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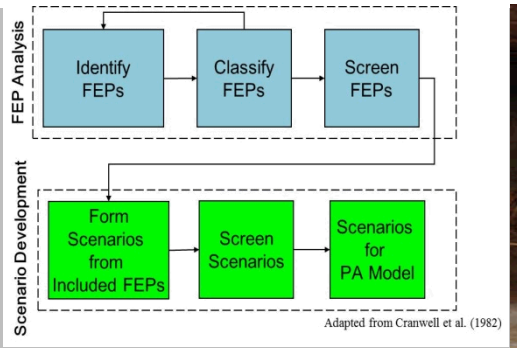

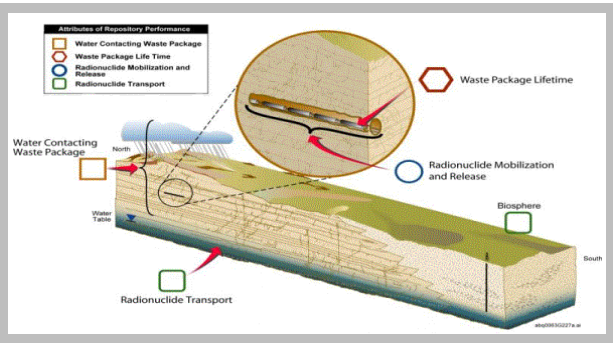

Scenario Comprehensiveness and Completeness in the U.S.

Geoff Freeze, Ross Kirkes, and Christi Leigh
Sandia National Laboratories

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U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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Overview of US Programs

- US programs (YM and WIPP) have undergone FEP and scenario completeness reviews by regulators

	SNF /HLW	SNF /HLW (Generic)	Transuranic (TRU)
Site	Yucca Mountain, Nevada (YM)	N/A	Waste Isolation Pilot Plant (WIPP)
Implementer	Office of Civilian Radioactive Waste Management (OCRWM)	Dept. of Energy, Office of Nuclear Energy (DOE-NE) Used Fuel Disposition Campaign (UFD)	Dept. of Energy, Office of Envir. Management (DOE-EM)
Regulator	Nuclear Regulatory Commission (NRC) 10 CFR 63 Envir. Protection Agency (EPA) 40 CFR 197	Nuclear Regulatory Commission (NRC) 10 CFR 60 ? Envir. Protection Agency (EPA) 40 CFR 191 ?	Envir. Protection Agency (EPA) 40 CFR 191, 40 CFR 194

Scenario Comprehensiveness, Completeness, and Sufficiency

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- It is impossible to demonstrate comprehensiveness or completeness, in the sense that it is impossible to exhaustively identify all possible FEPs and interactions within a complex and evolving system [NEA 1999]
- It is possible, however, to list a range of broadly-defined FEPs that might be relevant to consider in safety assessments [NEA 1999]
- "Reasonable expectation" [40 CFR 197.14 and 10 CFR 63.102(j)]
  - Requires less than absolute proof because absolute proof is impossible to attain … due to uncertainty of projecting long-term performance
  - Does not exclude important parameters … simply because they are difficult to precisely quantify to a high degree of confidence

Scenario Comprehensiveness, Completeness, and Sufficiency

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- A variety of methods should be used to formulate an initial list [NEA 1992, p. 23]. Some common FEP identification methods include [NEA 1999, pp. 26-27]:
  - Development from existing lists of FEPs
  - Brainstorming
  - Top-down elicitation from a classification schemes
  - Hybrid procedures

- Confidence can be gained through a combination of [BSC 2005]:
  - Formal and systematic reviews (both top-down and bottom-up)
  - Audits and comparisons with other FEP lists
  - Application of more than one classification scheme

YM Scenario Development Timeline

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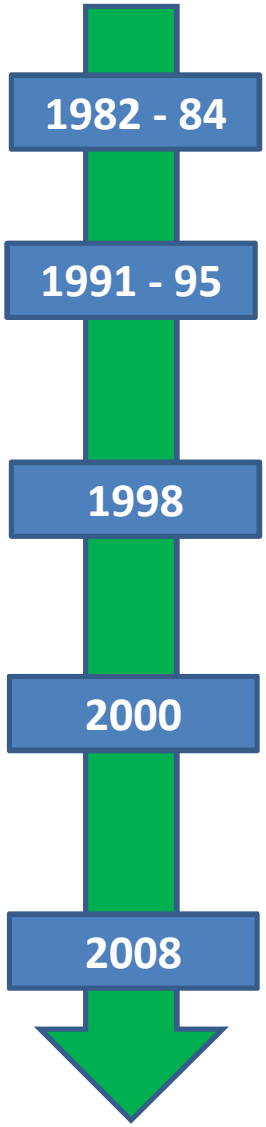

	Scenario Classes	FEP Analysis
PA-EA	Nominal (undisturbed) Igneous (eruption)	Informal
PA-91 PA-93 PA-95	Nominal (with early WP failure) Igneous (intrusion) Human Intrusion	Informal
TSPA-VA	Nominal (with early WP failure and igneous and seismic WP damage) Igneous (eruption) Human Intrusion	Semi-formal (from 1261 NEA)
TSPA-SR	Nominal Igneous (intrusion, eruption) Human Intrusion	Formal 328 YM FEPs
TSPA-LA	Nominal (undisturbed) Early WP/DS failure Igneous (intrusion, eruption) Seismic (ground motion, fault displace.) Human Intrusion	Formal 374 YM FEPs

Formal, iterative FEP and Scenario development

YM TSPA-LA FEP Regulator (NRC) Guidance (NUREG-1804)

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- Acceptance Criterion 1 - Identification of a List of FEPs is Adequate
  - Review Method 1 (Identification of a List of FEPs)
    - Verify that the [YM FEP List] includes all features, events, and processes having a potential to influence repository performance.
    - Use knowledge gained reviewing the Yucca Mountain site and regional [data] to assess the completeness of the features, events, and processes list.
    - The staff should use, as appropriate, available generic lists of features, events, and processes (e.g., NEA, 1997), as a reference to determine the completeness of the [YM FEP List].
- Acceptance Criterion 3 - Identification of Scenario Classes is Adequate
  - Review Method 3 (Formation of Scenario Classes)
    - Determine whether the resulting scenario classes are mutually exclusive and include all events that have not been screened from the performance assessment.
    - The comprehensive features, events, and processes list includes, but is not limited to, potentially disruptive events …

YM TSPA-LA FEP Comprehensiveness and Completeness

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- Comprehensiveness of the YM FEP List derives initially from its development from:
  - The NEA International FEP Database, V1.0
    - the best available compilation of FEPs from multiple programs.
  - YM documents identified issues unique to the YMP design and setting (unsaturated fractured tuff)
    - top-down event tree logic diagrams for certain events and processes
    - site characterization; igneous, seismic, and tectonic activity, climate change, and criticality reports
  - Brainstorming by subject matter experts during technical FEP identification workshops

YM TSPA-LA FEP Comprehensiveness and Completeness

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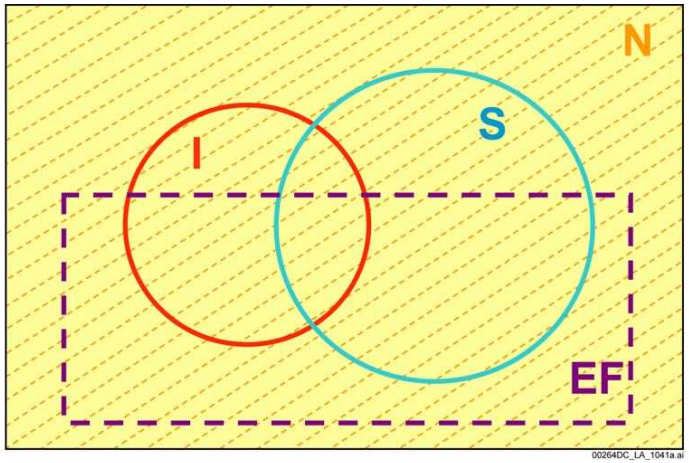
- Comprehensiveness and completeness of the YM FEP list was enhanced by:
  - Application of multiple FEP classification schemes
    - NEA-basis, TSPA-SR scheme, re-categorized TSPA-LA scheme
  - Audit against the updated NEA International FEP Database V2.0
    - No new FEPs were identified
  - Audit performed against an alternate independent top-down generated YMP FEP list (BSC 2005, Appendix B)
    - No new FEPs were identified
  - Use of the FEP matrix
    - Mapping of FEPs to matrix boxes (intersections of the features axis and the process/event axis) provides a top-down “check” against the bottom-up FEP identification
  - Potential FEP Log
    - Formal tracking and resolution of “issues” (i.e., potential new FEPs)

YM TSPA-LA FEP Comprehensiveness and Completeness

- Confidence in the completeness of the YM FEP list was demonstrated through continual reviews by subject matter experts, licensing and performance assessment team members, external reviewers, and others
  - As the FEP list evolved, fewer new potential FEPs were identified during each successive review cycle.
  - Over time, the nature of those potential FEPs also changed, so that they were predominantly variants or finer details of existing FEPs, rather than new unique issues.

YM TSPA-LA Scenario Comprehensiveness and Completeness

- 4 Scenario Classes (nominal, seismic, igneous, early failure)
  - Derived from scenarios from past TSPA analyses
  - All included FEPs captured in at least one scenario class
  - Independent, but not mutually exclusive
- Human Intrusion evaluated separately



N = nominal; I = igneous; S = seismic; EF = early failure

The overlap of areas indicates that these futures are independent and not mutually exc
[Source: SNL 2008, Figure 6-2; YM SAR Figure 2.2-2].

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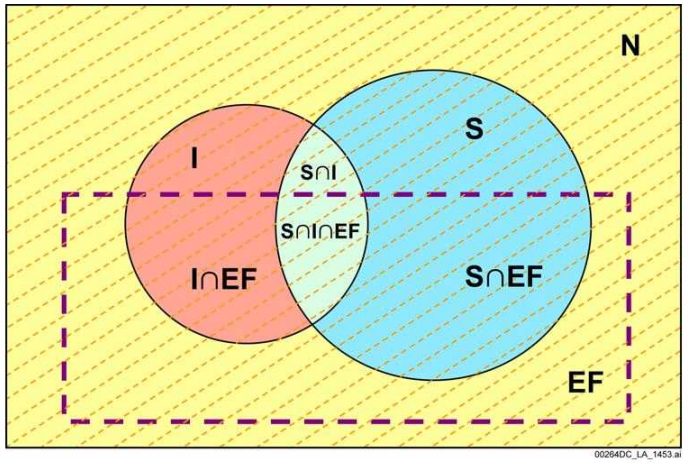

N = nominal; I = igneous; S = seismic; EF = early failure; S∩I = seismic/igneous;
I∩EF = igneous/early failure; S∩EF = seismic/early failure; S∩I∩EF = seismic/igneous/early failure;
These futures are independent and mutually exclusive.
[Source: SNL 2008, Figure 6-3; YM SAR Figure 2.2-3].

YM TSPA-LA Scenario Comprehensiveness and Completeness

- Nominal Scenario Class
  - Contains FEPs that are expected to occur (probability near 1.0, but with uncertain consequences)
  - Represents the most plausible evolution of the repository system
- Seismic, Igneous, and Early Failure Scenario Classes
  - Contain combinations of FEPs that have low probability of occurrence (but greater than screening criteria), but might produce potentially adverse conditions
  - Contain many of the nominal FEPs
  - Represent low-probability permutations of the expected evolution of the repository system

UFD FEP Comprehensiveness

- UFD FEPs are mapped to the FEP Matrix organizational structure
  - Comprehensiveness indicated by presence/absence of "empty" matrix cells
  - Completeness cannot yet be demonstrated
    - Need site-specific FEP identification and screening
- UFD Scenarios not yet developed
  - Undisturbed only to date

Characteristics, Processes, and Events / Features and Components	Characteristics	Processes											Events					
	(CP) Characteristics	(TM) Mechanical and Thermal-Mechanical	(TH) Hydrologic and Thermal-Hydrologic	(TC) Chemical and Thermal-Chemical	(TB) Biological and Thermal-Biological	(TT) Transport and Thermal-Transport	(TR) Thermal	(RA) Radiological	(LG) Long-Term Geologic	(CL) Climatic	(HP) Human Activities (long timescale)	(OP) Other	(NC) Nuclear Criticality	(EF) Early Failure	(SM) Seismic	(IG) Igneous	(HE) Human Activities (short timescale)	(OE) Other
Waste and Engineered Barriers Region																		
(WF) Waste Form and Cladding																		
• Commercial SNF & Cladding																		
• Commercial HLW Glass																		
• Naval SNF & Cladding																		
• Defense SNF & Cladding																		
• Defense HLW																		
• Other																		
(WP)Waste Package and Internals				1														
• Commercial SNF																		
• Commercial HLW																		
• Naval																		
• Defense SNF																		
• Defense HLW																		
• Other Packages																		
(BB) Buffer/Backfill																		
• Waste Package Buffer																		
• Tunnel/Drift/Room Backfill	1	2				2												
(MW) Emplacement Tunnels/ Drifts and Mine Workings																		
• Open Excavations			1														1	
• Drift Support																		
• Liners																		
• Other																		
(SP) Seals/Plugs																		
• Drift/Panel Seals/Closures																		
• Shaft Seals		1		1														
• Plugged Boreholes																		
Geosphere and Natural Barriers Region																		
(HR) Host Rock (Repos. Horizon)																		
• Bedded or Domal Salt	1	1				2						1						
• Disturbed Rock Zone	1	1	1			2												
• Interbeds and Seams	1					2												
(OU) Other Geologic Units																		
• Aquifer(s)																		
• Unsaturated Zone																		
• Pressurized Brine Reservoir(s)																		
Surface Region																		
(BP) Biosphere																		
• Natural Surface and Near-Surface Environment																		
• Flora and Fauna																		
• Humans																		
• Food and Drinking Water																		
• Dwellings and Man-Made Surface Features/Materials																		
System Region																		
(RS) Repository System																		
• Assessment Basis																		
• Pre-closure and Operational																		
• Other Global	1																	

WIPP FEP and Scenario Chronology

- 1978-1988 (Site Characterization)
  - No systematic FEP approach
  - Scenarios developed based on current scientific understanding and level of concern
  - Major scenarios were identified during this period
    - Undisturbed Performance
    - Human Intrusion
- 1989-1992 (Preliminary Performance Assessment)
  - NRC FEP approach using short list of 23 FEPs, based on past literature
  - Major scenarios refined, no new scenarios developed
- 1993-1998 (Certification)
  - Full FEP implementation

WIPP FEP
Comprehensiveness and Completeness

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- Lessons learned from early (up to 1992) WIPP FEP work:
  - FEPs were sufficient to identify major scenarios and focus preliminary PA modeling
  - Work was not sufficient to demonstrate comprehensiveness
    - Many FEPs weren't discussed
    - No systematic documentation
    - Some screening arguments lacked sufficient rigor to satisfy technical reviewers (exclusion by assertion)
  - Some important processes were overlooked in experimentation and modeling
    - E.g., colloidal transport
- Conclusion – Regulatory process (certification) would need more structured FEP analysis

WIPP FEP
Comprehensiveness and Completeness

- Confidence in the comprehensiveness and appropriateness of the 1996 WIPP FEP list was supported by:
  - Development from other FEP lists
    - Nine lists from different countries used as a starting point
      - Swedish SKI was single most important source
    - Participation in the International FEP Database
  - List extended through review of WIPP project literature
  - Classification into 3 main categories
    - Natural, Waste and Repository-Induced, and Human-Initiated
  - Documented simplification of list by aggregation and elimination of redundancy
  - Formal reviews
    - Formal presentations and reviews with stakeholders and regulator
    - Formal documented reviews within the project
    - Cross-mapping requested by regulator

WIPP Scenario Comprehensiveness and Completeness

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- Preliminary PAs (1989-92) were used develop major scenarios

- PAs leading to Certification (1993-95) used refined scenarios based on full FEP implementation
  - Evolving regulations and input from stakeholders and peers led to refinement and development of appropriate scenarios
    - Undisturbed Performance (UP)
    - Disturbed Performance (DP)
      - Human (Drilling) Intrusion (E1, E2)
      - Mining (M)

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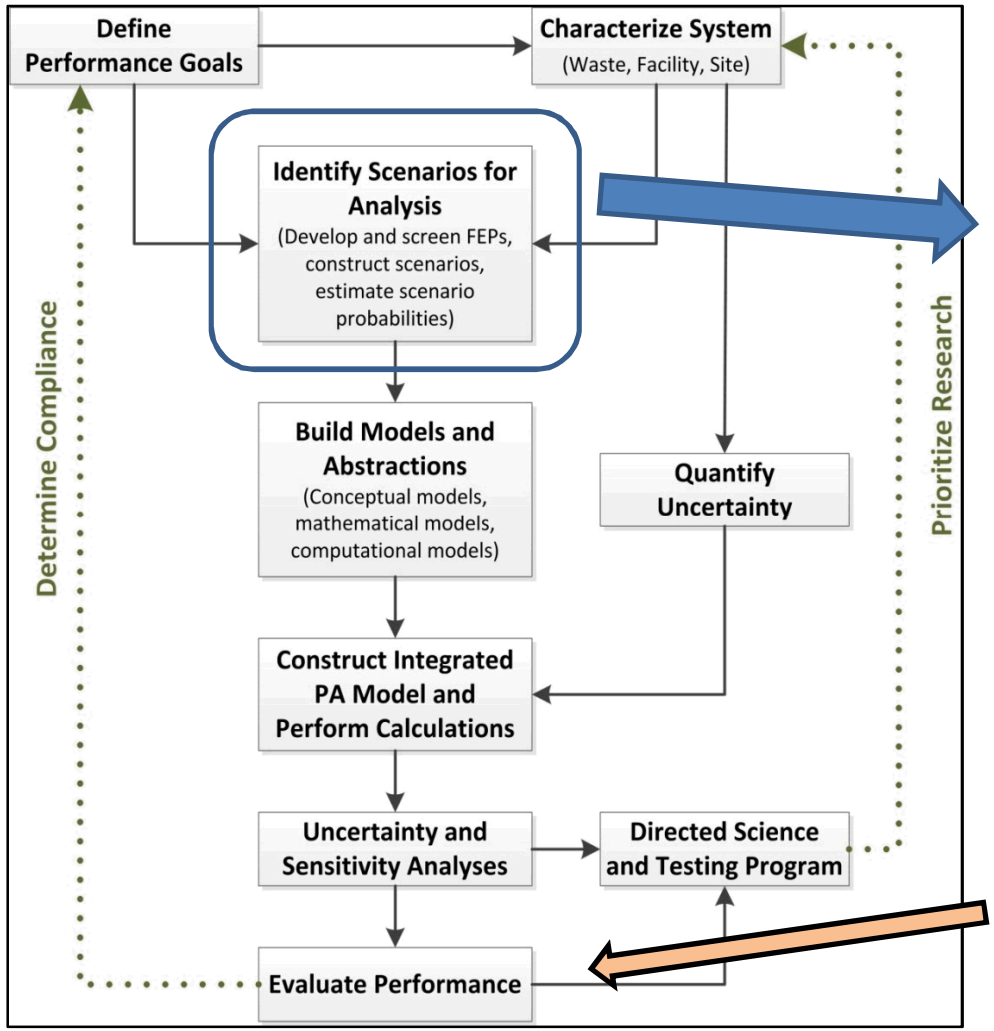
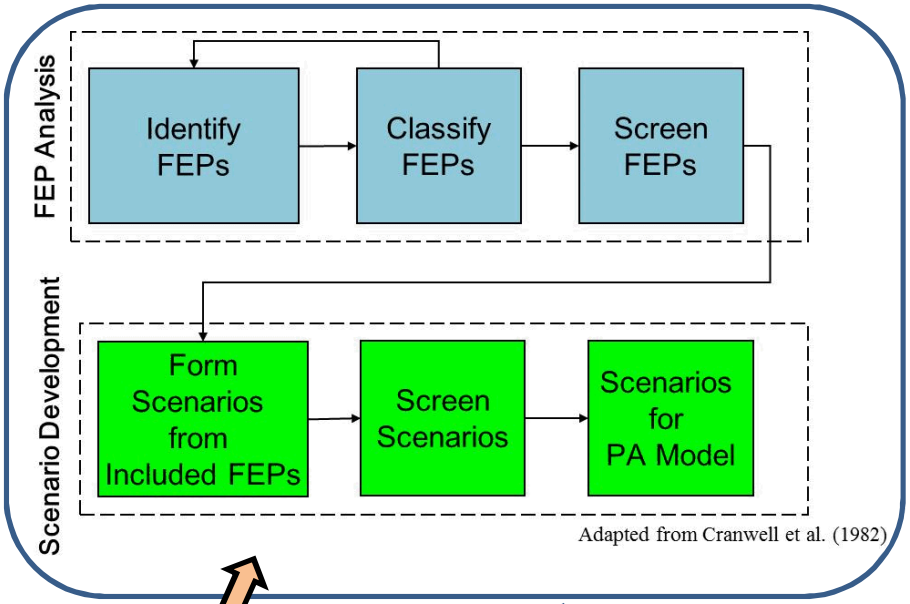
Backup Slides

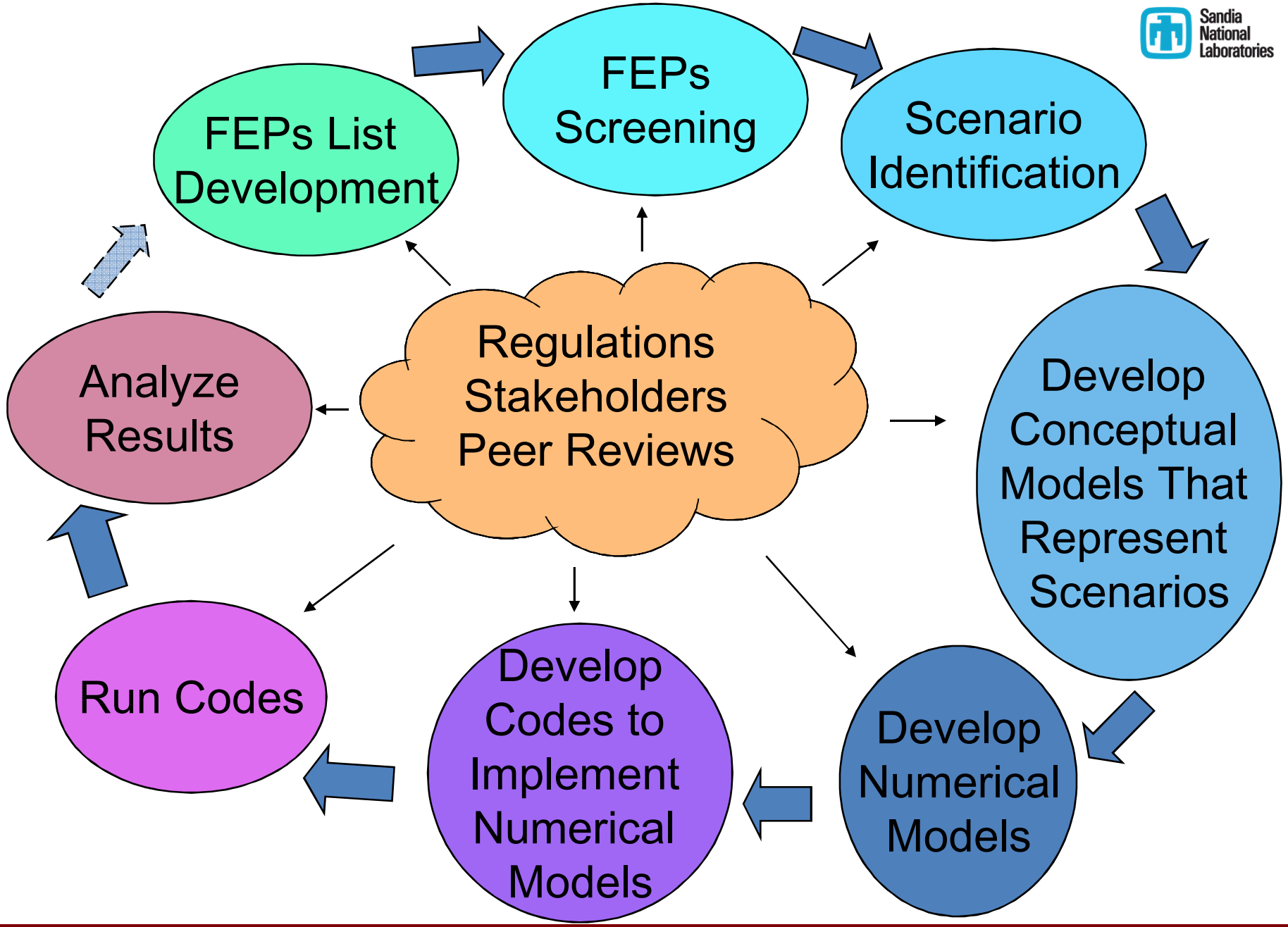
PA Methodology





Regulations

Scenario = a well-defined, connected sequence of FEPs that can be thought of as an outline of a possible future condition of the potential repository system (NEA 2003)


FEPs List Development
FEPs Screening
Scenario Identification
Develop Conceptual Models That Represent Scenarios
Develop Numerical Models
Develop Codes to Implement Numerical Models
Run Codes
Analyze Results
Regulations
Stakeholders
Peer Reviews

YMP Scenario Classes (TSPA-LA)

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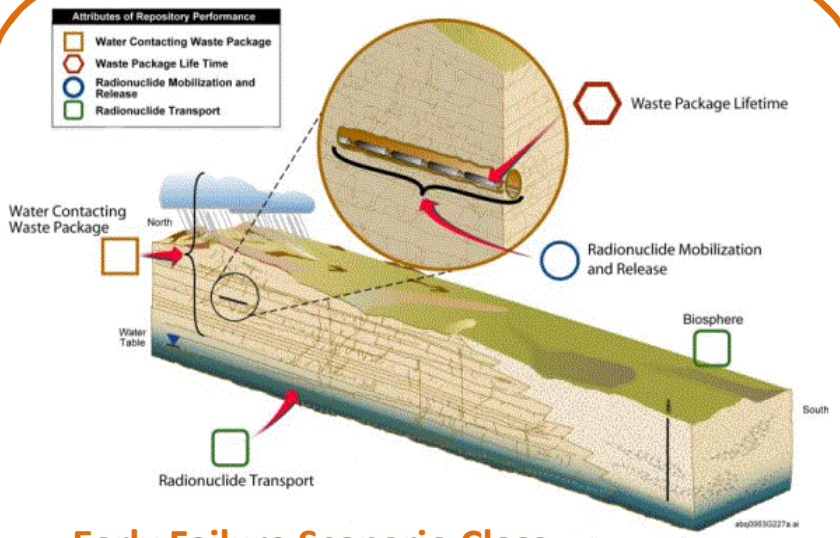
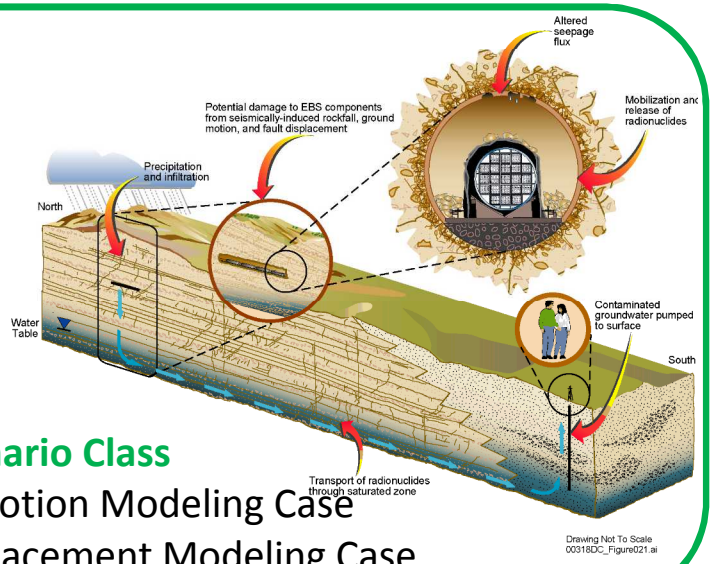
- **Nominal Scenario Class**
  - Nominal (Undisturbed) Modeling Case

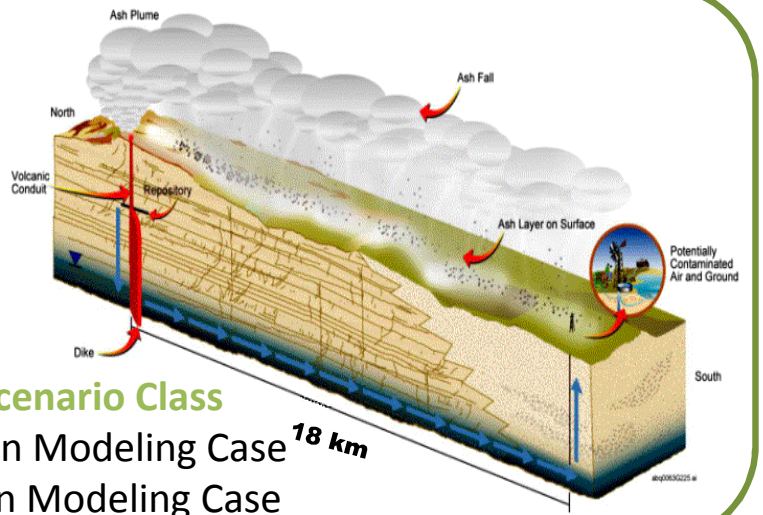


- **Early Failure Scenario Class**
  - Waste Package (WP) Modeling Case
  - Drip Shield (DS) Modeling Case

- **Human Intrusion**
  - Separate evaluation of a stylized drilling scenario
  - (per 10 CFR 63.322; 40 CFR 197.26)



- **Seismic Scenario Class**
  - Ground Motion Modeling Case
  - Fault Displacement Modeling Case



- **Igneous Scenario Class**
  - Intrusion Modeling Case
  - Eruption Modeling Case

YM FEP Matrix

- Process or event acting upon or within a feature or features
- Similar to interaction matrices and influence diagrams
  - SKB Rock Engineering System (RES)
  - UK Nirex Master Directed Diagram (MDD)

Total FEPs 152 Included 222 Exclude		REPOSITORY PROCESSES AND EVENTS											
		Hydrologic and Thermal-Hydrologic	Chemical and Thermal-Chemical	Mechanical and Thermal-Mechanical	Microbiological	Radiological	Characteristics	Transport	Igneous	Seismic	Criticality	Early Failure	Human Intrusion
REPOSITORY SUBSYSTEM PHYSICAL ELEMENTS AND FEATURES	Topography and Surficial Soils	I=8 X=3	I=0 X=1	I=0 X=1			I=3 X=2		I=0 X=1	I=0 X=1			
	Unsaturated Zone Above	I=30 X=29	I=3 X=7	I=1 X=5	I=0 X=2		I=7 X=9	I=0 X=6	I=2 X=4	I=2 X=5			
	Emplacement Drifts	I=27 X=18	I=22 X=33	I=5 X=24	I=3 X=8	I=0 X=4	I=9 X=20	I=11 X=20	I=6 X=3	I=5 X=8	I=0 X=4		I=3 X=7
	Backfill/Seals	I=0 X=4	I=0 X=4	I=1 X=6			I=0 X=6	I=0 X=3					
	Drip Shield	I=1 X=3	I=2 X=10	I=6 X=15	I=0 X=2	I=0 X=1	I=3 X=0		I=1 X=0	I=3 X=1		I=1 X=0	I=1 X=0
	Waste Package	I=0 X=3	I=11 X=14	I=7 X=17	I=1 X=1	I=0 X=1	I=3 X=2	I=2 X=0	I=1 X=2	I=3 X=3	I=0 X=8	I=1 X=0	I=1 X=0
	Cladding	I=0 X=1	I=3 X=17	I=7 X=18	I=0 X=2	I=0 X=1	I=2 X=1	I=1 X=0	I=1 X=0	I=3 X=1			
	Waste Form	I=0 X=2	I=17 X=16	I=8 X=13	I=1 X=3	I=0 X=1	I=16 X=6	I=14 X=4	I=1 X=0	I=3 X=1	I=0 X=8		I=1 X=0
	Pallet	I=0 X=1	I=2 X=1	I=4 X=6	I=1 X=1	I=0 X=1	I=1 X=0		I=1 X=0	I=3 X=1			
	Invert	I=4 X=4	I=11 X=4	I=4 X=10	I=0 X=4	I=0 X=1	I=3 X=3	I=12 X=10	I=1 X=1	I=3 X=2	I=0 X=4		
	Unsaturated Zone Below	I=18 X=13	I=3 X=11	I=0 X=4	I=1 X=2		I=7 X=11	I=7 X=12	I=2 X=5	I=2 X=6	I=0 X=4		
	Saturated Zone	I=13 X=10	I=4 X=5	I=0 X=3	I=1 X=2		I=10 X=7	I=10 X=11	I=2 X=5	I=2 X=5	I=0 X=4		
	Biosphere	I=4 X=0	I=1 X=1			I=6 X=3	I=23 X=17	I=23 X=12	I=3 X=1				
	System	I=2 X=0		I=0 X=3		I=1 X=0	I=18 X=31		I=3 X=3	I=3 X=6			I=3 X=10

WIPP FEP
Comprehensiveness and Completeness

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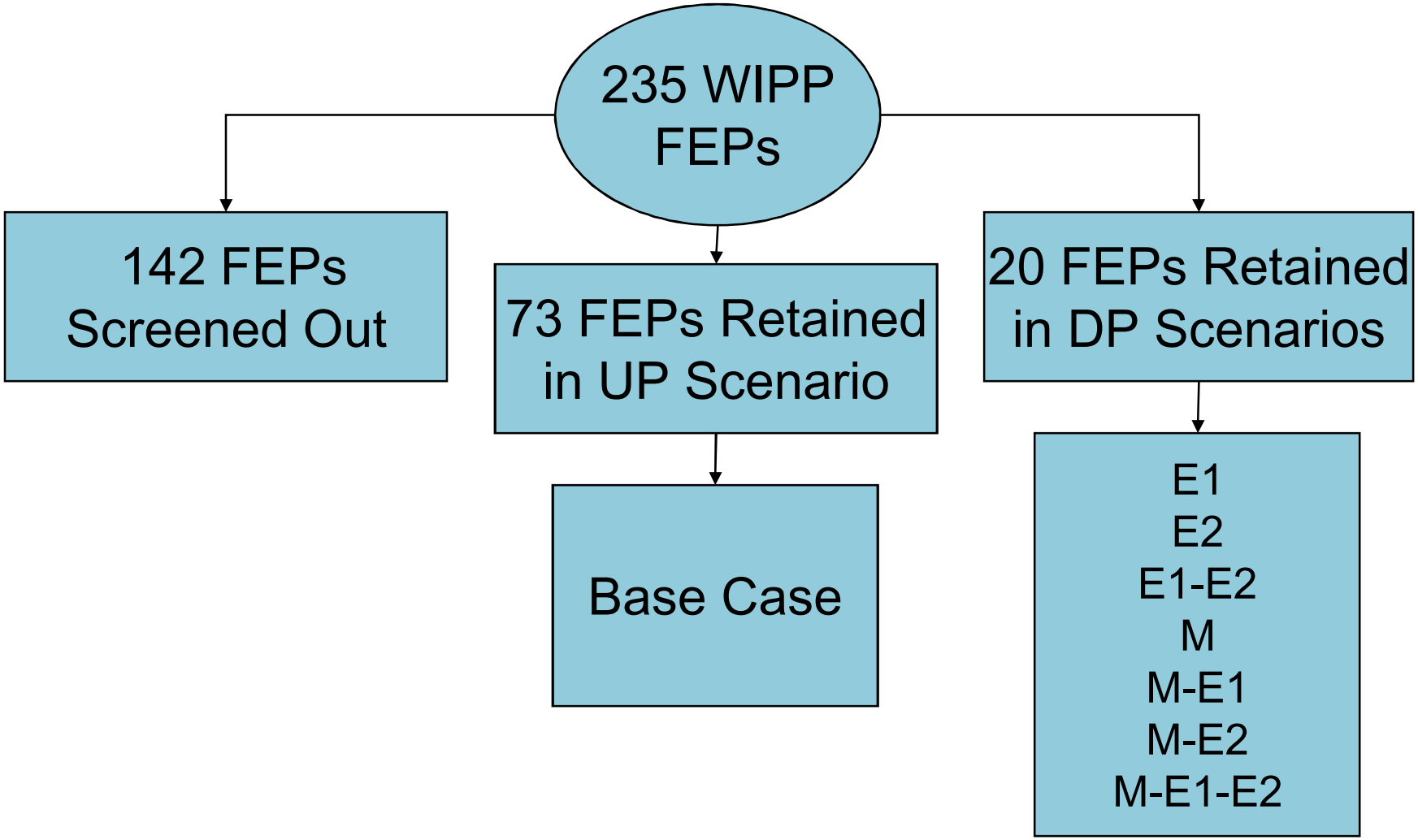
- How do you build a comprehensive FEP list?
  - Review FEP lists from other programs (e.g., NEA FEP Database)
  - Review WIPP project literature
    - FEP identification begins with site characterization
  - Include everything initially
    - Wait until the next step to begin screening
  - Document consideration of every issue that was raised
  - Use FEP Classification to facilitate review for comprehensiveness
  - Use FEP Screening to further demonstrate comprehensiveness and completeness

WIPP Scenarios



WIPP DP Scenarios

- E1 – drilling intrusion into pressurized brine pocket
- E2 – drilling intrusion that does not hit brine
- E1-E2 – drilling intrusion into the repository that was previously hit by an intrusion that intercepted a brine pocket
- M – mining
- M-E1 – mining in combination with E1
- M-E2 – mining in combination with E2
- M-E1-E2 – mining in combination with E1-E2