# Modeling Disruptive Events Using the *β*-SOAR Model: Levels of *β*-SOAR Model Flexibility in Applications and Initial Insights

J. Gwo,[1] T. Ahn,[1] and X. He[2]

[1]U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Material Safety and Safeguards, Division of High-Level Waste Repository Safety, Washington, DC 20555, U.S.A.

[2]Center for Nuclear Waste Regulatory Analyses (CNWRA®), Southwest Research Institute®, 6220 Culebra Road, San Antonio, Texas 78238, U.S.A.

International High Level Radioactive Waste Management Conference 2011,

Albuquerque, New Mexico

April 10 – 14, 2011

# Acknowledgement and Disclaimer


- The authors wish to thank colleagues at NRC and CNWRA for assisting in developing and integrating the disruptive event component model and for reviewing this paper. In particular, we are in debt to Dr. Osvaldo Pensado for his generous input in integrating the seismic event consequence component with the waste package component of the $\beta$-SOAR model.


- The NRC staff views expressed herein are preliminary and do not constitute a final judgment or determination of the matters addressed or of the acceptability of any licensing action that may be under consideration by the NRC. This paper is also an independent product of the CNWRA® and does not necessarily reflect the view or regulatory position of the NRC.

# Introduction

- A scoping exercise and analysis is underway at NRC to consider a variety of potential geological disposal and repository design concepts for US high-level waste and spent nuclear fuel.
- U.S. NRC and CNWRA developed the generic performance assessment model, *Scoping of Options and Analyzing Risk*, beta version (***β*-SOAR**), to derive preliminary insights and enhance regulatory readiness.
- Five key model components: Waste Form, Waste Package, Near Field, Far Field, and Biosphere.
- **Disruptive events**, defined here as events that have definitive effects on the conditional annual dose with predefined probabilities or frequencies, were not considered or implemented in *β*-SOAR.

# $\beta$-SOAR Levels of Flexibility

- Three levels of flexibilities are available in $\beta$-SOAR, a Performance Assessment (PA) model built on the software platform GoldSim: (1) Selections of model parameters from the **Dashboard**; (2) Modifications to **model parameters** in the model or database; (3) Modifications to or addition of **model elements/components**.

- Single disruptive events or events of similar nature (e.g., early failure of waste packages) can be modeled with levels 1 & 2 in a straightforward manner.

- This paper focuses on Level 3 flexibility of $\beta$-SOAR.

# Seismic Events

- Seismic events are assumed and modeled as discrete events occurring independently of one another in time.

- The probability of $n$ events occurring in a time step $\Delta t$ (yr) can be represented as a Poisson distribution

$$P(n) = \frac{(\lambda \Delta t)^n e^{-\lambda \Delta t}}{n!}$$

where $\lambda$ is the mean event frequency (1/yr) of the Poisson process.

- The number of events that may occur during a time step is obtained randomly from the CDF and uniformly distributed within the time step.

# Seismic Events: Assumptions

- Geologic disposal is in saturated groundwater formations.

- Waste package mobility under saturated conditions is similar to that under unsaturated conditions during a seismic event. Waste packages may be impacted with potential stress corrosion cracking (SCC) on contact with host rocks, engineered components, or other free moving waste packages.

- Near field buffer and backfill, if present, are not damaged by seismic events.

# Waste Package Damage

- Potential Waste Package Materials: copper, titanium, stainless steel, and carbon steel.

- Crack area density, or crack area per unit damage area resulting from seismicity, due to mechanical, stress corrosion cracking is expressed as

$$\delta = C\frac{\sigma}{E}$$

where $\delta$ is the crack area density ($m^2/m^2$), $C$ is scaling or uncertainty factor accounting for crack network geometry, $\sigma$ is yield stress (MPa) and $E$ is Young's modulus (MPa).

# Waste Package Damage (continued)

- Assumptions: seismic event waste package damage area similar to alloy 22, similar geometry of cracks and crack size, uncertainty factor ranges from 1 to 8.

- Estimated crack area density (ratio of crack size to seismic damage area) range, using generic material strength data,

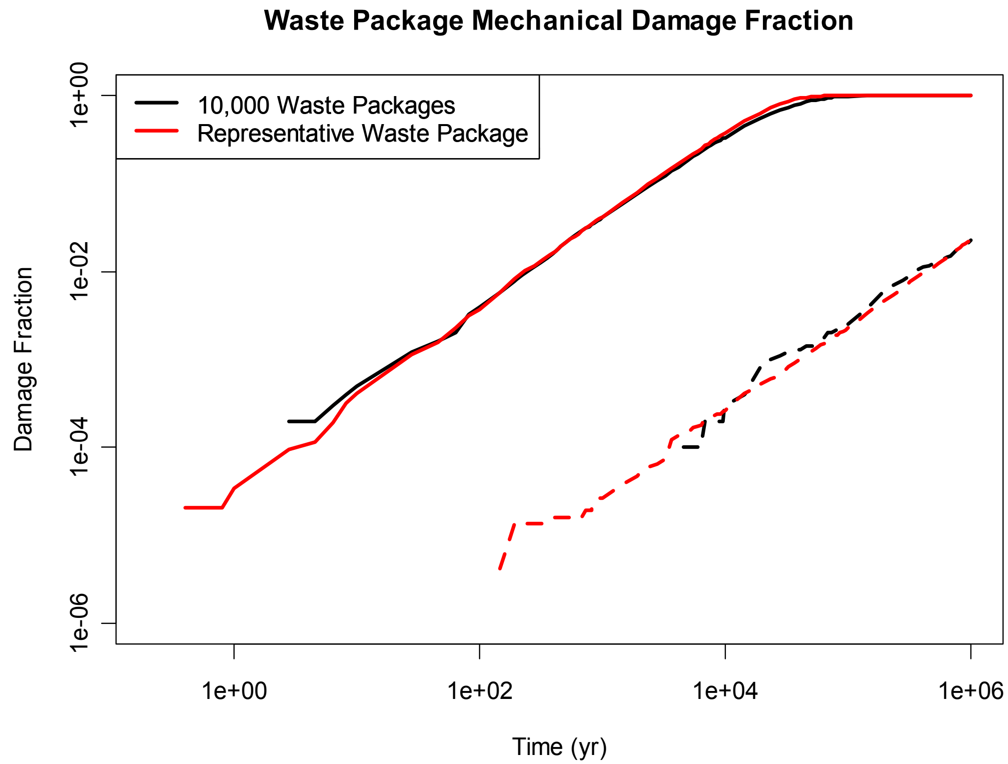
| Material | Lower Bound | Upper Bound |
|---|---|---|
| Stainless Steel | 0.16% | 1.17% |
| Copper | 0.05% | 2.08% |
| Carbon Steel | 0.18% | 0.91% |
| Titanium | 0.15% | 7.31% |
| Alloy 22 | 0.29% | 1.17% |

# Representative Waste Package

- $\beta$-SOAR uses a representative waste package concept.

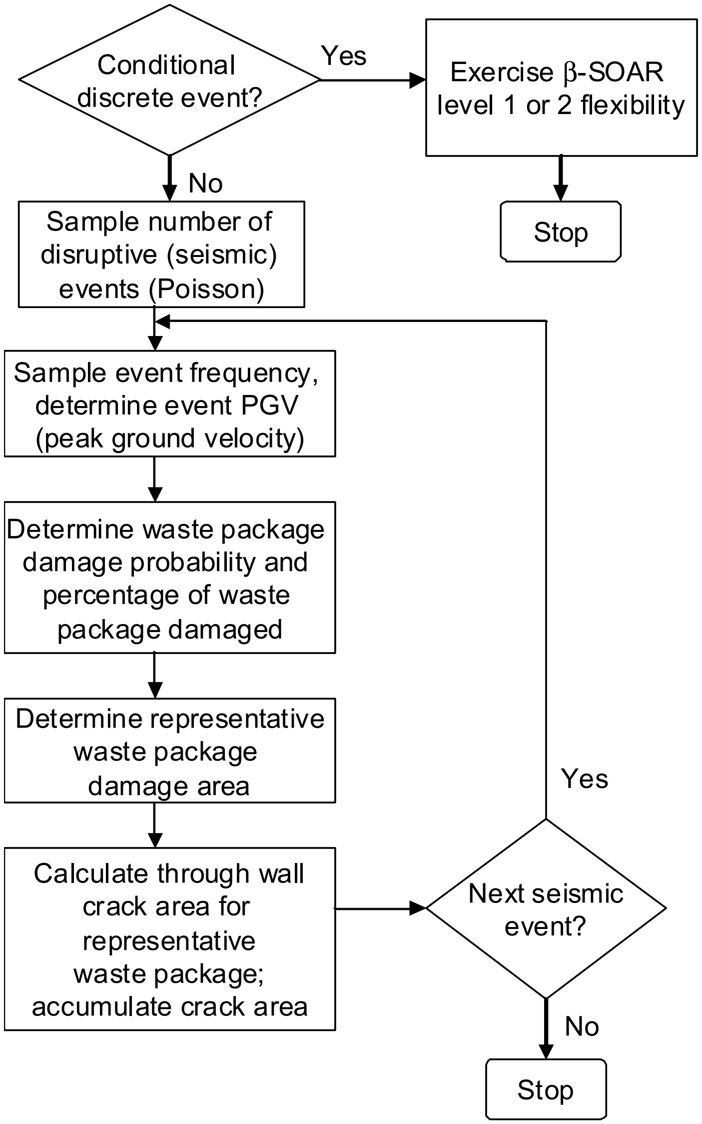
- Waste package damage assumptions:
  - Repository consists of same type of waste package with the same waste package material;
  - Total number of waste packages damaged by a seismic event is proportional to the probability that a waste package may be damaged;
  - For a subsequent event, damage may not occur to those waste packages that have previously been damaged until all the waste packages are damaged;
  - Thickness of waste package in simulations reported here is fixed, for the purpose of isolating effects of seismic damage to waste packages.

# Waste Package Damage




History of mean fractions of waste package damaged mechanically in a repository with (dashed lines) and without (solid lines) buffer/backfill; representative waste package material is carbon steel.

# Model Implementation

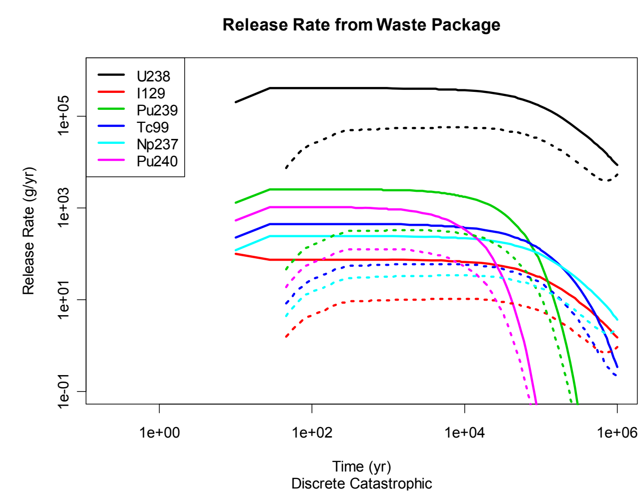


# Required Inputs

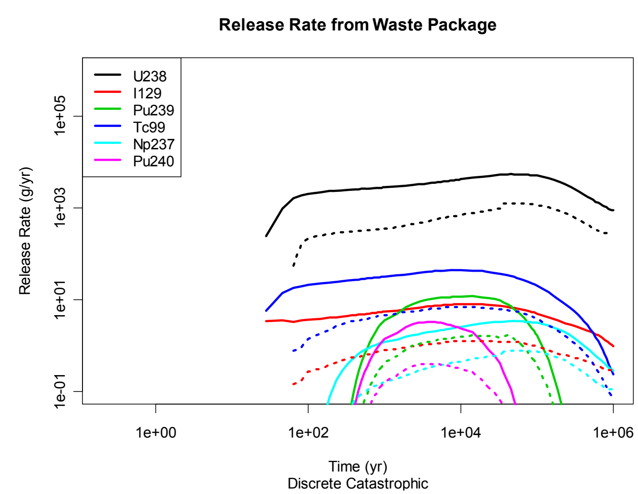
- Disruptive Events
  - Discrete events: Event time; event frequency;
  - Seismic events: Mean seismic frequency; seismic hazard curve; Seismic event frequency probability density function.
- Waste Package Damage
  - Discrete events: Fraction of waste package damaged;
  - Seismic events: Waste package damage area as a function of peak ground velocity; uncertainty factor for crack area density.

# Preliminary Results

## Discrete Event




Release from Waste Package

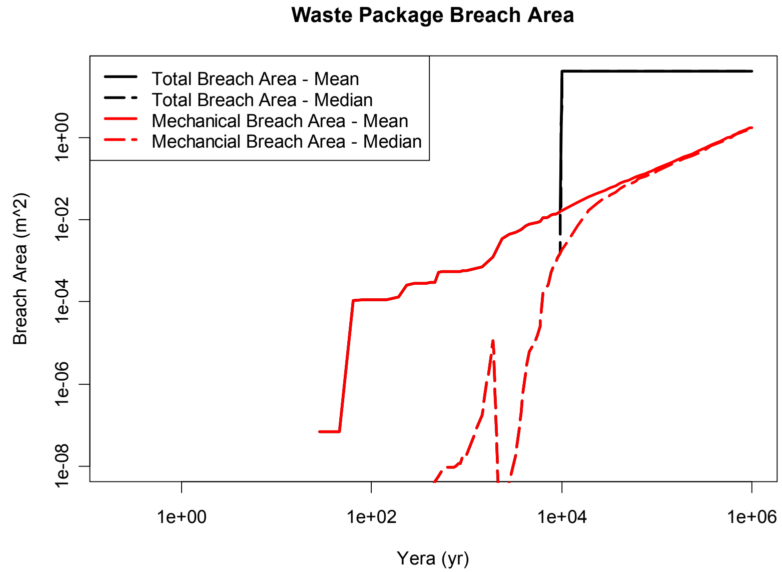



Release at Far Field Exit Point

The release rates shown in the figures were obtained with the assumptions that (1) the discrete event damages all waste package materials at year 10, (2) the waste form, however, is intact, (3) no buffer and backfill materials, e.g., bentonite, are present in the near field, and (4) radionuclide release from waste form, near and far field transport are under reducing conditions. Dashed lines are the baseline case without the event.

# Preliminary Results

## Seismic Event (1)

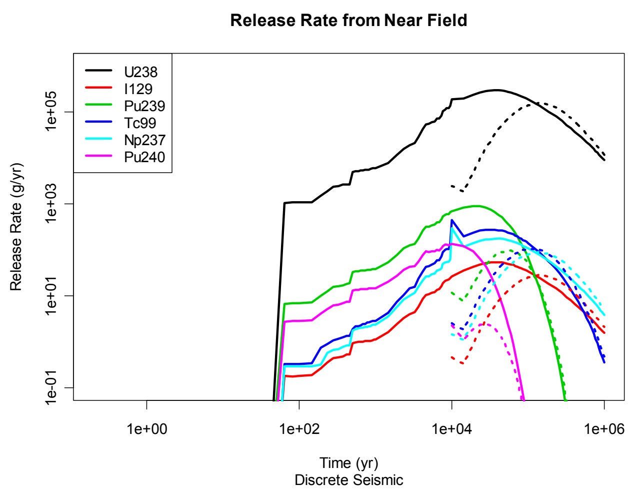


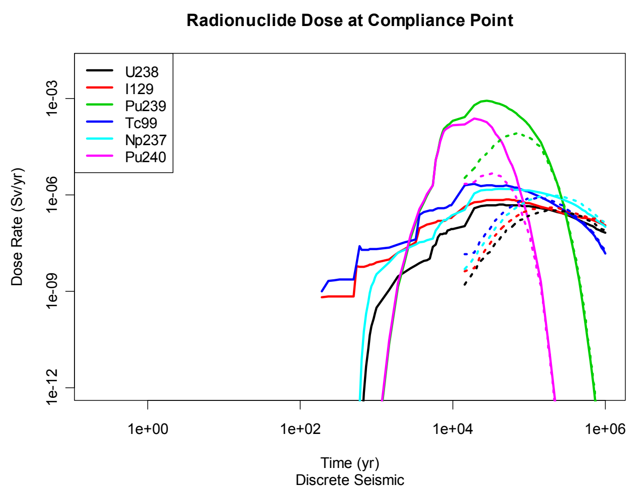

Calculated waste package breach area

The calculations shown in this and the next two figures were obtained with the assumptions that (1) repository is located in groundwater saturated granitic geologic formation, (2) no buffer or backfill materials, (3) radionuclide release from waste form, near and far field transport are under reducing conditions, (4) carbon steel is the representative waste package, (5) mean seismic event frequency is $4.3 \times 10^{-4}$ 1/yr, and (6) hazard curve, seismic frequency and waste package damage characteristics as specified in Refs. 5 and 8.

# Preliminary Results

## Discrete Event




Release from the Near Field

Radionuclide Doses at Far Field Exit Point

The calculation shown in the figures were obtained for the seismic ground motion test case (solid lines) and the baseline test case (dashed lines).

# Reduction of Uncertainties

- Further considerations on the following items
  - Effects of waste package emplacement method, e.g., borehole and tunnel, on waste package damage and failure from disruptive events;
  - Integrity of backfill materials, and its evolution over the lifetime of a disposal system;
  - Likelihood of waste package damage in the presence of and during the degradation of various proposed buffer and backfill materials;
  - Effects of general and localized corrosion on waste package thickness and strength during disruptive events;
  - Waste package damage area and through wall crack network geometry for a variety of waste packages;
  - Quantitative seismic-induced stress corrosion cracking model.

# Conclusions

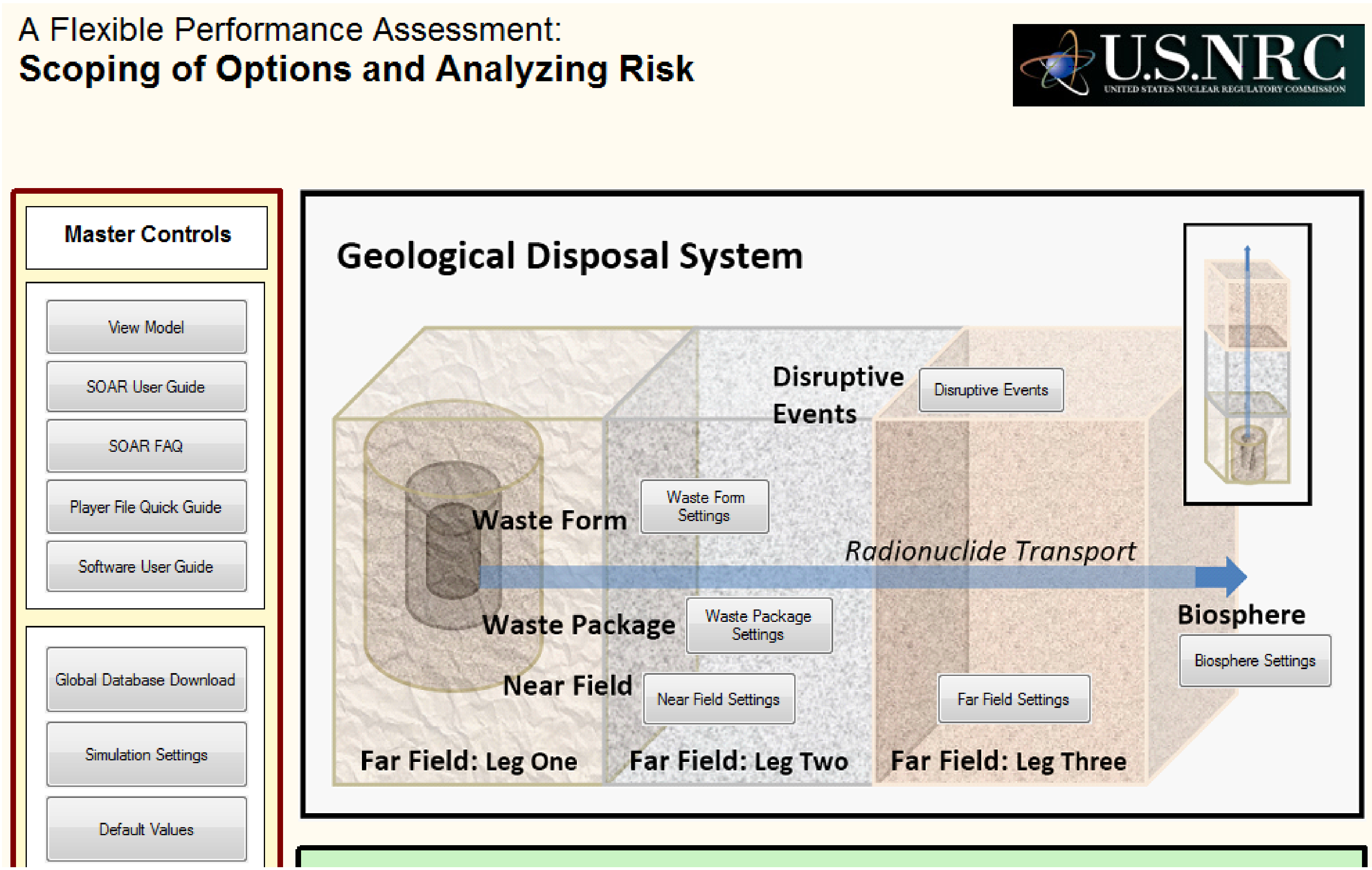
- A disruptive event and consequence model prototype was tested and integrated with the *β*-SOAR model.

- Two test cases, a discrete waste package damage bounding event and a seismic ground motion event, were evaluated using the prototype model.

- The effects of backfill materials and their degradation on waste package damage and failure resulting from seismic events, and the likelihood of waste package damage, waste package damage area and through wall crack networks produced by seismic events need further considerations to reduce model uncertainty.

# Backup Slide

# Backup Slide – Beta SOAR Main Dashboard



# Backup Slide – Beta SOAR Example Model Elements