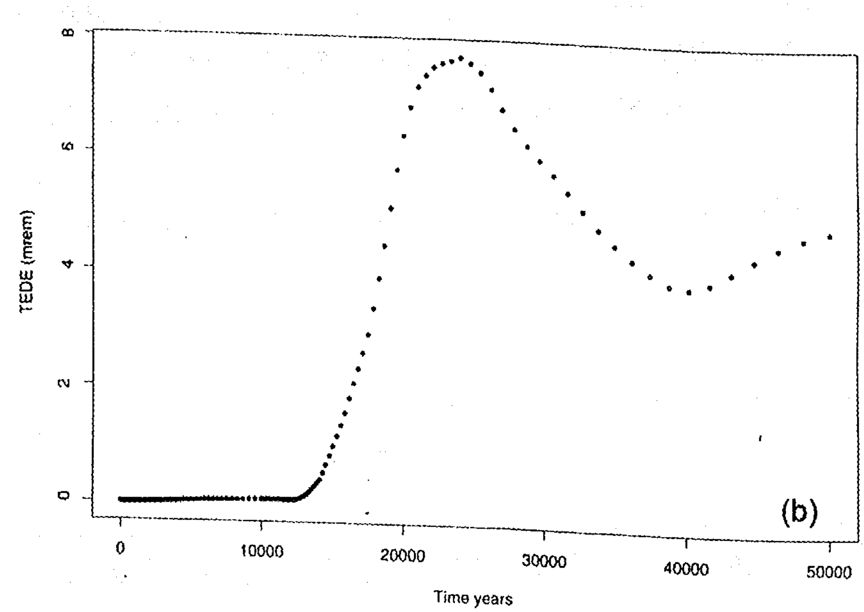


Figure. TPA3.2 Outputs (a) Nominal Case of particle model (McCartin, 1999) (b) Grain Model (Contardi, 1999)

SUPPORTING DATA

(1) Activation Energies are from immersion tests (Wilson, 1990)

(2) Three groups of dissolution rate

- J-13 well water, synthetic groundwater, granitic groundwater, tap water, and distilled water: (2.4×10^{-4} ~5.4) mg m^{-2} d^{-1} at room temperature (RT)
- chloride solution: (5×10^{-3} ~5.7) mg m^{-2} d^{-1} at RT
- carbonate solution: (0.23 ~ 3.3) at RT

(3) Tests of particles may increase the dissolution rate by as high as a factor 10 compared with grain tests, but the difference depends on (1) details of sample types such as size or oxidation state, (2) spent-fuel types such as fresh, archived, or different burnup, and (3) contribution of grain boundary inventory.

SUMMARY

(1) The dissolution rate of spent fuel in oxidative J-13 well water containing Ca and Si ions is approximately 10 ~ 100 times lower than that in pure carbonate solution. A representative kinetics of this lowered dissolution was presented.

(2) Dissolution rates from various models were compared. Uncertainties associated with grain boundary opening and the release of grain boundary dissolution were discussed.

(3) To refine the present model, literature data obtained in mineral waters were tabulated.

FUTURE WORK

(1) Sample the activation energy and the rate constant in the PA exercise

(2) Use DOE's new data obtained in J-13 well water

SUPPORTING DATA

Calculated Values of Activation Energy, Q (kJ mol^{-1} K^{-1}), from Immersion Tests Based on Soluble Radionuclides

^{137}Cs	^{90}Sr	^{99}Tc	^{129}I
18(10),16	-37 (-32), -14	33(28),26	29(33), 24

- The first for HBR fuels and the second for TP fuels
- All from PNL-7169 except the parentheses from PNL-7170 RT data

Dissolution Rate (mg/[m^2-day]) (U, otherwise specified)	Temperature (°C)	Sample Type	Test Method Solution	References
3	22	PWR: archived SF particles	flow-through J-13	Gray and Wilson, PNL-10540, 1995
0.85 (^{137}Cs) 0.96 (^{99}Tc) 0.54 (down to 0.19) (^{90}Sr)	25	SF particles	immersion J-13	derived from Gray and Wilson, PNL-10540, 1995, analysis of Wilson, 1990 (3.9×10^{-7}/d → 0.54 mg/[m^2-d] from SF particle tests
3×10^{-2}	25	powder particles UO_2 44 ~ 105 µm (Grains decrease diss. rate by a factor of an approx. max. 10, but these are bigger particles than grains)	flow-through $NaHCO_3$ + $CaCl_2$ Ca $(NO_3)_2$ + silicic acid	Gray and Wilson, 1995
5×10^{-3}	25	powder particles UO_2 44 ~ 105 µm (The same as particles)	flow-through $NaHCO_3$ + $CaCl_2$ + Ca $(NO_3)_2$ + silicic acid	Gray and Wilson, 1995
4.5	25	UO_2	DIW + Ca + Si	UCRL-ID-108314, 1998
8×10^{-3}	25	grains, UO_2	flow-through U3SW $NaSiO_3$	Tait, 1997
2.5×10^{-2}	25	grains, UO_2	flow-through U3SW $CaCl_2$	Tait, 1997

Dissolution Rate (mg/[m^2-day]) (U, otherwise specified)	Temperature (°C)	Sample Type	Test Method Solution	References
2×10^{-1} (^{137}Cs, ^{90}Sr) 1×10^{-1}	25	CANDU SF particles	flow-through SCSSS + 0.185 M Ca^{2+} + 0.00027 M SiO_4^{4-}	Tait and Luht, 1997
1.4×10^{-2} (^{90}Sr)	25	PWR, BWR and CANDU fuel, assumed SF particles	immersion SKB, NNWSI Canadian	Grambow et al., 1990, see also Forsyth, 1986 and Stroess-Gascoyne et al., 1985
0.35 ~ 1.8	25	BWR SF (Swedish)	immersion bent/ox, seq/ox log (p_{O_2}/p_{CO_2}) = -3.1 ~ -3.5	reviewed by Grambow, 1989
0.30 ~ 2.0 (Initial value)	25	UO_2, pellet 4.5 cm^2/9.8 g	immersion stat/ox synthetic groundwater log (p_{O_2}/p_{CO_2}) = -3.2 ~ -3.5	reviewed by Grambow, 1989 Ollila, 1997 (need confir.)
2.4×10^{-4} (Sr) (Slowed-down rate)	25	SIMFUEL 4 cm^2/8-grams (~ 1 cm particles)	immersion with and without replenishment Granitic, pH=8.2	Sandino et al., 1991
3.1 ~ 5.4 (Initial value)	25	SIMFUEL 50 ~ 315 μm	immersion synthetic groundwater	Garcia-Serrano et al., 1996

Dissolution Rate (mg/[m^2-day]) (U, otherwise specified)	Temperature (°C)	Sample Type	Test Method Solution	References
0.069	20 ~25	BWR (Swedish) fuel & clad 2 cm long segments (assumed SF particles)	immersion Allard synthetic groundwater	Forsyth 1986
0.028 (^{90}Sr)	25	CANDU 5 cm section fuel/ clad	immersion distilled water	Stroess-Gascoyne et al. 1985
0.14 ~ 0.69 (^{90}Sr)	25	CANDU 5 cm section fuel/ clad	Immersion tapwater DDH_2O	Stroess-Gascoyne 1997

Dissolution Rate (mg/[m^2-day]) (U, otherwise specified)	Temperature (°C)	Sample Type	Test Method Solution	References
0.95 ~ 5.7 (Initial value) (Equivalent initial values that Gray derived should be lower.)	25	UO_2 - 100 ~ 300 µm - 900 ~ 1100 µm - pellet	immersion 0.01 M, pH=8 $NaClO_4$	Casas et al., 1993
0.17	25	SIMFUEL 100 ~ 300 µm	flow-through (comparable with Gray),pH = 8.6, $NaClO_4$	Bruno et al., 1995
0.005	25	UO_2 SIMFUEL 100 ~ 300 µm	batch pH = 8.6 $NaClO_4$	Bruno et al., 1995
0.23 ~ 3.3	25	SIMFUEL 100 ~ 300 µm	flow-through (comparable with Gray) pH = 8.4 ~ 8.6 $NaCl/NaHCO_3$	Bruno et al., 1995
0.21 ~ 1.27	25	UO_2 SIMFUEL 100 ~ 300 µm	batch pH = 8.5 $NaCl/NaHCO_3$	Bruno et al., 1995
0.84 ~ 2.40	25	UO_2 100 ~ 300 µm	flow-through (comparable with Gray) 10^{-4} ~ 0.05 M NaCl, 1mM $[HCO_3^-]$	de Pablo 1997

ALTERNATIVE RELEASE MODELS

Presented by
William M. Murphy
210/522-5263 (wmurphy@swri.edu)
Center for Nuclear Waste Regulatory Analyses

and

Richard B. Codell
U.S. Nuclear Regulatory Commission

May 25, 1999
San Antonio, Texas

DOE/NRC Total System Performance Assessment
Technical Exchange

Attachment 13

THREE OF SEVERAL ALTERNATE SOURCE TERM MODELS IN NRC/CNWRA TOTAL-SYSTEM PERFORMANCE ASSESSMENT

- Base Case: Regression of Data (Gray et al.,) for the Dissolution Rate of Spent Fuel in a Multicomponent Solution with an Arrhenius Temperature Extrapolation

- Natural Analog Oxidation Rate: Release Rate Based on Maximum Average Oxidation Rate Estimated for the Nopal I Uranium Deposit at Peña Blanca, Mexico

- Schoepite Solubility: Release Rate Based on Schoepite Solubility as a Function of Temperature, pH, and Uranyl Carbonate Speciation, and Release of Matrix Radioelements in Proportion to Uranium

(Gap and Grain Boundary Species Are Released Rapidly in All Cases; Solubility Limits for All Radioelements are Respected in All Cases)

NOPAL I URANIUM DEPOSIT AT PEÑA BLANCA, MEXICO: NATURAL ANALOG FOR THE PROPOSED REPOSITORY AT YUCCA MOUNTAIN

- \+ Fractured Silicic Volcanic Host Rocks
- \+ Unsaturated Zone Hydrology in Semi-Arid Climate
- \+ Primary Uraninite (Analog of Spent Fuel) Almost Completely Oxidized to Uranyl Phases, e.g., Schoepite, Soddyite, and Uranophane
- \+ Relevant Time Scales: Uraninite Deposition ~ 8 million years ago; Oxidizing Conditions > 3 million years.
- – Evidence for Hydrothermalism Involving Acid-Sulfate Conditions
- – Evidence for an Episode of (Rapid?) Oxidative Alteration

MAXIMUM AVERAGE OXIDATIVE ALTERATION RATE OF URANINITE AT NOPAL I

$$R_o = (U_e / t) + F\,C$$

- U_e: Amount of Oxidized Uranium Remaining (320 metric tons)
- t: Minimum Time Period of Oxidative Alteration (3 million years = U-Pb Age of Late Forming Uranophane)
- F: Maximum Volumetric Water Flow (Average Precipitation × Oversized Cross Section = 1200 $m^3\ yr^{-1}$)
- C: Uranium Concentration in Exiting Water (10^{-7} M Based on Uranyl Mineral Solubility Calculations)
- R_o: Maximum Average Oxidation Rate = 140 g yr^{-1}

NOPAL MAXIMUM AVERAGE OXIDATIVE ALTERATION RATE SCALED TO THE PROPOSED REPOSITORY AT YUCCA MOUNTAIN

140 g yr^{-1} × 63,000 / (320 + 88) (ratio of uranium masses) = 22 kg yr^{-1}

- Oxidative Alteration Rate is a Maximum Limit on Release Rate from the Spent Fuel Matrix

- Peña Blanca Data Demonstrate that Oxidative Alteration is Rapid Relative to Removal of Uranium from the System

SCHOEPITE SOLUBILITY

- Uranyl Minerals are Stable in the Yucca Mountain Environment Relative to Spent Nuclear Fuel
- Natural, Laboratory, and Crystallographic Evidence Points to Incorporation of Minor Radioelements in the Structures of Secondary Uranyl Minerals
- Thermodynamic Data Permit Calculation of Schoepite Solubility as a Function of Temperature, pH, and Aqueous Speciation
- Uranyl Minerals Have Retrograde Solubilities with Temperature
- Solutions Passing Through the Waste Package Are Assumed to Be Saturated with Respect to Schoepite and to Contain Other Spent Fuel Matrix Species in Proportion to Uranium

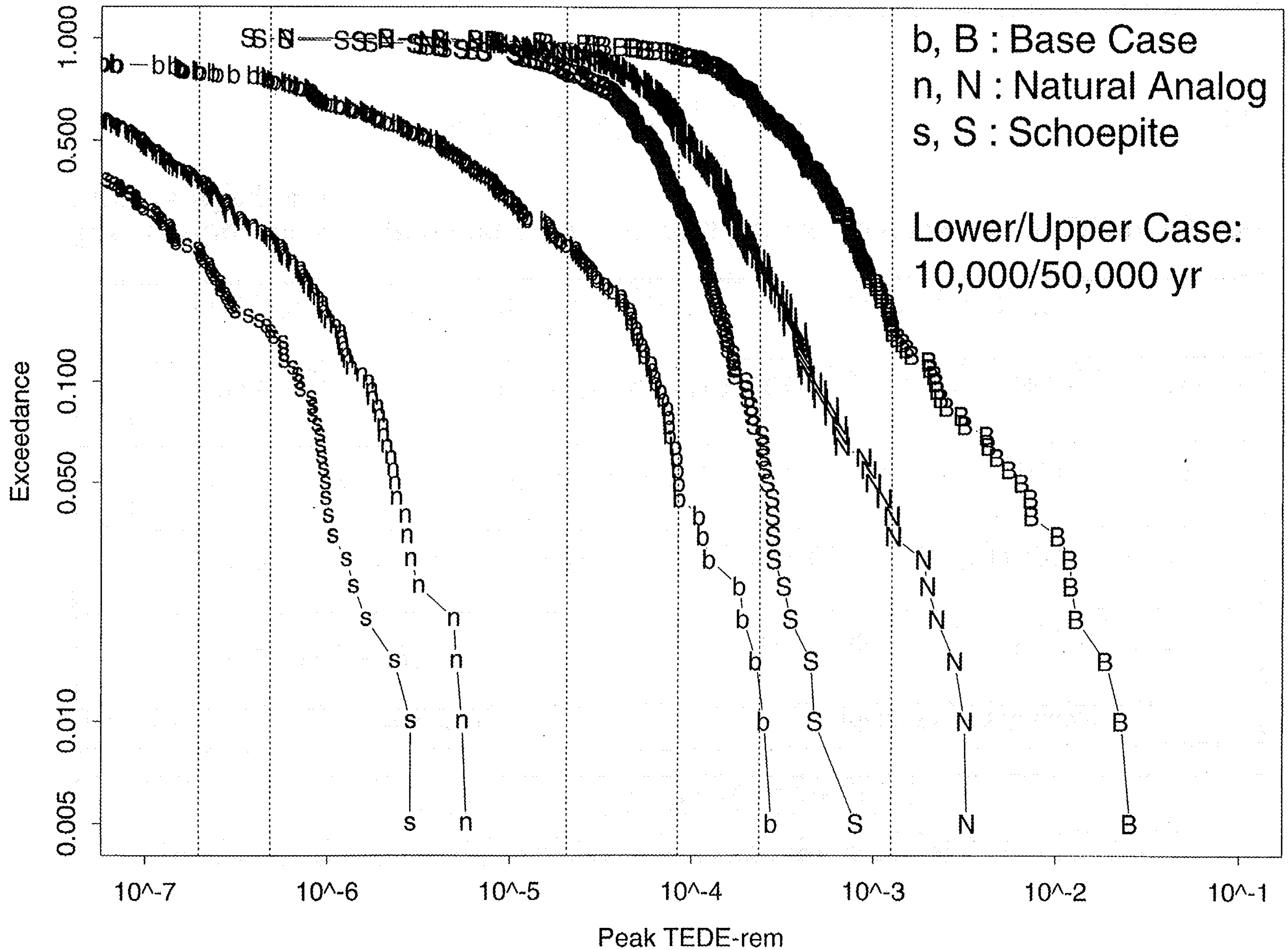
REACTIONS AND MASS ACTION RELATIONS FOR SCHOEPITE SOLUBILITY

Number	Reaction	Mass Action Relation
0	$UO_2(OH)_2 + 2H^+ \rightleftharpoons UO_2^{2+} + 2H_2O$	$[UO_2(OH)_2] = [UO_2^{2+}] / K_0[H^+]^2$
1	$UO_2CO_3 + H^+ \rightleftharpoons UO_2^{2+} + HCO_3^-$	$[UO_2CO_3] = [UO_2^{2+}][HCO_3^-] / K_1[H^+]$
2	$UO_2(CO_3)_2^{2-} + 2H^+ \rightleftharpoons UO_2^{2+} + 2HCO_3^-$	$[UO_2(CO_3)_2^{2-}] = [UO_2^{2+}][HCO_3^-]^2 / K_2[H^+]^2$
3	$UO_2(CO_3)_3^{4-} + 3H^+ \rightleftharpoons UO_2^{2+} + 3HCO_3^-$	$[UO_2(CO_3)_3^{4-}] = [UO_2^{2+}][HCO_3^-]^3 / K_3[H^+]^3$
4	$UO_3 \bullet 2H_2O + 2H^+ \rightleftharpoons UO_2^{2+} + 3H_2O$	$[UO_2^{2+}] = K_4[H^+]^2$

The temperature dependence of the equilibrium constants is given by the Van't Hoff equation

$$\ln K_i = \ln K_i^0 + \frac{\Delta H_i^0}{R}\left[\frac{1}{T^0} - \frac{1}{T}\right] \qquad (3)$$

Yucca Mountain CCDF for Peak Annual Dose at 20 km Distance



QUALIFICATIONS FOR THE ANALOG SOURCE TERM MODEL

- Possible Nonconservatism
  - Evidence for episodic secondary mineral formation at 3 million years and episodic uranium mobilization at 400,000 years and at 50,000 years
- Conservatisms Adopted in the Model
  - Minimum period of oxidation based on ages of late forming uranophane
  - Upper bound on infiltration equal to precipitation over a large area
  - Model release rate equal to oxidation rate

QUALIFICATIONS FOR THE SCHOEPITE SOLUBILITY SOURCE TERM MODEL

- Possible Nonconservatisms
  - All radionuclides (except gap and grain boundary inventories) are incorporated in schoepite in proportion to their concentrations in the spent fuel matrix
  - More stable tertiary phases (e.g., uranophane) may form and release initially coprecipitated radionuclides.
- Conservatism adopted in the model
  - A role for secondary phases for control of the radionuclide source term is realistic.

OBSERVATIONS

- Both natural analog and schoepite source term models yield lower doses than the NRC TPA3.2 base case model.

- Both natural analog and base case uranium releases depend on sampled uranium solubility limits. Schoepite solubility model releases depend on calculations of uranium solubility as a function of temperature and solution chemistry.

- Cumulative release of ^{237}Np from the EBS at 50,000 years for the natural analog model is 14 percent of the base case release, and for the schoepite solubility model it is 0.07 percent of the base case release.

- Consideration of the role of secondary phases could reduce conservatism in performance assessment models for Yucca Mountain.

- Natural analog information can contribute to performance assessment.

NEAR-FIELD DRIPPING AND THERMAL MODELS

Presented by
Debra L. Hughson
210/522-3805 (dhughson@swri.edu)
Center for Nuclear Waste Regulatory Analyses

May 25, 1999

San Antonio, Texas

DOE/NRC Technical Exchange on
Total System Performance Assessments for Yucca Mountain

IMPORTANCE TO PERFORMANCE ASSESSMENT

- Differences in the Amount of Seepage Into the Emplacement Drifts and Onto WPs Lead to Calculated Radionuclide Releases That Vary by Several Orders of Magnitude.
- Seepage Into Drifts and Onto WPs Is a Complex Process With Large Uncertainties. Both DOE and NRC Performance Assessments Use a Much Simplified Approach to Seepage Abstraction. Given the Large Uncertainties It Is Desirable to Err on the Conservative Side.

CONCERNS

- Data Needed to Characterize Heterogeneity Have Not Been Collected in the Main Repository Block
- Existing Models Do Not Capture the Scales of Variability
- Degradation of Emplacement Drifts Is Neglected
- Several Thousands of Years of WP Performance Are Gained by Assuming No Dripping Occurs During the Thermal Period

OUTLINE

- Seepage Into Drifts Process Model
  - Model scales and fracture properties
  - Drift degradation
- Thermal Abstraction
  - Neglecting seepage during thermal period

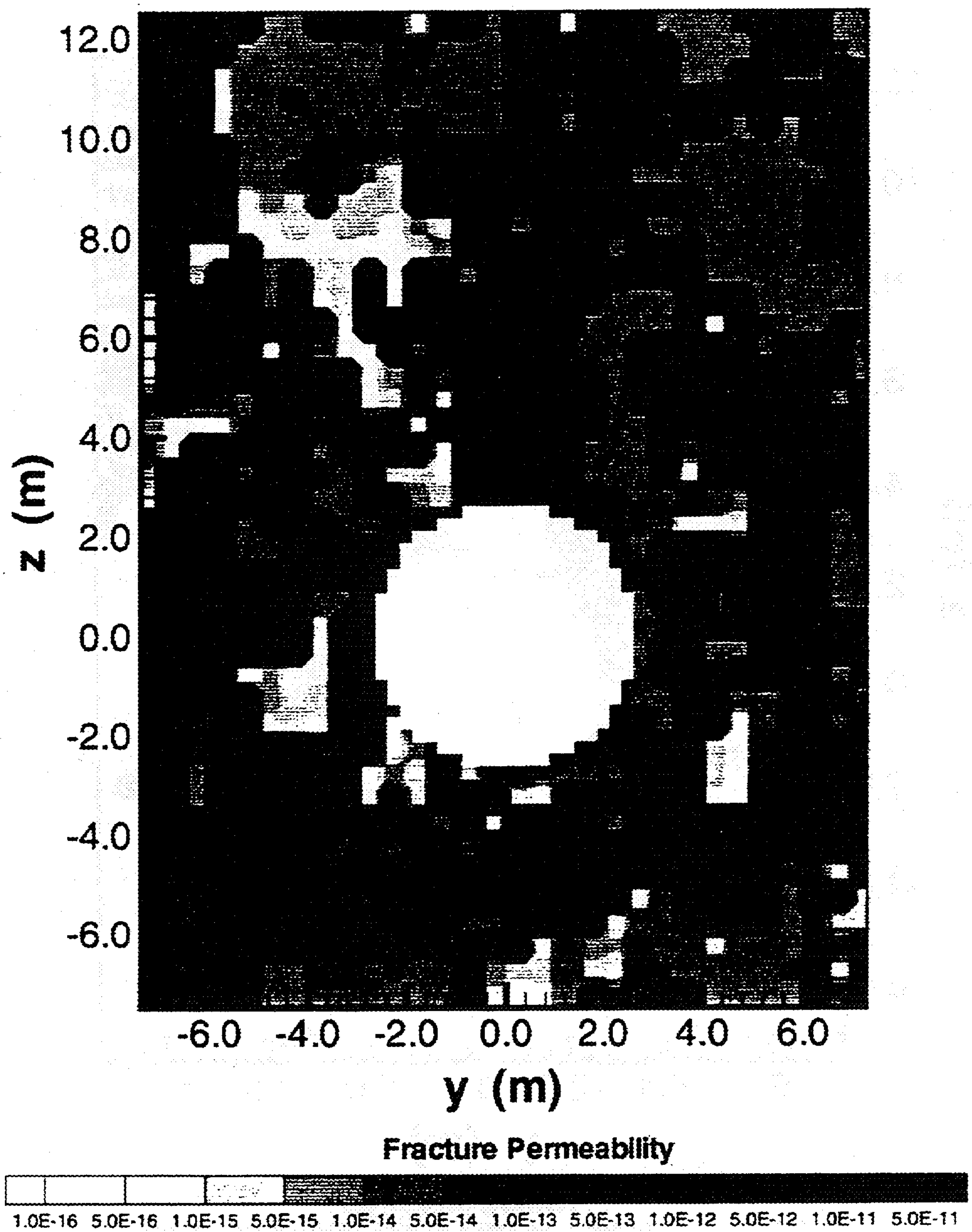


Figure 2-58b. Simulated Heterogeneous-Permeability Field for Vertical Slice 2 of the 3-D Block

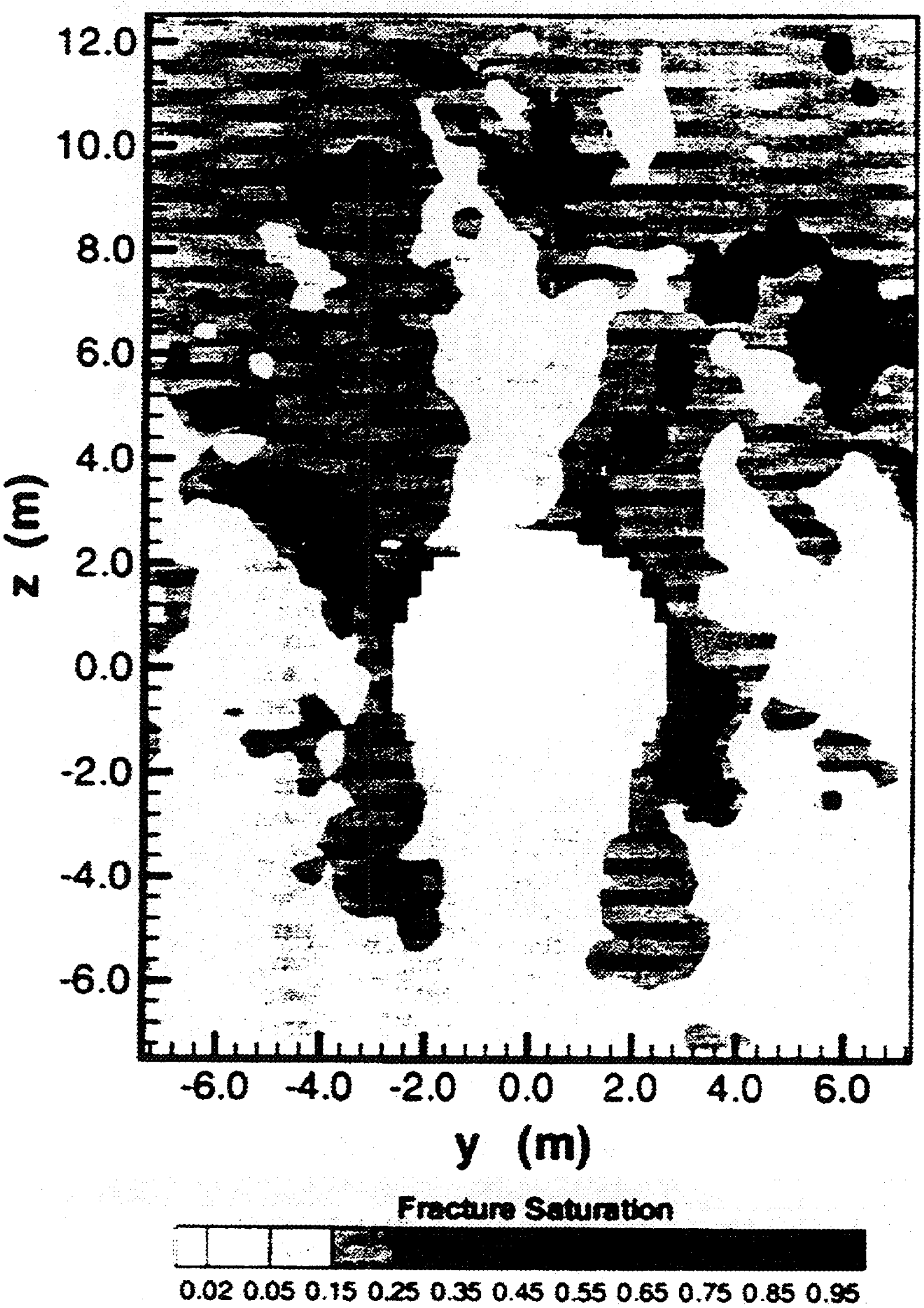
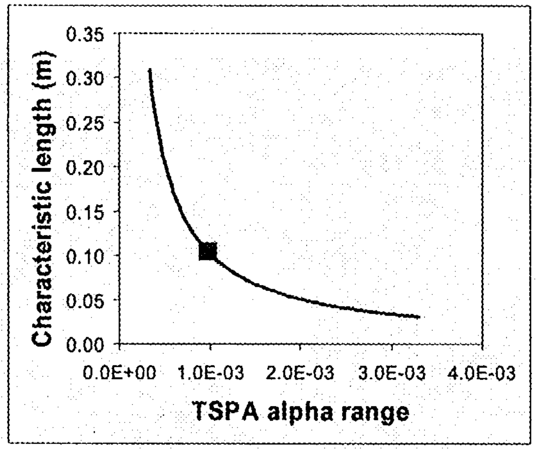


Figure 2-71a. Calculated Saturation Profiles in Fracture Continuum on Slice 1 of the 3-D Block at $t = t_p = 1$ Year

BASE CASE PARAMETERS AND PHYSICAL INTERPRETATION



Fracture Permeability
$k_s = 10^{-14}, 10^{-13}, 10^{-12}\ m^2$

Fracture Alpha Parameter
$\alpha = 3.3E\text{-}4, 9.7E\text{-}4, 3.3E\text{-}3\ Pa^{-1}$

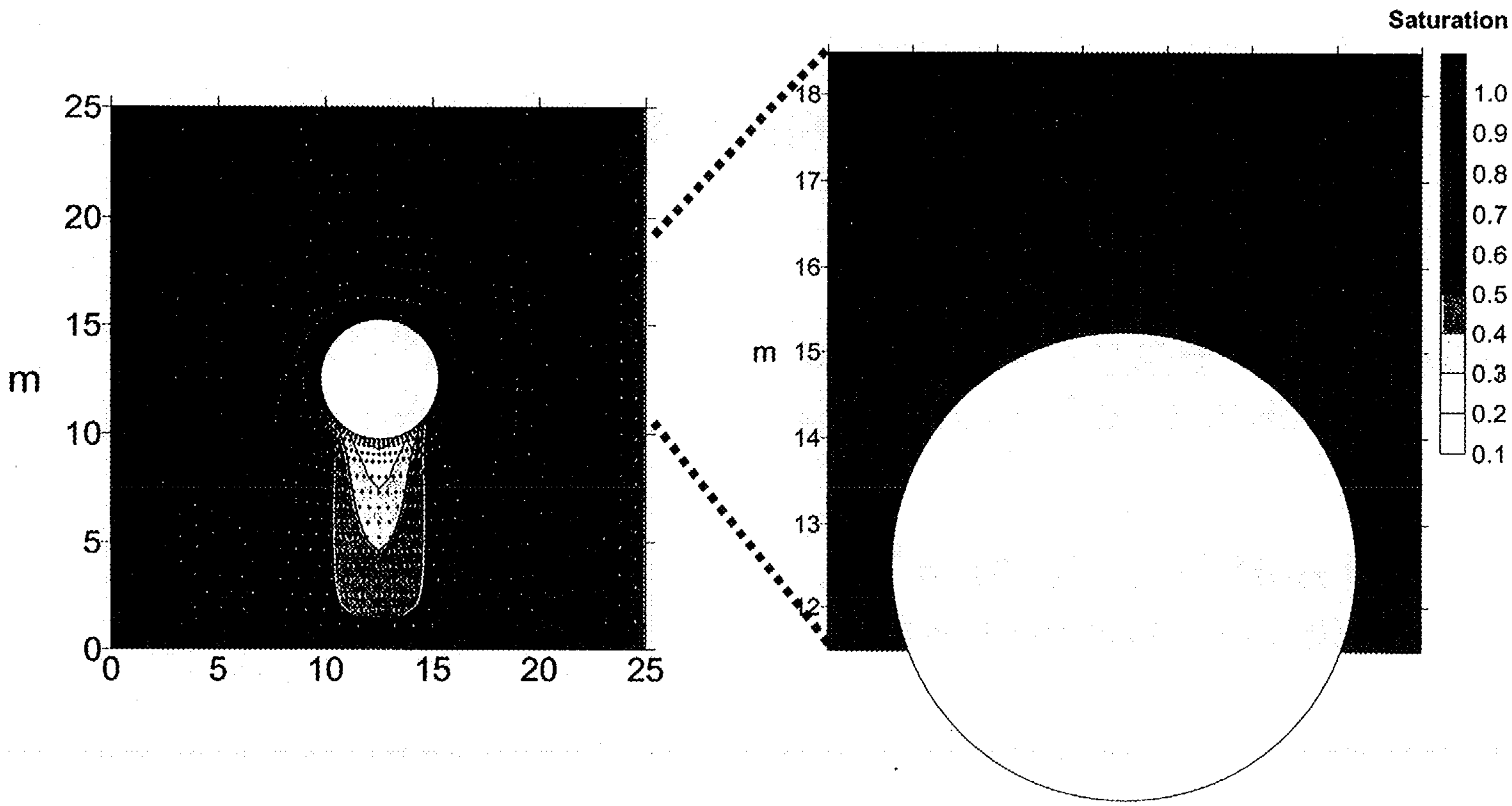
Threshold Percolation Flux

$$q^* = \frac{k_s}{\vartheta}$$

ϑ Is Dimensionless Potential, a Function of α and Drift Radius

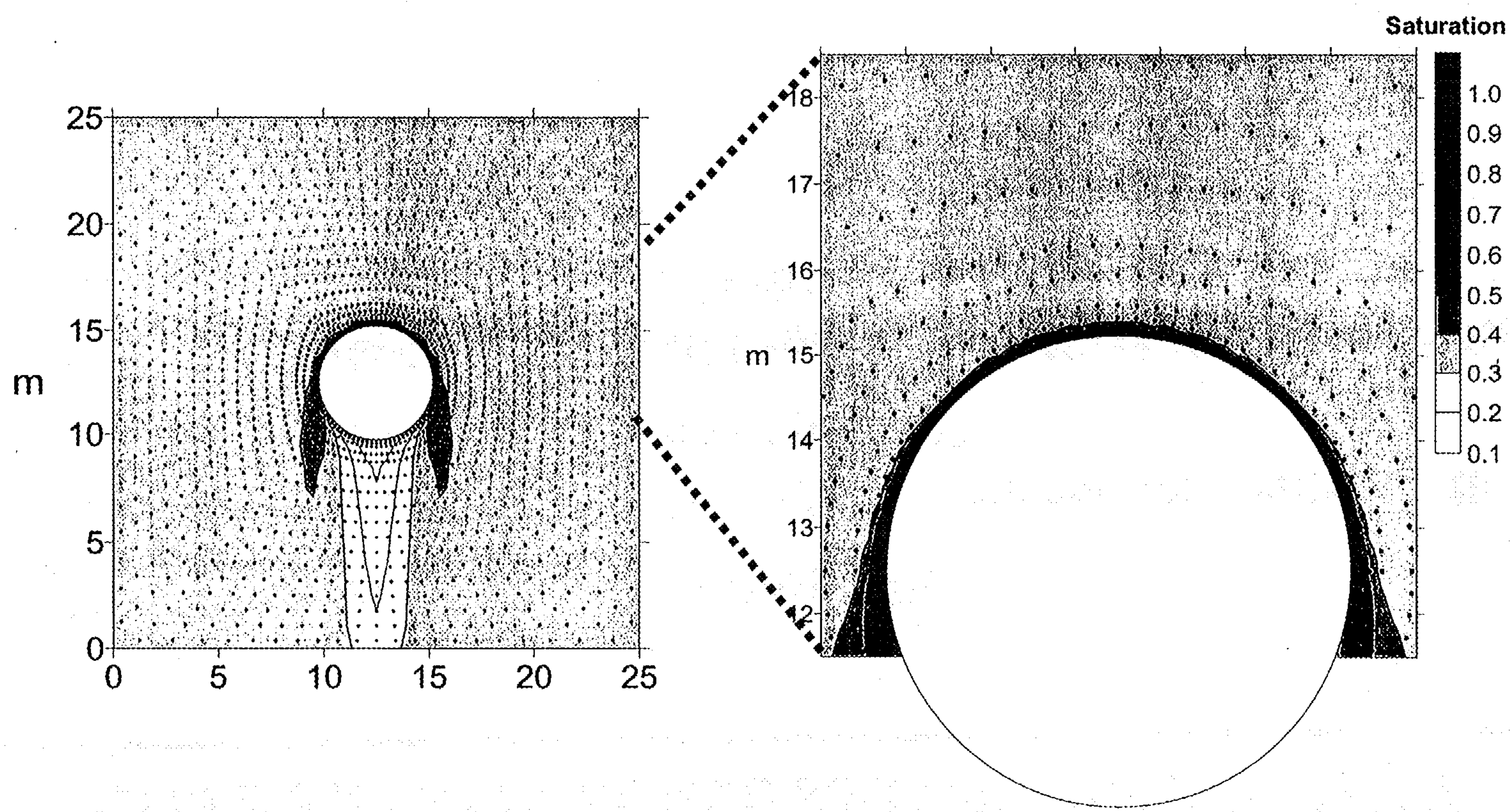
BOUNDARY LAYER FORMED WITH MEDIAN

$\alpha = 9.7 \times 10^{-4}$ Pa^{-1}



BOUNDARY LAYER FORMED WITH MAXIMUM

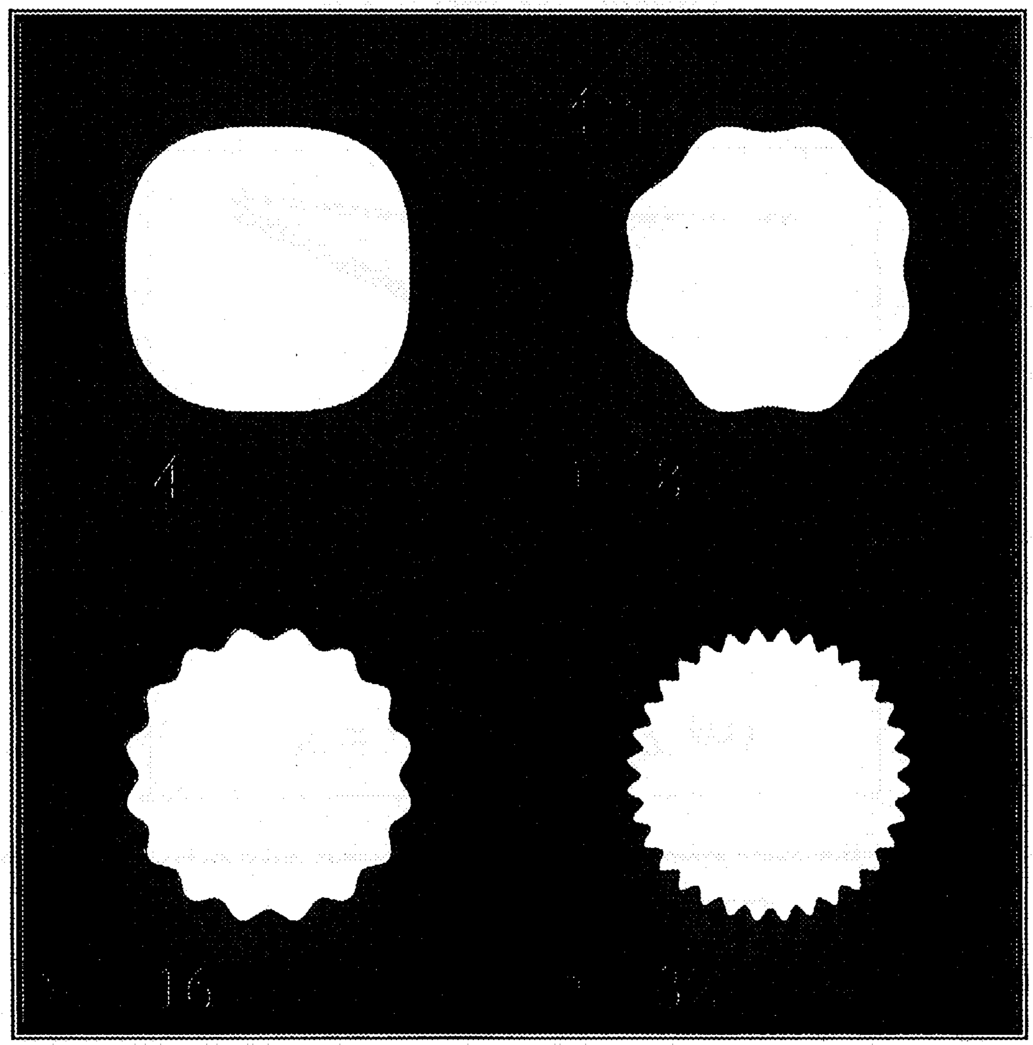
$\alpha = 3.3 \times 10^{-3}$ Pa^{-1}



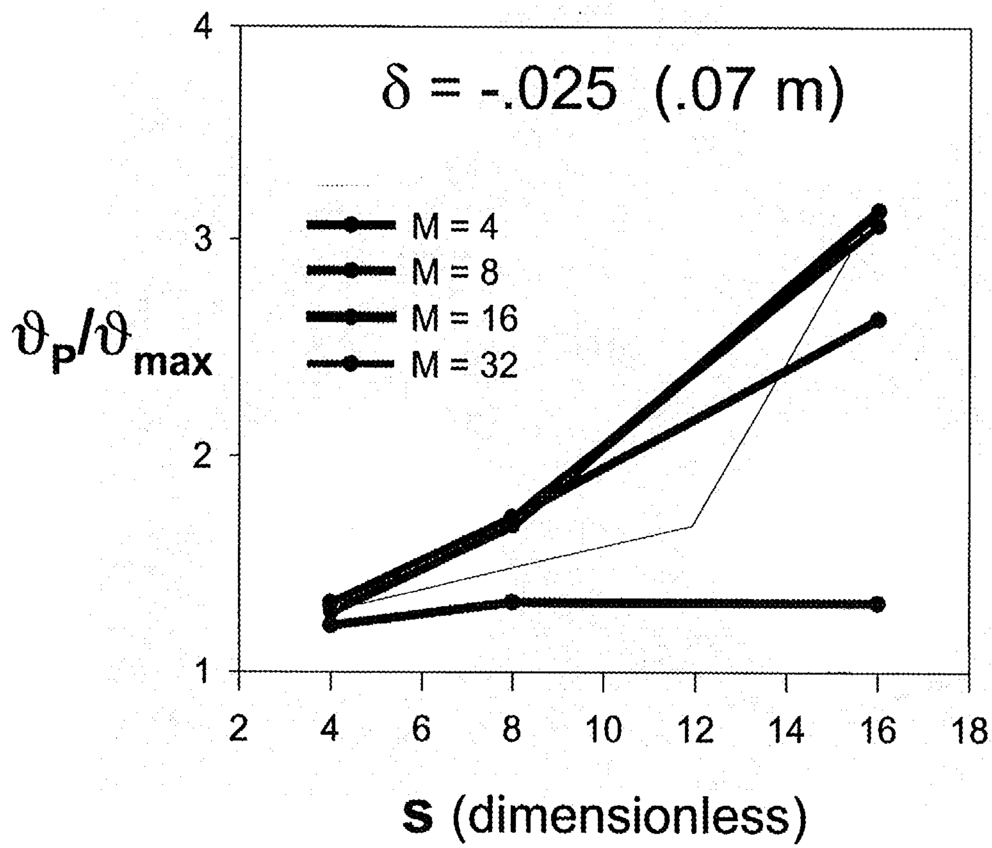
COMMENTS ON SCALE AND HETEROGENEITY

- Model Scales and Fracture Properties
  - Heterogeneity in the alpha parameter within the boundary layer may be important
- Drift Degradation and Wall Irregularity: What Happens If the Boundary Layer Shape Is Perturbed?

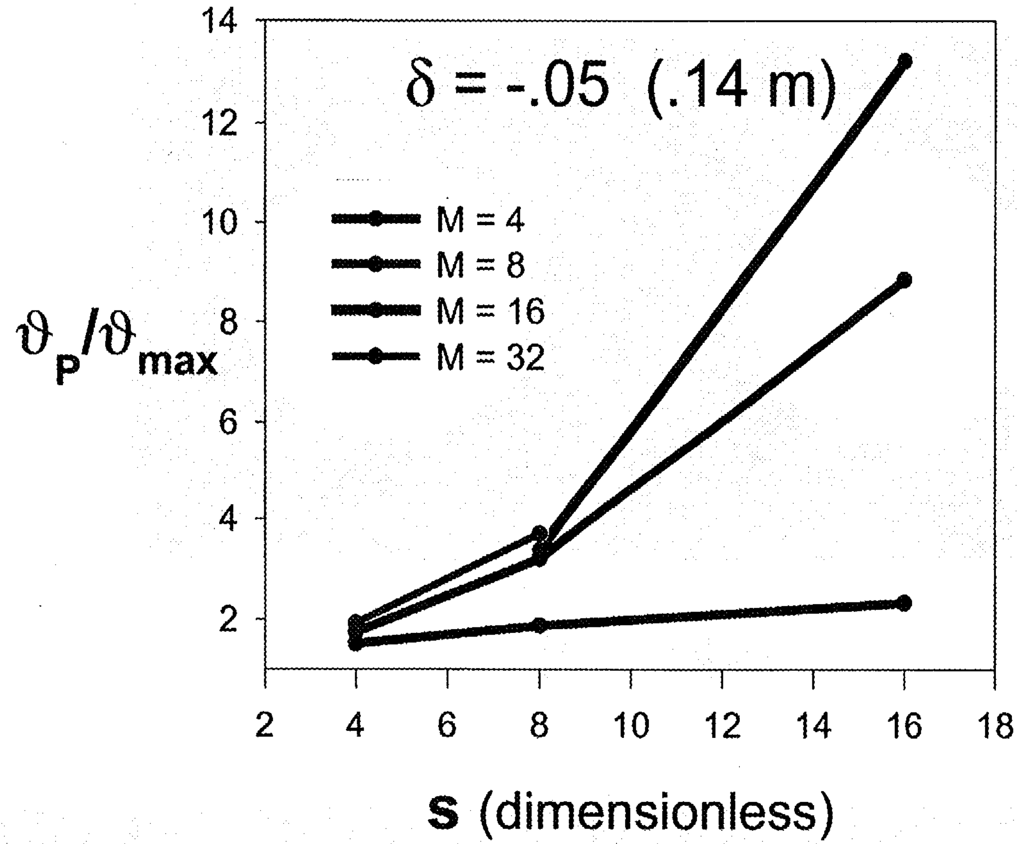
MODEL SHAPES FOR DRIFT DEGRADATION



FACTOR BY WHICH THRESHOLD PERCOLATION FLUX IS DECREASED

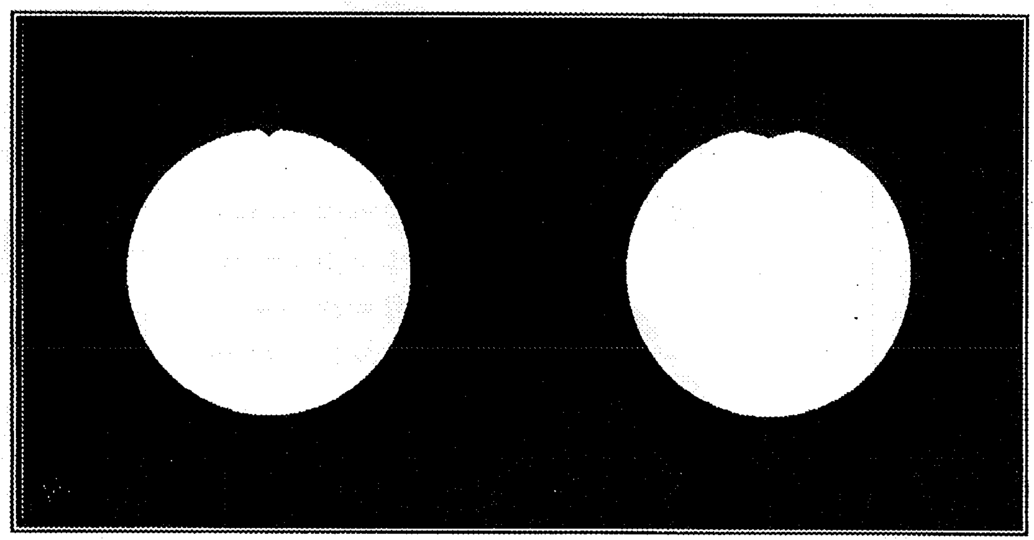


FACTOR BY WHICH THRESHOLD PERCOLATION FLUX IS DECREASED

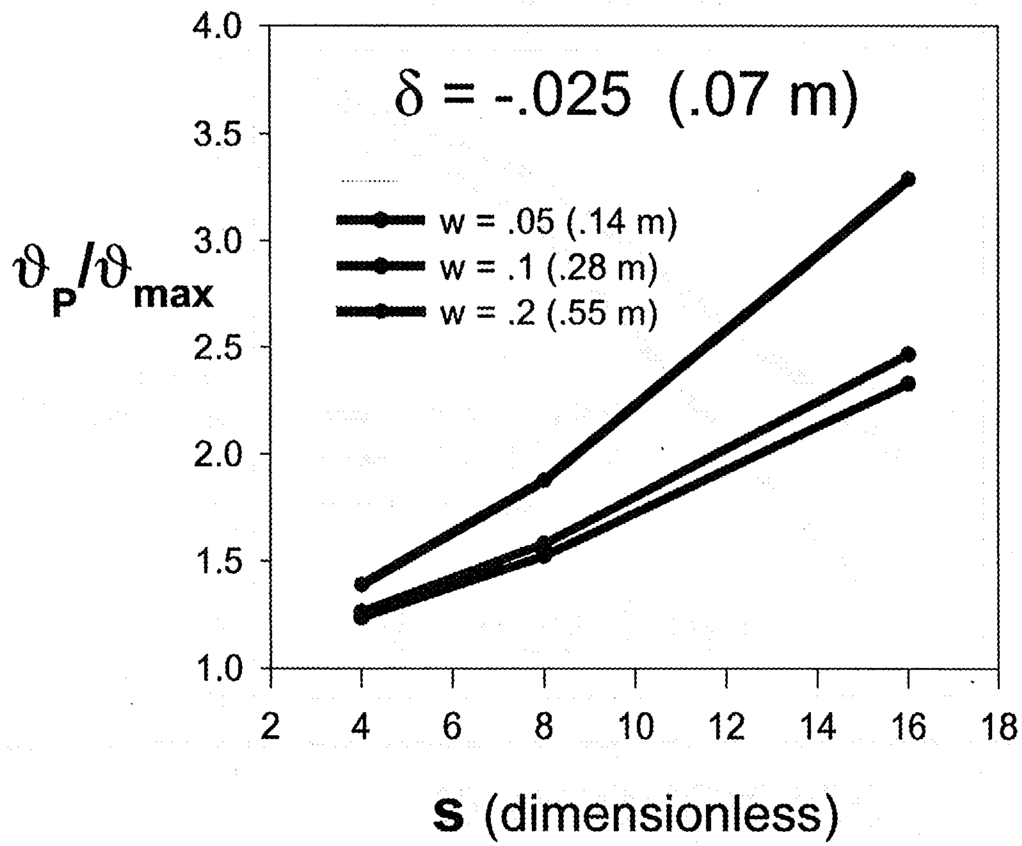


MODEL SHAPES FOR DRIFT DEGRADATION

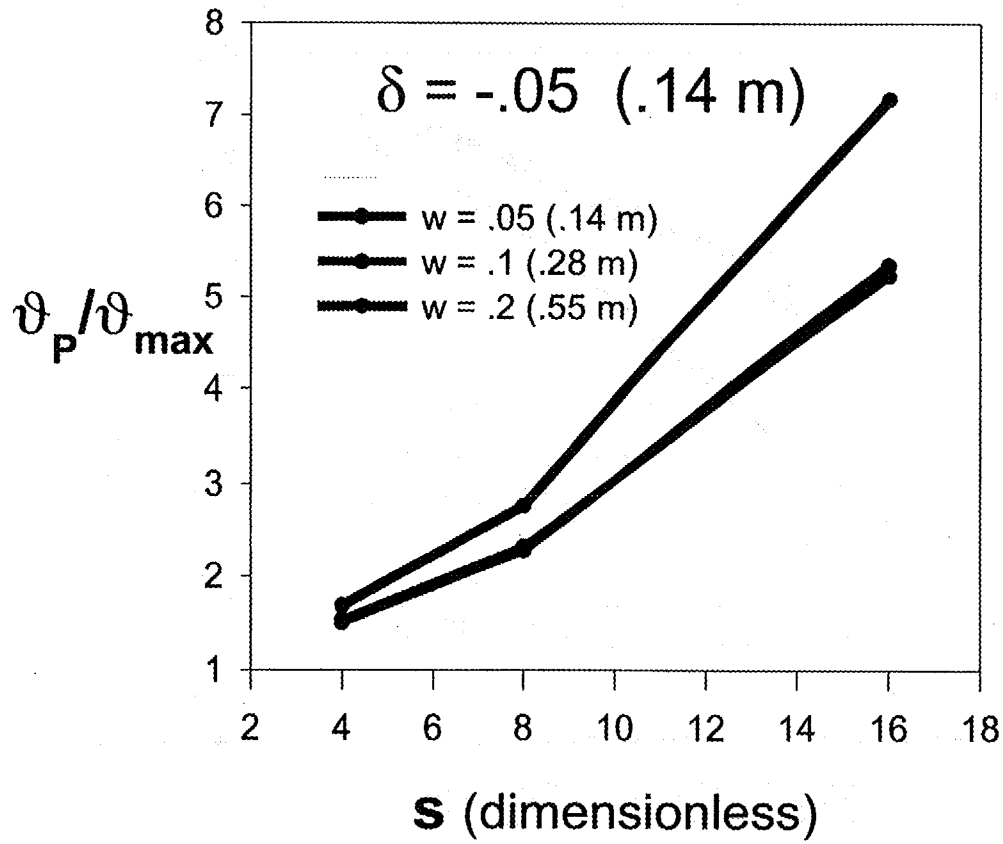
$\delta = .14m$



FACTOR BY WHICH THRESHOLD PERCOLATION FLUX IS DECREASED



FACTOR BY WHICH THRESHOLD PERCOLATION FLUX IS DECREASED



COMMENTS ON DRIFT DEGRADATION

Irregularities in the Range of 15 cm Can Result in Order of Magnitude Decreases in Threshold Percolation Flux for s Less Than 16. Note the Dramatic Increase in This Reduction Factor With Increasing s. Larger s Corresponds to the Larger α, (i.e., smaller characteristic length scale, representative of the larger vertical fractures.)

THERMAL-HYDROLOGICAL CONCERNS IN TSPA-VA

- TH Processes on Seepage Are Required for the Entire Repository Performance Period. TH Driven Flow Cannot Be Neglected for the Initial 5,000 years After Waste Emplacement

- Penetration of the Boiling Isotherm by Flow Down a Fracture Is Omitted. The Assumption That Water Will Not Contact the WP Until WP Temperature Decreases Below Boiling Is Not Conservative.

SUPPORTING TECHNICAL BASIS

- Theoretical Analysis, O.M Phillips
- Numerical Simulations, K. Pruess
- Laboratory Scale Heater Experiments, R. Green.
- Field Scale Observations in the G-tunnnel at Climax

NRC INSIGHTS ON TREATMENT OF THE NATURAL SYSTEM IN TSPA-VA AND COMPARISONS WITH TPA 3.2

Gordon Wittmeyer
(210) 522-5082 gwitt@swri.org
Center for Nuclear Waste Regulatory Analyses

Contributors: S. Mohanty, R. Janetzke, J. Weldy, R. Rice,
T. McCartin, J. Firth, R. Codell

May 25-27, 1999
San Antonio, Texas

NRC/DOE Technical Exchange on Total System Performance Assessment for Yucca Mountain

Attachment 15

OBJECTIVES

- Outline Approaches Used by NRC and DOE (As Interpreted by NRC) to Develop Abstracted Models of the Natural System for Use in Performance Assessments
- Identify Significant Differences in DOE and NRC Modeling Approaches
- Present Limited Results Depicting the Difference in Repository Performance Estimates Using TSPA-VA "Abstracted Models" and "Parameters" in the TPA 3.2 Code
- Detailed Discussions: Groundwater Velocity in SZ
- (J. Winterle), Retardation in Alluvium (D. Turner), Dose Conversion Factors (P. LaPlante)

NATURAL SYSTEMS

- Infiltration and Deep Percolation
- Unsaturated Zone Flow and Transport
- Saturated Zone Flow and Transport
- Radionuclide Concentration Dilution Due to Well Pumping
- Biosphere and Dose Conversion Factors

INFILTRATION AND DEEP PERCOLATION

- Time Period Of Climate Change
  - TSPA-VA: Sample Range of 0 to 10,000 Years for Present Climate Followed by 80,000 to 100,000 Years of Long-term Average Climate
  - TPA 3.2: 10,000 Years of Present Climate (or Slightly Hotter/drier) Followed by 100,000 Year Wetter/cooler Sinusoidal Climate Cycle

- Average Areal Mean Infiltration at Start
  - TSPA-VA: 3.9 to 11 mm/yr, I=7.65 Mm/yr for 60%, 3×I for 10% and I/3 for 30%
  - TPA-3.2: 1-10 mm/yr Uniformly Sampled for All Sub-areas, 5.5 mm/yr Mean

INFILTRATION AND DEEP PERCOLATION

- Water Table Rise
  - TSAP-VA: 80 m for Long-term Average Climate, 120 m for Superpluvial
  - TPA 3.2: Not Accounted For

- Increased Precipitation at Glacial Max
  - TSPA-VA: Two Times Current for Pluvial, Three Times for Superpluvial
  - TPA 3.2: At Glacial Max 1.5 to 2.5 Times Current

- Change in Temperature at Glacial Maximum
  - TSPA-VA: 10 C Decrease
  - TPA 3.2: Uniform 5 to 10 C Decrease

INFILTRATION AND DEEP PERCOLATION

- Precipitation to Shallow Infiltration
  - TSPA-VA: Abstractions From Process-level Models of Water and Energy Balance, Including Runoff and Plant Transpiration
  - TPA 3.2: Abstractions From Process-level Models of Water and Energy Balance, Does Not Include Runoff/run-on or Plant Transpiration
- Shallow Infiltration to Deep Percolation
  - TSAP-VA: 3D Steady-state Model, 15 Deterministic Simulations
  - TPA 3.2: No Lateral Diversion, Deep Percolation Equals Sub-area Average Shallow Infiltration

UNSATURATED ZONE FLOW AND TRANSPORT

- Flow From Repository to Water Table
  - TSPA-VA: Detailed 3D Model That Suggests Significant Lateral Diversion
  - TPA 3.2: 1D Vertical Streamtubes for Each of the Seven Sub-areas, No Lateral Diversion
- Matrix Diffusion
  - TSPA-VA: Treated in Transport Model
  - TPA 3.2: Not Accounted for in Unsaturated Zone
- Retardation in Fractures
  - TSPA-VA: No Sorption
  - TPA 3.2: Not Modeled

UNSATURATED ZONE FLOW AND TRANSPORT

- Effects of Intervening Perched Zones
  - TSPA-VA: Low Permeability Region That Laterally Diverts Flow at Base of TSw
  - TPA 3.2: Not Considered

- Flow Model
  - TSPA-VA: Dual Permeability, for Base Case Steady-state Flow is Confined to Fractures
  - TPA 3.2: Fracture Flow When Flow Rate Exceeds Saturated K of the Matrix

- Treatment of Faults As Fast Paths
  - TSPA-VA: Accounted for in 3D Model
  - TPA 3.2: Not Modeled

UNSATURATED ZONE FLOW AND TRANSPORT

- Colloids
  - TSPA-VA: 1D Transport in Fractures with Colloid Partition Coefficient
  - TPA 3.2: Not Modeled
- Dispersion
  - TSPA-VA: Mean Dispersion Length of 20 m over 300 m Thickness
  - TPA 3.2: Longitudinal Dispersion Equal to 10% of Path Length
- Sorption on Rock Matrix
  - TSPA-VA: Kd Approach
  - TPA 3.2: Kd Approach

SATURATED ZONE FLOW AND TRANSPORT

- Darcy Flux
  - TSPA-VA: 2.3 m/yr Long-Term Average in Streamtubes
  - TPA 3.2: Varies Among and Along Streamtubes (Typical Value 0.3 m/yr)

- Treatment of Alluvium
  - TSPA-VA: 10% of Realizations Have no Alluvium in Streamtubes. for 90% That do, Sampled Length Varies From 0 to 6 km
  - TPA 3.2: Varies with Streamtubes (8-12 km). Fixed for All Realizations

- Alluvium Porosity
  - TSPA-VA: Mean of 0.25, Standard Deviation Truncated Normal is 0.075
  - TPA 3.2: Uniform from 0.1 to 0.15

SATURATED ZONE FLOW AND TRANSPORT

- Tuff Porosity
  - TSPA-VA: 1×10^{-5}, 0.02, 0.23 Log-triangular
  - TPA 3.2: 0.001 to 0.01 Log-uniform

- Longitudinal Dispersion
  - TSPA-VA: Mean 2.0, Standard Deviation 0.753, Log-normal
  - TPA 3.2: 0.01 Fraction of Path length for Tuff, 0.1 Fraction of Path Length in Alluvium

- Retardation for Important Nuclides
  - TSPA-VA: Np237, K_d 5-15 mL/g, Uniform; I129 K_d =0; Tc99 K_d =0
  - TPA 3.2: Np237, K_d 1-3900 mL/g, Log-normal; I129, K_d 0-0.23 mL/g, Log-uniform; Tc99, K_d 0-1.7 mL/g, Log-uniform. (Actually Use Rds)

BOREHOLE DILUTION AND TRANSVERSE DISPERSION

- Borehole Dilution
  - TSPA-VA: Not Accounted For.
  - TPA 3.2: Pumping at Receptor Location Uniform From 6,200,000 to 18,000,000 m^3 per Year
- Transverse Dispersion
  - TSPA-VA: Accounted for by Dilution Factor, 1-100 Uniformly Distributed
  - TPA 3.2: Not Accounted For

BOREHOLE DILUTION AND TRANSVERSE DISPERSION

- Equivalence Between TSPA-VA Dilution Factor and TPA 3.2 Borehole Dilution Effect Achieved by Using Pumping Rates (In TPA 3.2) from 146,300 to 14,630,000 m^3 per Year.
  - TSPA-VA: 146,300 m^3 per Year Flows Through Repository Footprint and SZ. Multiply this Flow Rate by the Dilution Factor (1,100) to Obtain Equivalent Dilution Volume.

- For TSPA-VA Radionuclide Concentrations Are Added. This Approach Does Not Conserve Mass, but Would be Conservative From the Standpoint of Safety.

TPA CALCULATIONS WITH TSPA-VA DATA

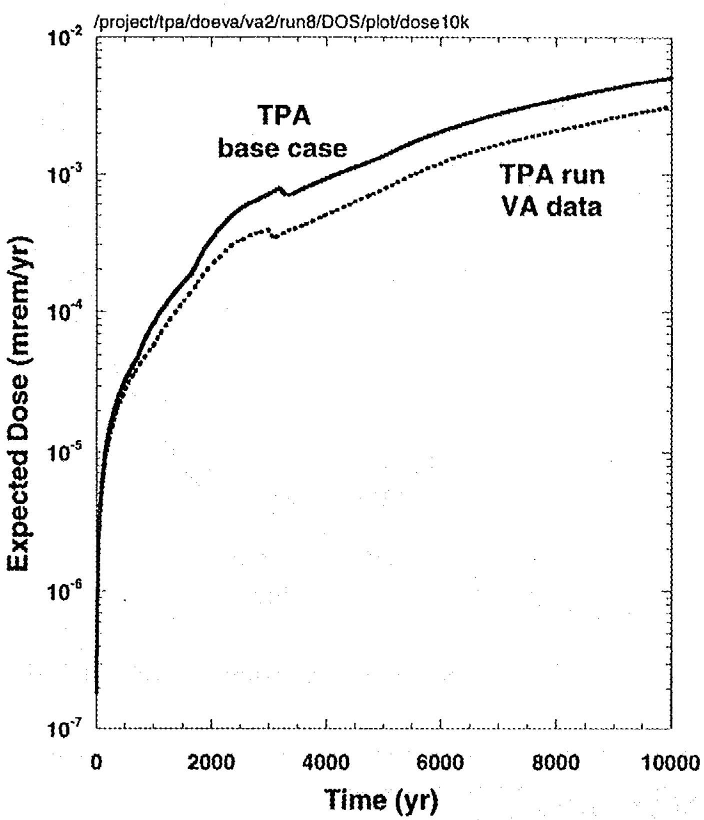
SZFT Transport

Parameter	TPA 3.2	TSPA-VA
Alluvium R_d for Np	Log-normal: 1.0, 3.9×10^3	Log-normal: 8.7×10, 2.6×10^2
Alluvium R_d for I	Log-uniform: 1.0, 4.0	Constant: 1.0
Alluvium R_d for Tc	Log-uniform: 1.0, 30.0	Constant: 1.0
Fracture Porosity Saturated Tuff	Log-uniform: 1×10^{-3}, 1×10^{-2}	Log-triangular 1×10^{-5}, 2×10^{-2}, 2.3×10^{-1}
Porosity of Saturated Alluvium	Uniform: 1×10^{-1}, 1.5×10^{-1}	Truncated Normal: 0.25, 0.075

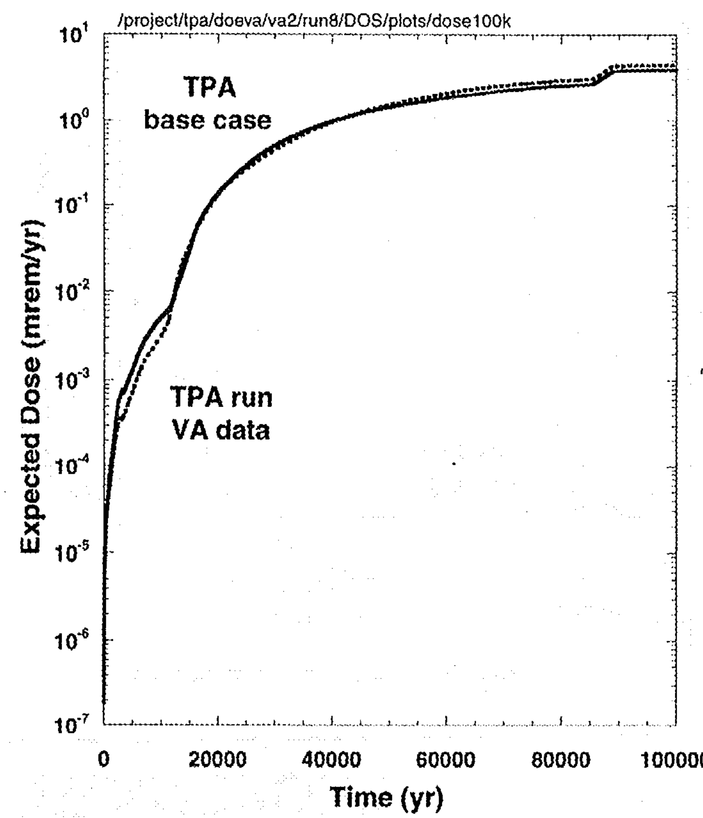
Dilution

Parameter	TPA 3.2	TSPA-VA
Well Pumping Rate for Farming Receptor Group Located Greater than 20 km from YM (Gal/day)	Uniform: 4.5×10^6, 1.3×10^7 (6.2×10^6, 1.8×10^7 m^3/yr)	Log-uniform: 1.07×10^5, 1.07×10^7 (1.46×10^5, 1.46×10^7 m^3/yr)

TPA 3.2 RUN WITH TSPA-VA UZ FLOW AND TRANSPORT

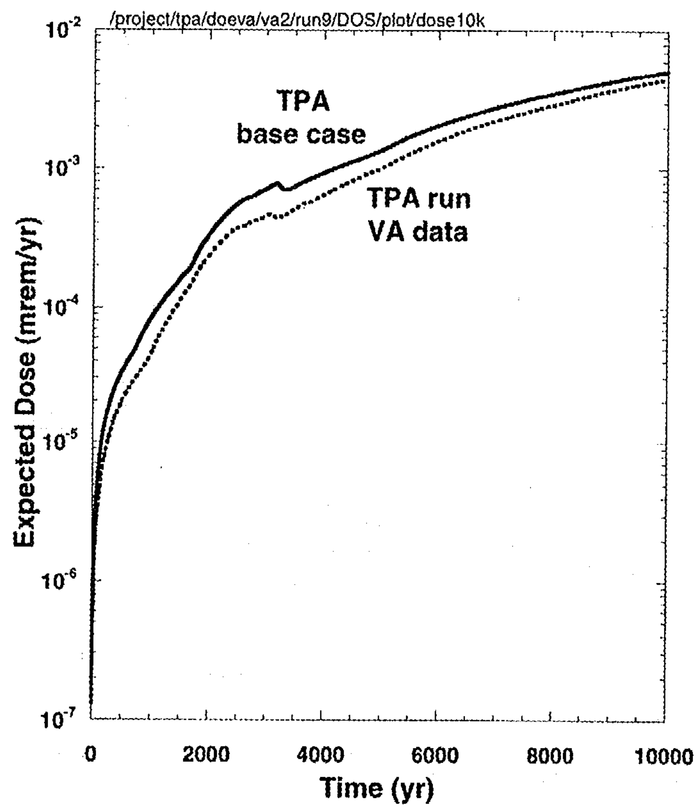


10,000 years

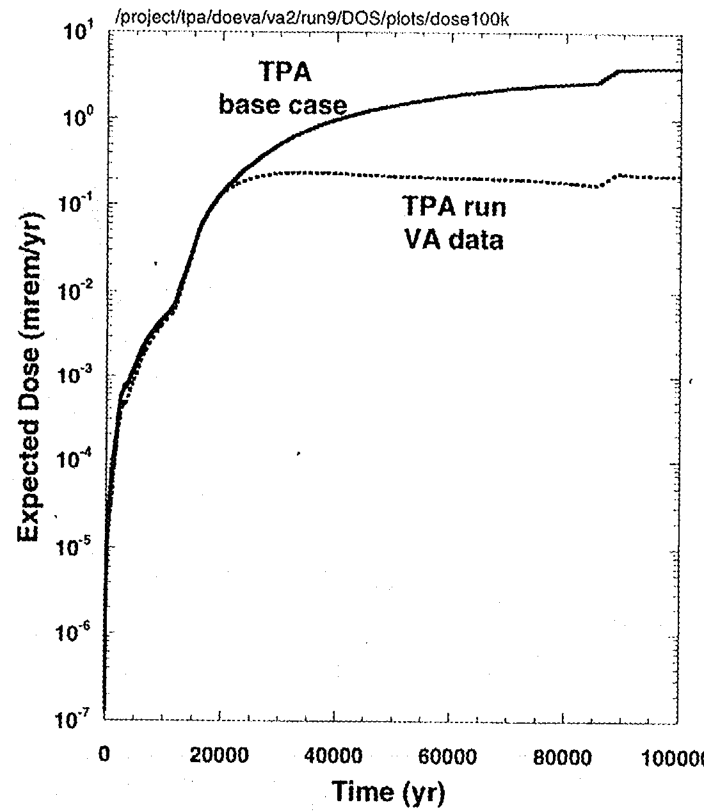


100,000 years

TPA 3.2 RUN WITH TSPA-VA SZ FLOW AND TRANSPORT

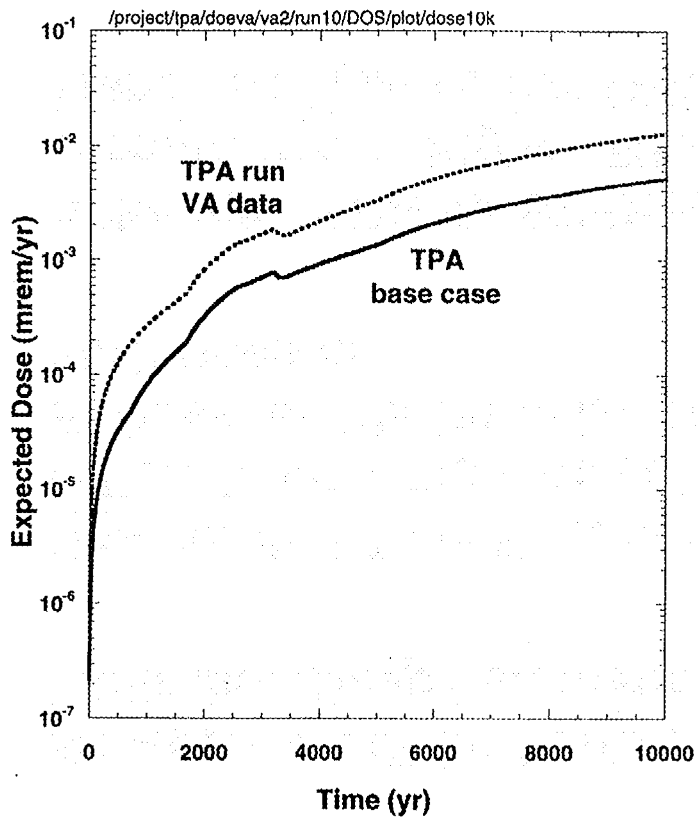


10,000 years

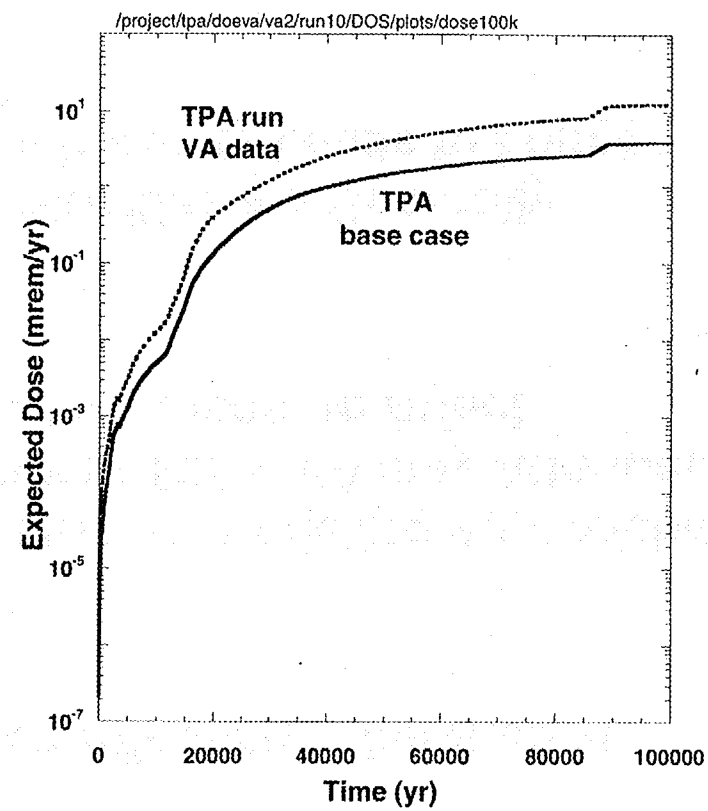


100,000 years

TPA 3.2 RUN WITH TSPA-VA DILUTION



10,000 years



100,000 years

SUMMARY AND CONCLUSIONS

- No Apparent Major Performance-Affecting Difference in Infiltration/Deep Percolation

- Unsaturated Zone Flow and Transport Modeling Approaches Differ. Greater Presence of CHnv in TSPA-VA may Attenuate Release. Matrix Diffusion Does Not Appear to Affect Performance.

- Although TSPA-VA SZ Darcy Velocities are Generally Greater, Use of Higher Effective Porosity Leads to Longer Transport Times Than TPA 3.2

- Smaller Overall Values for Dilution in TSPA-VA Appear to Produce Higher Average Doses than TPA 3.2

GROUNDWATER VELOCITY IN THE SATURATED ZONE

Presented by

Jim Winterle

210/522-5249 (jwinterle@swri.edu)

Center For Nuclear Waste Regulatory Analyses

San Antonio, Texas

May 26, 1999

DOE/NRC Technical Exchange on

Total System Performance Assessments for Yucca Mountain

Attachment 16

FACTORS AFFECTING GROUNDWATER VELOCITY

- Hydraulic Gradient
  - Fairly well-characterized in volcanic tuff aquifer
  - Poorly characterized in alluvial aquifer

- Aquifer Hydraulic Conductivity
  - Fairly well-characterized in volcanic tuff aquifer
  - Poorly characterized in alluvial aquifer

- Flow Porosity
  - High uncertainty in both tuff and alluvial aquifer flow systems

FLOW POROSITY IN THE VOLCANIC TUFF AQUIFER

- Often Mistakenly Equated With Fracture Porosity

- Attempted Definition:
  - The volume fraction of interconnected open fractures, rubble zones, and, higher-permeability matrix through which the great bulk of flow occurs

- Estimates Range Over Orders of Magnitude:
  - 8.6% from Iodide tracer test (Geldon et al., 1997); [2.8% from CNWRA analysis of the same tracer test]
  - Range of 0.37% to 12% from multiple tracer test (Reimus, 1998, draft report)
  - Range of 0.001% to 10% SZ expert elicitation project (range of best guesses from 0.1% to 1%)

FLOW POROSITY IN THE VOLCANIC TUFF AQUIFER

- What Values Are Appropriate for TSPA?
  - Tracer tests use some nonconservative assumptions
    - neglect background hydraulic gradient
    - assume 2D horizontally confined flow
  - Lower values → more conservative → values on the order of 0.1% may be reasonable
  - TSPA-VA used mean value of 2% → set artificially high to implicitly account for matrix diffusion
  - Importance to repository Is diminished if significant fraction of transport distance is through alluvium

FLOW POROSITY IN THE ALLUVIAL AQUIFER

- Poorly Characterized at Present: Nye County Wells Will Help Characterize Southern End of Flow Path
- A 6 Km Data Gap Will Remain After Nye County Wells Are Completed
- Range of 6% to 40% From SZ Expert Elicitation Project (Best Guesses Are 12% to 25%)
- Flow Porosity Could Be Significantly Less If Flow Occurs in Buried Stream Channels or Fractured Clays
- Flow Porosity in Alluvial Aquifer May Be Among the Most Important SZ Transport Parameters If a Significant Fraction of Transport Distance Is Through Alluvium

TRANSPORT DISTANCE THROUGH ALLUVIUM

- Poorly Characterized at Present
- The Location and Geometry of the Tuff / Valley-fill Aquifer Transition Is Unknown
- Horizontal Anisotropy Needs to Be Bounded:
  - north-south orientation of fractures and faults in volcanic tuff aquifer can divert flow southward
  - flow to the south results in lower fraction transport distance through alluvium
  - SZ expert elicitation recognizes the significant potential for horizontal anisotropy

SUMMARY

- Importance of Groundwater Velocity in the Tuff Aquifer Cannot Be Discounted Until Relative Transport Distances Through Tuff and Alluvium Are Better Defined

- Groundwater Velocity in the Alluvial Aquifer Remains Poorly Characterized but Data Is Rapidly Emerging From the Nye County Drilling Program

- A Reasonable Determination of Relative Transport Distances Through Tuff and Alluvium Requires:
  - delineation of tuff-alluvium contact
  - reasonable bound on horizontal anisotropy in the tuff aquifer

GEOCHEMICAL RADIONUCLIDE SORPTION MODELS FOR TOTAL PERFORMANCE ASSESSMENT 3.2

Presented by
David R. Turner
210/522-2139 (dturner@swri.edu)
Center for Nuclear Waste Regulatory Analyses

May 26, 1999
San Antonio, Texas

DOE/NRC Technical Exchange on
Total System Performance Assessments for Yucca Mountain

Attachment 17

GEOCHEMICAL SORPTION MODELS FOR TPA 3.2

BACKGROUND

- Sensitivity analyses using TPA Version 3.1 indicate that an alternative conceptual model with no retardation in the geosphere results in the highest Mean Peak Annual Dose for both 10,000 and 50,000 year time periods (Nuclear Regulatory Commission, 1999)
- Current Performance Assessment (PA) models assume a constant sorption coefficient (K_D) for each radionuclide and each hydrostratigraphic unit
- In real systems, K_D is a complex function of system chemistry and mineralogy
- Stochastic approaches typically use probability distribution functions (PDFs) to represent variability in K_D
- K_D PDFs are based on expert judgement, limited laboratory experimental conditions and do not reflect possible covariance among radionuclides exhibiting similar sorption behavior
- Geochemical sorption models that can be combined with existing hydrochemical and mineralogical information can be used to provide better constraints on PA sorption parameters

GEOCHEMICAL SORPTION MODELS FOR TPA 3.2

OBJECTIVES

- Develop abstractions that incorporate, at least indirectly, the effects of chemistry on radionuclide sorption coefficients.
- Develop abstracted models based on site-specific hydrochemical information

ASSUMPTIONS:

- Sorption behavior of Np(V) and U(VI) as a function of pH and carbonate concentration is similar for aluminosilicate minerals when normalized to effective surface area (A′). It is assumed that it is also true for other actinides such as Am(III), Pu(V), and Th(IV).
- The mean pore size in the matrix at YM is 0.1 µm (Travis and Nuttall, 1987), which is assumed to be true for all hydrostratigraphic units used in TPA.
- The water chemistries of Perfect et al. (1995) as screened and culled in Turner (1998) represent the likely range in water chemistry at YM.
- As appropriate, mean values from tpa.inp for solubility limits, density, and porosity are used in DLM simulations.

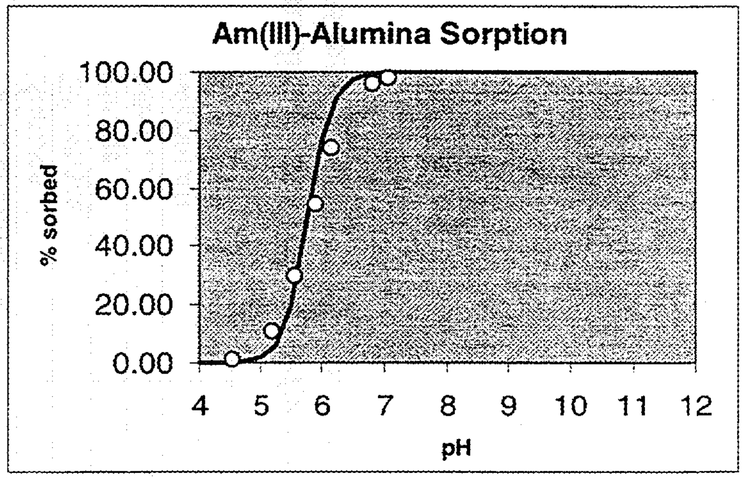
GEOCHEMICAL SORPTION MODELS FOR TPA 3.2

- **Identify sorption experiments that can be used to calibrate the DLM parameters.**
  - **Am(III), Th(IV), and Pu(V) sorption on γ-alumina (Righetto et al., 1988; 1991);**
  - **Np(V) and U(VI) sorption on montmorillonite (Turner et al., 1998a; Pabalan and Turner, 1997).**
- **Determine the DLM parameters for these experiments.**

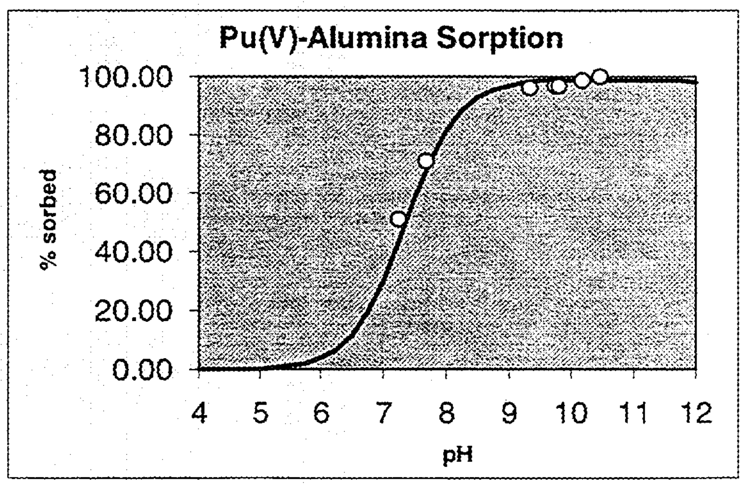
Radionuclide-Mineral	Surface Complex	Binding-Constant	Reference
Np(V)-montmorillonite	$>AlO^-$	-9.73	Turner et al. (1998a)
	$>AlOH_2^+$	8.33	Turner et al. (1998a)
	$>SiO^-$	-7.20	Turner et al. (1998a)
	$>AlO\text{-}NpO_2(OH)^-$	-13.79	Turner et al. (1998a)
	$>SiOH\text{-}NpO_2^+$	4.05	Turner et al. (1998a)
U(VI)-montmorillonite	$>AlO^-$	-9.73	Pabalan and Turner (1997)
	$>AlOH_2^+$	8.33	Pabalan and Turner (1997)
	$>SiO^-$	-7.20	Pabalan and Turner (1997)
	$>AlO\text{-}UO_2^+$	2.70	Pabalan and Turner (1997)
	$>SiO\text{-}UO_2^+$	2.60	Pabalan and Turner (1997)
	$>AlO\text{-}(UO_2)_3(OH)_5^\circ$	-14.95	Pabalan and Turner (1997)
	$>SiO\text{-}(UO_2)_3(OH)_5^\circ$	-15.29	Pabalan and Turner (1997)
Am(III)-γ alumina	$>AlO^-$	-9.73	Turner and Sassman (1996)
	$>AlOH_2^+$	8.33	Turner and Sassman (1996)
	$>AlO\text{-}Am^{2+}$	4.66	This study [Turner(1995)]
Pu(V)-γ alumina	$>AlO^-$	-9.73	Turner and Sassman (1996)
	$>AlOH_2^+$	8.33	Turner and Sassman (1996)
	$>AlO\text{-}PuO_2^\circ$	-2.18	This study [Turner(1995)]
Th(IV)-γ alumina	$>AlO^-$	-9.73	Turner and Sassman (1996)
	$>AlOH_2^+$	8.33	Turner and Sassman (1996)
	$>AlO\text{-}Th^{3+}$	15.3	This study [Turner(1995)]

GEOCHEMICAL SORPTION MODELS FOR TPA 3.2

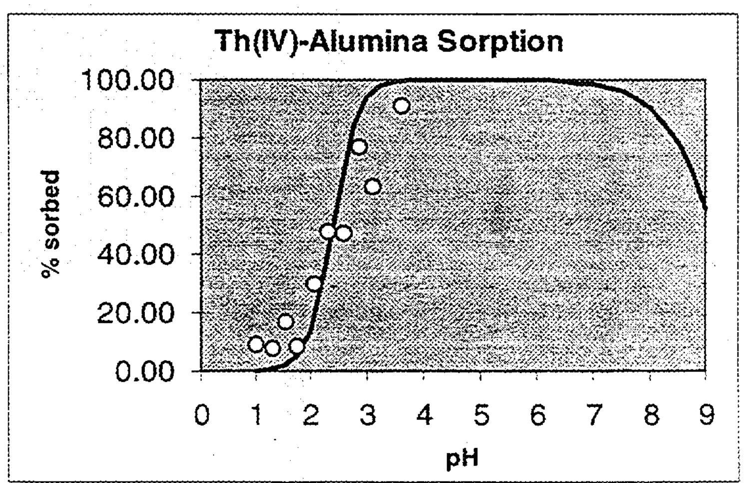
Righetto et al. (1988)
$Am(III)_{total}$ = 5E-11 M
M/V = 0.01 g/L (γ alumina)
BET = 130 m^2/g
A' = 13.0 m^2/g
T_{XOH} = 4.990E-07 M



Righetto et al. (1991)
$Pu(V)_{total}$ = 2e-10 M
M/V = 0.20 g/L (γ alumina)
BET = 130 m^2/g
A' = 13.0 m^2/g
T_{XOH} = 9.972E-06 M



Righetto et al. (1988)
$Th(IV)_{total}$ = 1e-11 M
M/V = 0.01 g/L (γ alumina)
BET = 130 m^2/g
A' = 13.0 m^2/g
T_{XOH} = 4.990E-07 M



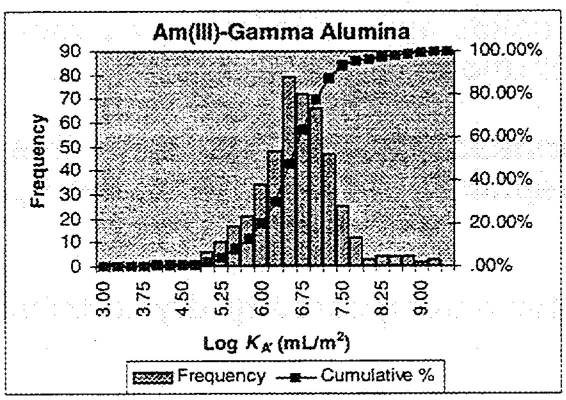
GEOCHEMICAL SORPTION MODELS FOR TPA 3.2

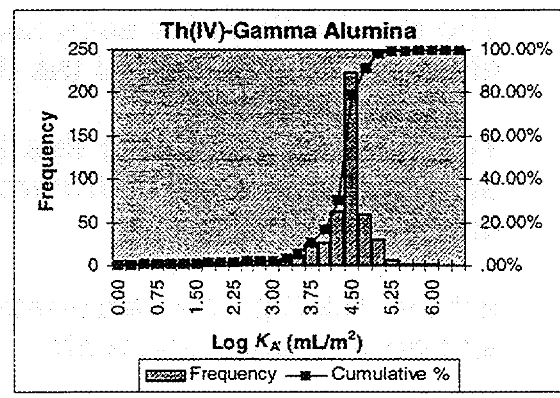
Descriptive Statistics:

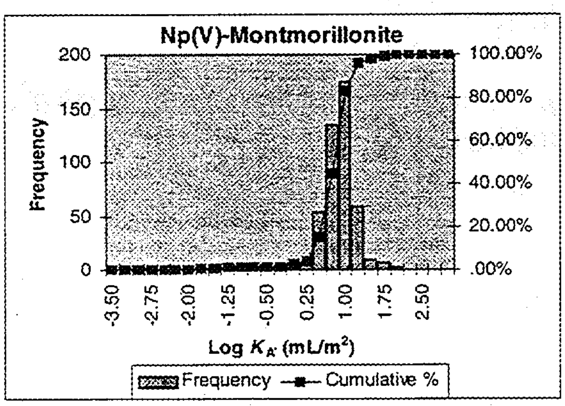
log K_A, (mL/m^2)	*Am(III)*	*Np(V)*	*Pu(V)*	*Th(IV)*	*U(VI)*
Mean	6.549	0.742	2.707	4.248	-0.032
Median	6.539	0.773	2.715	4.330	0.002
Mode	6.337	0.738	2.650	4.439	-0.158
Standard Deviation	0.748	0.422	0.305	0.583	0.975
Sample Variance	0.560	0.178	0.093	0.340	0.951
Kurtosis	1.924	26.576	5.055	34.228	12.928
Skewness	0.118	-3.556	-0.148	-4.414	-2.318
Range	5.958	5.140	2.974	7.715	9.407
Minimum	3.160	-3.264	0.906	-1.780	-6.837
Maximum	9.119	1.876	3.881	5.935	2.570
Count	460	460	460	460	460

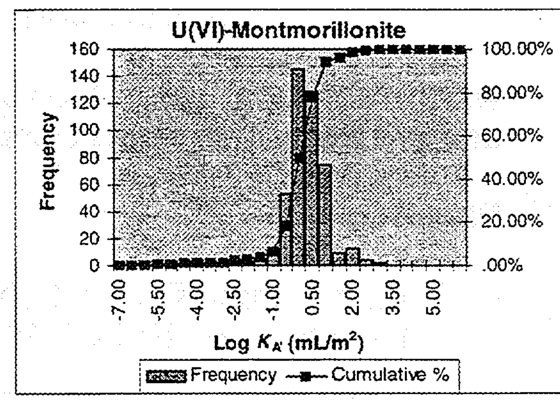
- **Normalized to effective surface area, K_A, (in mL/m^2), these sorption coefficient distributions can be recast in terms of K_D for each of the hydrostratigraphic units used in TPA**

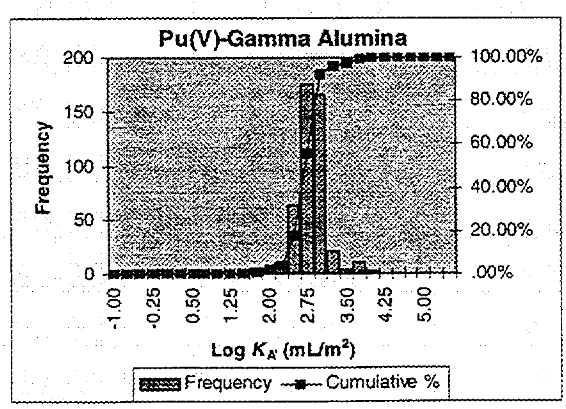
GEOCHEMICAL SORPTION MODELS FOR TPA 3.2











GEOCHEMICAL SORPTION MODELS FOR TPA 3.2

- The distributions for each radionuclide appear to be log normal, although the kurtosis of the distributions varies

- The final step in using this information in TPA is to apply this distribution to each hydrostratigraphic unit and transform the $K_{A'}$ into K_D (in mL/g)

- Arthur (1996) presents a relationship among porosity, dry density, and pore radius such that:

$$\text{Specific Surface Area} = \frac{3\phi_r}{\rho_r r}$$

where φ_r is porosity of the rock, ρ_r is density of the rock in g/m^3, and r is the radius of the pore in meters.

- Data Sources:

  - φ_r, ρ_r - input file for TPA 3.1.4
  - r - Travis and Nuttall (1987)

Unit	φ_r (m^3/m^3)	ρ_r (kg/m^3)	r (m)	SA (m^2/g)
TSw	0.12	2460	5.0E-08	2.9
CHnv	0.33	2260	5.0E-08	8.8
CHnz	0.32	2400	5.0E-08	8.0
PPw	0.28	2540	5.0E-08	6.6
UCF	0.28	2420	5.0E-08	6.9
BFw	0.12	2570	5.0E-08	2.8
UFZ	0.12	2630	5.0E-08	2.7
SAV	0.125	2470	5.0E-08	3.0

Measured surface areas: 2.6 to 10 m^2/g Triay et al. (1996):

GEOCHEMICAL SORPTION MODELS FOR TPA 3.2

$K_D = K_{A'} \times A'$ five radioelements for each of eight hydrostratigraphic units using water chemistry of Perfect et al. (1995) (n = 460 samples):

Log KD(m3/kg)	Am(III)-TSw	Am(III)-CHnv	Am(III)-CHnz	Am(III)-PPw	Am(III)-UCF	Am(III)-BFw	Am(III)-UFZ	Am(III)-SAV
Mean	4.011	4.493	4.452	4.368	4.387	3.996	3.980	4.026
Median	4.002	4.484	4.443	4.359	4.378	3.987	3.971	4.017
Mode	3.800	4.282	4.240	4.157	4.176	3.784	3.769	3.814
Std Deviation	0.748	0.748	0.748	0.748	0.748	0.748	0.748	0.748
Minimum	0.623	1.105	1.064	0.980	0.999	0.608	0.592	0.638
Maximum	6.581	7.063	7.022	6.938	6.957	6.566	6.550	6.596

Log KD(m3/kg)	Np(V)-TSw	Np(V)-CHnv	Np(V)-CHnz	Np(V)-PPw	Np(V)-UCF	Np(V)-BFw	Np(V)-UFZ	Np(V)-SAV
Mean	-1.796	-1.313	-1.355	-1.438	-1.419	-1.811	-1.827	-1.781
Median	-1.764	-1.282	-1.324	-1.407	-1.388	-1.780	-1.795	-1.750
Mode	-1.800	-1.318	-1.359	-1.443	-1.423	-1.815	-1.831	-1.785
Std Deviation	0.422	0.422	0.422	0.422	0.422	0.422	0.422	0.422
Minimum	-5.802	-5.320	-5.361	-5.445	-5.425	-5.817	-5.833	-5.787
Maximum	-0.661	-0.179	-0.221	-0.304	-0.285	-0.677	-0.692	-0.647

Log KD(m3/kg)	Pu(V)-TSw	Pu(V)-CHnv	Pu(V)-CHnz	Pu(V)-PPw	Pu(V)-UCF	Pu(V)-BFw	Pu(V)-UFZ	Pu(V)-SAV
Mean	0.169	0.651	0.610	0.527	0.546	0.154	0.138	0.184
Median	0.177	0.659	0.618	0.534	0.554	0.162	0.146	0.192
Mode	0.112	0.595	0.553	0.470	0.489	0.097	0.081	0.127
Std Deviation	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305
Minimum	-1.631	-1.149	-1.190	-1.274	-1.255	-1.646	-1.662	-1.616
Maximum	1.343	1.825	1.784	1.700	1.719	1.328	1.312	1.358

Log KD(m3/kg)	Th(IV)-TSw	Th(IV)-CHnv	Th(IV)-CHnz	Th(IV)-PPw	Th(IV)-UCF	Th(IV)-BFw	Th(IV)-UFZ	Th(IV)-SAV
Mean	1.711	2.193	2.151	2.068	2.087	1.695	1.680	1.725
Median	1.792	2.274	2.233	2.149	2.168	1.777	1.761	1.807
Mode	1.901	2.383	2.342	2.259	2.278	1.886	1.870	1.916
Std Deviation	0.583	0.583	0.583	0.583	0.583	0.583	0.583	0.583
Minimum	-4.317	-3.835	-3.877	-3.960	-3.941	-4.333	-4.348	-4.303
Maximum	3.397	3.879	3.838	3.754	3.774	3.382	3.366	3.412

Log KD(m3/kg)	U(VI)-TSw	U(VI)-CHnv	U(VI)-CHnz	U(VI)-PPw	U(VI)-UCF	U(VI)-BFw	U(VI)-UFZ	U(VI)-SAV
Mean	-2.569	-2.087	-2.129	-2.212	-2.193	-2.584	-2.600	-2.555
Median	-2.536	-2.054	-2.095	-2.179	-2.160	-2.551	-2.567	-2.521
Mode	-2.695	-2.213	-2.255	-2.338	-2.319	-2.711	-2.726	-2.681
Std Deviation	0.975	0.975	0.975	0.975	0.975	0.975	0.975	0.975
Minimum	-9.375	-8.893	-8.934	-9.018	-8.998	-9.390	-9.406	-9.360
Maximum	0.032	0.514	0.473	0.389	0.409	0.017	0.001	0.047

GEOCHEMICAL SORPTION MODELS FOR TPA 3.2

- **For each radionuclide, this method results in the same distribution for each hydrostratigraphic unit, since K_D is determined by multiplying $K_{A'}$ by unit-specific constant (A′)**

- **This information was used to develop correlation coefficients between each of the radionuclides for $K_{A'}$ (and therefore K_D):**

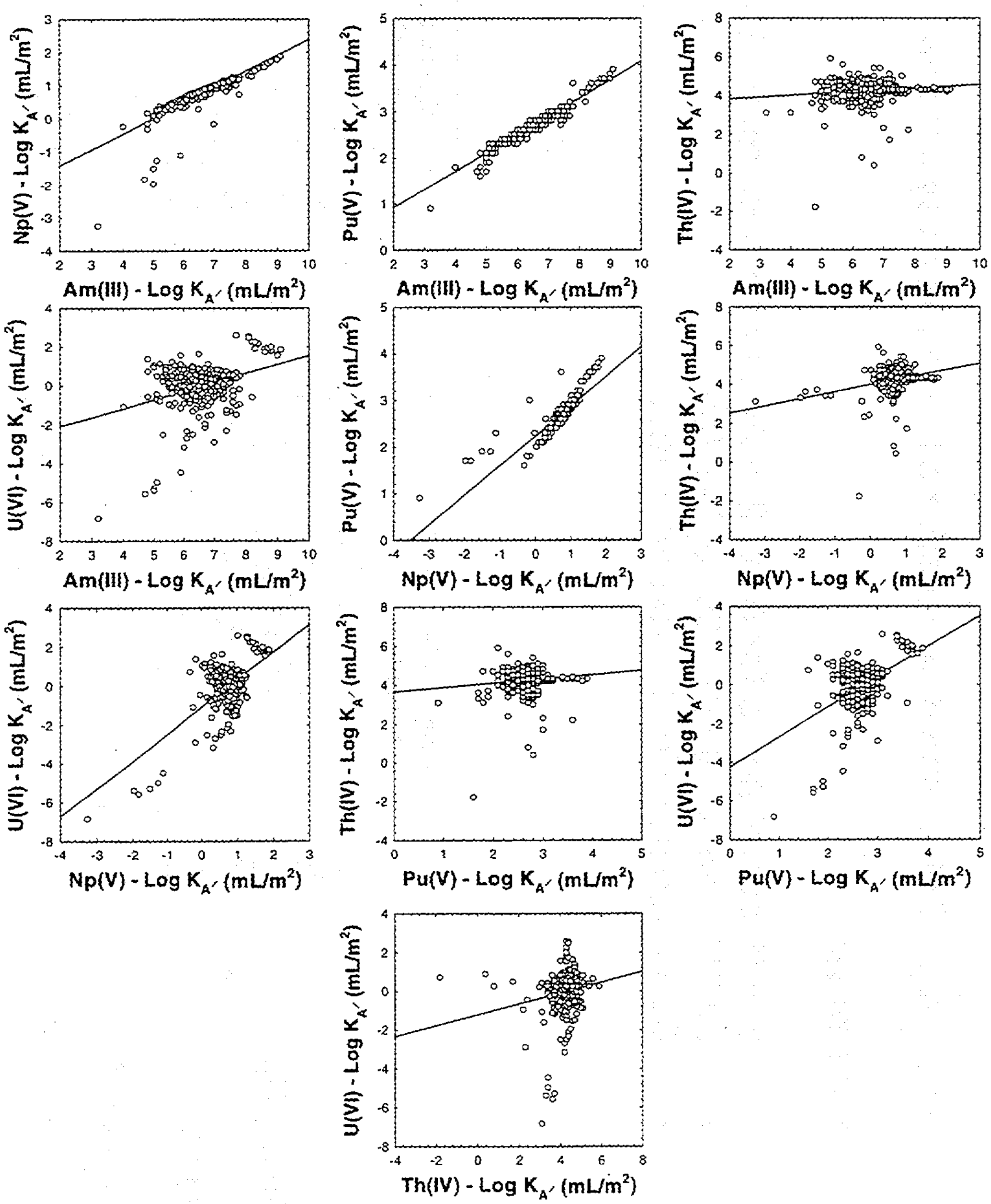
$K_{A'}$ (mL/m^2)	Am(III)	Np(V)	Pu(V)	Th(IV)	U(VI)
Am(III)	1				
Np(V)	0.9056	1			
Pu(V)	0.9025	0.9629	1		
Th(IV)	-0.0350	-0.0448	-0.0682	1	
U(VI)	0.3420	0.4073	0.4787	-0.0174	1

For log $K_{A'}$ (and log K_D), the correlation coefficients are different:

log $K_{A'}$ (mL/m^2)	Am(III)	Np(V)	Pu(V)	Th(IV)	U(VI)
Am(III)	1				
Np(V)	0.8373	1			
Pu(V)	0.9640	0.8814	1		
Th(IV)	0.1120	0.2599	0.1087	1	
U(VI)	0.3455	0.6097	0.4894	0.1648	1

GEOCHEMICAL SORPTION MODELS FOR TPA 3.2

- **Implementation of the Geochemical Sorption Model in TPA 3.2**



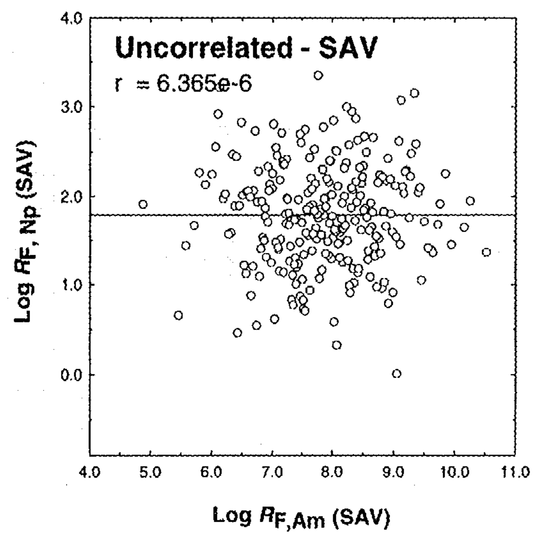
GEOCHEMICAL SORPTION MODELS FOR TPA 3.2

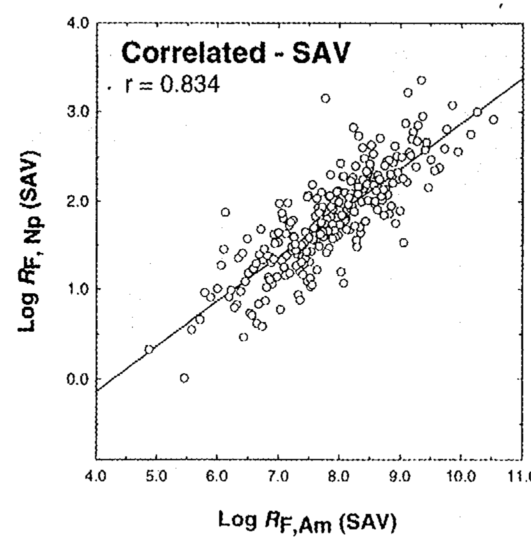
- First step: Determine if correlations being properly implemented in TPA 3.2
- Four runs:
  - 2 with correlations for SAV, 2 without correlations for SAV
  - 50,000 years, 20 km, 250 realizations
  - Database tracking 20 radionuclides

Am(III)-Np(V)

Input:

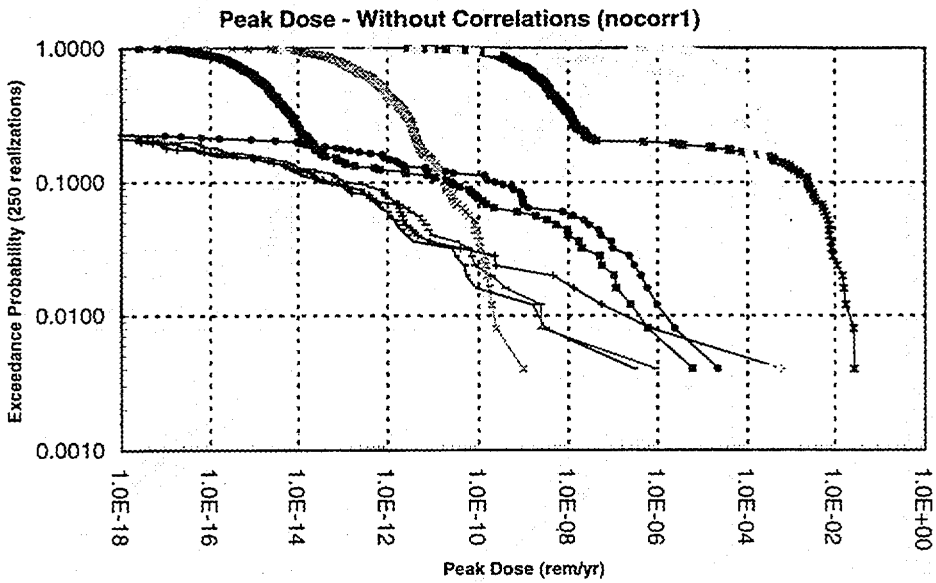
r = 0.8373

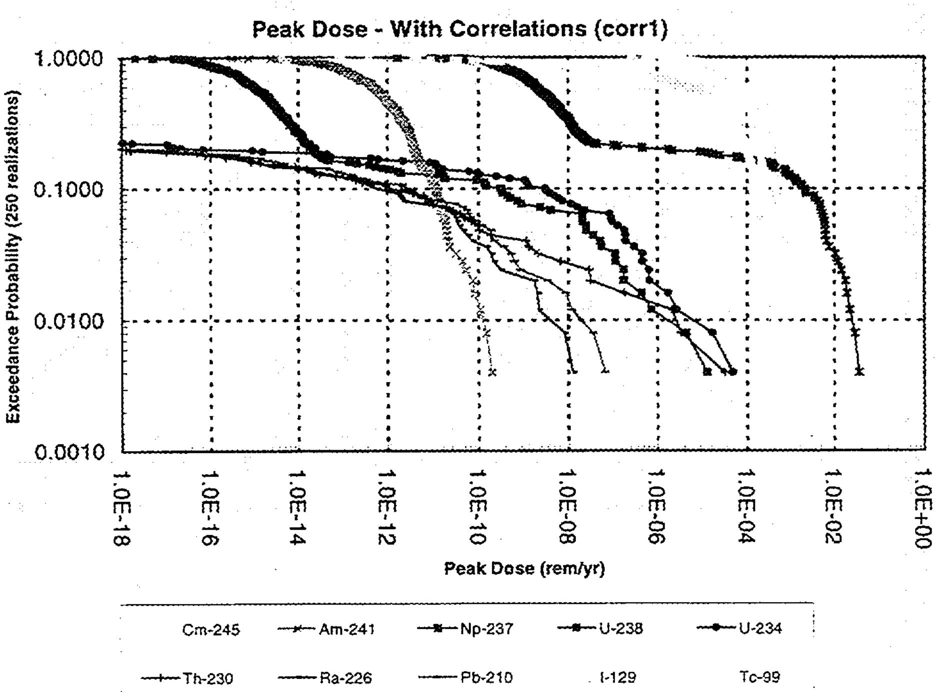




GEOCHEMICAL SORPTION MODELS FOR TPA 3.2

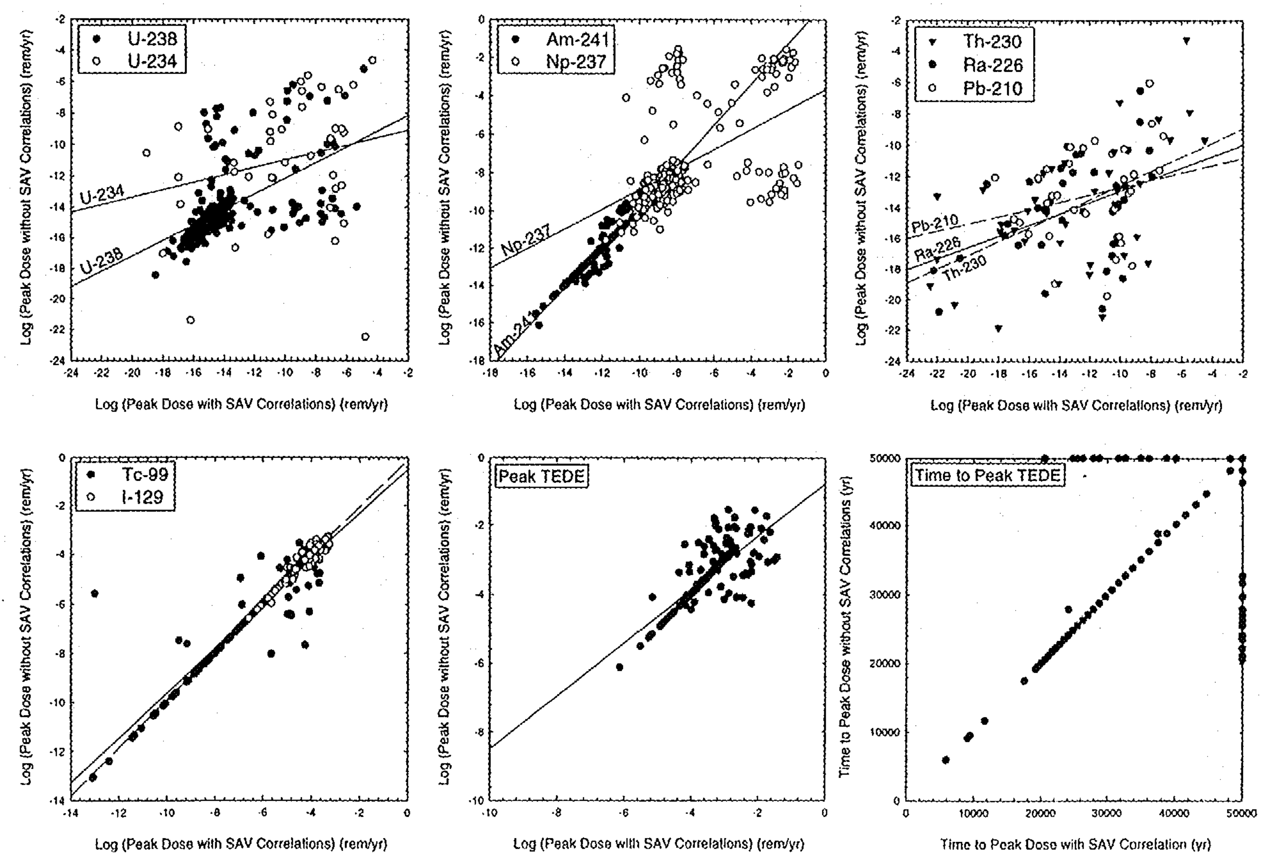
- **Comparison of Results:**





GEOCHEMICAL SORPTION MODELS FOR TPA 3.2

- **Comparison of Results (with and without SAV correlations):**



GEOCHEMICAL SORPTION MODELS FOR TPA 3.2

- Radionuclides most affected include those with correlations:

  - U-238
  - U-234
  - Np-237
  - Th-230
  - Am-241

- Also affected:

  - Ra-226
  - Pb-210

  From the decay chain U-234 → Th-230 → Ra-226 → Pb-210

- Radioelements that do not show up at 50,000 y (Pu) may be more important at longer times

- Correlations may be relevant to radionuclides that TPA suggests are important (Cm-245,246) to dose at 50,000 y. These may be simulated using Am(III) as a homologue

GEOCHEMICAL SORPTION MODELS FOR TPA 3.2

SUMMARY AND CONCLUSIONS

- Geochemical sorption models (DLM) applied for Am, Np, Pu, Th, and U using site-specific hydrochemistry
- Limits established for PA sorption parameter PDFs for different hydrostratigraphic units
- Correlations (10 total) among five radioelements developed for sorption parameters in the alluvium
- TPA 3.2 correctly implemented correlations in LHS
- Presence of correlations produce effects on Peak Dose for TPA 3.2 simulations at 50,000 years, 20 km

GEOCHEMICAL SORPTION MODELS FOR TPA 3.2

Arthur, R.C. 1996. *SITE-94: Adaptation of Mechanistic Sorption Models for Performance Assessment Calculations.* SKI Report 96:34. Stockholm, Sweden: Swedish Nuclear Power Inspectorate.

Bertetti, F.P., R.T. Pabalan, and M.G. Almendarez. 1998. Studies of neptunium^{V} sorption on quartz, clinoptilolite, montmorillonite, and α-alumina. E.A. Jenne. ed. *Adsorption of Metals by Geomedia.* New York, NY: Adademic Press, Inc.: 131-148.

U.S. Nuclear Regulatory Commission. 1999. *NRC Sensitivity and Uncertainty Analyses for a Proposed HLW Repository at Yucca Mountain, Nevada, Using TPA 3.1.* NUREG-1668, Vol. 2. Washington, DC: NRC.

Pabalan, R.T., and D.R. Turner. 1997. Uranium(6+) sorption on montmorillonite: Experimental and surface complexation modeling study. *Aqueous Geochemistry* 2: 203-226.

Pabalan, R.T., D.R. Turner, F.P. Bertetti, and J.D. Prikryl. 1998. Uranium^{VI} sorption onto selected mineral surfaces. E.A. Jenne. ed. *Adsorption of Metals by Geomedia.* New York, NY: Adademic Press, Inc.: 99-130.

Perfect, D.L., C.C. Faunt, W.C. Steinkampf, and A.K. Turner. 1995. *Hydrochemical Data Base for the Death Valley Region, California and Nevada.* USGS Open-File Report 94-305. Denver, CO: U.S. Geological Survey.

Righetto, L., G. Bidoglio, B. Marcandalli, and I.R. Bellobono. 1988, Surface interactions of actinides with alumina colloids. *Radiochimica Acta* 44/45:73-75.

Righetto, L., G. Bidoglio, G. Azimonti, and I.R. Bellobono. 1991. Competitive actinide interactions in colloidal humic acid-mineral oxide systems. *Environmental Science and Technology* 25: 1913-1919.

Travis, B.J., and H.E. Nuttall. 1987. *Two-Dimensional Numerical Simulation of Geochemical Transport in Yucca Mountain.* LA-10532-MS. Los Alamos, NM: Los Alamos National Laboratory.

Triay, I.R., A. Meijer, J.L. Conca, K.S. Kung, R.S. Rundberg, and E.A. Strietelmeier. 1996a. *Summary and Synthesis Report on Radionuclide Retardation for the Yucca Mountain Site Characterization Project.* Milestone 3784. Los Alamos, NM: Chemical Science and Technology Division, Los Alamos National Laboratory.

Turner, D.R. 1995. *A Uniform Approach to Surface Complexation Modeling of Radionuclide Sorption.* CNWRA 95-001. San Antonio, TX: CNWRA.

Turner, D.R. 1998. *Radionuclide Sorption in Fractures at Yucca Mountain, Nevada: A Preliminary Demonstration of Approach for Performance Assessment.* CNWRA Letter Report. San Antonio, TX: CNWRA.

Turner, D.R. and S.A. Sassman. 1996. Approaches to sorption modeling for high-level waste performance assessment. *Journal of Contaminant Hydrology* 21: 311-332.

Turner, D.R., R.T. Pabalan, and F.P.Bertetti. 1998a. Neptunium(V) sorption on montmorillonite: An experimental and surface complexation modeling study. *Clays and Clay Minerals* 46: 256-269.

Turner, D.R., G.W. Wittmeyer, and F.P. Bertetti. 1998b. *Radionuclide Sorption in the Alluvium at Yucca Mountain, Nevada: A Preliminary Demonstration of Approach for Performance Assessment.* CNWRA Letter Report. San Antonio, TX: CNWRA.

Turner, D.R., R.T. Pabalan, J.D. Prikryl, and F.P. Bertetti. 1999. Radionuclide sorption at Yucca Mountain, Nevada - Demonstration of an alternative approach for performance assessment. J. Lee and D. Wronkiewicz, eds. *MRS Symposium Proceedings: Scientific Basis for Nuclear Waste Management - XXII.* Pittsburgh, PA: MRS: (in press).

Turner, D.R., and R.T. Pabalan. 1999. Abstraction of mechanistic sorption model results for performance assessment calculations at Yucca Mountain, Nevada. *Waste Management.* (in revision).

NRC INSIGHTS ON DOSE CONVERSION FACTORS

Presented by
Patrick A. LaPlante
(301)881-0289 (plaplante@swri.org)
Center for Nuclear Waste Regulatory Analyses

Contributors: L. Deere, B. Hill, C. McKenney

May 25-27, 1999
San Antonio, Texas

NRC/DOE Technical Exchange on Total System Performance Assessment for Yucca Mountain

Attachment 18

OUTLINE

- Objectives
- Background
- Dose Conversion Implementation
- Comparison of DCFs
- Effect of DCF Differences on TPA 3.2 Results (Base Case)
- Confirmatory Calculations
- VA Review: Technical Issues
- Summary and Conclusions

OBJECTIVES

- Highlight Major Similarities and Differences Between NRC and TSPA-VA in Approach to Dose Conversion
- Present NRC and TSPA-VA Differences in Results of DCF Calculations
- Present the Effects of DCF Differences on Performance Calculations
- Identify Aspects of DOE-VA Approach that Need Clarification
- Present Technical Concerns with TSPA-VA

BACKGROUND

- Technical Objective for PA: Convert Estimated Radionuclide Concentrations in Groundwater and Soil to All-pathway Dose
  - Use Site-specific Parameters and Exposure Assumptions
  - Include Capabilities to Assess Parameter Uncertainties and Variation
- Dose Conversion Factor (DCF or BDCF) in This Context is a Multiplier That Converts Radionuclide Concentrations to Dose. DCFs Account for Processes and Pathways that Affect Potential Human Exposures to Radionuclides in the Biosphere

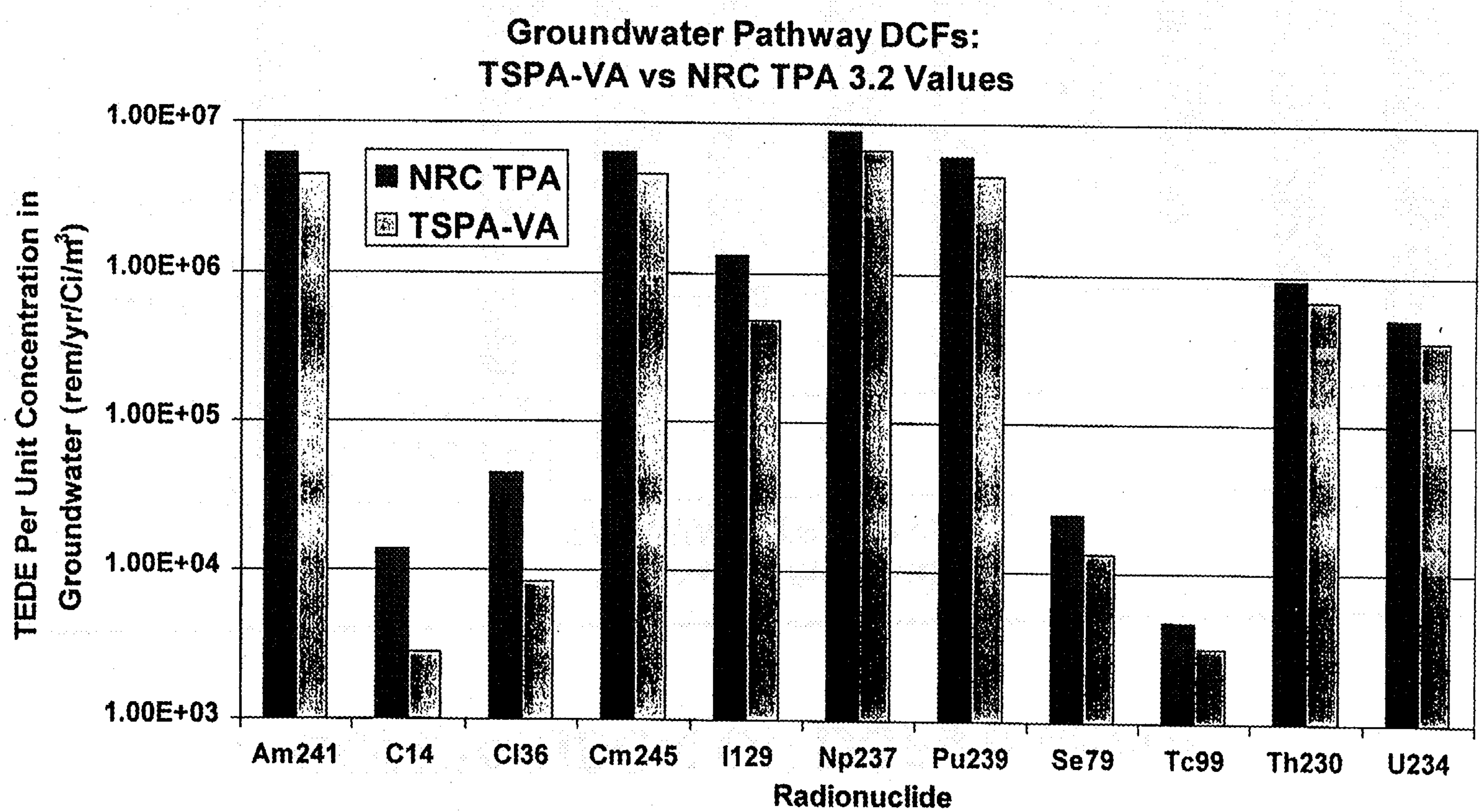
DOSE CONVERSION IMPLEMENTATION

- Similarities
  - NRC and DOE Calculate DCFs Outside of PA Code
  - PNLs GENII-S Code is Used for DCF Calculations
  - Exposure Scenario (Amargosa Farmer)
  - Many Parameter Values are Equivalent
- Differences
  - DOE Samples BDCF Distributions (Stochastic)
  - NRC Currently Uses Mean DCF (Deterministic)

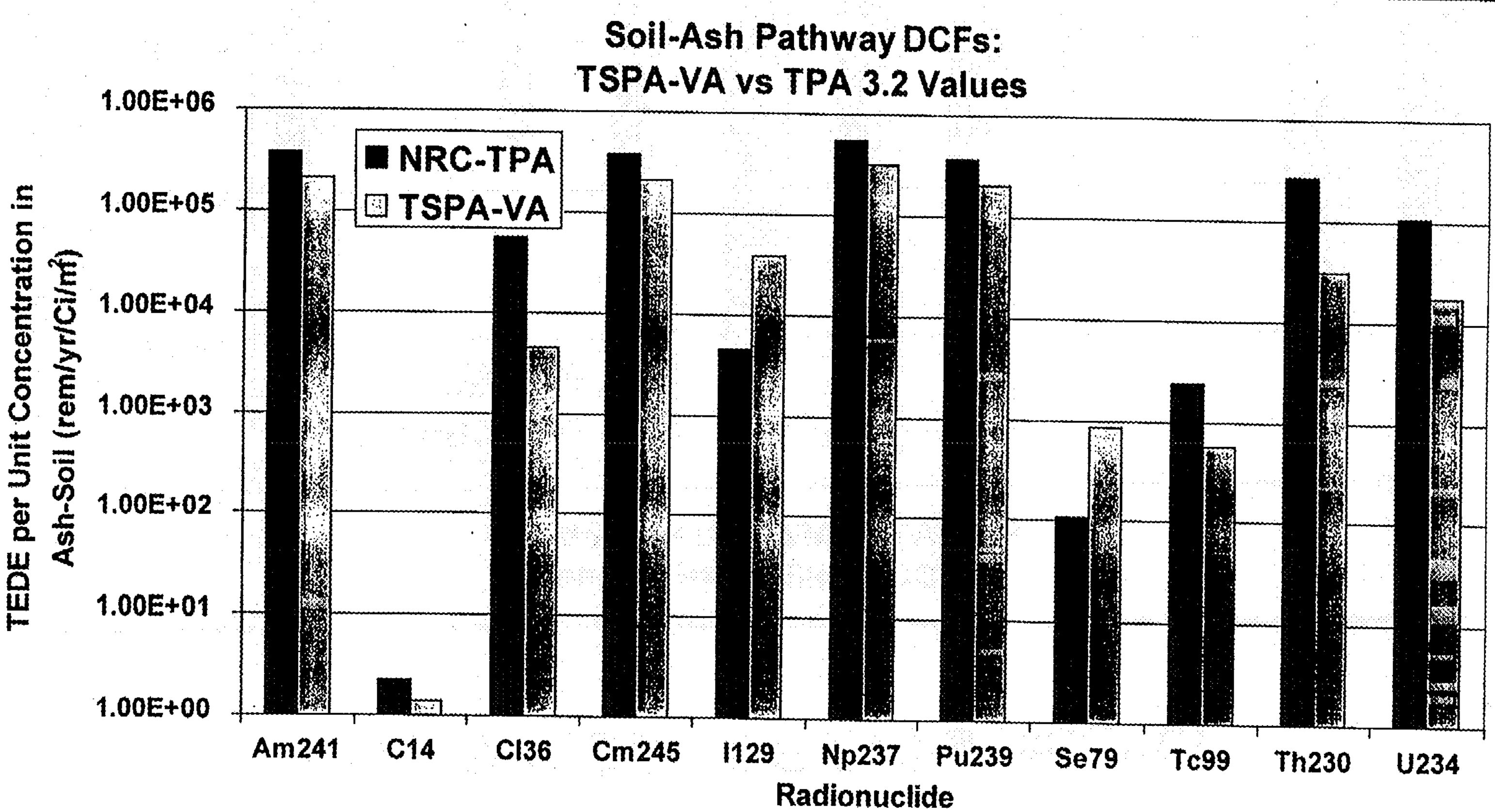
COMPARISON OF DCFs

- TSPA-VA and NRC Groundwater Pathway DCFs
  - NRC Values Are Higher by About 25%
  - Prior Sensitivity Studies Show Consumption Rates are Important Parameters for DCF Calculations
  - TSPA-VA Site-specific Consumption Rates Are Significantly Less than the Generic Values Used by NRC
- Volcanic Ash Pathway DCFs
  - NRC Values Are Higher
  - TSPA-VA Information on These Calculations Lacks Sufficient Detail to Determine the Cause of Differences
- Pluvial Period DCFs
  - NRC Values Are Less than TSPA-VA Because DOE Considers Effect of Increased Rainfall on Irrigation Rates is Minimal

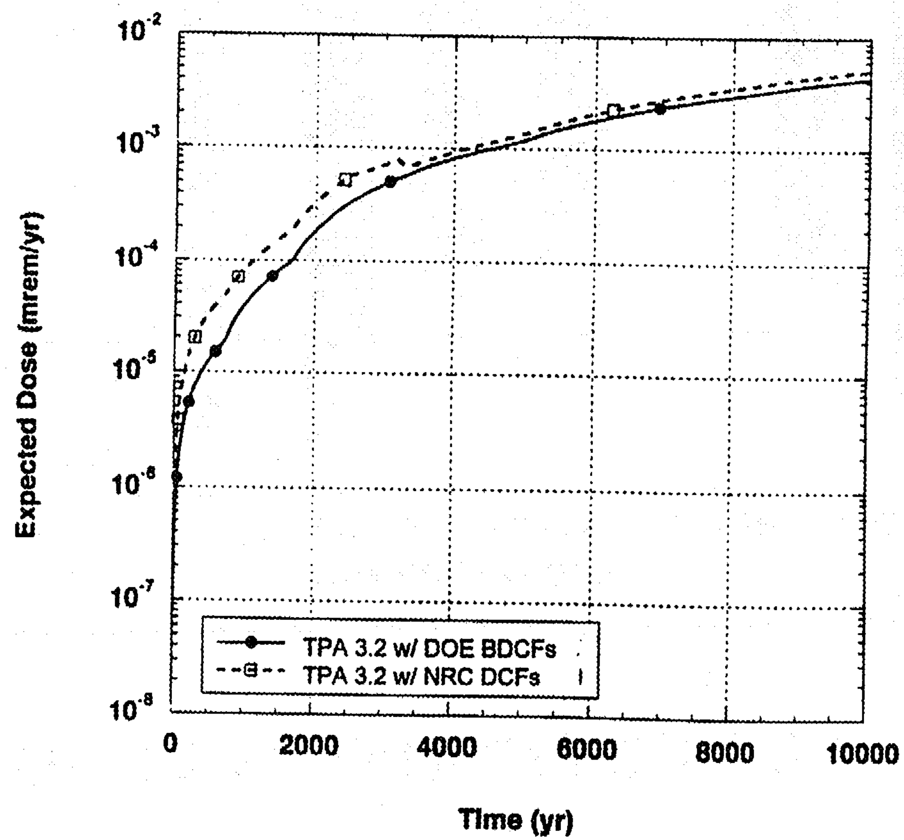
COMPARISON OF DCFs (cont'd)



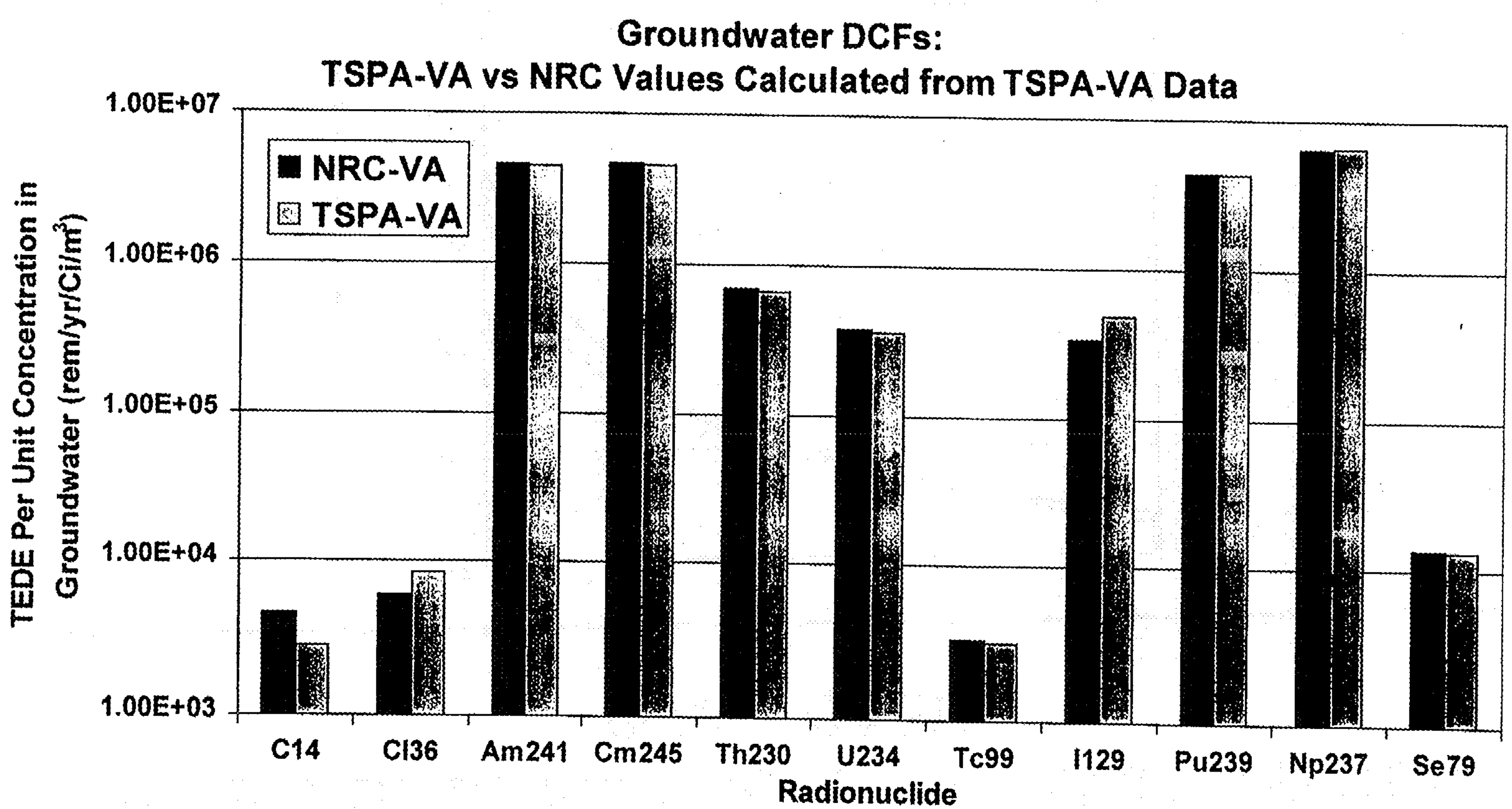
COMPARISON OF DCFs (cont'd)



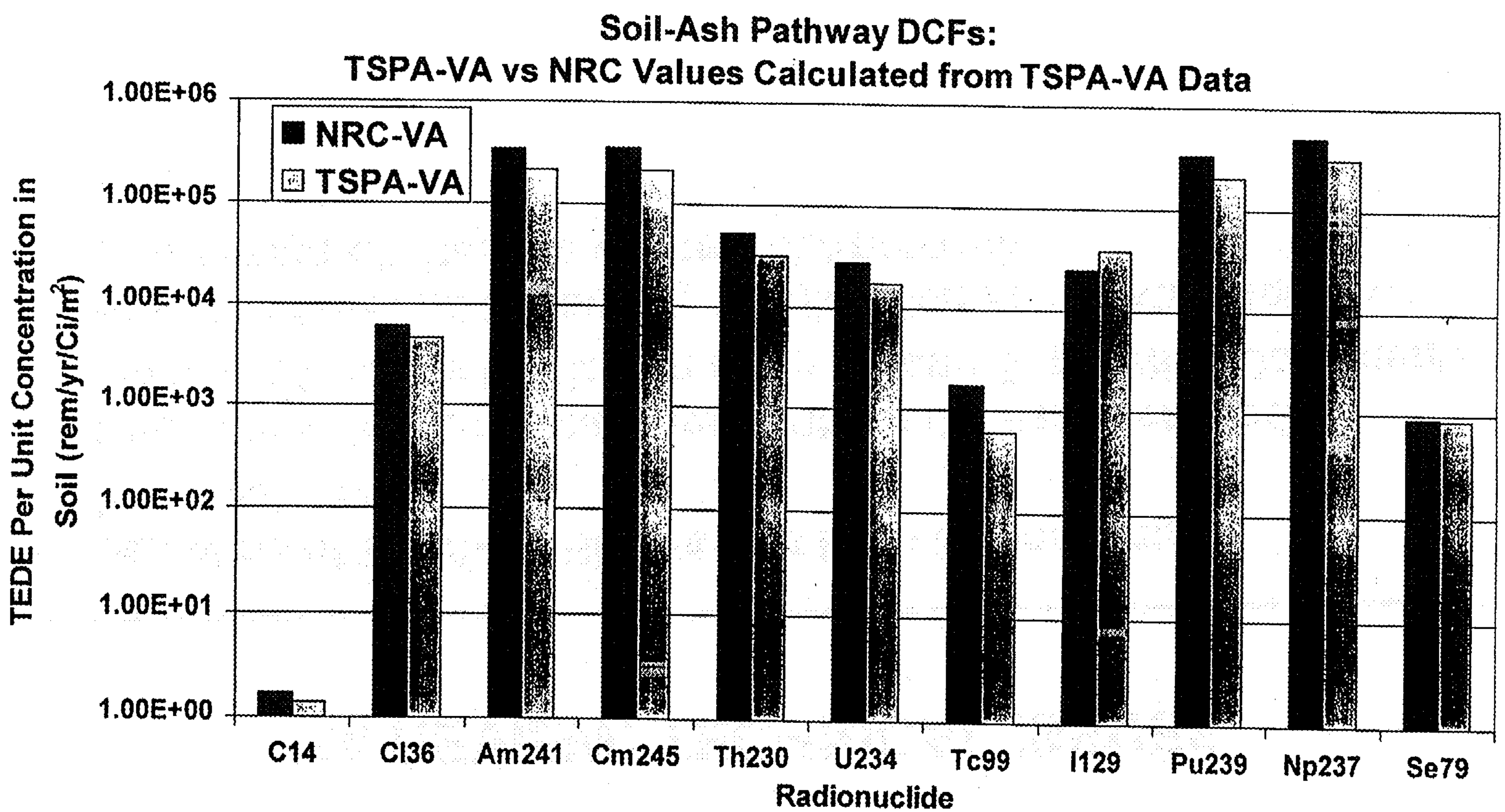
EFFECT OF DIFFERENCES ON TPA 3.2 RESULTS (BASE CASE)



CONFIRMATORY CALCULATIONS



CONFIRMATORY CALCULATIONS (cont'd)



VA REVIEW: TECHNICAL ISSUES

- Sampling of TSPA-VA BDCFs Can Lead to Modeling Inconsistencies
- Documentation for Some Important Input Parameters and Modeling Choices is Missing From VA and Supporting Documents
- Results of PA and Sensitivity Studies Can Focus Attention on Addressing Limitations of Current Approach

SAMPLING BDCFs: POTENTIAL PROBLEMS

- TSPA-VA: BDCF Sampling is "Completely Correlated" So That "If A Large BDCF is Sampled For One Radionuclide, then Large BDCFs Are Sampled For All Radionuclides"
- Such Correlation Assumes Important Dose Parameters Are the Same For All Radionuclides But Sensitivity Analyses Show Differences Exist:
  - Tc-99: High Plant Uptake ~ Importance Of Plant Pathway
  - I-129: High Animal Uptake ~ Importance Of Animal Pathway
  - In GENII-S Calculations, A Realization Could Sample "High" For Key Plant Pathway Parameters And "Low" For Key Animal Pathway Parameters Leading To High Tc-99 And Low I-129 BDCFs
- Additional Information On The TSPA-VA Approach is Needed to Clarify the Potential for Such Inconsistencies

SAMPLING BDCFs: POTENTIAL PROBLEMS (cont'd)

- Sampling Twice Disrupts Original Dose Code Output Vector Assignments and Creates Modeling Inconsistencies
  - Sampling is Done First for GENII-S Stochastic BDCF Calculations
  - BDCF Distributions Are Then Re-sampled by TSPA Code
  - In Each GENII-S Realization, a Suite of Parameter Values Are Sampled that Describes a Potential Biosphere Reality
  - In Each GENII-S Realization, BDCFs Are Calculated to Estimate the Dose From Each Radionuclide for *That* Set of Biosphere Conditions
  - For Each TSPA Realization, *Total* Dose Should Equal the Sum of the Radionuclide-specific Doses (Calculated Under Identical Biosphere Conditions for Each Radionuclide)

SAMPLING BDCFs: POTENTIAL PROBLEMS (cont'd)

- Resampling From BDCF Distributions Does Not Ensure That the Radionuclide-specific Doses Being Summed Per Realization Are Based on the Same Set of Biosphere Conditions
  - E.g., For a Realization, Sampled Value From the Tc-99 BDCF Distribution is Unlikely to Be Based on the Same Irrigation Rate Than the Sampled BDCF for Np-237, Thus the Biosphere Conditions Vary With Each Radionuclide
- Varying Biosphere Conditions by Radionuclide Could Bias the Total Dose Calculated for Each Realization

- Identification of Potential Problems Should Not Lead to Abandonment of a Stochastic Approach, but Modifications May Be Needed

DOCUMENTATION OF DOSE PARAMETERS IN TSPA-VA

- Leach Factors
  - No Documentation for this Potentially Important Removal Mechanism Affecting Groundwater Pathway BDCFs
- Mass Loading Factor for Ash Blanket
  - Lack of Discussion on this Key Parameter for Igneous Activity Dose Suggests the Value for Soil Mass Loading Is Used
  - Ash Properties Are Unlikely to Be Same As Soil
- Internal Dosimetry Modeling Choices
  - Important Fixed Parameters in GENII-S Code
  - Internal Dose Factor Library/Solubility Choices Not Discussed
- GENII-S Default Parameters
  - No Documentation for Parameters that Could Significantly Affect Dose (Animal Intakes, Breathing Rates, Dry/wet Ratios)

SENSITIVITY RESULTS CAN FOCUS IMPROVEMENTS

- Dose Modeling Parameter Choices Were Previously Limited by the Large Number of Radionuclides
- TPA Results that Show a Reduced Set of Radionuclides Dominate the Calculated Dose Can Focus Attention on Key Radionuclide-Specific Parameters. Example:
  - DCF Sensitivity Results Show Key Parameters for Each Radionuclide
    - Soil-to-plant Transfer Factor is Important for Tc-99 DCF but Less Important for Np-237 or I-129
  - Site Relevance Can Be Improved by Focusing Work
    - Is Generic IAEA Factor Representative of YM Soil and Plant Conditions?
    - Do Previous EPA NTS Studies Have Site-relevant Information on Tc-99?

SUMMARY AND CONCLUSIONS

- In General, the TSPA-VA Methods for Calculating BDCFs Are Consistent With the Present NRC Approach
- Use of TSPA-VA BDCFs in TPA 3.2 Does Not Produce Substantial Difference in Results for the Base Case
- Enhancements for TSPA-VA Such As the Demographic Survey (e.g., Local Consumption Rates) Appear to Account for Lower Values of Many TSPA-VA BDCFs
- TSPA-VA Information Gaps Affect NRC Ability to Reproduce Some BDCFs (e.g., Primarily for Volcano Exposure Scenario)
- DOE Should Consider Potential Modeling Inconsistencies Introduced by Sampling BDCF Distributions
- Sensitivity Information Can Focus Improvements in Biosphere Modeling (e.g., Site Relevance of Important Parameters)

DISRUPTIVE EVENTS

May 25-27, 1999
DOE/NRC Technical Exchange on
Total System Performance Assessments
for Yucca Mountain

James R. Firth
301-415-6628 - JRF2@nrc.gov
Division of Waste Management
High-Level Waste Branch

Contributors: Amit Ghosh (CNWRA), Britt Hill (CNWRA), Simon Hsiung (CNWRA), Buck Ibrahim (NRC), John Stamatakos (CNWRA)

Attachment 19

UNDERSTANDING OF VA APPROACH

EVENTS CONSIDERED BY DOE (TSPA-VA)

1. Seismic Activity

   - Failure from Rockfall
   - Accelerated Corrosion
   - Also Included within "Juvenile Failure"

2. Basaltic Igneous Activity

   - Failure from Magma and Ash Interactions with Waste Packages
   - Airborne Transport
   - Enhanced Source Term for Releases to Groundwater
   - Changes to Groundwater Flow in Saturated Zone

EVENTS CONSIDERED BY DOE (TSPA-VA)

3. Nuclear Criticality

   - Criticality Within Waste Package

     - Commercial Spent Nuclear Fuel and Aluminum Clad Spent Nuclear Fuel
     - Changes to Inventory within Waste Package

   - Potential for Out-of-Package Criticality

4. Inadvertent Human Intrusion

   - Single Waste Package Penetrated
   - Borehole Extends to Saturated Zone
   - Waste from the Package is Assumed to Reach Saturated Zone [550 kg, 2100 kg]
   - Event Occurs 10,000 Years After Closure

NRC APPROACH

NRC TREATMENT OF DISRUPTIVE EVENTS (TPA 3.2)

1. Seismic Activity

- Impact Load from Falling Rock Used to Calculate Induced Waste Package Stress
- Impact Load Determined from Rock Size and Distance Rock Falls
  - Size Based on Joint Spacing and Yield Zone Thickness
- Maximum Allowable Strain Used As Failure Criterion (2% Total Strain)
- Fractional Rockfall Area Modeled as a Function of Ground Acceleration
- Failures from Multiple Seismic Events Assumed to Occur at Preestablished Times for Efficient Calculations

NRC TREATMENT OF DISRUPTIVE EVENTS (TPA 3.2)

2. Igneous Activity

- Emphasis on Extrusive Events (to Date)
- Use of Reasonably Conservative Estimate for Probability of Extrusive Events
- ~100% HLW from Failed Waste Packages Entrained in Ash
- Modified Convective-Dispersive Model of Suzuki Used for Tephra Transport
- Wind is Assumed to Blow in Direction of Critical Group

NRC TREATMENT OF DISRUPTIVE EVENTS (TPA 3.2)

3. Fault Displacement

- Modeled for New or Inadequately Characterized Faults
- 50% of Fault Displacement Occurs on these New or Inadequately Characterized Faults
- Effective Recurrence Rate for these Faults Estimated to be 200,000 years
- Fault Displacement Exceeding a Pre-established Threshold Results in Waste Package Failure of All Waste Packages within Fault Zone
- Only Waste Packages within Fault Zone May Fail from Fault Displacement

Process-Level Presentations with Technical Basis

- Simon Hsiung (Seismicity: Rockfall)
- Brittain Hill (Igneous Activity: Volcanism)

UNDERSTANDING OF DIFFERENCES

TREATMENT OF DISRUPTIVE EVENTS

DISRUPTIVE EVENTS	DOE (TSPA-VA)	NRC (TPA 3.2)
Igneous Activity: Intrusive Events	*	*
Igneous Activity: Extrusive Events	*	*
Igneous Activity: Indirect Effects	*	
Seismicity: Waste Package Failure (Rockfall)	*	*
Seismicity: Accelerated Corrosion (Rockfall)	*	
Fault Displacement		*
Criticality	*	
Human Intrusion	*	

EXTRUSIVE IGNEOUS EVENTS

ASSUMPTION	DOE (TSPA-VA)	NRC (TPA 3.2)
Probability	$6x10^{-9}$	$1x10^{-7}$
Number of Conduits in Repository	0 - 4	1
Size of Conduit	2 - 125 m	1 - 50 m
Potential Number of Waste Packages Affected	0 - 136 (Mean: ~ 1.8)	1 - 10
Waste Package Breach	Possible for T ≥ 800°C and Thinning of CRM ≥ 50%	100% of Intersected WPs
Inventory in Failed WPs Available for Incorporation	50%	100%
Incorporation of Available Waste Into Ash	30%	~100%
Wind Directed Towards Critical Group	14%	100%
Accompanying Intrusive Event	No	Yes

INTRUSIVE IGNEOUS EVENTS

ASSUMPTION	DOE (TSPA-VA)	NRC (TPA 3.2)
Probability	1.5×10^{-8} (Includes Indirect Effects Scenario)	1×10^{-7} (Probability was Constrained to Equal That for Extrusive Events)
Intrusive Event May Occur without Associated Extrusive Events	Yes	Yes (NRC Sensitivity Studies Have Not Included Intrusive Events without an Associated Extrusive Event)
Failure of Waste Packages Not Directly Contacted by Intruding Magma	Yes, within 1 Dike Width	No
Potential Number of Waste Packages Affected	0 - 170	1 - 65
Waste Package Breach	<100%; Reductions from: Fragmentation Depth Below Repository	100%
HLW Dissolution in Magma	Yes	No

ROCKFALL

ASSUMPTIONS	DOE (TSPA-VA)	NRC (TPA 3.2)
Size of Rocks	Based on Fracture Spacing	Based on Fracture Spacing and Yield Zone within Rock
Rockfall Size	Function of Damage Level	Function of Rock Quality
Waste Package Integrity	Time Variant Based on Waste Package Corrosion Estimates	Time Invariant; Maximum Allowable Strain Failure Criterion
Area Affected by Rockfall	Affected Areas are a Function of Rock Quality and Peak Ground Velocity	Related to the Magnitude of Seismic Ground Acceleration and Independent of Rock Quality
Other Factors Used to Reduce Number of Affected Waste Packages	(1) Rocks May Miss Waste Packages (2) Availability of Sufficiently Large Rock	None
Effect on Cladding	Not Clear	N/A
Accelerated Corrosion	Increase in Localized Corrosion Rate	Not Considered
Timing of Failures	Multiple Failure Times Possible	Occur at Midpoint of Time Interval (4 Intervals Used)

PATHS FORWARD ON IGNEOUS ACTIVITY RISK ASSESSMENTS FOR YUCCA MOUNTAIN

Brittain E. Hill
Senior Research Scientist
Center for Nuclear Waste Regulatory Analyses
(210) 522-6087, bhill@swri.edu

Contributors: C. Connor, J. Firth (NRC) J. Trapp (NRC), J. Weldy

May 25–27, 1999
NRC–DOE Technical Exchange on
Total System Performance Assessments
for Yucca Mountain

Attachment 20

SIGNIFICANCE OF IA TO TSPA

- Although not required, TSPA-VA evaluated igneous events.
  - Comments warranted to provide timely guidance for subsequent DOE-TSPAs
- TSPA-VA concludes almost no impact on performance from volcanism.
  - Staff question technical bases for numerous process models
- Modeling igneous disruptive events for a repository is a challenge as there are few data or analogs for these conditions.
  - This challenge can be met reasonably and expeditiously
- Current staff analyses show the approximately 1 mrem/yr expected annual dose from volcanism is the largest contribution to total-system risk during a 10,000 yr performance period.
  - Staff note some components of these analyses may under or over estimate risk.
  - Ongoing work to evaluate conservatisms and reduce uncertainties
- DOE will need to present acceptable data, models, and analyses in licensing to adequately address risks from igneous events.

STATUS OF PRIMARY TSPA-VA CONCERNS

Staff's primary technical concerns with TSPA-VA analyses apparently are being addressed by DOE

Informal, collegial communication is greatly facilitating the issue resolution process

- Source-zone models reduce average probability of volcanic disruption $<10^{-8}$/yr, in contrast to prior models used for subissue resolution
  - 1/99 Appendix 7: Average igneous event probability of 1.5×10^{-8}/yr from PVHA = average DOE probability of volcanic disruption.
  - 1/99 Appendix 7: Upper probability bound of 10^{-7}/yr from PVHA also will be used in DOE risk assessments, in addition to average value.

- Eruption characteristics underestimate disruptive capabilities of YMR volcanoes
  - 2/99 Workshop: Greater reliance will be placed on active, violent strombolian analogs to YMR volcanoes.

STATUS OF PRIMARY TSPA-VA CONCERNS, cont.

- Waste Package resilience during volcanic events not supported by models or data with sufficient technical basis
  - 2/99 and 4/99 Workshops: Additional models and data needed to support conclusions of waste package resilience, including coupled thermal, mechanical, and chemical effects of igneous events.

- Effects of igneous events on HLW-form poorly constrained
  - 2/99 Workshop: Additional models and data needed to evaluate waste-form characteristics during igneous events.

- Airborne contaminant plume bypassed the critical group location for most simulations
  - 2/99 Workshop: Parallel approach to groundwater contaminant plume (i.e., always directed toward critical group) is reasonably conservative.

POTENTIALLY SIGNIFICANT SOURCES OF UNCERTAINTY

Magma–Repository Interactions

- Ascending magma has ≈10 MPa overpressure and contains volatiles, thus will flow into drifts

- Scoping calculations indicate large sources of resolvable uncertainty:

  – Intrusion response to rock-stress regime around drifts?

  – Flow velocity into open or partially backfilled drifts?

  – Amount of compaction or mobilization of backfill?

  – Extent of magma flow into drifts?

  – Temperature and composition of magma+gas after emplacement?

  – Conduit characteristics at drift interface?

POTENTIALLY SIGNIFICANT SOURCES OF UNCERTAINTY

Magma–Repository Interactions, cont.

- Relevance to 10,000 yr performance:

  – Flow into a dominantly backfilled drift can compact backfill and disrupt some fraction of waste packages in the drift.

  – Flow into nonbackfilled drifts potentially fails most or all of the waste packages in the intersected drift.

  – 10^{-7} annual event probability and hydrologic transport times probably limit contributions to expected annual dose to <1 mrem/yr.

  – In contrast, lateral breakout of conduit along drift roof may enhance source-term for volcanic transport and increase expected annual dose.

- Technical basis thus needed to evaluate potentially important contributions to expected annual dose from modified volcanic eruption.

POTENTIALLY SIGNIFICANT SOURCES OF UNCERTAINTY

Airborne Particle Concentrations thru Time

- Expected annual dose calculations need to consider contributions from tephra deposits up to 1,000's of years old.
- These deposits are eroded from YMR (>80 ka) and analogs have limitations:
  - Climate, topography, vegetation affect deposit character
- Current assumption is conservative:
  - Airborne particle concentration is constant through time
- Need technical basis to evaluate 0–10,000 yr after eruption:
  - Amount of airborne particulates available in juvenile fall deposits
  - Fine-particle redistribution mechanisms
  - Deposit erosion or burial in YMR setting
  - Leaching of radionuclides from deposit

CONCLUSIONS

- TSPA-VA analyses provide limited technical bases for IA models
  - Inadequate for screening, additional work needed for acceptable models.

- Post-VA interactions show acceptable IA modeling approaches can be developed before licensing.

- Current staff analyses show igneous events make a large contribution total-system risk during the first 10,000 yr post-closure and will need to be evaluated acceptably.

- Active magma-repository interactions may affect a larger number of waste packages than currently modeled with passive interaction; this consequently may increase total-system risk.

- Characteristics of contaminated tephra-fall deposits through time are likely over estimated, but models currently lack a sufficient technical basis to reduce the associated total-system risk.

- Additional work can quantify and reduce these current levels of uncertainty.

ROCKFALL ABSTRACTION MODELS

Presented by

Simon Hsiung

210/522-5209 (shsiung@swri.org)

Center for Nuclear Waste Regulatory Analyses

May 25-27, 1999

San Antonio, Texas

DOE/NRC Technical Exchange on

Total System Performance Assessments For Yucca Mountain

FUNDAMENTAL APPROACH

- Estimate Size of Rockfalls
- Assess Damages of the Rockfalls to Waste Packages

UNDERSTANDING OF VA APPROACH

- Approach for Estimating Size of Rockfalls
  - Sample peak ground velocities from hazard curve at a predetermined time
    - Four time periods were used
  - Calculate the drift damage levels using the peak ground velocities determined above
    - Damage level was originally developed for assessing drift damage due to rockbursts for underground mines in Sudbury, Ontario
    - Damage level is a function of rock quality
      - Higher quality rock suffers less damage

UNDERSTANDING OF VA APPROACH (CONT'D)

– Determine size of rockfall by associating damage levels with probability density function (PDF) of rock sizes
  - Distribution of rock sizes is calculated based on mapped joint spacing data from the Exploratory Studies Facility
  - The rock size PDF is not presented clearly in the TSPA-VA Analyses Technical Basis Document
  - It is not clear how the size of a rockfall for a particular damage level is determined from the rock size PDF

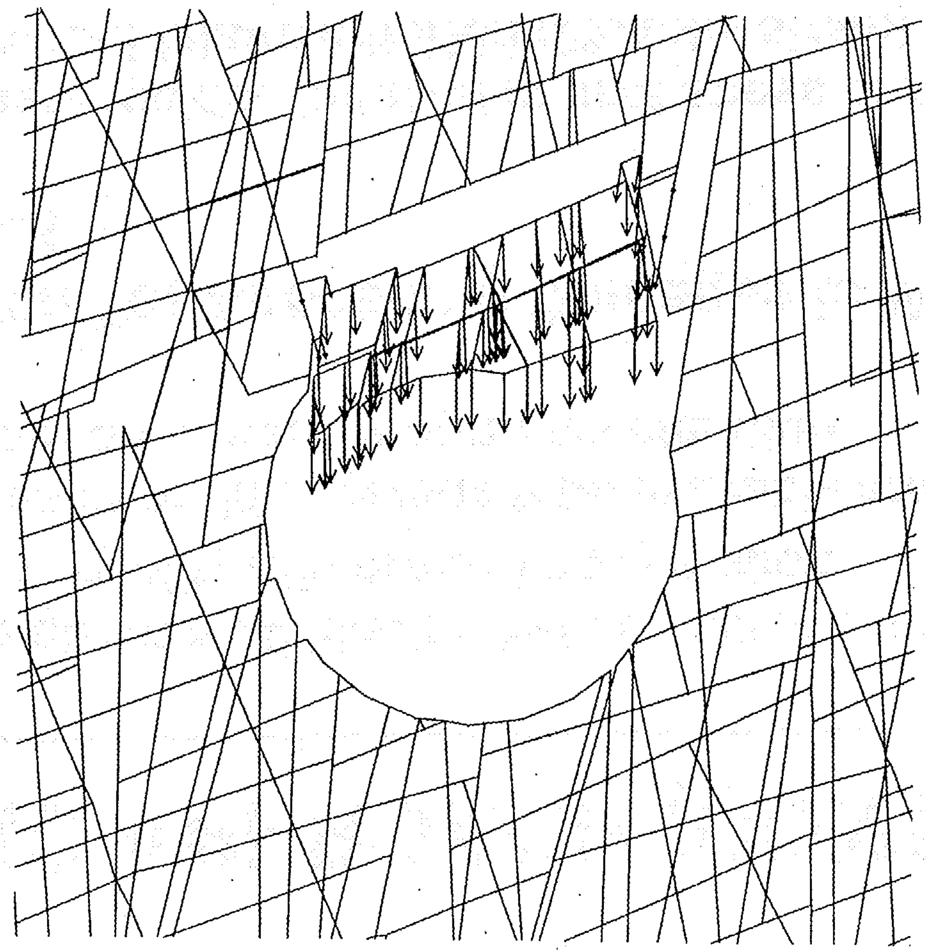
UNDERSTANDING OF VA APPROACH (CONT'D)

- Approach For Assessing Damages to Waste Packages
  - Compare size of rockfall to the critical rock size that is required to damage waste package at the time of impact
    - Critical rock size is pre-determined using dynamic modeling of rock impact on waste package
    - Critical rock size is a function of waste package degradation
    - Crack initiation and through cracking

NRC APPROACH

- **Approach for Estimating Size of Rockfalls**
  - Determine time history and magnitude of peak ground accelerations
  - Calculate sizes of rockfall and compute impact load & stress
    - Volume is determined by joint spacing and height of rock blocks that can fall
    - Height is sampled randomly between joint spacing and height of yield zone (taking into account probability of coherent rock blocks to fall)

UDEC MODELING RESULT INDICATING POTENTIAL FOR COHERENT ROCK BLOCKS TO FALL



NRC APPROACH (CONT'D)

- Height of rock blocks that can fall is a function of rock quality and ground acceleration
- Area of rockfall versus total available area is a function of peak ground acceleration

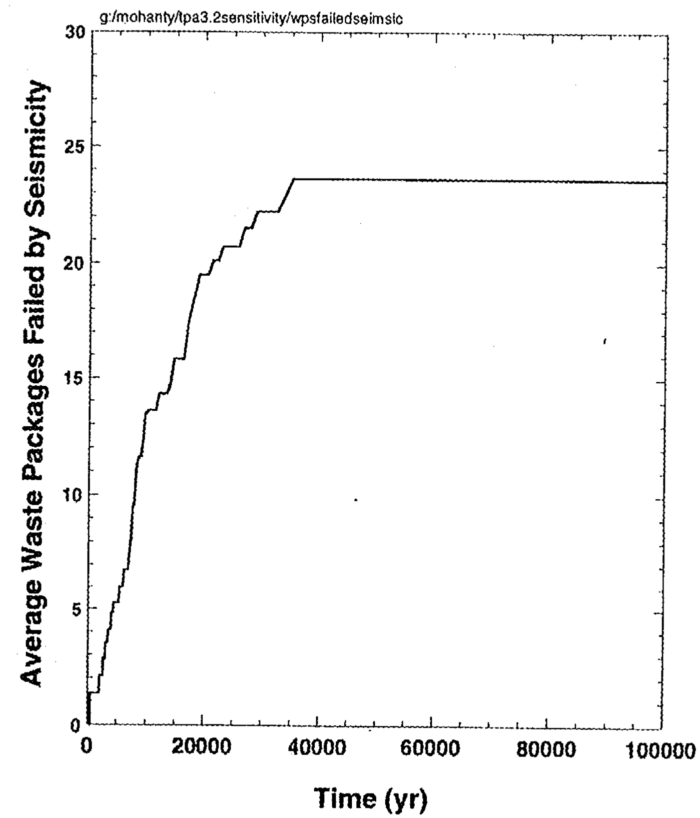
- Approach For Assessing Damages to Waste Packages
  - Compare rockfall induced impact stress to a pre-determined failure criterion (2% total strain)

COMPARISON OF DOE AND NRC ROCKFALL MODELS

- NRC Approach is More Conservative in Estimating Size of Rockfall
  - Potential for coherent rock blocks to fall is considered
- NRC Approach is More Conservative in Applying Failure Criterion
  - Between DOE crack initiation and through cracking criteria
- DOE Approach is More Conservative by Including Corrosion of Waste Packages
- Other Differences and Similarities Will be Discussed in a Separate Presentation

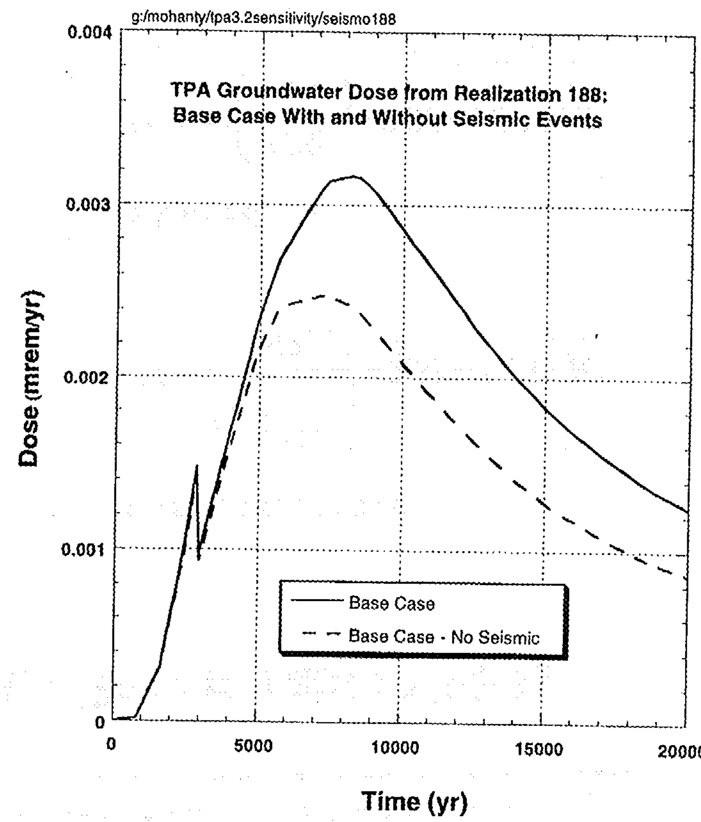
WP FAILURE DUE TO ROCKFALL

- Treated as a Part of Base Case
- Number of Realizations: 250
- 22 Realizations With Rockfall-Induced WP Failures (9%)
- 13-33 WPs Failed in the Realizations With Rockfall-Induced Failures
- Failure Time: 400-35,000 yrs
- Average Rockfall-Induced Failure (All Realizations): 2



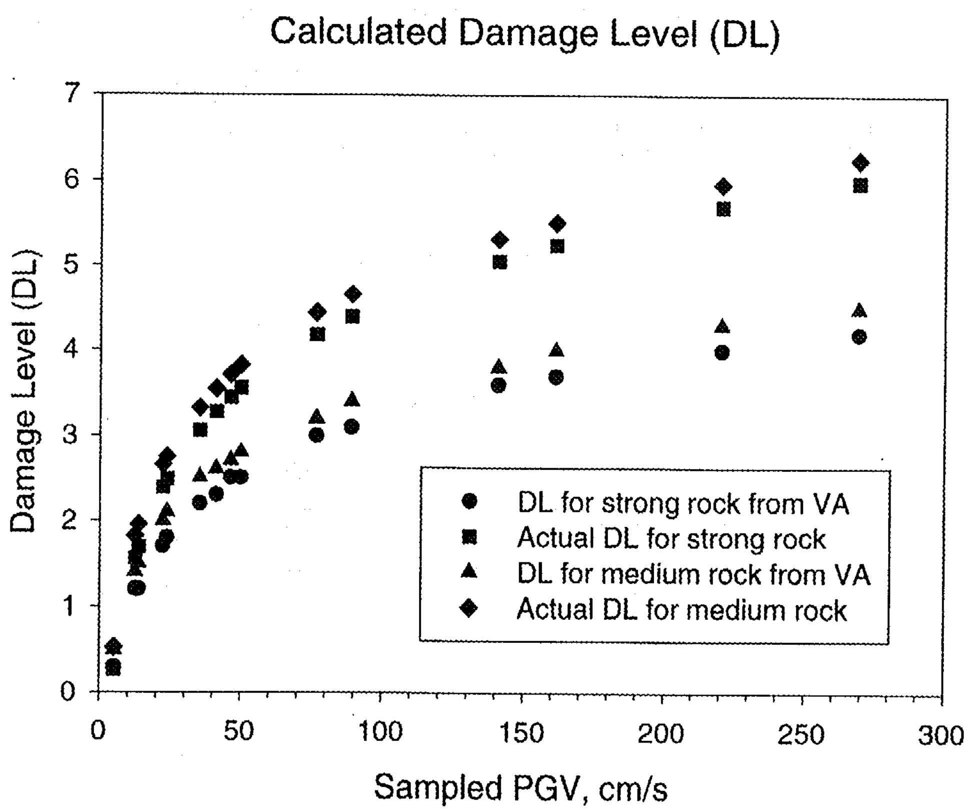
DOSE FROM ROCKFALL

- Figure Shows the Worst-Case Realization (i.e., Largest Contribution From Rockfall-Induced Failure to Dose in 10,000 yrs)
  - A peak dose of 3.17 micro-rem/yr at 8,180 yr
- Case Without Rockfall-Induced Failure
  - A peak dose of 2.48 micro-rem/yr at 7,150 yr
  - 22% difference compared to the worst-case realization



ERROR IN DAMAGE LEVEL CALCULATION?

- **Data from TSPA-VA Technical Basis Report Table 10-30a**



Correct Equation

$$DL = \frac{\ln\left(\frac{PGV}{5}\right)}{\ln(2)} - 2.33 + 1.33 * IC$$

VA used

$$DL = \ln\left(\frac{PGV}{5}\right) - 2.33 + 1.33 * IC$$

VA DL is 40% smaller than the actual value for strong rock and 30% smaller for medium rock

ROCKFALL EFFECT UNDER THE NEW ALTERNATIVE DESIGN

- Drip Shield Should Reduce and Defer the Rockfall Effect on Waste Package Integrity
- Rockfall May Effect Drip Shield Performance
- If Backfill is Considered, Rockfall Effect May No Longer be a Concern

5/26/99

NRC Issue Resolution Status Report FY 99 Schedule (Send to DOE and others)

1. Evolution of Near-field Environment ---------------------------- 6/18/99*

2. Thermal Effects on Flow -- 7/08/99*

3. Igneous Activity -- 7/09/99*

4. Unsaturated Flow under Isothermal Conditions ------------- 7/16/99*

5. Radionuclide Transport -- 8/06/99

6. Structural Deformation and Seismicity ------------------------ 8/27/99

7. Repository Design and Thermo-Mechanical Effects ------ 9/17/99

8. Container Life and Source Term -------------------------------- 9/24/99

9. Performance Assessment -- 9/30/99

NOTE: "*" = Currently in review.

Attachment 22

FRAMEWORK FOR THE YUCCA MOUNTAIN REVIEW PLAN

DOE/NRC TECHNICAL EXCHANGE ON
TOTAL SYSTEM PERFORMANCE ASSESSMETS FOR YUCCA MOUNTAIN
May 25 - 27, 1999

Christiana H. Lui
High-Level Waste and Performance Assessment Branch
Division of Waste Management
Office of Nuclear Material Safety and Safeguards
(301)415-6200/CXL@NRC.GOV

Attachment 23

ELEMENTS OF THIS PRESENTATION

- Principles
- Features
- Outline
- Relationship to the Content of License Application (§63.21)
- Integration of Issue Resolution Status Reports into the Yucca Mountain Review Plan
- Relationship to DOE Repository Safety Strategy and Principal Factors
- Advantages of the Approach
- Schedule

PRINCIPLES

1. Staff is responsible to defend the conclusion of its review of Yucca Mountain License Application (YMLA). DOE is responsible to make sure that an adequate safety case is made in the YMLA.

2. Performance-based site-specific rule should be accompanied by a performance-based site-specific review plan
   - Focus NRC staff's evaluation on DOE's safety case including site characterization and experimental work necessary and sufficient to support the safety case

3. To produce a streamlined, transparent and effective performance-based review plan consistent with the Yucca Mountain licensing strategy paper (SECY-97-300) and with the guidance document for streamlining the HLW program

4. Review should be done in an integrated fashion and the integration should take place at the technical staff level
   - The YMRP should be formulated based on staff's current understanding of DOE's approach and staff's IPA effort
   - The framework should be sufficiently flexible to accommodate changes in DOE's approaches

FEATURES

- Areas of Review
- Acceptance Criteria
- Review Procedure
- Evaluation Findings
- References

OUTLINE

II.A REPOSITORY SAFETY PRIOR TO PERMANENT CLOSURE

AREAS OF REVIEW: Compliance demonstration to meet §63.111 (Pre-closure Performance Objectives), §63.112 (Requirements for an ISA) and Subpart F (Performance Confirmation Program)

REVIEW CHAPTER(S)

II.A.1 Integrated Safety Analysis

Content of YMLA to be reviewed in this chapter: §63.21(c)((1) (Site Description), §63.21(c)(2) (Integrated Safety Analysis), §63.21(c)(3) (Materials, Codes and Standards in Design and Construction), §63.21(c)(4) (Description of EBS), §63.21(c)(14) (Radioactive Effluents Control Program), etc.

II.A.2 Retrievability Plan and Alternate Storage

Content of YMLA to be reviewed in this chapter: §63.21(c)(19) (Retrieval and Alternate Storage Plans)

II.A.3 Performance Confirmation Program

Content of YMLA to be reviewed in this chapter: §63.21(c)(20) (Performance Confirmation Program)

Possibly Other Chapters

EVALUATION FINDINGS

In reviewing the content of application identified above, if the staff found that all acceptance criteria in these review chapters have been satisfied, the licensee has successfully demonstrated meeting the pre-closure performance objectives in §63.111 and the technical requirements in §§63.112.

II.B REPOSITORY SAFETY AFTER PERMANENT CLOSURE

AREAS OF REVIEW: Compliance demonstration to meet §63.113 (Post-closure Performance Objectives), §63.114 (Requirements for PA), §63.115 (Requirements for Critical Group) and Subpart F (Performance Confirmation Program)

REVIEW CHAPTER(S)

II.B.1 Performance Assessment

Content of YMLA to be reviewed in this chapter: §63.21(c)(1) (Site Description), §63.21(c)(3)(Material and Codes and Standards Used in Construction), §63.21(c)(4)(i)(EBS Design), §63.21(c)(7) (Performance Assessment), §63.21(c)(8) (Stylized Human Intrusion Analysis), §63.21(c)(10)(Use of Expert Elicitation), etc.

II.B.2 Performance Confirmation

Content of YMLA to be reviewed in this chapter: §63.21(c)(20) (Performance Confirmation) and §63.21(c)(21) (Identification and Schedule for Resolution)

Possibly Other Chapters

EVALUATION FINDINGS

In reviewing the content of application identified above, if the staff found that all acceptance criteria in these review chapters have been satisfied, the licensee has successfully demonstrated meeting the post-closure performance objectives in §63.113 and the technical requirements in §§63.114 and 63.115 and the post-closure sections in Subpart F.

II.C ADMINISTRATIVE AND PROGRAMMATIC REQUIREMENTS

AREAS OF REVIEW: Compliance demonstration to meet Subpart D (Records, Reports, Tests, and Inspections), Subpart G (Quality Assurance) and Subpart H (Training and Certification of Personnel)

REVIEW CHAPTER(S)

II.C.1 Records, Reports, Tests, and Inspections)
Content of YMLA to be reviewed in this chapter: §63.21(c)(17) (Record Keeping), etc.
II.C.2 Quality Assurance Program
Content of YMLA to be reviewed in this chapter: §63.21(c)(11) (QA Program)
II.C.3 Training and Certification of Personnel
Content of YMLA to be reviewed in this chapter: §63.21(c)(22) (Administrative and Programmatic Requirements), etc.
Other Chapters

EVALUATION FINDINGS

In reviewing the content of application identified above, if the staff found that all acceptance criteria in these review chapters have been satisfied, the licensee has successfully demonstrated meeting the requirements in Subpart D, Subpart G and Subpart H.

LINKING §63.21 TO THE PERFORMANCE-BASED YUCCA MOUNTAIN REVIEW PLAN (PRELIMINARY)

Content of Application (§63.21)	Review Done in YMRP Chapter(s)
(b) General Information	I.A, I.B, I.C, I.D and I.E
(c)(1) Site Description	II.A.1 and II.B.1
(c)(2) Integrated Safety Analysis	II.A.1
(c)(3) Materials, Codes and Standards in Design and Construction	II.A and II.B.1
(c)(4) Description of EBS	II.A and II.B.1
(c)(5) Site Investigation	II.A and II.B
(c)(6) Thermal Effects	II.B
(c)(7) Performance Assessment	II.B.1
(c)(8) Stylized Human Intrusion Analysis	II.B.1
(c)(9) Technical Basis for Models	II.A.1 and II.B.1
(c)(10) Expert Elicitation	II.A and II.B
(c)(11) QA Program	II.C.2
(c)(12) Waste Inventory	II.A and II.B.1
(c)(13) Parameters Influence Design	II.A and II.B
(c)(14) Radioactive Effluents Control Program	II.A.1

Content of Application (§63.21)	Review Done in YMRP Chapter(s)
(c)(15) Land Access After Permanent Closure	II.C
(c)(16) Emergency Planning	II.A.2 or II.C
(c)(17) Record Keeping	II.C.1
(c)(18) Decontamination/Dismantlement of Surface Facilities	II.C
(c)(19) Retrieval and Alternate Storage Plans	II.A.3
(c)(20) Performance Confirmation Program	II.A.4 and II.B.2
(c)(21) Schedule and Program for Design Resolution	II.A.4 and II.B.2
(c)(22) Administrative and Programmatic Requirements	II.C.3

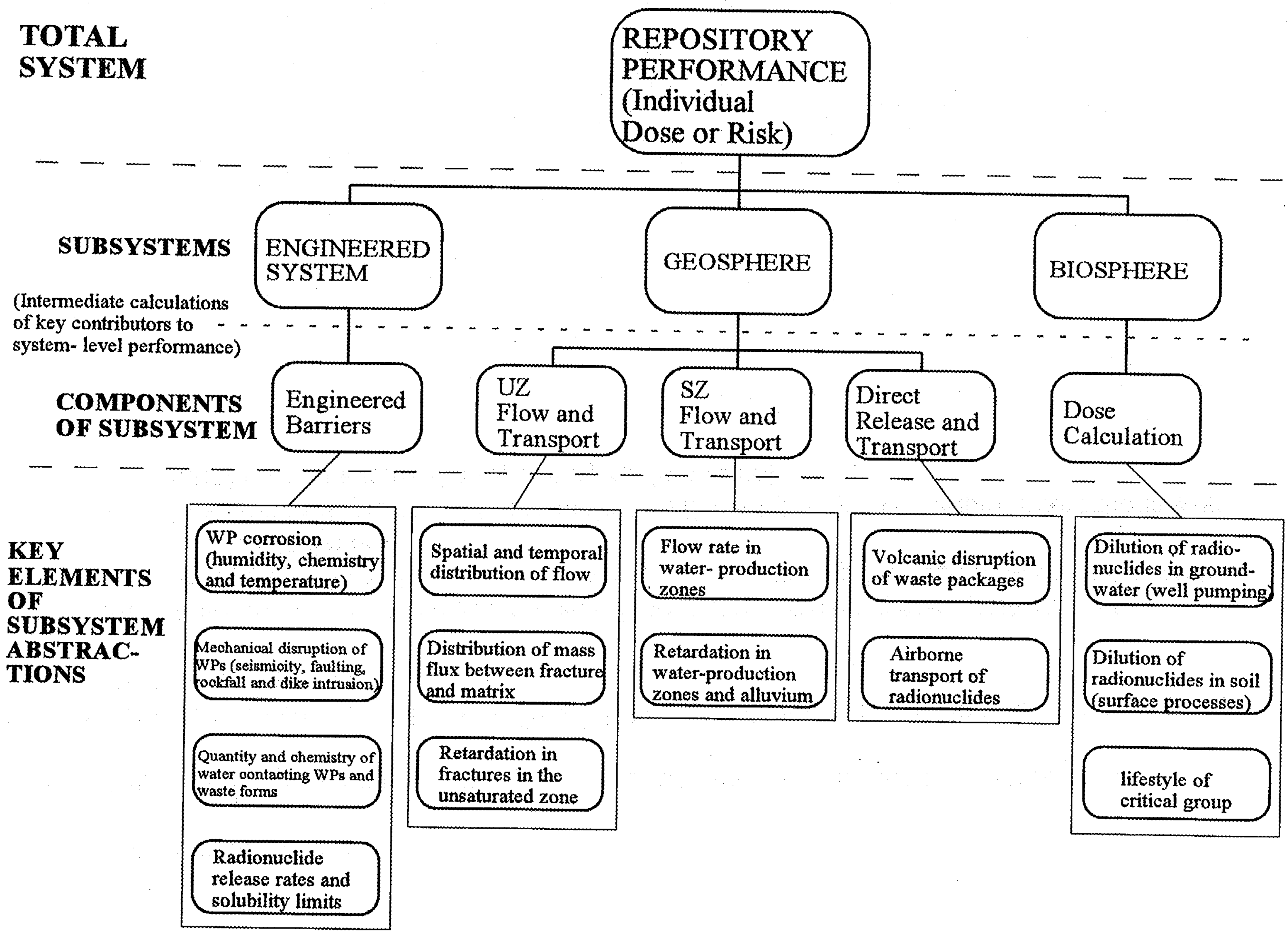
NOTE: Some of the entries currently under §63.21 will be modified (e.g., use of expert elicitation in both pre- and post-closure), consolidated or moved to the technical requirement subpart (e.g., §63.21(c)(5) to §63.114), i.e., leaving §63.21 strictly "content". The sequence will be re-arranged to reflect a more logical structure in the final rule.

BACKGROUND

- SECY 97-300 describes staff's strategy in developing Part 63 and the Yucca Mountain Review Plan

- Total System Performance Assessment and Integration IRSR sets up the framework for the post-closure portion of the Yucca Mountain Review Plan, other IRSRs identify their relationship to the TSPA using the flowdown diagram

- To avoid duplication and keep a consistent set of acceptance criteria and review methods
  - All acceptance criteria and review methods will be developed under the Yucca Mountain Review Plan starting FY2000
  - The status of issue resolution will continued to be documented in the IRSRs



Flowdown diagram for total system performance assessment.

INTEGRATED SUBISSUES

Integrated Subissues are

- The bottom tier of the flowdown diagram for post-closure performance assessment

- Developed based on review of DOE's TSPAs, knowledge of the design options and site characteristics and staff's IPA effort

- Integrated processes, features, and events that could impact system performance
  - providing KTIs an integration framework for describing their contribution in the context of PA calculations
  - facilitating integration at the technical staff level (Many KTIs require interactions with other KTIs in evaluating repository performance)

II.B.1 PERFORMANCE ASSESSMENT REVIEW

System Description and Demonstration of Multiple Barriers
Develop acceptance criteria and review procedures for technical criteria §63.114(h), §63.114(i) and §63.114(j); Evaluation Findings and References

Scenario Analysis
Develop acceptance criteria and review procedures for technical criteria §63.21(c)(5)?, §63.21(c)(6), §63.114(d), §63.114(e), §63.115(a) and §63.115(b); Evaluation Findings and References

Model Abstraction
Develop acceptance criteria and review procedures for technical criteria §63.114(a), §63.114(b), §63.114(c), §63.114(f) and §63.114(g) in the following proposed integrated subissues (the list may be modified to reflect the existing DOE approach and staff's IPA work):

- SPATIAL AND TEMPORAL DISTRIBUTION OF FLOW
- WP CORROSION
- MECHANICAL DISRUPTION OF WASTE PACKAGES
- QUANTITY AND CHEMISTRY OF WATER CONTACTING WASTE PACKAGES AND WASTE FORMS
- RADIONUCLIDE RELEASE RATES AND SOLUBILITY LIMITS
- DISTRIBUTION OF MASS FLUX BETWEEN FRACTURE AND MATRIX
- RETARDATION IN FRACTURES IN THE UNSATURATED ZONE
- FLOW RATES IN WATER PRODUCTION ZONES
- RETARDATION IN WATER PRODUCTION ZONES AND ALLUVIUM
- VOLCANIC DISRUPTION OF WASTE PACKAGES
- AIRBORNE TRANSPORT OF RADIONUCLIDES
- DILUTION OF RADIONUCLIDES IN GROUNDWATER DUE TO WELL PUMPING
- DILUTION OF RADIONUCLIDES IN SOIL DUE TO SURFACE PROCESSES
- LIFESTYLE OF CRITICAL GROUP

Demonstration of the Overall Performance Objective
Acceptance criteria, review methods, evaluation findings and references on whether DOE's analysis of repository performance has demonstrated compliance with §63.113(b) and §63.113(d)

RELATIONSHIP BETWEEN INTEGRATED SUBISSUES AND KTI SUBISSUES (PRELIMINARY)

Integrated Subissue	Relevant KTI Subissues
Spatial and Temporal Distribution of Flow (UZ)	SDS-3: Fracturing and structural framework
	TEF-1: Sufficiency of thermal-hydrologic testing to assess reflux
	USFIC-3: Present day shallow infiltration
	USFIC-4: Deep percolation (present and future)
WP Corrosion (temperature, humidity, and chemistry)	CLST-1: Effects of corrosion on lifetime of containers
	ENFE-2: Effects of coupled THC processes on WP chemical environment
	RDTME-3: Thermal-mechanical effects on underground facility design and performance
Mechanical Disruption of Waste Packages	CLST-2: Effects of materials stability and mechanical failure on the lifetime of the container
	RDTME-2: Design of the geologic repository operations area for the effects of seismic events and direct fault disruption
	RDTME-3: Thermal-mechanical effects on underground facility design and performance
	SDS-2: Seismicity
	SDS-4: Tectonics and crustal conditions

Integrated Subissue	Relevant KTI Subissues
Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms	CLST-1: Effects of corrosion on lifetime of containers
	CLST-3: Rate of degradation of spent nuclear fuel
	CLST-4: Rate of degradation of high-level waste glass
	ENFE-1: Effects of coupled THC processes on seepage and flow
	ENFE-2: Effects of coupled THC processes on WP chemical environment
	ENFE-3: Effects of coupled THC processes on chemical environment for radionuclide release
	RDTME-3: Thermal-mechanical effects on underground facility design and performance
	USFIC-3: Present day shallow infiltration
	USFIC-4: Deep percolation (present and future)
Radionuclide Release and Solubility Limits	ENFE-3: Effects of coupled THC processes on chemical environment for radionuclide release
Distribution of Mass Flux Between Fracture and Matrix (UZ)	ENFE-1: Effects of coupled THC processes on seepage and flow
	SDS-3: Fracturing and structural framework
	USFIC-4: Deep percolation (present and future)
Retardation in Fractures in the Unsaturated Zone	RT-3: Nuclide transport through fractured rock

Integrated Subissue	Relevant KTI Subissues
Flow Rates in Water Production Zones	SDS-3: Fracturing and structural framework
	USFIC-5: Saturated zone ambient flow conditions and dilution
Retardation in Water Production Zones and Alluvium	RT-2: Nuclide transport through alluvium
	USFIC-6: Matrix diffusion
Volcanic Disruption of Waste Packages	IA-2: Consequences of igneous activity
	SDS-4: Tectonics and crustal conditions
Airborne Transport of Radionuclides	IA-2: Consequences of igneous activity
Dilution of Radionuclides in Groundwater Due to Well Pumping	USFIC-5: Saturated zone ambient flow conditions and dilution
Dilution of Radionuclides in Soil Due to Surface Processes	IA-2: Consequences of igneous activity
Lifestyle of Critical Group	USFIC-5: Saturated zone ambient flow conditions and dilution

RELATIONSHIP OF THE INTEGRATED SUBISSUES TO DOE REPOSITORY SAFETY STRATEGY AND PRINCIPAL FACTORS

Key Attributes of DOE Repository Safety Strategy	Principal Factors	Integrated Subissues
Limited water contacting waste packages	Precipitation and infiltration of water into the mountain	Spatial and temporal distribution of flow
	Percolation of water to depth	
	Seepage of water into drifts	
	Effects of heat and excavation on water flow	
	Dripping of water onto waste packages	Quantity and chemistry of water contacting waste packages and waste forms
	Humidity and temperature at waste packages	Waste packages corrosion
Long waste package lifetime	Chemistry of water on waste packages	Quantity and chemistry of water contacting waste packages and waste forms
	Integrity of outer waste package barrier	Waste package corrosion
	Integrity of inner waste package barrier	
Low rate of release of radionuclides from breached waste packages	Seepage of water into waste packages	Quantity and chemistry of water contacting waste packages and waste forms
	Integrity of spent nuclear fuel cladding	

Key Attributes of DOE Repository Safety Strategy	Principal Factors	Integrated Subissues
	Dissolution of uranium oxide and glass waste forms	Radionuclide release rates and solubility limits
	Solubility of neptunium	
	Formation and transport of radionuclide-bearing colloids	
	Transport through and out of engineered barrier system	
Radionuclide concentration reduction during transport from the waste packages	Transport through unsaturated zone	Distribution of mass flux between fracture and matrix
		Retardation in fractures in the unsaturated zone
	Flow and transport in saturated zone	Flow rates in water-production zones
		Retardation in water-production zones and alluvium
	Dilution from pumping	Dilution of radionuclides in groundwater due to well pumping
	Biosphere transport and uptake	Dilution of radionuclides in soil due to surface processes
		Lifestyle of critical group

ADVANTAGES OF THE APPROACH

- Review of both the pre-closure and post-closure safety cases are performance-based
  - A top-down approach to evaluate whether the YMLA has met the performance objectives
  - Encompassing all related activities
  - The iterative cycle of performance assessment ↔ data collection is clearly and closely maintained
  - Clearly indicate why DOE's supporting data is acceptable or deficient in the context of how that work has been used in DOE's safety cases
  - Minimizing duplication of acceptance criteria and review methods
  - Modification to or elimination of possibly overly prescriptive acceptance criteria in the IRSRs
  - The requirements under §63.21 and any RAIs are clearly justified in this context

- Leading to a streamlined, transparent and integrated review plan

SCHEDULE OF PLANNED ACTIVITIES FOR THE YUCCA MOUNTAIN REVIEW PLAN

Activity	Completion Date	Purpose
1. DOE/NRC Total System Performance Assessment (TSPA) Technical Exchange at CNWRA	May 25 - 27, 1999	Preliminary discussion with DOE on the approach for Yucca Mountain Review Plan
2. TSPAI Issue Resolution Status Report	September 30, 1999	This IRSR will become part of the Yucca Mountain Review Plan (YMRP) or be referenced by the YMRP.
3 Final Part 63 with Yucca Mountain Review Plan Annotated Outline	To the Commission by November 30, 1999	To submit to the Commission the final Part 63 and a risk-informed performance-based YMRP annotated outline
4. Public meetings in Nevada after finalizing Part 63	January/February 2000	To present and clarify the final Part 63 and the accompanied YMRP
5. Interactions with DOE	January/February 2000	To present and clarify the final Part 63 and the accompanied YMRP
6. Yucca Mountain Review Plan, Rev. 0	March 31, 2000	Staff's initial attempt to expand the annotated outline into a risk-informed performance-based review plan. it will contain TBD sections that will be developed in the future revisions of this review plan.
7. Future Revisions of Yucca Mountain Review Plan	September 30, 2000 (Rev. 1); September 30, 2001 (Rev. 2)	To update and publish YMRP prior to key DOE milestones: Site Recommendation and License Application. The last revision (Rev. 2) would be published five months before the current expected Yucca Mountain License Application submission date (March 1, 2002)

Defense-in-Depth Philosophy In Proposed Regulations for HLW Disposal at Yucca Mountain

May 26, 1999
DOE/NRC Technical Exchange on
Total System Performance Assessment for Yucca Mountain

Tim McCartin
(tjm3@nrc.gov)
(301) 415-6681
Division of Waste Management
Performance Assessment and HLW Integration Branch

OUTLINE

- Definition of Defense-in-Depth Concept
- High-Level Waste Regulation (Proposed Part 63)
- Requirements for Multiple Barriers
- Quantitative Approaches

DEFENSE-IN-DEPTH

"Risk-Informed and Performance-Based Regulation" (Commission White Paper, issued 3/11/99) defined the concept of defense-in-depth as follows:

(Emphasis added)

"Defense-in-depth is an element of the NRC's Safety Philosophy that **employs successive compensatory measures to** prevent accidents or **mitigate damage if a malfunction**, accident, **or naturally caused event occurs** at a nuclear facility. The defense-in-depth philosophy **ensures that safety will not be wholly dependent on any single element** of the design, construction, maintenance, or operation of a nuclear facility. The net effect of incorporating defense-in-depth into design, construction, maintenance, and operation is that **the facility or system in question tends to be more tolerant of failures and external challenges**."

POST-CLOSURE REPOSITORY PERFORMANCE OBJECTIVES

Part 63

- 25 mrem annual dose limit
  - performance assessment (PA) must include analysis of uncertainty in dose estimates

- demonstration of the capability of multiple barriers (both engineered and natural).

- stylized calculation of human intrusion

PART 63 REQUIREMENTS FOR MULTIPLE BARRIERS

- No quantitative requirements for individual barriers
- Barrier is defined as any material or structure that prevents or substantially delays movement of water or radioactive materials.
- Requires DOE to:
  1) identify those design features of the engineered barrier system, and natural features of the geologic setting, that are considered barriers important to waste isolation;
  2) describe the capability of these barriers to isolate waste, taking into account uncertainties in characterizing and modeling the barriers; and
  3) provide the technical basis for the description of the capability of these barriers.
- Affords DOE flexibility to identify barriers important to waste isolation and select approach for demonstrating their contribution.
  - **DOE has the responsibility to identify and demonstrate their capability to isolate waste**

DEMONSTRATION OF MULTIPLE BARRIERS

1) Barriers should be representative of distinct features, characteristics or attributes of the repository system, for example:
   - engineered barriers, unsaturated zone, alluvium of the saturated zone

2) Barrier capability should be explained in terms of preventing or substantially delaying the movement of water or radioactive materials, for example:
   - waste package delays releases for many years
   - unsaturated zone "shields" repository from water, deep percolation only a small fraction of annual precipitation
   - unsaturated zone limits the number of wetted packages, and, thereby, limiting amount of radioactive waste available for release to ground water
   - alluvium in saturated zone significantly delays movement of many radionuclides by sorption

3) Rigor of needed technical basis for a barrier's capability proportional to its importance to performance, for example:
   - laboratory and field measurements
   - analog studies

USING QUANTITATIVE APPROACHES

- Many quantitative techniques are available that can provide additional insights, support explanation of the barrier's capability, and illustrate barrier's relationship to performance, for example:
  - sensitivity analysis
  - importance analysis
  - "one-off" analysis
  - analysis beyond 10,000 years

- NRC is open to any approach that:
  1) makes PA and capability of multiple barriers more transparent, and
  2) supports more informed licensing decisions

YUCCA
MOUNTAIN
PROJECT

Studies

VA Results from Importance (DID) Analysis

Presented to:
DOE/NRC Technical Exchange on
Total System Performance Assessment
San Antonio, Texas

Presented by:
Larry Rickertsen
Regulatory and Licensing
CRWMS M&O

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

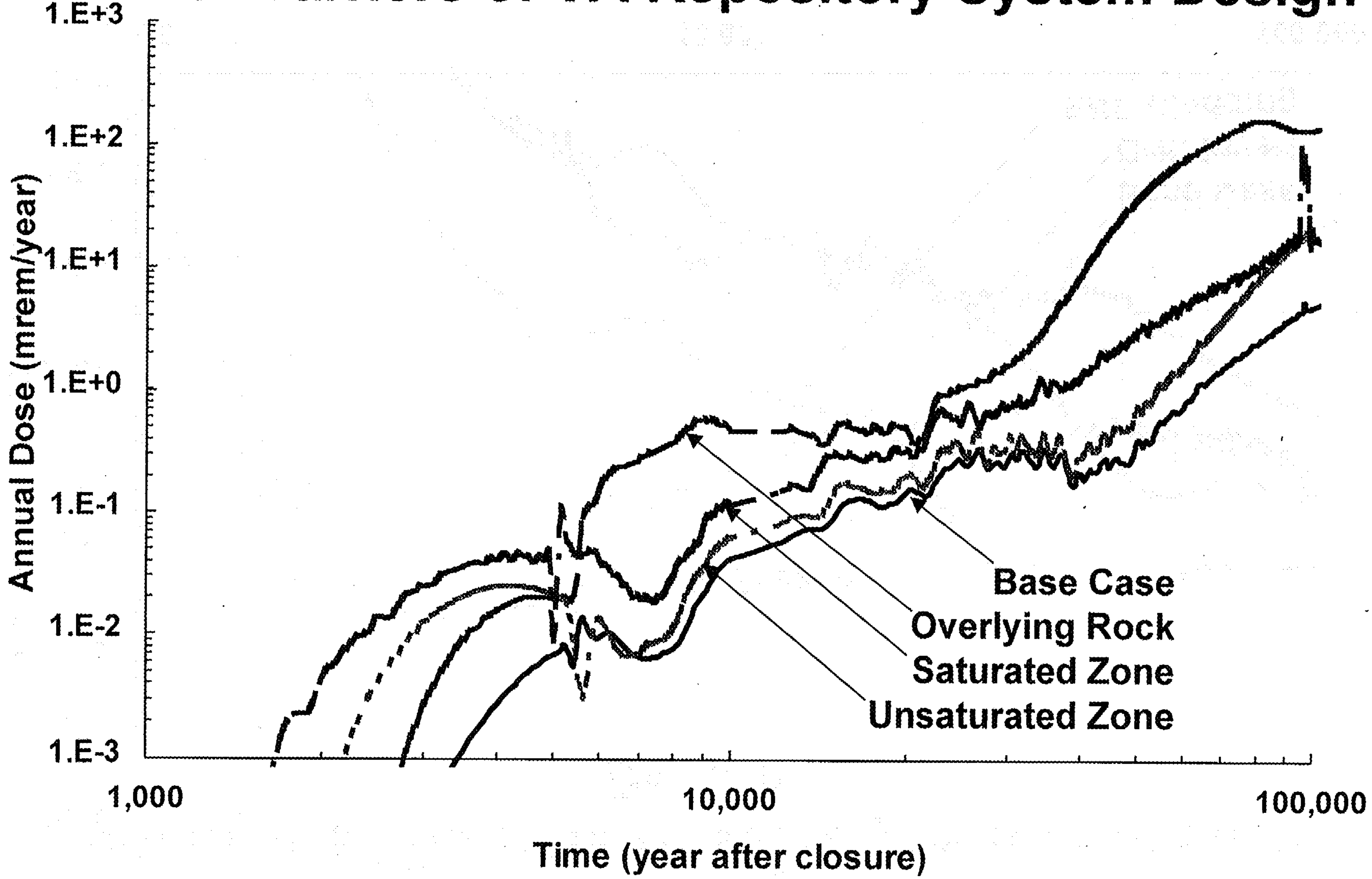
May 25-27, 1999

Attachment 25

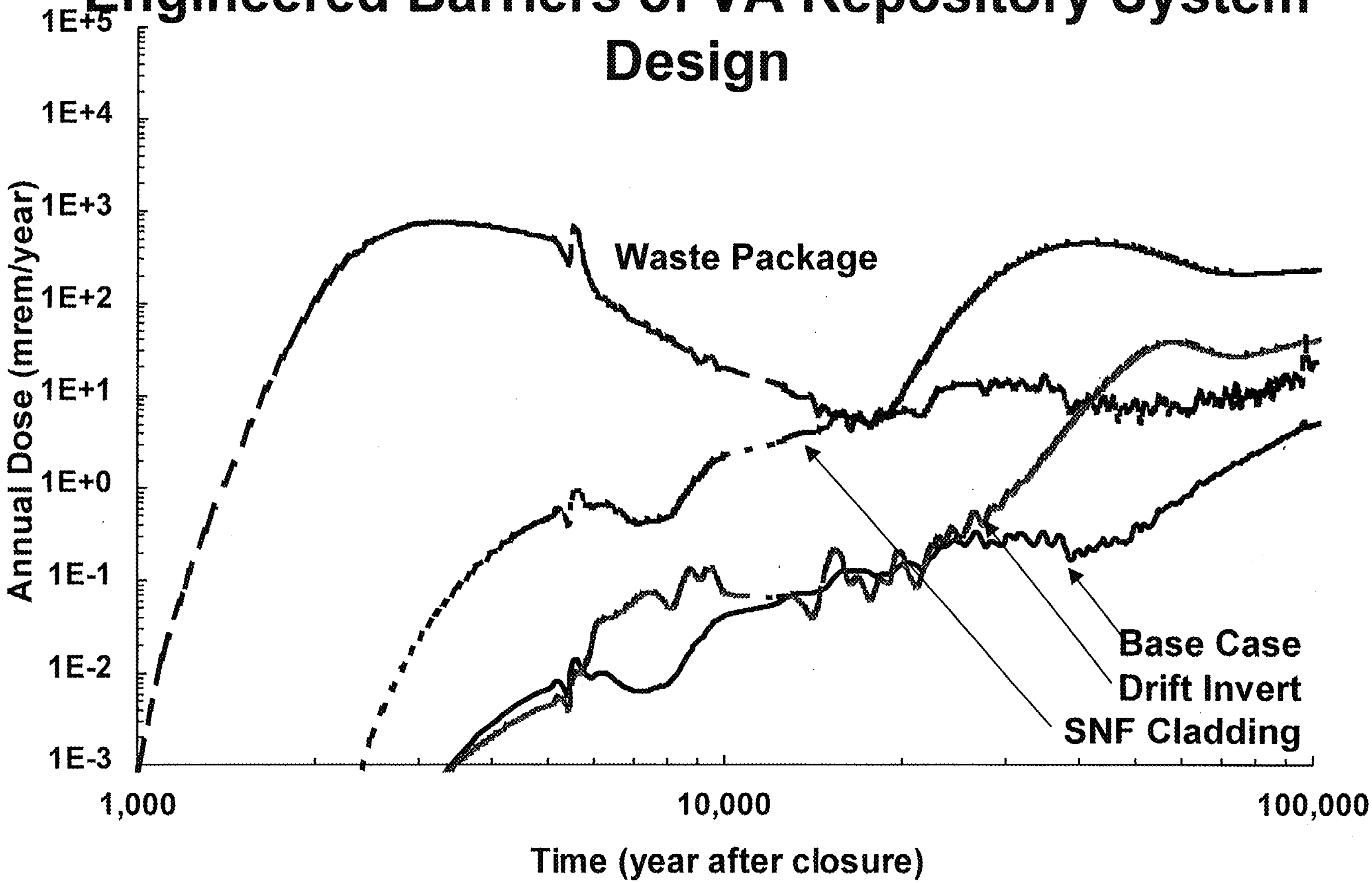
Overview

- Issues identified at the 1/25/99 NWTRB meeting
- NRC letter highlighting potential issues
  - Potential differences in concepts of neutralization and importance analysis
  - Potential differences in how TSPA codes and models are used to represent the system
  - Desirability of resolving issues with importance analysis well in advance of licensing
- Objective here is to address these three issues

Neutralizing Water/Radionuclide Barrier Functions Natural Barriers of VA Repository System Design



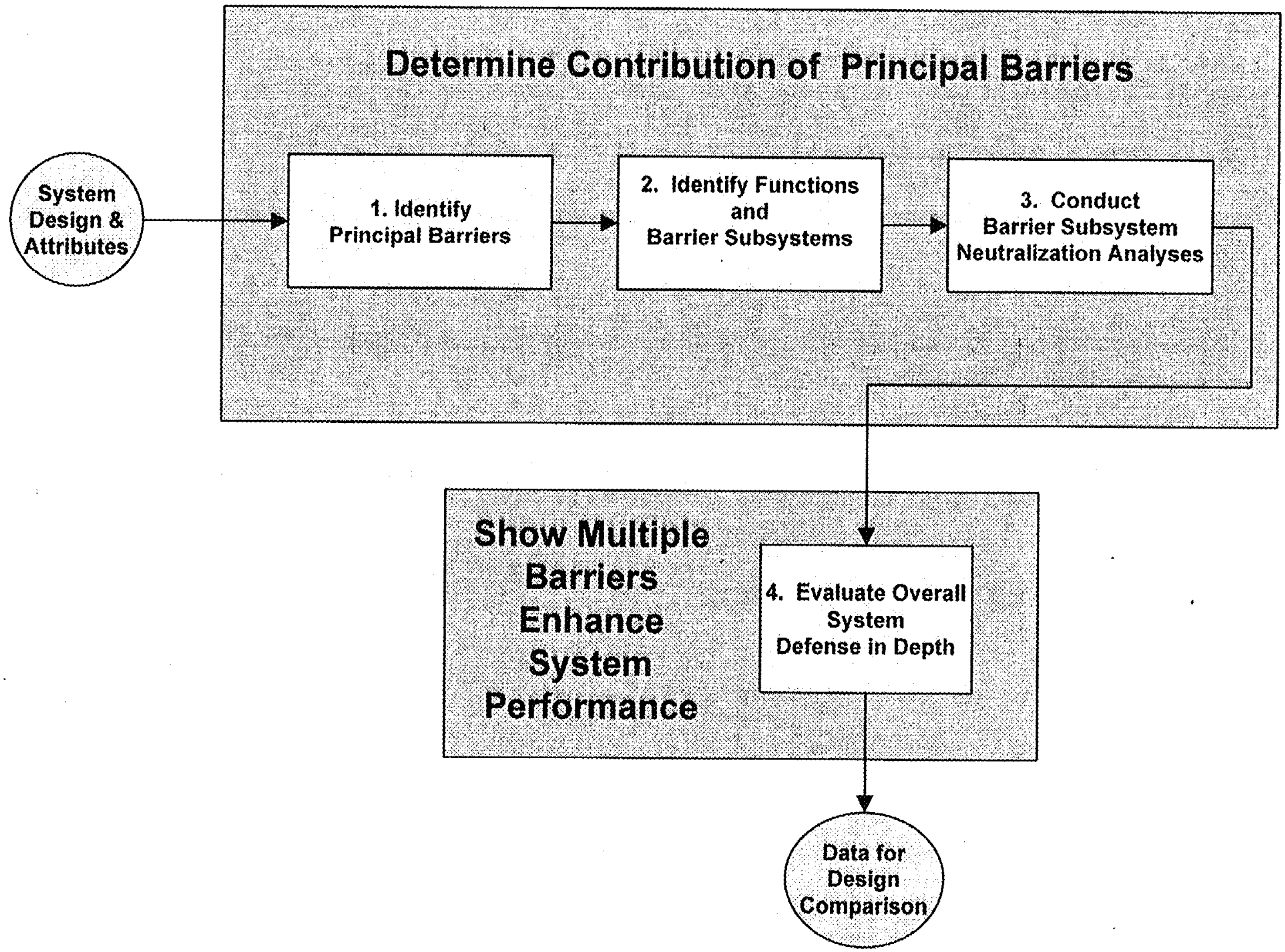
Neutralizing Water/Radionuclide Barrier Functions Engineered Barriers of VA Repository System Design



Question 1: Concepts of Neutralization and Importance Analysis

- Summary of concept
- Limitations of the application to the VA system

Approach for VA Evaluation



1. Identify Principal Barriers

- Candidates identified in TSPA analyses
- Barriers are features that inhibit movement of water or radioactive materials
  - Fractional rate of transmission < 10-4 per year or
  - Travel time delay > 1,000 years
- Principal Barriers for VA Reference System
  - Overlying rock units (barriers to water)
  - Waste package barriers (barriers to water)
  - Cladding (barrier to water)
  - Drift invert (barrier to radionuclide transport)
  - Unsaturated zone (UZ) radionuclide transport barriers
  - Saturated zone (SZ) radionuclide transport barriers

2. Identify Functions and Barrier Subsystems for Neutralization

- Identify function (e.g., barrier function)
- Identify each barrier subsystem contributing to the function
- Also identify combinations of barriers subject to "common-mode" issues
  - Occurrences affecting multiple barriers
  - Failure of one barrier affects another
  - Common source of model uncertainty

3. Neutralize Barriers--Determine Contribution of Each Barrier

- Neutralize each barrier system with respect to the function at issue
- Object is to determine contribution to base case performance: barrier is completely neutralized
- Difference indicates contribution--however, assessment must consider all neutralizations

4. Assess Overall Postclosure Defense in Depth

- Use simple measure
  - Consider difference relative to those of other barriers--indicates degree of defense in depth
  - Consider difference relative to standard--indicates significance of uncertainties in models for barrier
- Measure indicates whether performance depends unduly on any single barrier
- Measure indicates whether uncertainties in any principal barrier are compensated by performance of others

Summary: Concepts of Neutralization and Importance Analysis

- Concepts of the Approach
  - An approach to assessing contribution of principal barriers
  - Provides transparency in evaluating roles of barriers
  - Permits examination of importance of model assumptions
- Issues
  - Neutralization models complex except in limited situations
  - Simple neutralizations limit assessment of coupled effects
  - Functions most profitably neutralized
  - Impact of model uncertainty on the approach itself

Question 2: Use of PA Models and Codes in Representing the System

- Comparison of DOE and NRC models
- Causes for differences in results
- Using the approach to examine the importance of model assumptions and uncertainty

Comparison of DOE and NRC Models--Seepage

- Fraction wetted
  - Results directly proportional to fraction.
  - TSPA-VA: 1 to 10 percent under current climate. Up to 25 percent under long-term average climate.
  - TPA 3.2: 0 to 100 percent (uniform)
- Flow Rate
  - Not too important for advectively-dominated release because all exposed technetium and iodine flushed from WP for even very low flow rate.
  - TSPA-VA: Based on percolation flux.
  - TPA 3.2: Based on a reflux model that can significantly delay water contacting the waste.

Comparison of DOE and NRC Models-- Waste Package Degradation

- Corrosion Processes (CRM)
  - Both TPA 3.2 and TSPA-VA consider localized and uniform corrosion of CRM.
  - Both models utilize temperature switch for CRM.
- Timing of Waste Package Failure: Corrosion
  - TSPA-VA: slightly less than 10,000 years to more than 700,000 years.
  - TPA 3.2: slightly greater than 10,000 years to slightly less than 50,000 years.
- Variability in Corrosion Failure
  - TSPA-VA: considerable
  - TPA 3.2: little

Comparison of DOE and NRC Models-- Other Waste Package Failure Modes

- **Juvenile Failures**
  - TSPA-VA: 1-10, coupled with seepage toward smaller number of "true" juvenile failures. Always in same repository location.
  - TPA 3.2: 10-4 to 10-2 of the waste packages within a subarea.
- **Disruptive Events**
  - TSPA-VA: No assessment in nominal case.
  - TPA 3.2: Consequence modules result in failures within 10,000 years.
  - Need to weight consequences with occurrence probability.
  - Detailed evaluation not yet complete.

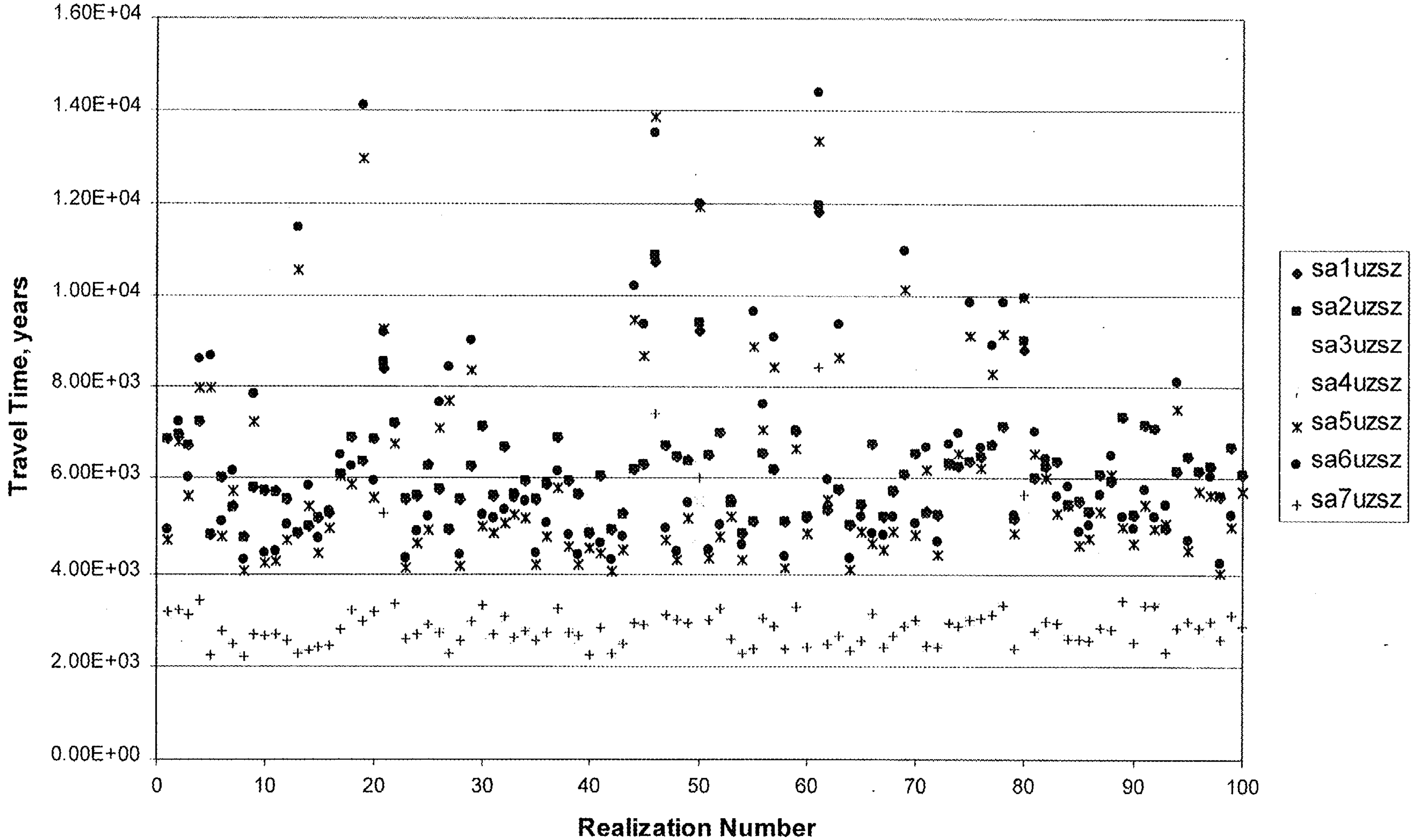
Comparison of DOE and NRC Models-- Waste Form Degradation

- Types
  - For CSNF, both models have similar degradation rates after the thermal pulse (2-3×10-3/yr). At initial times, TPA 3.2 is ~10+ times higher.
  - TSPA-VA: CSNF, HLW, DSNF
  - TPA 3.2: CSNF only
- Fraction wetted in WP
  - TSPA-VA: Entire surface area not covered by cladding is exposed. Changes with time.
  - TPA 3.2: 0 to 100 percent (uniform). Different for each failure mode and subarea, which creates variability. Constant throughout simulation.

Comparison of DOE and NRC Models--
Saturated Zone

- SZ is main natural barrier in TPA 3.2
  - Following figure shows total groundwater travel time from repository to 20 km in TPA 3.2. Most of the travel time is SZ.
- Alluvium
  - TSPA-VA: 0 to 6 km.
  - TPA 3.2: 10 km.
- Retardation in Alluvium (Rd)
  - Particularly important for 10,000 year period.
  - TSPA-VA: 1 for Tc and I; ~50 for Np.
  - TPA 3.2 (includes retardation of Tc and I in alluvium):
    - » Tc: 1 to 30, loguniform (8.5)
    - » I: 1 to 4, loguniform (2.2)
    - » Np: 1 to 3900, lognormal (170)

UZ + SZ Groundwater Travel Times in TPA 3.2 Analyses

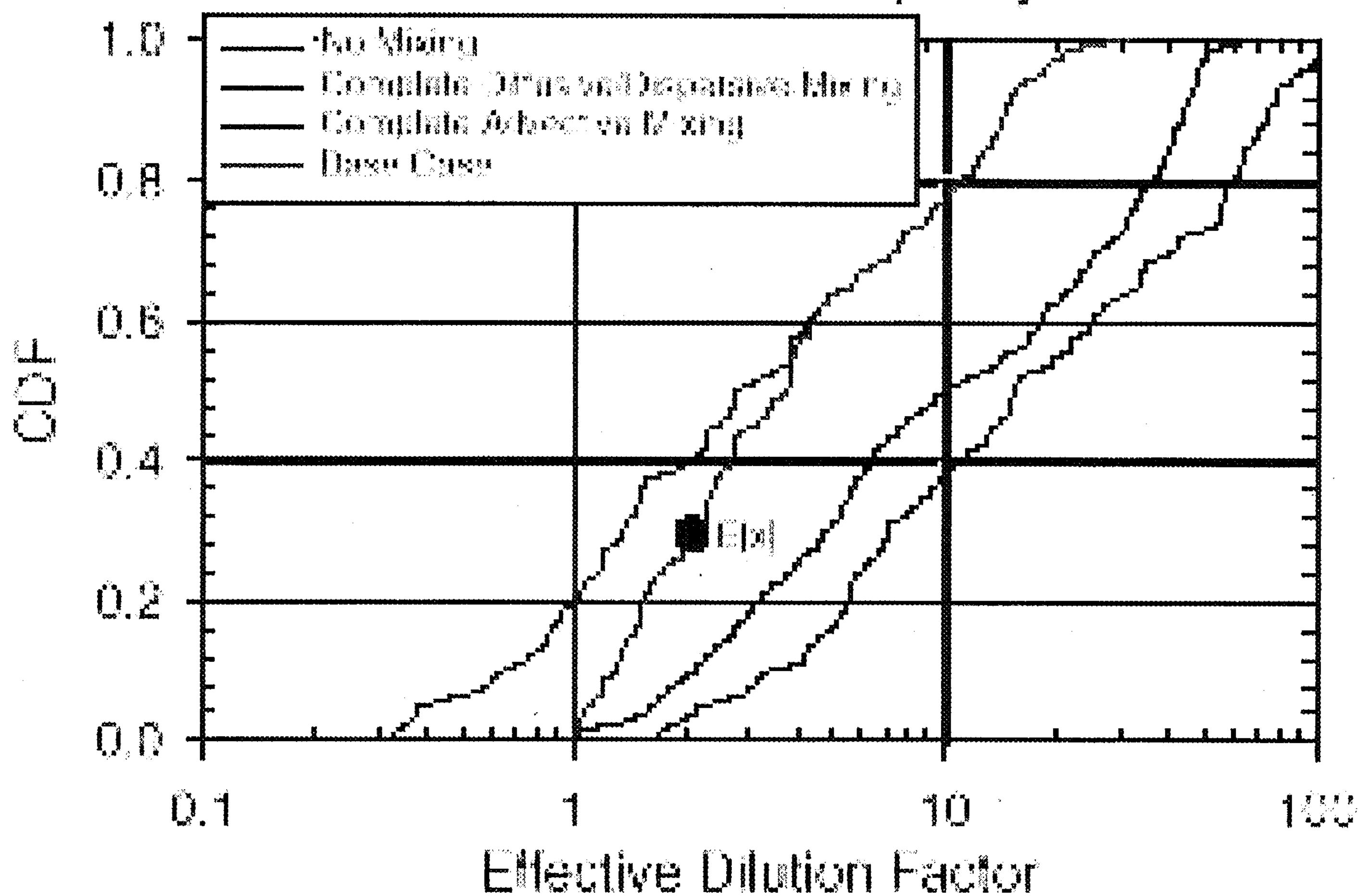


Comparison of DOE and NRC Models-- Biosphere

- **Dilution Volume**
  - TSPA-VA: 27,000 m^3/yr in current climate. 146,000 m^3/yr in long-term-average climate. Multiplied by dilution factor (see following figure).
  - TPA 3.2: 6 to 18 million m^3/yr
- **Dose Conversion Factors**

	Tc99		I129		Np237	
Pathway	Current	Pluvial	Current	Pluvial	Current	Pluvial
Direct Exposure	6.8×10^{-1}	4.3×10^{-1}	5.3×10^{2}	3.6×10^{2}	6.3×10^{3}	4.6×10^{3}
Inhalation	5.8×10^{-3}	3.7×10^{-3}	2.4×10^{-1}	1.7×10^{-1}	1.5×10^{3}	1.0×10^{3}
Animal Ingestion	1.4×10^{2}	8.7×10^{1}	8.5×10^{5}	4.9×10^{5}	2.0×10^{5}	1.2×10^{5}
Crop Ingestion	3.0×10^{3}	1.6×10^{3}	2.4×10^{5}	1.2×10^{5}	5.0×10^{6}	2.5×10^{6}
Drinking Water	1.6×10^{3}	1.6×10^{3}	1.8×10^{5}	1.8×10^{5}	3.8×10^{6}	3.8×10^{6}
Total TPA 3.2	4.7×10^{3}	3.3×10^{3}	1.3×10^{6}	7.9×10^{5}	9.0×10^{6}	6.4×10^{6}
TSPA-VA (LTA)	3.1×10^{3}		4.7×10^{5}		6.5×10^{6}	

Dilution Factor at 100,000 years



Comparison of NRC and DOE Calculations

- **Comparison**

	NRC	DOE
Peak Annual Dose (10,000 yrs-- Juvenile Failure)	0.004 mrem/yr	0.008 mrem/yr
Annual Dose at 50,000 yrs (I-129 +Tc-99)	0.6	0.2
Waste Package Neutralized (10,000 years)	0.6	770

- **Important differences in the models**
  - Waste package juvenile failure and degradation
  - Cladding
  - Retardation in saturated zone
  - Dilution

Comparison of NRC and DOE Neutralizations

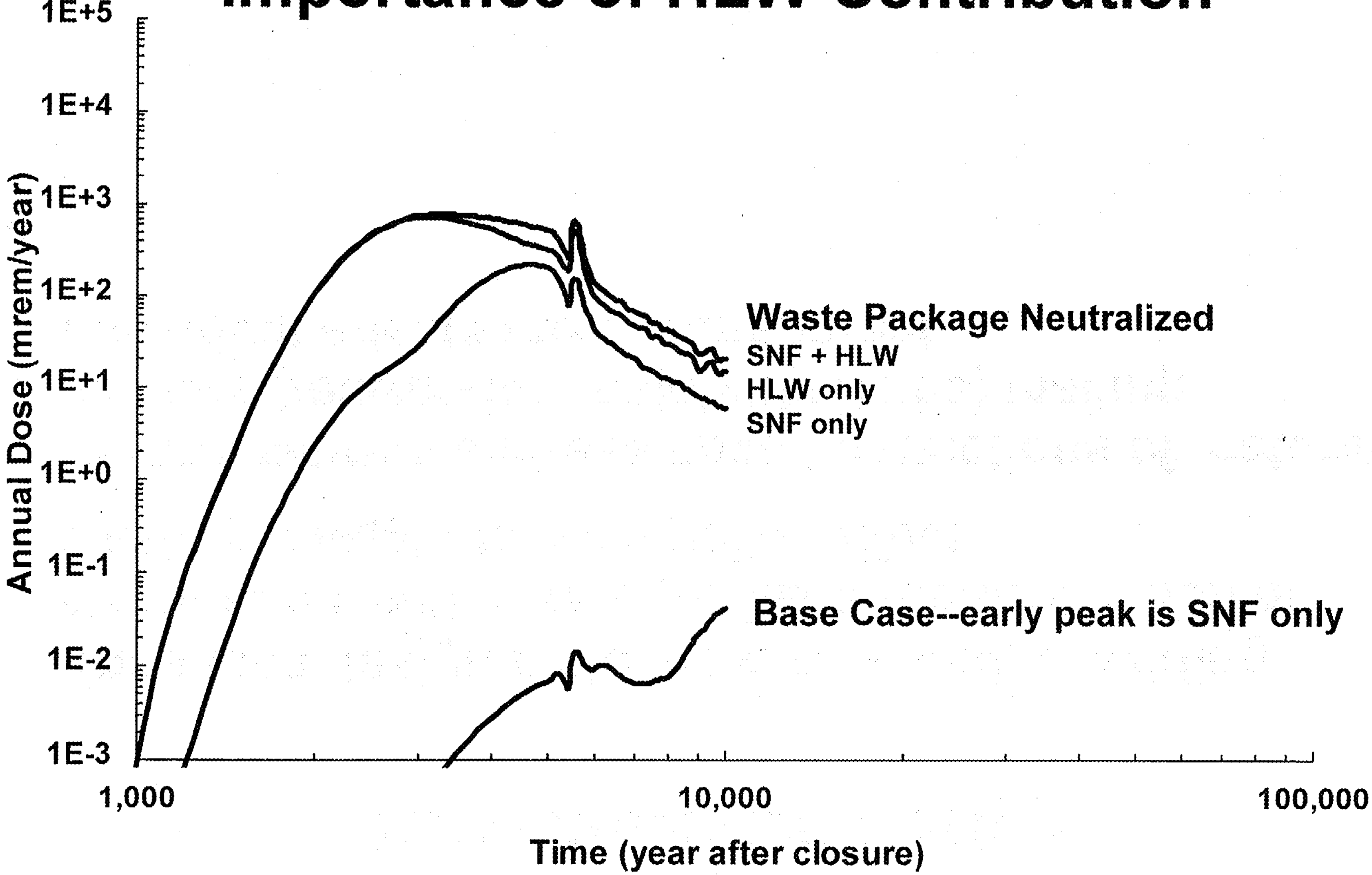
- **NRC neutralization scales according to number of SNF waste packages:**

$$(.004)\frac{(SNF \bullet 6500)}{(SNF \bullet 39)} \approx 0.7$$

- **DOE neutralization scales according to SNF packages and dilution factor**
- **Another key effect however is contribution of HLW:**

$$(.008)\frac{\left(.014 \bullet SNF \bullet \dfrac{7700}{3300 \bullet D} + HLW \bullet \dfrac{1700}{160 \bullet D}\right)}{.014 \bullet SNF /(3300 \bullet D / 3.7)} \approx 230 + 540 \approx 770$$

Waste Package Neutralization Indicates Importance of HLW Contribution



Barriers Importance (DID) Assessment for Recommended Design

- Enhanced design includes drip shield, providing redundancy with waste package--neutralization of waste package shows smaller effect
- Neutralizations address specific functions of natural barriers (retardation, solubility limits) making individual effects more transparent

Barriers Importance Approach for LA

- Application to VA design suggested value of design enhancement and improvement of certain models
- That application provided some value in increasing the transparency of the TSPA-VA calculation
- However evaluation of approach not yet complete:
  - Effect of combinations of uncertainties not yet evaluated--considering utility of probabilistic approach
  - Need to consider contributions/detriments of other functions (e.g., thermal effects)
- DOE continuing to evaluate and will adopt an approach that both provides transparency and demonstrates multiple barriers enhance system performance

YUCCA
MOUNTAIN
PROJECT

Studies

Reference Design for Site Recommendation

Presented to:
DOE/NRC Technical Exchange on Total System
Performance Assessment
San Antonio, Texas

Presented by:
Rob Howard
Manager, Engineered Barrier Systems/CRWMS M&O
Performance Assessment Operations

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

May 25 - 27, 1999

Attachment 26

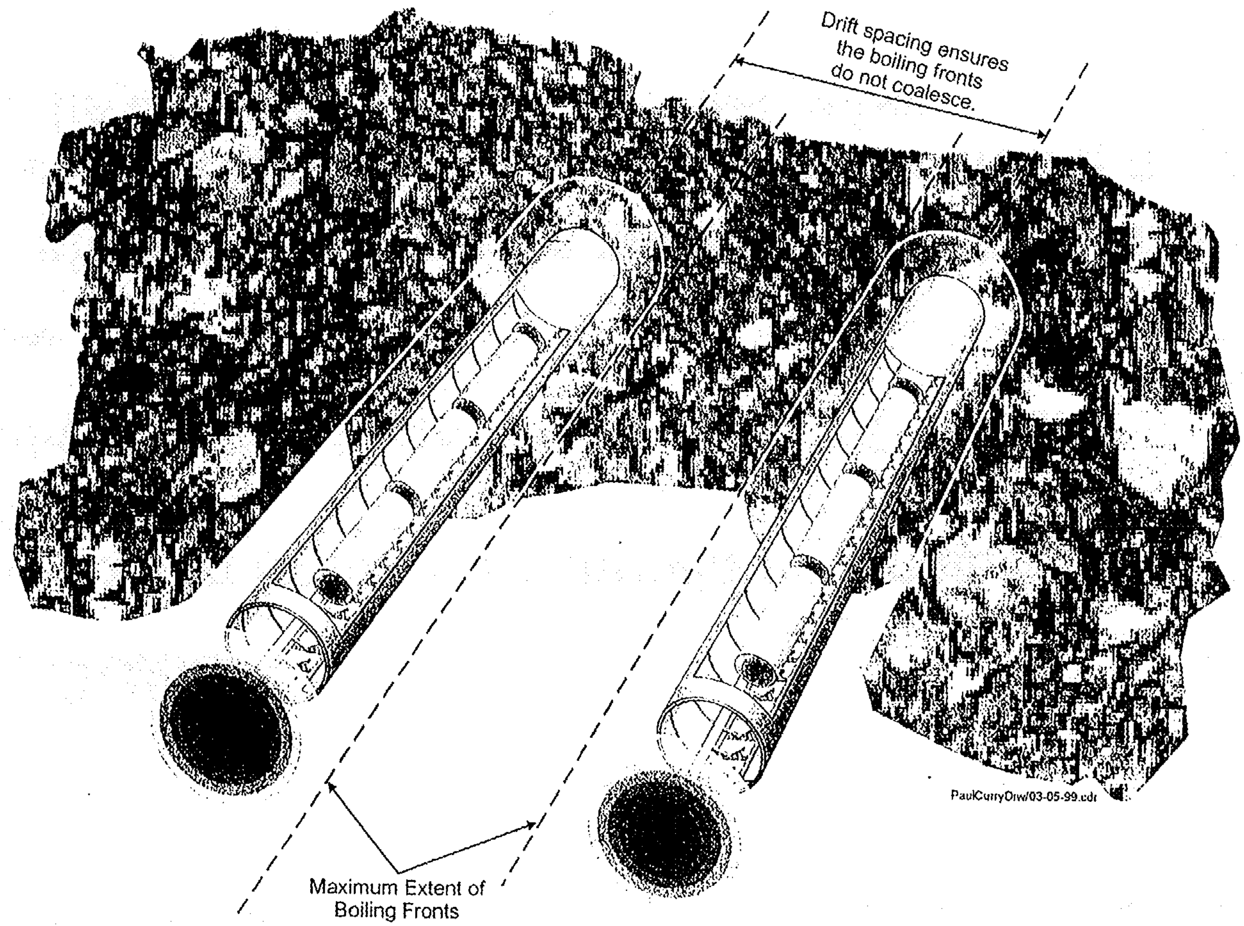
Background

- The potential to improve overall system performance was discussed in the Viability Assessment (VA)
- VA reference design included engineered barrier options that complement the natural barriers
  - Emplacement drift backfill
  - Drip shield with backfill
- The need to evaluate Design Alternatives has been identified internally and externally

Site Recommendation Reference Design

- Thermal Goals
  - Ensure boiling fronts from individual emplacement drifts do not coalesce
  - Maintain cladding temperatures < 350°C
- Rationale
  - Permit shedding of water in pillars during thermal pulse
  - Reduce uncertainty associated with the amount of water that enters the drifts during the thermal pulse

Site Recommendation Design - Shedding in Pillars



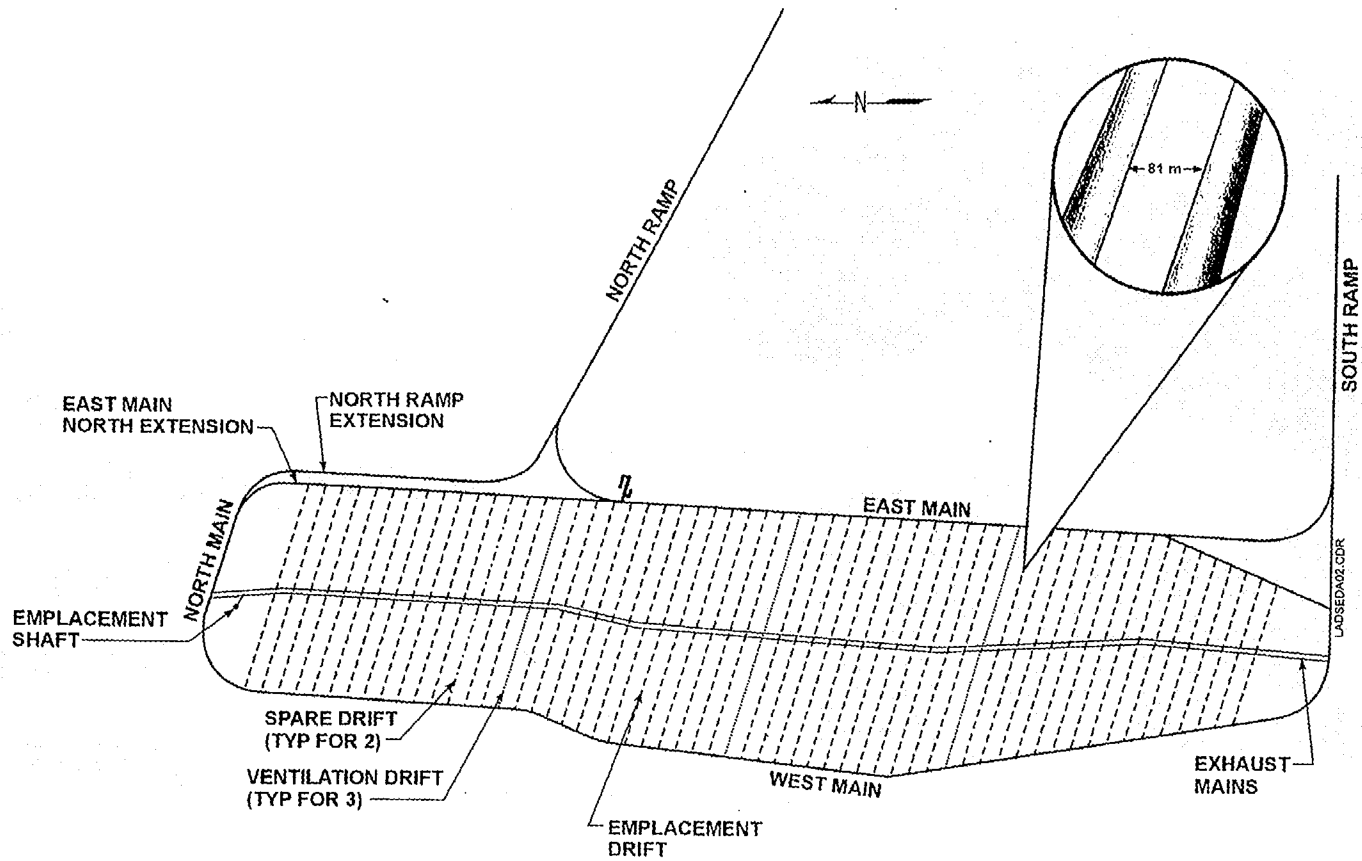
Site Recommendation Reference Design

- Design Features Include:
  - Blending of assemblies
  - Outer layer corrosion resistant material waste package
  - Pre-closure ventilation
  - Dripshields
  - Backfill

Site Recommendation Reference Design

- Mass Loading and Footprint Design
  - Areal mass loading: 60 MTHM/acre
  - Drift spacing: 81 meters (center to center)
  - Emplacement in upper block: ~1060 acres
  - Total emplacement drift length: 54,000 meters
  - Total access drift length: 33,400 meters
  - 10,039 Total Waste Packages

Site Recommendation Reference Design

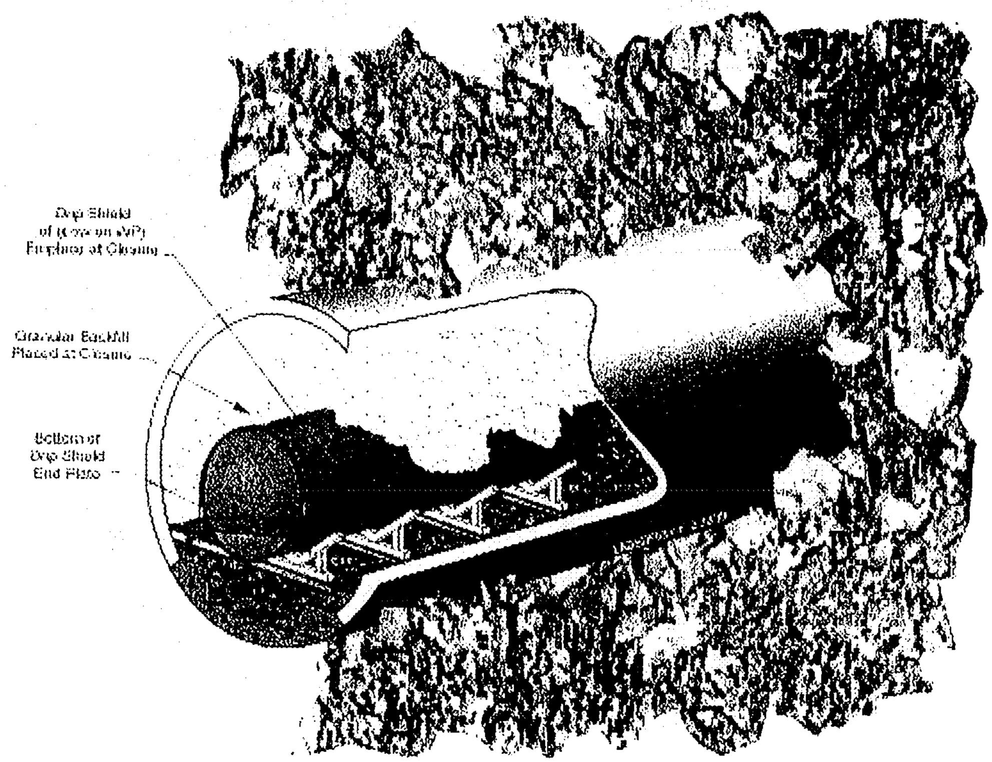


EDA 2 - 60 MTU/ACRE - 81.0 m C/C

Site Recommendation Reference Design

Drift Layout

- Line Loading
- 5.5 m diameter
- Steel sets ground support
- Dripshields
- Backfill

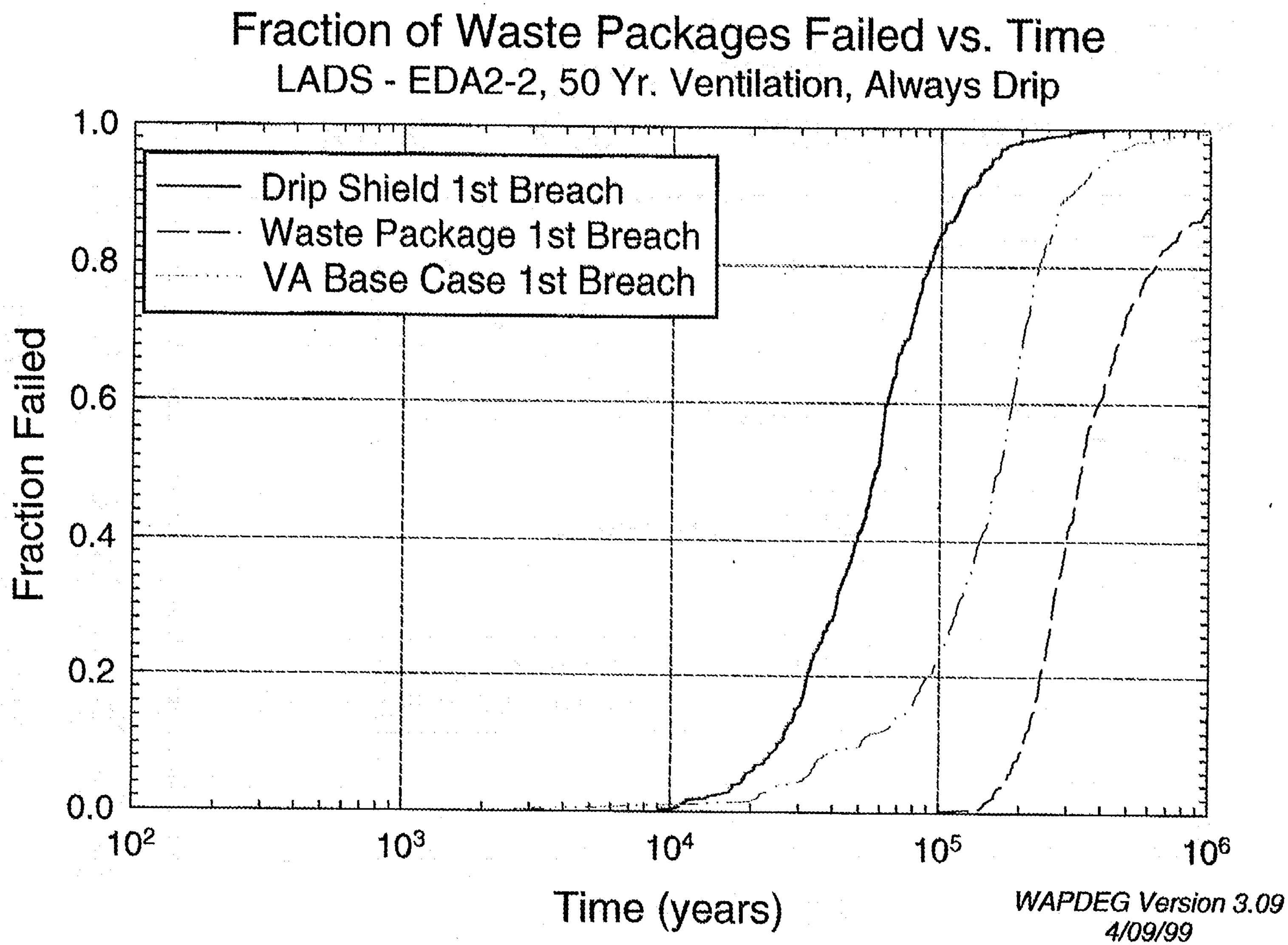


Site Recommendation Reference Design

- Waste Package Design
  - Outer layer waste package material: 2 cm Alloy 22 over 5 cm stainless steel (316NG)
  - 21 PWR/44 BWR Spent Nuclear Fuel (SNF) assembly waste packages
  - Average initial waste package heat output: 9.3 kW
  - Blending ensures that maximum initial waste package heat output is within 20% of average (11.2 kW max)

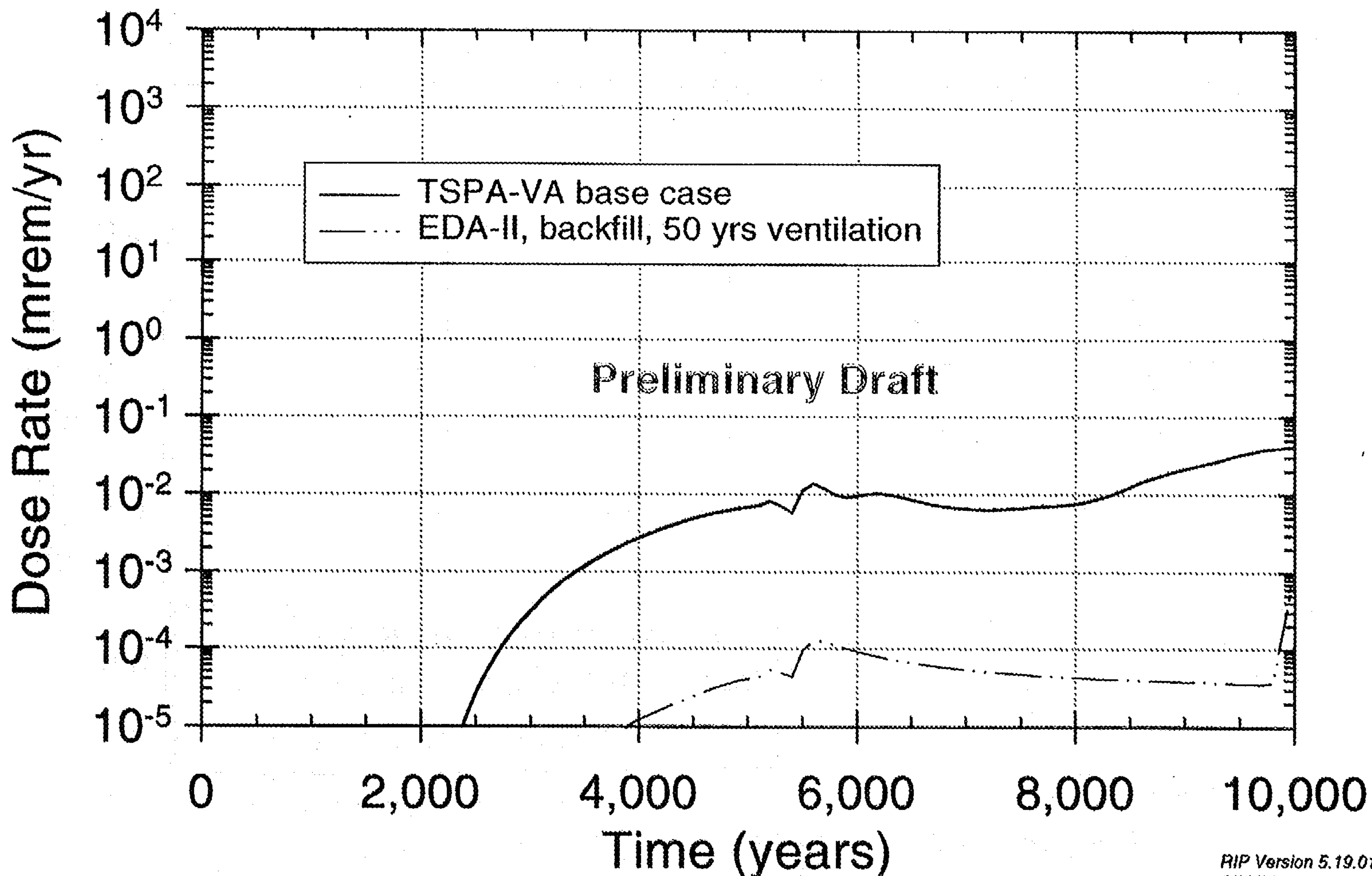
Site Recommendation Reference Design

- Thermal Management
  - SNF assembly blending conducted to ensure a more even distribution of heat in emplacement drifts
  - Pre-closure ventilation conducted to ensure that thermal goals are not violated during post-closure period
    - » ~2-5 cubic meters per second airflow in emplacement drifts over a 50 year period
  - Closure possible at 50 years


Fraction of Waste Packages Failed vs. Time
LADS - EDA2-2, 50 Yr. Ventilation, Always Drip
Drip Shield 1st Breach
Waste Package 1st Breach
VA Base Case 1st Breach
Fraction Failed
0.0
0.2
0.4
0.6
0.8
1.0
10^2
10^3
10^4
10^5
10^6
Time (years)
WAPDEG Version 3.09
4/09/99

10,000-yr Expected-Value Total Dose-Rate History

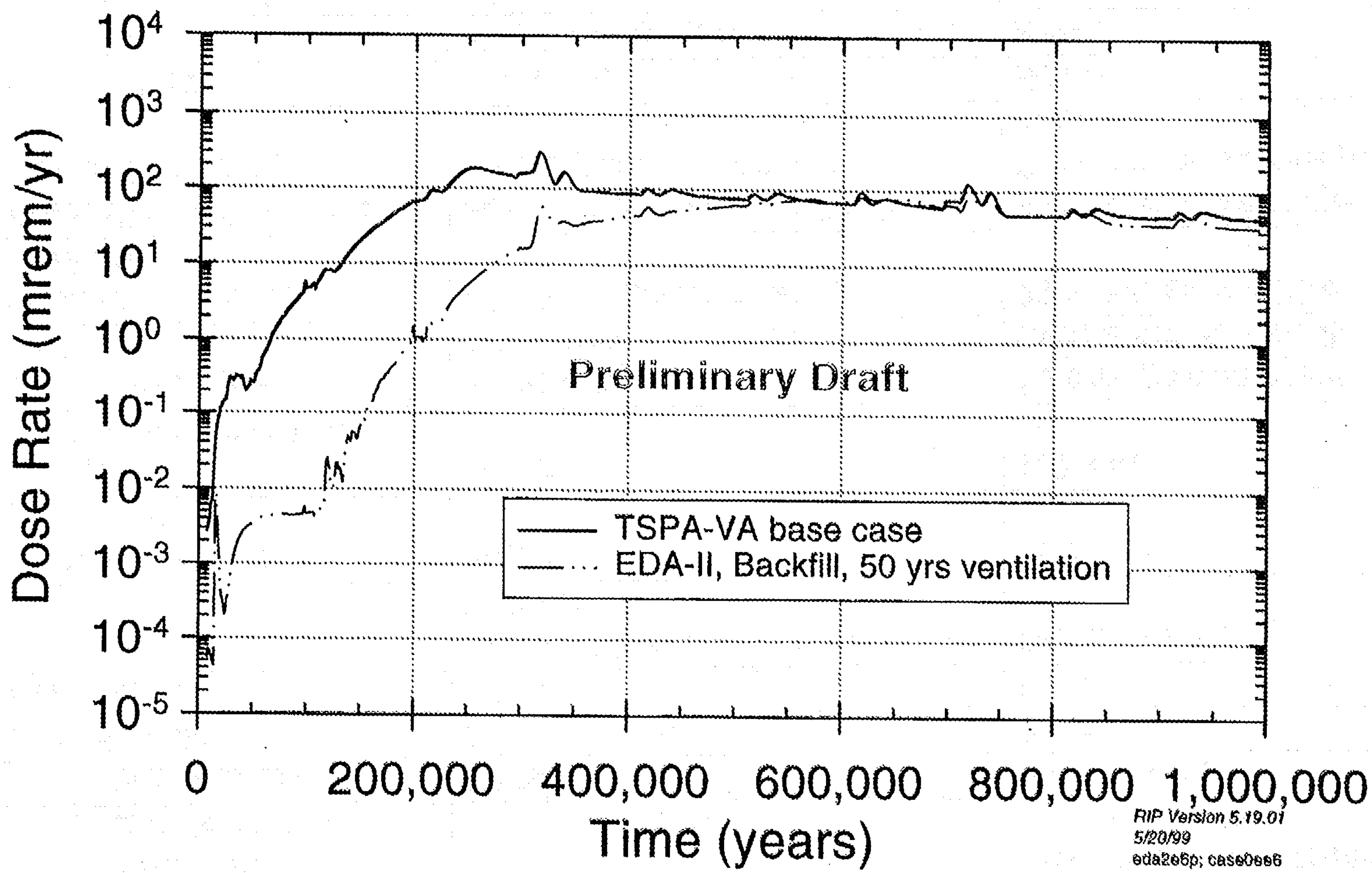
All Pathways, 20 km



RIP Version 5.19.01
5/20/99
case0ee4;eda2e4p

1,000,000-yr Expected-Value Total Dose-Rate History

All Pathways, 20 km



Comparison of Enhanced Design Alternative II to VA Design

Design Characteristics	EDA II	Viability Assessment Design
Areal Mass Loading	60 MTU/acre	85 MTU/acre
Drift Spacing	81 m	28 m
Drift Diameter	5.5 m	5.5 m
Invert	Steel with sand or gravel ballast	Concrete lining
Number of waste packages	10,039	10,500
Length of emplacement drifts	54 km	107 km
Waste Package Materials	2 cm Alloy-22 over 5 cm stainless steel 316L	10 cm carbon steel over 2 cm Alloy-22
Maximum Waste Package	21 PWR assemblies	21 PWR assemblies
Peak Waste Package Power (blending)	20% above average PWR waste package power	95% above average PWR waste package power
Drip Shield	2 cm Ti-7	None
Backfill	Yes (may become an option)	None
Preclosure period	50 yrs	50 yrs
Preclosure ventilation rate	2-10 m^3/s	0.1 m^3/s

YUCCA MOUNTAIN PROJECT

Studies

Overview of DOE's Strategy for the Postclosure Safety Case

Presented to:
DOE/NRC Technical Exchange on Total System Performance Assessment
San Antonio, Texas

Presented by:
Abraham Van Luik
Senior Technical Advisor for Performance Assessment
Office of Licensing and Regulatory Compliance
U.S. Department of Energy

U.S. Department of Energy
Office of Civilian Radioactive Waste Management

May 25-27, 1999

Attachment 27

Focus of Postclosure Safety Case for the License Application

- Focus is the postclosure performance objective of proposed rule
- The safety case will focus on principal factors affecting postclosure performance
- TSPA will integrate these factors to demonstrate compliance with the performance objective
- The safety case will provide additional information to support finding of reasonable assurance
  - Performance margin
  - Defense in depth (multiple, diverse barriers)
  - Barriers importance assessment

Safety Case Addresses Four Key Attributes of the Repository System

- Key Attributes
  - Limited water contacting the waste package
  - Long waste package lifetime
  - Limited mobilization and release of radionuclides from breached waste packages
  - Retardation and dilution of radionuclides moving away from breached waste packages
- The principal factors are those that are most important to these attributes
- TSPA is conducted to determine how well the system, expressed in terms of these factors, performs

Principal Factors of the VA System Design

Key Attributes of Repository System	Principal Factors
Limited water contacting waste packages	Precipitation, infiltration into the mountain, percolation to depth, and seepage into drifts
	Effects of heat and excavation on flow
	Integrity of drip shield
Long waste package lifetime	Humidity and temperature at waste package
	Chemistry of water on waste package
	Integrity of outer waste package barrier
	Integrity of inner waste package barrier
	Seepage into the waste package
Limited mobilization and release of radionuclides from breached waste packages	Integrity of spent nuclear fuel cladding
	Dissolution of SNF and HLW glass waste forms
	Radionuclide solubility
	Formation of radionuclide-bearing colloids
	Integrity of drift invert
Retardation and dilution of radionuclides moving away from breached waste packages	Transport through the unsaturated zone
	Flow and transport in the saturated zone
	Dilution from pumping
	Biosphere transport and uptake

Updating the Safety Case

- TSPA-VA, considering these factors, showed waste isolation with moderate confidence
- We are increasing confidence in the safety case
  - Enhancements to the system design
  - Improved process models and TSPA components
- We are also prioritizing the safety case to get at its essential elements--the Principal Factors
- The result of this effort will be a focused safety case--this will have important implications for the TSPA

Preliminary Analyses of the System Design Recommended for LA

- The information shows most of the radionuclides would be isolated by the site alone
- Important factors
  - Seepage into the emplacement drifts
  - Dissolved radionuclide concentration limits
  - Retardation of radionuclide transport in UZ and SZ
  - Dilution
- These factors alone are effective in reducing the peak annual dose of the less-mobile radionuclides well below the proposed standard

Preliminary Analyses of Recommended Design (continued)

- Engineered barriers provide additional confidence, particularly with respect to small fraction of relatively mobile radionuclides
- Important factors
  - Environments affecting engineered barriers and waste package
  - Juvenile failures and degradation of EBS and Waste Package barriers
  - SNF cladding initial condition and degradation
- Thus the system provides multiple barriers that enhance postclosure performance

Strategy is Now to Complete the Postclosure Safety Case

- Identification of remaining issues and possible further focusing
- Specification of additional information needed regarding principal factors to satisfy IRSR acceptance criteria and KTIs
- Integration of all information supporting the safety case through Process Model Reports (e.g., SZ Flow and Transport Process Model Report)
- Completion of TSPA and other analyses to satisfy the applicable requirements of 10 CFR Part 63

YUCCA
MOUNTAIN
PROJECT

Studies

Implementing DOE's Strategy for the Postclosure Safety Case

Presented to: DOE/NRC Technical Exchange on Total System Performance Assessment

Presented by: Dennis Richardson
Manager, Licensing and Repository Safety System Engineering
CRWMS M&O

May 26, 1999

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Attachment 28

Steps in the Strategy to Complete the Postclosure Safety Case

1 Update design and improve TSPA model components

2 Identify all factors affecting postclosure performance of the recommended system design

3 Identify the Principal Factors

4 Develop Process Model Reports to provide all relevant information regarding these factors

5 Ensure analyses complete and case is prepared to address postclosure performance objective

1 Update Design and Improve TSPA Model Components

- Process is underway--you have already heard of the efforts to enhance the design and you will be hearing of the efforts to improve the TSPA models
- You will hear how we are working to improve the models and underlying data in areas where feasible and where such changes affect overall assessment
- In other areas, we intend to adopt conservative, bounding models where appropriate
- We will also consider additional design options where those are appropriate

2 Identify all Factors Affecting Postclosure Performance

- Start from 19 principal factors for VA system design
- Augment list of factors to address new design features (e.g., drip shield environments and degradation)
- Ensure integration of factors, process models, and TSPA components
- Updated list of factors includes 38 factors for the nominal scenario and 12 additional factors for disruptive event scenarios

3 Identify Principal Factors

- Rank factors according to importance to postclosure performance
- Determine major remaining issues
- Assess value of additional information for each factor
  - Feasibility of resolving issues
  - Particular importance of uncertainties to safety case

4 Develop Process Model Reports

- Document technical basis of the process models (e.g., UZ flow and transport, near-field environments)
  - Postclosure safety case to support SRR
  - Postclosure safety case for LA
- Provide all information relevant to principal factors sufficient to satisfy acceptance criteria of IRSRs
- Provide information regarding other factors (e.g., to justify bounding representation)

5 Ensure Analyses Complete and Case is Prepared

- Complete design and physical picture of safety case
- Update TSPA process models and complete PMRs
- Complete TSPA analyses consistent with applicable requirements of 10 CFR Part 63
- Complete additional aspects of safety case to support NRC's finding of reasonable assurance
  - Performance margin
  - Defense in depth (multiple, diverse barriers)
  - Barriers importance assessment

YUCCA
MOUNTAIN
PROJECT

Studies

Process Model Reports (PMRs)

Presented to:
DOE/NRC Technical Exchange on
Total System Performance Assessment

Presented by:
Miguel Lugo
Process Model Report Manager
Regulatory and Licensing
CRWMS M&O

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

May 25-27, 1999

Attachment 29

Process Model Reports (PMRs) Purpose

- The purpose is to document the technical basis supporting each TSPA process model
  - Supports the postclosure safety case for SR/LA
- PMRs will focus the development of technical information on what is relevant to developing a defensible TSPA
  - i.e., the information the Project is relying upon to demonstrate postclosure compliance
- The PMR development process will ensure traceability of data, information, and references

PMR Scope

The following PMRs will be developed

1 Integrated Site Model

2 Unsaturated Zone Flow and Transport

3 Near Field Environment

4 Engineered Barrier System Degradation and Flow/Transport

5 Waste Package Degradation

6 Waste Form Degradation

7 Saturated Zone Flow and Transport

8 Biosphere

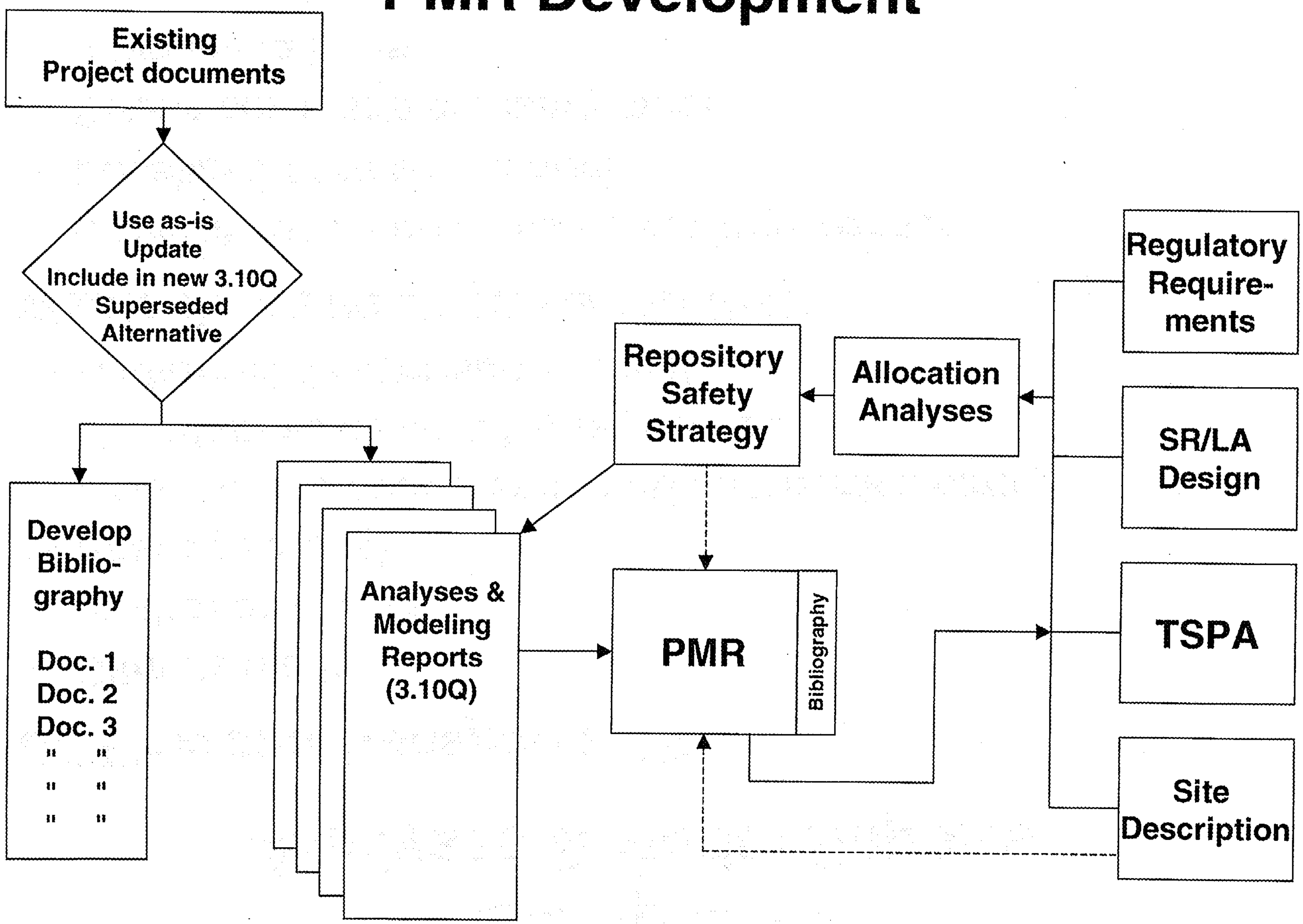
9 Tectonic Hazards

PMR Scope

(Continued)

- **PMRs will contain:**
  - Descriptions of the models, submodels, and abstractions
    - » Relationship to principal factors
  - Relevant data and data uncertainties
  - Assumptions and bases
  - Model results (outputs)
  - Code verification/model validation information
  - Opposing views
  - Information to support regulatory evaluations
    - » NRC Key Technical Issues

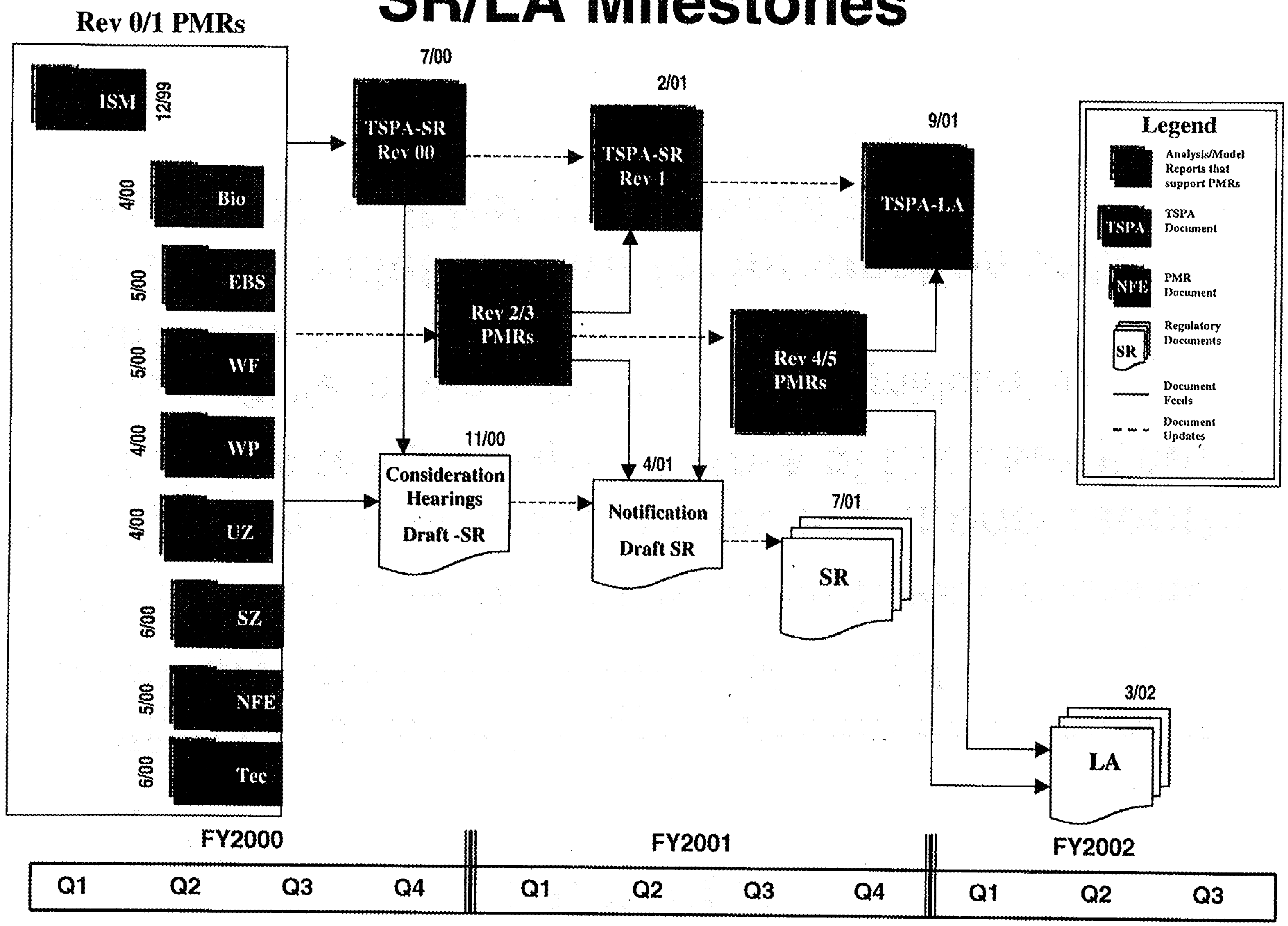
PMR Development



Examples of Analyses & Model Reports

- UZ Flow and Transport PMR
  - Climate model
  - Infiltration model
  - Seepage model
  - Analysis of fracture and matrix properties data
  - Mountain-scale coupled processes
  - Radionuclide Transport model
- Waste Package Degradation PMR
  - General corrosion of waste package barrier
  - Localized corrosion model
  - Stress corrosion cracking model
  - Juvenile failures

Linkage of Major Programmatic SR/LA Milestones



Summary

- The PMR process is being implemented to ensure traceability and transparency of models
  - Will document the technical basis for TSPA process models
- PMRs, and supporting analyses and model reports, will address the principal factors of the safety case
  - Focus will be on those factors most significant to performance
- The PMR schedule allows for information to be incorporated as it becomes available

YUCCA
MOUNTAIN
PROJECT

Studies

Implementing the DOE Strategy-the Path Forward

Presented to
DOE/NRC Technical Exchange on Total System Performance Assessment
San Antonio, Texas

Presented by:
Larry Rickertsen
Regulatory and Licensing
CRWMS M&O

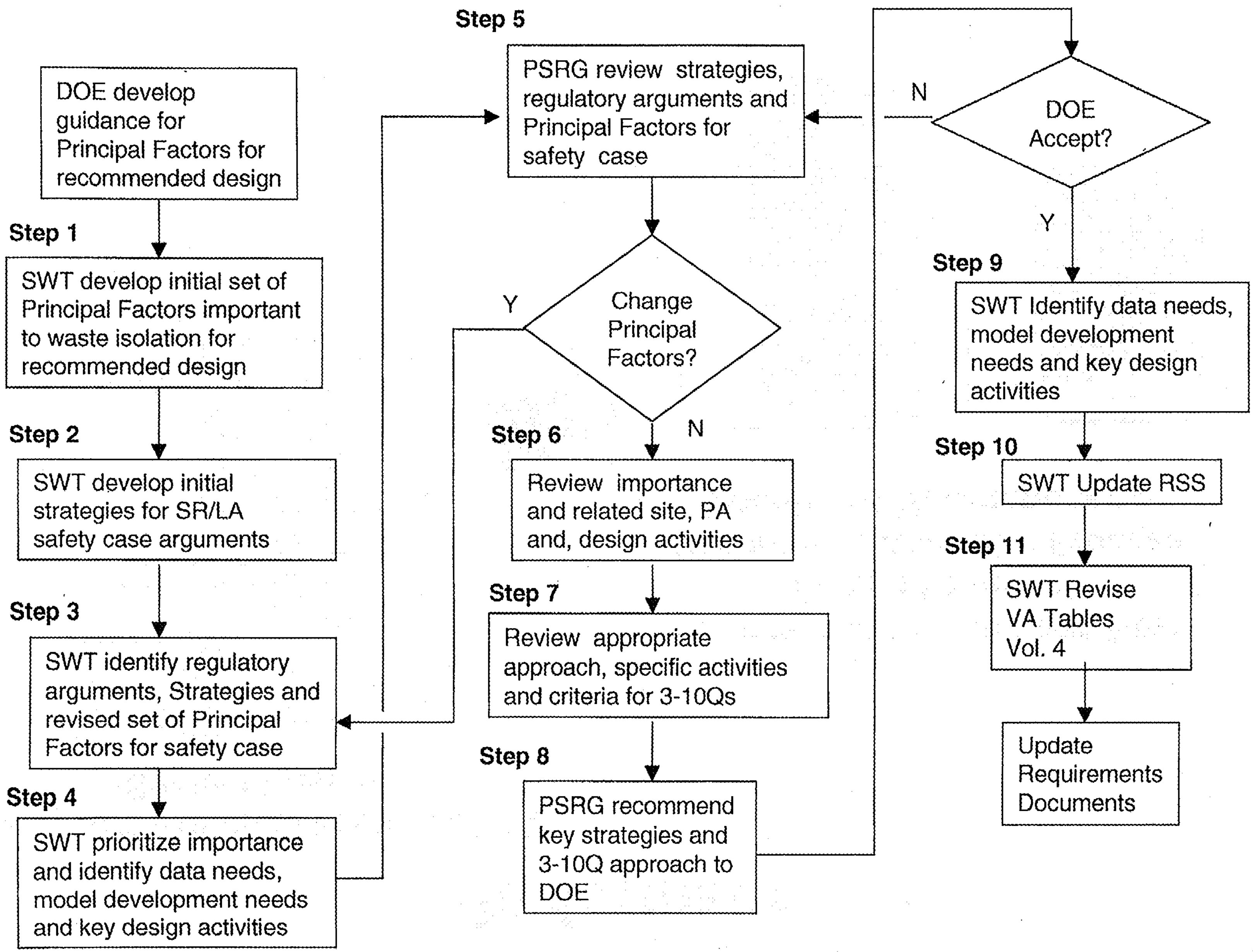
U.S. Department of Energy
Office of Civilian Radioactive Waste Management

May 25-27, 1999

Attachment 30

Performance Allocation Process

- Comprehensive process to identify the factors of principal importance to postclosure performance and to integrate site, design, and performance assessment work to address them
- The process we are following is shown in the following diagram


Step 5
PSRG review strategies, regulatory arguments and Principal Factors for safety case
DOE develop guidance for Principal Factors for recommended design
N
DOE Accept?
Y
Step 1
SWT develop initial set of Principal Factors important to waste isolation for recommended design
Y
Change Principal Factors?
Step 9
SWT Identify data needs, model development needs and key design activities
Step 2
Step 6
N
Step 10
SWT Update RSS
SWT develop initial strategies for SR/LA safety case arguments
Review importance and related site, PA and, design activities
Step 11
Step 3
Step 7
SWT Revise VA Tables Vol. 4
SWT identify regulatory arguments, Strategies and revised set of Principal Factors for safety case
Review appropriate approach, specific activities and criteria for 3-10Qs
Step 8
Update Requirements Documents
Step 4
PSRG recommend key strategies and 3-10Q approach to DOE
SWT prioritize importance and identify data needs, model development needs and key design activities

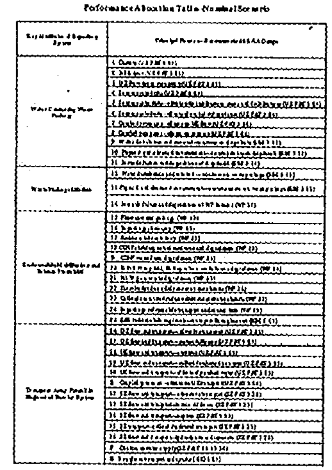
Identify Factors Potentially Important to Performance

Start From Principal Factors of VA System Design

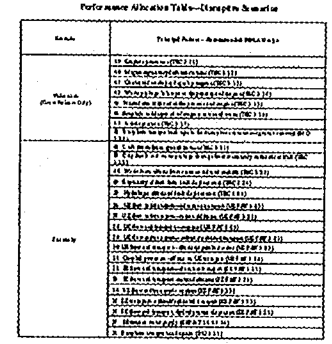
Key Attributes of Repository System	Principal Factors
Limited water contacting waste packages	Precipitation, infiltration into the mountain, percolation to depth, and seepage into drifts
	Effects of heat and excavation on flow
	Integrity of drip shield
Long waste package lifetime	Humidity and temperature at waste package
	Chemistry of water on waste package
	Integrity of outer waste package barrier
	Integrity of inner waste package barrier
	Seepage into the waste package
Limited mobilization and release of radionuclides from breached waste packages	Integrity of spent nuclear fuel cladding
	Dissolution of SNF and HLW glass waste forms
	Radionuclide solubility
	Formation of radionuclide-bearing colloids
	Integrity of drift invert
Retardation and dilution of radionuclides moving away from breached waste packages	Transport through the unsaturated zone
	Flow and transport in the saturated zone
	Dilution from pumping
	Biosphere transport and uptake

Augment List to Address New Design Features
Integrate Factors with Process Models, TSPA Components

Performance Allocation Table–Nominal Scenario



Performance Allocation Table–Disruptive Scenarios



Factors Potentially Important in Nominal Scenario

Key Attributes of Repository System	Principal Factors—Recommended SR/LA Design
Water Contacting Waste Package	1. Climate (UZ F&T 3.8.1)
	2. Infiltration (UZ F&T 3.8.2)
	3. UZ flow above repository (UZ F&T 3.8.3)
	4. Seepage into drifts (UZ F&T 3.8.4)
	5. Seepage into drifts--effects of major fracture zones and fault features (UZ F&T 3.8.4)
	6. Seepage into drifts--effects of partial drift collapse (UZ F&T 3.8.4)
	7. Coupled processes - effects on UZ flow (UZ F&T 3.8.6)
	8. Coupled processes - effects on seepage (UZ F&T 3.8.6)
	9. Water distribution and removal--moisture on drip shield (EBS 3.1.1)
	10. Physical and chemical environment---environments on drip shield (EBS 3.1.2)
	11. Juvenile failure and degradation of drip shield (EBS 3.1.4)
Waste Package Lifetime	12. Water distribution and removal—moisture on waste package (EBS 3.1.1)
	13. Physical and chemical environment—environments on waste package (EBS 3.1.2)
	14. Juvenile failure and degradation of WP barriers (WP 3.1)
Radionuclide Mobilization and Release From EBS	15. Flow in waste package (WF 3.9)
	16. In-package chemistry (WF 3.8)
	17. Radionuclide inventory (WF 3.1)
	18. CSNF cladding initial condition and degradation (WF 3.2)
	19. CSNF waste form degradation (WF 3.3)
	20. DSNF, Navy fuel, Pu disposition waste forms degradation (WF 3.4)
	21. HLW glass waste degradation (WF 3.5)
	22. Dissolved radionuclide concentration limits (WF 3.6)
	23. Colloid-associated radionuclide concentration limits (WF 3.7)
	24. In-package radionuclide transport and source term (WF 3.9)
	25. EBS radionuclide migration—transport through invert (EBS 3.1.3)
Transport Away From The Engineered Barrier System	26. UZ flow and transport—advective transport (UZ F&T 3.8.5)
	27. UZ flow and transport—matrix diffusion (UZ F&T 3.8.5)
	28. UZ flow and transport—sorption (UZ F&T 3.8.5)
	29. UZ flow and transport—colloid-facilitated transport (UZ F&T 3.8.5)
	30. UZ flow and transport—effects of perched water (UZ F&T 3.8.5)
	31. Coupled processes--effects on UZ transport (UZ F&T 3.8.6)
	32. SZ flow and transport—advective transport (SZ F&T 3.2.3)
	33. SZ flow and transport--matrix diffusion (SZ F&T 3.2.3)
	34. SZ flow and transport--sorption (SZ F&T 3.2.3)
	35. SZ transport--colloid-facilitated transport (SZ F&T 3.2.3)
	36. SZ flow and transport--hydrodynamic dispersion (SZ F&T 3.2.3)
	37. Dilution in water supply (SZ F&T 3.6.3.3.3.4)
	38. Biosphere transport and uptake (BIO 3.2.1)

Factors Potentially Important in Disruptive Scenarios

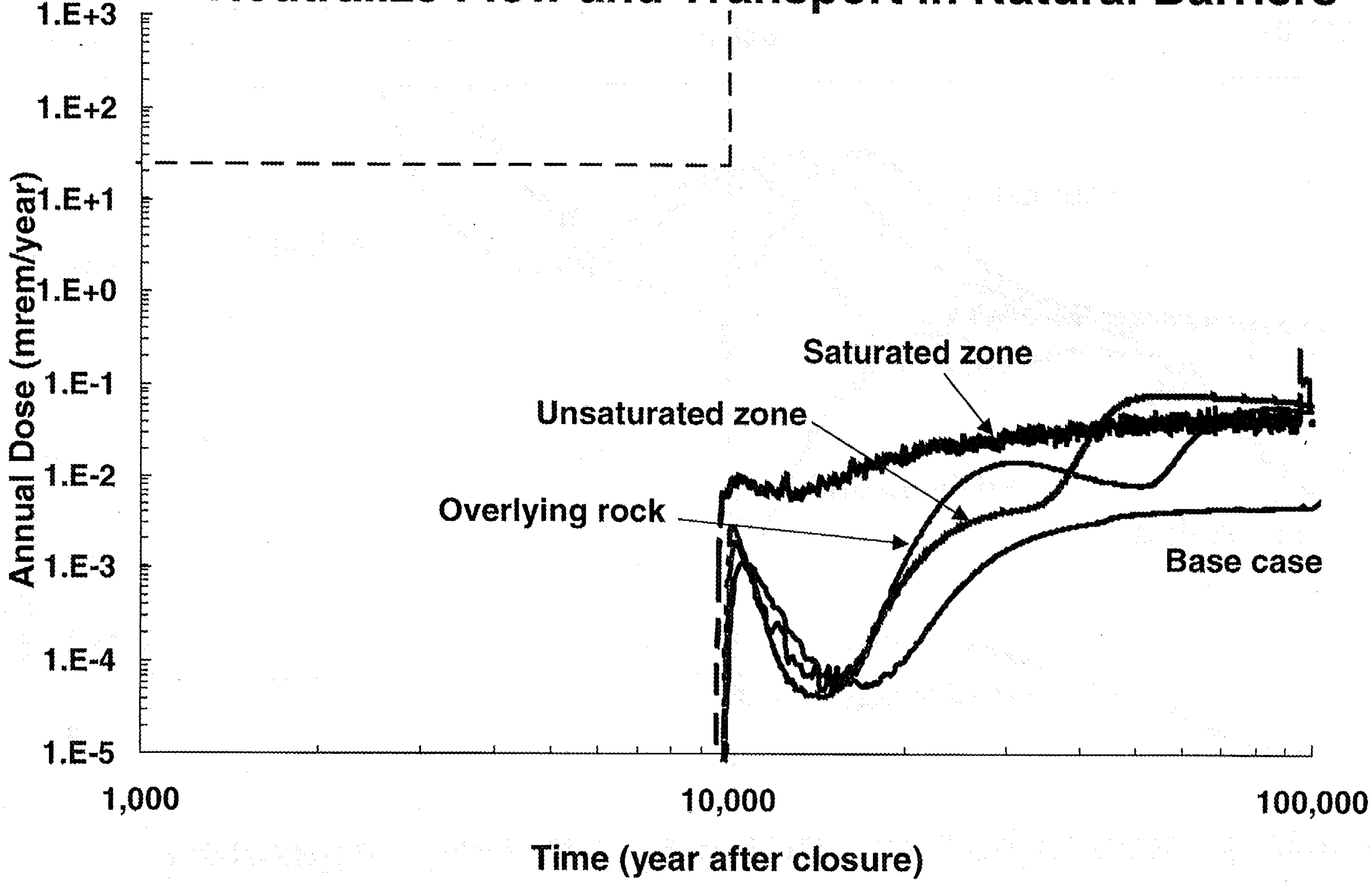
Scenario	Principal Factors—Recommended SR/LA Design
Volcanism (Direct Release Only)	39. Eruptive processes (TEC 3.1.1)
	40. Magma-repository drift interactions (TEC 3.1.2)
	41. Contact of waste packages by magma (TEC 3.1.3)
	42. Waste package behavior in the presence of magma (TEC 3.1.4)
	43. Waste form behavior in the presence of magma (TEC 3.1.5)
	44. Eruption and dispersal of magma-entrained waste (TEC 3.1.6)
	45. Ash deposition (TEC 3.1.7)
	38. Biosphere transport and uptake for disruptive scenarios—igneous activity) (BIO 3.2.1)
Seismicity	46. Drift effects from ground motion (TEC 3.2.1)
	47. Drip shield and waste package damage from seismically-induced rockfall (TEC 3.2.2)
	48. Waste form effects from seismic-induced rockfall (TEC 3.2.3)
	49. Repository effects from fault displacement (TEC 3.2.4)
	50. Hydrologic effects of fault displacement (TEC 3.2.5)
	26. UZ flow and transport—advective transport (UZ F&T 3.8.5)
	27. UZ flow and transport—matrix diffusion (UZ F&T 3.8.5)
	28. UZ flow and transport—sorption (UZ F&T 3.8.5)
	29. UZ flow and transport—colloid-facilitated transport (UZ F&T 3.8.5)
	30. UZ flow and transport—effects of perched water (UZ F&T 3.8.5)
	31. Coupled processes--effects on UZ transport (UZ F&T 3.8.6)
	32. SZ flow and transport—advective transport (SZ F&T 3.2.3)
	33. SZ flow and transport--matrix diffusion (SZ F&T 3.2.3)
	34. SZ flow and transport--sorption (SZ F&T 3.2.3)
	35. SZ transport--colloid-facilitated transport (SZ F&T 3.2.3)
	36. SZ flow and transport--hydrodynamic dispersion (SZ F&T 3.2.3)
	37. Dilution in water supply (SZ F&T 3.6.3.3.3.4)
	38. Biosphere transport and uptake (BIO 3.2.1)

Identify Principal Factors

- Rank factors according to importance to postclosure performance
- Determine major uncertainties
- Assess value of additional information for each factor

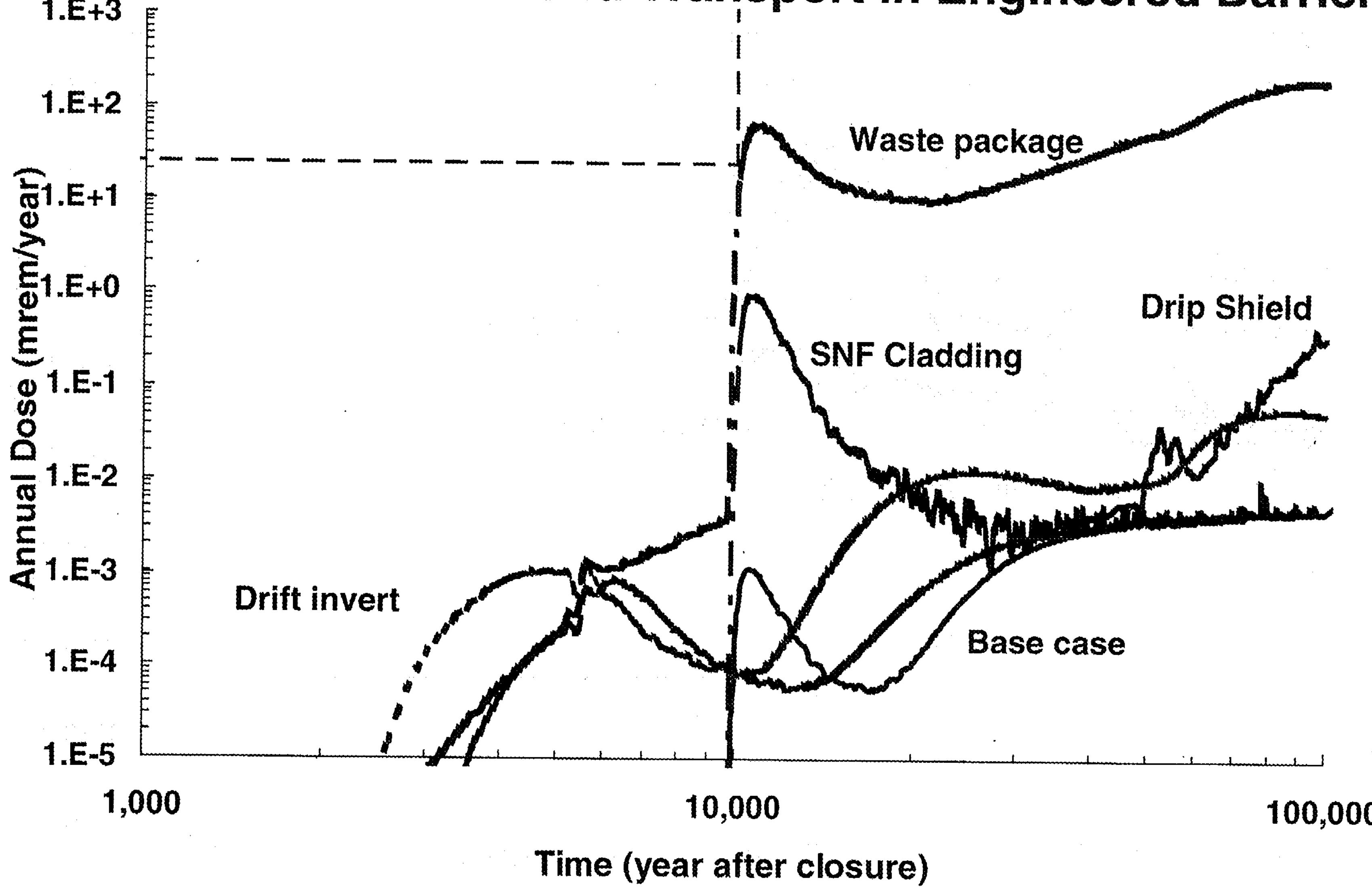
Nominal Scenario--Single Juvenile Failure

Neutralize Flow and Transport in Natural Barriers

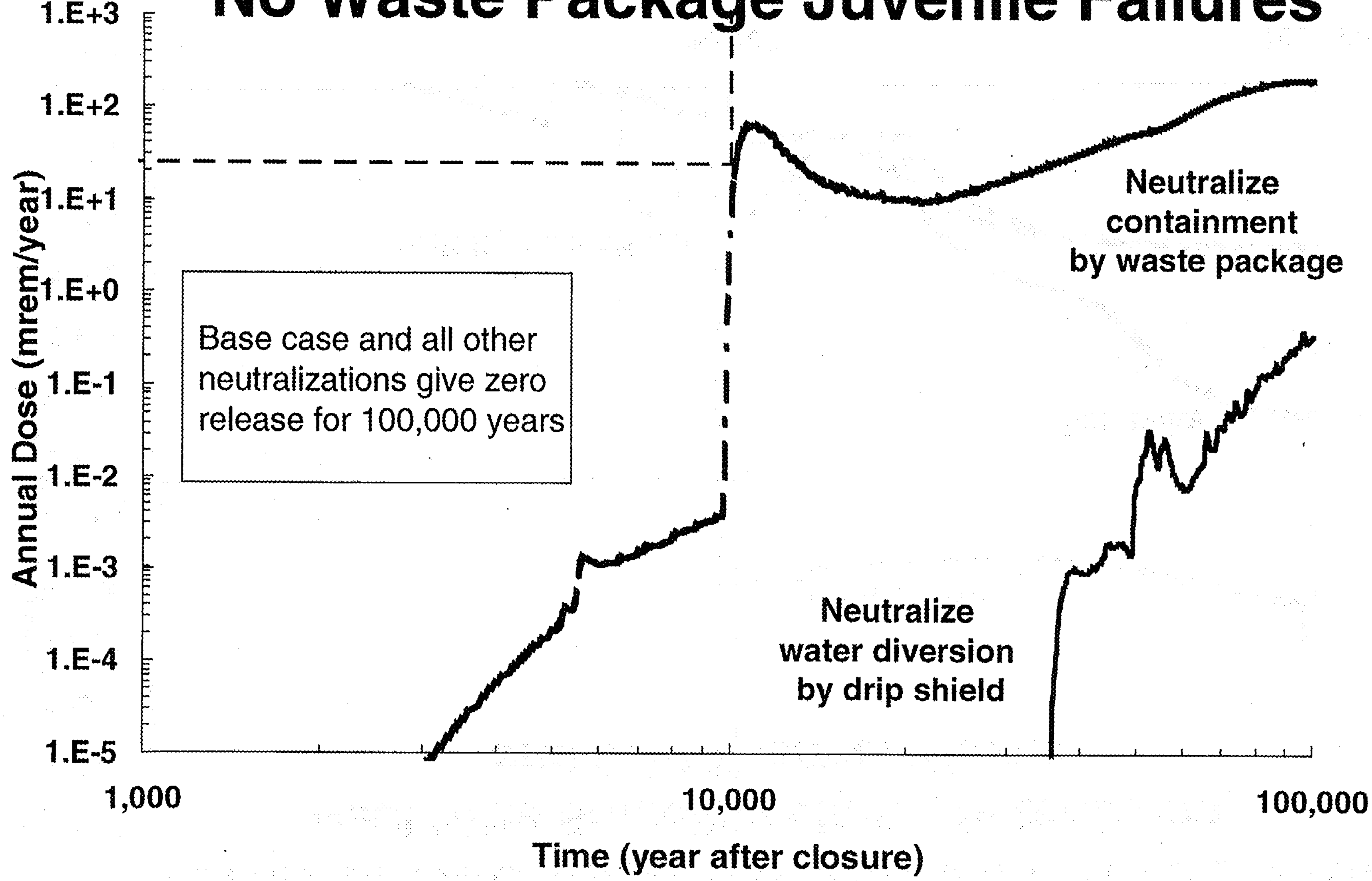


Nominal Scenario--Single Juvenile Failure

Neutralize Flow and Transport in Engineered Barriers

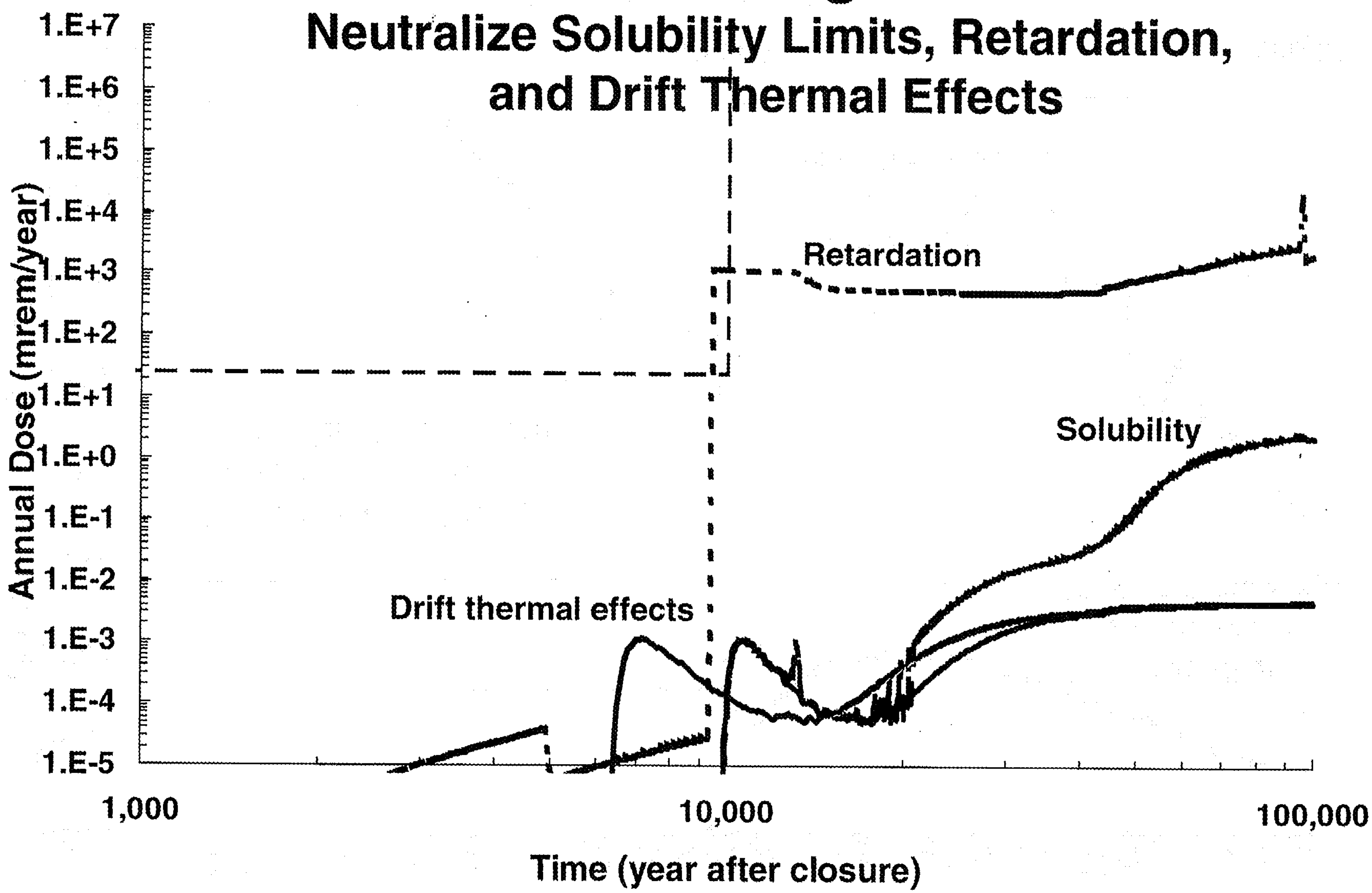


Nominal Scenario--
No Waste Package Juvenile Failures



Nominal Scenario--Single Juvenile Failure

Neutralize Solubility Limits, Retardation, and Drift Thermal Effects



Develop Elements of SR/LA Safety Case

- Ranking process is not yet complete--high ranking factors so far are

Seepage into drifts	Environments on EBS and waste package
Juvenile failure and degradation of drip shield	Juvenile failure and degradation of WP barriers
CSNF cladding initial condition and degradation	Dissolved radionuclide concentration limits
Colloid-associated radionuclide concentration limits	UZ flow and transport—sorption
SZ flow and transport--sorption	Dilution in water supply

- At the completion of this process, the principal factors and key remaining issues will be identified
- Then the physical picture of system performance will be developed in terms of the principal factors

Additional Steps

- Identify data and model development needs and key design activities
- Review content of Process Model Reports and supporting AP3.10Q reports
- Update Repository Safety Strategy
- Revise VA Tables Vol. 4
- Update Requirements Documents

YUCCA
MOUNTAIN
PROJECT

Studies

Overview of Major Site Recommendations, Environmental Impact Statements, and License Application Milestones and Schedule

Presented to:
DOE/NRC Technical Exchange on Total System
Performance Assessment
San Antonio, Texas

Presented by:
Abraham Van Luik
Senior Technical Advisor for Performance Assessment
Office of Licensing and Regulatory Compliance
U.S. Department of Energy

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

May 25-27, 1999

Attachment 31

Objectives of DOE TSPA-Related Presentations (27 May 1999)

- Discuss the TSPA in the context of the overall SR/LA plan
- Present general information on the driving forces, planned technical content, and schedule for TSPA SR and TSPA-LA
- Provide more detailed information on development of the TSPA-SR

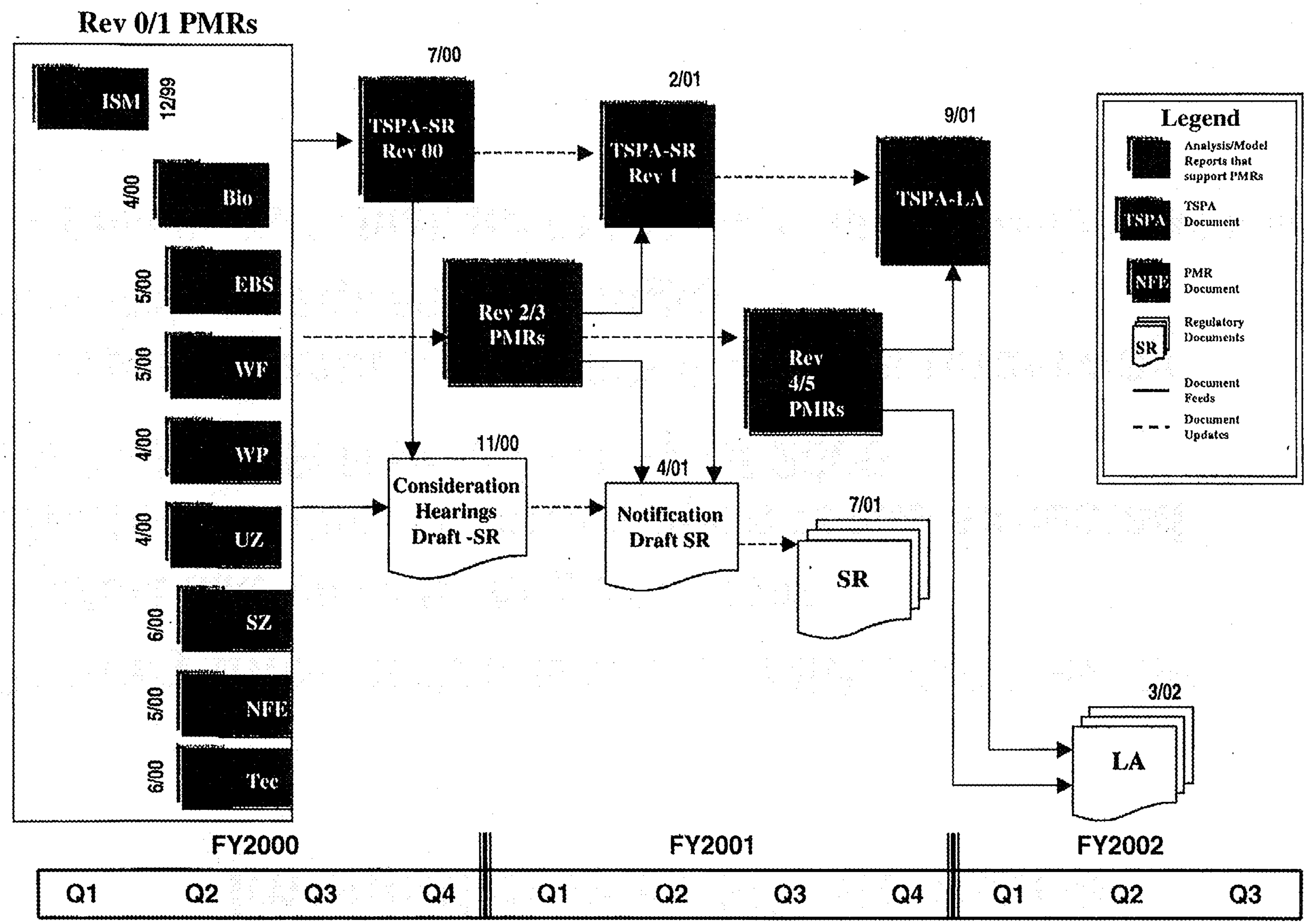
Objectives of This Presentation

- Provide an overview of major programmatic milestones for SR, EIS, and LA
- Discuss the general focus and linkage of major milestones
- Show the schedule for delivery of the major milestones

Major DOE Programmatic SR/LA Milestones

- Draft Environmental Impact Statement
- Final Environmental Impact Statement
- Process Model Reports
- Consideration Hearing Draft SR
- Notification Draft SR
- Final Site Recommendation
- Draft License Application
- Final License Application

Linkage of Major Programmatic SR/LA Milestones

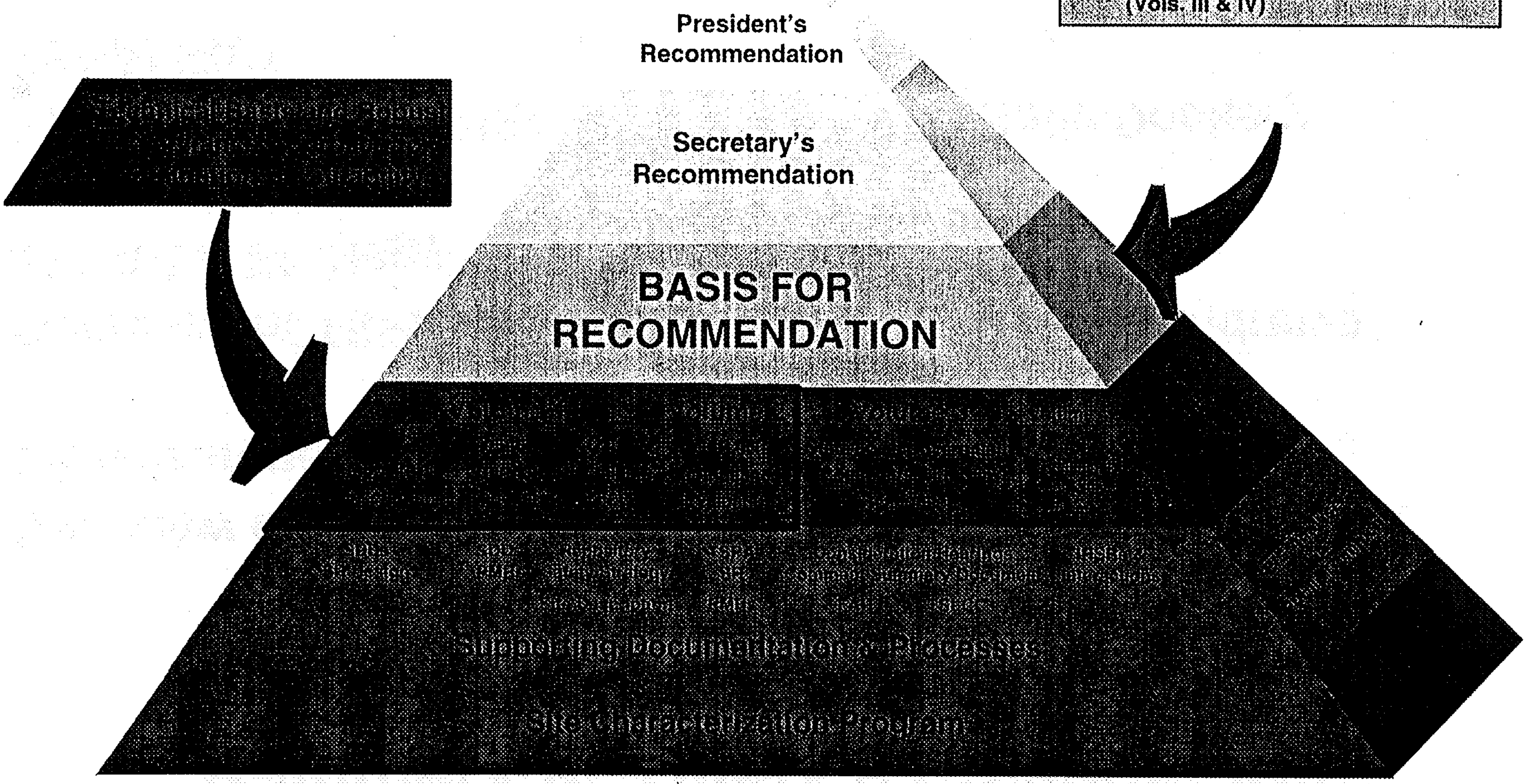


Implications of SR Schedule

- Primary information feeds to TSPA-SR Rev. 00
  - Must take place by August of 1999
- Limited additional information feeds expected for TSPA-SR Rev. 01 - July of 2000
- A reprioritization of FY2000 work is underway assuming requested budget
  - Possibility is high for FY2000 not being at requested level

Site Recommendation Documentation Structure*

Include:
- Compelling argument based on "Technical Basis" (Vols. I & II)
- Public Policy Considerations (Vols. III & IV)



* Assuming the site is found to be suitable

Summary of Today's Presentations

	Presenter
Overview of Major SR, EIS, and LA Milestones	Abraham Van Luik
Overview of TSPA-SR, and TSPA-LA Strategy	Robert Andrews
YMP Response to NRC's TSPAI IRSR	Holly Dockery
Summary of TSPA-SR Methods and Assumptions	Jerry McNeish

Summary of DOE Presentations

	Presenter
Approach to Features, Events and Processes Development and Screening for TSPA-SR	Peter Swift
Planned Updates of Natural System Model Abstractions for TSPA-SR	Mike Wilson
Planned Updates of Engineered System Model Abstractions for TSPA-SR	Dave Sevougian
Planned Updates of the TSPA-SR Model to Improve Tracebility	Vinod Vallikat
Possible Approach to Evaluate Human Intrusion Requirement of Proposed Part 63	Jerry McNeish

YUCCA
MOUNTAIN
PROJECT

Studies

Overview of Total Systems Performance Assessment-Site Recommendation (TSPA-SR) and Total Systems Performance Assessment-License Application (TSPA-LA) Strategy

Presented to:
DOE/NRC Technical Exchange on Total System Performance Assessment,
San Antonio, Texas

Presented by:
Robert W. Andrews
Manager, Performance Assessment Operations
CRWMS M&O

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

May 25-27, 1999

Attachment 32

Overview of this Presentation

- Major TSPA-SR Drivers (Goals/Objectives/Requirements)
  - Yucca Mountain Project priorities under Nuclear Culture
  - Comments on TSPA-VA
  - Implementation of proposed EPA standards, NRC regulatory requirements and DOE guidelines
    - » 40 CFR 197
    - » 10 CFR 63
    - » 10 CFR 963
  - NRC's IRSR acceptance criteria (and draft Yucca Mountain Review Plan)
- Philosophy and scope of TSPA-SR Iterations
- Schedule of TSPA-SR

Yucca Mountain Project's Priorities under the Nuclear Culture (Dyer 11/25/98)

- YMP is placing emphasis on the transition from a project centered around data collection, testing and analysis to a project focussed on meeting regulatory requirements and defensibility of RW products under a nuclear culture

Yucca Mountain Project's Priorities under the Nuclear Culture (Dyer 11/25/98)

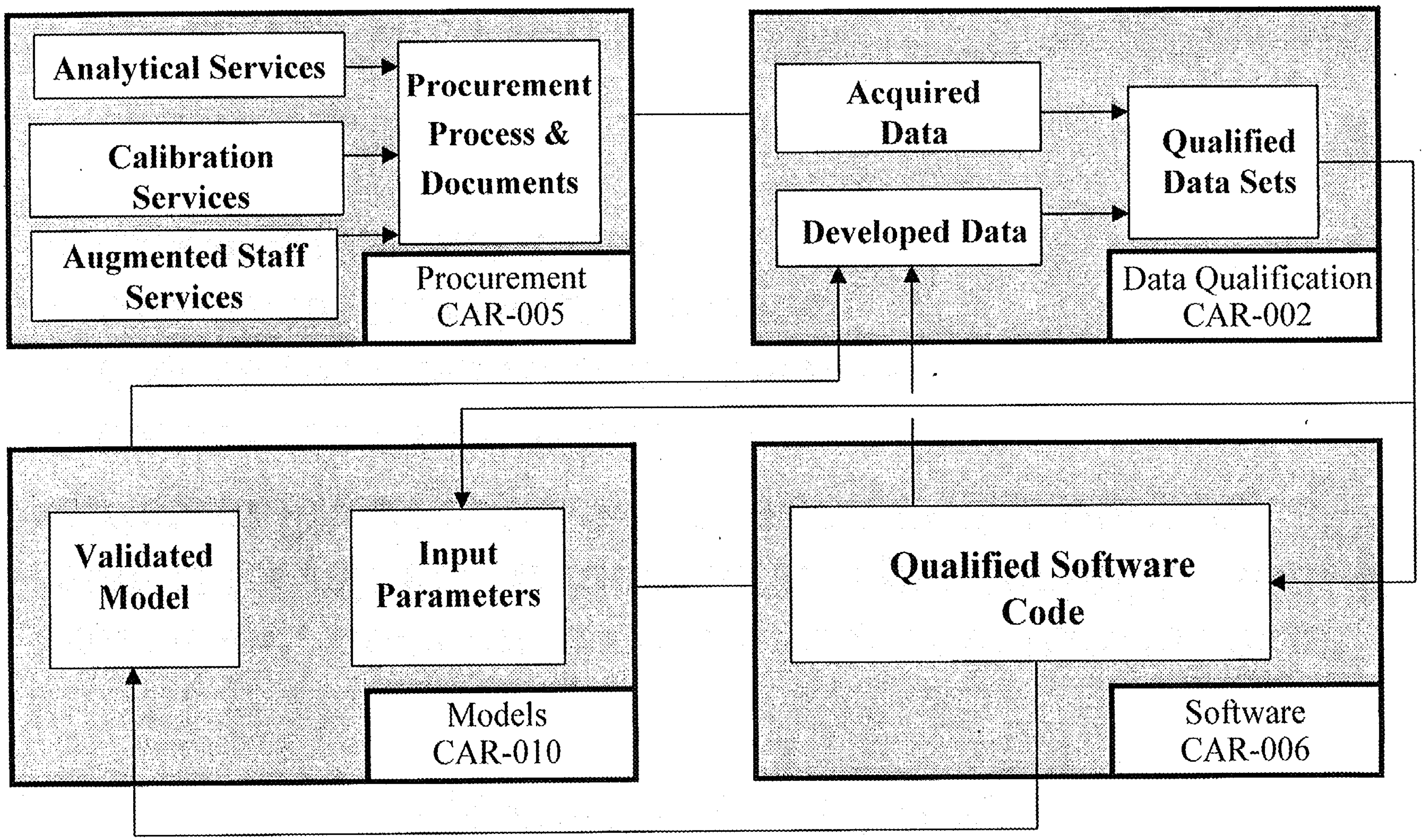
(Continued)

- **YMP's priorities under a nuclear culture include:**
  - Ensure the defensibility of RW products by developing and maintaining the validity, traceability, reproducibility and retrievability of data, information, and products used to prepare RW products
  - Meeting the site recommendation schedule (July 2001) using the principle of minimal, necessary and sufficient work
  - Expeditious implementation and improvement of procedures and processes
  - Completing the required technical work and design necessary to support the LA schedule

Goal to Improve the Defensibility of Products: Corrective Actions

- Four major corrective action requests (CARs) exist related to validity, traceability, reproducibility and retrievability of data, information and products
  - CAR-98-002 Data Qualification
  - CAR-98-005 Procurement of Services
  - CAR-98-006 Software Qualification
  - CAR-98-010 Model Control

Integrated CAR Relationships



Goal to Improve the Defensibility of Products: Corrective Actions

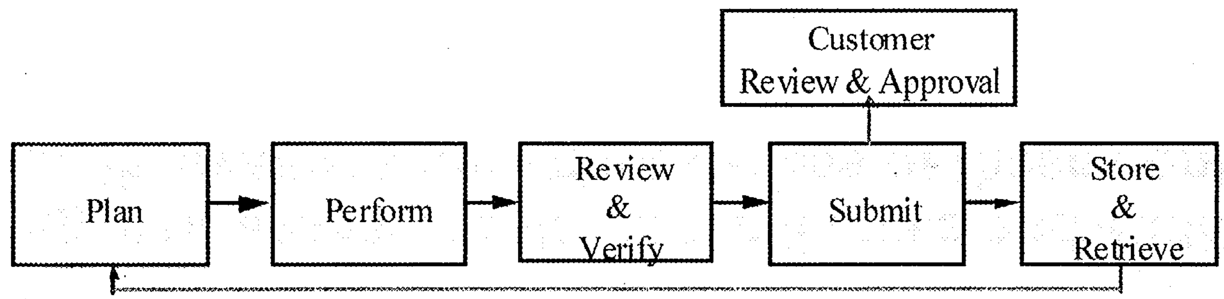
- Responses to these CARs have identified
  - Remedial actions
  - Actions to determine extent of conditions
  - Root causes
  - Actions to preclude recurrence
    - » includes revised procedures and training
- All actions are scheduled for completion by 10/29/99
- DOE's OQA and NRC are conducting surveillance's of the interim completion milestones

Goal to Implement Improved Processes & Procedures

- Process Validation and Re-engineering (PVAR) effort has resulted in
  - 19 processes being identified for improvement/consolidation
  - 27 new Administrative Procedures developed and 49 procedures cancelled
  - Training to be conducted in June 1999

Goal to Implement Improved Processes and Procedures

Clear Concise Guidance to Users



AP-2.13Q Technical Product Development Planning AP-3.13Q Design Control AP-5.2Q Testing Work Packages	AP-AC.1Q Expert Elicitation AP-5.2Q Testing Work Packages AP-SIII.1Q Scientific Notebooks AP-3.15Q Managing Document Inputs AP-3.10Q Analyses & Models AP-3.11Q Technical Reports AP-3.12Q Calculations AP-3.19Q Specifications/Drawings AP-SI.1Q Software Management AP-3.14Q Transmittal of Design Input	AP-2.14Q Review of Technical Products AP-2.12Q Peer Review AP-3.12Q Calculations AP-3.19Q Specifications/ Drawings AP-3.20Q Technical/Design Verification AP-SI.1Q Software Management AP-5.1Q Procedure Preparation, Review, and Approval	AP-17.1Q Record Source Responsibilities for Inclusionary Records AP-3.4Q Level 3 Change Control AP-6.1Q Controlled Documents AP-SIII.3Q Data Coordinators' Identification and Submittal of Data to the Technical Data Management System	AP-3.15Q Managing Document Inputs AP-6.1Q Controlled Documents AP-17.1Q Records Source Responsibilities for Inclusionary Records AP-SI.1Q Software Management AP-SIII.3Q Data Coordinators' Identification and Submittal of Data to the Technical Data Management System

<u>Infrastructure Support</u>

1. AP-5.1Q Procedure Preparation, Review, and Approval
2. AP-2.1Q Indoctrination and Training of Personnel
3. AP-2.2Q Verification of Education and Experience of Personnel
4. AP-9.1Q Control of Special Processes
5. AP-REG-001 Lessons Learned Program

Note: This Slide Depicts 1st Tier PVAR Procedures

Goal to Implement Improved Processes & Procedures
(Continued)

- All data, analyses, models and software used as a basis for TSPA-SR will be controlled in accordance with improved procedures
  - Training, self-assessments, surveillances and audits will continually evaluate the effectiveness of these controls

Goal to Implement Improved Processes & Procedures

(Continued)

- Performance-based QA audit conducted of PA Operations on May 3-14, 1999
  - Observations included strong team integration, positive attitudes towards nuclear culture and thorough understanding of roles and responsibilities
  - 5 process recommendations
  - 1 Deficiency Report (development of work direction under AP-3.10Q)

Summary of Major Technical Drivers on TSPA-SR

- Interpretation of TSPA-VA results
- Comments received on TSPA-VA
  - NRC (6/98;3/99)
  - Performance Assessment Peer Review Panel (2/99)
  - NWTRB (11/98;4/99)
  - ACNW (4/99)
- Changes in
  - repository and waste package designs
  - process models
- Focus on key information to address specific regulatory requirements

NRC Staff Review of TSPA-VA

- Comments on TSPA-VA from SECY-99-074 note general agreement between the DOE and NRC approaches with five major areas where significant differences exist
- Unclear whether sufficient data on waste package corrosion under conditions applicable to the proposed repository, can be acquired to demonstrate compliance with NRC requirements
- Data and models of the quantity and chemistry of dripping water are inadequate to describe the process of dripping under ambient and thermally-altered conditions

NRC Staff Review of TSPA-VA
(Continued)

- The saturated zone has not been sufficiently characterized to the proposed 20-km receptor location to adequately assess its contribution to performance
- Volcanic disruption analyses are
  - i) not representative of YM basaltic volcanism
  - ii) based on insufficient data to evaluate WP and WF behavior under appropriate conditions
  - iii) based on assumptions which are inconsistent with those used elsewhere

NRC Staff Review of TSPA-VA

(Continued)

- Implementation of QA Program has raised the issue of whether data/products will be acceptable and appropriately qualified

Key Findings of the PA Peer Review Panel on TSPA-VA

- TSPA-VA and TSPA-SR have significantly different objectives. Recognition of this distinction should be an important element of a path forward
  - Objective of TSPA-VA was on "probable behavior"
  - Objective of TSPA-SR (& LA) will be on reasonable assurance that repository complies with regulatory limits
- Use of simplified bounding analyses may be necessary to achieve the desired level of confidence (for TSPA-SR & -LA)

Key Findings of the PA Peer Review Panel on TSPA-VA

(Continued)

- "For cases in which it is feasible to improve either the component models or their underlying data, the Panel recommends that efforts be made to implement such improvements wherever such changes would affect the overall assessment
- Where conservative bounding analyses do not result in unduly pessimistic estimates of the total system performance, the Panel recognizes that it may not be cost-effective to spend additional time and effort refining the assessments and making them more realistic

Key Findings of the PA Peer Review Panel on TSPA-VA

(Continued)

- For those issues for which, by virtue of their complexity, it is not feasible to produce more realistic models supported by data, the Panel recommends that a combination of bounding analyses and design changes be applied"

NWTRB Comments on TSPA-VA

- Identifying important sources of uncertainty, estimating the magnitude of those uncertainties, reducing critical uncertainties through focussed research and evaluating the effect of residual uncertainty on repository performance are essential for supporting a defensible site-suitability determination and license application
- Eliminating all uncertainty is not possible or necessary

NWTRB Comments on TSPA-VA
(Continued)

- DOE should evaluate alternate repository designs that have the potential to reduce uncertainties in projected repository performance
- Agrees with PA Peer Review Panel that additional data are required to improve the credibility of the TSPA

ACNW Comments on the TSPA-VA

- DOE should provide a TSPA of sufficient transparency so NRC staff can readily determine the interrelationships among all models of the TSPA
- Supporting evidence should be provided at the model level
- NRC should provide guidance on what are acceptable model assumptions and parameter uncertainty
- NRC should identify attributes of defense in depth

Philosophy of Future TSPA Iterations

- Initial TSPA iterations (-91, -93, -95) were scoping in nature
- TSPA-VA placed controls on the abstracted model inputs, software, analyses and documentation
- All future TSPA's, (-SR Rev. 00, -SR Rev. 01, and -LA) will have controls on all data, models, software, analyses and documentation
  - any changes will be controlled under the change control process, which includes conducting impact analyses
- TSPA-SR Rev. 00 forms the fundamental controlled basis to which incremental changes may be made

TSPA-SR Overall Scope

- Develop process models, abstraction models and TSPA model
  - Incorporate features most significant (including potentially detrimental features, events and processes) to performance
  - Include uncertainty in conceptual models and parameters
- Identify and screen relevant features, events and processes (FEPs)

TSPA-SR Overall Scope

(Continued)

- Conduct analyses using process, abstraction and total-system models in accordance with applicable QA controls for data, models, and software
- Document analyses and technical basis in the TSPA-SR document and Process Model Reports
- Summarize analyses and basis in Vol. II of the Site Recommendation Report

Scope and Content of Future TSPA Iterations

- Consideration Hearings Draft TSPA-SR (Rev. 00)
  - Screen FEPs using regulatory criteria
  - Use controlled models, analyses, software and data
  - Evaluate mean total-system performance incorporating uncertainty
  - Conduct stylized human intrusion scenario analysis
  - Perform limited subsystem performance evaluations

Scope and Content of Future TSPA Iterations
(Continued)

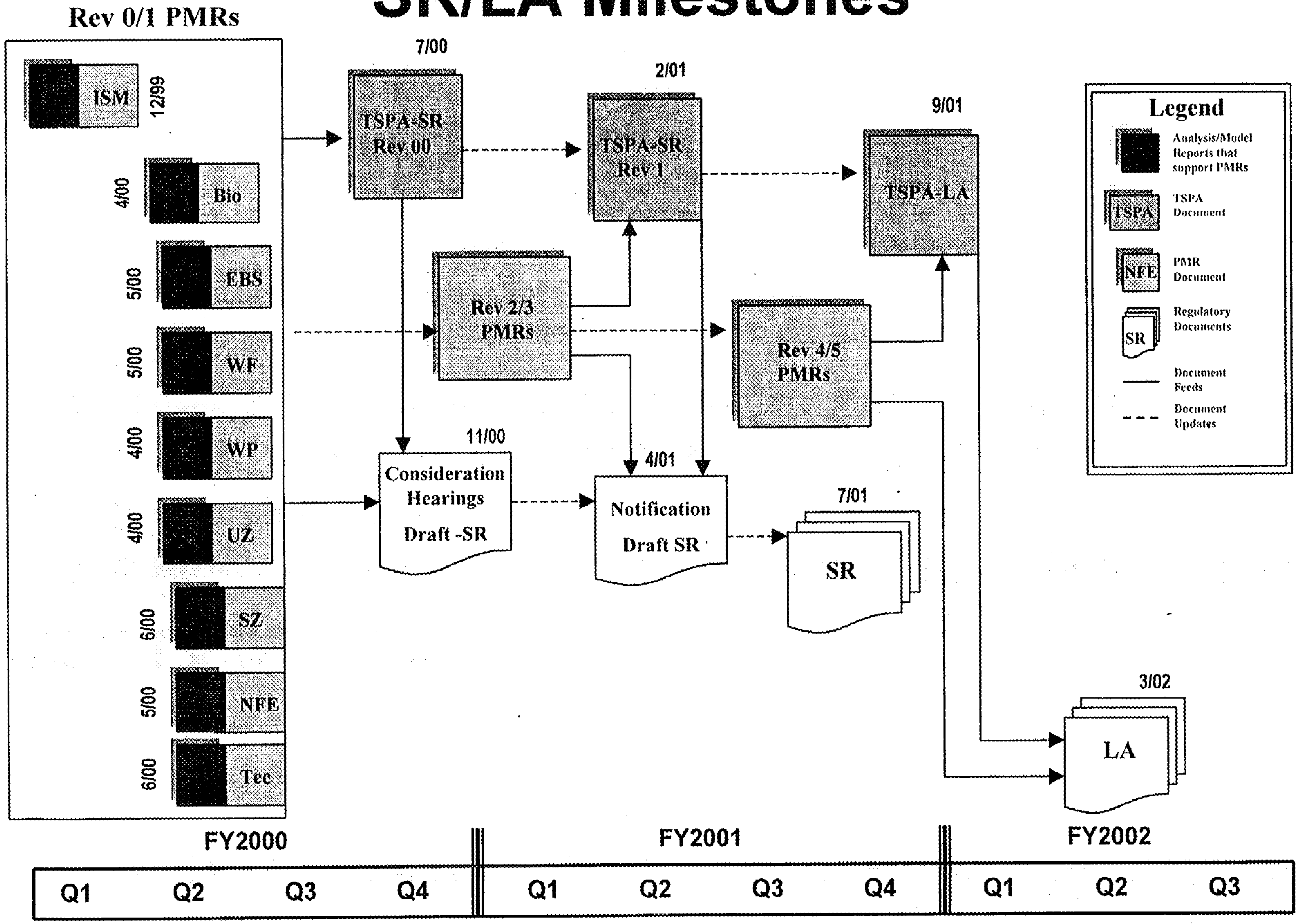
- **Notification Draft TSPA-SR (Rev. 01)**
  - Respond to comments on Rev. 00
  - Revise Rev 00 analyses with applicable, significant changes in models or data (including qualification of TBV information)
  - Conduct subsystem performance evaluations
  - Conduct specific multiple barrier analyses
  - Document results and interpretation in accordance with regulatory acceptance criteria

Scope and Content of Future TSPA Iterations

(Continued)

- TSPA-LA (Rev 02)
  - Respond to comments on TSPA-SR Rev. 01 (especially NRC sufficiency comments)
  - Revise Rev. 01 analyses with applicable, significant changes in models or data (includes qualification of TBV information)

Linkage of Major Programmatic SR/LA Milestones



Schedule of Major Inputs to SR Consideration Hearings Draft

	Preliminary Draft	Draft	Final
SR-Suitability Criteria Compliance Evaluation (Vol. II)	4/00	7/00	11/00
TSPA-SR Document Rev. 00	4/00	7/00	9/00
TSPA-SR Rev. 00 Analyses	1/00	3/00	4/00
Process Model Reports Rev. 00/01	8/99-2/00	10/99-4/00	1/00-6/00
Process & Abstraction Models and Analyses Rev. 00	3/99-10/99	6/99-1/00	7/99-2/00

Schedule of Major Inputs to SR Notification Draft

	Preliminary Draft	Draft	Final
SR-Suitability Criteria Compliance Evaluation (Vol. II)	1/01	2/01	3/01
TSPA-SR Rev. 01	12/00	1/01	2/01
TSPA-SR Rev. 01 Analyses	11/00	12/00	1/01
Process Model Reports Rev. 02/03	8/00	10/00	11/00
Process & Abstraction Models and Analyses Rev. 01	4/00	6/00	7/00

Summary

- TSPA-SR Rev 00 will place all data, models, analyses, and software under baseline control
- Focus of TSPA-SR will be on the minimal, necessary and sufficient information, to provide technical basis for compliance evaluation

Summary
(Continued)

- As recommended by the PA Peer Review Panel, the TSPA-SR will include
  - Conservative bounding analyses if the results are not unduly pessimistic
  - Combinations of bounding analyses and design changes for complex issues where it is not feasible to produce more realistic models
  - Limited improvement in component models (and underlying data) where such changes significantly affect the overall TSPA

YUCCA
MOUNTAIN
PROJECT

Studies

DOE Response to NRC's Total System Performance Assessment and Integration Issue Resolution Status Report

Presented to:
DOE/NRC Technical Exchange on
Total System Performance Assessment
San Antonio, Texas

Presented by:
Holly A. Dockery
Deputy Manager, Performance Assessment Operations
Sandia National Laboratories/CRWMS M&O

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

May 25-27, 1999

Attachment 33

Purpose of TSPA and Integration IRSR

- Issue Resolution Status Reports (IRSRs) "are the primary mechanism that the NRC staff will use to provide DOE with feedback on Key Technical Issue (KTI) sub-issues"
- The objective of the TSPA and Integration KTI and IRSR is to "describe an acceptable methodology for conducting assessments of repository performance and using these assessments to demonstrate compliance with the overall performance objective and requirement for multiple barriers"

Status of TSPAI IRSR Development with Respect to Key Subissues

1. Demonstration of Overall Performance Objective

   Will be developed in Rev. 2

2. Demonstration of Multiple Barriers

   Will be developed in Rev. 2

3. Model Abstraction

   Rev. 0 discussed input analysis and model abstraction

   Rev. 1 updates model abstraction acceptance criteria, review methods, and technical basis for acceptance criteria

4. Scenario Analysis

   Rev. 1 discusses acceptance criteria

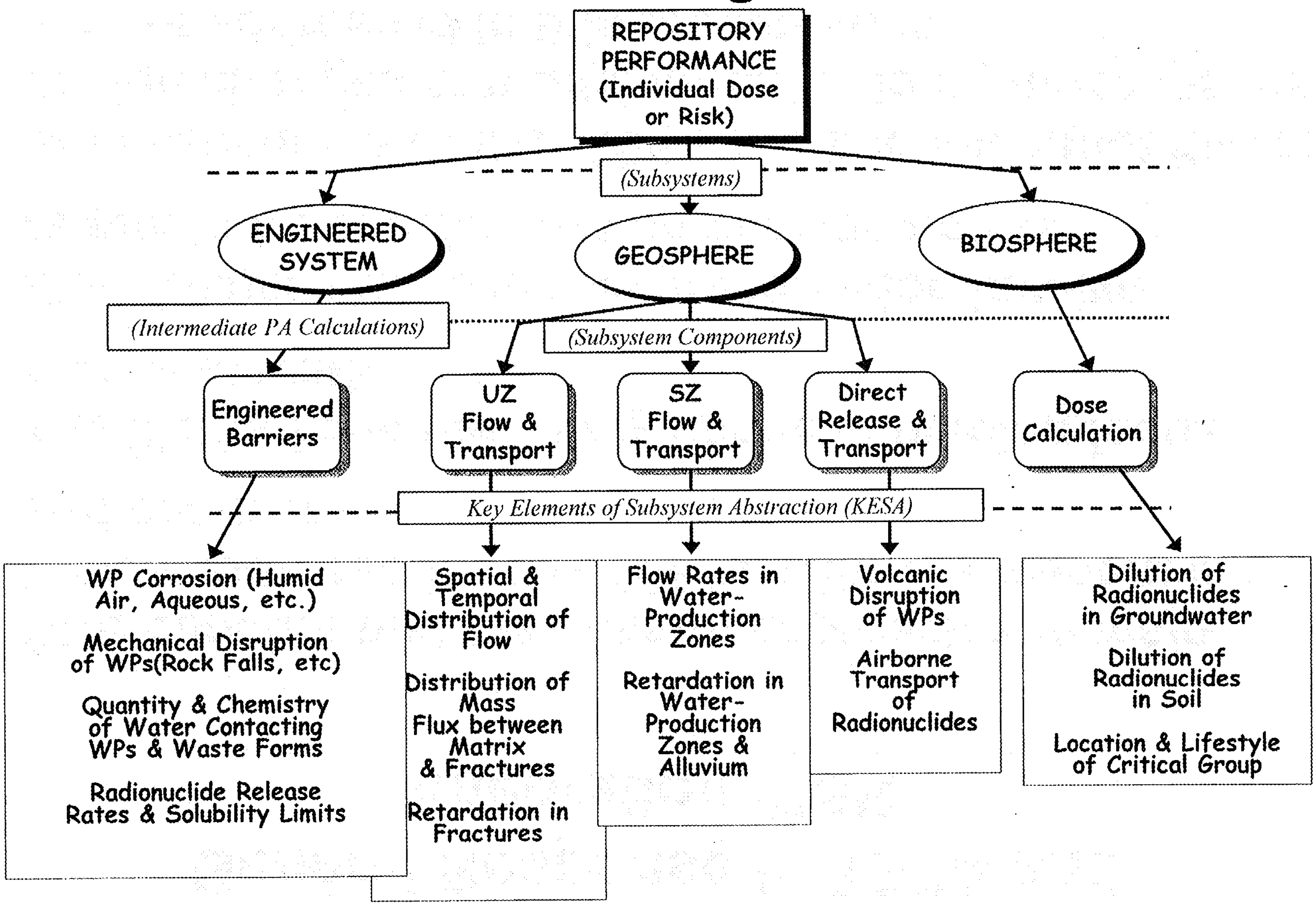
5. Transparency and Traceability of the Analyses

   Will be developed in Rev. 2

Format of TSPAI IRSR

- Organization of IRSR includes
  - 2 Programmatic Acceptance Criteria
    - » P1- Appropriate QA procedures and qualification have been applied to data, models, or codes
    - » P2 - Expert elicitations can be used if conducted under acceptable procedures
  - 5 Technical Acceptance Criteria
    - » T1- Data and Model Justification
    - » T2- Data Uncertainty and Verification
    - » T3- Model Uncertainty
    - » T4- Model Verification
    - » T5- Integration
  - 14 Key Elements of Subsystem Abstraction (KESAs)

NRC Flowdown Diagram for TSPA



General Response to TSPA and Integration IRSR

- DOE concurs that the general approach and major topics addressed in the TSPAI IRSR are reasonable and complete
- The IRSRs have been very useful in helping focus technical work
- Most issues raised in this presentation involve requests for clarification on specific points
- Some elements of the IRSR have become moot due to design changes or model modifications; those issues are not addressed in this presentation

Use of IRSRs in DOE Planning

- The draft NRC Issue Resolution Status Reports have provided guidance in the development of the PA models and approach
- Prioritization of future work in Volume 4 of the Viability Assessment was based, in part, on the appropriate IRSRs
- IRSRs were used as a basis for identifying technical issues addressed in the PA Abstraction/Testing workshops, along with results of previous Yucca Mountain TSPAs and on NWTRB, ACNW, and PA Peer Review comments

General Criterion P1

- Criterion P1: "the collection, documentation, and development of data, models and/or computer codes have been performed under acceptable QA procedures, or if the data, models and/or computer codes were not subject to an acceptable QA procedure, they have been appropriately qualified"

Criterion P1 - Discussion

- Criterion P1, related to the adherence to appropriate procedures, clearly shows that one of the primary responsibilities of the DOE is to conduct work under adequate controls in order to demonstrate traceability, consistency, and sufficiency
- The DOE has committed itself to conducting work (including the TSPA) in a controlled environment
- Implementation of the PVAR procedures will help ensure that DOE will meet criterion P1

General Criterion T1

- **Data and Model Justification - "Sufficient data (field, laboratory, and/or natural analog) are available to adequately support the conceptual models, assumptions, boundary conditions and define all relevant parameters implemented in the TSPA"**

General Criterion T1 - Discussion

- Discussion:
- The criterion does not discuss what constitutes "sufficient" data
- The criterion does not recognize that some information - such as alternative conceptual models, model abstractions, and probability distributions - may be obtained by methods other than direct field or lab testing (i.e., expert elicitation, expert judgement)

General Criterion T1- Recommendations

Recommendations for consideration:

- **Indicate that determination of "sufficiency" of information will depend on:**
  - whether additional information is more likely to simply corroborate previous results, or if the information is more likely to invalidate prior modeling results
  - how much a change in the information is likely to change the analysis results
- **Indicate in narrative that data or models be consistent with existing data (lab, field, and/or natural analog), or other information sources (i.e., expert judgement or expert elicitation)**

General Criteria T2 and T4

- T2 - "Data Uncertainty and Verification - Parameter values, assumed ranges, probability distributions, and/or bounding assumptions used in the TSPA are technically defensible and reasonably account for uncertainties and variabilities"
- T4 - Model Verification - "Models implemented in the TSPA provide results consistent with output of detailed process models or empirical observations or both"

General Criteria T2 and T4 - Discussion and Recommendation

Discussion:

- Use of "Verification" in title of criteria appears to be inconsistent with definition in NUREG-0856, which discusses the precision with which a computer code should reproduce test problems

Recommendation for consideration:

- Eliminate the word "verification" from the titles of criteria T2 and T4. "Data Uncertainty and Consistency" and "Model Consistency" might be less ambiguous titles

General Criterion T4 - Discussion and Recommendation

Discussion:

- In some cases, YMP will be using direct output from process models as the “abstraction”. In other cases, the abstraction may be based on analog or other types of information or an expert elicitation rather than output from a process model

Recommendation for consideration:

- Revise the criterion to include other methods for establishing the validity and reasonableness of TSPA models, such as technical review

Scenario Analysis, Section 4.4 - Observation

- Minor inconsistencies in language between IRSR and proposed Part 63
  - Part 63 refers to “features, events, and processes; IRSR refers only to “events and processes”
  - This IRSR introduces the concept of screening on “credibility”, which is a term that does not appear in Part 63, in this context

Scenario Analysis, Section 4.4.3

- Criterion T2 - "The probability assigned to each category of processes and events is consistent with site information; well documented, and appropriately considers uncertainty"

Screening of Processes and Events, Section 4.4.3 - Discussion

Discussion:

- As worded, this criterion could be interpreted to require probability estimates for all FEPs, regardless of their consequences. This is inconsistent with the intent of Criterion T4 in the same section, which allows the omission of FEPs if they do not significantly affect the expected annual dose

Screening of Processes and Events, Section 4.4.3 - Recommendations

Recommendations for consideration:

- Reorder criteria in Section 4.4.3 so that T2 (consistency of probability estimates) follows T3 and T4 (the probability and consequence screening criteria)
- Reword T2 so that it applies only when probability estimates are required, rather than under all circumstances

Summary

- This IRSR has proven to be a very effective communication tool for conveying NRC expectations for development of the DOE TSPA
- The DOE has several general recommendations, including:
  - It would be useful to define "sufficiency" of information and models in terms of significance in determining compliance with the performance measure, as well as in terms of the likelihood of whether the information or data would corroborate rather than challenge modeling results
  - It would also be useful to recognize peer review as a valid method for assessing the representativeness and applicability of information and models
- The DOE is eager to receive information on Subissues 1, 2, and 5 that will be included in Rev. 2

YUCCA
MOUNTAIN
PROJECT

Studies

TSPA-SR: Methods/Assumptions Overview

Presented to:
DOE/NRC Technical Exchange on Total System
Performance Assessment
San Antonio, Texas

Presented by:
Jerry A. McNeish, TSPA Department Manager
Duke Engineering and Services/CRWMS M&O
Performance Assessment Operations

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

May 25-27, 1999

Attachment 34

Topics

- Describe TSPA SR Methods and Assumptions Document
- Define IRSR linkage
- Define Analysis Approach
- Describe Types of Results

TSPA Methods and Assumptions Document: Strategy

- Obtain guidance from IRSR acceptance criteria, TSPA-VA PA Peer Review, NWTRB
- Identify minimal, necessary, and sufficient work required
- Ensure QA control, traceability, and transparency
- Provide resilient, robust analyses

TSPA Methods and Assumptions Document: Schedule

- Schedule
  - M&O Draft -- July 2, 1999
  - Submitted to DOE -- August 13, 1999
  - Acceptance by DOE Mgmt -- September 29, 1999

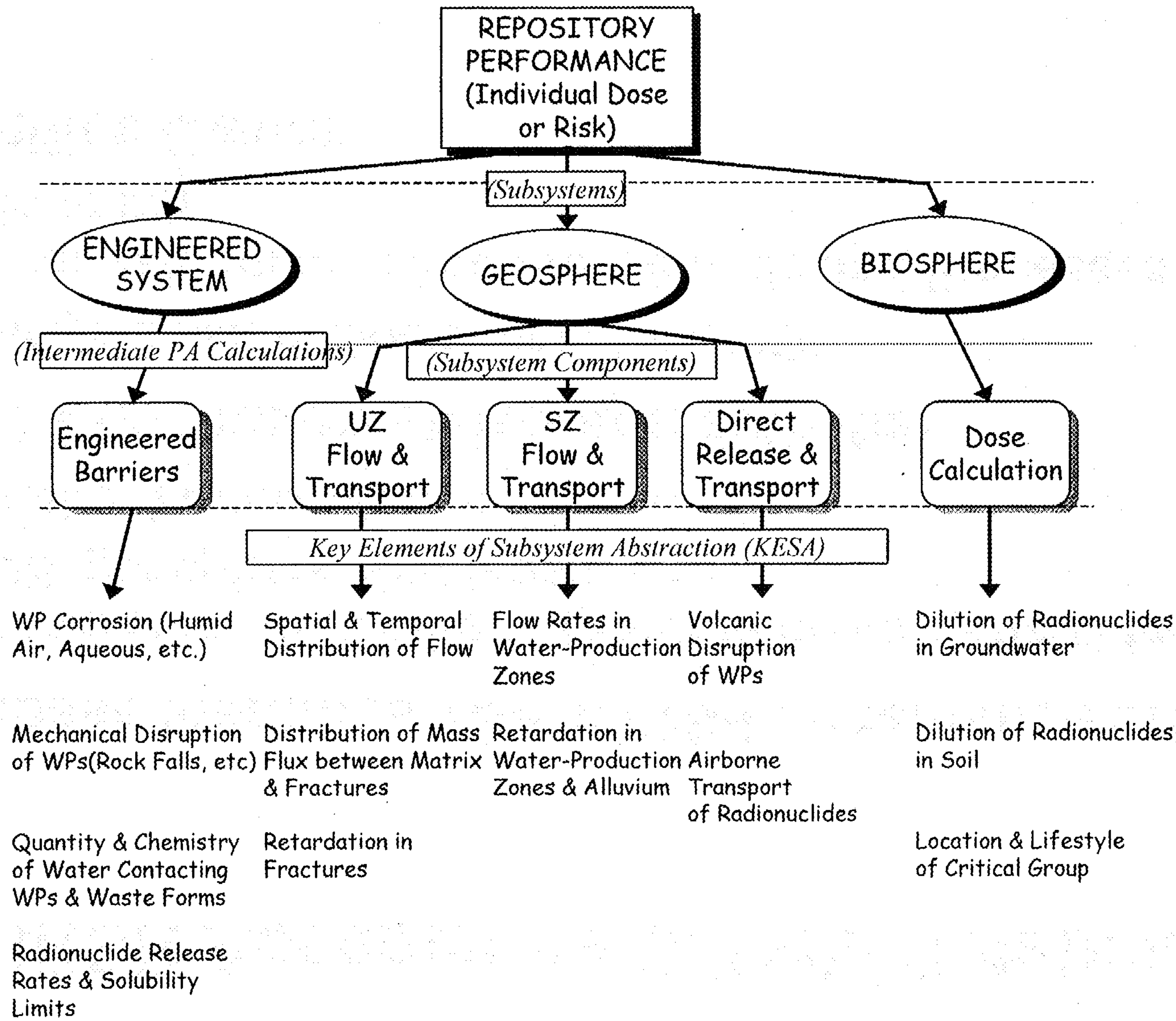
TSPA-SR Methods/Assumptions Document

- 1.0 INTRODUCTION
  - 1.1 Purpose and Scope
  - 1.2 TSPA Documentation for SR/LA
  - 1.3 Document Organization
- 2.0 COMPLETENESS OF THE TSPA
  - 2.1 Features, Events and Processes (FEPs) Approach
  - 2.2 NRC Issue Resolution Status Reports
  - 2.3 PA Peer Review Comments
  - 2.4 Other Issues
- 3.0 COMPONENTS OF THE TSPA MODEL
  - 3.1 Unsaturated-Zone Flow and Transport
  - 3.2 Thermohydrology
  - 3.3 In Drift Geochemical Environment
  - 3.4 Waste Package Degradation
  - 3.5 Waste Form Degradation
  - 3.6 Engineered Barrier System Transport
  - 3.7 Saturated Zone Flow And Transport
  - 3.8 Biosphere
  - 3.9 Disruptive Events

TSPA-SR Methods/Assumptions Document
(continued)

- 4.0 TSPA STRUCTURE AND ANALYSES
  - 4.1 TSPA Model Architecture
  - 4.2 Quality Assurance/Software Configuration Management
  - 4.3 Nominal Scenario Dose Analyses
  - 4.4 Disruptive Scenarios Analyses
  - 4.5 Combined Nominal and Disruptive Scenario Analyses
  - 4.6 Uncertainty and Sensitivity Analyses
  - 4.7 Multiple Barrier Analyses
  - 4.8 Alternative Design Analyses
  - 4.9 Human Intrusion Analysis
- 5.0 REFERENCES

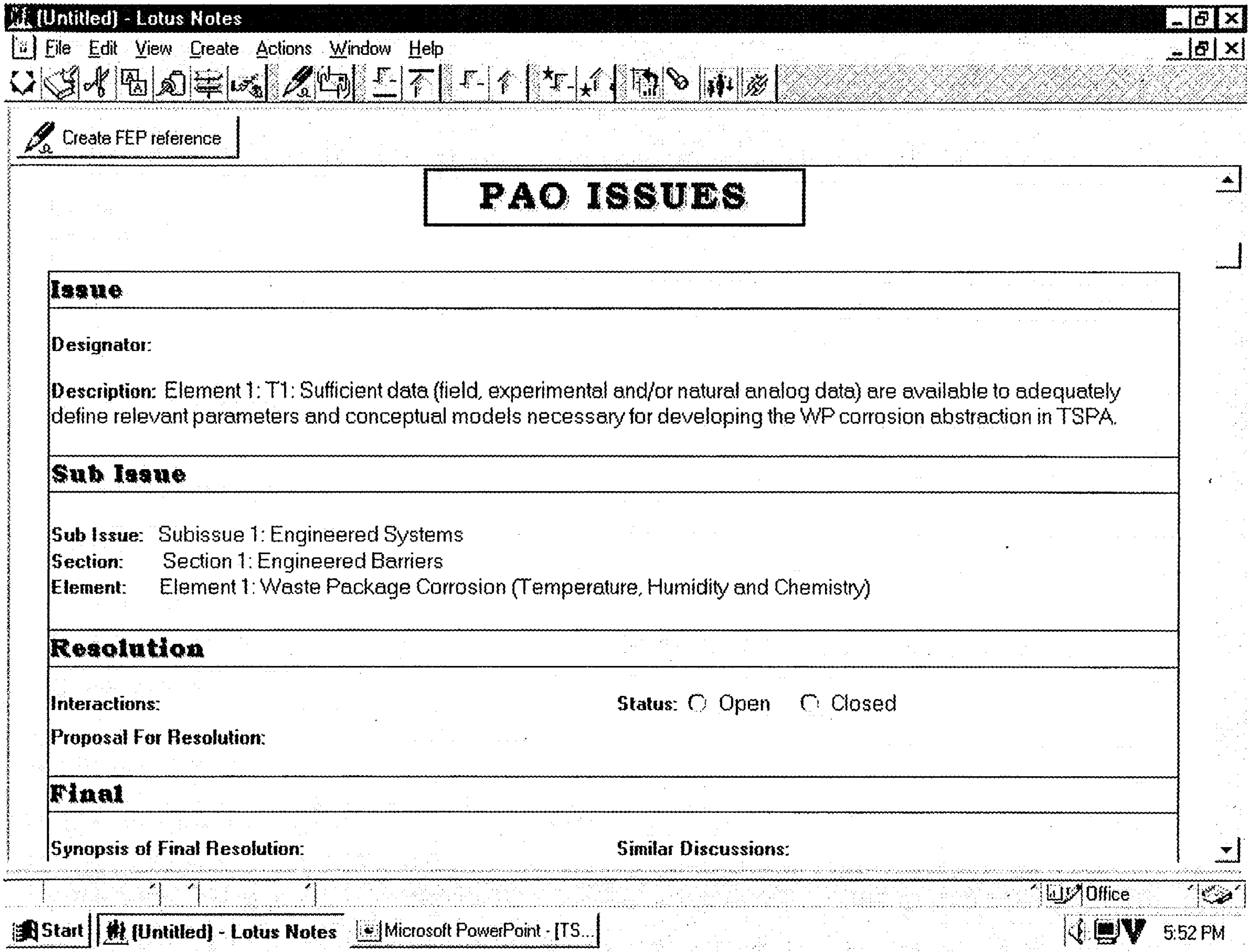
Structure of NRC IRSR Development



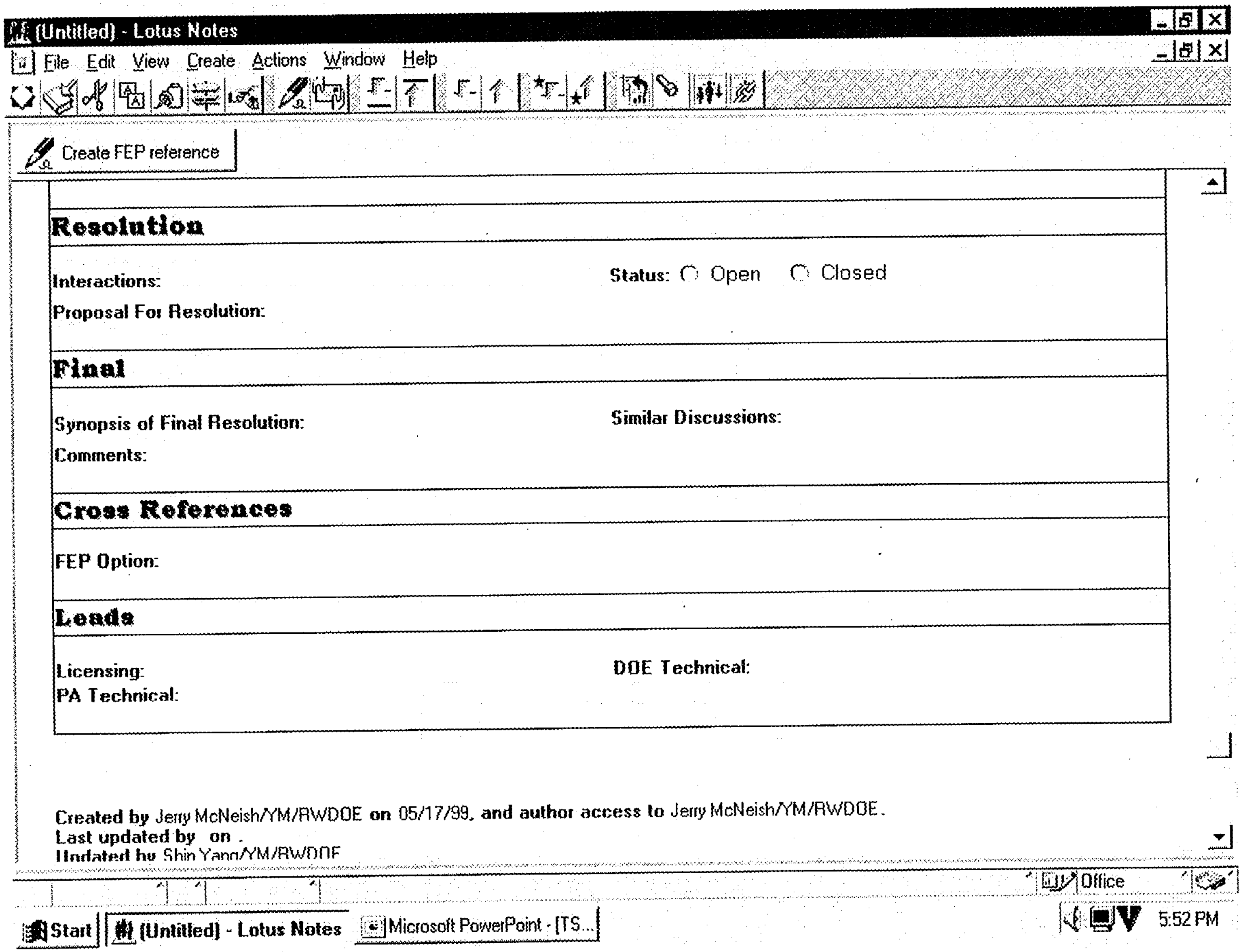
IRSR Acceptance Criteria Database

- Database identifies TSPAI IRSR acceptance criteria
  - 5 main areas with criteria (programmatic, general technical, EBS, geosphere, and biosphere)
  - Total of 72 acceptance criteria
- Tracks resolution status and activities
  - Analysis/Model Document (AP3.10Q)
  - Cross-reference to Features, Events and Processes (FEPs) screening
- Identifies Owner

IRSR Acceptance Criteria Database



IRSR Acceptance Criteria Database



Proposed 10 CFR Part 63 (TSPA)

- § 63.2 Performance assessment means a probabilistic analysis that:
  - (1) Identifies the features, events, and processes that might affect the performance of the geologic repository; and
  - (2) Examines the effects of such features, events, and processes on the performance of the geologic repository; and
  - (3) Estimates the expected annual dose to the average member of the critical group as a result of releases from the geologic repository
- § 63.113 (b) ...the expected annual dose to the average member of the critical group shall not exceed 25 mrem TEDE at any time during the first 10,000 years after permanent closure...

Proposed 10 CFR Part 63 (TSPA)

- § 63.114 Any performance assessment shall...
  - » (d) Consider only events that have at least one chance in 10,000 of occurring over 10,000 years
  - » (e) Provide the technical basis for either inclusion or exclusion of specific features, events and processes of the geologic setting. Specific features, events, and processes of the geologic setting must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission
  - » (f) Provide the technical basis for either inclusion or exclusion of degradation, deterioration, or alteration processes of engineered barriers in the performance assessment, including those processes that would adversely affect the performance of natural barriers. Degradation, deterioration, or alteration processes of engineered barriers must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission

Proposed 10 CFR Part 63
(Multiple Barriers)

- 63.102(h) => multiple barriers required (both natural and engineered)
- 63.113(a) => multiple barriers required
- 63.114(h) => identify EBS/NE features considered barriers important to waste isolation
- 63.114(i) => describe capability of barriers to isolate waste, taking into account uncertainties in characterizing and modeling them
- 63.114(j) => provide technical basis for analyses in support of 63.114(i)

PA Process

- Identify applicable IRSR's/Acceptance Criteria
- Identify and screen FEPs
- Conduct/document PA Workshops
- Develop TSPA Methods and Assumptions Document
- Develop/conduct PA analyses and modeling (AP3.10Q)
- Provide PMR support
- Develop TSPA Site Recommendation (TSPA-SR)
  - Rev 00 - April 2000
  - Rev 01 - December 2000
- Develop TSPA License Application (TSPA-LA)

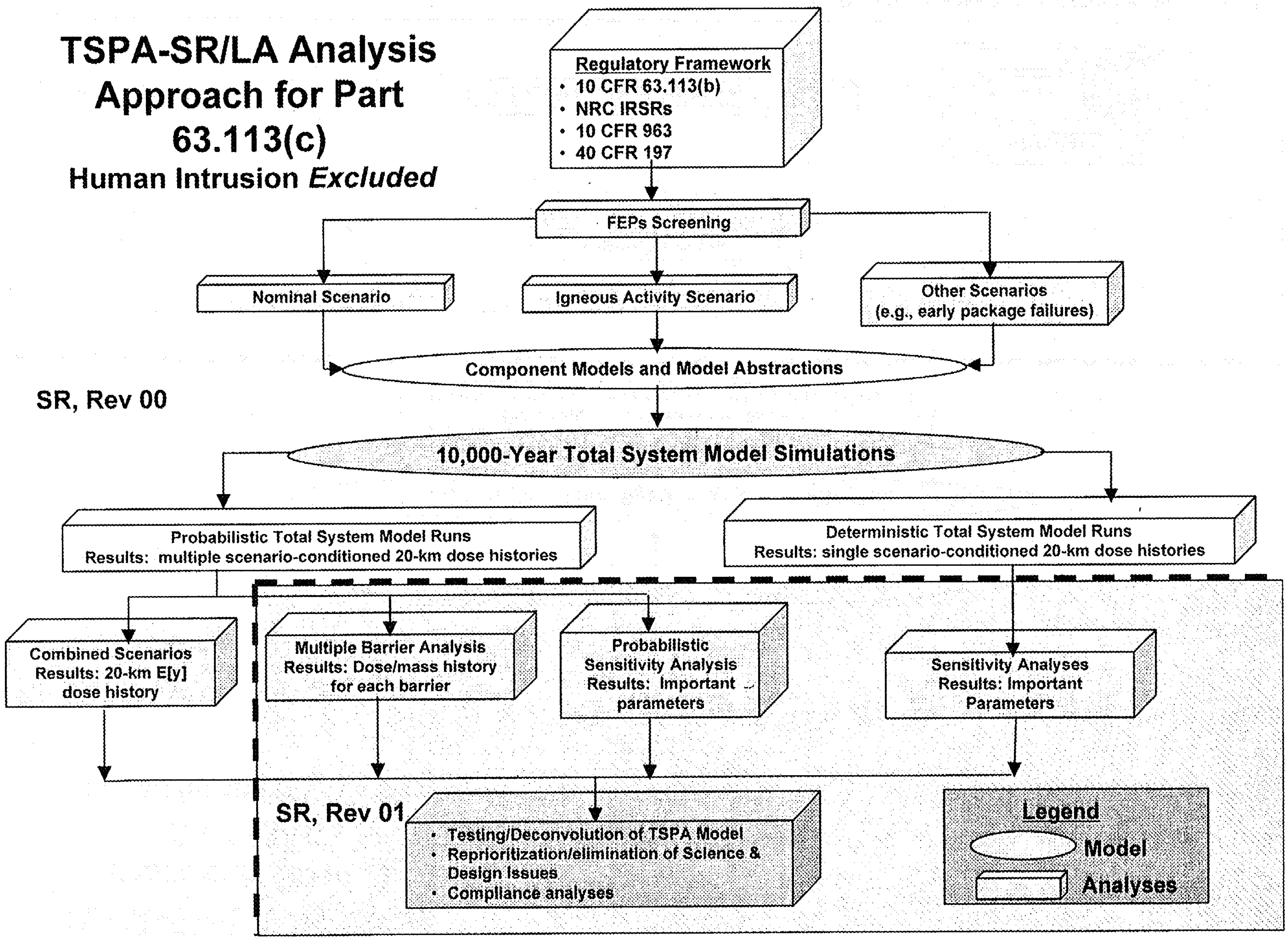
PA Workshops

	Dates	PMR
• UZ Flow and Transport	12/14-16	UZ
• Waste Form	2/2-4	WF
• Disruptive Events	2/9-11	Tect.
• SZ Flow and Transport	2/16-17	SZ
• Biosphere	2/18	Bio
• T-H/Coupled Processes	3/24-25	NFE
• Waste Package	4/20-21	WP
• NFE/EBS Transport	4/13-15	EBS

Goals and Objectives of PA Workshops

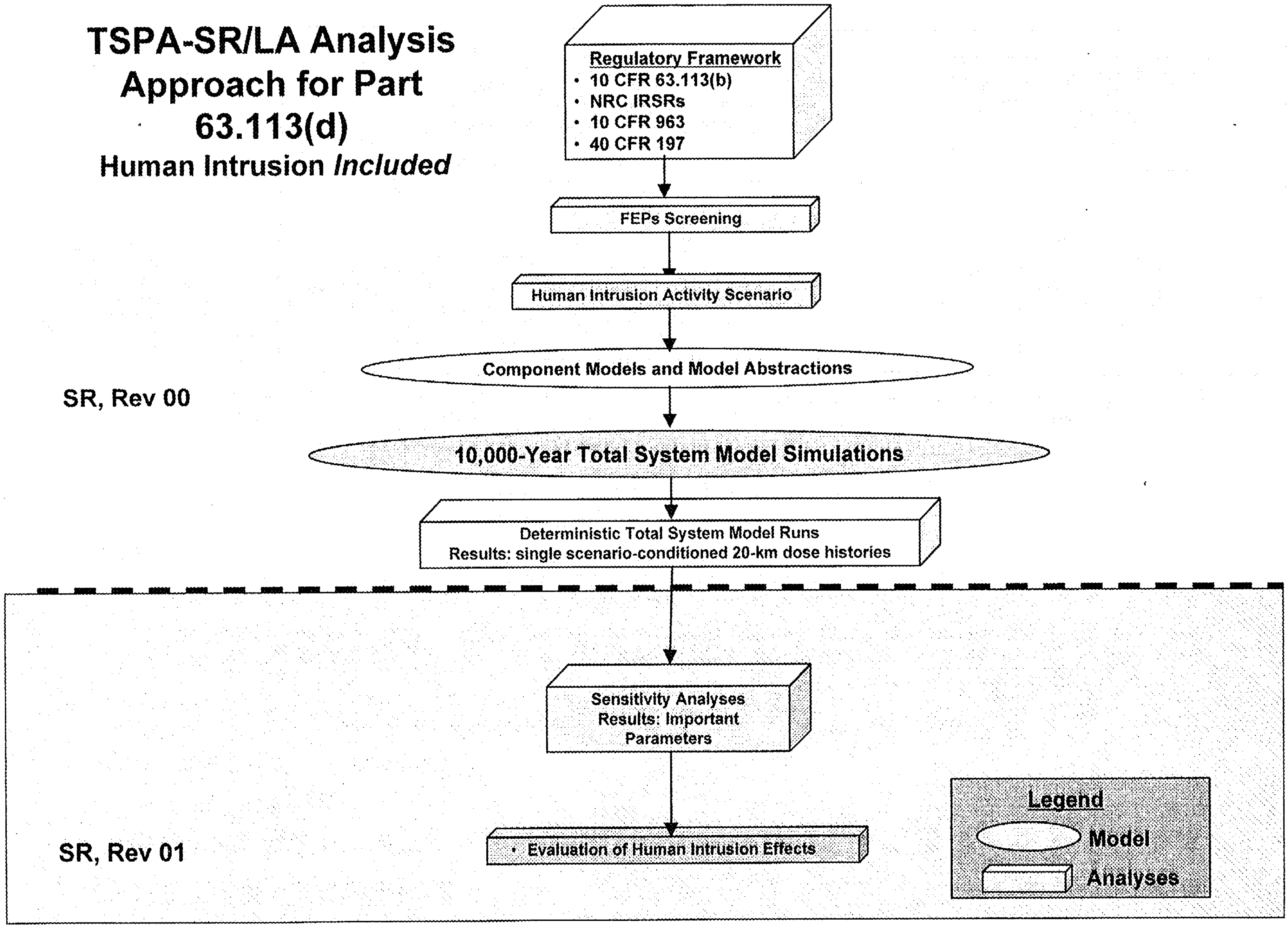
- Summarize Viability Assessment (VA)
- Summarize VA issues and concerns
- Summarize IRSR acceptance criteria
- Discuss FEPs
- Prioritize analyses required for SR
- Develop work plans (AP3.10Q's) to deal with issues/FEPs

TSPA-SR/LA Analysis Approach for Part 63.113(c)
Human Intrusion *Excluded*

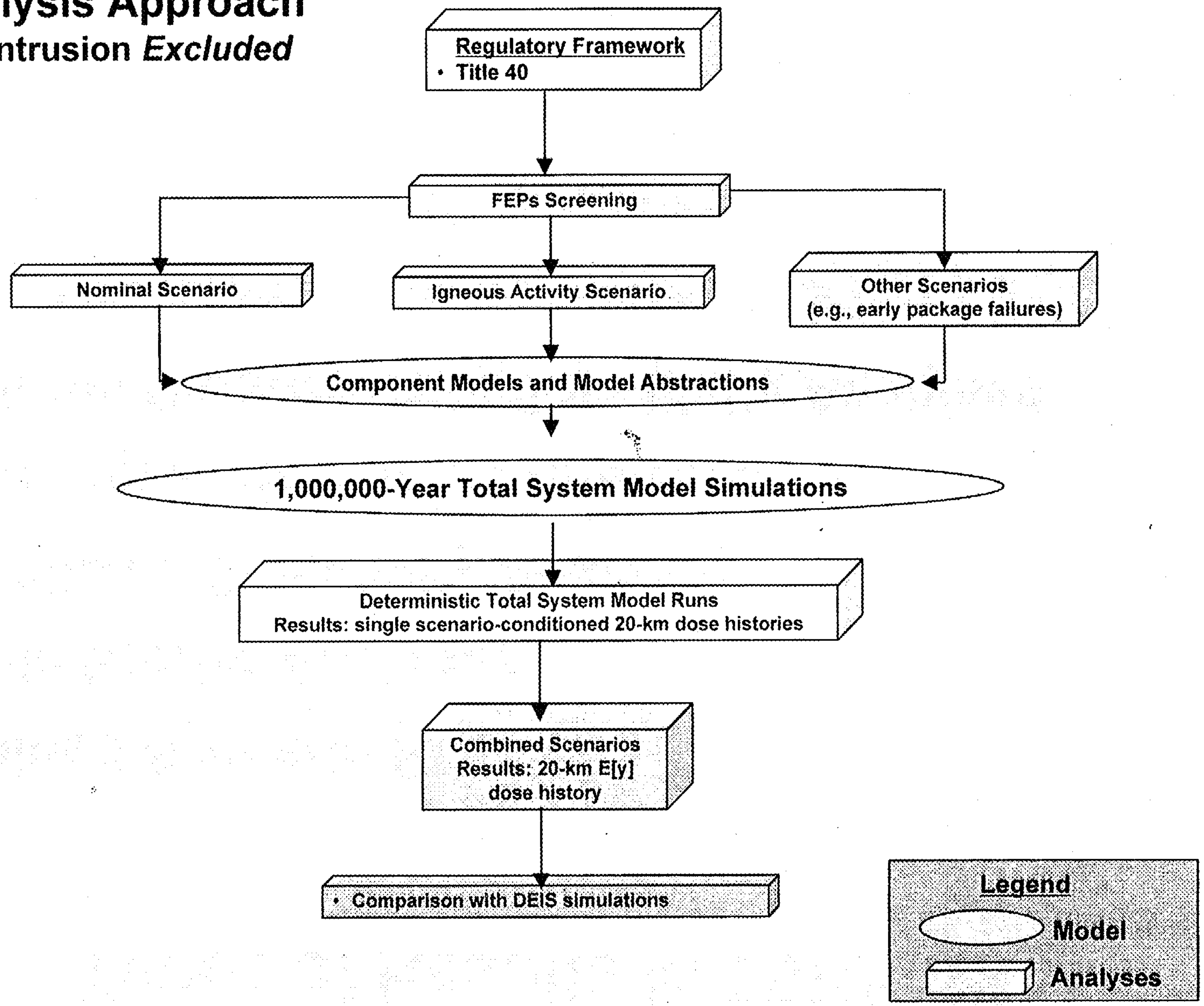


TSPA-SR/LA Analysis Approach for Part 63.113(d)

Human Intrusion *Included*



EIS Analysis Approach
Human Intrusion *Excluded*



Types of Results in TSPA-SR

- Combined Scenario Results
- Multiple Barrier Analyses
- Probabilistic Sensitivity Analyses
- Subsystem Performance Analyses
- Additional Deterministic Sensitivity Analyses

Summary

- TSPA Methods/Assumptions Document to provide roadmap for TSPA-SR analyses
- IRSR/FEP's utilized to identify key components of analyses
- Analyses designed to evaluate compliance with proposed 10 CFR Part 63

YUCCA MOUNTAIN PROJECT

Studies

Current Status of Feature, Event, and Process Screening and Scenario Selection for the Total System Performance Assessment - Site Recommendation

Presented to:
DOE/NRC Technical Exchange on
Total System Performance Assessment
San Antonio, Texas

Presented by:
Peter Swift - TSPA Core Team
Sandia National Laboratories/CRWMS M&O
Performance Assessment Operations

Geoff Freeze - Computational Sciences Section Manager,
Duke Engineering & Services/CRWMS M&O
Performance Assessment Operations

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

May 25 - 27, 1999

Attachment 35

Outline of Presentation

- Summary of Yucca Mountain Project (YMP) Features, Events, and Processes (FEPs) Approach
- Current Status of FEP Database
- Structure for Completing FEP Screening
- Current Status of Scenario Selection
- Combining Scenario Results into the Overall Expected Annual Dose
- Conclusions

Five Steps in Scenario Development

Identify and classify features, events, and processes potentially relevant to the long-term performance of the disposal system

Screen FEPS using well-defined criteria to identify those that should be included in the TSPA and those that can be excluded

Construct scenarios from the retained FEPS

Screen scenarios using well-defined criteria

Specify implementation of scenarios in the TSPA

FEPs in Proposed 10 CFR Part 63

§ 63.2 Performance assessment means a probabilistic analysis that:

(1) Identifies the features, events, and processes that might affect the performance of the geologic repository; and

(2) Examines the effects of such features, events, and processes on the performance of the geologic repository; and

(3) Estimates the expected annual dose to the average member of the critical group as a result of releases from the geologic repository

FEPs in Proposed 10 CFR Part 63
(Continued)

§ 63.114 Any performance assessment shall...

(d) Consider only events that have at least one chance in 10,000 of occurring over 10,000 years

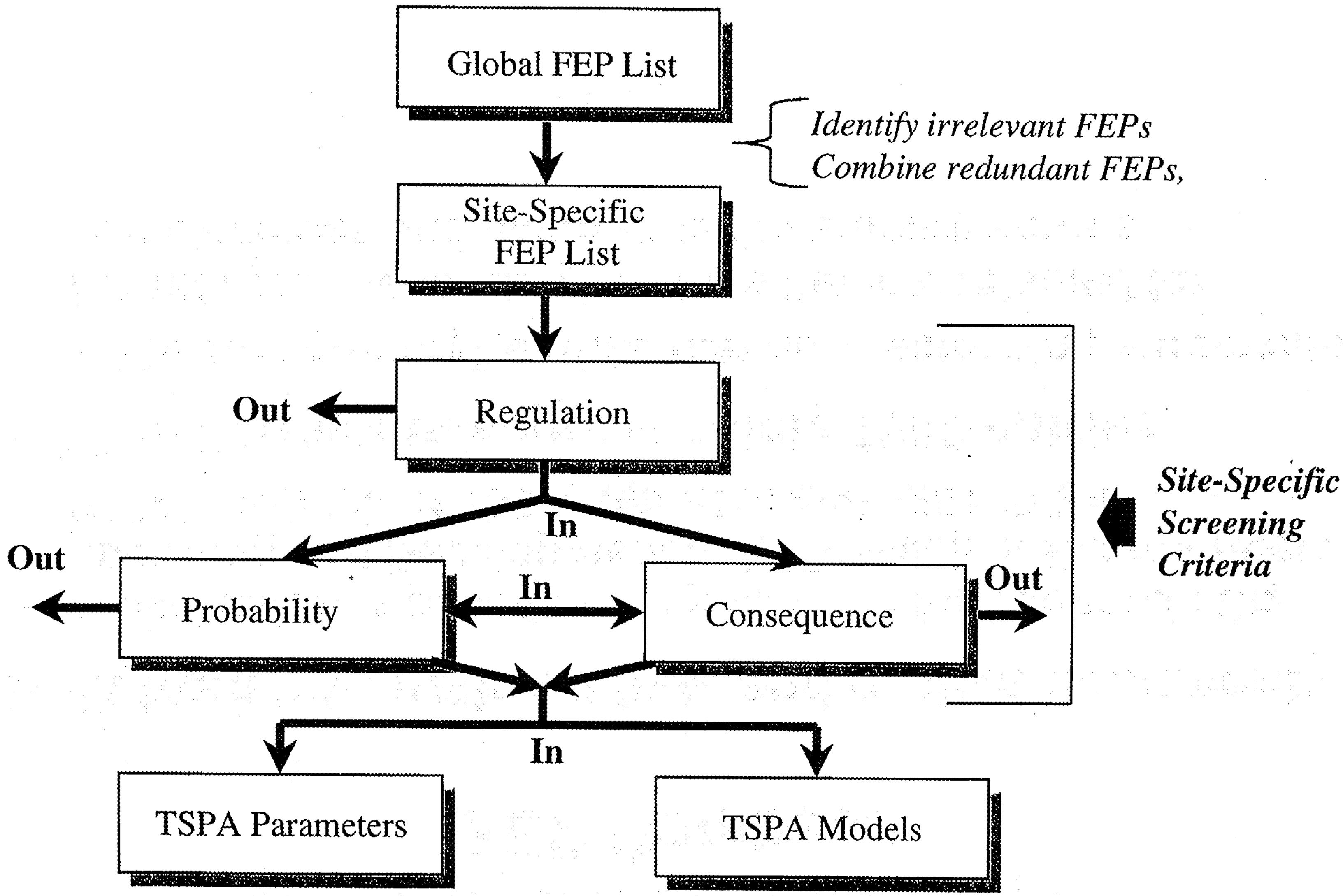
(e) Provide the technical basis for either inclusion or exclusion of specific features, events and processes of the geologic setting. Specific features, events, and processes of the geologic setting must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission.

FEPs in Proposed 10 CFR Part 63
(Continued)

§ 63.114 Any performance assessment shall...

(f) Provide the technical basis for either inclusion or exclusion of degradation, deterioration, or alteration processes of engineered barriers in the performance assessment, including those processes that would adversely affect the performance of natural barriers. Degradation, deterioration, or alteration processes of engineered barriers must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission

Screening Features, Events, and Processes



The Yucca Mountain Project FEP Database

- Built from international lists and project documents
  - organization is based on Organization for Economic Co-operation and Development (OECD)-Nuclear Energy Agency (NEA) draft list of 150 categories and 1261 FEPs
- YMP list contains approximately 1800 entries
  - ~ 450 are "primary" entries that need screening arguments
  - the rest are "secondary" entries that are retained for completeness and mapped to the primary entries

The Yucca Mountain Project FEP Database

(Continued)

- Each FEP entry will include
  - a description of the FEP
  - a summary of the screening argument (with references)
  - a summary of the TSPA disposition for retained FEPS (with references)
- FEP Database functions as an annotated library catalog: technical basis for screening decisions resides in the supporting documentation

Organization and Functionality of the FEP Database

- Four first-order categories developed by the NEA
  - 0.x.x Assessment Basis FEPs
    - » FEPs related to the purpose and scope of the analysis
    - » Most 0.x FEPs for Yucca Mountain are resolved by regulation or policy
  - 1.x.x External FEPs
    - » natural and human FEPs independent of the long-term behavior of the disposal system (e.g., long-term geologic processes, climate, human intrusion)
  - 2.x.x. Disposal System Environment FEPs
    - » FEPs that operate within the disposal system
  - 3.x.x Disposal System Radionuclide/Contaminant FEPs
    - » FEPs related to radionuclide release/transport/exposure/dose

Organization and Functionality of the FEP Database

(Continued)

- Maintained in both Claris Filemaker and Microsoft Access
- Electronic Form allows keyword searches, filters, and sorts within the database
  - Users can design their own searches
  - Direct links to primary reference documents are not available

Draft Example Page from FEP Database

FEPS - [FEPS Directory]

File Edit Insert Records Window Help

Apply Filter | Last Filter | New Filter | Save Filter | Retrieve Filter | Back | Forward | Other Form Directory | Exit

ID	YMP FEP No.	NEA CATEGORY	FEP NUMBER	FEP NAME	PRIMARY/SECONDARY	SCREENING (INCLUDE/EXCLUDE	WORKSHOP	OWNER(s)
531	2.1.03.01.00	2.1.03ca	YM130	Cladding Degradation Before YMP Receives It	Primary entry		WF	V. Pasupathi (WF/Cladding)
536	2.1.03.02.01	2.1.03cf	YM135	Cladding Degradation Mechanisms at YMP, Pre-	Secondary entry, see 2.1.03ch,cm		WF	V. Pasupathi (WF/Cladding)
537	2.1.03.02.02	2.1.03cg	YM136	Corrosion (of cladding)	Secondary entry, see 2.1.03ch		WF	V. Pasupathi (WF/Cladding)
538	2.1.03.02.00	2.1.03ch	YM137	General Corrosion (of cladding)	Primary entry	Exclude	DSNF,WF	V. Pasupathi (WF/Cladding)
539	2.1.03.02.03	2.1.03ci	YM138	Microbial Corrosion (MIC) (of cladding)	Secondary entry, see 2.1.03ch	Exclude	DSNF,WF	V. Pasupathi (WF/Cladding)
540	2.1.03.02.04	2.1.03cj	YM139	Acid Corrosion from Radiolysis (of cladding)	Secondary entry, see 2.1.03ch	Exclude (?)	DSNF,WF	V. Pasupathi (WF/Cladding)
541	2.1.03.02.05	2.1.03ck	YM140	Localized Corrosion - Pitting (of cladding)	Secondary entry, see 2.1.03ch	Include	DSNF,WF	V. Pasupathi (WF/Cladding)
542	2.1.03.02.06	2.1.03cl	YM141	Localized Corrosion - Crevice Corrosion (of	Secondary entry, see 2.1.03ch	Include	DSNF,WF	V. Pasupathi (WF/Cladding)
543	2.1.03.04.00	2.1.03cm	YM142	Creep Rupture (of cladding)	Primary entry	Exclude	DSNF,WF	V. Pasupathi (WF/Cladding)

Record: 2 of 39 (Filtered)

All text is draft

Draft Example Page from FEP Database

FEPS [FEPS All Fields]

File Edit Insert Records Window Help

Apply Filter | Last Filter | New Filter | Save Filter | Retrieve Filter | Back | Forward | Other Form | All Fields | Exit

ID 543 **NEA CATEGORY** 2.1.03cm **FEP NUMBER** YM142 **INTERNAL MAPPING** Primary entry

YMP FEP No. 2.1.03.04.00 **FEP NAME** Creep Rupture (of cladding) **TIME(thermal/post-thermal)** thermal & post-thermal

LOCATION(UZ/EBS/SZ) EBS **TYPE(nominal/disturbed)** NA

FEP DESCRIPTION 2.2 Creep Rupture - Produces single small perforation that releases fission gas and relieving stress. Occurs early, when temperatures are high. Independent of WP integrity.
Dependency: Time at elevated temperatures (YMP)

RELEVANCE Relevant **SCREENING (INCLUDE/EXCLUDE)** Exclude

SCREENING ARGUMENT Creep failure was postulated as the dominant failure mode for fuel in dry storage but has not been observed. DOE sponsored the development of a cladding creep rupture model by Chin and Gilbert (1989). This model was developed for studying temperature limits of cladding for interim storage of spent fuel, and is based on different theoretical failure mechanisms. The dominant failure mechanism is void formation and decohesion at grain boundaries. In earlier cladding failure analyses for the YMP, Santanam et al. (1992) and McCoy (1995) used the Chin model.

TSPA DISPOSITION Not an issue. Will contribute to cladding failure rates in some high temperature design alternatives such as rod consolidation. Current models are sufficient.

REFERENCE Numerous test and models for cladding creep
TSPA-VA, Chapter 6 Section 6.3.1.1.5

MODIFIED BY Al Schenker **MODIFIED ON DATE** 3/31/99 **MODIFIED ON TIME** 1:41:33 PM

WORKSHOP DSNF,WF

OWNER(s) V. Pasupathi (WF/Cladding)

NOTES

All text is draft

Record: 9 of 39 (Filtered)

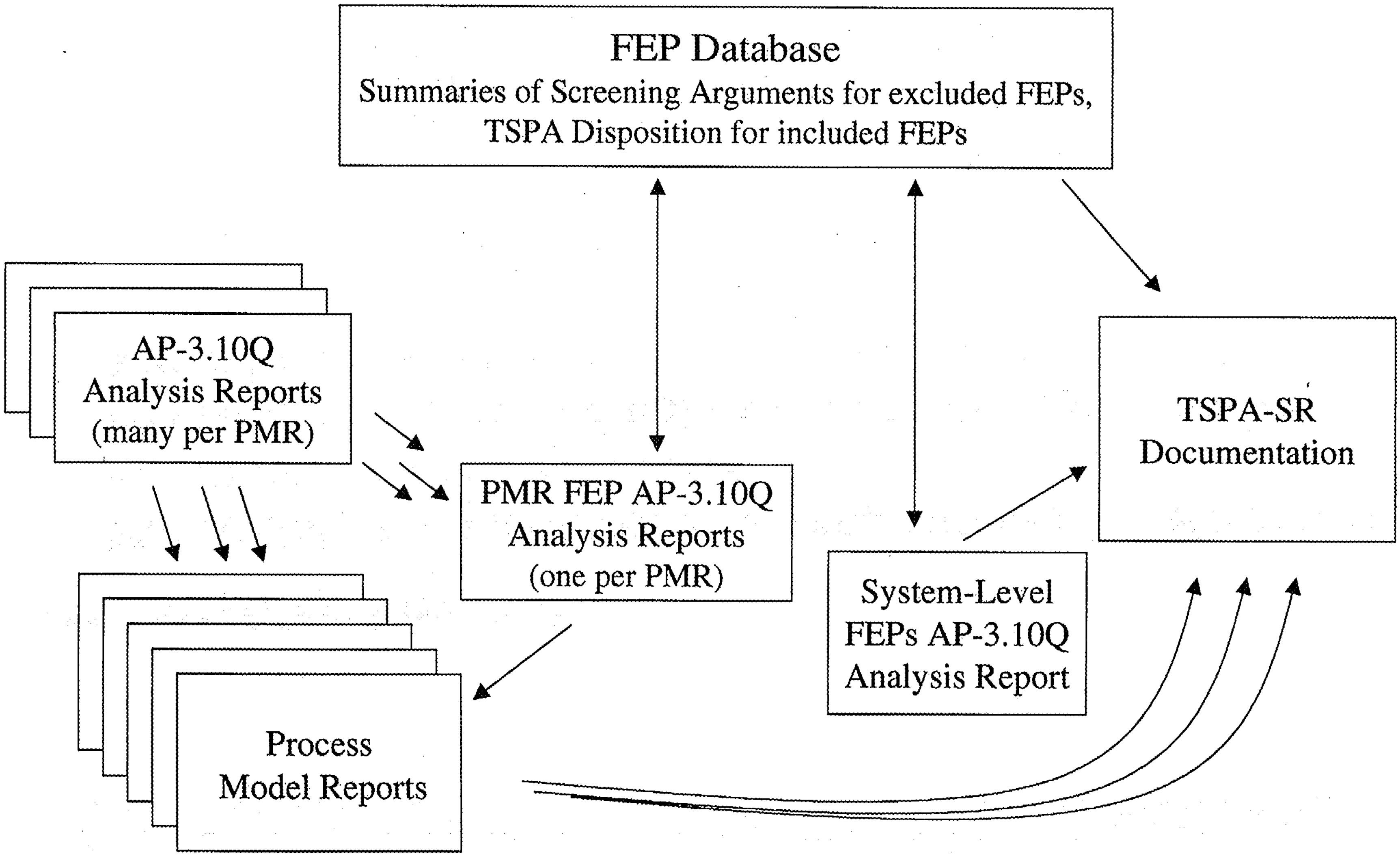
Schedule for the TSPA-SR FEP Database

- Present
  - Developmental stage
- July 1999: Rev. 0
  - Controlled Electronic Database (YAP-SV.1Q)
  - Will contain complete list of FEPs to date, mapping to Process Model Reports and Work Plans
  - Will not contain screening arguments

Schedule for the TSPA-SR FEP Database

- March 2000: Rev. 1.0
  - Will contain summaries of screening arguments referenced to completed analysis reports
  - Will be prepared and completed in parallel with Process Model Reports and TSPA-SR documentation

Documenting the Technical Basis for FEP Screening



Quality Assurance of the Features, Events, and Processes Database

- Database developed under AP-3.10Q work plan
  - Checking and review of screening arguments within database is limited to verification that entries are consistent with the supporting technical documents
  - Technical checking and review of screening arguments occurs during preparation of the supporting technical documents
    - » subject matter experts retain ownership of the technical content
- Controlled database maintained under YAP-SV.1Q

Current Status of FEP Screening and Scenario Selection
(Preliminary, Final Status TBD)

- Volcanism and premature failure of the waste package are the only disruptive events retained for scenario selection
- Criticality will be screened out during the first 10,000 years on the basis of low probability
- Seismic rockfall will be treated in the nominal scenario

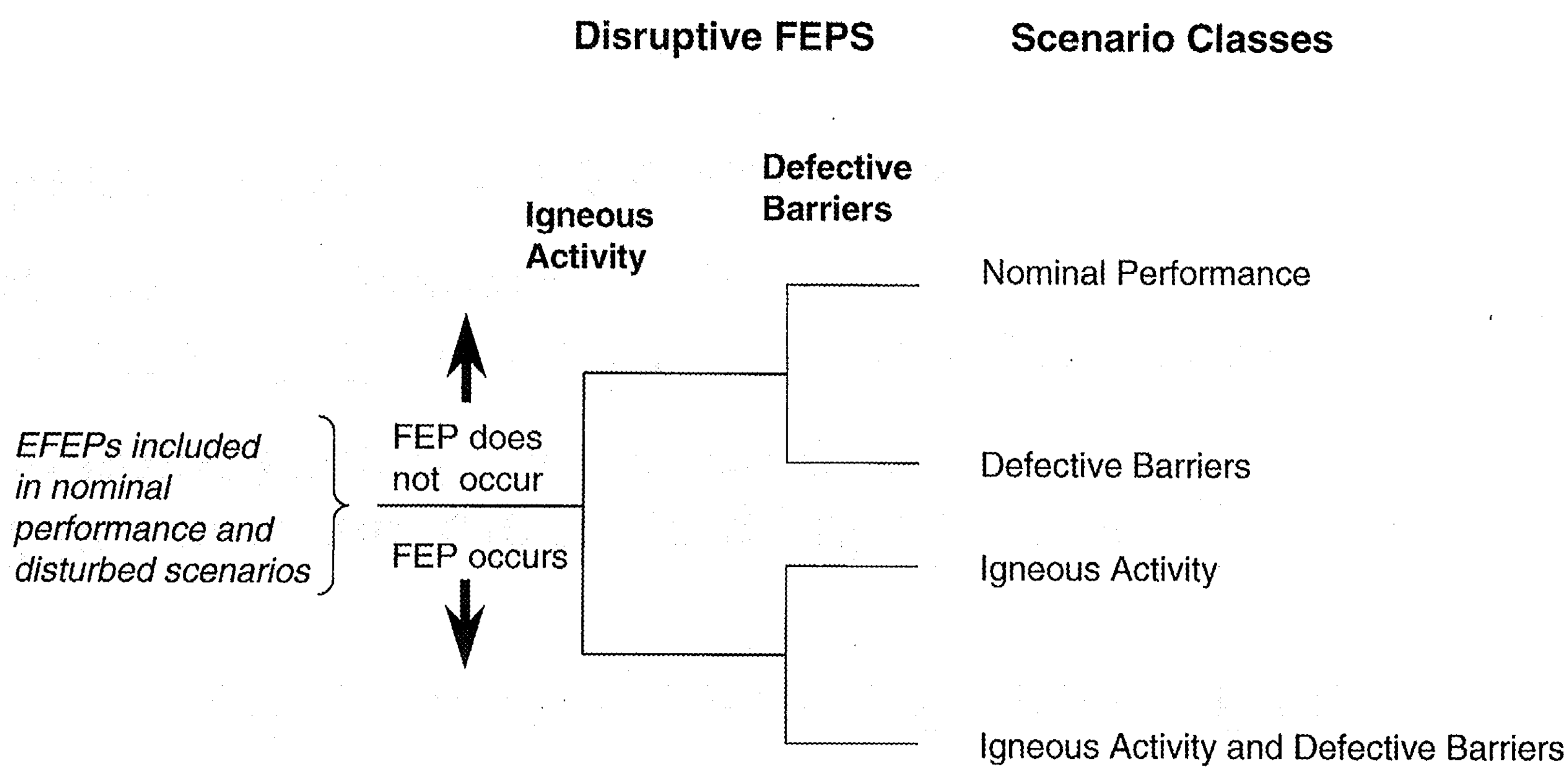
Current Status of FEP Screening and Scenario Selection (Preliminary, Final Status TBD)

(Continued)

- Other seismic effects (e.g., direct faulting, seismic pumping) will be screened out
- All other FEPs will either be included in the nominal scenario or screened out
- Human Intrusion is a special case

Example Logic Diagram for Yucca Mountain

(consistent with the proposal of 5/4/99 to treat premature waste package failure as a possible consequence of initial defects in waste packages and drip shields)



Example Latin Square Diagram for Yucca Mountain

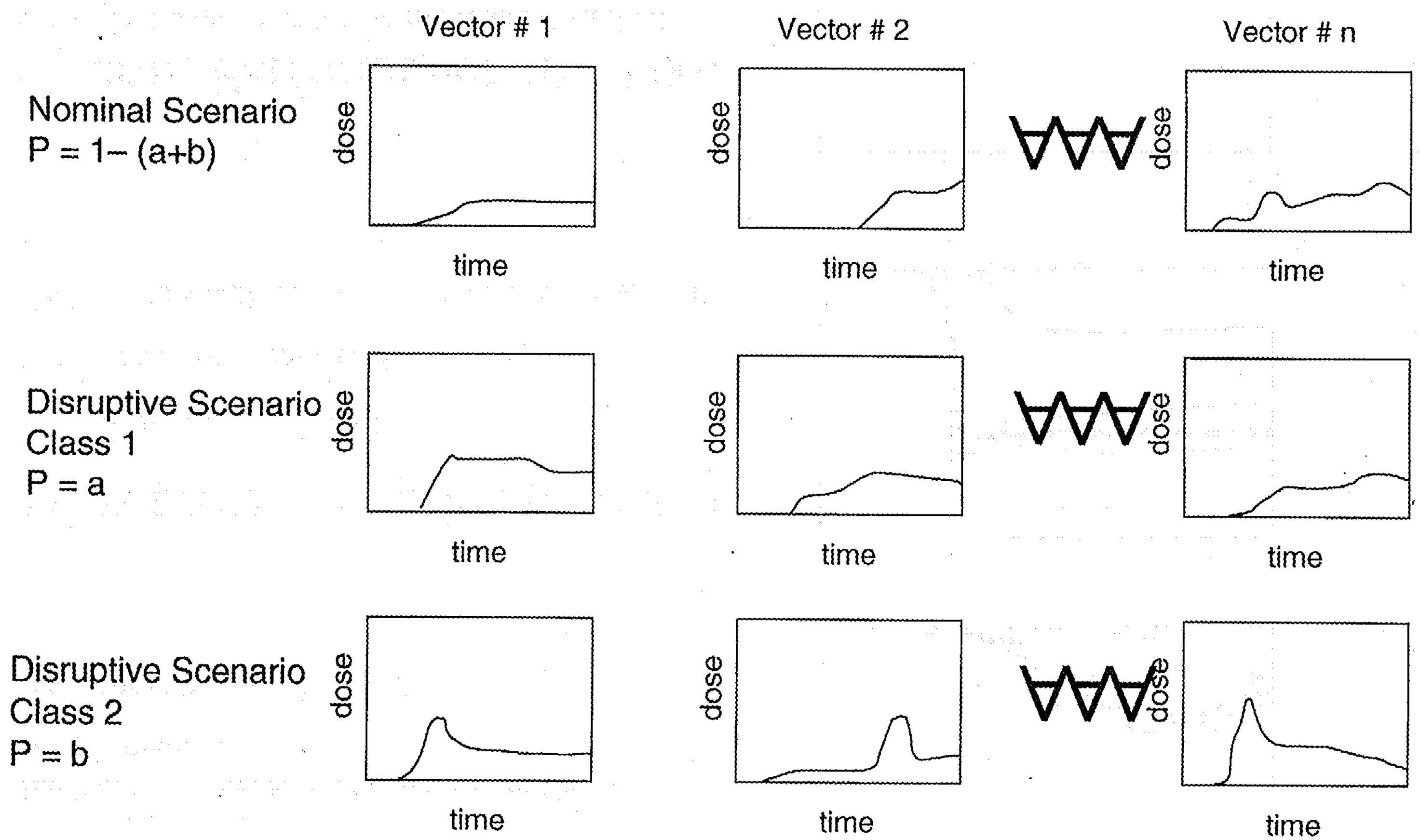
(consistent with the proposal of 5/4/99 to treat premature waste package failure as a possible consequence of initial defects in waste packages and drip shields)

	Defective Barriers Exist	Defective Barriers Do Not Exist
Igneous Activity Occurs	Igneous Activity and Defective Barriers	Igneous Activity
Igneous Activity Does Not Occur	Defective Barriers	Nominal Performance

Combining Results: Nominal and Disruptive Scenarios

- Overall performance (i.e., the annual dose) is the weighted average (or distribution) of time histories for all scenario classes
  - includes probability-weighted consequences of all scenarios in the analysis
  - includes uncertainty from both Monte Carlo simulation and scenario probability assignment

Example Calculation of Expected Annual Dose Curve



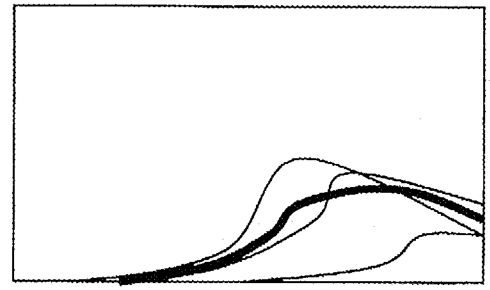
Overall expected dose curve calculated by averaging curves for each scenario class and then summing average curves for each scenario class weighted by scenario class probability

Example Display of Calculated Overall Performance
Dose vs. Time

Nominal Scenario (P = 0.99)

Each curve represents a single Monte Carlo sample element

Each curve has equal weight

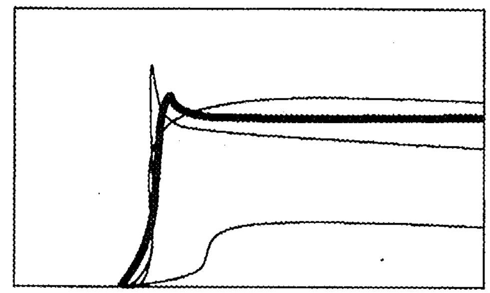


Disruptive Scenarios (P = 0.01)

(e.g., volcanic activity)

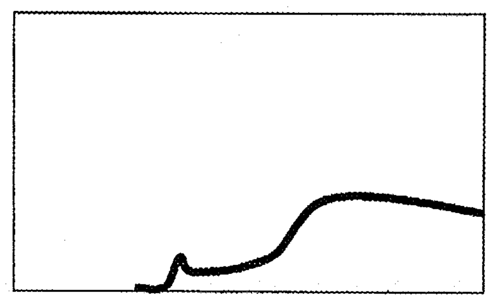
Each curve represents a subscenario

Each curve weighted by the subscenario probability



Overall Performance (P = 1.00)

Curve is the mean of the nominal and disturbed scenarios means, weighted by scenario probability



Summary of the Applications of the FEP Screening Process and the Database

- **Within the Yucca Mountain Project**
  - FEP screening is the basis for selecting TSPA scenarios
  - FEP database verifies completeness of analysis by identifying outstanding issues
  - FEP database and screening process address NRC TSPAI IRSR Acceptance Criteria (Rev. 1.0, Section 4.4)

Summary of the Applications of the Screening Process and the Database

- For NRC and other reviewers
  - Documentation of the completeness of the analysis
  - Searchable electronic entry point into issue resolution--an annotated table of contents to technical issues
  - Links to specific IRSR issues can be built in

YUCCA
MOUNTAIN
PROJECT

Studies

Natural-System Models for Total System Performance Assessment-Site Recommendation

Presented to:
DOE/NRC Technical Exchange on
Total System Performance Assessment
San Antonio, Texas

Presented by:
Michael L. Wilson - TSPA Core Team
Sandia National Laboratories/CRWMS M&O
Performance Assessment Operations

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

May 25-27, 1999

Attachment 36

Overview

- This presentation focuses on changes from VA to SR in the natural-system models:
  - Climate and infiltration (UZFT PMR)
  - Unsaturated-zone flow and transport (UZFT PMR)
  - Seepage into emplacement drifts (UZFT PMR)
  - Thermal hydrology and coupled processes (NFE PMR)
  - Saturated-zone flow and transport (SZFT PMR)
  - Biosphere (Biosphere PMR)

Relevant NRC Key Technical Issues

- Unsaturated and saturated flow under isothermal conditions
- Thermal effects on flow
- Repository design and thermal-mechanical effects
- Evolution of the near-field environment
- Total system performance assessment and integration

Drivers for Model Changes

- Quality assurance
- New repository design
- New regulations (proposed NRC 10 CFR Part 63; EPA 40 CFR Part 197 when it comes out)
- NRC IRSR acceptance criteria and comments on the VA
- Comments from PAPR, NWTRB, USGS
- New data for several models

Quality Assurance

- A large part of the current effort is bringing everything up to "Q" standards
  - All computer codes must be qualified
  - All data must be qualified (may need to qualify some older data via peer review or other method)
  - Strict process control for passing of information from one group to another
  - Strict requirements for planning and carrying out analyses
  - All documentation checked against source data and references to ensure traceability

Climate Change

- Updated climate model: "monsoon" state after about 600 years, "glacial transition (GT)" state after about 2000 years. (VA: change to "long-term average (LTA)" at a time sampled from 0 to 10,000 years.) We are concentrating on 10,000 years
- Uncertainty in climate "amplitude":
  - Monsoon climate is warmer and wetter than present. Lower bound is present-day Yucca Mountain; upper bound is like Nogales, AZ
  - Glacial-transition climate is cool and wet. Lower bound is like Beowave, NV; upper bound is like Spokane, WA. Similar to the LTA climate used in VA

Surface Infiltration

- Several model improvements, including runoff/run-on, temperature dependence, vegetation dependence, and snow pack. Geologic framework has also been updated
- Infiltration uncertainty being developed by varying input parameters over reasonable ranges in a stochastic analysis
- Preliminary results indicate lower mean net infiltration for wet climate than was used for VA (about 20 mm/yr for GT, as compared to about 40 mm/yr for LTA), but greater range

Unsaturated-Zone Flow

- Improved basis for fracture-matrix coupling ("active fracture" model)
- Numerical mesh aligned with individual repository drifts
- Alternative conceptual models of flow through/around perched water being investigated

Seepage into Drifts

- New data from Exploratory Studies Facility (ESF) tests provide better basis for conceptual models and parameter ranges
- Several additional effects being investigated for possible inclusion:
  - Thermal effects
  - Effects of rockfall/drift collapse
  - Effects of THC/THM coupled processes
- Seepage uncertainty derived from input-parameter uncertainty, primarily fracture hydrologic properties (Same basic method as VA)

Thermal Hydrology

- SR design changes that affect Thermal Hydrology (TH):
  - Lower thermal load
  - Waste-stream "blending"
  - Waste packages much closer together ("line load")
  - Drifts much farther apart
  - Preclosure ventilation
  - Drifts backfilled at closure

Thermal Hydrology
(Continued)

- Thermal effects on seepage and water & gas composition being included
- Thermal effects on far-field flow and transport being investigated for possible inclusion

Coupled Processes

- **The following are being investigated for possible inclusion:**
  - THC processes
  - THM processes
  - Effects on temperature and relative humidity at waste package and drip shield
  - Effects on seepage into drifts
  - Effects on mountain-scale liquid and gas flow

Unsaturated-Zone Transport

- Improved EBS/UZ transport coupling being developed to reduce artificial dilution
- Higher fracture porosities (10^{-2} vs. 10^{-4}), based on gaseous-tracer and seepage tests
- New data on flow and transport properties from Busted Butte test
- New colloid-transport process model being developed, in conjunction with Nevada Test Site (NTS) modeling (for both UZ and SZ transport)

Saturated Zone Flow and Transport

- New 3-D process model being developed; dual-porosity formulation, utilizing available data on flowing-interval spacing. Horizontal permeability anisotropy may be included
- New data from Nye County wells
- Improved UZ/SZ transport coupling being developed to reduce artificial dilution
- Particle-tracking method used to reduce numerical dispersion
- Uncertainty in SZ flow based on SZ expert elicitation

Saturated Zone Flow and Transport

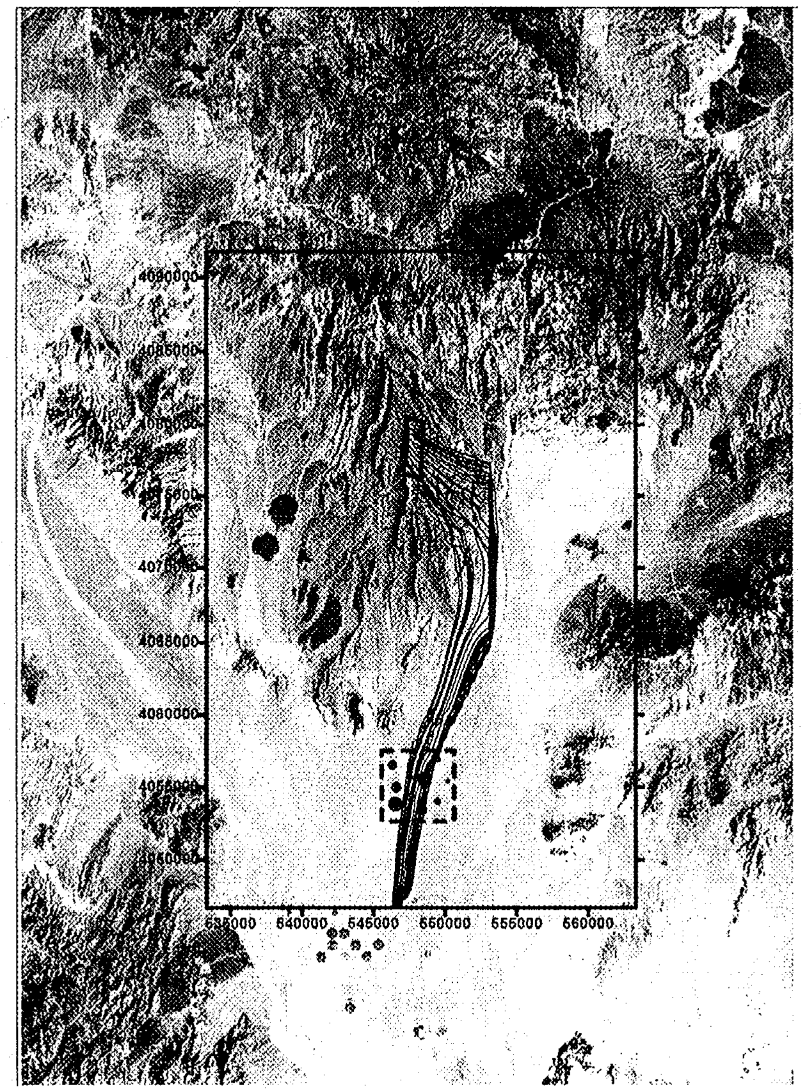
(Continued)

- Two methods of calculating radionuclide concentration are being pursued:
  - Divide radionuclide flux from entire plume into water-usage rate for small farming community (suggested by NRC in proposed 10 CFR Part 63)
  - Take maximum radionuclide concentration in plume at given distance (might be needed for EPA groundwater-protection standard and/or Reasonably Maximally Exposed Individual)
- We are assuming that the compliance point is 20-km downstream from the repository

Saturated Zone Flow and Transport

(Continued)

- First method of calculating radionuclide concentration assumes capture and blending of all radionuclide mass in a hypothetical community water supply
- Second method assumes a small individual well at the location of maximum concentration



Biosphere

- Dose receptor: average member of the critical group within farming community of about 100 people (from proposed 10 CFR Part 63)
  - Critical group being defined from survey data
  - Water usage defined by farming-community needs
- Improved handling of radionuclide buildup/removal in soil
- Including uncertainty in water usage and crop distribution/irrigation, as well as receptor parameters (e.g., consumption rates) and biosphere transfer coefficients

Summary

- Important drivers for changes from VA to SR:
  - Quality assurance
  - New repository design
  - New regulations (proposed 10 CFR 63; 40 CFR 197 when out)
- New data for several models (notably seepage tests, Busted Butte, Nye County wells)
- New models for SZ and colloids
- Progress in coupled processes
- Several other improvements, including improved EBS/UZ and UZ/SZ transport coupling

YUCCA
MOUNTAIN
PROJECT

Studies

Treatment of Engineered Barriers in TSPA-SR

Presented to:
NRC/DOE Technical Exchange on TSPA
San Antonio, Texas

Presented by:
S. David Sevougian, TSPA Core Team
DE&S/CRWMS M&O
Performance Assessment Operations

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

May 25 - 27, 1999

Attachment 37

Overview

- This presentation focuses on changes from TSPA-VA to TSPA-SR in the engineered-barrier-system models:
  - Waste package and drip shield (WP PMR)
  - Waste form (WF PMR)
  - In-drift geochemical environment (EBS PMR)
  - EBS transport (EBS PMR)

Drivers for Model Changes

- Regulatory requirements
  - NRC IRSRs and associated acceptance criteria
  - New regulations (proposed NRC 10 CFR Part 63; EPA 40 CFR Part 197)
- Design requirements
  - New repository design
  - New waste package design (including drip shield)

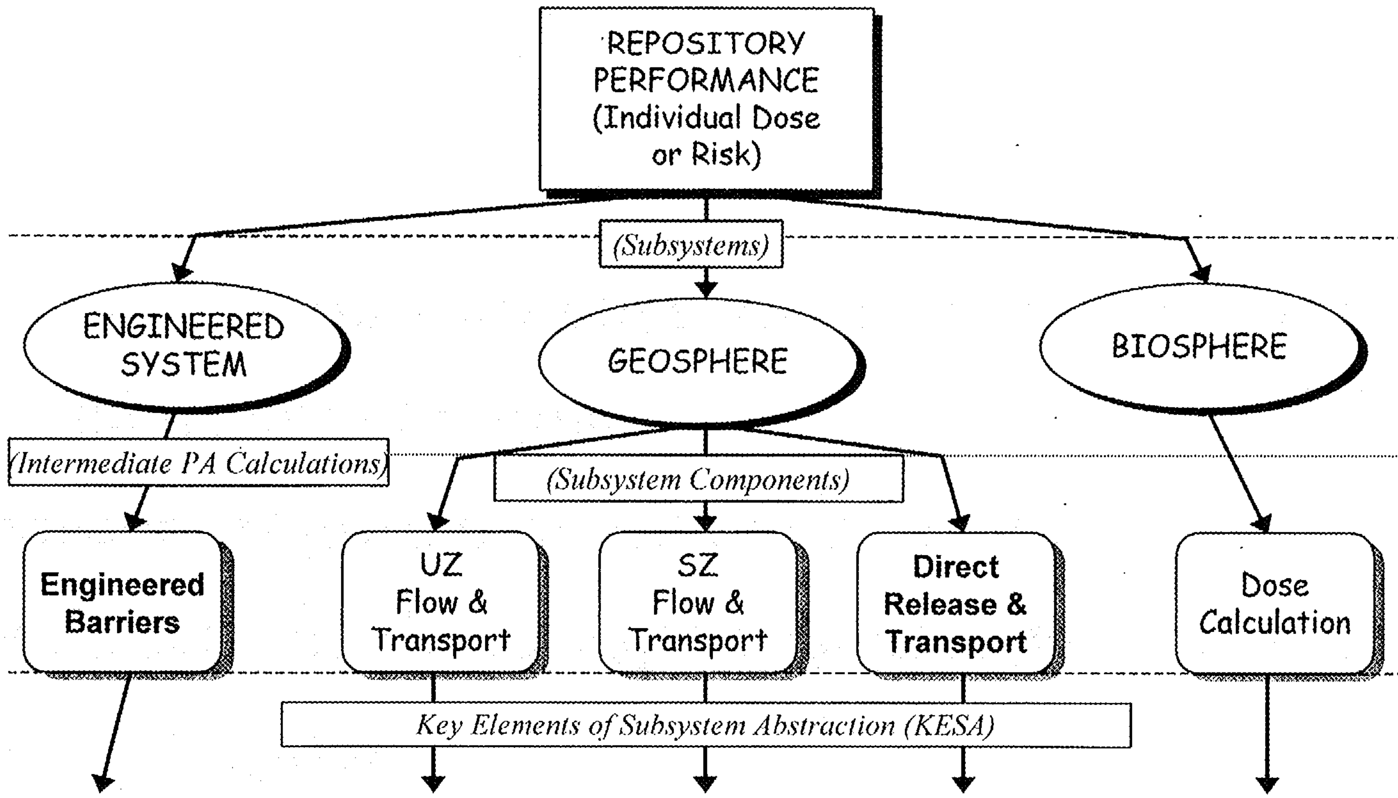
Drivers for Model Changes

(Continued)

- Technical requirements
  - NRC, NWTRB, and PAPR comments on adequacy of models and data used in TSPA-VA
  - New data for several models
- Quality assurance requirements—control and traceability of
  - Data
  - Models & analyses
  - Software

NRC Key Technical Issues and IRSRs Relevant to the Engineered Barriers

- Container life and source term
- Evolution of the near-field environment
- Igneous activity
- Repository design and thermal-mechanical effects
- Structural deformation and seismicity
- Thermal effects on flow
- Total system performance assessment and integration



WP Corrosion (Humid Air, Aqueous, etc.)

Mechanical Disruption of WPs(Rock Falls, etc)

Quantity & Chemistry of Water Contacting WPs & Waste Forms

Radionuclide Release Rates & Solubility Limits

Spatial & Temporal Distribution of Flow

Distribution of Mass Flux between Matrix & Fractures

Retardation in Fractures

Flow Rates in Water-Production Zones

Retardation in Water-Production Zones & Alluvium

Volcanic Disruption of WPs

Airborne Transport of Radionuclides

Dilution of Radionuclides in Groundwater

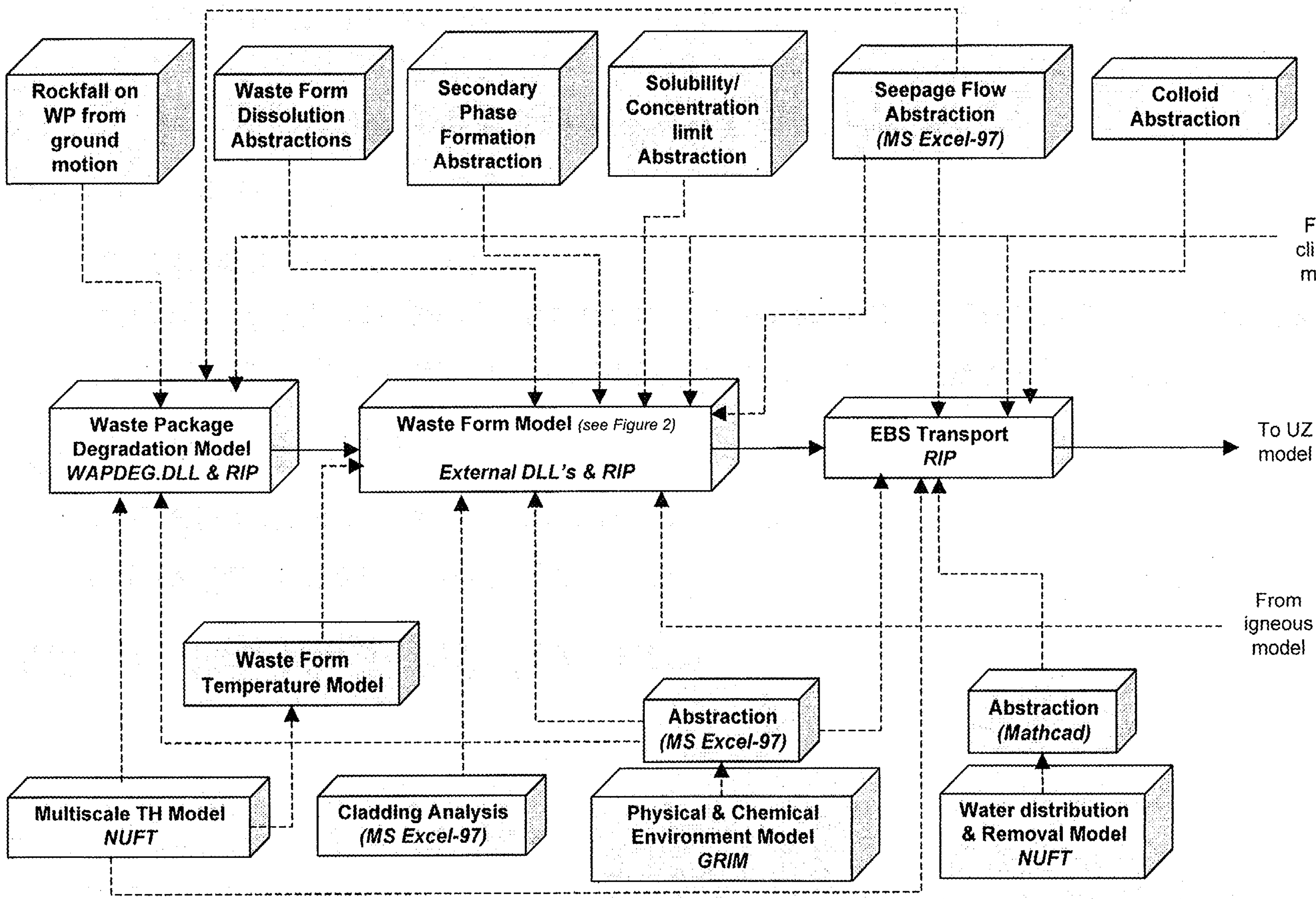
Dilution of Radionuclides in Soil

Location & Lifestyle of Critical Group

EBS & Waste Package Design Changes for TSPA-SR

- Waste Package (WP) design
  - Alloy 22 outer barrier (20 mm)
  - 316 stainless steel inner barrier (50 mm)
- Drip shield (DS)
  - Ti Grade 7 (20 mm) to protect WP from dripping water
  - Allows WPs to pass through "windows of susceptibility" to localized corrosion
- Backfill/invert
  - Quartz sand or crushed tuff ("large" grained)
    - » provide protection for drip shield and WP against rockfall
    - » protects Ti dripshield from reaction with Fe ground support
    - » diffusion barrier

Wiring Diagram for TSPA-SR EBS Models



Performance Goals of Waste Package & Drip Shield in TSPA-SR

- Long-lived waste packages:
  - Waste package failure is defined as an initial perforation through waste container wall (i.e., first pit penetration, first crack propagation, or first patch opening)
- Limited radionuclide release, controlled by:
  - Size of perforations of waste container subsequent to failure
  - Limited water flow through drip-shield/waste-package perforations for those packages contacted by seeps
  - Low invert diffusion coefficient for packages not contacted by seeps

Planned Improvements for TSPA-SR Waste-Package Model

- Models and abstractions based on Project-developed experimental data where feasible
  - More defensible process-model basis for corrosion rate abstractions and local exposure conditions, including the associated variability and uncertainty
  - Where Project data are not available, use available literature data
- Minimize use of expert elicitation

Planned Improvements for TSPA-SR Waste-Package Model

(Continued)

- Additional degradation processes will be evaluated and incorporated in models, if warranted
  - For Alloy 22:
    - » stress corrosion cracking (SCC)
    - » effects of phase stability and aging on localized corrosion, SCC, and rockfall damage
  - For Ti Grade-7 drip shield:
    - » SCC
    - » hydrogen-induced cracking (HIC)
- Include effects of material/manufacturing defects and rockfall damage (if no backfill) by coupling these defects with normal corrosion processes—causes enhanced crevice/pitting corrosion and SCC

Planned Improvements for TSPA-SR Waste-Package Model

(Continued)

- Changes to key model parameters in waste-package conceptual models, if warranted:
  - Random sampling for patch size
  - Random sampling for fraction of WP surface wetted by drips
  - Alternative conceptual models for sequence of WP barrier degradation
    - » patch by patch degradation for both barriers (VA model)
    - » entire surface of inner barrier subject to corrosion following first patch penetration of outer barrier
  - Cyclic wet and dry under dripping

Other Features of WP Model for TSPA-SR

- Because simultaneous WP/DS failures before 10,000 years are so unlikely, requires modified approach to demonstrate consequences in the probabilistic TSPA simulations, either
  - Importance sampling of early (juvenile) WP/DS failures within nominal scenario simulations, or
  - Separate scenarios for early failures
    - » the separate-scenarios time histories then averaged during post-processing with the nominal scenario (which may be zero)

Other Features of WP Model for TSPA-SR
(Continued)

- Variability and uncertainty of WP and DS degradation will be represented in WAPDEG analysis, based on the variability and uncertainty both of individual corrosion processes and of exposure conditions in the repository

Performance Goals of Waste Form in TSPA-SR

- Limited radionuclide release, controlled by:
  - Water contact
  - Degradation of Zircaloy cladding on commercial spent nuclear fuel
  - Degradation/alteration of various waste form types
  - Mobilization of radionuclides
    - » dissolution into aqueous phase (limited by solubility)
    - » attachment to mobile colloids (limited by colloid stability)
    - » gaseous phase transport
  - In-package advection/diffusion through alteration products

Planned Improvements for TSPA-SR Waste-Form Model

- Inventory & package groupings
  - Revised waste stream estimate for most fuel types
  - Possibly additional BWR/PWR source term groupings to ensure greater consistency between heat output and radioisotope inventory
  - Stainless-clad fuel rods packaged into a limited number of packages—not averaged throughout the Zircaloy-clad inventory
  - Plutonium MOX and glass waste included (distributed in HLW and CSNF packages)
  - Evaluate whether to track additional radioelements:
    - » Tc, I, Np, U, Pu, Se, Pa, and C tracked in VA
    - » reevaluate Ac, Ra, Th, Am, Pd, and Cl

Planned Improvements for TSPA-SR Waste-Form Model

- Cladding model (if credit is taken)
  - More defensible estimate of uncertainties in juvenile failure & mechanical failure distributions
  - Reevaluation of localized corrosion model, e.g., DHC
  - Improved temperature history on surface of cladding
- Waste-form matrix degradation
  - Evaluate whether to use alternative CSNF rate law (due to carbonates/silicates)
  - Improved rate equation for N-Reactor fuel (DSNF) based on recent experimental data
  - Vapor hydration model for borosilicate (HLW) glass, which could lead to higher release rates when liquid water is able contact waste

Planned Improvements for TSPA-SR Waste-Form Model

- Dissolved concentration limits
  - Replace 1993 expert-elicitation pure-phase concentration limits ("solubilities") with more recent NEA data, literature data, and Project experiments
  - Revision of mixed-phase concentration limits based on experimental observations—extension of lower bound of Np concentration distribution (secondary phases)

Planned Improvements for TSPA-SR Waste-Form Model

(Continued)

- Colloids
  - In addition to Pu, consider Am
  - More defensible relationship for colloid concentration
  - Incorporate newly available experimental data for reversible sorption/desorption on colloids
  - For irreversible sorption use new desorption test data as conservative upper bound to Benham test data
- In-package transport: see EBS transport

"Performance Goals" of EBS Transport & In-Drift Geochemical Environment (IDGE) in TSPA-SR

- **Limited water contact, controlled by**
  - Dripshield
  - Backfill
- **Long-lived waste packages and drip shields, controlled by**
  - Favorable chemical environment
- **Limited radionuclide release, controlled by:**
  - Favorable chemical environment
  - Slow transport through invert

Planned Improvements for TSPA-SR IDGE/EBS Model

- Chemical composition model of seepage water flowing through backfill, as it affects drip shield degradation
- Effect of salt buildup on WP/DS corrosion
  - lowers vapor pressure and causes condensation of water on WP at higher temperatures
  - Experiments currently being conducted at various T
- Better experimental basis & model for flow diversion in the drift (1/4-scale model)
  - Fraction of drift seepage entering DS
  - Fraction of DS seepage entering WP

Planned Improvements for TSPA-SR IDGE/EBS Model

(Continued)

- In-package chemical environment
  - Feeds WP inside-out corrosion
  - Different chemical environment inside HLW & DSNF waste packages compared to CSNF, if warranted
- In-package transport (if credit is taken)
  - In-package hydrology model, fraction of waste-form surface contacted by advecting water
  - In-package evaporation—no transport out of the WP until liquid can form
  - Basket degradation and waste-form settling
  - In-package sorption—types of degradation phases, linear vs. nonlinear models, available sites

Planned Improvements for TSPA-SR IDGE/EBS Model

(Continued)

- THC model of flow and transport within invert
  - Diffusion coefficient in a non-concrete invert (a function of saturation, which is a function of flux)
  - Physical/chemical property changes in the invert due to precipitation/dissolution (i.e., permeability changes)

Planned Improvements for TSPA-SR IDGE/EBS Model
(Continued)

- **Major uncertainties/variabilities to be quantified**
  - Flow diversion uncertainty through DS and WP (based on experiments)
  - Boundary-condition uncertainty on the chemical composition of water entering drift
    - » from UZ far-field flow and transport model (one chemical composition per flow field, probably 12 total)
  - Repository-scale variability in temperature, relative humidity, and infiltration

Planned Bounding Assumptions for TSPA-SR IDGE Models

- Set of reactions simplified in a conservative sense
- Choose equilibrium over kinetic, where bounding and where data is limited
- Conservative corrosion rates for package internals
- Normative salt approach because no thermodynamic data available for high ionic-strength solutions in the presence of carbonates and silicates

Quality Assurance

- Process-level models and data and their abstractions, including associated software, will be documented and controlled in accordance with applicable procedures, e.g., AP-3.10Q, YAP-SIII.3Q, and AP-SI.1Q
- Fully qualified version of WAPDEG (version 4.0)
- Coupling of TSPA model (WINRIP) and WAPDEG to facilitate TSPA uncertainty analysis and to improve data traceability & control

Quality Assurance
(Continued)

- Qualified IDGE code (GRIM)
  - Connected flow-through geochemical mixing cells
  - Traceability, control, reproducibility, documentation
- Qualified data for concentration limits

Summary

- Important drivers for changes from VA to SR/LA:
  - Quality assurance
  - New repository and waste-package/drip-shield design
  - New regulations (proposed 10 CFR 63; 40 CFR 197 when out)
- New data for several models (notably waste-package degradation, water diversion around DS/WP, and colloids)

Summary
(Continued)

- Planned improvements to engineered barrier models if warranted, e.g., for WP degradation, radionuclide concentration limits, EBS flow and transport, in-drift geochemical environment
- Bounding models/assumptions for some FEPs

YUCCA MOUNTAIN PROJECT

Studies

Control and Traceability of Analyses

Presented to:
DOE/NRC Technical Exchange on
Total System Performance Assessment
San Antonio, Texas

Presented by:
Vinod Vallikat
Technical Lead, TSPA Implementation
Duke Engineering & Services/CRWMS M&O
Performance Assessment Operations

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

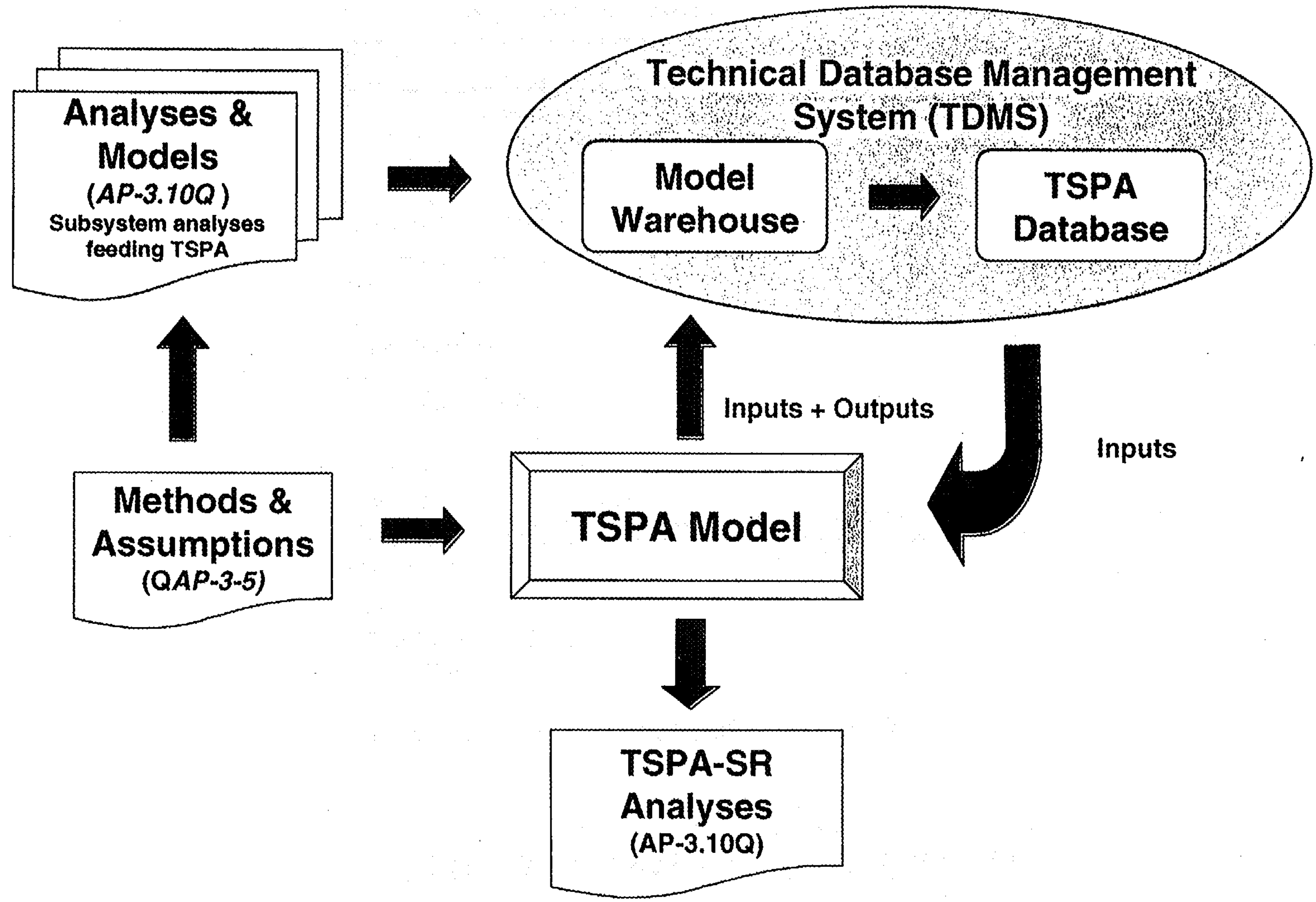
May 25 - 27, 1999

Attachment 38

Objectives and Outline

- To present the framework of control, traceability and transparency of TSPA analyses
  - Overall information flow to TSPA model
  - Improvements to RIP
  - Control of information transfer to TSPA model
  - Modular design of TSPA model
  - Documentation of TSPA model

Information Flow to TSPA Model



Example of Data in TDMS

Automated Technical Data Tracking System (ATDT)

Technical Data Information View Change History

Data Tracking Number:

MO9903MWDLWC51.000 (Link to MWD)

Title:

Description:

LICENSE APPLICATION DESIGN SELECTION (LADS) TOTAL SYSTEM PERFORMANCE RESULTS FOR LINE LOAD (FEATURE 12), WASTE PACKAGE CRMS - DUAL CRM (FEATURE 14) AND CANISTERED ASSEMBLIES (FEATURE 18).

Acquired or Developed Data:

DEVELOPED

Data Preparer/Originator:

ERB, N J - M&O/DUKE

Submittal Date:

03/17/1999

Governing Plan:

SITE CHARACTERIZATION PLAN

Qualification Status:

NOT QUALIFIED

Parameters:

Parameter Name	TBV	Q 1	Q 2	Q 3	Q 4	Q 5	Date	Qual Accn No
REPOSITORY INTEGRATION PROGRAM (RIP) MODEL	N							

Source Data DTN(s) used for this DTN:

- LL980708604242.031
- LL980709604242.041
- MO9807MWDRIP00.000
- MO9811MWDWAP02.000
- MO9812MWDLAC47.000
- MO9812MWDWPC49.000

Improvements to RIP

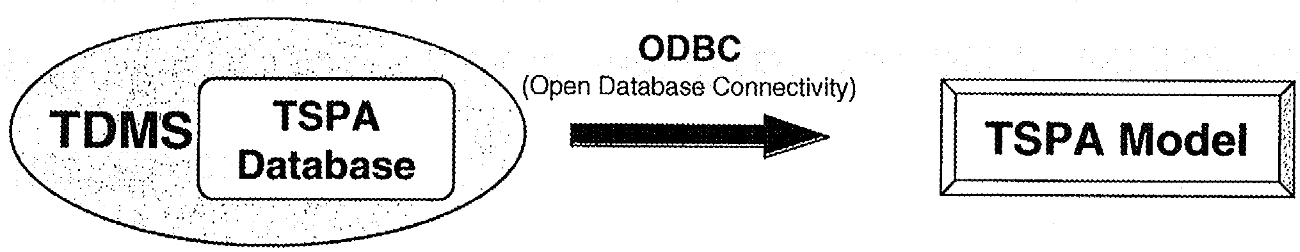
- WINRIP - RIP with windows interface will be used as the main integrating shell for linking all the component codes together and conducting TSPA calculations
- Key Improvements to DOS version of RIP:
  - Object oriented design
  - Direct links to databases and spreadsheets

Units and Conversion Factors Built Internally

- Improved capability to obtain results at intermediate points
- Input and output contained in a single file
- User interface includes: status bar, toolbars and context sensitive menus

Control of Information Transfer

- All inputs to TSPA model imported directly from a database
- Relational database management system
  - Part of Technical Database Management System (TDMS)
  - Subset of TDMS containing only TSPA inputs



Control of Information Transfer
(Continued)

- Advantages
  - Control version of data used (based on effective date)
  - Eliminate analyst input error
  - Provide transparency of data used in the TSPA model
  - Enhance reproducibility

Control of Information Transfer

(Continued)

- Information directly imported includes:
  - Constants
  - Probability distributions
  - Look up tables
  - Files for external codes

Control of Information Transfer

(Continued)

- **Along with parameter definitions, reference information imported includes:**
  - Document title
  - Accession number or catalog number from Technical Information Center
  - Data tracking number from TDMS
  - Qualification status
  - Date stamp
  - Web address (providing direct link to TDMS over M&O intranet)

Modular Design of TSPA Model

- TSPA model will be organized into modules representing different subsystem components
  - Enhance transparency
  - Easy navigation
  - Facilitates inclusion of alternative conceptual models
  - Flexibility for conducting sensitivity analyses
- These self-contained modules will contain:
  - All associated parameters and calculations
  - Parameter level documentation
  - Intermediate results at every component level

Modular Design of TSPA Model
(Continued)

- **Facilitate Review:**
  - Self-contained modules will allow review of each component independently
  - Interpreting and checking final dose results based on intermediate results

Documentation of TSPA Model

- The entire TSPA model will be documented in a Model and Analyses Document (AP-3.10Q procedure)
- Emphasis of this document will be on how each subsystem component is implemented within the TSPA model. Appropriate references and DTN for all the inputs will also be provided in this document

Documentation of TSPA Model
(Continued)

- This document along with other Model and Analyses documents describing individual subsystem components provide a good structure for documenting the entire TSPA analyses

Summary

- Obtaining inputs electronically from a database that is part of TDMS ensures version control of data used and also enhances transparency and traceability of TSPA analyses
- Modular design of TSPA model facilitates saving intermediate results and also provides a good mechanism for review of individual subsystem components

Summary
(Continued)

- Parameter level documentation provides a framework to follow the trail of information used in the TSPA analyses to the data collection point, thus following a strict top-down approach

YUCCA MOUNTAIN PROJECT

Studies

Human Intrusion Analyses for Future TSPAs

Presented to:
DOE/NRC Technical Exchange on
Total System Performance Assessment
San Antonio, Texas

Presented by:
Jerry McNeish, TSPA Dept Manager, CRWMS M&O/DE&S
R. W. Barnard, K. N. Gaither, CRWMS M&O/SNL
N. Erb CRWMS M&O/DE&S
Performance Assessment Operations

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

May 25-27, 1999

Attachment 39

Outline

- Philosophy of human-intrusion analyses
- Proposed 10 CFR 63 Human Intrusion Scenario
- TSPA-VA Human Intrusion Scenario
- Potential Scenarios Considered for TSPA-SR

Background

- Human intrusion is a "special case" in proposed 10 CFR 63 regulation
  - Analyses should test the resilience of the repository to a stylized drilling incident
  - Much of the drilling scenario is specified in the proposed regulations
    - » Analyses are largely deterministic
- Areas where regulation is silent leads to ambiguities in modeling details

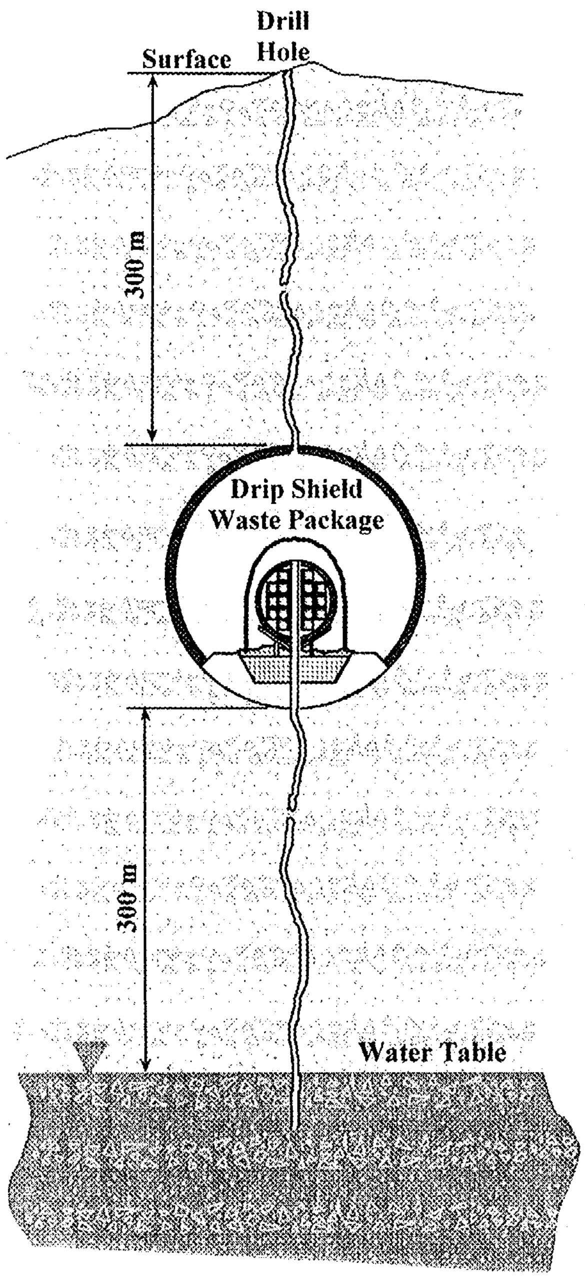
Philosophy in Proposed 10 CFR 63 that Influences Human Intrusion Scenarios

- Intent of analyses is to "... show that the repository exhibits some resilience to a breach of engineered and geologic barriers ..."
- Current drilling practices and equipment typical of resource exploration are to be assumed
  - Avoids making speculative assumptions about future human technology and social structures

Philosophy of Proposed 10 CFR 63

(Continued)

- A stylized intrusion scenario removes from consideration many imponderables
  - Probability of penetrating the waste package
  - Probability of detection and remediation
  - Effectiveness of institutional controls
- Performance measure is the same as for TSPA base case, except:
  - Probability of occurrence is not applied to consequences



Scenario Specifications in Proposed 10 CFR 63

- Assumptions
  - Event occurs 100 years post-closure
  - Current drilling practices
  - Single, nearly vertical borehole through one drip shield and waste package to water table
  - Borehole not adequately sealed

Additional Assumptions Required for Modeling Human Intrusion Scenarios

- Size of borehole
- Area/volume of waste exposed
- Thermal conditions near waste package
- Seepage conditions into drift
- Permeability of borehole
- Waste mobilization and transport processes

Possible Human Intrusion Scenarios Identified by DOE

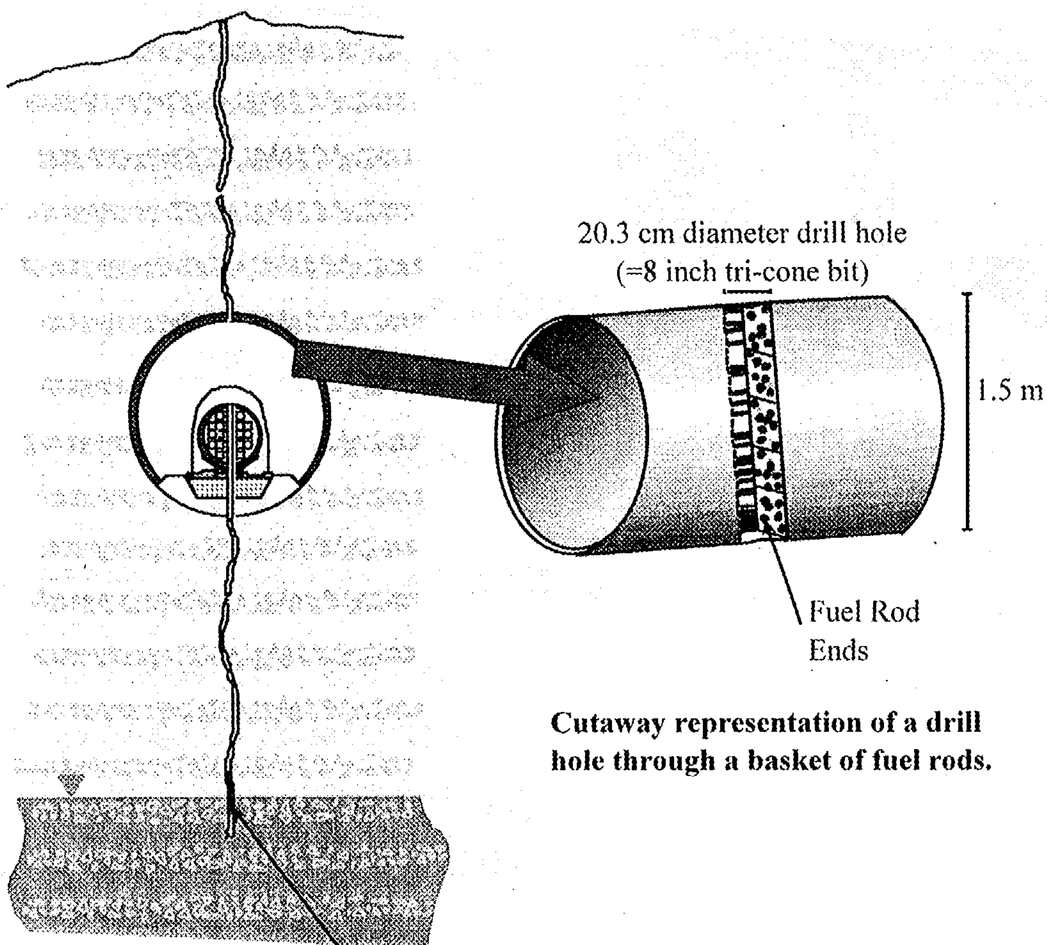
1) Waste in solid form reaches saturated zone (TSPA-VA human intrusion scenario)

2) Advective flow into and through waste package

3) Diffusive mobilization of waste from package

- **Note: Scenarios are listed in:**
  - **Expected decreasing level of consequence**
  - **Expected increasing degree of plausibility**

Scenario 1: Solid Waste at SZ (TSPA-VA Scenario)

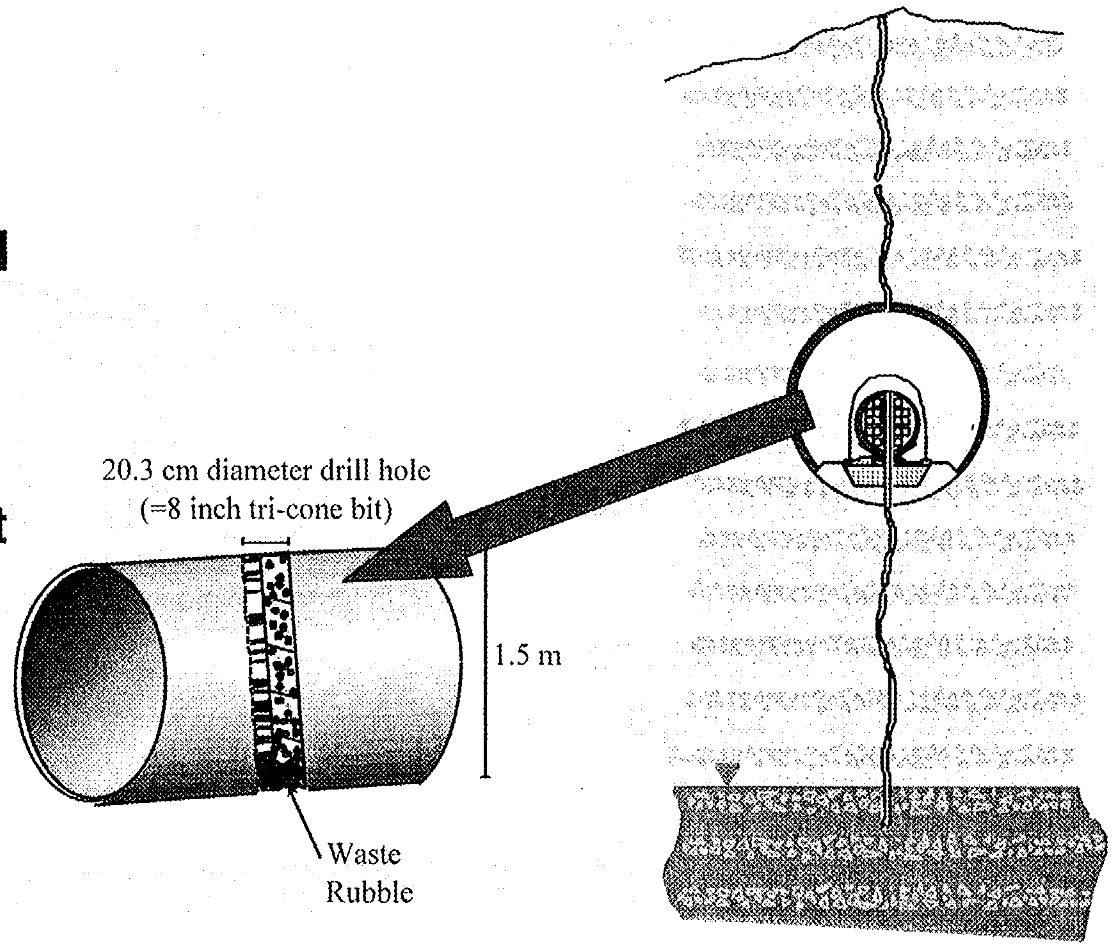


Cutaway representation of a drill hole through a basket of fuel rods.

- **Volume of waste removed ~ 0.05 m^3**
  - **~500 kg of CSNF**
- **Travel time to SZ is "instantaneous"**
  - **Waste dissolves and is transported in SZ from time of incident for 10,000 years**
- **Extremely low probability**
  - **will not be investigated further**

Scenario 2: Advective Flow into Package

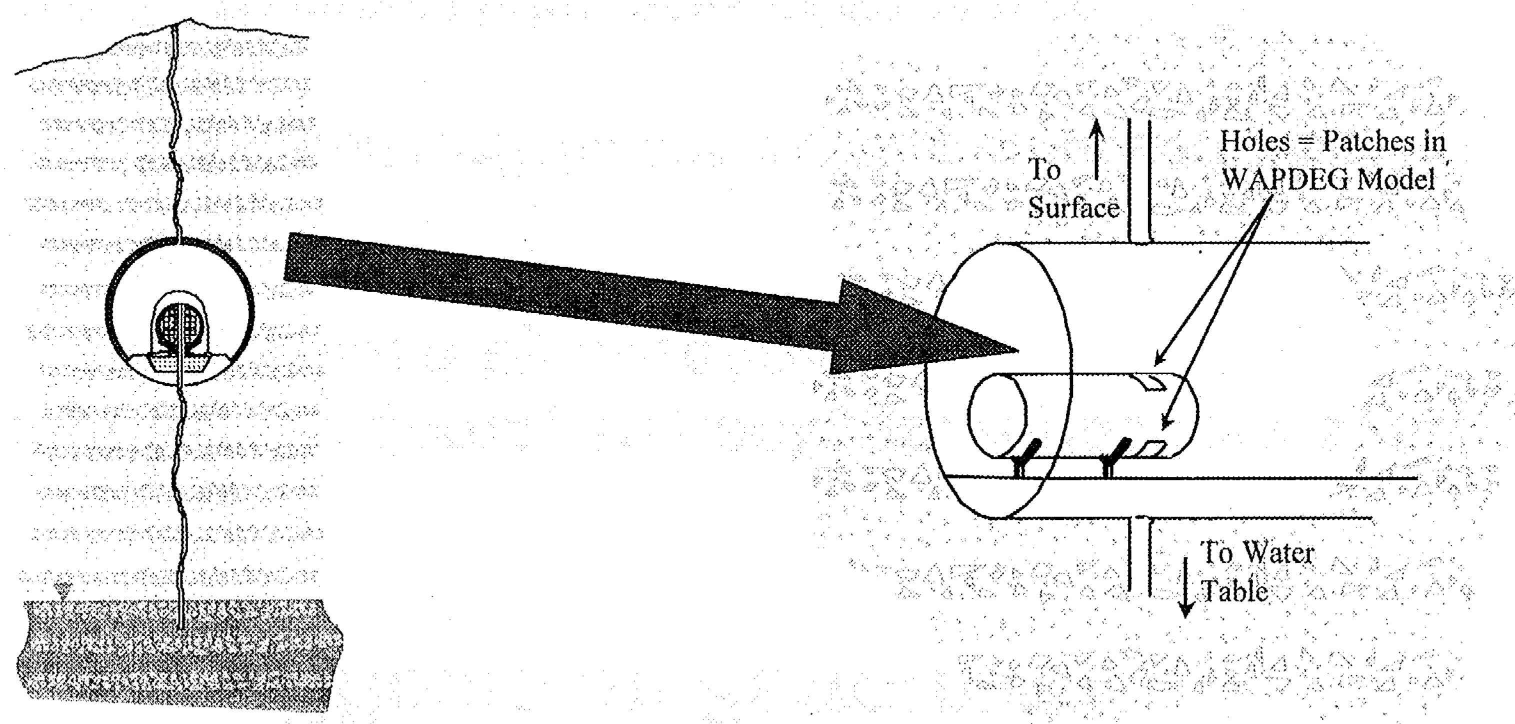
- Liquid water from improperly sealed borehole enters waste package
- Waste dissolves and is transported through UZ and SZ
  - Dissolution and advective transport calculated in RIP, bypassing WP model
  - Borehole in UZ is fast path
  - Assume no travel time in UZ



Cutaway representation of a drill hole through a basket of fuel rods.

Scenario 3: Diffusive Processes Mobilize Waste

- Similar to juvenile failure modeled in TSPA-VA
- Waste-form mobilization calculated in RIP as diffusion
- Drilled hole is equivalent to two "patches" (top and bottom) as modeled in WAPDEG



Effects on Performance

- Except for the damaged package, repository system is not compromised by borehole
- Scenario 1
  - Not considered realistic nor meeting proposed 10CFR63 objectives
  - Only SZ transport influences performance
- Scenarios 2 and 3 test attributes of repository systems (e.g., waste dissolution, thermal conditions, hydrologic conditions, isolation of packages, geologic barrier)

Summary

- Alternative human-intrusion scenarios presented follow specifications in proposed 10 CFR 63
  - Analyses will make reasonably bounding assumptions for key properties of the stylized scenarios
- Resilience of potential repository systems to human intrusion can be investigated in a limited fashion
  - Model parameters can be chosen specific to the Yucca Mountain site
  - Model parameters are within ranges used in base-case analyses