YUCCA MOUNTAIN PROJECT

Studies

Evaluation of EBS Processes: Near field geochemical environment, Waste form degradation/mobilization, EBS transport

Presented to:
Nuclear Waste Technical Review Board
Performance Assessment Panel
Albuquerque, New Mexico

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U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

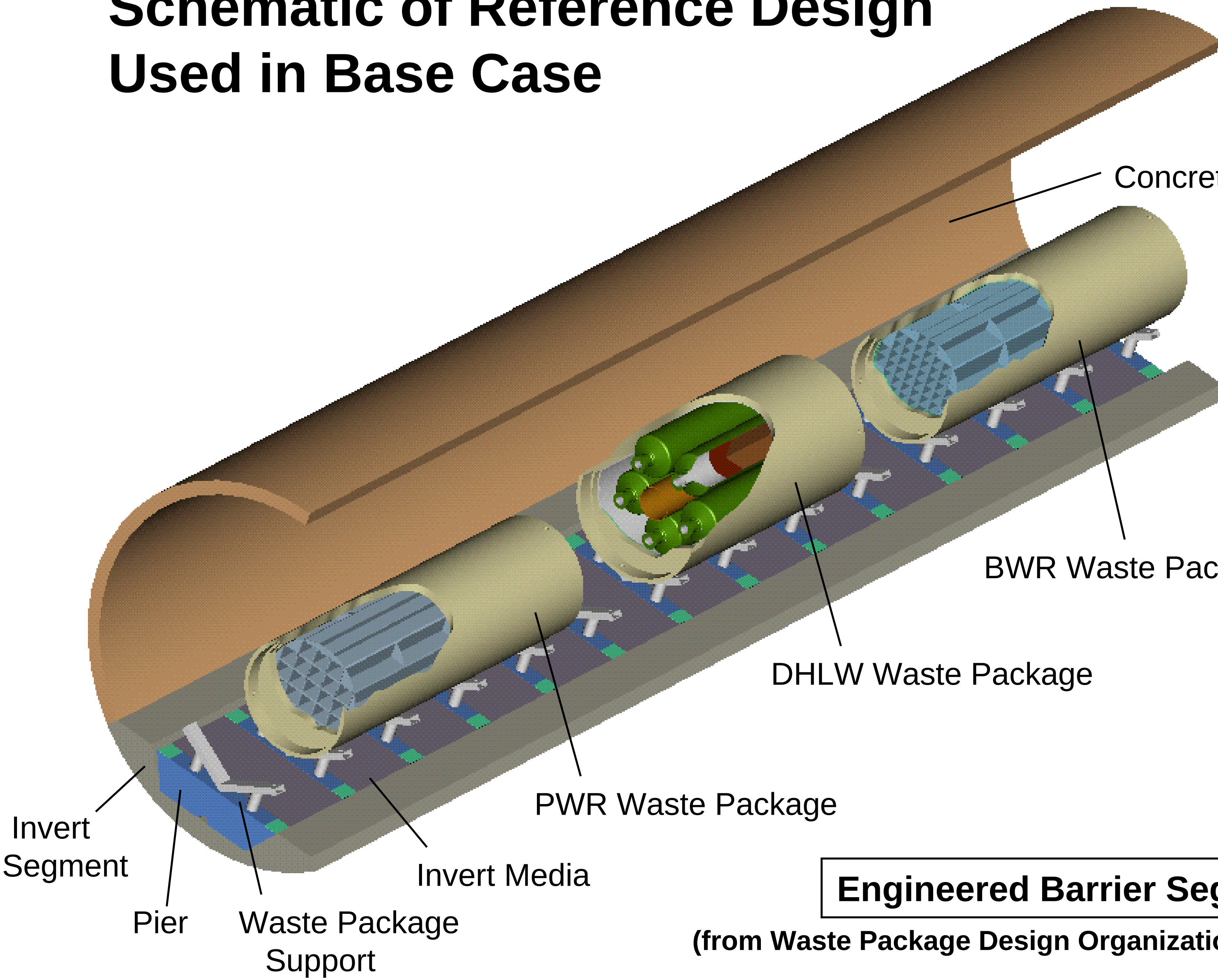
Outline

- Near Field Geochemical Environment
  - Conceptual Models
  - Bases for NFGE Models
  - Results from NFGE Models
- Waste Form Degradation
  - Conceptual Models
  - Bases for WF Degradation Models
  - Results from WF Degradation Models

Outline
(Continued)

- **Radionuclide Mobilization**
  - **Conceptual Models**
  - **Bases for WF Mobilization Models**
  - **Results from WF Mobilization Models**
- **Engineered Barrier System Transport**
  - **Conceptual Models**
  - **Bases for EBS Models**
  - **Results from EBS Models**

Schematic of Reference Design Used in Base Case



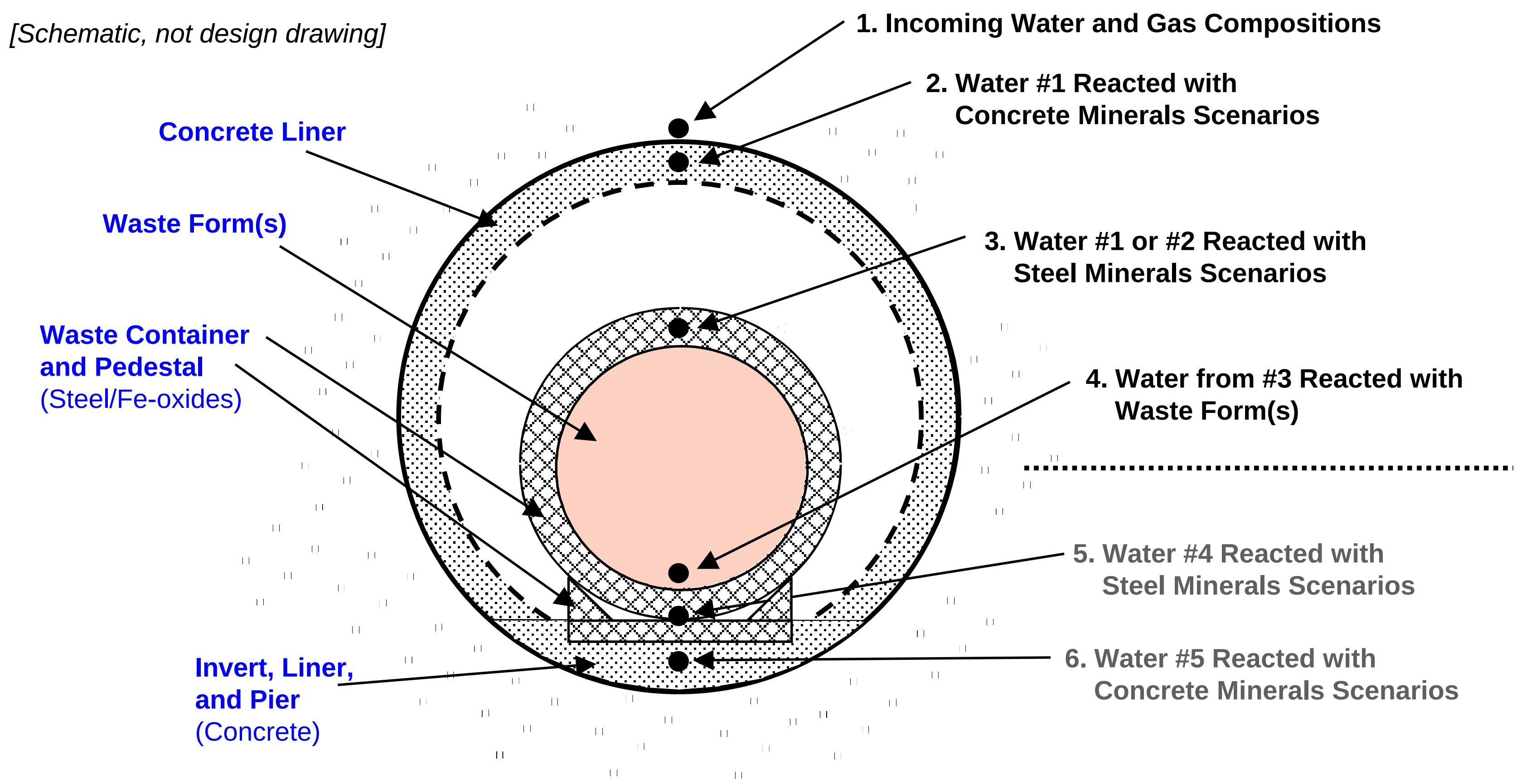
Engineered Barrier Segment

(from Waste Package Design Organization, 1998)

NFGE Conceptual Model

- **Discretize the EBS to evaluate**
- **Scenarios defined based on thermal conditions**
- **Locations defined based on discrete locations within the EBS**
- **Evaluate gas and water compositions at the various locations within the EBS**

TSPA-VA Base-Case Near-Field Geochemical Environment

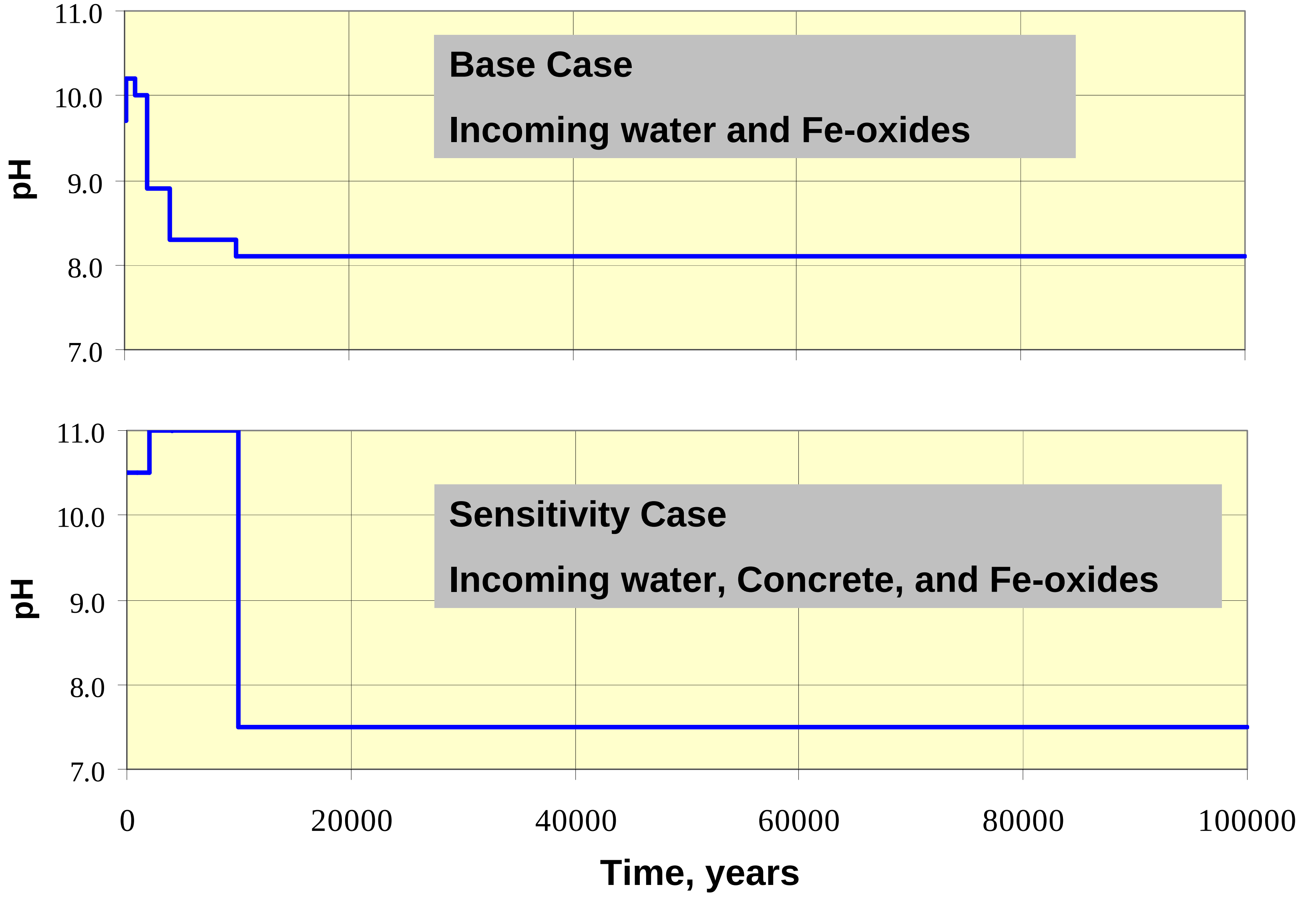


Schematic Representation of Materials Included for Base-Case NFGE and Locations along a Conceptual Pathway for Evaluation of Water Compositions [modified from M&O, 1998 B00000000-01717-2200-00200].

NFGE Abstraction Summary

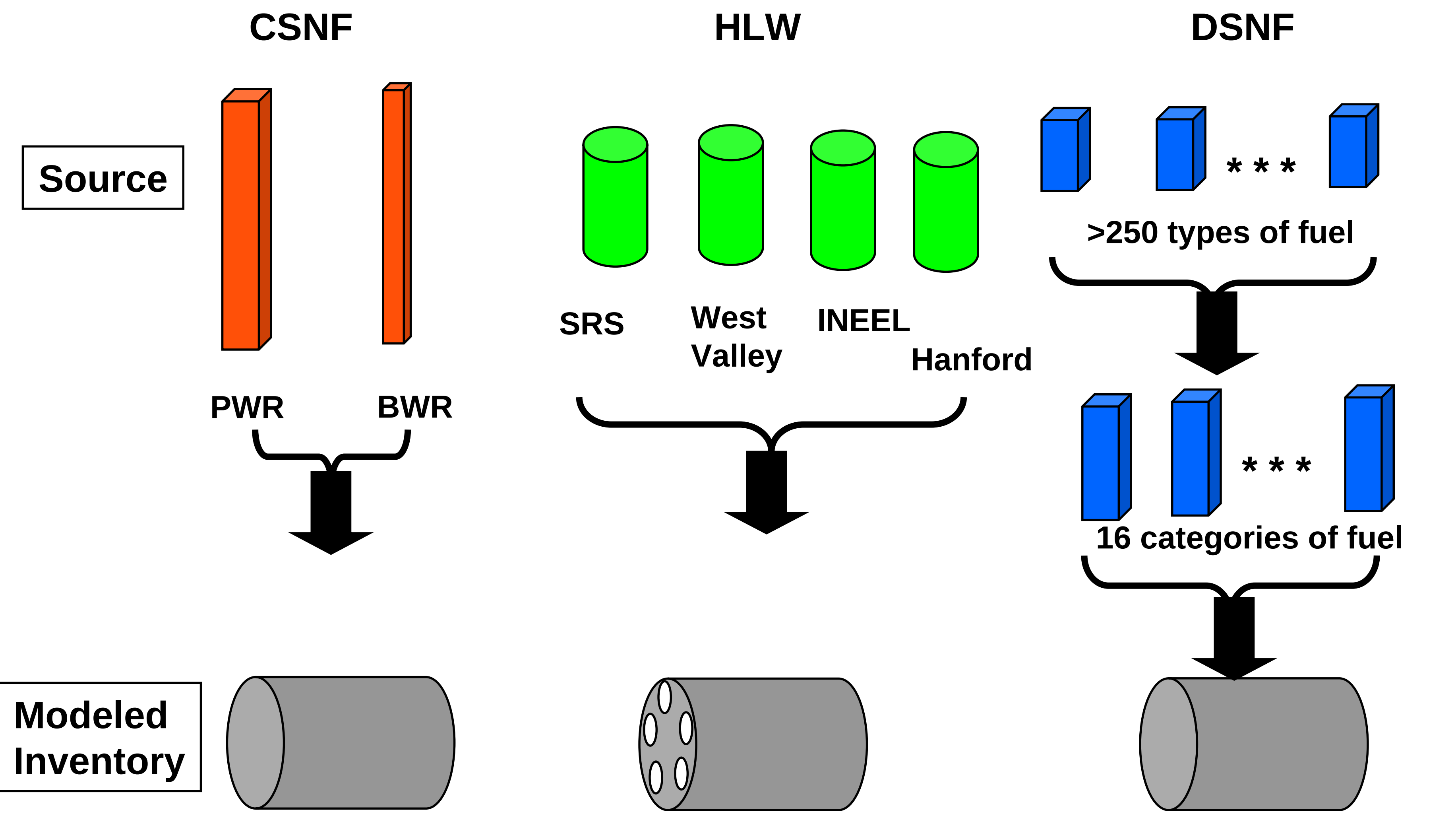
- Develop NFGE Gas and Water Compositions as f(t)
  - Input: gas flux & air-mass fraction from 2-D Mtn Scale TH results
  - Input: air composition (pO_2 and pCO_2) from pore-gas and single heater test data
- Calculate NFGE Water Composition as f(location, t)
  - include thermal effects on incoming water (boiling, pCO_2)
  - include in-drift reactions
  - include in-package reactions with spent fuel
- Output: pH, $\sum CO_3^{-2}$, and I (ionic strength) as f(t)

pH of water flowing into waste package



[Revised 20-Apr-98, NFGErev01reslt.ppt]

Waste Form Inventory Abstraction



Blended BWR/PWR
21 PWR Pkg
63,000 MTHM

Blended HLW
5-pack
4,667 MTHM

Surrogate DSNF
2,333 MTHM

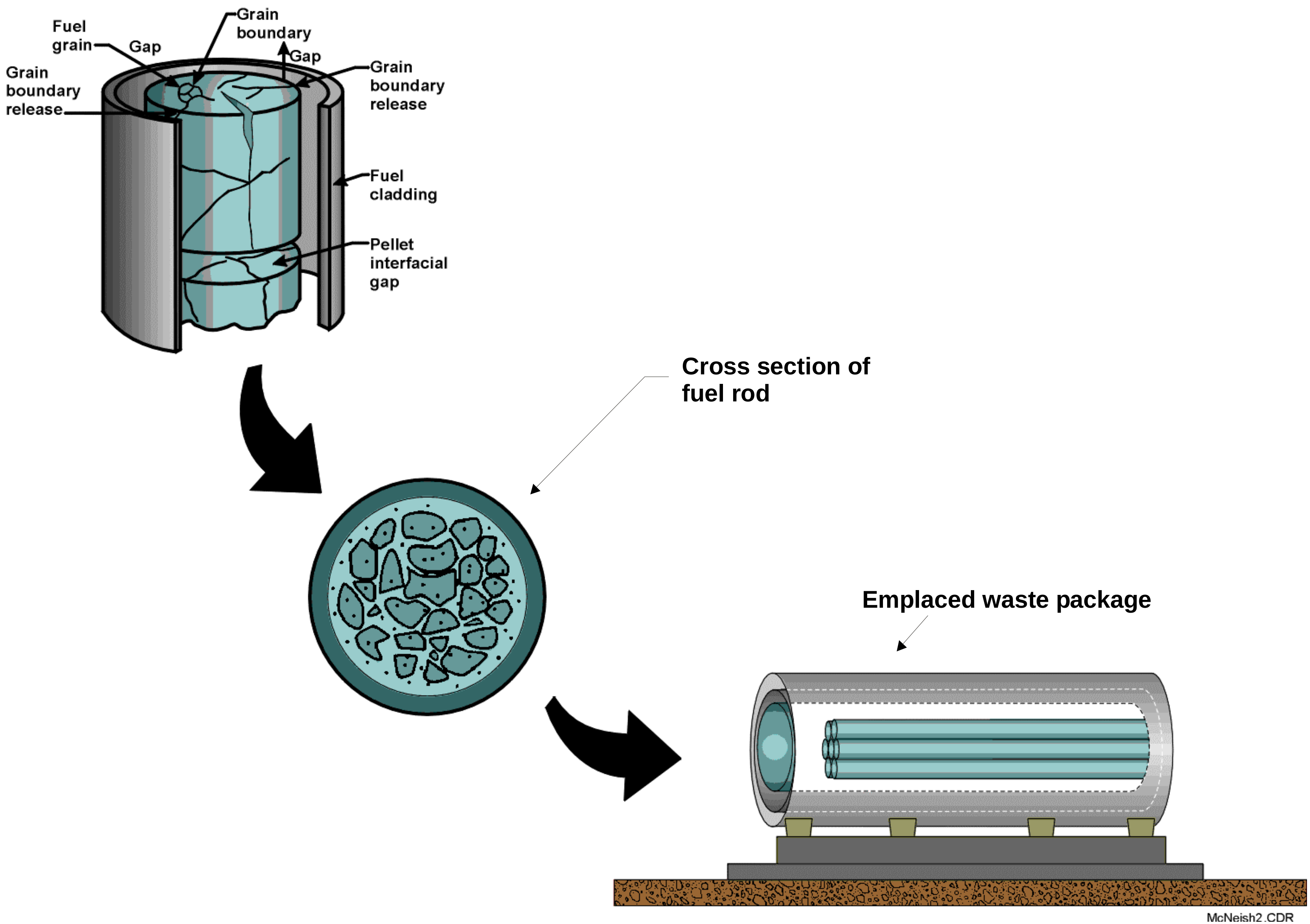
Waste Form Degradation/Radionuclide Mobilization Conceptual Model

- Assume waste forms exposed to the drift environment upon failure of the waste package and cladding.
- Assume water films adsorbed on porous alteration product layers provide aqueous conditions
- Waste form degradation is represented by an "Intrinsic Dissolution Rate" equation
- Radionuclides are considered potentially available for mobilization congruent with this dissolution

Waste Form Degradation/Radionuclide Mobilization Conceptual Model
(Continued)

- Mobilization of highly soluble radionuclides at this dissolution rate, into either diffusive or advective EBS transport
- Most radionuclides are mobilized at aqueous solubility limits
- A preliminary representation of aqueous concentrations limited by secondary phase formation has been prepared, but is not in the initial base-case

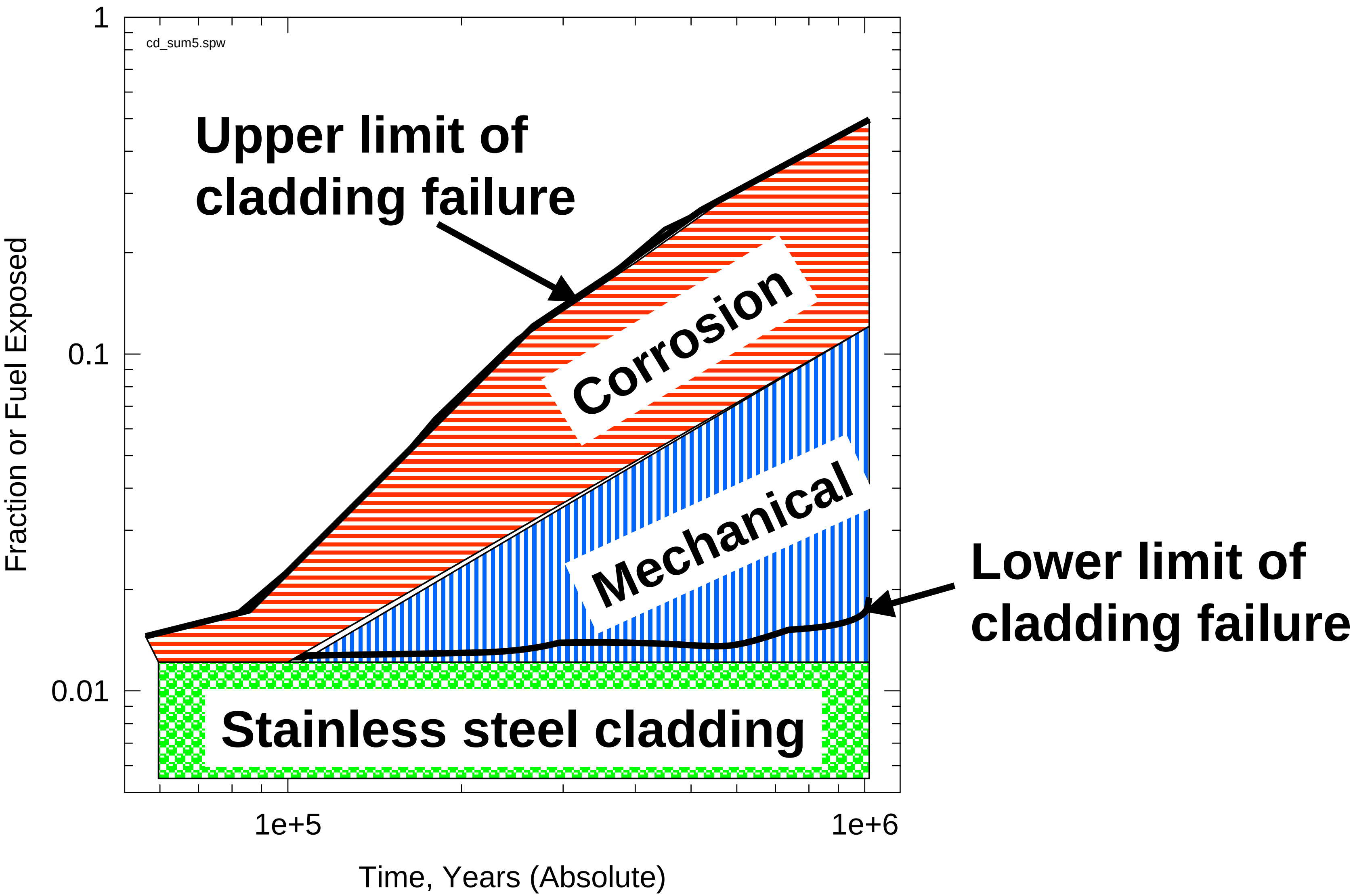
Waste Form Schematic

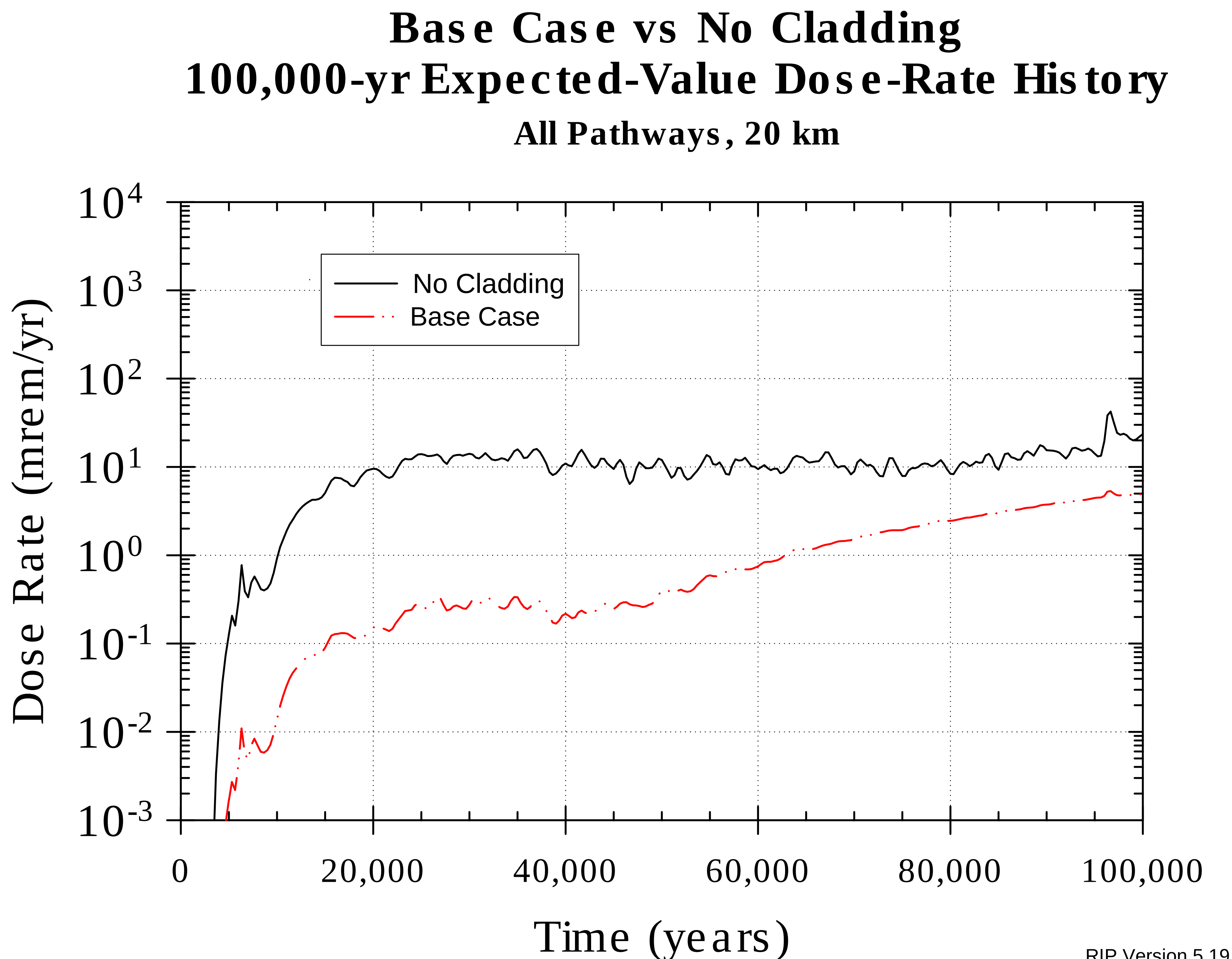


Failure Modes in Cladding Model

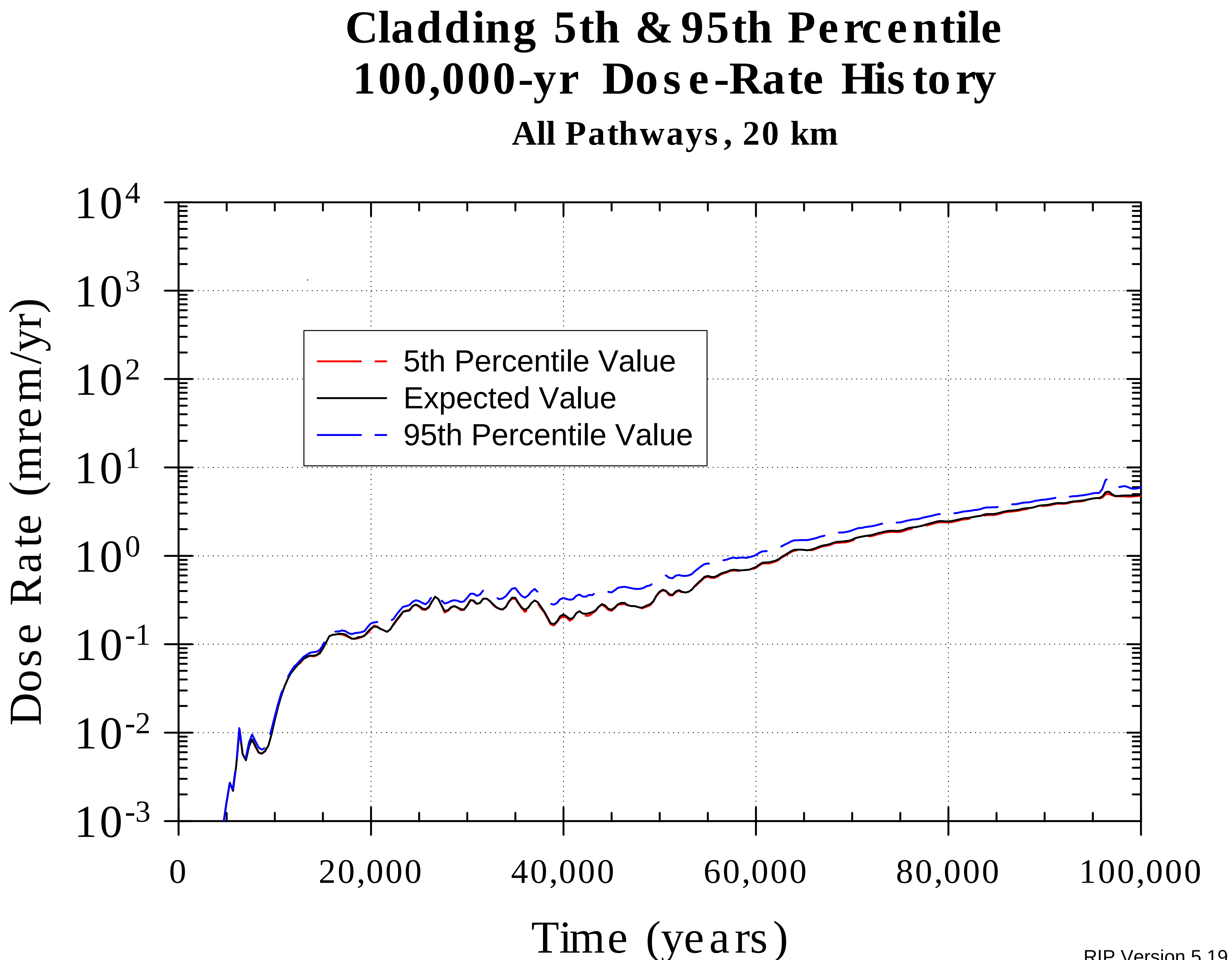
- Juvenile cladding failure
  - early time failure of cladding
- Stainless Steel cladding failure
  - assumed to fail at time of waste package failure
- Creep (strain) cladding failure
- Mechanical failure
  - due to rod breakage from rockfall
- Corrosion of cladding
  - corrosion model similar to C-22 corrosion

Cladding Degradation



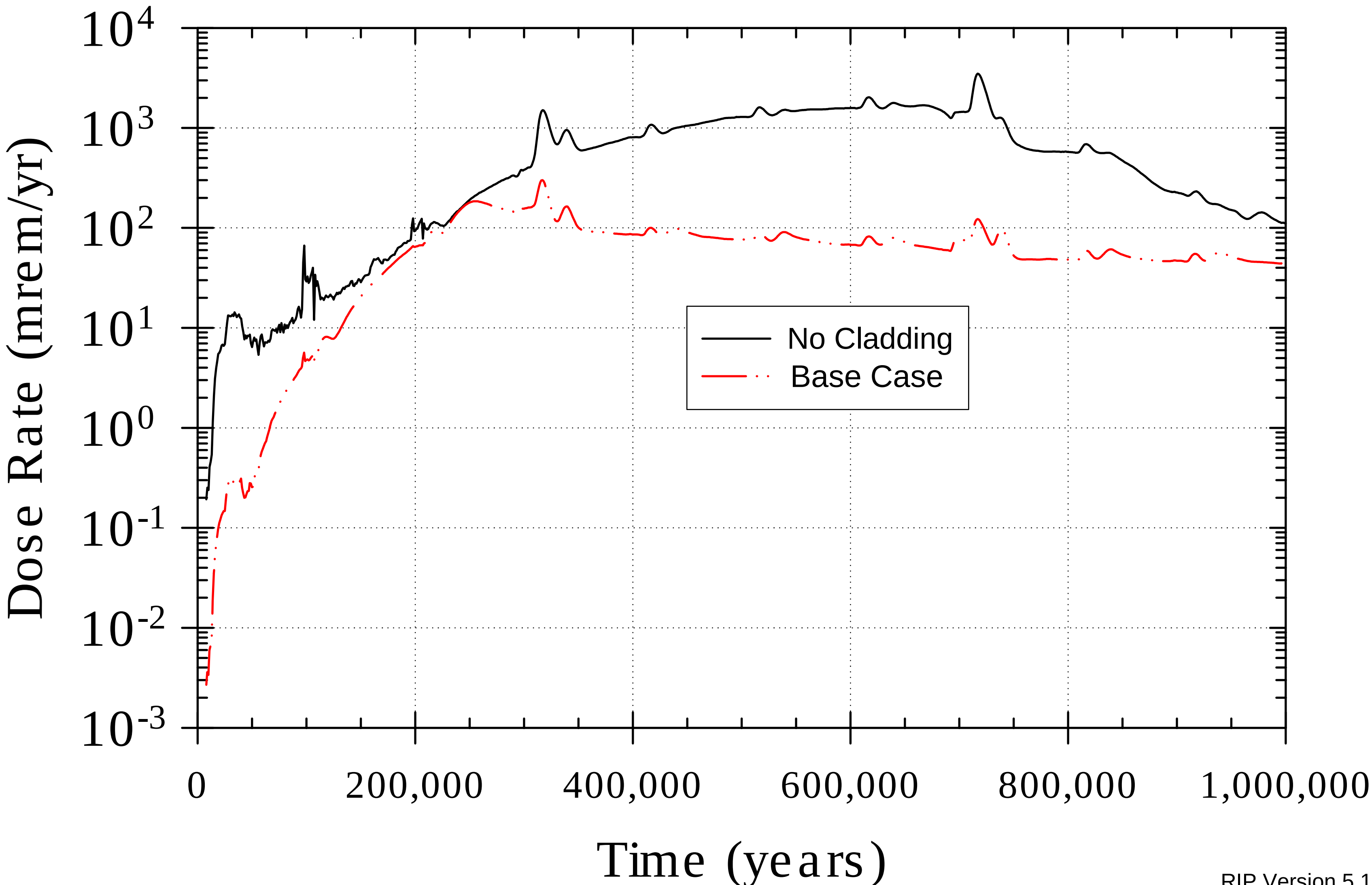


Base Case vs No Cladding
100,000-yr Expected-Value Dose-Rate History
All Pathways, 20 km
No Cladding
Base Case
Dose Rate (mrem/yr)
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
0
20,000
40,000
60,000
80,000
100,000
Time (years)
RIP Version 5.19



Cladding 5th & 95th Percentile
100,000-yr Dose-Rate History
All Pathways, 20 km
5th Percentile Value
Expected Value
95th Percentile Value
Dose Rate (mrem/yr)
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
0
20,000
40,000
60,000
80,000
100,000
Time (years)
RIP Version 5.19

Base Case vs. No Cladding
1,000,000-yr Expected-Value Dose-Rate History
All Pathways, 20 km



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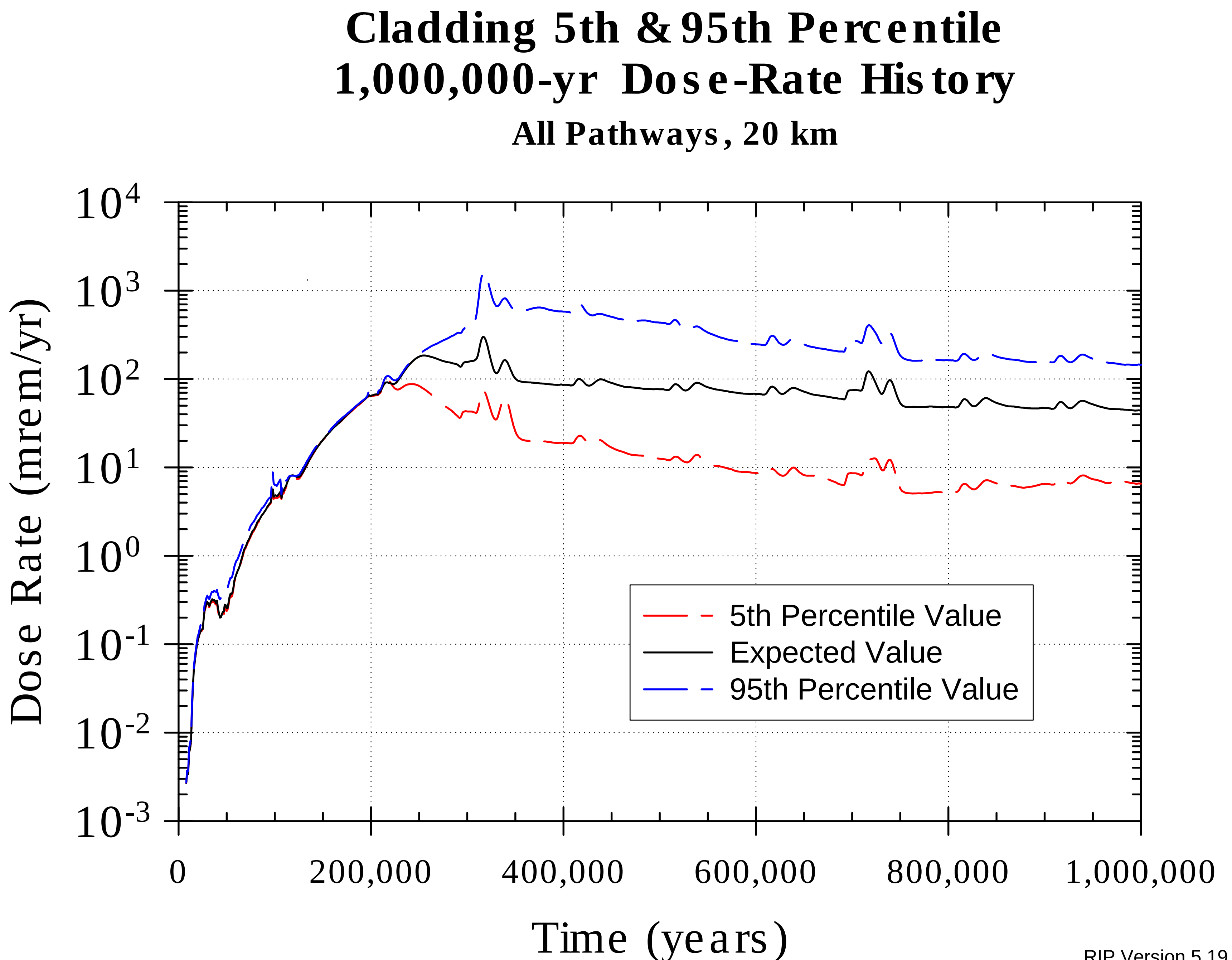
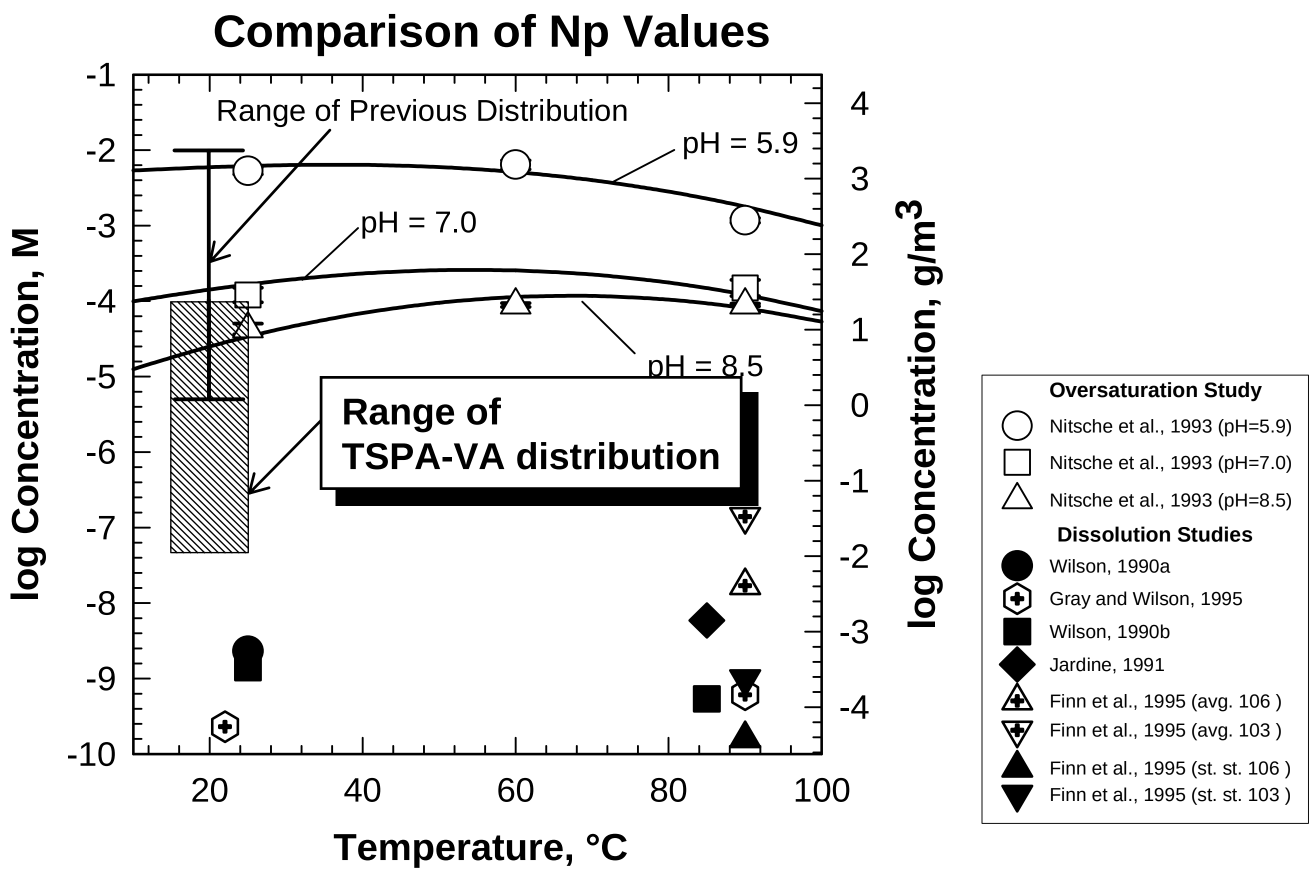

Cladding 5th & 95th Percentile
1,000,000-yr Dose-Rate History
All Pathways, 20 km
Dose Rate (mrem/yr)
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
0
200,000
400,000
600,000
800,000
1,000,000
Time (years)
5th Percentile Value
Expected Value
95th Percentile Value
RIP Version 5.19

Radionuclide Solubilities

- Most radionuclides are released into the EBS transport process at their solubility limit
- Solubilities are sampled over a range with a minimum, maximum, average and probability distribution function
- In the current Base Case, solubilities (except Np) are the same as used in TSPA-95.
- After review, Np solubility has been reduced from TSPA-95 values by a factor of 100 (M&O, 1998)

Range of Solubility-Limited Np Concentrations

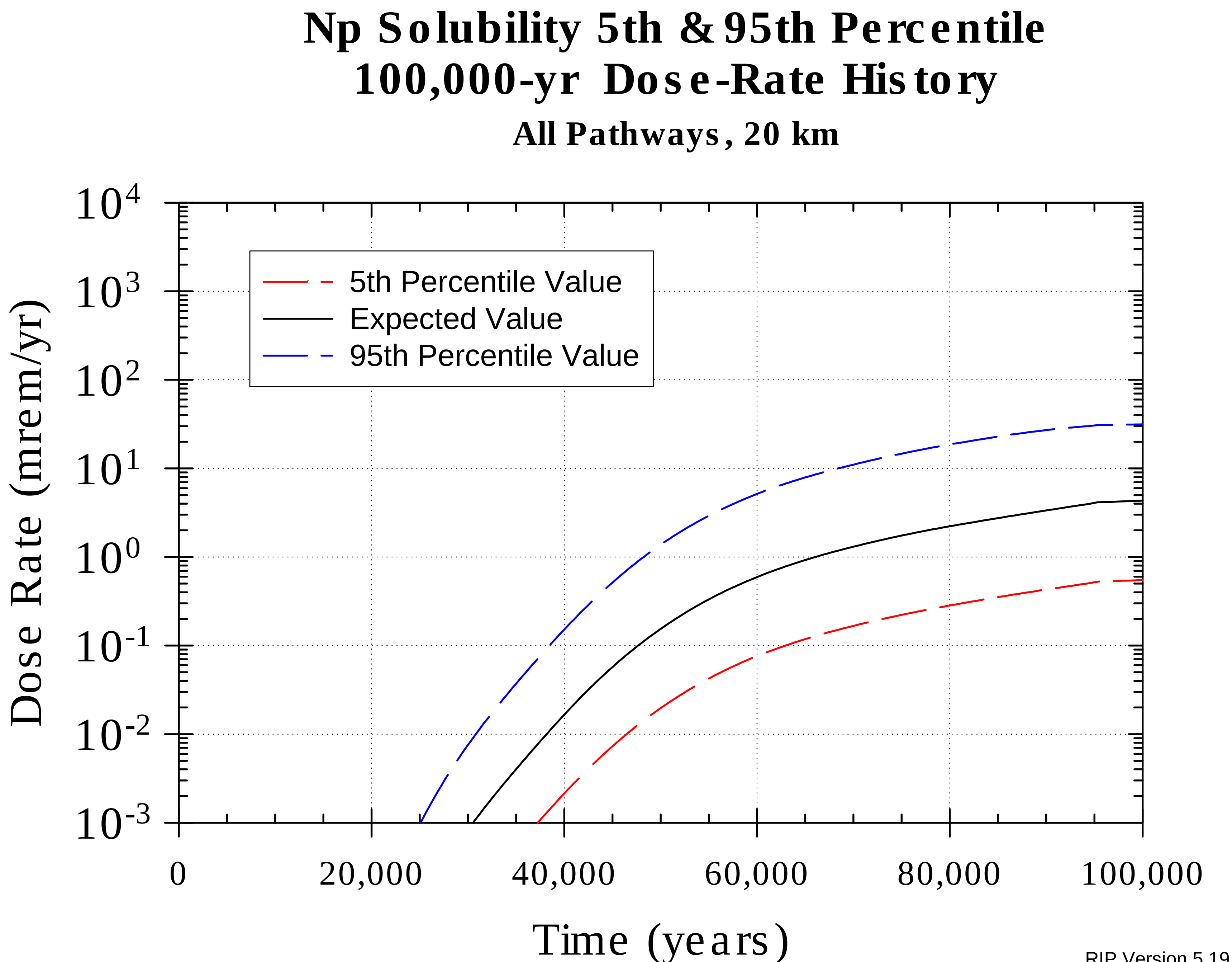


(from M&O, 1998)

Note: Np solubility 100 times less than TSPA-95

Summary of Change for Neptunium

- **Nitsche et al. Studies Used Concentrated Solutions from Np-salts to Approach from Oversaturation**
- **Thermochemical Data Suggest that Phases Formed in Studies Represent Metastable Solids**
- **Synthesized Results of Dissolution Studies**
  - **Does spent fuel in J-13-like fluids (starting with zero Np) reach such high values at steady state?**
    - » **flow-through tests**
    - » **drip tests**
    - » **batch studies**
  - **All Measured Np Concentrations Lower Than Needed to Saturate Phases in Nitsche et al. Studies**
    - » ***highest* time-averaged value is 1/37 of the *lowest* elicited value and steady-state values are even lower**
- **Metastable Phases not Expected to Apply, Stable Phases like NpO_2 Should Keep Np Below about 1/100 of the Elicited Range**



Np Solubility 5th & 95th Percentile
100,000-yr Dose-Rate History
All Pathways, 20 km
Dose Rate (mrem/yr)
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
5th Percentile Value
Expected Value
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20,000
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Time (years)
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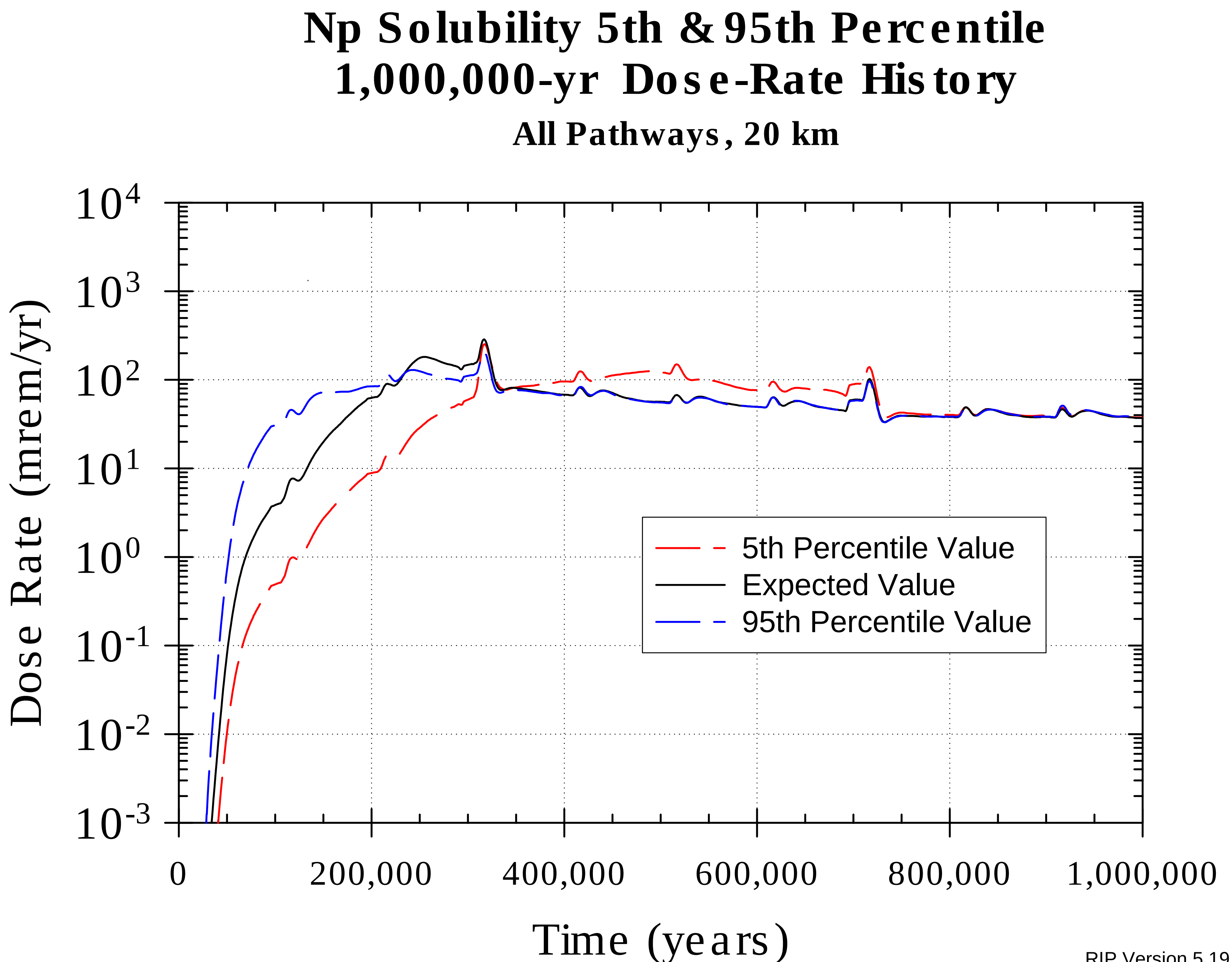
Np Solubility 5th & 95th Percentile
1,000,000-yr Dose-Rate History
All Pathways, 20 km
Dose Rate (mrem/yr)
10^{4}
10^{3}
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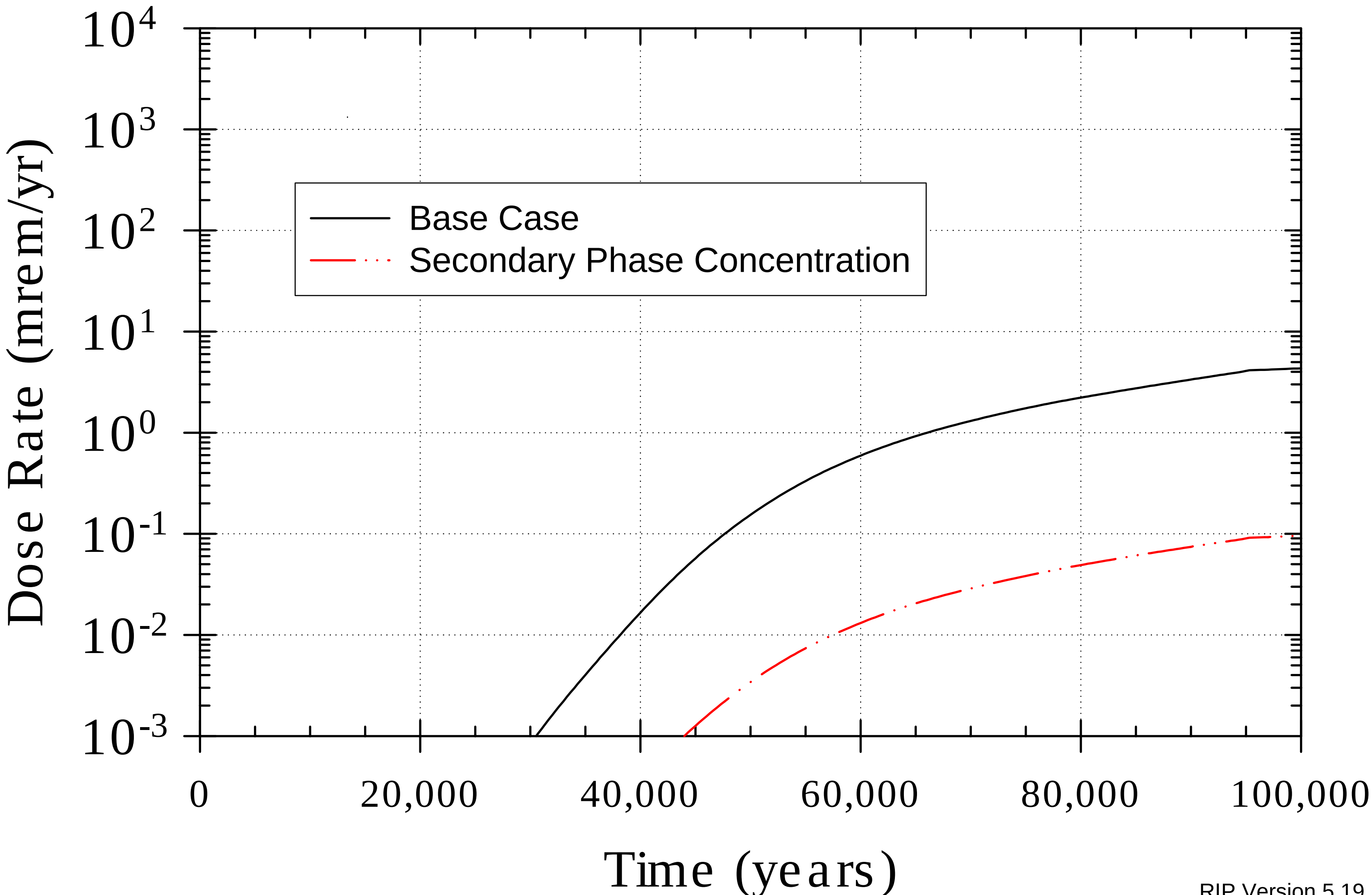
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
0
200,000
400,000
600,000
800,000
1,000,000
Time (years)
5th Percentile Value
Expected Value
95th Percentile Value
RIP Version 5.19

Sensitivity to Np Solubility Model
100,000-yr Expected-Value Dose-Rate History
All Pathways, 20 km



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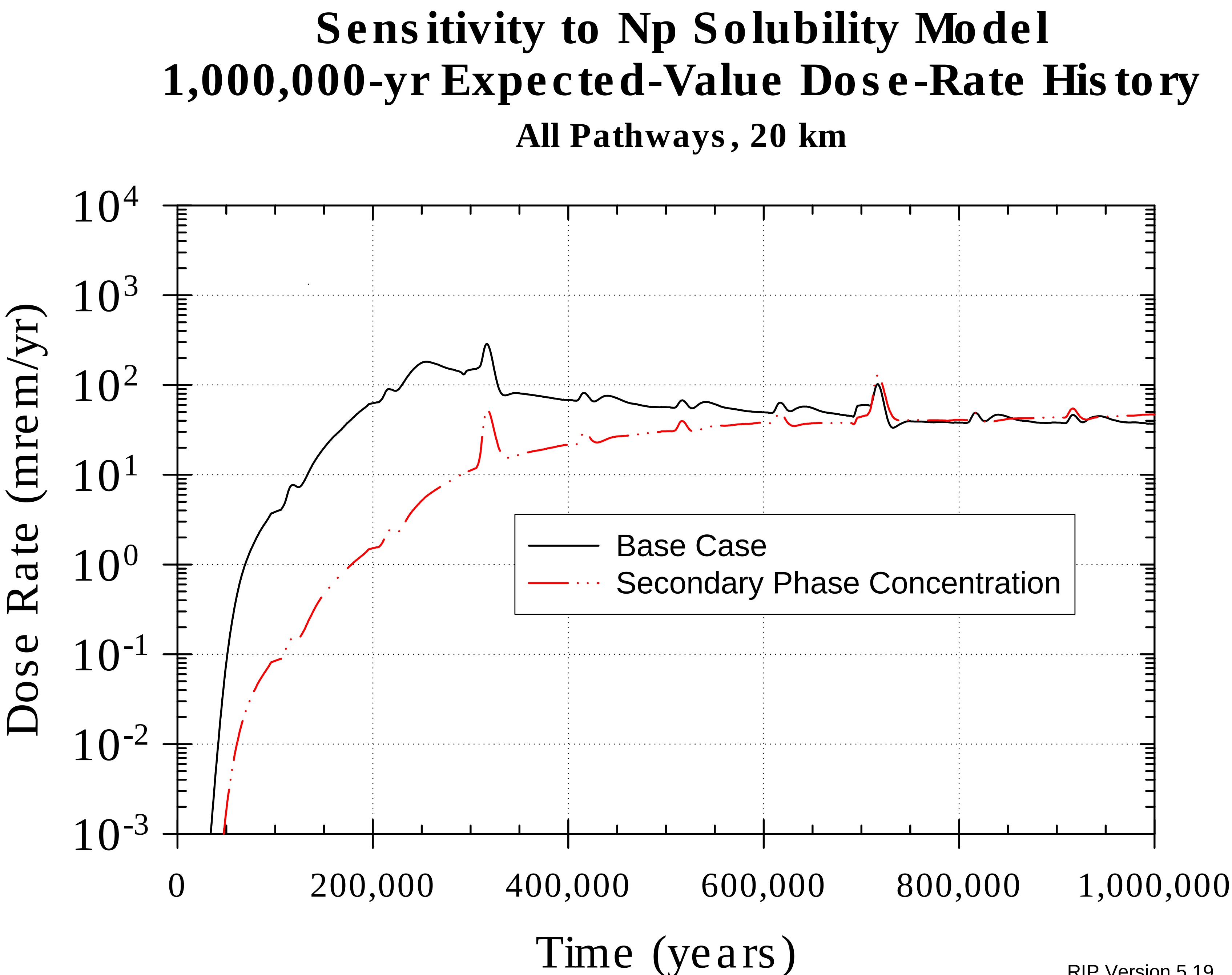
Sensitivity to Np Solubility Model
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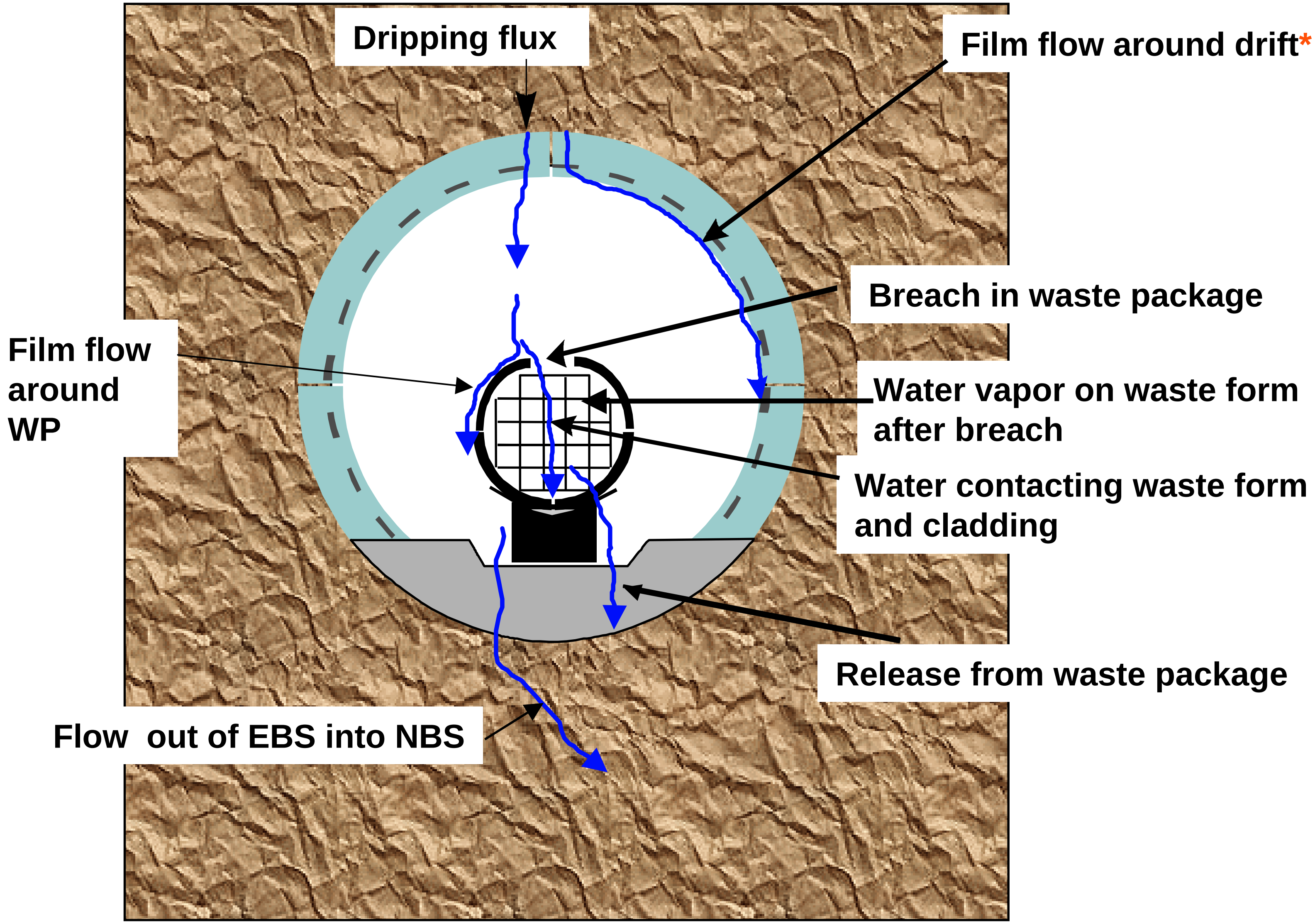
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
0
200,000
400,000
600,000
800,000
1,000,000
Time (years)
Base Case
Secondary Phase Concentration
RIP Version 5.19

Colloidal Plutonium Transport - Base Case

- May increase release from waste package and decrease travel time in near field and far field
- Significance depends on stability and reversibility of RN attachment
- Four colloid types considered in TSPA-VA: clay, iron oxide, “spent-fuel waste-form” and “glass waste-form”
- Reversible sorption considered in TSPA-VA base case with ratio of amount mobilized on colloid to amount dissolved (= K_c) ranging from 10^{-5} to 10 based on laboratory data

Conceptual model of all potential water flow pathways through the EBS



*Not in base case

Engineered Barrier System Transport

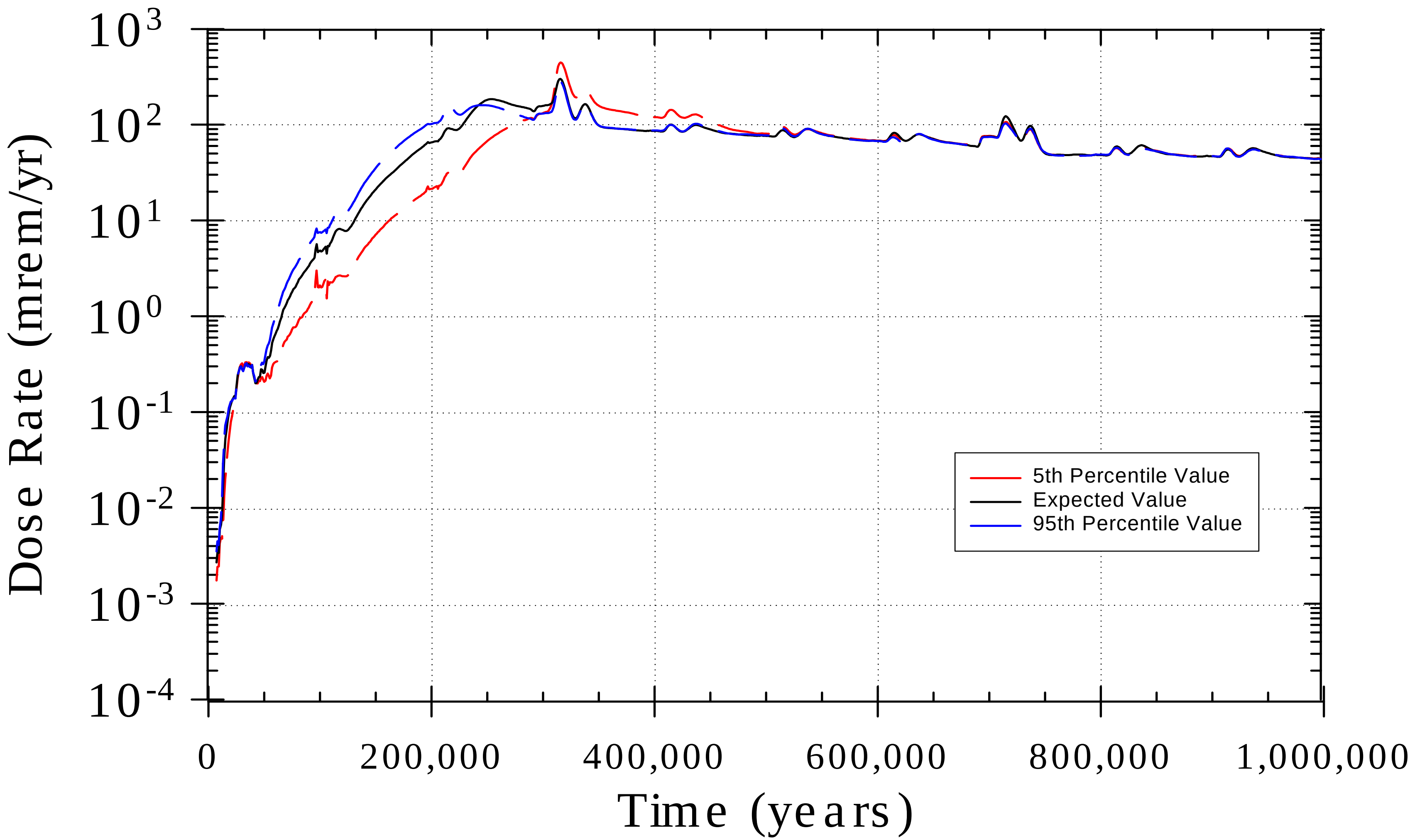
EBS release occurs when:

- WP is breached allowing air and/or water into can
- Clad is breached allowing air and/or water into WF
- Waste form degrades
- RN's are mobilized (dissolved and colloidal)
- RN's transport through EBS by advection and diffusion

Performance improves if:

- Protect WP from drips
- Clad remains substantially intact (protected from high heat and mechanical disruption)
- WF degradation very slow
- RN's less mobile (insoluble, little colloid mobilization)
- RN's transport slowly (advective and diffusive barriers, retardation)

Sensitivity of dose to seepage into waste package



Summary/Conclusions

- NFGE information included in TSPA-VA
- Improvements in waste form degradation and radionuclide mobilization models
- CSNF dissolution model has been extended to consider temperature, burnup, $\sum CO_3^{-2}$, pH and O_2
- HLW glass dissolution model has been updated
- Np elemental solubility updated
- Colloid mobilization has been added

Summary/Conclusions
(continued)

- **Significant effect on EBS transport performance**
  - Waste Package (and cladding) longevity
  - Np Solubility
  - Advection control
  - Colloid control (if necessary)
- **Additional data requirements**
  - Interaction of water with waste package and waste form
  - Nature of advective and diffusive flow paths in EBS
  - Geochemistry along flow paths in EBS