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Model Abstraction of Stainless Steel Waste Package Degradation

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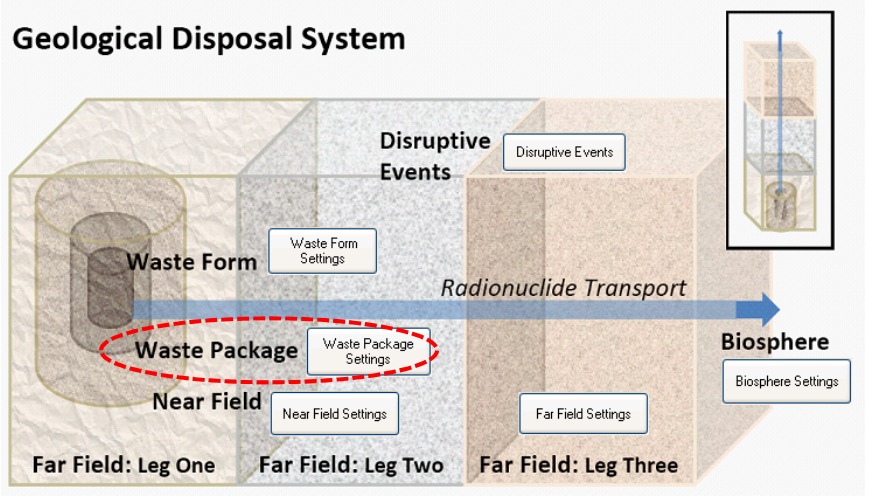
Introduction

- U.S. NRC and CNWRA have been developing a flexible performance assessment model — Scoping of Options and Analyzing Risk (β-SOAR)

- The objective is to provide risk and performance insights for a variety of potential spent nuclear fuel and high-level radioactive waste geological disposal concepts

- Waste Package Component model specifically accounts for corrosion of waste package materials



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Waste Package Materials in β-SOAR

- Copper, carbon steel, stainless steel, and titanium materials were selected to represent different corrosion behaviors in the scoping analysis
- Potential host geologic disposal system
  - Oxidizing
  - Reducing
- Using stainless steel as one of the waste package materials, general and localized corrosion processes are abstracted and conceptualized to estimate
  - waste package failure times
  - the extent of damage to the waste package surface

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Model Abstraction

- Considered two waste package failure mechanisms
  - General corrosion modeled to represent progressive failures distributed over time
  - Conversely, localized corrosion modeled to cause failure of a fraction of the waste packages at discrete times
- Other degradation processes (e.g., stress corrosion cracking) were not explicitly considered in the current model version, but may be considered in later versions

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Model Abstraction — General Corrosion

- Assumed to be a gradual material thinning process proceeding in a relatively slow and uniform manner compared to localized corrosion

- The waste package failure time is calculated as the time at which the corrosion front penetrates the material thickness, using the equation

$$t_{gc} = \frac{L}{R_{gc}}$$

t_{gc} — waste package failure time by general corrosion
L — thickness of waste package material
R_{gc} — general corrosion rate

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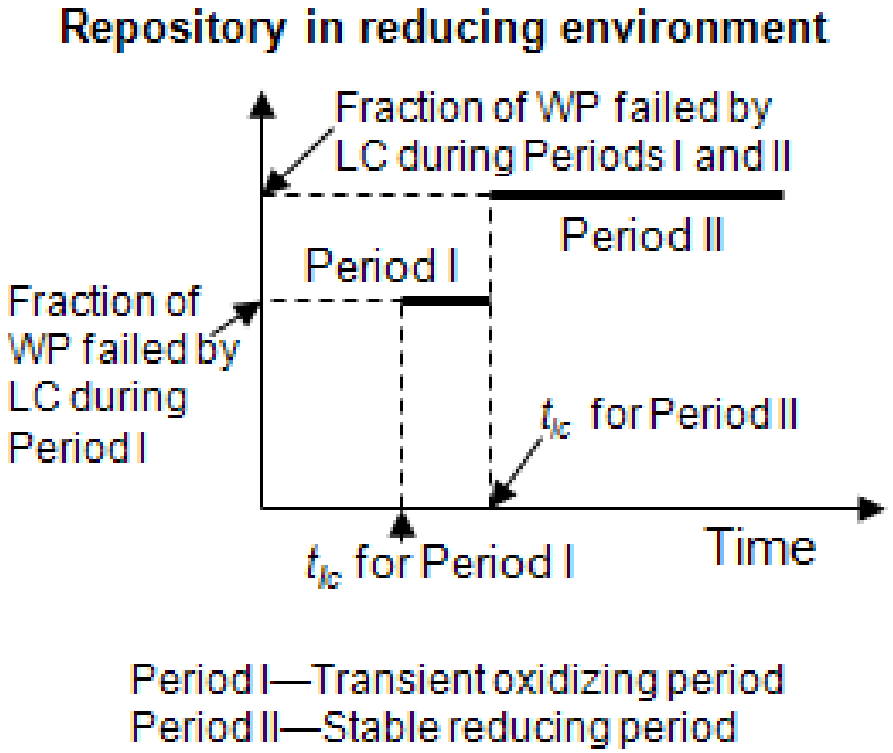
Model Abstraction — Localized Corrosion

- Assumed to cause waste package failure at different, discrete times depending on the redox conditions
- In a reducing environment
  - a two-step function constructed (Periods I and II)
  - initial transient oxidizing period (Period I)
  - fraction failed by localized corrosion based on the possibility for localized corrosion to occur



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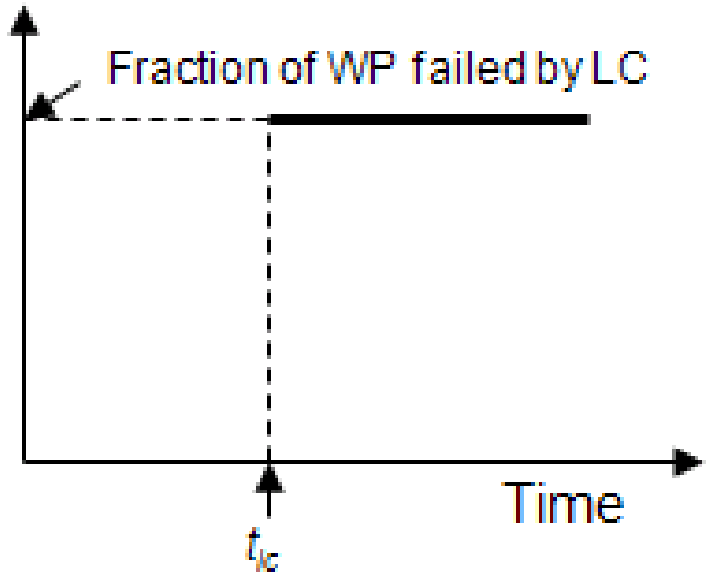
Localized Corrosion Model in Oxidizing Environment

- A single-step function defining the fraction of waste packages failed by localized corrosion as a function of time is constructed for each realization

- The fraction of waste packages failed by localized corrosion is sampled from a distribution based on the probability for localized corrosion under oxidizing conditions



WP—Waste package
LC—Localized corrosion
t_{lc}—Failure time by localized corrosion

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Waste Package Breached Areas

- Radionuclide releases into the region surrounding the waste packages are proportional to the breached area
- The model considers two distinct breached area fractions: one for localized corrosion and the other for general corrosion
- For waste package radionuclide release computations, however, a combined breached area per failed waste package is computed at each time step as a function of the general and localized corrosion breached area and the number of waste packages failed

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Waste Package Breached Areas (continued)

- Two different approaches in β-SOAR were implemented to compute the breached area per failed waste package as a function of time: stepwise and weighted average

- In the stepwise approach, after the waste package with the highest general corrosion rate fails, the breached area steps to the larger number of the breached area even if other waste packages may not have failed (overestimate)

- In the weighted average approach, the breached area per failed waste package is computed as a weighted average of breached areas by general and localized corrosion

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General Corrosion Model Input Parameters

- Built upon knowledge and experience gained from domestic and international performance assessments for a variety of geologic disposal options
- General corrosion rates in oxidizing or reducing media
  - Represented as probability distributions to reflect uncertainties of environmental conditions
- The general corrosion breached area fraction assumed to be one

GC_FractionAreaBreached

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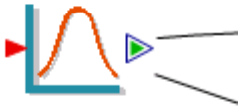
Localized Corrosion Model Input Parameters

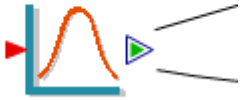
- Probability of waste package failure by localized corrosion

Prob_LC_Period_I

Prob_LC_Period_II

- Localized corrosion failure time


LC_FailureTime_Period_I


LC_FailureTime_Period_II

- Localized corrosion breached area fraction
  - Based on literature information and engineering judgment


LC_FractionAreaBreached

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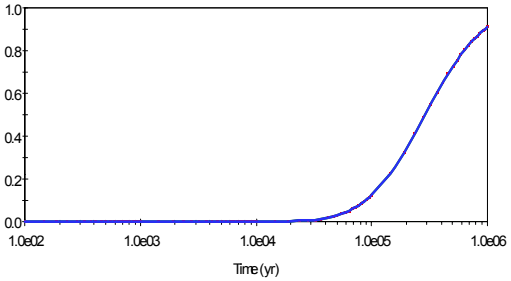
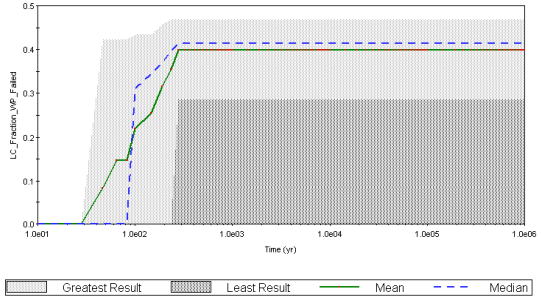
Waste Package Component Model Output Example

- Geologic disposal in oxidizing environment
  - General corrosion rates: 0.01–3 μm/yr with log-normal distribution
  - Failure time by localized corrosion: 30–280 years with log-uniform distribution
  - Fraction of waste packages failed by localized corrosion: 0.25, 0.45, 0.5 with triangular distribution
  - Fraction of waste package breached area by localized corrosion : 0.001, 0.1216, 0.2 with log-triangular distribution

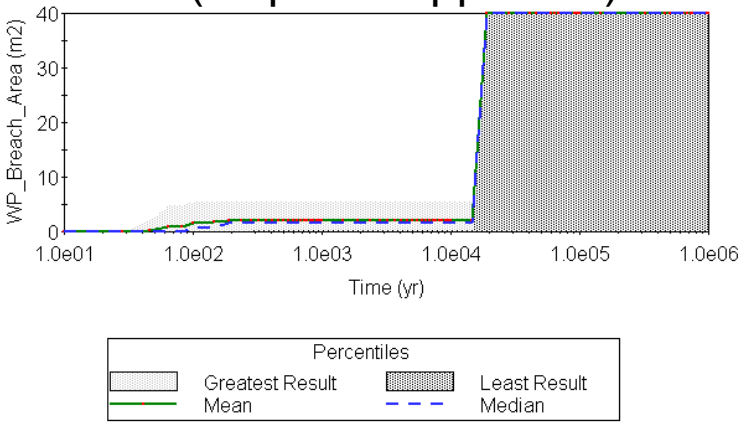
Fraction of waste packages failed by general corrosion



Fraction of waste packages failed by localized corrosion



Waste package breached area (stepwise approach)



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Waste Package Component Model Flexibilities

- Incorporate other waste package materials (e.g. copper, carbon steel, titanium alloys, and others)
- Consider alternative geologic disposal system configurations
- Approximate additional failure mechanisms beyond general and localized corrosion by modifying the distributed and stepwise failure (e.g., stress corrosion cracking, discrete events such as early failure and human intrusion, or other disruptive events)

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Summary and Conclusions

- A model using stainless steel as one of the waste package materials was developed in the performance assessment model β-SOAR

- The general and localized corrosion processes were abstracted and conceptualized to estimate waste package failure times and the extent of damage for disposal systems located in either oxidizing or reducing environments

- This model is flexible to account for chemical degradation (i.e., corrosion) of various waste package materials

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Acknowledgments

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