Modeling the Engineered Barrier System for the Proposed Yucca Mountain Repository

Presented to:
DOE-EM Performance Assessment Community of Practice Technical Exchange Meeting

Presented by:
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Los Alamos National Laboratory

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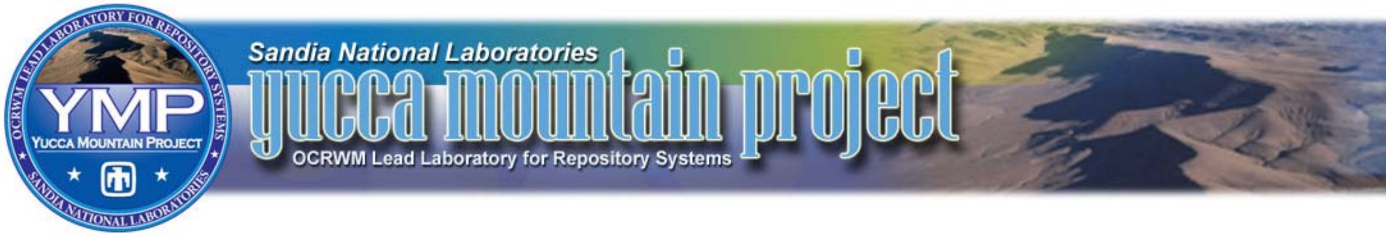
Yucca Mountain Lead Laboratory Partners



- Apogen / QinetiQ
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- RHYM
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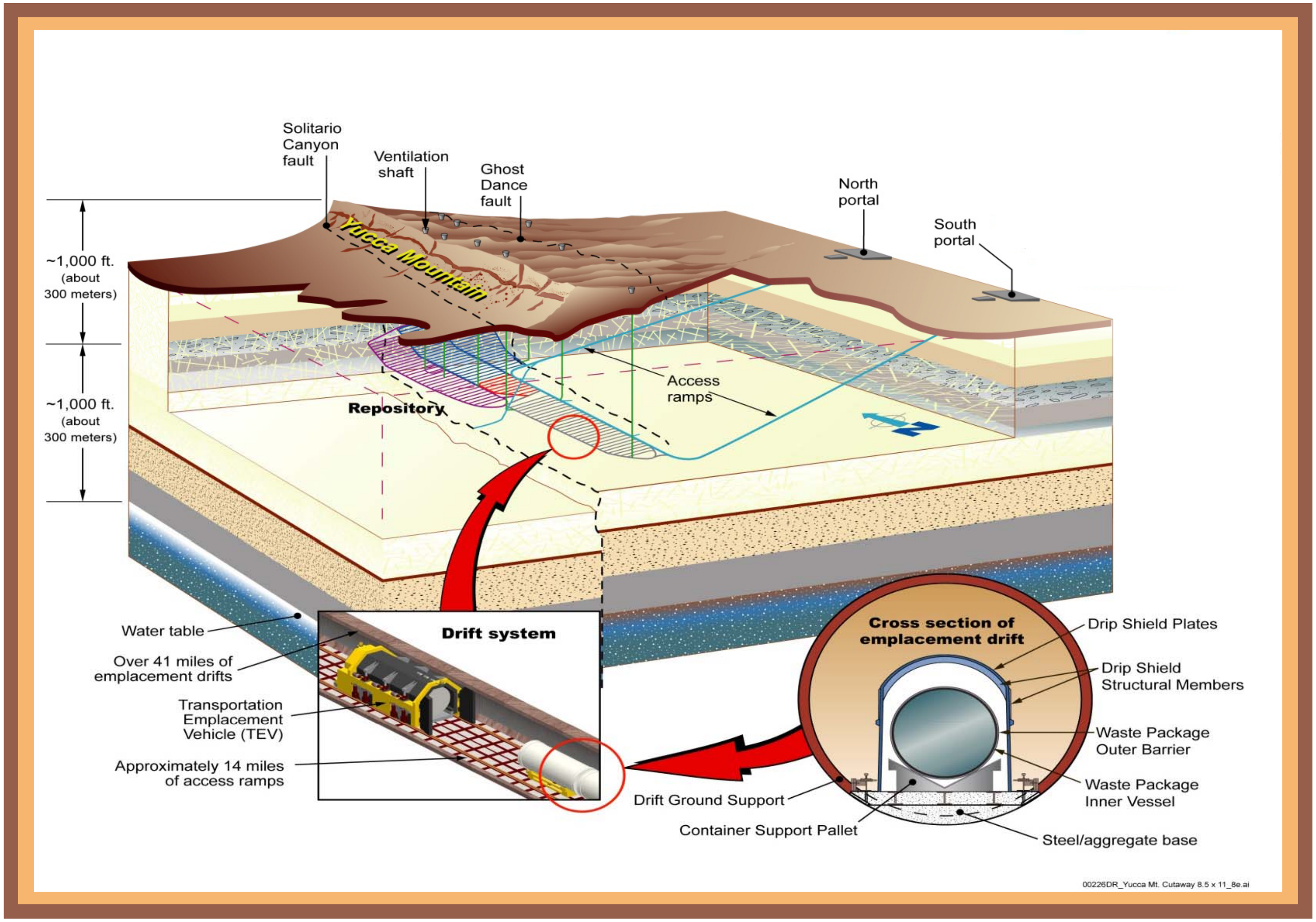
- Sala & Associates
- SSA
- Stoller
- URS

OUTLINE

- YMP Engineered Barrier System Overview
- Total System Performance Assessment Overview
- Waste Package and Drip Shield Corrosion
  - General Corrosion
  - Localized Corrosion
  - Stress Corrosion Cracking
- Waste Form Degradation
  - Cladding
  - Spent Nuclear Fuel
  - Defense High Level Waste Glass
- Questions and Answers

The Natural and Engineered Barrier System



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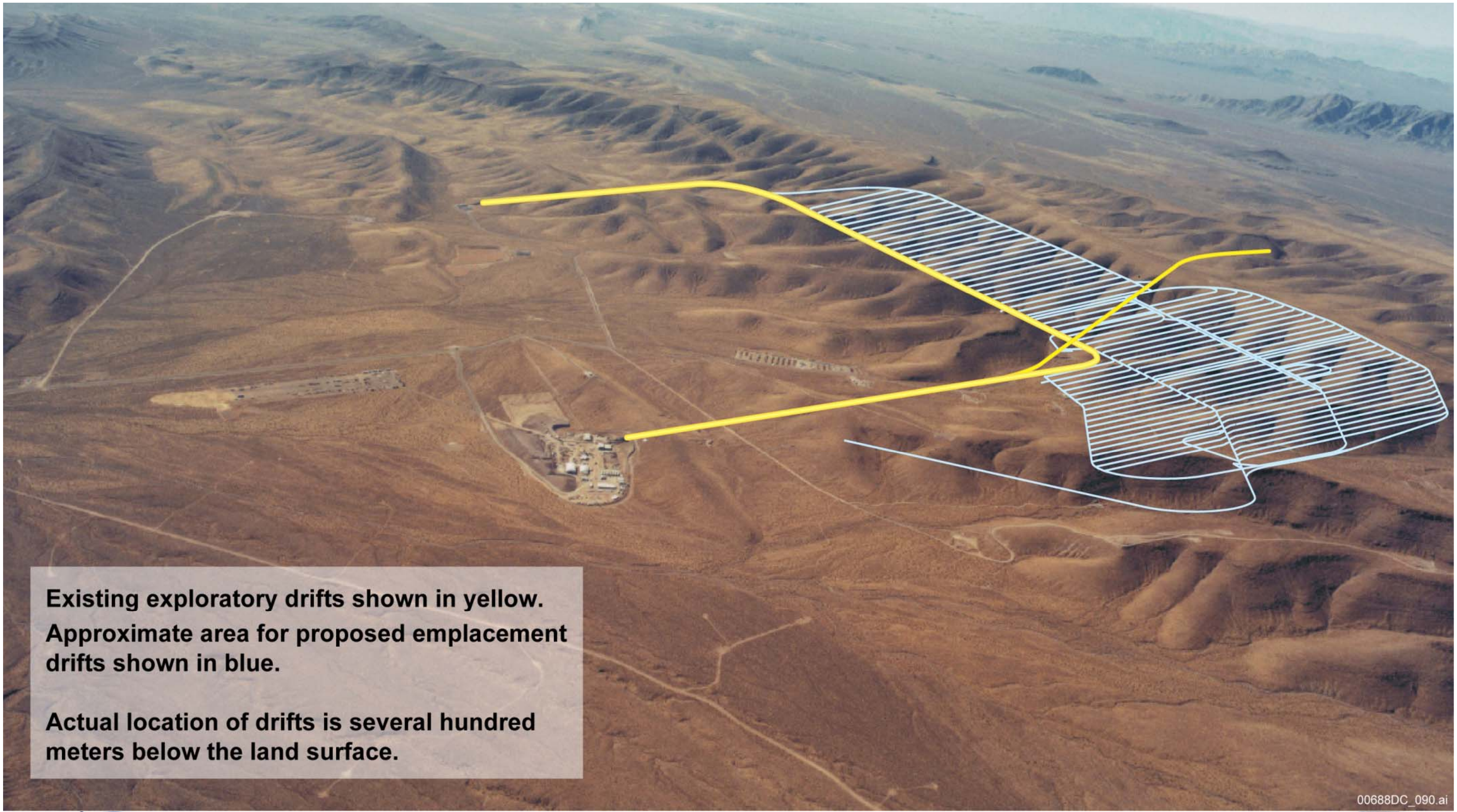
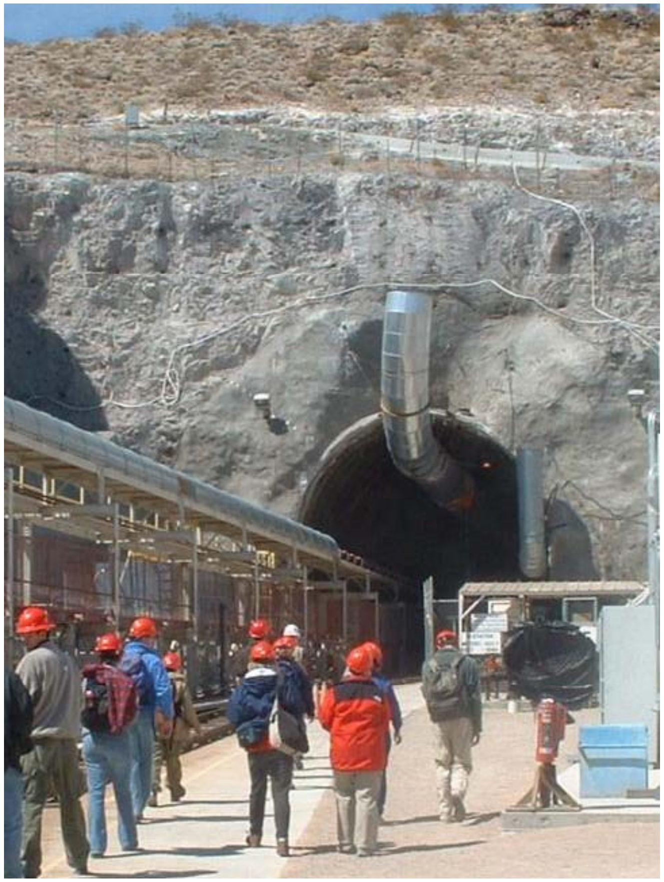
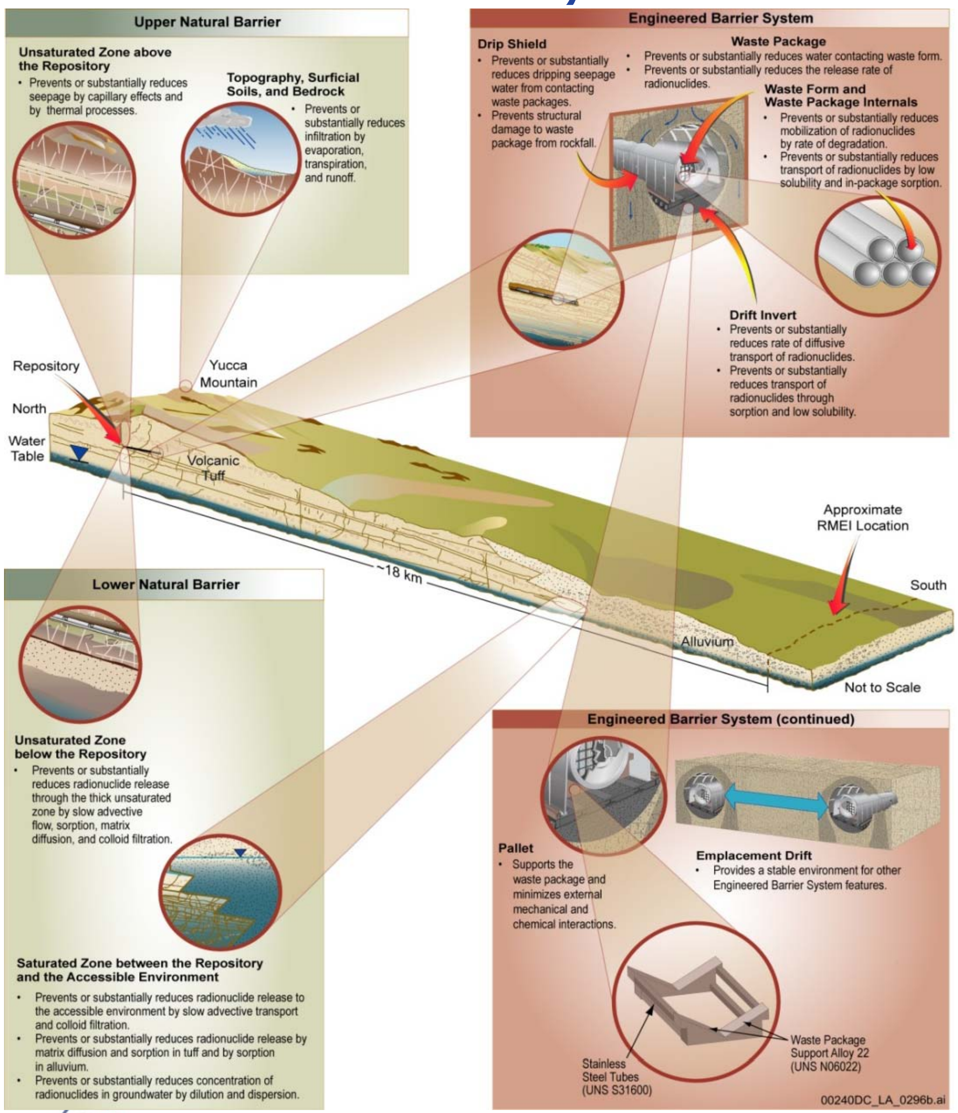
LOCATIONS OF EXPLORATORY AND EMPLACEMENT DRIFTS



Yucca Mountain Exploratory Studies Facility

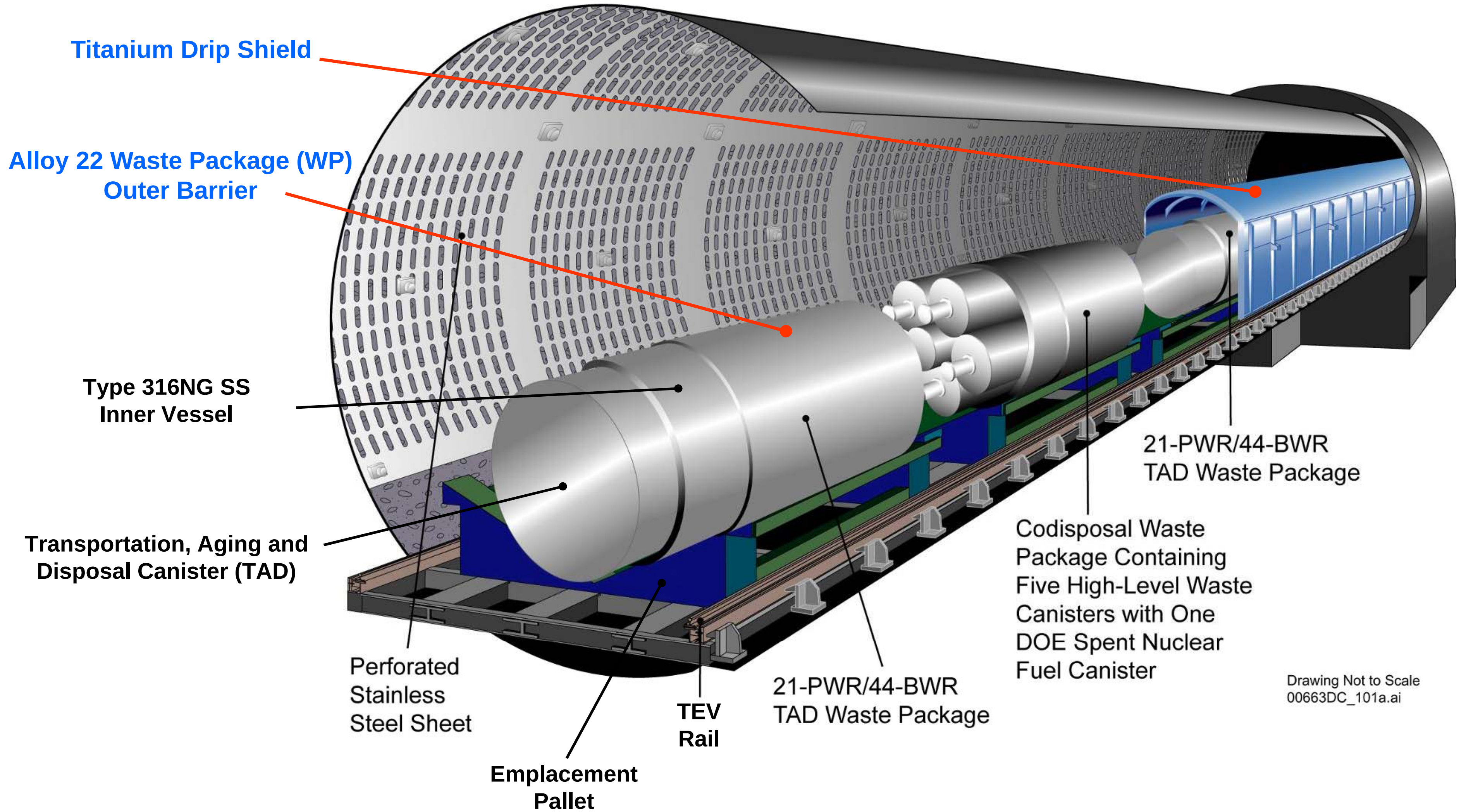


Barriers, Features and Components

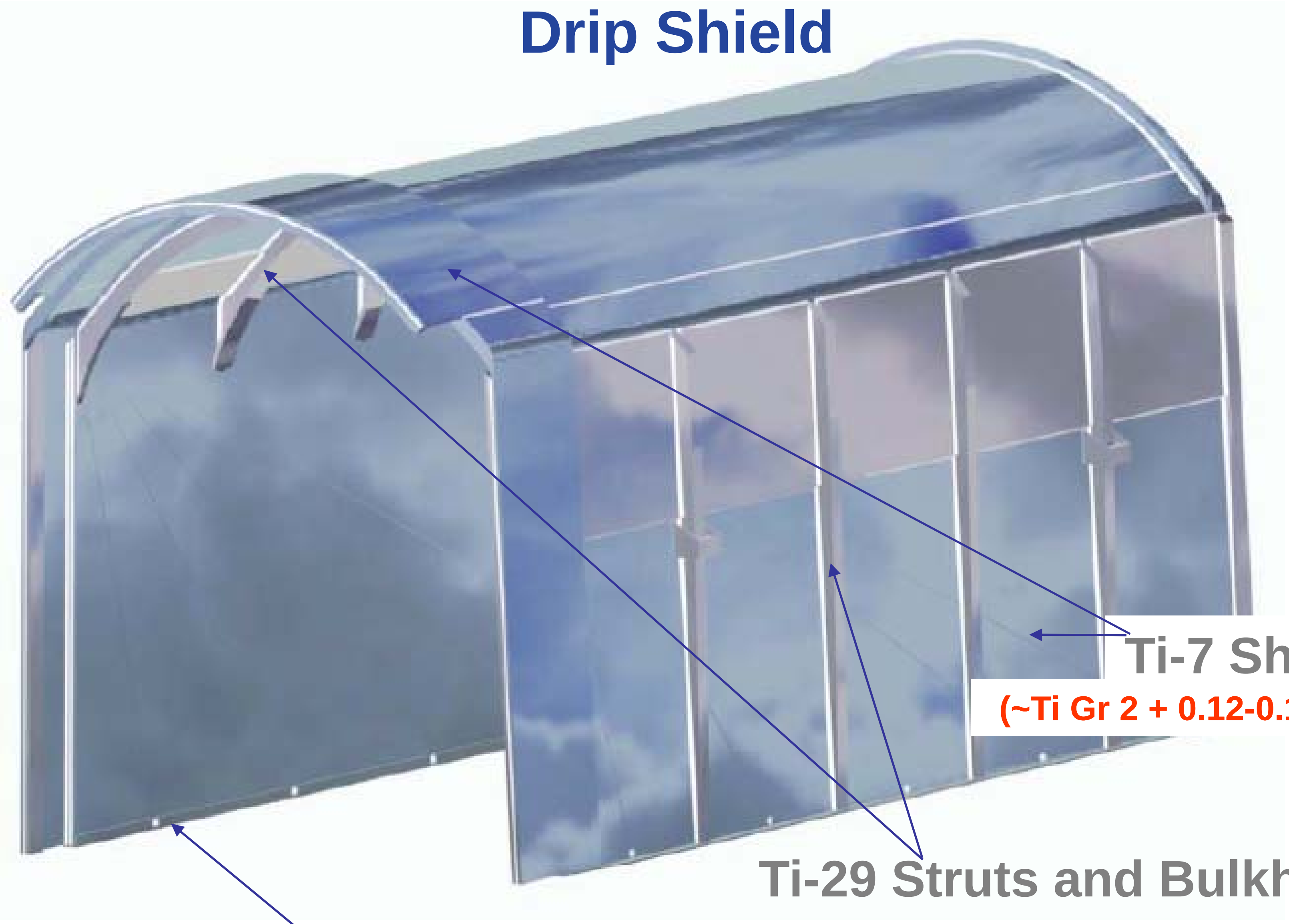


- Features and Components
  - Surface soils and topography
  - Unsaturated zone above the repository
  - Drip shield
  - Waste package
  - Cladding
  - Waste form
  - Invert
  - Unsaturated zone below the repository
  - Saturated zone

The Engineered Barrier System



Drip Shield


Ti-7 Shell
(~Ti Gr 2 + 0.12-0.15% Pd)
Ti-29 Struts and Bulkheads
(Ti Gr 5 + 0.08-0.14% Ru)
Alloy 22 Feet

The Primary Purpose of the Engineered Barrier System is to Delay or Reduce the Rate of Water Contacting the Waste, Limiting Radionuclide Release

Waste Sources for Yucca Mountain

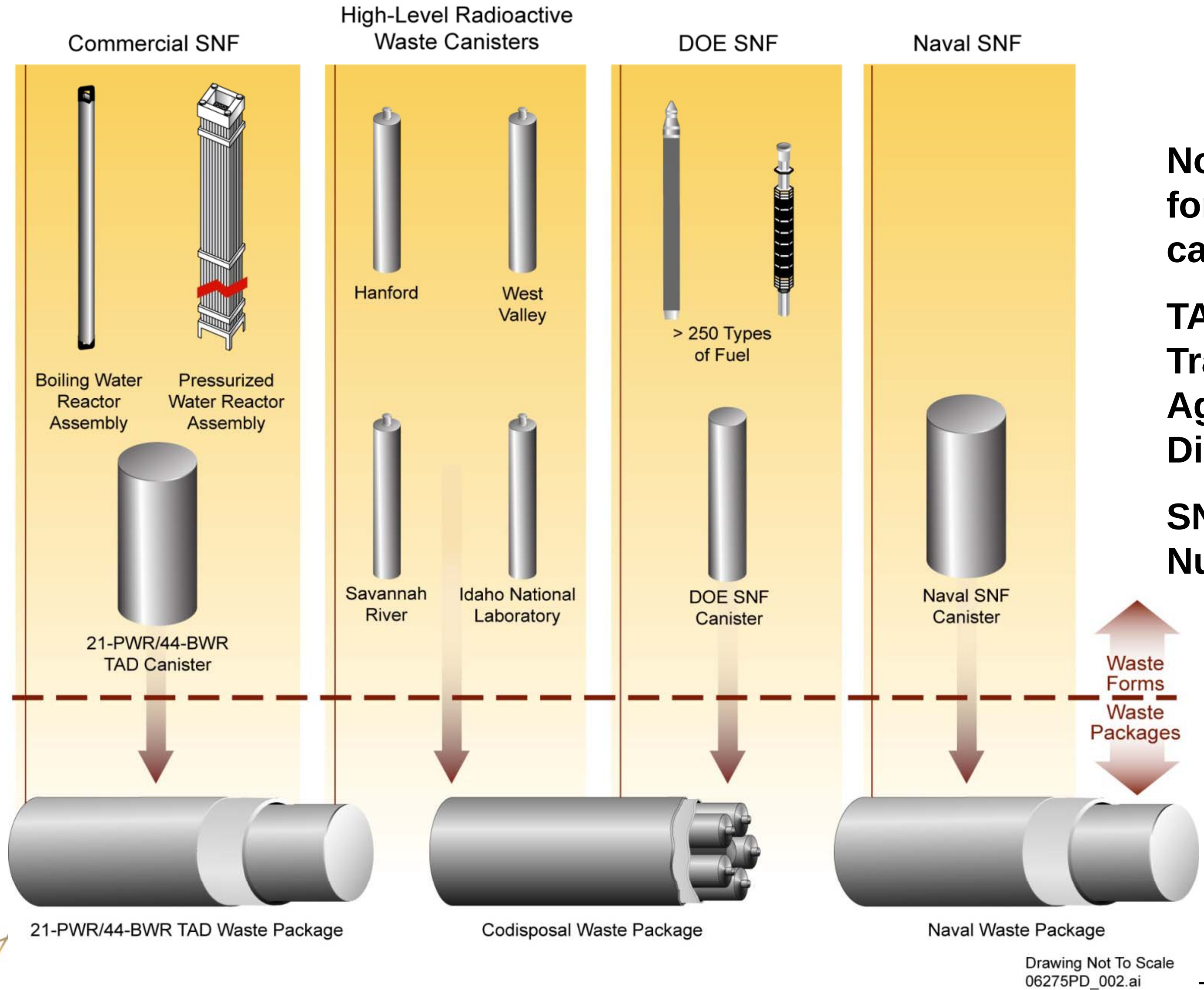
Commercial Spent Nuclear Fuel:
63,000 MTHM (~7500 waste packages)

DOE & Naval Spent Nuclear Fuel:
2,333 MTHM
(65 MTHM naval spent fuel in ~400 waste packages)
(DSNF packaged with HLW)

DOE & Commercial High-Level Waste:
4,667 MTHM
(~3000 waste packages of co-disposed DSNF and HLW)

DSNF: Defense Spent Nuclear Fuel
HLW: High Level Radioactive Waste
MTHM: Metric Tons Heavy Metal

Waste Form/Waste Packages in the LA



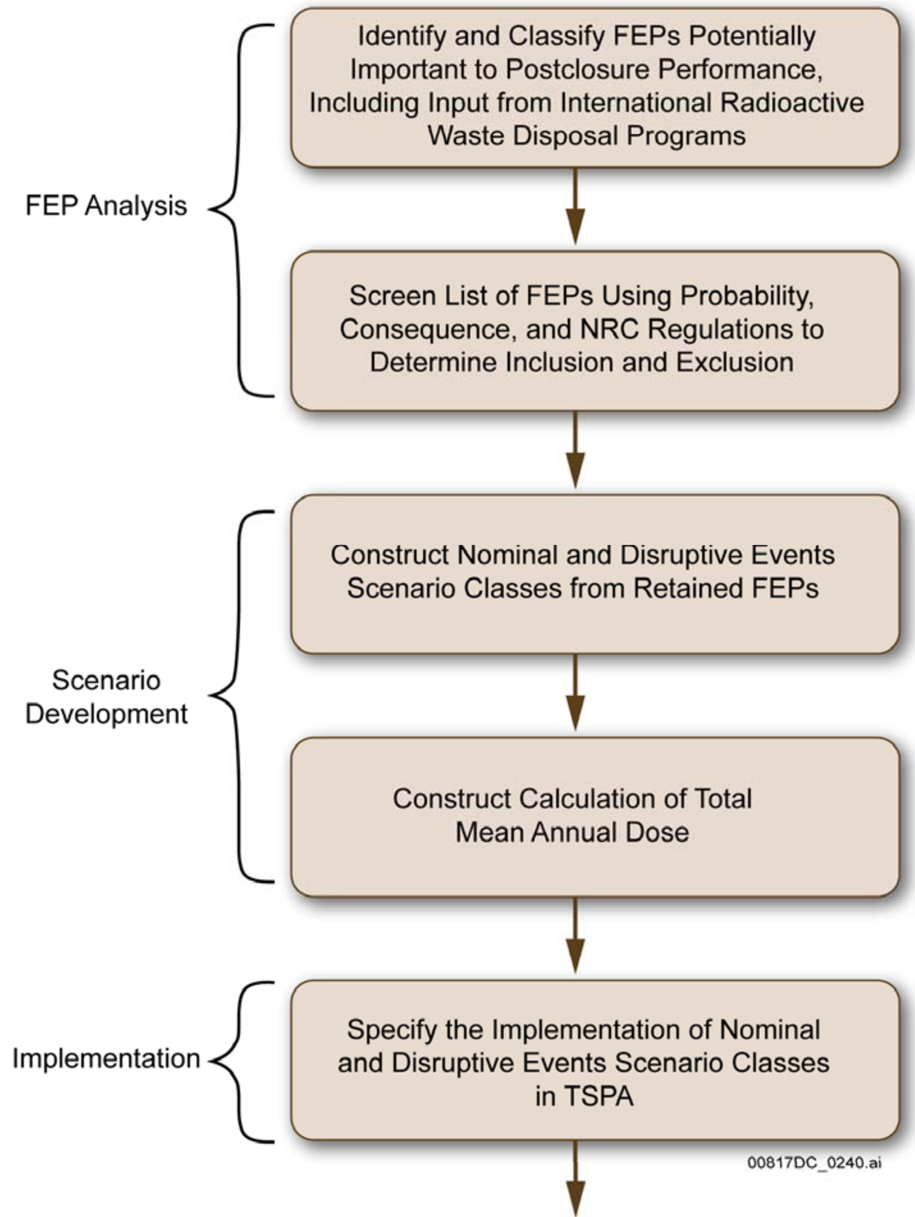
Notes: All waste forms are canisterized

TAD = Transportation, Aging and Disposal

SNF = Spent Nuclear Fuel

Evaluating FEPs and Defining Scenarios

- Probability and significance criteria for FEPs provided in 10 CFR 63.114
- 374 FEPs evaluated
  - 222 excluded from TSPA
  - 152 included
- Four scenario classes defined for analysis



TSPA-LA Scenarios

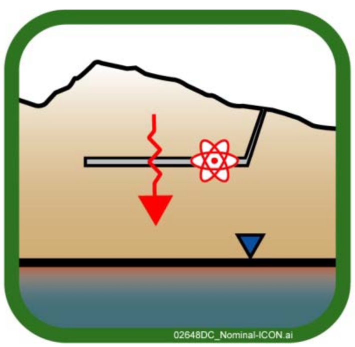
Four scenario classes divided into seven modeling cases

Nominal Scenario Class

- Nominal Modeling Case (included with Seismic Ground Motion for 1,000,000-yr analyses)

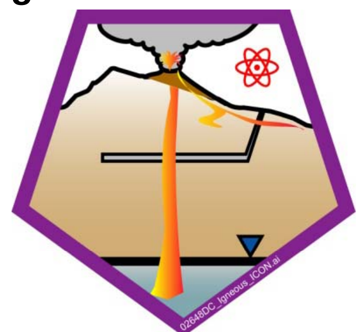
Early Failure Scenario Class

- Waste Package Modeling Case
- Drip Shield Modeling Case



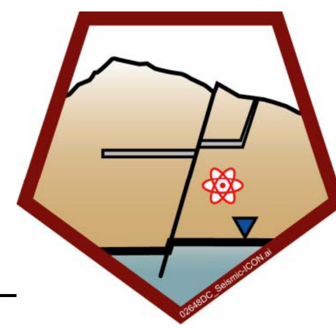
Igneous Scenario Class

- Intrusion Modeling Case
- Eruption Modeling Case

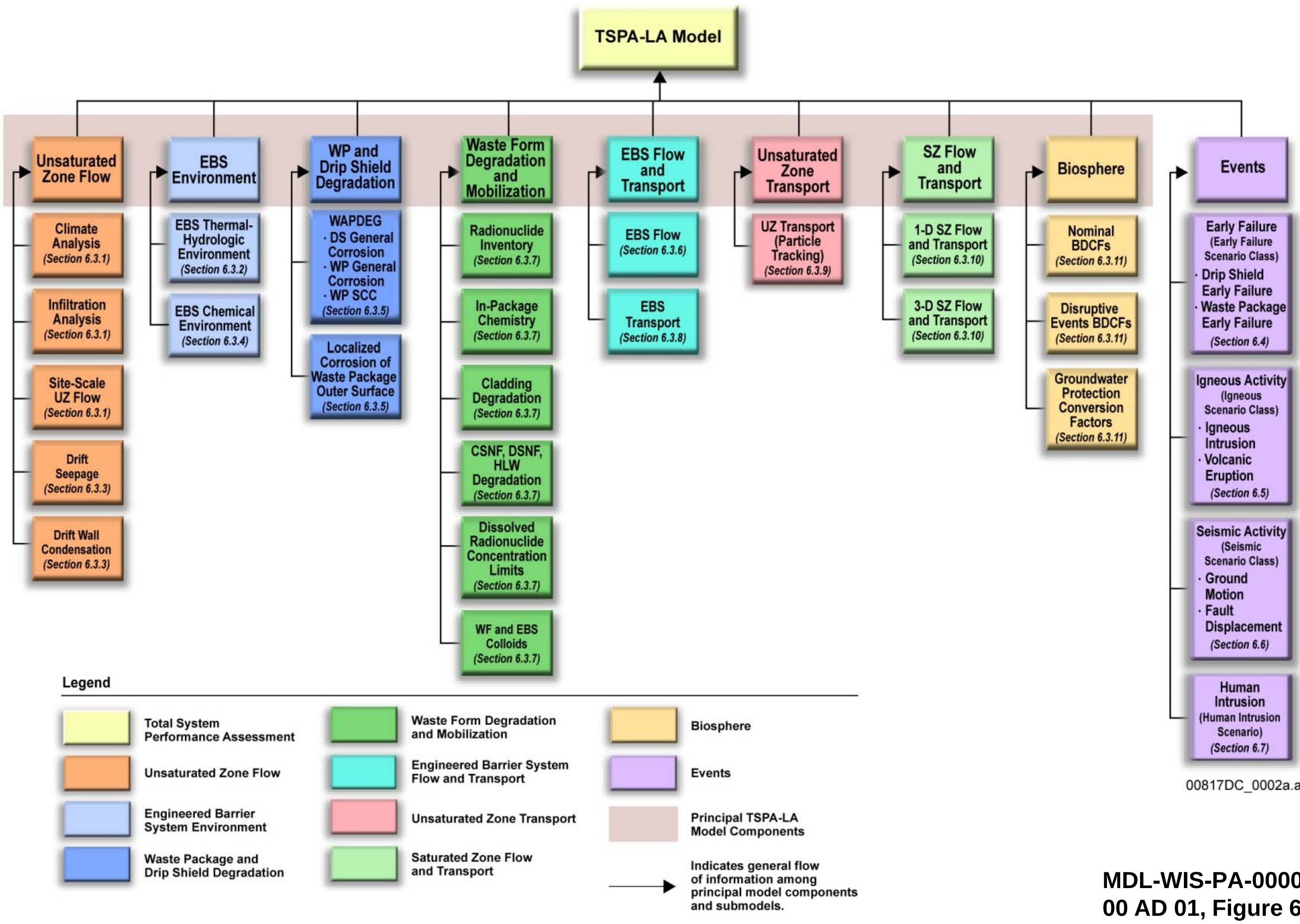


Seismic Scenario Class

- Ground Motion Modeling Case
- Fault Displacement Modeling Case



TSPA SYSTEM MODEL



MDL-WIS-PA-000005 REV 00 AD 01, Figure 6-1

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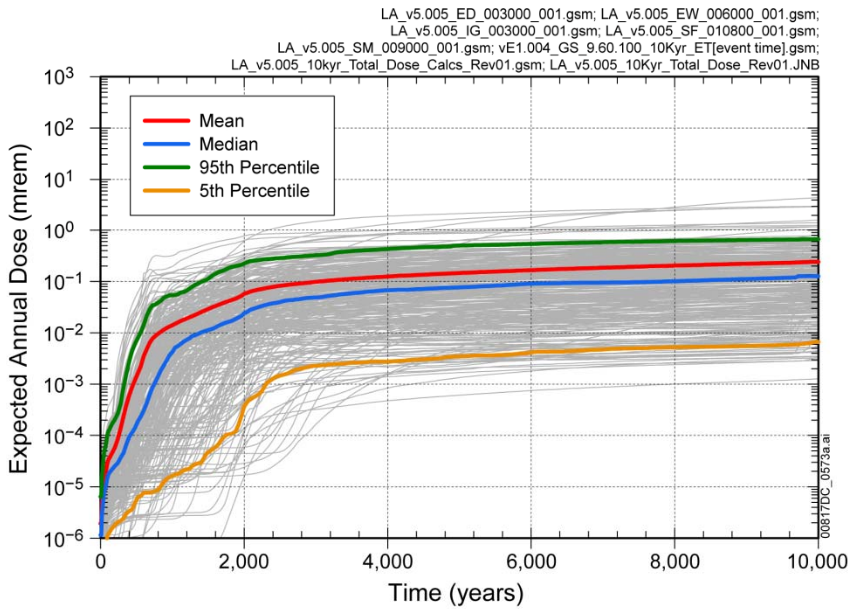
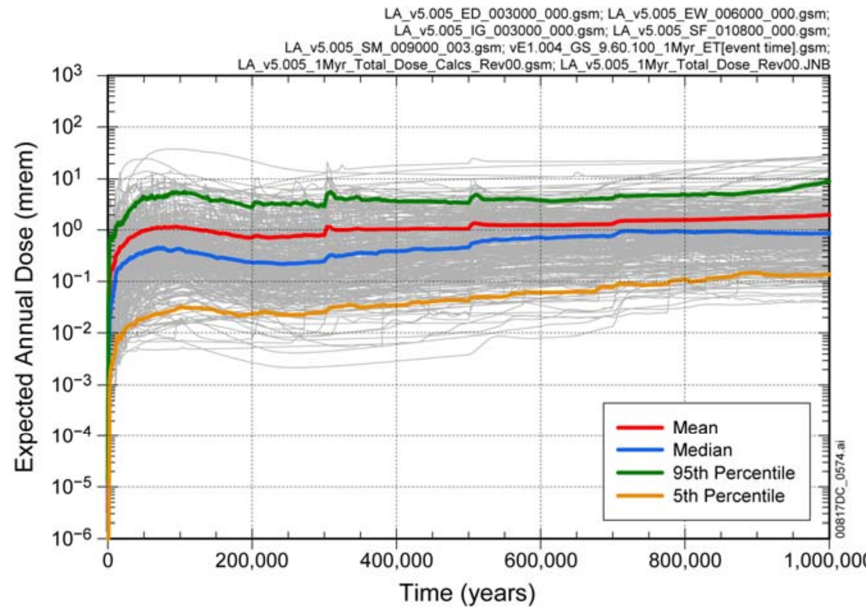
Total System Performance Assessment Results

Total Mean Annual Dose



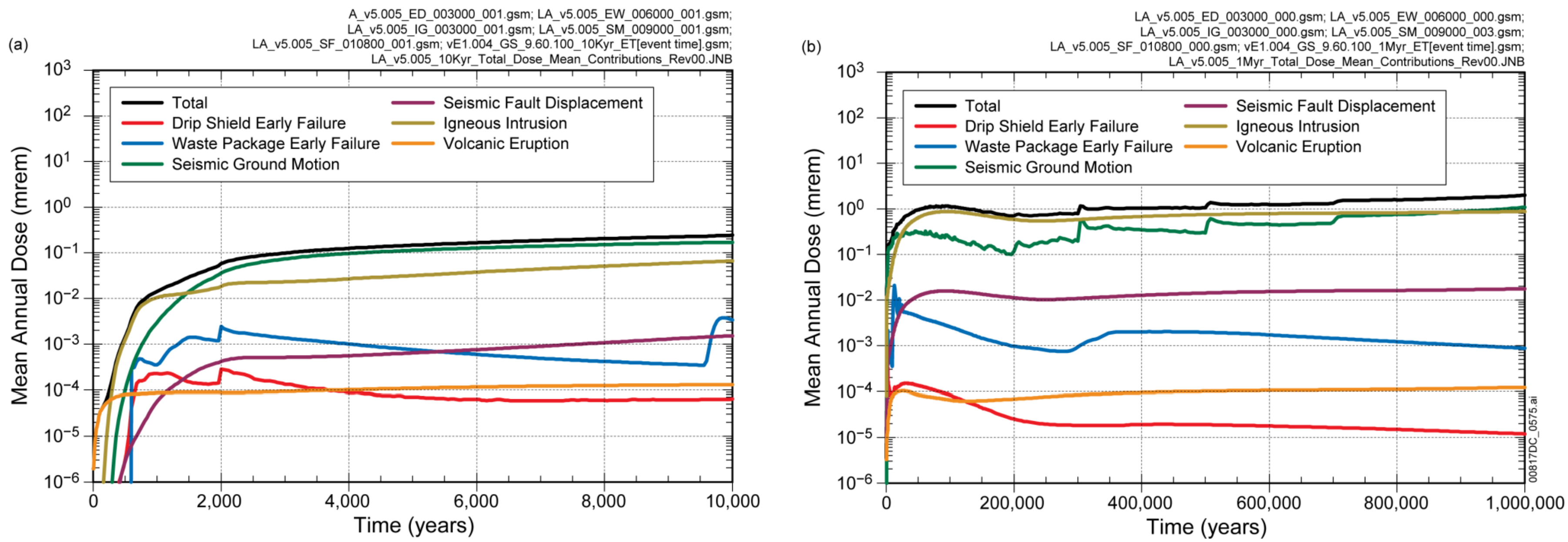
10,000 years



1,000,000 years

MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.1-1[a] and Figure 8.1-2[a]

Modeling Cases Contributing to Total Mean Annual Dose



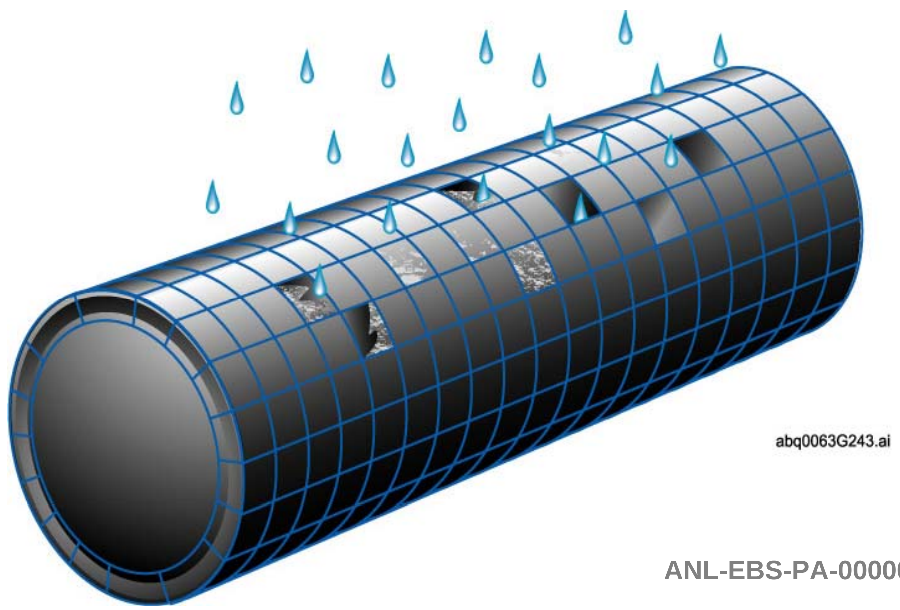
10,000 years

1,000,000 years

MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.1-3[a]

Objectives of Waste Package and Drip Shield Degradation Abstraction

- Provide EBS flow and transport model and waste form degradation and mobilization model
  - Number of patch and crack breaches per failed waste package (WP)
  - Number of drip shield failures (DS)
  - Number of early failed WPs and DSs



ANL-EBS-PA-000001

Engineered System Materials

- Drip Shield
  - Grade 7 Titanium plates
  - Grade 29 Titanium supports
  - Grade 7 / Grade 28 / Grade 29 welds

	Al	Pd	Ru	Ti	V
Grade 7	-	0.12-0.25	-	Bal.	-
Grade 28	2.5-3.5	-	0.08-0.14	Bal.	2-3
Grade 29	5.5-6.5	-	0.08-0.14	Bal.	3.5-4.5

- Waste Package
  - Annealed Alloy 22
  - Annealed Alloy 22 welds (longitudinal weld)
  - Stress relieved Alloy 22 welds (circumferential closure weld)

Alloy 22 Composition (N06022)							
Co	Cr	Fe	Mn	Mo	Ni	V	W
2.5 max	20-22.5	2.0-6.0	0.5 max	12.5-14.5	Bal.	0.35 max	2.5-3.5

Alloy 22 has an impressive analog - Hastelloy C

Exposed at Kure Beach, North Carolina since 1941 - 250 meters from ocean

Original mirror finish still intact after salt and debris washed from surface

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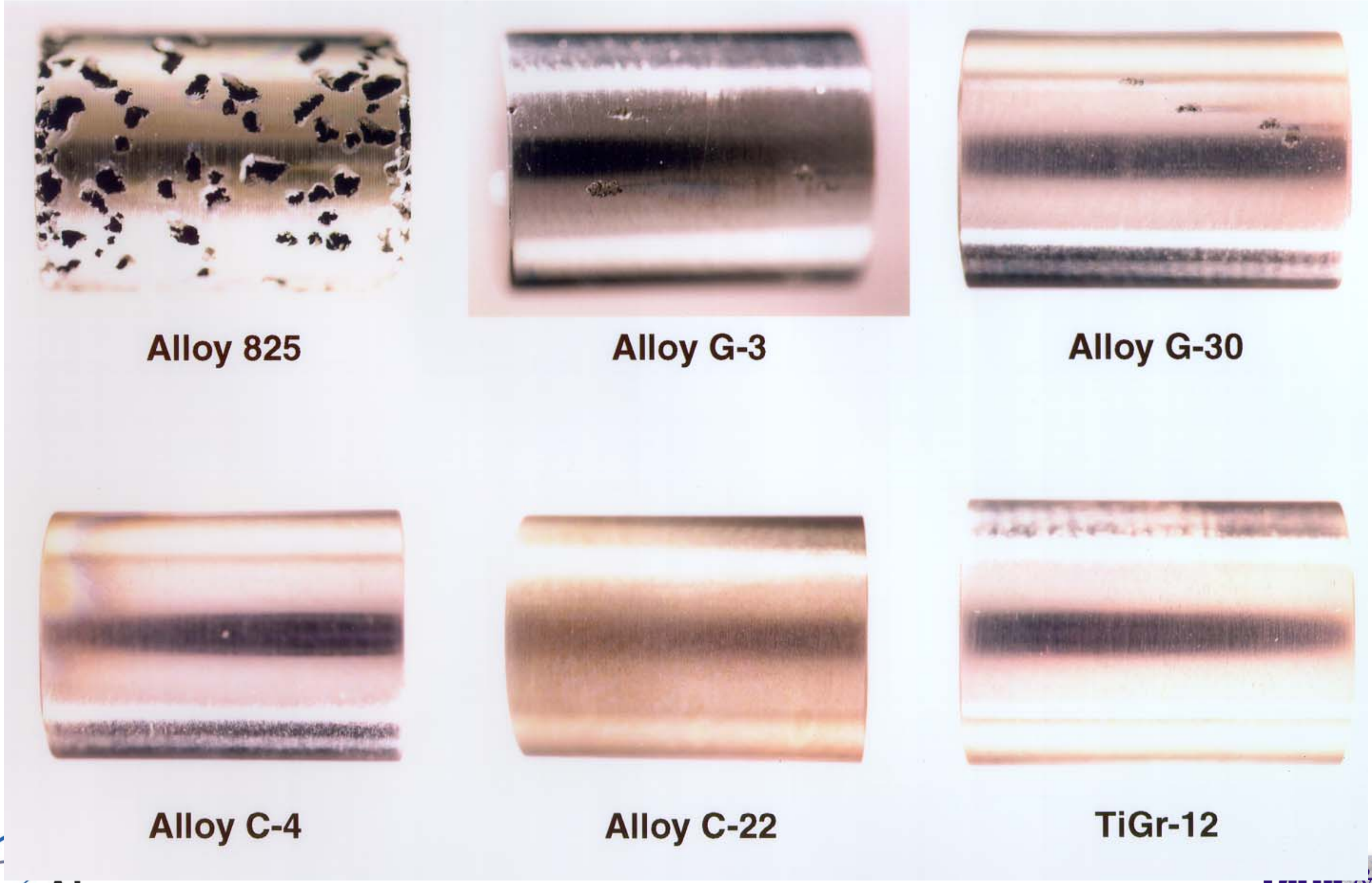
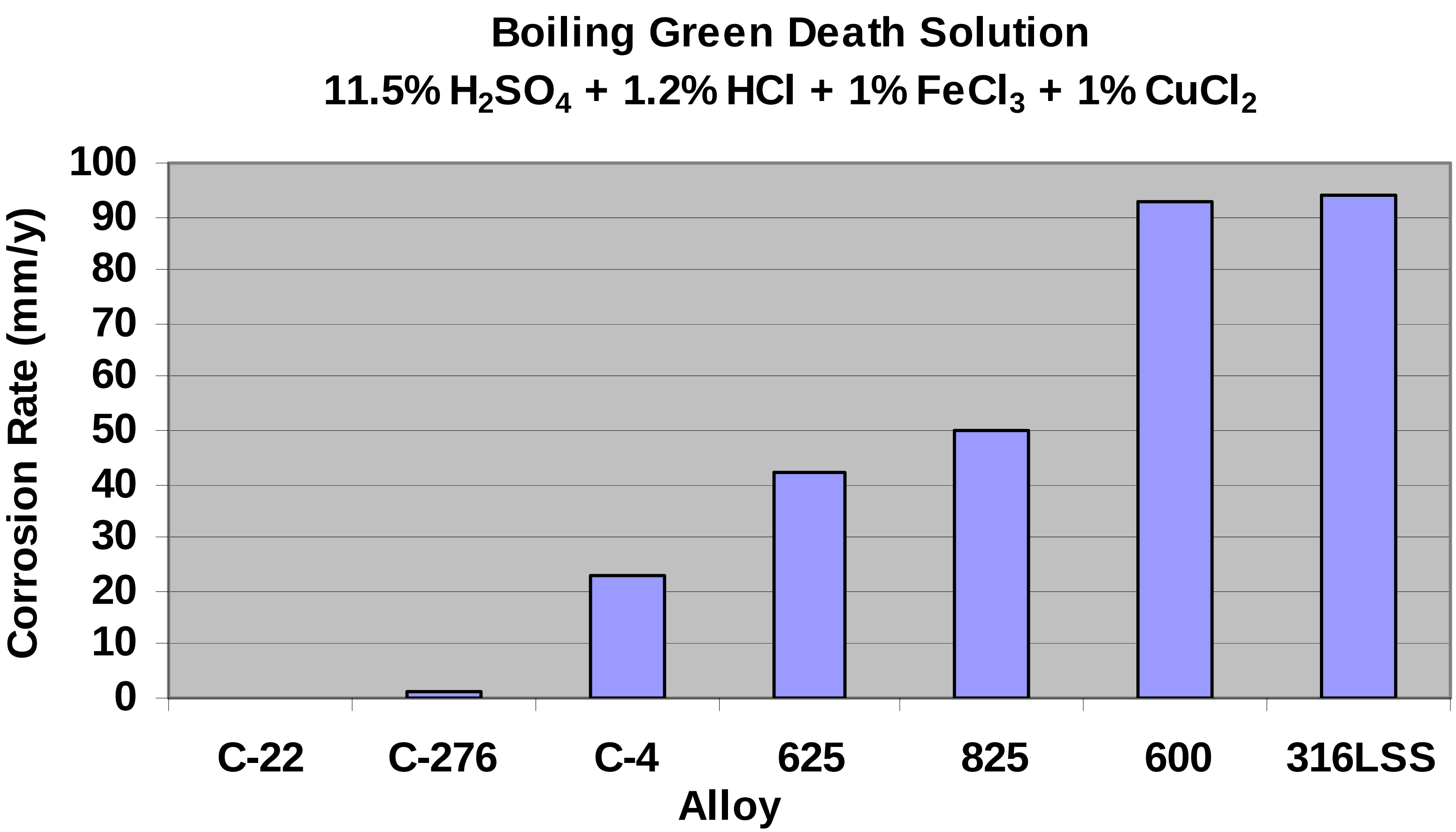
Outstanding Pitting Resistance of Alloy 22:

Superior to Other Candidate Materials



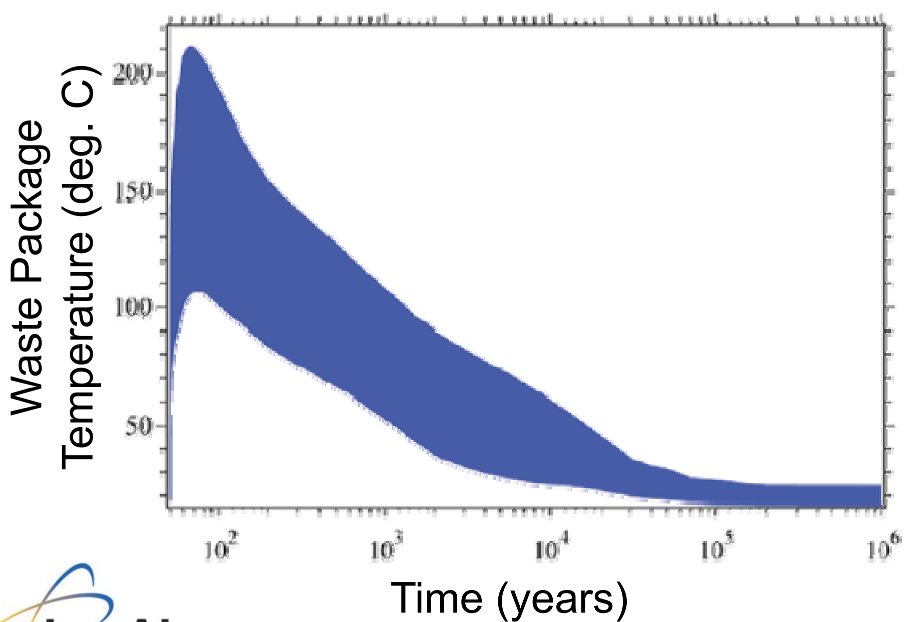
Localized Corrosion of Engineering Alloys

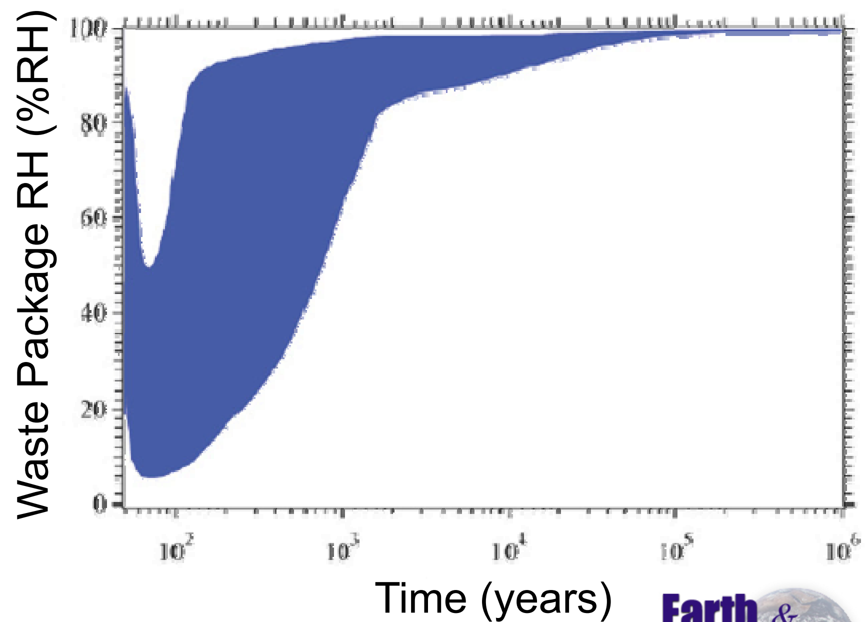


Green Death Solution: Solution Removed From Scrubbers Used to Wash Acidic Gases with Sea Water.

Environments That May Potentially Contact the Barrier Materials

- Seepage environments
  - **Electrolyte chemistry defined by ambient water composition**
  - **Unlimited contaminant supply**
  - **Electrolyte may be continuous**
- Deliquescent environments
  - **Electrolyte chemistry defined by salt-bearing dusts deposited during repository ventilation**
  - **Limited contaminants**
  - **Electrolyte bound in the dust layer as droplets**





Two Types of Chemical Environments

Deliquescence

- Dust containing soluble salts deposited on the WP during preclosure
- Multi-salt assemblages control deliquescence at higher temperatures
- NO_3^- is needed at high T
- Brine compositions become dilute as T decreases and RH increases
- Amount of brine is limited:
  - 1.8 μL/cm^2 (18 μm thick layer) at 120°C – decreasing with increasing temperature
- Chemistry is moderated by contact with rock-forming minerals in dust
- Brines can change with time due to degassing, deliquescence

Seepage

- Seepage may occur after cooldown (T_{WP} < 105°C)
- WP outer barrier is protected by the drip shields
- Residence time (equilibrium with T, RH at WP surface) controls the corrosion environment
- Chemical conditions (pH, Cl^-, NO_3^-, NO_3^-/Cl^-) are potentially corrosive during the early stages of cooldown
- Chemical fractionation may occur during transport

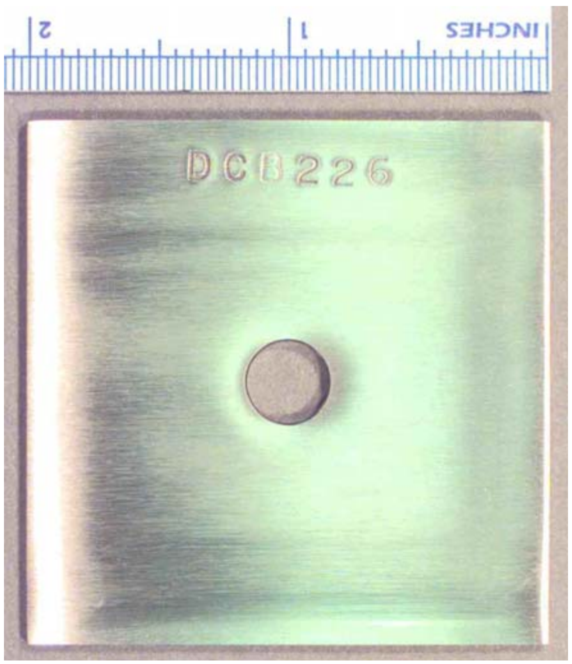
Long Term Corrosion Test Facility
(Lawrence Livermore National Laboratory)

Test facility tanks

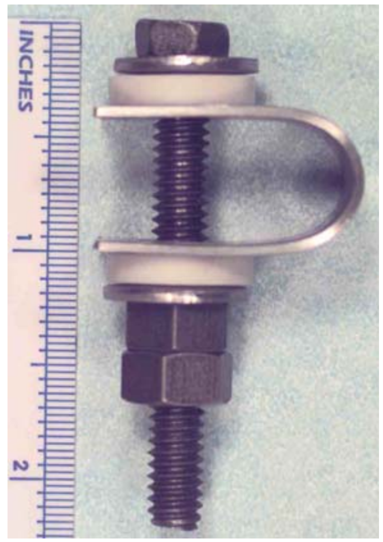
Test specimen rack

Evaluation of General, Localized, Galvanic and Stress Corrosion
Over 20,000 specimens tested

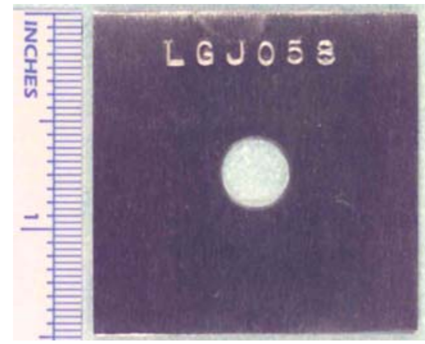
4 Types of Specimens In Test



Crevice Coupon



U-Bend Specimen



Galvanic Coupon

Weight Loss Coupon

Long-Term Exposure Testing Conditions

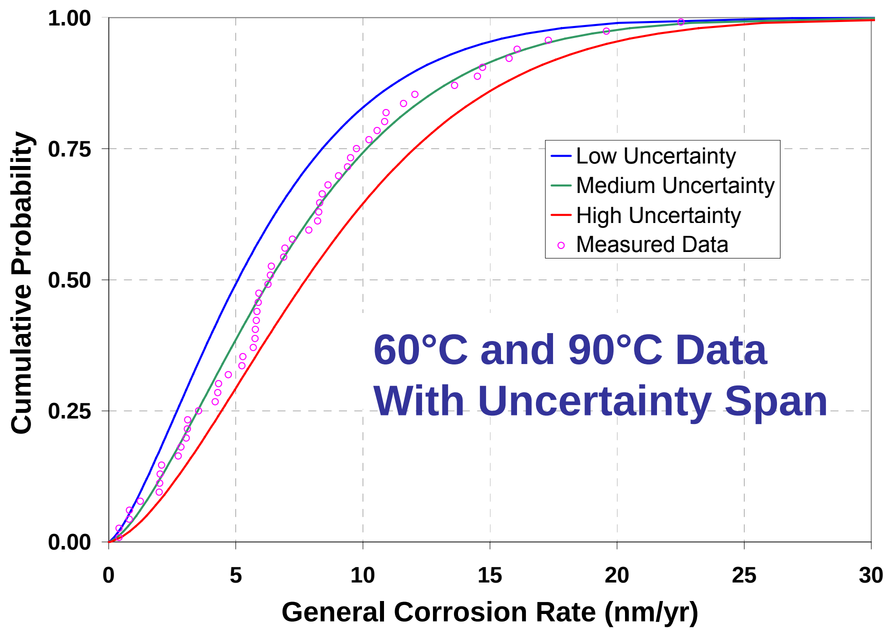
- Electrolytes: Simulated dilute water (SDW), Simulated acidified water (SAW) and Simulated concentrated water (SCW)
- Temperatures: 60ºC and 90ºC
- Specimen configurations: welded and non-welded, creviced and non-creviced
- Specimen locations: inundated, atmospheric and waterline

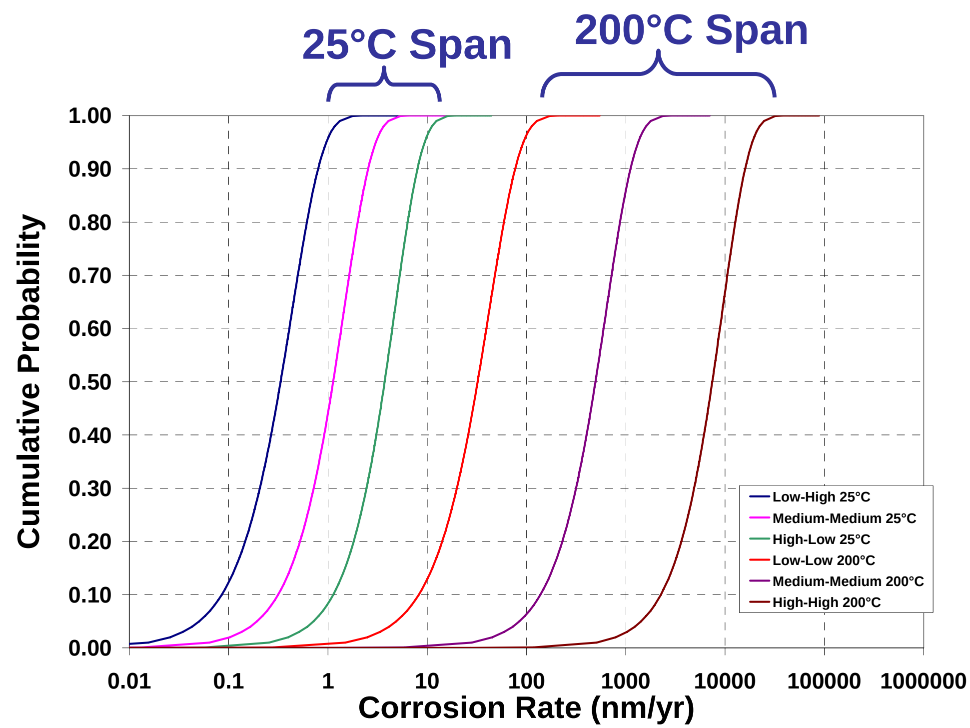
Ion	SDW 60°C and 90°C	SCW 60°C and 90°C	SAW 60°C and 90°C
K	34	3,400	3,400
Na	409	40,900	37,690
Mg	1	<1	1,000
Ca	0.5	<1	1,000
F	14	1,400	0
Cl	67	6,700	24,250
NO_3	64	6,400	23,000
SO_4	167	16,700	38,600
HCO_3	947	70,000	0
Si	27 (60°C) 49 (90°C)	27 (60°C) 49 (90°C)	27 (60°C) 49 (90°C)
Nominal pH	9.8 to 10.2	9.8 to 10.2	2.7

(concentrations are in parts per million)

WP General Corrosion

- 5-yr crevice geometry specimen weight-loss
- Activation energy from polarization resistance

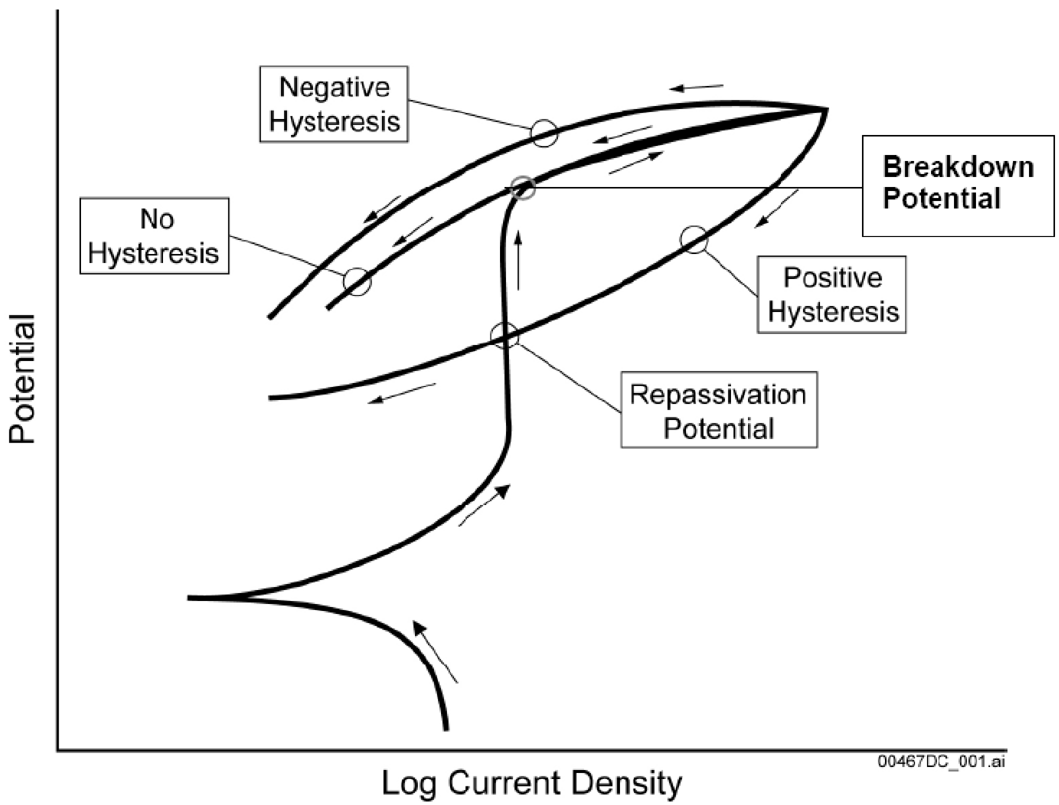




Localized Corrosion is Modeled to Initiate When A Critical Potential Criterion is Met

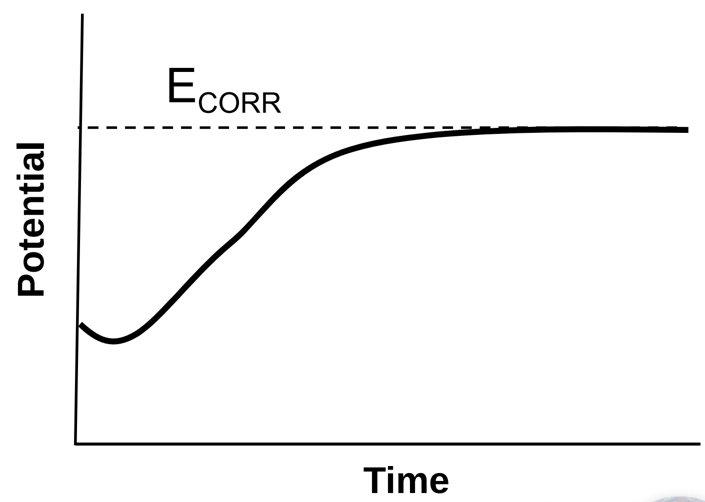
If $\Delta E \leq 0$, initiate localized corrosion

$\Delta E = E_{RCREV} - E_{CORR}$

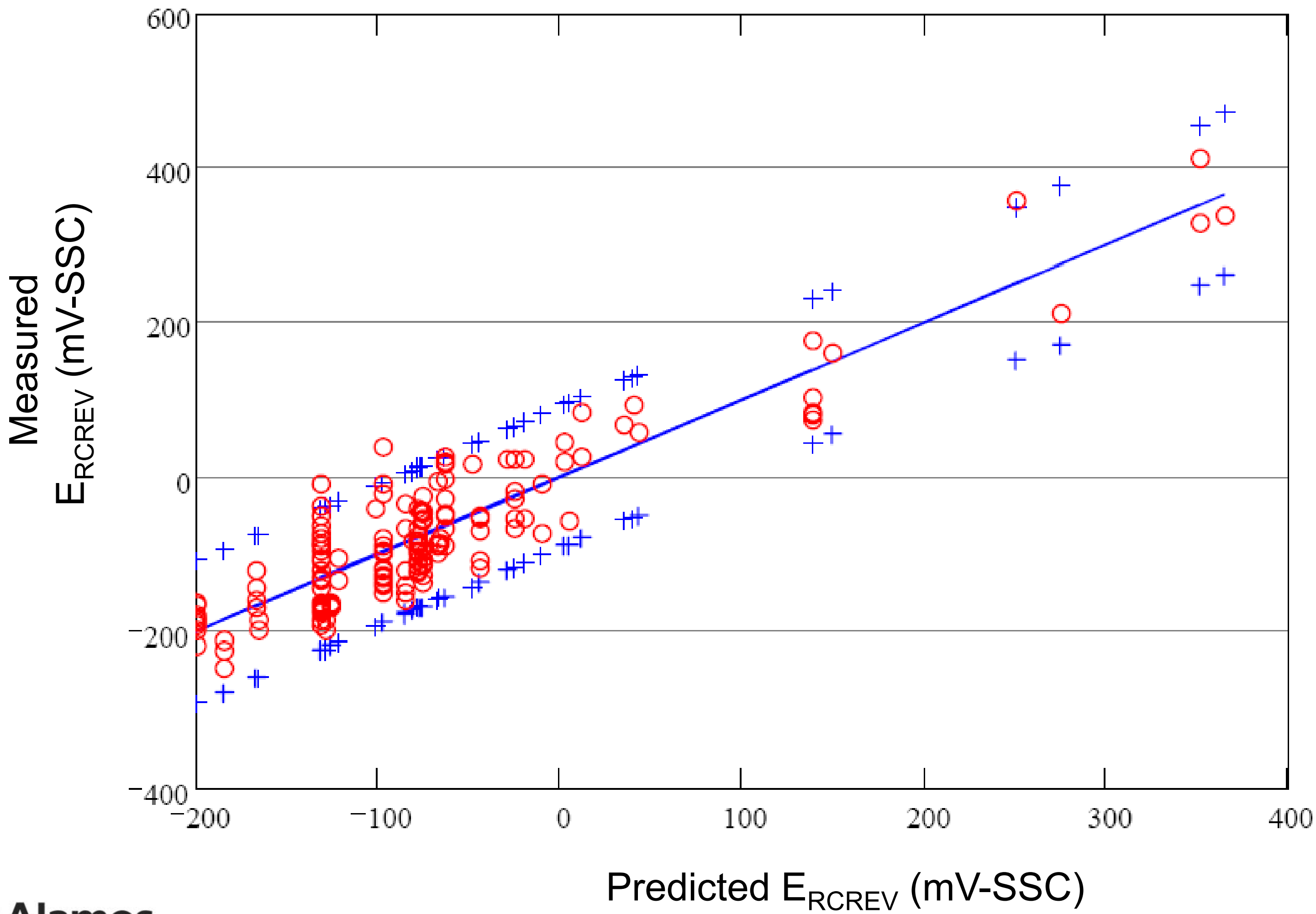


E_{RCREV} = crevice repassivation potential: the potential below which a propagating crevice will repassivate

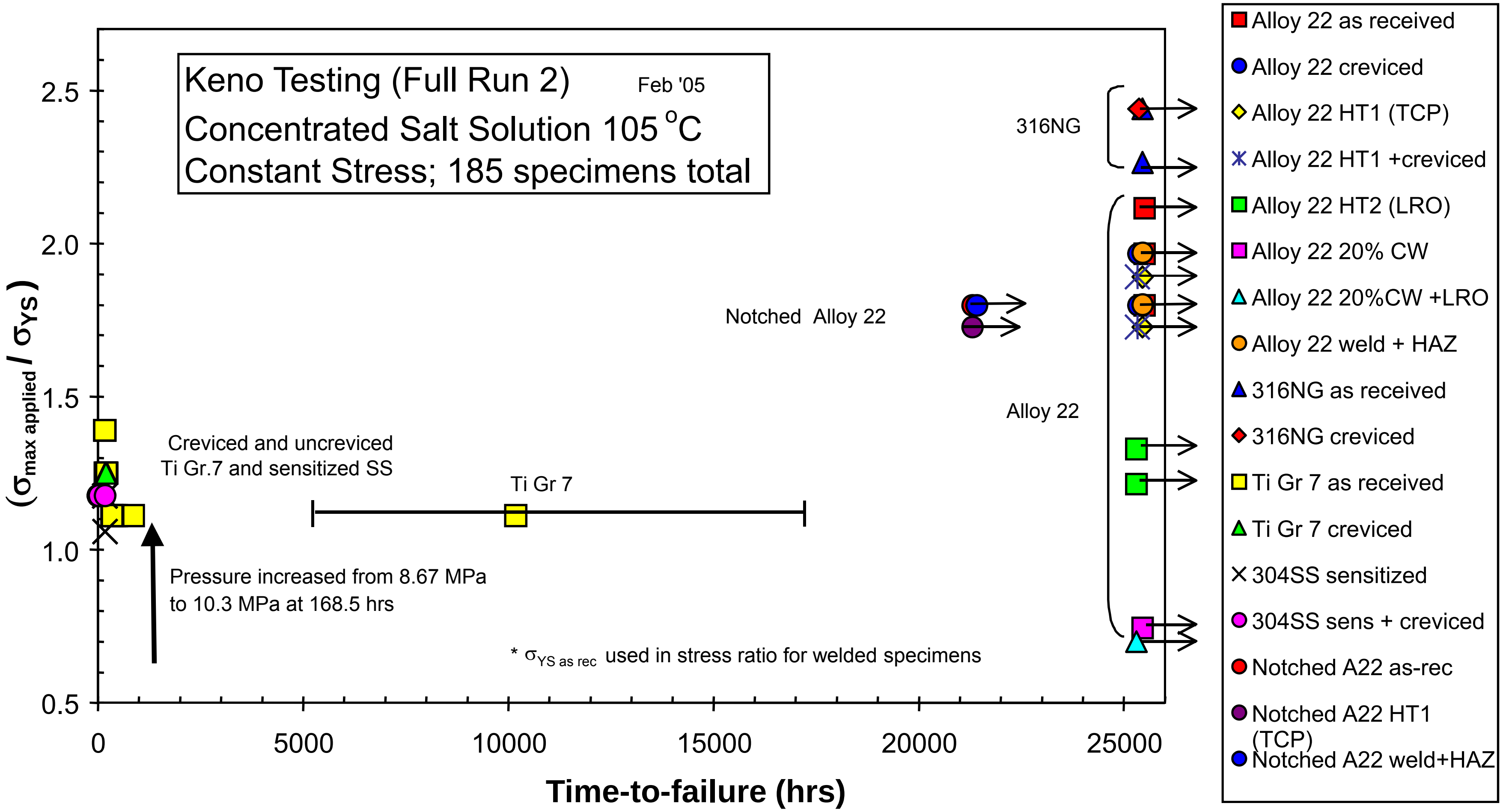
E_{CORR} = corrosion potential: the potential recorded for Alloy 22 following a long-term exposure to an electrolyte



Crevice Repassivation Potential is Modeled to Depend on [Cl$^-$], [NO$_3^-$], and Temperature



Data used for SCC Model



None of 120 Alloy 22 specimens have failed after 25,000 hours on test*

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Andresen et al., 12th Int'l Conference on Environmental Degradation, Salt Lake City, August 14-18, 2005

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Waste Form Modeling

- Civilian Spent Nuclear Fuel Cladding
  - No credit taken for postclosure performance
  - Effort involved in onsite cladding inspection outweighs the benefits
  - Recognized as unrealized performance margin

- Civilian Spent Nuclear Fuel
  - Inventory Uncertainty
    - Arrival Scenarios, Burnup
  - Inventory
    - Gap/Grain Boundary available for immediate release
    - Matrix Inventory releases as result of degradation
  - Matrix Degradation
    - Based upon experimental results
    - Surface area, temperature, pH, carbonate level, oxygen partial pressure

Waste Form Modeling (cont.)

- Defense Spent Nuclear Fuel
  - Inventory Uncertainty
    - Waste Package Heterogeneity
  - Assumed to Degrade Instantaneously

- Defense High Level Waste Glass
  - Inventory Uncertainty
    - Arrival Scenario,
    - Glass Loading,
    - Waste Package Heterogeneity
  - Degradation
    - Based Upon Experimental Results
    - Surface area, pH, relative humidity, temperature

Questions?