YUCCA
MOUNTAIN
PROJECT

Studies

Overview of Total System Performance Assessment - Viability Assessment

Presented to:
Nuclear Waste Technical Review Board

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Waste Management

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Purpose of Volume 3

- Report results of total-system performance assessment analyses
  - Deterministic base case
  - Probabilistic base case
  - Disturbed events effects (volcanism, human intrusion, nuclear criticality)
  - Comparative analyses
  - Design option analyses
- Provide overview of component models
- Provide input to Licensing Plan (Volume 4)
  - identify most critical components and parameters
  - provide guidance for prioritizing future site and design work

Use of TSPA Deterministic Base Case

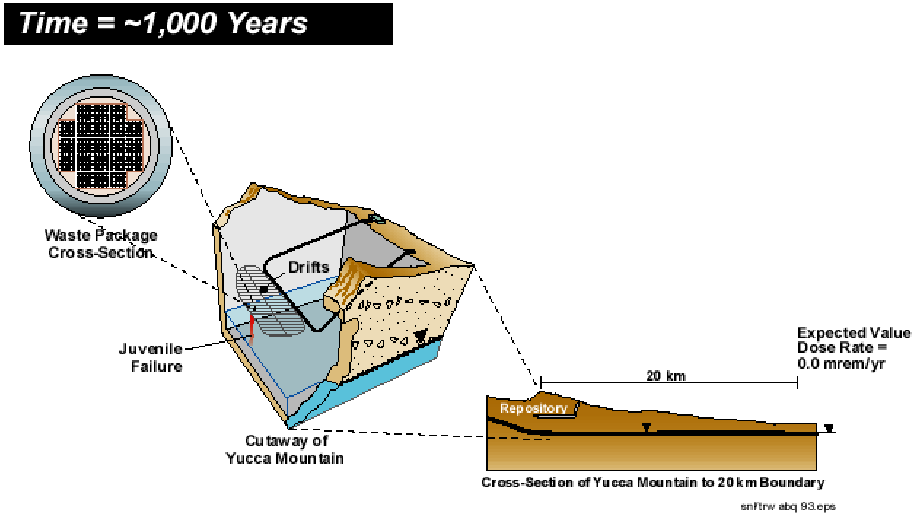
- **Also called the “expected value case”, the deterministic base case was a single realization**
- **Uncertain input parameters were sampled at the mean of their range**
- **The usefulness of the base case is to illustrate the relative influence of various components or sub-components on individual dose results**
- **A deterministic base case would not be used to assess system performance against a regulatory requirement**

Use of TSPA Probabilistic Base Case

- The probabilistic approach uses linked deterministic models with their related parameter uncertainty propagated using a Monte Carlo technique
- Multiple realizations are used to define the range in dose rate
- Probabilistic analyses will ultimately be used to develop the safety case for Licensing

Summary of Results - Emplacement to Several Thousand Years Post-Closure

- Thermal output causes heat in the surrounding rock to rise above boiling until about 1000 years, drying rock out to 10 m from drift wall
- Degradation of outer carbon steel layer begins at several hundred to several thousand years

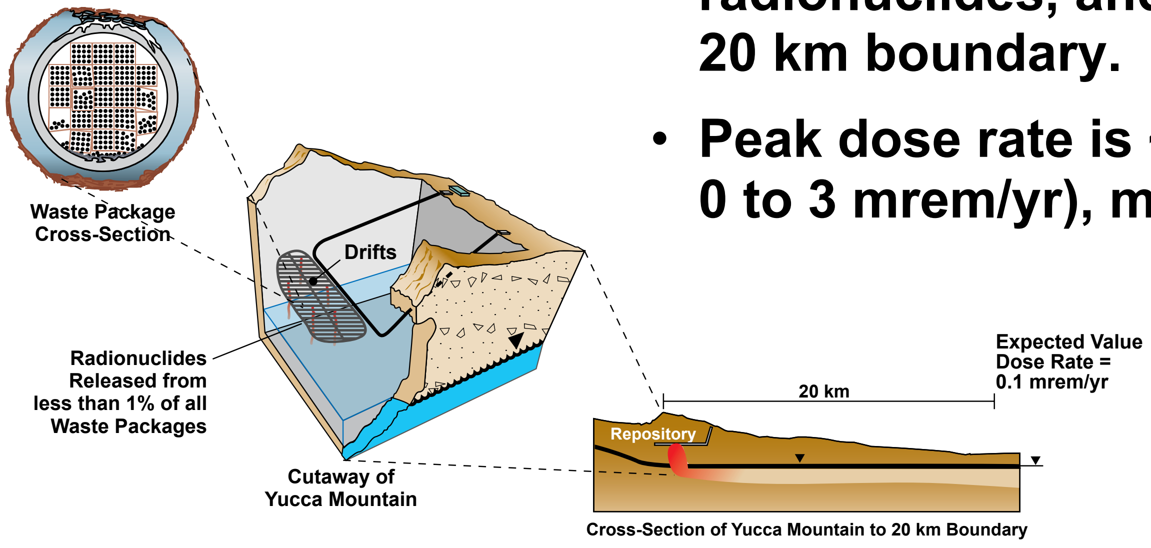


- The inner Alloy-22 layer of some packages, where temperatures drop more quickly, also begins to degrade
- One juvenile failure occurs
- No dose consequence occurs during this time

Summary of Results
Several Thousand Years to 10,000 Years

- **Drift wall returns to ambient temperatures and fluid flow is re-established**
- **Dripping water occurs at some locations**
- **Waste packages continue to corrode and some inner layers are breached (about 1% of the total in the expected value case)**

Time = ~10,000 Years



Cross-Section of Yucca Mountain to 20 km Boundary

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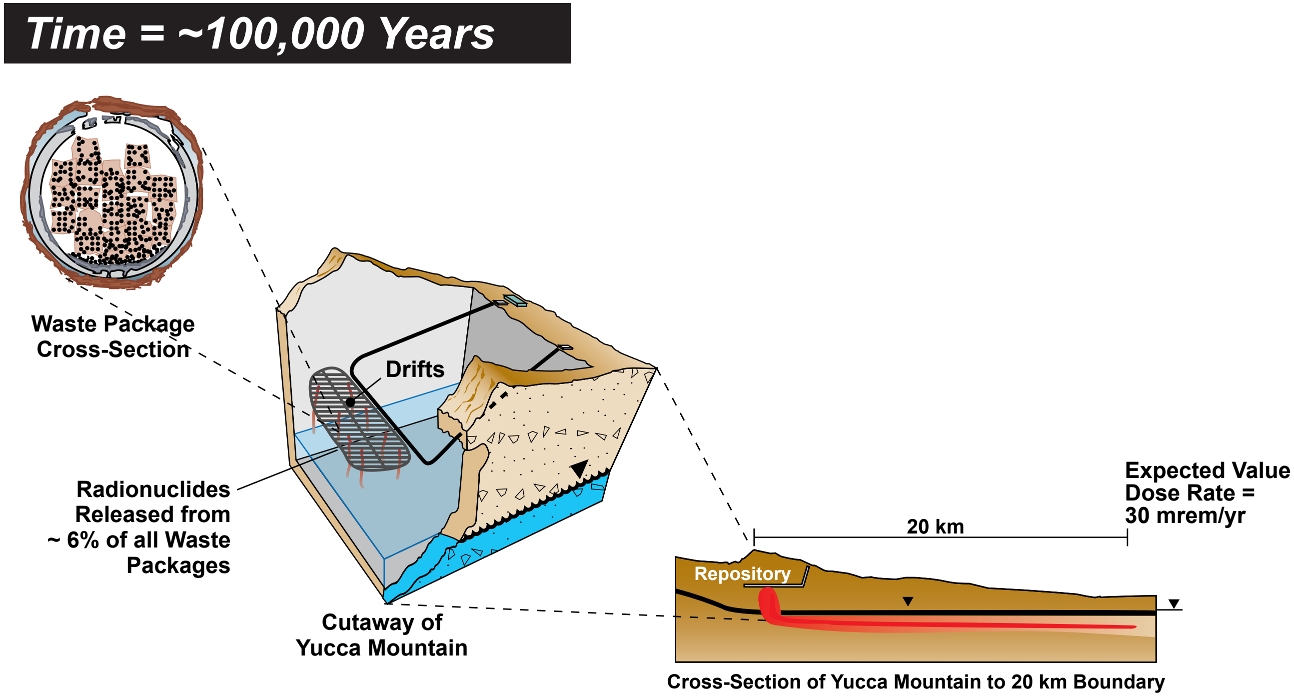
- **Water enters packages, mobilizes radionuclides, and carries nuclides to 20 km boundary.**
- **Peak dose rate is ~0.04 mrem/yr (range 0 to 3 mrem/yr), mainly from Tc and I**

Summary of Results
10,000 Years to 100,000 Years

- Percentage of seeps in the repository varies with climate changes
- Waste packages continue to be breached (about 6% of the total)
- Expected value for peak dose rate at the 20 km boundary is 5 mrem/yr (range 0-300 mrem/yr) with Np as dominant contributor to dose



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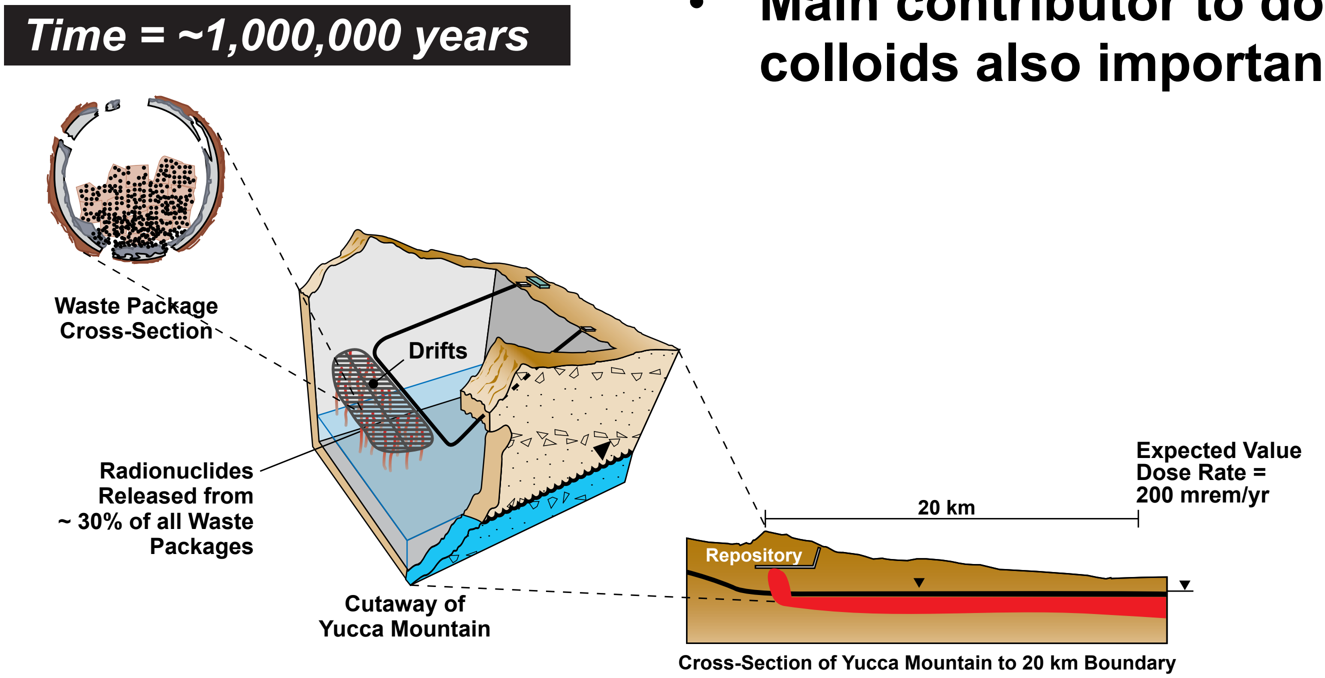
Summary of Results
100,000 Years to 1 Million Years

- Packages contacted by seeps continue to corrode and fail (~30% of total)
- Some packages not contacted by seeps fail (1-2%)
- Peak dose rate at 20 km is ~300 mrem/yr (ranging from 0.1 - 3000 mrem/yr)
- Main contributor to dose is Np, but Pu on colloids also important



Cross-Section of Yucca Mountain to 20 km Boundary

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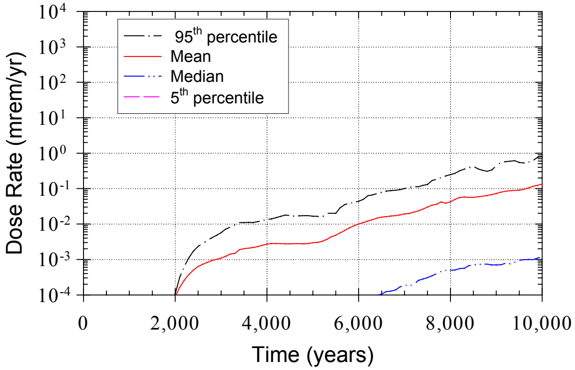
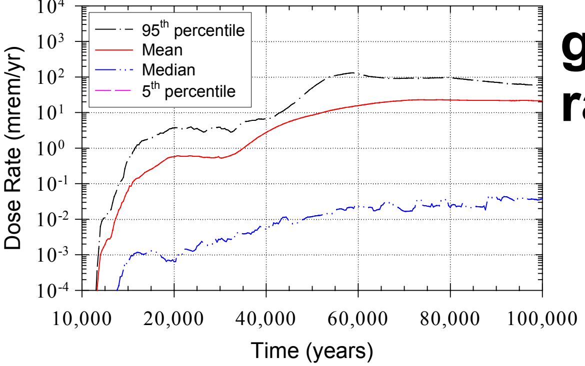
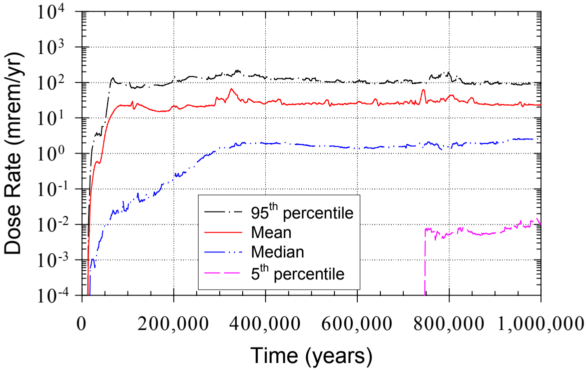
Time Variation of Statistical Descriptors of the Calculated Dose-Rate Distribution



- **Curves generated from mean, median, and 5th and 95th percentiles at each time step (100 years), consistent with methodology proposed in draft 10 CFR Part 63 (as posted on the internet)**



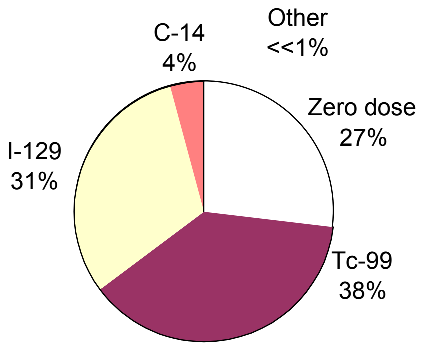
- **For 10,000 and 100,000 year graphs, 5th percentile dose rate is zero**



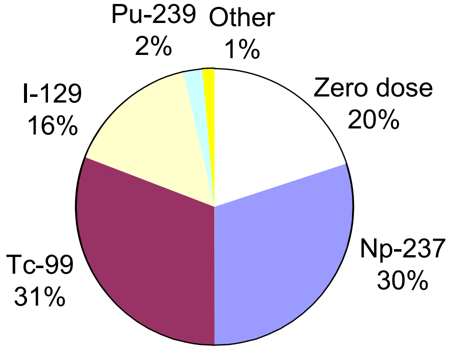
These analyses represent an all pathways individual dose rate at 20 kilometers using ICRP-30.
These results are model-specific and may be insufficient for future licensing proceedings.

Average Contributions to Peak Dose Rate of Different Radionuclides for Three Periods

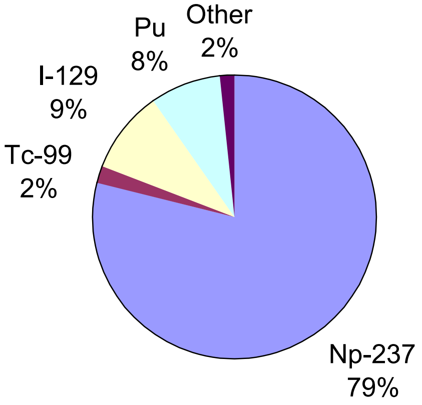
10,000-Year Period



100,000-Year Period



1,000,000-Year Period



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Purpose of Comparative Analyses

- Primary goal is to determine the sensitivity of the TSPA results to the uncertainty in the parameters and the models
- Two types of sensitivity studies were performed on the TSPA results
  - Regression-based sensitivity analyses
  - “One-off” sensitivity analyses

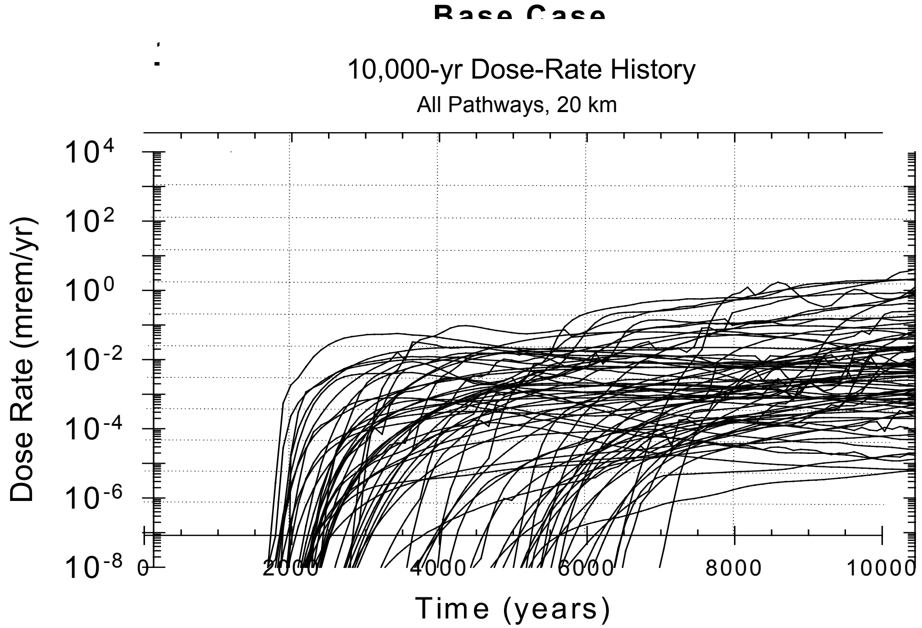
Summary of Uncertainty Analysis for TSPA-VA

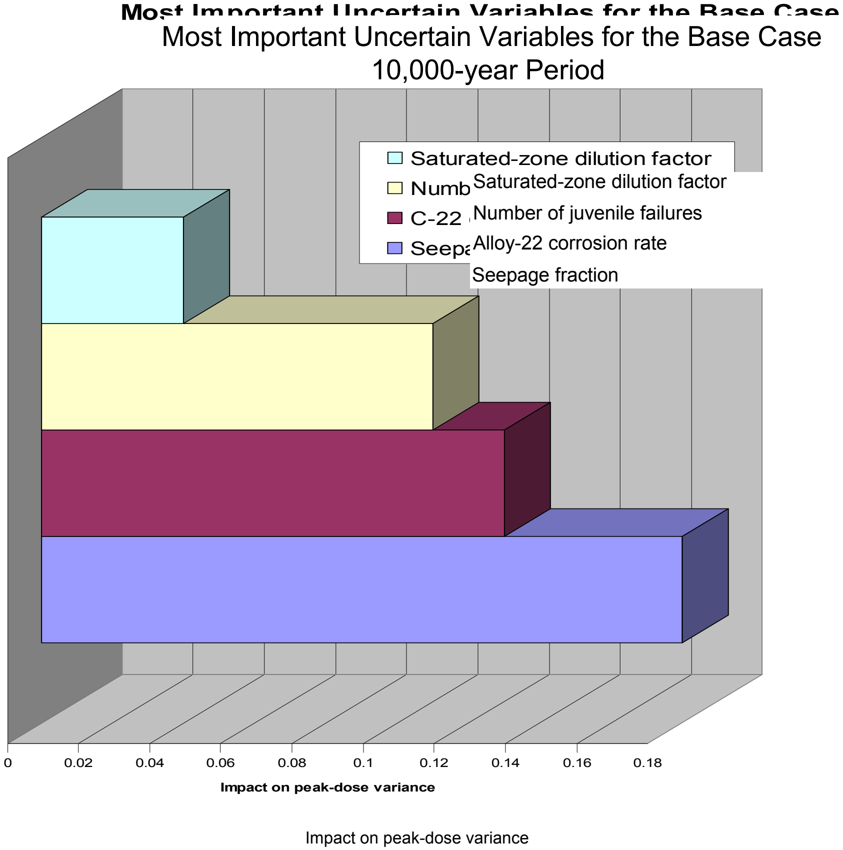
Attributes of the Repository Safety Strategy	Principal Factors	Heterogeneity/ Variability in Base Case	Uncertainty Addressed in Base Case (Chapter 4.3)	Uncertainty Addressed in Comparative Analysis (Chapter 5)
Limited water contacting waste packages	Precipitation and infiltration of water into the mountain	✓	✓	✓
	Percolation to depth	✓	✓	✓
	Seepage into drifts	✓	✓	✓
	Effects of heat and excavation on flow			✓
	Dripping onto waste package	✓		
	Humidity and temperature at waste package	✓		
Long waste package lifetime	Chemistry on waste package			✓
	Integrity of outer waste package barrier	✓	✓	
	Integrity of inner waste package barrier	✓	✓	✓
Low rate of release of radionuclides from breached waste packages	Seepage into waste package		✓	✓
	Integrity of spent fuel cladding		✓	✓
	Dissolution of UO_2 and glass waste-form		✓	✓
	Solubility of Np-237		✓	✓
	Formation of radionuclide-bearing colloids		✓	✓
	Transport within and out of waste package			✓
Radionuclide concentration reduction during transport from the waste packages	Transport through unsaturated zone	✓	✓	
	Transport in saturated zone	✓	✓	
	Dilution from pumping			✓
	Biosphere transport uptake		✓	✓

Regression-Based Sensitivity Analyses

- Purpose is to determine which parameters contribute the most uncertainty to the TSPA results
- Performed on results of probabilistic base case run, sampling from all uncertain parameters simultaneously
  - All parameters retain their assigned range of uncertainty
  - Interactions among the various parameters are maintained
- Suite of results examined using:
  - Scatter plots
  - Regression analyses
  - Contributors to variance

TSPA Regression-Based Analyses for 10,000 year Performance Period





28 realizations have no waste package failures and no doses

These analyses represent an all pathways individual dose rate at 20 kilometers using ICRP-30.
These results are model-specific and may be insufficient for future licensing proceedings.

Responses to Specific Panel Questions About TSPA-VA

- **Assessment of relative uncertainty and conservatisms in TSPA-VA models**
- **Cladding model assumptions**
- **Saturated zone flow and transport model assumptions**
- **TSPA-VA and Defense-in-Depth**

Assessment of TSPA Model Conservatism

- Goal of TSPA-VA model development was to match information and be as realistic as possible
- No model was included if it was judged to be clearly non-conservative
- Wide rage of opinion in whether some models are conservative, realistic, or non-conservative
  - The confidence in these models reflects where there is large uncertainty or diversity of opinion
  - Objective of future work is to address these areas with the most uncertainty and most influence on performance

Confidence and Conservatism in TSPA-VA Models

Attributes of the Repository Safety Strategy	Principle Factors Associated with VA Reference Design	Confidence in VA Models	Significance of Uncertainty to Performance	Relative Conservatism of Model
Limited water contacting waste packages	Precipitation and infiltration of water into the mountain	**4**	◒	**R/C**
	Percolation to depth	**3**	◒	**R**
	Seepage into drifts	**2**	●	**R/C**
	Effects of heat and excavation on flow	**1 - 2**	◒	**R?**
	Dripping unto waste package	**2**	◒	**R/C**
	Humidity and temperature at waste package	**5**	○	**R**
Long waste package lifetime	Chemistry on waste package	**3**	◒	**R?**
	Integrity of outer waste package barrier	**4**	◒	**R**
	Integrity of inner waste package barrier	**3**	●	**R?**
Low rate of release of radionuclides from breached waste packages	Seepage into waste package	**3**	◒	**R?**
	Integrity of spent fuel cladding	**3**	●	**R?**
	Dissolution of UO_2 and glass waste form	**4**	◒	**R**
	Solubility of Np-237	**4**	◒	**R?**
	Formation of radionuclide-bearing colloids	**2**	◒	**R?**
	Transport within and out of waste package	**3**	◒	**C?**
Radionuclide concentration reduction during transport from the waste package	Transport through unsaturated zone	**2**	●	**R/C**
	Transport in saturated zone	**2**	◒	**R/C**
	Dilution from pumping	**5**	◒	**C**
	Biosphere transport uptake	**5**	○	**R**

LEGEND

R = Realistic
C = Conservative
NC = Nonconservative

Low	**Medium**	**High**
○	◒	●
1	**.......................**	**7**

TSPA-VA Cladding Model

- **Two types of cladding included in analyses**
  - **Stainless steel**
    - » **assumed to fail very rapidly (immediately after the waste package fails)**
    - » **only present on 1.15% of total commercial spent fuel**
  - **Zircaloy**
    - » **primary cladding type expected in repository**
    - » **three failure mechanisms included in TSPA analyses**
      - ¤ **"juvenile" failure (defects present at time of waste acceptance)**
      - ¤ **corrosion failure (general localized corrosion in repository)**
      - ¤ **mechanical failure (e.g., due to rock-fall)**
- **Failure analyses showed delayed hydride cracking, creep, generalized corrosion, stress corrosion cracking, and unzipping effects are negligible**

Zircaloy “Juvenile” Failure Model

- **Assumptions**
  - early failure fraction due to defects introduced in the reactor or during handling or storage was found to be 0.1%
  - includes calculated effects of creep rupture, delayed hydride cracking, and hydride reorientation
  - most mechanisms leading to early failure not assumed to operate in cooler repository environment
- **Supporting data**
  - distributions based on industry data from in-reactor, storage pool, and dry storage studies
  - failure distribution two times higher than data reported by EPRI

Zircaloy Corrosion Model

- **Assumptions**
  - Corrosion rates assumed to be 10 to 1000 times less than Alloy-22
  - For each realization, cladding corrosion is assumed to start at the time of first penetration for the waste package
  - 0.28-40% of fuel area exposed is calculated over 1,000,000 years
- **Supporting Data**
  - Data available on generalized corrosion from numerous authors, including the Naval Nuclear Propulsion Program and EPRI
    - » Information on oxidation rates predict 4-53 microns of zircaloy corroded for 10,000 years at 180°C
    - » Temperature dependencies predict practically zero corrosion at repository temperatures
    - » Chemical conditions shown to initiate zircaloy corrosion not anticipated in repository
  - Caveat is that localized corrosion mechanisms and chemical conditions within the waste package are not well understood and introduce significant uncertainty

Zircaloy Mechanical Disruption Model

- **Assumptions**
  - **Mechanical disruption only occurs when waste package integrity is significantly disrupted (after about 100,000 years)**
  - **Mechanical failures assumed to continue linearly on a logarithmic scale from 100,000 to 1,000,000 years.**
  - **Fraction of fuel predicted to be exposed due to rockfall ranges from 0.2-11% over 1 million years**
- **Supporting Data**
  - **Based on information from structural analyses using measured fractures sizes to obtain rock fall characteristics**

TSPA-VA Saturated Zone Model

- **Assumptions**
  - Transport of radionuclides from beneath repository occurs in six 1-D stream tubes
  - Flow paths in the SZ derived from 3-D flow model (14 to 20 km in volcanic units and 0 to 6 km in alluvium)
  - Dilution factor used to account for transverse dispersion (1-100, expected value=10)
  - Groundwater flux scaled in response to climate change (scaling factor for long term average =3.9, for super pluvial = 6.1)
- **Supporting data**
  - Hydrogeologic framework model determines units encountered along flow path (significant uncertainty in location of volcanic/alluvial interface)
  - Uncertainty in dilution factor taken from SZ expert elicitation
  - Groundwater-flux scaling factors for climate change taken from SZ regional-scale flow modeling results

Robustness of TSPA-VA Results

- Components with relatively low confidence (1-2) are areas in which results could change significantly, however, most of these components are thought to be treated relatively conservatively
- Components with high confidence (4-5) are areas where models and results are not expected to change significantly
- Past TSPAs (YMP, NRC, EPRI) all show the same components as important
- Does rate history curves are broadly similar among recent TSPAs by YMP, NRC, and EPRI

TSPA-VA and Defense-in-Depth

- **Volume 3, the TSPA-VA, explicitly acknowledges the need for defense in depth analyses, but makes clear that the TSPA-VA does not provide such an analysis:**
  - **Page 6-2: "The assessment provided here is not final. It does not include the type of evaluation of a number of design options that will be conducted for the LA. Also, analyses to address design margin and defense in depth have not yet been completed."**
  - **Page 6-17: "In order to provide reasonable assurance that a repository at the Yucca Mountain site will not result in a significant long-term risk to public health or safety, the postclosure safety case must include" [several types of analyses not yet addressed, including:] "Analyses of the degree of design margin and defense in depth that could improve performance and mitigate uncertainties in performance."**

TSPA-VA and Defense-in-Depth

(Continued)

- Defense in depth is being addressed as part of the Enhanced Design Alternatives (EDA) effort currently in progress.
  - TSPA tools are being used to define the base case, and to evaluate performance with barriers being systematically neutralized in first order approximations of barrier's importance to performance
  - Defense in depth means that the neutralization of any barrier allows the system to still meet performance objectives.

Uses of TSPA-VA

- Provide insight into relative importance of various components and uncertainty in components
- Determine what may be achievable in terms of system performance
- Enhance our ability to communicate assumptions and results with various audiences
- Test our ability to produce traceable and transparent results
- Determine where our strengths and weaknesses lie in terms of data, assumptions, and models to describe processes, and QA

Uses of TSPA-VA

(Continued)

- **However, TSPA-VA can not be used to**
  - Assess compliance with a regulatory standard
  - Show defense-in-depth
  - Assess the importance of small design changes
  - Determine system suitability
- **Modeling improvements currently being made to the TSPA-VA total system and component models will allow a futureTSPA to support a system suitability finding in the Site Recommendation report**