Implementation of Repository Safety Strategy in TSPA-SR

Presentation to:
Nuclear Waste Technical Review Board (NWTRB)

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Alexandria, Virginia
September 14-15, 1999

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

Yucca Mountain Project

Outline

- **TSPA - an Element of the Repository Safety Strategy**
- **Objectives and Scope of TSPA-SR**
- **Changes from TSPA-VA to TSPA-SR to Address**
  - **regulatory requirements**
  - **comments received on TSPA-VA**
    - » **traceability**
    - » **transparency**
  - **enhanced analyses and models**
- **TSPA-SR Contents**

Elements of DOE's Repository Safety Strategy - Steps to Development of the Safety Case

- **Total system performance assessment**
  - **repository system concept**
  - **performance assessment analyses**
- **Design margin and defense-in-depth**
  - **sensitivity and importance analyses**
- **Explicit assessment of disruptive processes and events**
- **Insights from natural analogs**
- **Performance confirmation plan**
  - **long-term testing to confirm models used in analyses**

[Analysis of first 3 bullets documented in TSPA-SR]

Objectives of TSPA-SR

- **Provide part of technical basis for DOE decisions regarding site recommendation**
- **Evaluate system compliance with applicable post-closure performance requirements**
- **Evaluate significance of various barriers and barrier components to system performance**

Scope of TSPA-SR

- **Develop and apply TSPA methodology consistent with regulatory requirements**
- **Use reasonably representative models based on defensible process-level models and abstractions**
- **Calculate expected dose to average member of critical group**
- **Evaluate sensitivity of system performance to uncertainties in process and abstraction models**
- **Document assessments in a manner suitable to assure transparency and traceability**

Factors Driving Changes from TSPA-VA to TSPA-SR

- Repository Safety Strategy
- Regulatory requirements
  - Site specific criteria
  - IRSR acceptance criteria
- External and internal reviews of TSPA-VA
  - NRC; NWTRB; DOE; USGS; ACNW; Peer Review Panel
- New/revised site and design information
  - analyses; models; data
- Design changes
- Improved QA processes and procedures

Changes in Regulatory Requirements (10 CFR 63.113)

(a) The geologic repository shall include multiple barriers, consisting of both natural barriers and an engineered barrier system.

(b) The engineered barrier system shall be designed so that, working in combination with the natural barriers, the expected annual dose to the average member of the critical group shall not exceed 0.25 mSv (25 mrem) TEDE at any time during the first 10,000 years after permanent closure . . .

(c) *The ability of the geologic repository to limit radiological exposures to those specified in paragraph (b) of this section shall be demonstrated through a performance assessment* that meets the requirements specified at Sec. 63.114, uses the reference biosphere and critical group specified at Sec. 63.115, and excludes the effects of human intrusion.

Changes in Regulatory Requirements - Definition of Performance Assessment (10 CFR 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.

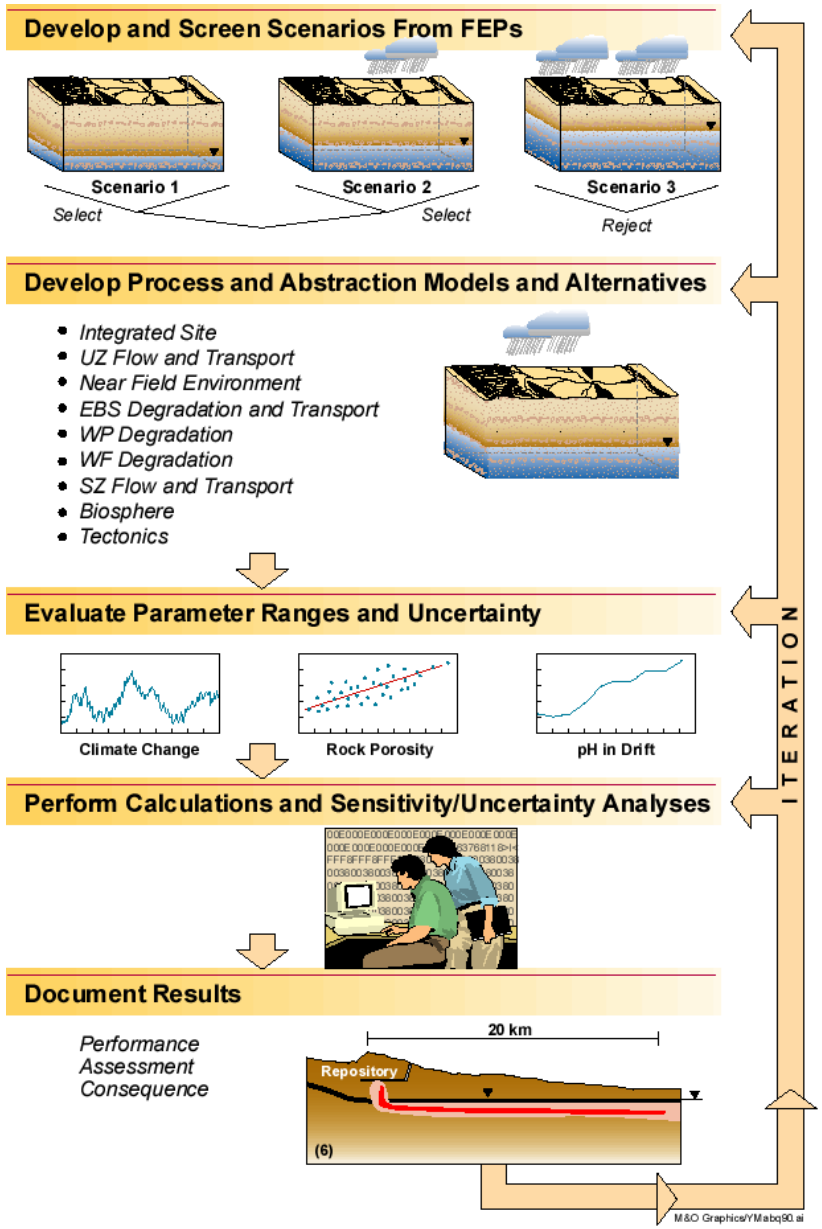
Comparison of VA and SR TSPA Requirements

TSPA Requirements	TSPA-VA	TSPA-SR
Performance Measure	Dose	Dose (& Concentration)
Criteria	Probable behavior	Expected dose
Group	Rural residential farmer	Average member of critical group / Reasonably maximally exposed individual
Location	20 km	20 km (or 5, 18, or 30 km)
Time	Peak dose to 1,000,000 years	10,000 years (Longer timeframes for informed decision making)

Comparison of VA and SR TSPA Requirements

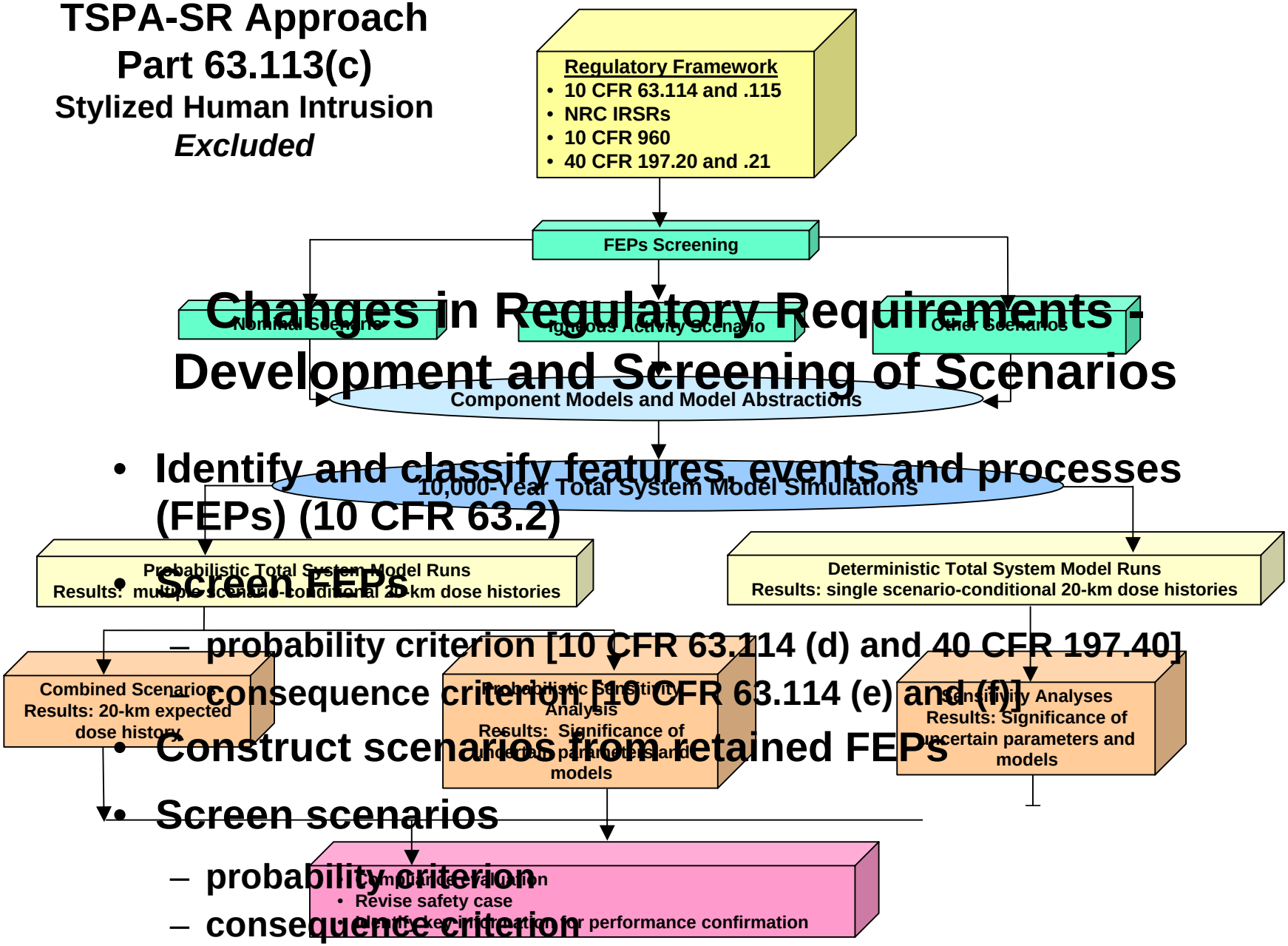
TSPA Requirements	TSPA-VA	TSPA-SR
FEPs	Analyzed separately	Screened; included in expected dose if $P>10^{-4}/10^{4}$ years
Human intrusion	Stylized calculation	Stylized calculation
Uncertainty analysis	Probabilistic analyses (mean of peaks)	Probabilistic analyses (peak of means)
Multiple barrier analyses	Sensitivity analyses	Barrier importance and sensitivity analyses

Performance Assessment Method



TSPA-SR Approach Part 63.113(c)

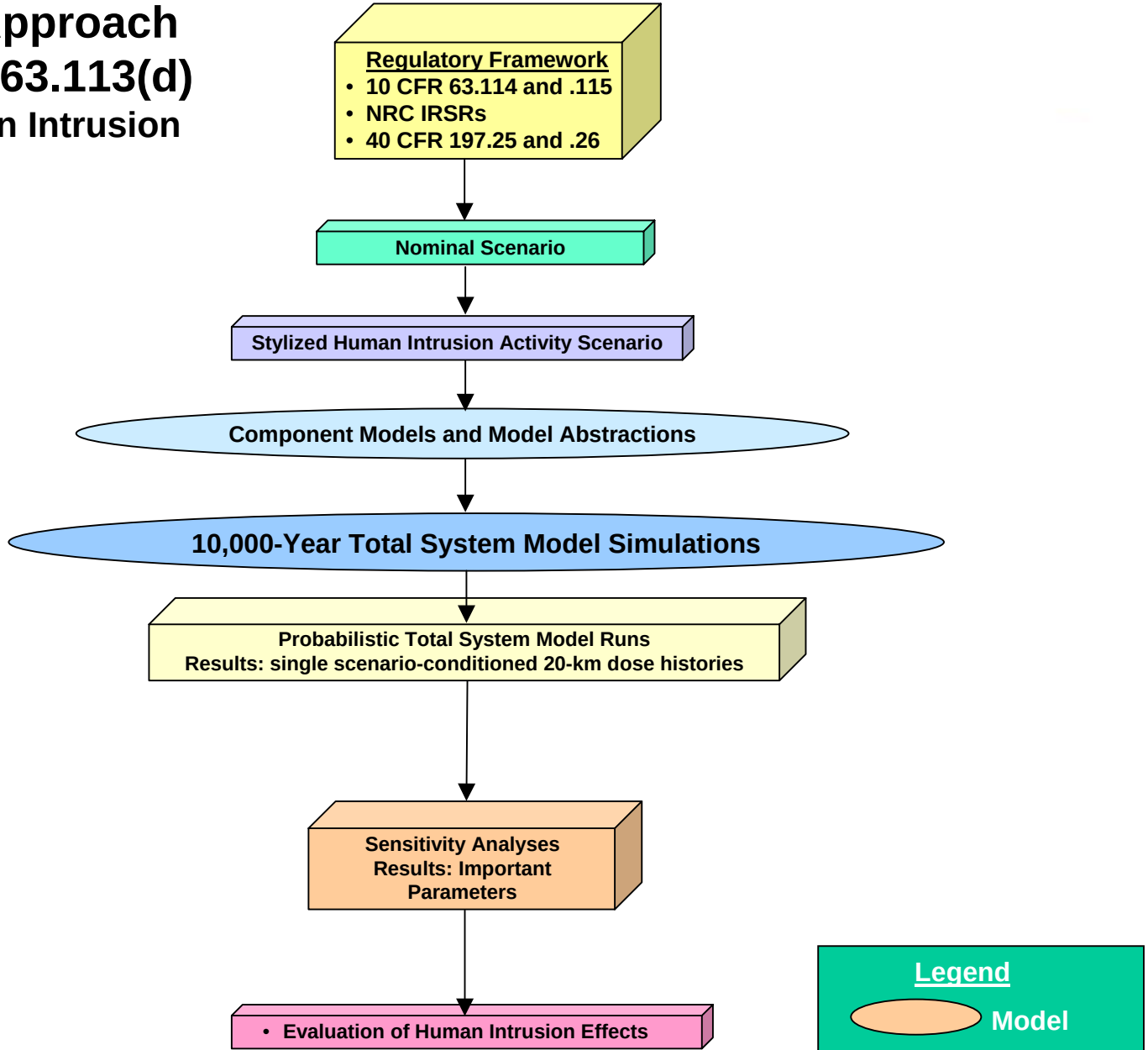
Stylized Human Intrusion *Excluded*



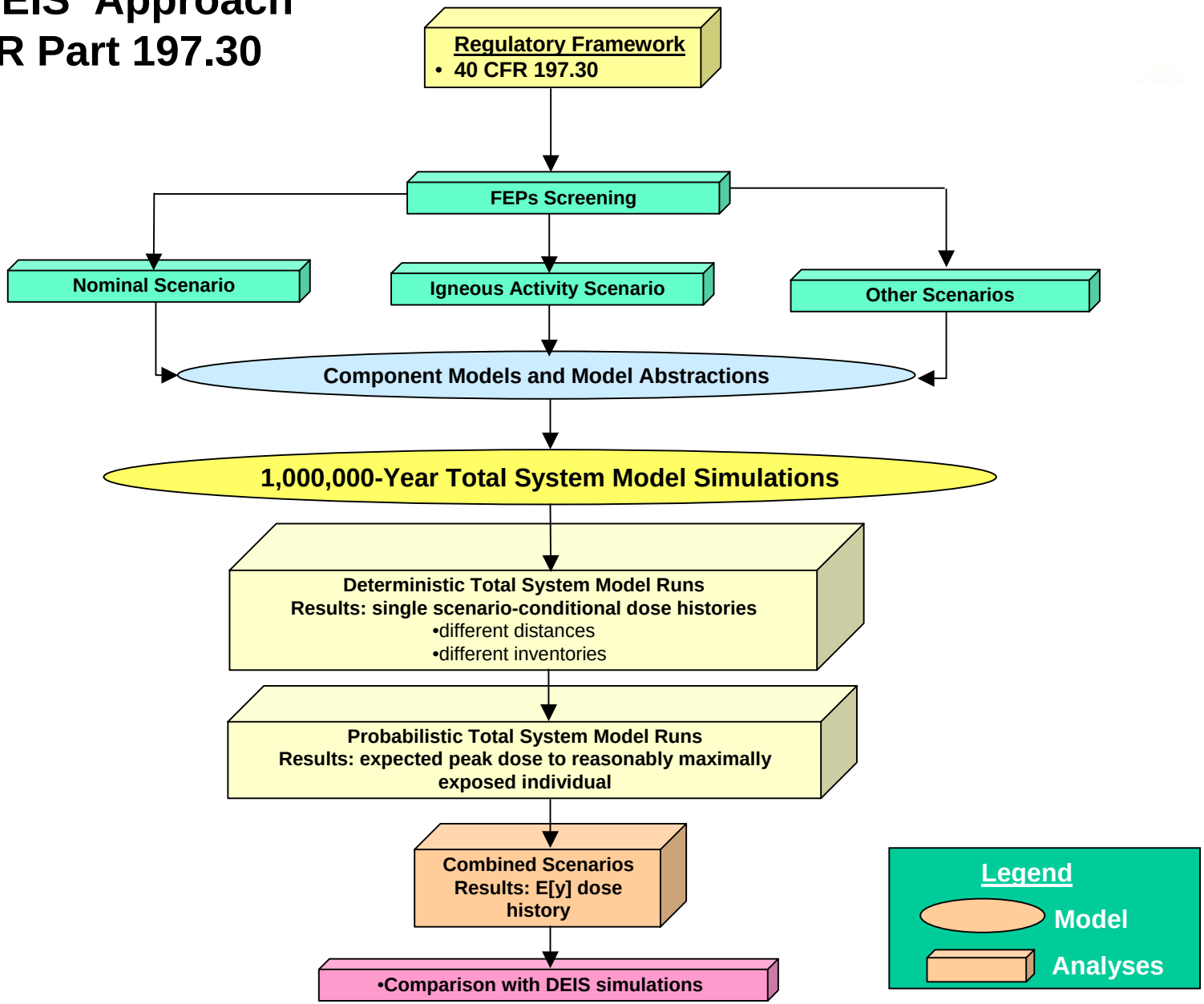
Changes in Regulatory Requirements - Development and Screening of Scenarios

- Identify and classify features, events and processes (FEPs) (10 CFR 63.2)
- Screen FEPs
  - probability criterion [10 CFR 63.114 (d) and 40 CFR 197.40]
  - consequence criterion [10 CFR 63.114 (e) and (f)]
- Construct scenarios from retained FEPs
- Screen scenarios
  - probability criterion
  - consequence criterion
- Implement retained scenarios in TSPA

TSPA-SR Approach
10 CFR Part 63.113(d)
Stylized Human Intrusion



TSPA-FEIS Approach
40 CFR Part 197.30



Synopsis of Issues and Concerns from Reviews of TSPA-VA

- **Traceability of model results to underlying models and data**
- **Transparency of model results**
- **Treatment of alternative models**
- **Definition of major assumptions and their effects on results and conclusions**
- **Validity/confidence in process and abstraction models**

Traceability of Process/ Abstraction Models

Regulatory Objectives

NRC-10 CFR Part 63
EPA-40 CFR Part 197
DOE-10 CFR Part 960

Technical Objectives/Criteria

NRC IRSR Acceptance Criteria; Observations on TSPA-VA
NWTRB Comments on VA
DOE Repository Safety Strategy
DOE and USGS Reviews of TSPA-VA
TSPA-VA Peer Review Suggestions
State of Nevada; Affected Units of Local Government
Public

Prior TSPAs

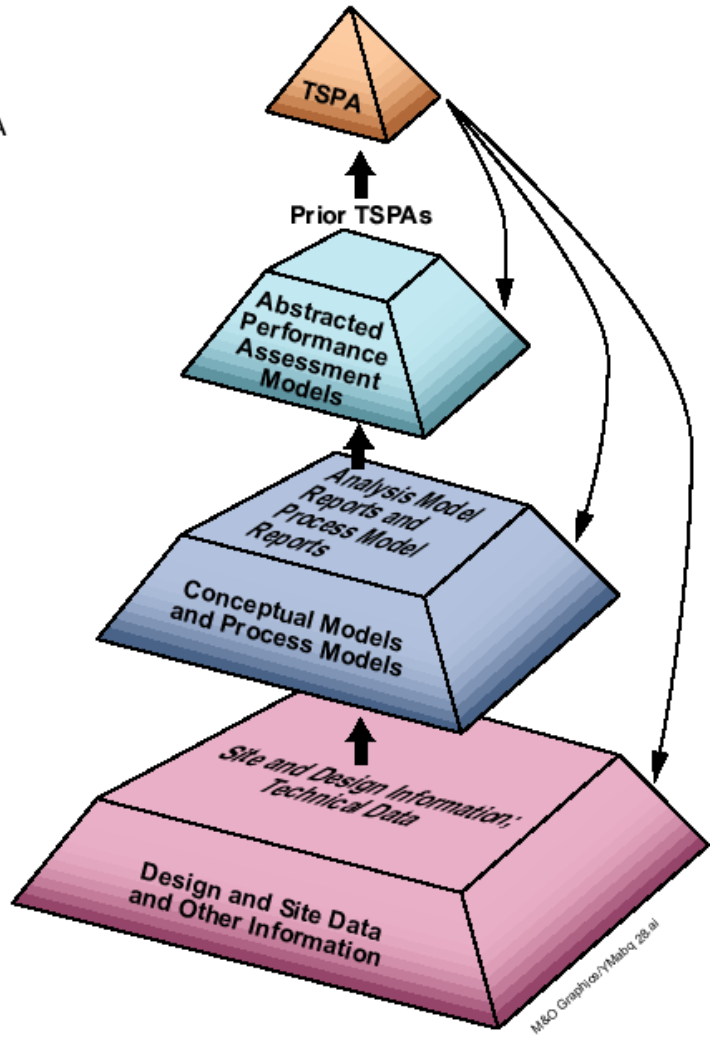
DOE TSPA-91, 93, 95, TSPA-VA, TSPA-DEIS
NRC IPA-1, -2, -3.1, -3.2
EPRI TSPA Phases 1, 2, and 3

Process Model Reports

Integrated Site Model
Unsaturated Zone Flow and Transport Model
Near-Field Enviroment Model
Engineered Barrier System Degradation Model
Waste Package Degradation Model
Waste Form Degradation Model
Saturated Zone Flow and Transport Model
Biosphere Model
Tectonics Model

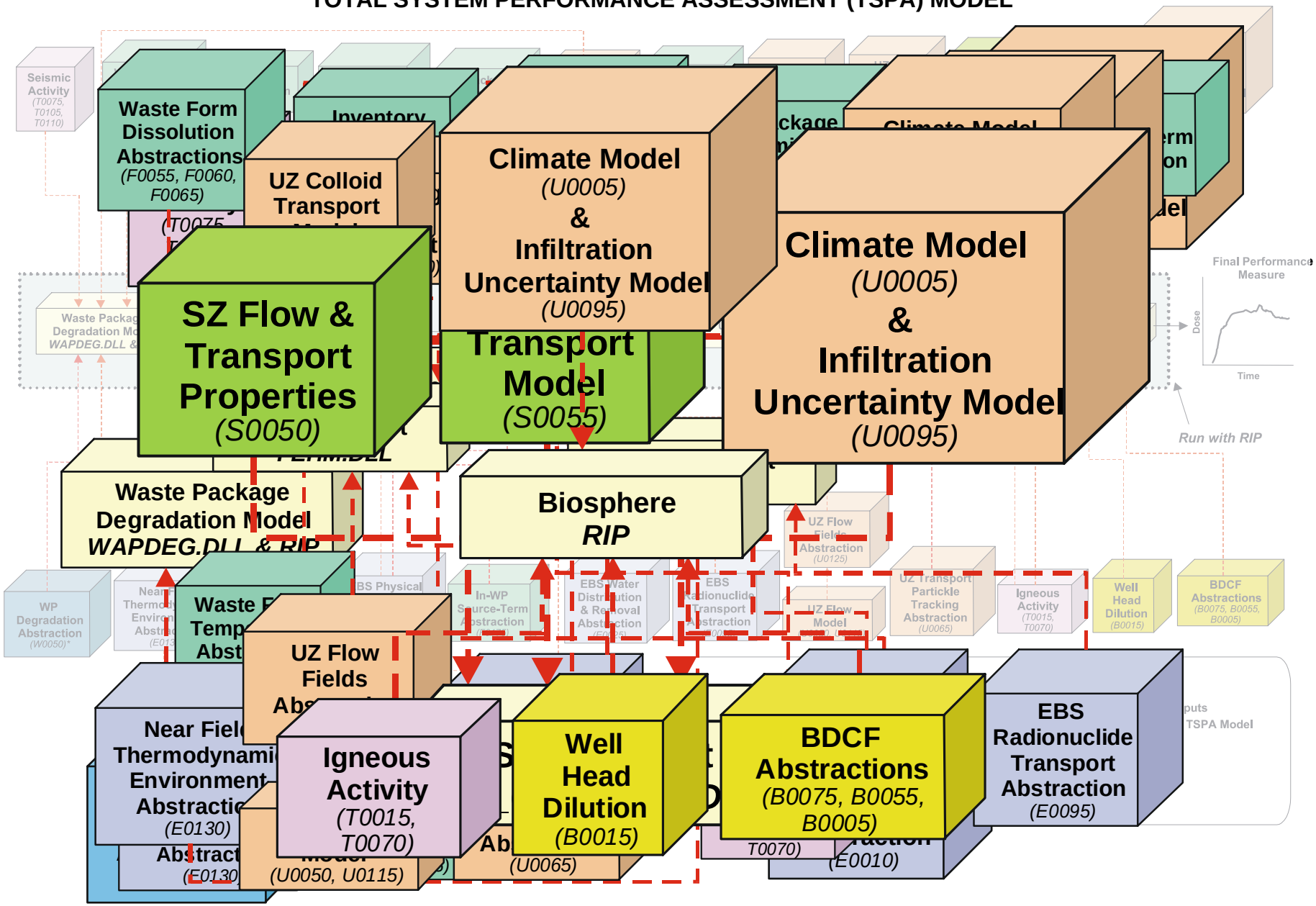
Site and Design Information

Site Description Document
Repository Design
Waste Package Design
Laboratory Data
In situ Data
Analog Data



Information Flow in TSPA-SR

TOTAL SYSTEM PERFORMANCE ASSESSMENT (TSPA) MODEL



Basis for Changes in Models from TSPA-VA to TSPA-SR

- **Revised design**
  - **near field and EBS environments**
  - **drip shield**
  - **waste package**
- **Critiques of VA assumptions/models**
- **Improved process models and their abstraction**
- **Selective use of reasonably conservative/bounded analyses/models**
- **Hierarchy of controlled software, analyses and models**
  - **Implementation of improved QA processes and procedures**

Approach to Defining Model Representations in TSPA-SR[1]

- **Use reasonable representations of process models where they are of sufficient defensibility**
- **For models of significant complexity or uncertainty, use reasonably bounded representations (using the Safety Case for guidance)**
- **Include uncertainty in models and parameters, as appropriate**
- **Incorporate alternative models considering their likelihood**

[1]See back-up slides for some examples

Development of Traceable Inputs to TSPA-SR and Possible Subsystem Performance Measures for Transparency

Key Attributes of System	Factors	Analysis/ Model Report Number	Analysis/Model Report Title	Possible Subsystem Performance Measures
Water Contacting Waste Package	Climate	U0005	Climate Model Abstraction	• Seepage fraction • Seepage flux
	Infiltration	U0095	Infiltration Uncertainty Abstraction	
	UZ flow above repository	U0125	UZ Flow Fields Abstraction	
	Seepage into drifts	U0120	Drift Seepage and Coupled Process Abstraction	
	Coupled processes - effects on UZ flow	U0115	UZ Coupled Process Flow Field Abstraction	
	Coupled processes - effects on seepage	U0120	Drift Seepage and Coupled Process Abstraction	
	Environment, (mechanical stress, moisture, temperature, and chemistry) on drip shield	N0065	NF Thermodynamic Environment Abstraction	
		E0010	EBS Physical Chemical Environment Abstraction	
		E0090	EBS Water Distribution and Removal Model	
	Performance of drip shield	W0075	Juvenile Failures	• Fraction of dripshields degraded • Area of degraded drip shield
		W0125	Abstraction of Model for Mechanical Damage and Failure of Drip Shield and Waste Package by Rockfall	
		W0005	Abstraction of Models for General Corrosion of Drip Shield and Waste Package Outer Barrier	
		W0040	Abstraction of Models for Pitting and Crevice Corrosion of Drip Shield and Waste Package Outer Barrier	
		W0045	Abstraction of Models for Stress Corrosion Cracking (SCC) of Drip Shield and Waste Package Outer Barrier and Hydrogen Induced Cracking (HIC) of Drip Shield	
		W0030	Failures Due to Mechanical Degradation	

Development of Traceable Inputs to TSPA-SR and Possible Subsystem Performance Measures for Transparency
(continued)

Key Attributes of System	Factors	Analysis/ Model Report Number	Analysis/Model Report Title	Possible Subsystem Performance Measures
Waste Package Lifetime	Environment, (mechanical stress, moisture, temperature, and chemistry) on waste package	E0010	EBS Physical Chemical Environment Abstraction	• Fraction of WPs wetted • Flux contacting WPs
		E0130	NF Thermodynamic Environment Abstraction	
		E0090	EBS Water Distribution and Removal Model	
	Performance of waste package barriers	W0075	Juvenile Failures	• Fraction of WPs degraded • Area of degraded WPs
		W0020	Aging and Phase Stability (APS) of Waste Package Outer Barrier (WPOB)	
		W0125	Abstraction of Model for Mechanical Damage and Failure of Drip Shield and Waste Package by Rockfall	
		W0005	Abstraction of Models for General Corrosion of Drip Shield and Waste Package Outer Barrier	
		W0040	Abstraction of Models for Pitting and Crevice Corrosion of Drip Shield and Waste Package Outer Barrier	
		W0045	Abstraction of Models for Stress Corrosion Cracking (SCC) of Drip Shield and Waste Package Outer Barrier and Hydrogen Induced Cracking (HIC) of Drip Shield	
		W0120	Abstraction of Models for Stainless Steel Structural Material Degradation	

Development of Traceable Inputs to TSPA-SR and Possible Subsystem Performance Measures for Transparency

(continued)

Key Attributes of System	Factors	Analysis/ Model Report Number	Analysis/Model Report Title	Possible Subsystem Performance Measures
Radionuclide Mobilization and Release from the Engineered Barrier System	Environment, (mechanical stress, moisture, temperature, and chemistry) within waste package	F0135	In-WP Temperature History	• Flux contacting WF
		F0130	In-WP Chemistry History	
		F0165	In-WP Hydrology History	
	CSNF waste form (with cladding or canister) performance	F0000	CSNF Inventory	• Fraction of WF contacted by water • Release rate from CSNF WF
		F0155	Cladding Degradation Abstraction	
		F0055	CSNF Degradation Model	
	DSNF, Navy fuel, Pu disposition waste form performance	F0005	DSNF Inventory	• Fraction of WF contacted by water • Release rate from DSNF and other WFs
		F0065	Other Waste Form Degradation Abstraction	
	HLW glass waste form (including canister) performance	F0010	HLW Inventory	• Fraction of WF contacted by water • Release rate from HLW glass
		F0060	HLW Glass Degradation	
	Dissolved radionuclide concentration limits	F0095	Dissolved Concentration Limits Abstraction	• Release rate from EBS • Cumulative release from EBS
	Colloid-associated radionuclide concentrations	F0115	Colloid Source Term Abstraction	
	In-package radionuclide transport	F0165	In –WP Hydrology History	
	EBS radionuclide migration—transport through invert	E0130	NF Thermodynamic Environment Abstraction	
		E0095	EBS Radionuclide Transport Abstraction	

Development of Traceable Inputs to TSPA-SR and Possible Subsystem Performance Measures for Transparency

(continued)

Key Attributes of System	Factors	Analysis/ Model Report Number	Analysis/Model Report Title	Possible Subsystem Performance Measures
Transport Away from the Engineered Barrier System	Advective pathways in the UZ	U0125	UZ Flow Fields Abstraction	• Release rate from UZ • Cumulative release from UZ
	Retardation of radionuclide migration in the UZ	U0065	UZ Transport Particle Tracking Abstraction	
		U0100	UZ/SZ Transport Properties	
	Colloid-facilitated transport in the UZ	U0065	UZ Transport Particle Tracking Abstraction	
	Coupled processes--effects on UZ transport	U0100	UZ/SZ Transport Properties	
	Advective pathways in the SZ	S0055	SZ Flow and Transport Model Abstraction	
		S0050	SZ Flow and Transport Stochastic Parameters	• Release rate from SZ at 20 km • Cumulative release from SZ at 20 km • Concentration in representative volume at 20 km
	Retardation of radionuclide migration in the SZ	B0050	SZ Flow and Transport Stochastic Parameters	
		U0100	UZ/SZ Transport Properties	
	Colloid-facilitated transport in the SZ	S0035	Colloid-Facilitated Transport	
	Dilution of radionuclide concentrations in the UZ and SZ	B0015	Water Usage	• Concentration at well head
		B0010	Critical Group	• Dose to average member of critical group
	Biosphere transport and uptake	B0075	Biosphere Dose Conversion Factors	

Development of Traceable Inputs to TSPA-SR and Possible Subsystem Performance Measures for Transparency

(continued)

Key Attributes of System	Factors	Analysis/ Model Report Number	Analysis/Model Report Title	Possible Subsystem Performance Measures
Effects of Potentially Disruptive Processes and Disruptive Events	Volcanic	T0015	Framework for Igneous Activity	• Direct Release rate to atmosphere from volcanic disruption • Dose to average member of critical group from volcanic disruption
		T0070	Consequence Analysis of Direct Release	
	Seismic	T0075	Framework for Seismicity/Structural	• Probability of seismicity /structural deformation • Fraction of WPs degraded
		T0110	Consequence Analysis Result	
	Criticality	N/A	To be addressed in criticality topical report	• Probability of criticality event
	Human Intrusion	N/A	To be addressed in TSPA-SR document	• Dose to average member of critical group from stylized human intrusion scenario

Scope and Content of TSPA-SR Rev. 00

- **Develop and screen FEPs using regulatory criteria and consequence modeling results**
- **Implement controlled models, analyses, software, and data**
- **Evaluate the reasonable representation of expected total-system performance incorporating uncertainty within a probabilistic framework, including the effects of disruptive events**
- **Conduct human intrusion scenario analysis**
- **Conduct sufficient subsystem and system sensitivity and uncertainty analysis to evaluate significance of uncertainty**

Scope and Content of TSPA-SR Rev. 01

- **Revise analyses and documentation in response to comments on Rev. 00 to the extent practicable**
- **Revise Rev. 00 analyses based on significant changes in models or data**
- **Conduct impact analyses evaluating the effect of increased data and software qualification**

Summary

- **Comprehensive TSPA-SR, suitable for DOE decision making, is being prepared consistent with applicable (yet evolving) regulations**
- **Revised and improved TSPA component models are being developed and synthesized**
- **Technical defensibility of component models will be presented in Analysis/Model Reports (AMRs) and Process Model Reports (PMRs)**
- **Conformance to QA requirements will help ensure transparency and traceability**

Back-Up Slides

- **Regulatory Requirements for TSPA**
- **Process for Calculating Expected Annual Dose**
- **Probable Model Changes from TSPA-VA to TSPA-SR**

Requirement to Conduct A Performance Assessment (10 CFR 63.113)

(a) The geologic repository shall include multiple barriers, consisting of both natural barriers and an engineered barrier system.

(b) The engineered barrier system shall be designed so that, working in combination with the natural barriers, the expected annual dose to the average member of the critical group shall not exceed 0.25 mSv (25 mrem) TEDE at any time during the first 10,000 years after permanent closure . . .

(c) The ability of the geologic repository to limit radiological exposures to those specified in paragraph (b) of this section shall be demonstrated through a performance assessment that meets the requirements specified at Sec. 63.114, uses the reference biosphere and critical group specified at Sec. 63.115, and excludes the effects of human intrusion.

Definition of Performance Assessment (10 CFR 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.

Requirement to Conduct A Performance Assessment (40 CFR 197.20)

- **The DOE must demonstrate, using performance assessment, that there is a reasonable expectation that for 10,000 years following disposal the reasonably maximally exposed individual receives no more than an annual committed effective dose equivalent of 150 microSievert (15 mrem) from releases from the undisturbed Yucca Mountain disposal system . . .**

Definition of Performance Assessment (40 CFR 197.12)

<u>Performance assessment</u> means an analysis that:

(1) Identifies the processes, events, and sequences of processes and events (except human intrusion), and their probabilities of occurring over 10,000 years after disposal, that might affect the Yucca Mountain disposal system;

(2) Examines the effects of those processes, events, and sequences of processes and events upon the performance of the disposal system; and

(3) Estimates the annual committed effective dose equivalent received by the reasonably maximally exposed individual, including the associated uncertainties, as a result of releases caused by all significant processes, events, and sequences of processes and events

Implementation of Performance Assessment Concepts 10 CFR 63.102 (j)

- **Demonstrating compliance with the postclosure performance objective specified at Sec. 63.113(b) requires a performance assessment to quantitatively estimate the expected annual dose, over the compliance period, to the average member of the critical group.**
- **The performance assessment is a systematic analysis that identifies the features, events, and processes that might affect performance of the geologic repository; examines their effects on performance; and estimates the expected annual dose.**
- **The features, events, and processes considered in the performance assessment should represent a wide range of both beneficial and potentially adverse effects on performance**

Implementation of Performance Assessment Concepts 10 CFR 63.102 (j)

- **Those features, events, and processes expected to materially affect compliance with Sec. 63.113(b) or be potentially adverse to performance are included, while events of very low probability of occurrence (less that one chance in 10,000 over 10,000 years) can be excluded from the analyses.**
- **The expected annual dose to the average member of the critical group is estimated using the selected features, events, and processes, and incorporating the probability that the estimated dose will occur.**

Requirements for Performance Assessment 10 CFR 63.114

Any performance assessment used to demonstrate compliance with

Sec. 63.113(b) shall:

(a) Include data related to the geology, hydrology, and geochemistry (including disruptive processes and events) of the Yucca Mountain site, and the surrounding region to the extent necessary, and information on the design of the engineered barrier system, used to define parameters and conceptual models used in the assessment

(b) Account for uncertainties and variabilities in parameter values and provide the technical basis . . .

(c) Consider alternative conceptual models of features and processes that are consistent with available data and current scientific understanding, and evaluate the effects that alternative conceptual models have on the performance of the geologic repository.

Requirements for Performance Assessment 10 CFR 63.114 (continued)

(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 in performance assessment . . .

(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 . . .

(g) Provide the technical basis for models used in the performance assessment . . .

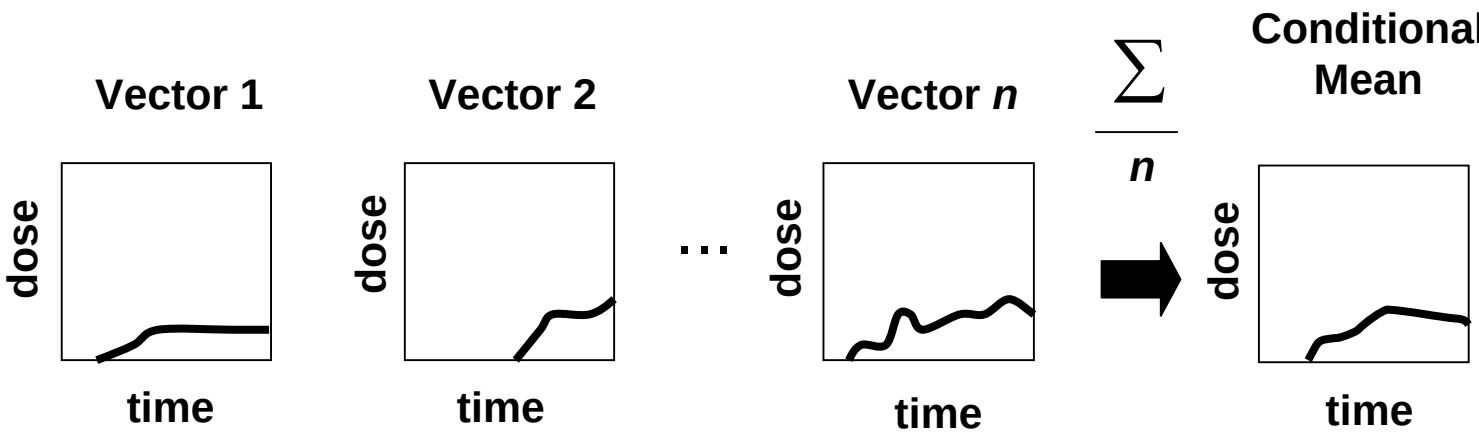
Requirements for Performance Assessment 10 CFR 63.114 (continued)

(h) Identify those design features of the engineered barrier system, and natural features of the geologic setting, that are considered barriers important to waste isolation.

(i) Describe the capability of barriers, identified as important to waste isolation, to isolate waste, taking into account uncertainties in characterizing and modeling the barriers.

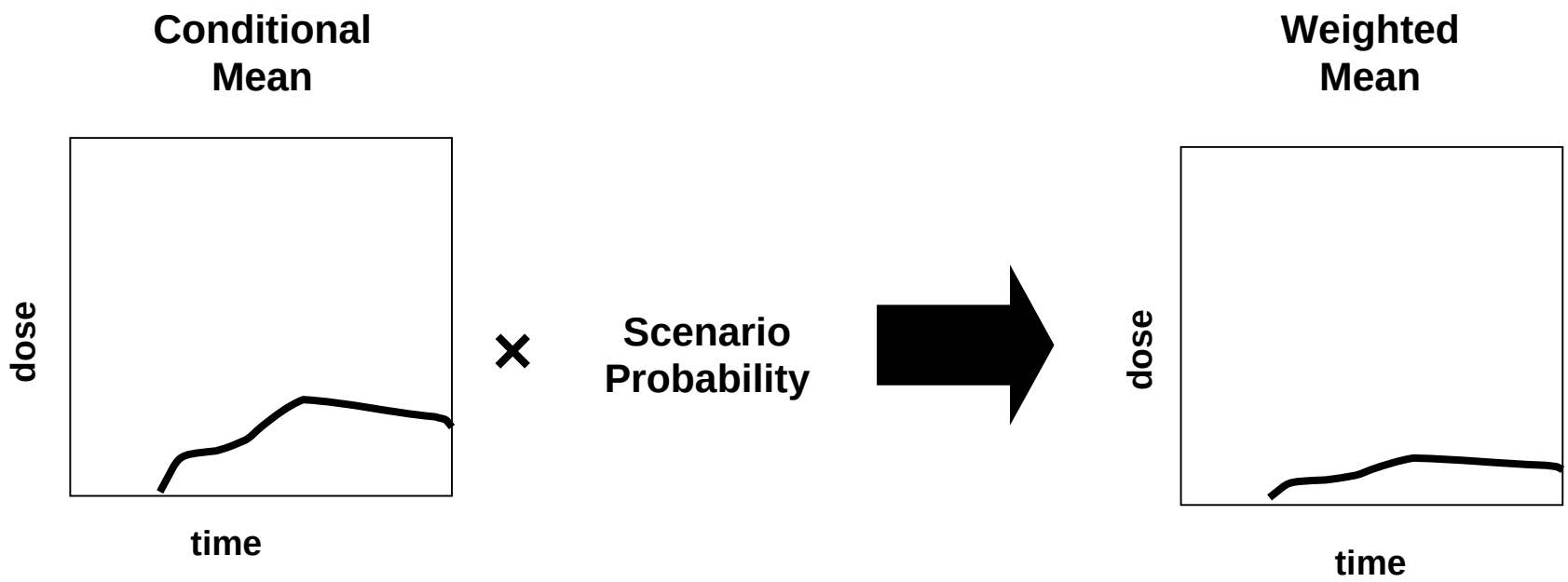
(j) Provide the technical basis for the description of the capability of barriers, identified as important to waste isolation, to isolate waste.

Calculating the Mean Annual Dose for a Single Scenario

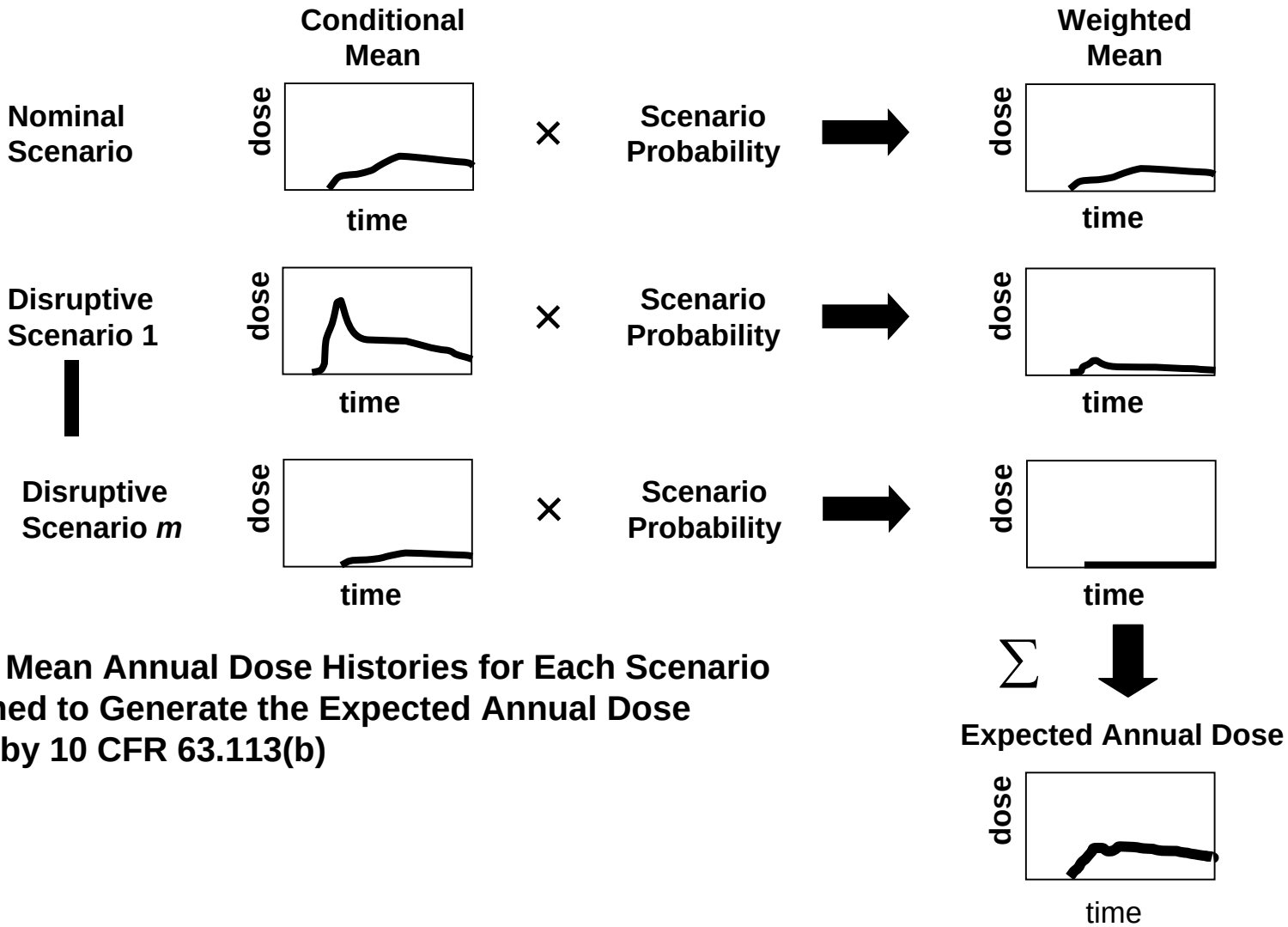


The mean of the *n* realizations (or vectors) displayed here is conditional on the occurrence of the scenario

Weighting the Conditional Mean by the Scenario Probability

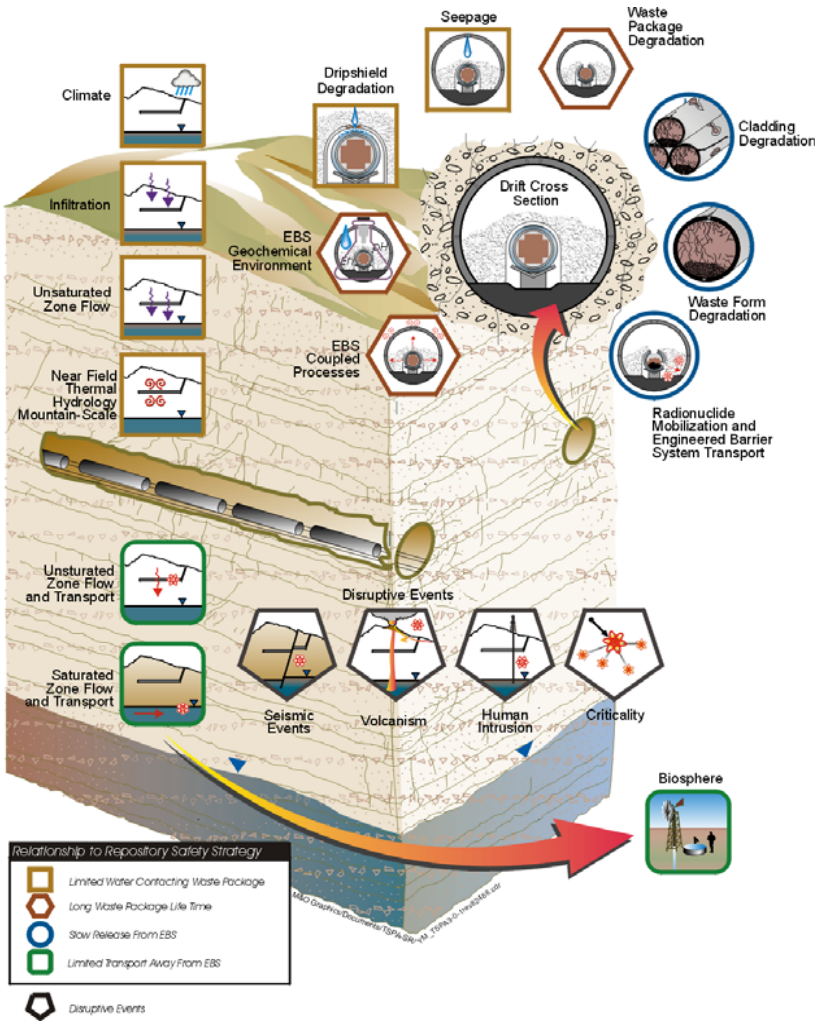


NRC's "Expected" Annual Dose



Weighted Mean Annual Dose Histories for Each Scenario are Summed to Generate the Expected Annual Dose Required by 10 CFR 63.113(b)

TSPA-SR Model Components



- **Major model components are related to the attributes of the repository safety strategy**
- **Natural and engineered barriers comprise the total system**
- **Each major component requires an explicit model to represent the relevant processes**

Probable Changes from TSPA-VA to TSPA-SR

- **Improved Climate Model**
  - present day, warmer/wetter than present, cooler/wetter glacial transition
- **Improved Infiltration Model**
  - surface water run off- run on
  - temperature and vegetation dependence
  - uncertainty explicitly quantified
- **Improved UZ Flow Model**
  - active fracture model for fracture-matrix interactions
  - alternative model for transport through perched water
- **Improved Drift-Scale Seepage Model**
  - new data from seepage tests in ESF
  - include effects of coupled processes
  - time varying with thermal-hydrologic effects

Probable Changes from TSPA-VA to TSPA-SR

(continued)

- **New THC Drift-Scale Model**
  - **reasonably bound incoming water compositions**
- **Revised TH Model**
  - **incorporates SR design**
  - **new information from Drift Scale Test**
- **New THM Drift-Scale Analyses**
  - **conservative parameters to bound seepage**
- **Improved In-Drift Geochemical Model**
  - **coupled chemical process effects**
  - **assume T-H-C process can be decoupled, calculated separately, then linked**
  - **include uncertainty in drift boundary conditions**
  - **reasonably bound salt build-up effects on chemistry**

Probable Changes from TSPA-VA to TSPA-SR

(continued)

- **New Drip-Shield Degradation Model**
  - **mechanistic analysis of manufacturing defects**
  - **include HIC**
  - **include rock fall and seismic loading effects**
- **Improved Waste Package Degradation Model**
  - **mechanistic analysis of manufacturing defects**
  - **additional corrosion mechanisms (SCC, long-term phase stability and thermal aging)**
  - **integrated with total system model**
  - **representative lab data used, not expert elicitation**

Probable Changes from TSPA-VA to TSPA-SR

(continued)

- **Revised Waste Form Categories**
  - **combine stainless clad CSNF with DSNF inventory**
  - **revised list of key radionuclides with updated inventories**
- **Revised Cladding Degradation Model**
  - **direct evaluation of clad unzipping**
  - **conservatively bound initial defect conditions**
- **Revised Waste Form Degradation Model**
  - **similar to VA, incorporating new data**
- **Revised Solubility Limits**
  - **based on analysis of data not elicitation results**
- **Improved Colloid Formation Model**
  - **new data on sorption/desorption**
  - **add Americium colloids**

Probable Changes from TSPA-VA to TSPA-SR

(continued)

- **Improved EBS Transport Model**
  - **in drift water distribution and removal**
  - **in package evaporation**
- **Improved UZ Transport Model**
  - **revised matrix diffusion model**
  - **revised colloid transport model**
  - **smaller release areas from EBS to UZ**
- **Improved SZ Flow and Transport Model**
  - **calibrated 3-D site scale flow model**
  - **smaller release areas from UZ to SZ**
- **Revised Biosphere Transport Model**
  - **updated water usage for critical group**
  - **dose conversion factors similar to VA**
  - **radionuclide buildup and removal in soils**

Probable Changes from TSPA-VA to TSPA-SR

(continued)

- **Revised Analysis of Volcanic Disruptive Events**
  - **incorporate risk into expected dose using probability-weighted disruptive event scenario**
  - **revised entrainment parameters**
- **Revised Analysis of Seismic Disruptive Events**
  - **incorporate risk into expected dose in nominal scenario or using probability-weighted disruptive event scenario**
  - **incorporate seismic effects in drift collapse analysis**