U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: HUMAN INTRUSION,
BASALTIC IGNEOUS ACTIVITY,
AND COMBINING CCDFs

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DALLAS, TX
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Human Intrusion

- Investigated two scenarios from human intrusion event tree

- Chose cases with presumed greatest consequences
  - Direct (mechanical) transport of waste
  - (Aqueous, gas transport in UZ slower)

- Processes modeled were abstracted
  - Modeled every FEP in path, but with simplifying assumptions

- Investigated two drilling-incident scenarios
  - Surface release
  - Release through saturated-zone transport

- Analyses included both base-case and sensitivity studies
Human Intrusion Event Tree

- Human Intrusion
  - Mining
  - Drilling
    - Exploratory Drilling
      - Hydrocarbon and Mineral Exploration
        - Drillhole Intercepts Waste
          - Direct Removal of Contaminants
            - Surface Deposition
              - Formation of Particulates
            - Deposition in Saturated Zone
              - Tuff Aquifer
            - Contact Exposure
              - Surface Weathering
            - Carbonate Aquifer
          - Drillhole does not Intercept Waste
            - Drilling Fluids Enhance Unsaturated Flow Field
              - Drilling Fluid Forms Locally Saturated Flow Field
            - Direct Removal of Contaminants
              - Surface Deposition
                - Contact Exposure
Assumptions--Conceptual

- Human intrusion occurs by 20th-century drilling practices
- Probability of drilling at site = 1.0
- Boreholes are drilled according to EPA drilling densities
- Probability of hit is based on geometry
- Transport is entirely mechanical
- Source term is primary determinant of release
- Direct hits and near misses contribute to releases
- Saturated-zone transport in tuff or carbonate aquifers
Surface Release Drilling Scenario

Drill Hole

Waste-Package Emplacement Hole

Spent-Fuel Rods in Damaged Waste Package

Input Drilling Fluid

Drill Stem

Return Circulation with Radionuclide Fragments

Return Circulation of Drilling Fluid
Saturated Zone Release Scenario

Well Casing Through Drift

Empty Borehole

Backfilled Drift

Breached Waste Package with Loose Spent-Fuel Rods

Saturated-Zone

Pile of Spent Fuel at Bottom of Borehole
Assumptions--Process

- Waste is uniformly distributed in potential repository
- Up to entire waste package can be released
- Contaminated rock occurs due to diffusion from packages
  - Based on PACE-90 results
- Mechanical transport:
  - Waste is entrained in drilling mud to surface
  - Waste falls down drillhole to saturated zone
- Source term used limited number of radionuclides
  (inventory includes decay and ingrowth from chains)
- Aqueous transport in saturated zone influenced by velocity and retardation
- Time of occurrence of drilling randomly chosen
Distribution of Radionuclides in Repository

Containers (Uniformly Distributed)

"Near-Miss" Area

Drill Holes (Randomly Distributed)

Drill Hole Contacting Container

Drill Hole in "Near-Miss" Area

(Not to scale)
Distribution of Surface Releases

Near Misses

Base Case
(3 boreholes/sq. km.)

Zero Releases

Direct Hits

Log of EPA Sum

Frequency
Conditional Probability Distribution for Surface Releases due to Drilling

Complementary cumulative probability vs. EPA sum
Effect of Increasing the Number of Boreholes Drilled over 10,000 Years

Complementary cumulative probability

EPA sum

- EPA limit
- Base Case (3 Holes/km^2)
- 30 Holes/km^2
- 60 Holes/km^2
Aqueous Releases from Tuff Aquifer Due to Human-Intrusion Drilling

Complementary cumulative probability

EPA sum

10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^0 10^1 10^2

EPA limit
Sum
C-14
Np-237
U-234
Tc-99
I-129
Se-79

\begin{align*}
\text{EPA limit} & : 10^{-1} \\
\text{Sum} & : 10^{-2} \\
C-14 & : 10^{-3} \\
Np-237 & : 10^{-4} \\
U-234 & : 10^{-5} \\
Tc-99 & : 10^{-6} \\
I-129 & : 10^{-7} \\
Se-79 & : 10^{-8}
\end{align*}
Overall Conditional CCDF for Three Drilling Scenarios—Surface, Tuff-Aquifer, Carbonate-Aquifer Releases
Conclusions

- Using these models, releases from human intrusion are below EPA limit.

- Drilling density must be increased greatly before releases approach EPA limit.

- Near misses do not come close to exceeding the EPA limit.

- Surface releases appear to be independent of site characteristics.

- Including the probability of drilling at the Yucca Mountain site will reduce the probabilities of releases further.

- Aqueous releases are highly dependent on estimates of ground-water velocity and retardation.

- Using more detailed models may not improve estimates.
Basaltic Igneous Activity

- Investigated one scenario from event tree
  - Investigated direct basaltic-dike intrusion into repository, followed by the release at the surface via volcanism
  - Other scenarios may actually have greater consequences

- Used abstracted models
  - Relied on prior analyses for model and parameters
  - Developed 2 simple models for the process

- Analyses included both base-case and sensitivity studies
Basaltic Igneous Activity Event Tree

**Basaltic Volcanism**

- Intrusion Acts Directly on Repository
  - Dike Forms
    - Transport of Waste Intact
    - No Waste Magma Contact
    - Magmatic Alteration of Waste
      - Basaltic Cone Forms
        - Waste is Expelled with Cinders and Flow
          - Direct Exposure
            - Surface Weathering
          - Waste Fragmented and Entrained
    - Basaltic Cone Forms
      - Waste is Expelled in Cinder Cone
        - Direct Exposure
        - Surface Weathering
  - Basaltic Cone Forms
    - Waste is Altered Chemically/Thermally and Entrained
      - Waste Entrained in Ash Plume
        - Direct Exposure
        - Surface Weathering
    - Basaltic Cone Forms
      - Waste is Expelled in Cinder Cone
        - Direct Exposure
        - Surface Weathering

- Intrusion Acts Indirectly on Repository
  - Surface Drainage Altered
  - Subsurface Drainage Altered
Conceptual-Model Assumptions

- Basaltic dike acts directly on waste packages
  - Dike passes directly through repository
  - Intrusion continues to surface

- Waste is fragmented and entrained in dike by thermo-mechanical effects

- Fragments are erupted as part of cinder cone or lava sheet at surface
  - Entrained radionuclides are released at surface
  - Waste is not encapsulated in lava
Interaction of Dike with Waste Package
Process Assumptions

- Amount of waste entrained is linearly related to volume of intersection of dike and repository
  - Geometric model of interaction
  - Field observations of volcanic activity

- Ranges for parameters (dike width, wall-rock fraction entrained, etc) elicited from Valentine (LANL)

- Probability of occurrence taken from Crowe's work (LANL)

- Because of low probability, conditional CCDF for consequences was calculated first
  - Used Monte Carlo simulations for dike-waste interaction
  - Final CCDFs calculated from conditional CCDFs and probabilities

- Sensitivity studies investigated reasonable parameter variations
Examples of Dike Trends and Lengths
Comparison of Two Models for Surface Release due to Basaltic Igneous Activity into Repository

Diagram: Graph showing the complementary cumulative probability against the EPA sum. The graph compares two methods:
- Method 1: Geometric
- Method 2: Surface Observations

The EPA limit is also indicated on the graph.
Conclusions

- **Direct releases are below EPA limit**
  - Models used conservative assumptions about transport processes
  - No cases were found from sensitivity studies with much larger releases

- **Releases from basaltic igneous activity do not contribute significantly to this estimate of total-system releases**

- **Future igneous-activity analyses should concentrate on indirect effects (e.g., changes in ground-water-flow patterns)**
Combining CCDFs

- Two methods for generating an overall CCDF:

1) Single Monte Carlo simulation with ALL important FEPs included

2) Identify scenario classes
   - Mutually exclusive and exhaustive
   - Calculate conditional CCDFs
   - Calculate final CCDF by weighting components

- TSPA used a modification of method 2
  - Identify specific scenarios and calculate conditional CCDFs
  - Combine CCDFs by various techniques
  - Combined CCDF is still conditional
Methods of Combining CCDFs

1) Weighted Sum--used for mutually exclusive scenarios
   - e.g., human intrusion cases

2) "Horizontal Addition"--done as an expedient for not calculating CCDFs with correlations
   - e.g., aqueous and gaseous cases
   - Associates high releases from one case with high releases from the other case
   - This technique is probably appropriate when one parameter is dominant for both processes

3) Probabilistic sum--used for completely independent scenarios
   - e.g., 6 UZ columns modeled by Total System Analyzer
   - Combine by randomly drawing EPA sums from each simulation
Aqueous Releases, Composite-Porosity Model Six Columns and Combination

Complementary cumulative probability

EPA sum

- EPA limit
- Combination
- Column 1
- Column 2
- Column 3
- Column 4
- Column 5
- Column 6
Combined Conditional CCDF for Gaseous and Aqueous (Composite-Porosity Model) Releases
Overall Conditional CCDF, Assuming Composite-Porosity Aqueous Transport
Overall Conditional CCDF, with Three Weightings of Composite-Porosity and Weeps Models

- EPA limit
- Composite-porosity flow
- Weeps flow
- 50%/50% combination
Summary of SNL's TSPA Analyses

- An analysis using abstracted models and data structures has been completed
  - Results of modeling are consistent with SNL's understanding of the process from more detailed modeling
  - Conditional CCDFs for four scenarios have been combined into an overall conditional CCDF