Risk, Uncertainty and Sensitivity Analyses in a Recent Safety Assessment of a Spent Nuclear Fuel Repository in Sweden

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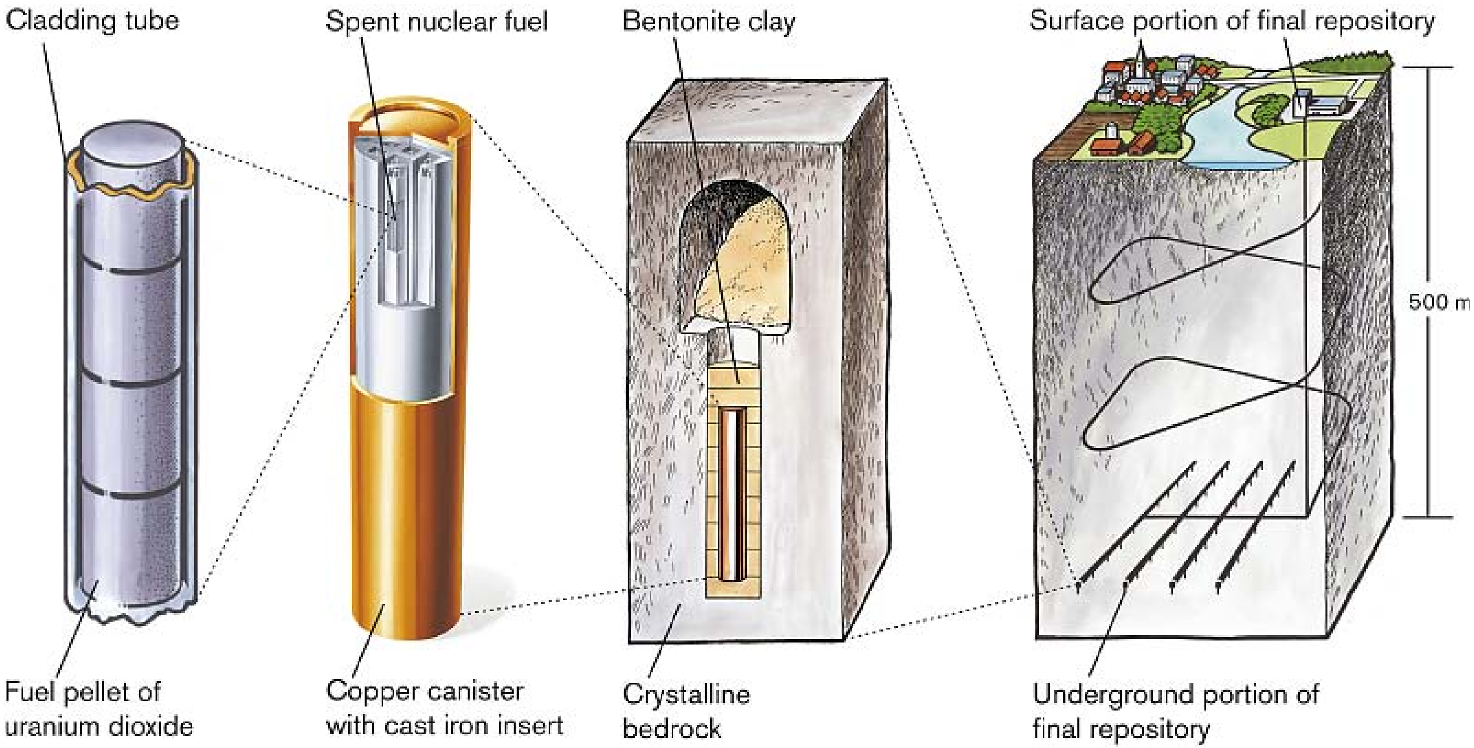
Outline

- Background:
  - Final repository for spent nuclear fuel in Sweden
  - Assessments of long-term safety
- Sensitivity analysis of risk driver in recent assessment
- Conclusions

The KBS-3 repository



Primary safety function: containment

Secondary safety function: retardation

Background: Final repository for spent nuclear fuel in Sweden

- SKB is currently pursuing site investigations for a final repository in two municipalities
  - Application to build final repository planned 2010
- The safety assessment SR-Can
  - Published in October 2006, SKB TR-06-09 (available at www.skb.se)
  - Reviewed by authorities aided by int'l team of experts during 2007
  - Based on initial data from site investigations
  - "Dress rehearsal" for licence application
- Ongoing: The safety assessment SR-Site
  - Supports license application to build final repository to be made in 2010
- Risk criterion, applicable 100,000 years after closure:
  - Individual annual risk of harmful effects must not exceed 10^{-6}
  - Corresponds to ≈ 1% of natural background radiation in Sweden.
- Time scale for the assessments: One million years

Introduction to sensitivity analysis

- Overall result of assessment
  - Most of the 6000 canisters will not fail during assessment period
  - Some tens of canisters assessed to fail due to enhanced corrosion
  - An additional few canisters assessed to fail due to earthquakes
- Enhanced corrosion gives main contribution to the calculated risk
  - The buffer is eroded so that its protective function is lost
  - This enhances the corrosion rate of the canister such that a small fraction of the canisters fail during the one million year assessment period
  - Radionuclides are then released and may reach the surface environment
- A number of uncertain factors influence buffer erosion, canister corrosion and radionuclide transport
- Useful to break down sensitivity analysis into these three phenomena
- Uncertainties are due to both lack-of-knowledge and, regarding hydraulic conditions, natural variability

Factors affecting erosion

- Fraction of assessment time during which erosion occurs; ***FracTime***
- Sensitivity to buffer loss; i.e. buffer mass loss required to lose buffer protective function, M_0
- Erosion rate constant, ***EroConst***
- Equivalent flow rate at deposition hole, ***Qeq***
  - Determined by hydraulic conditions in host rock
  - Two conceptual hydrogeological models
  - Large spatial variability over ensemble of deposition holes

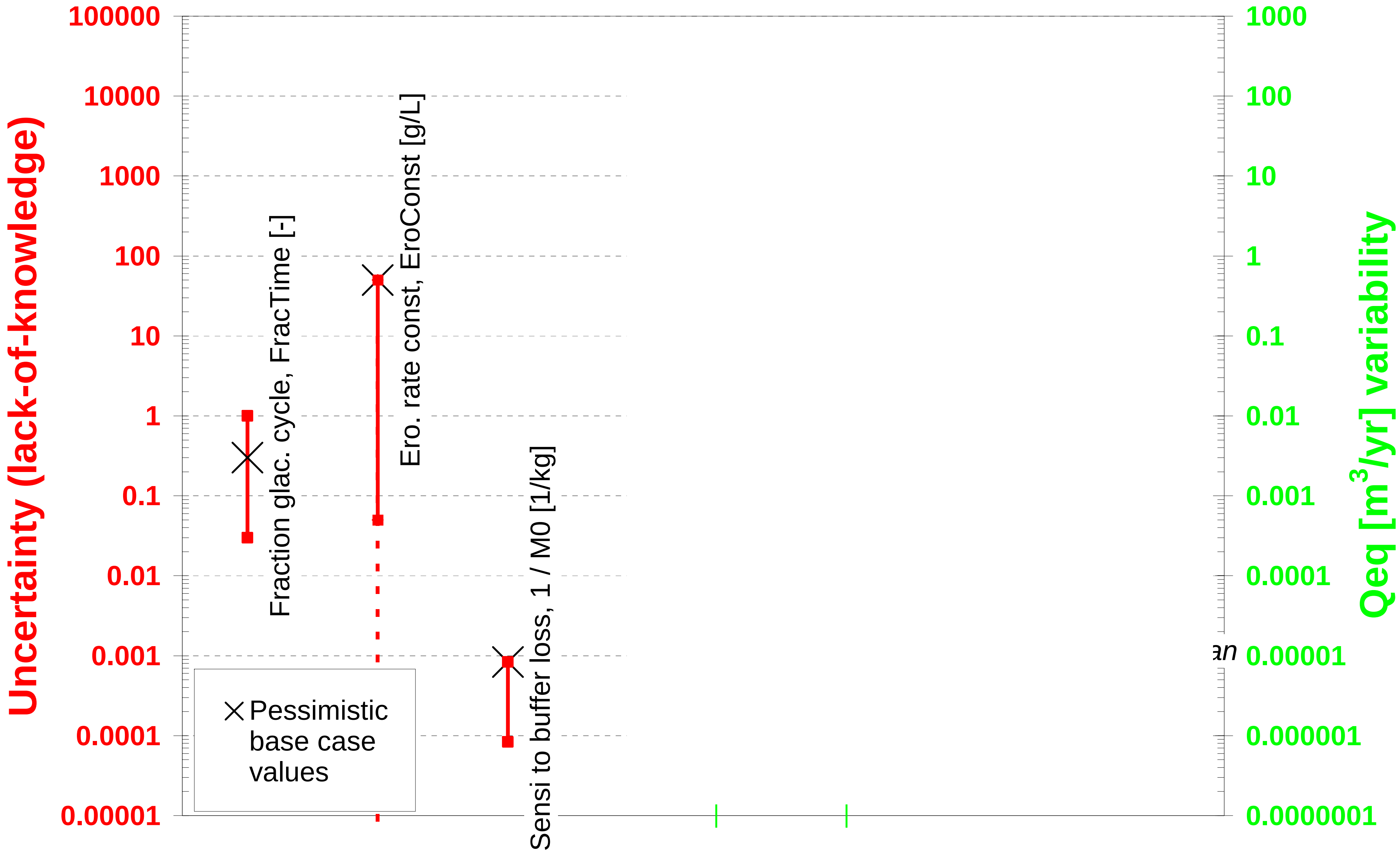
Model for erosion

- Simple model to calculate time required fro detrimental buffer loss in a deposition hole

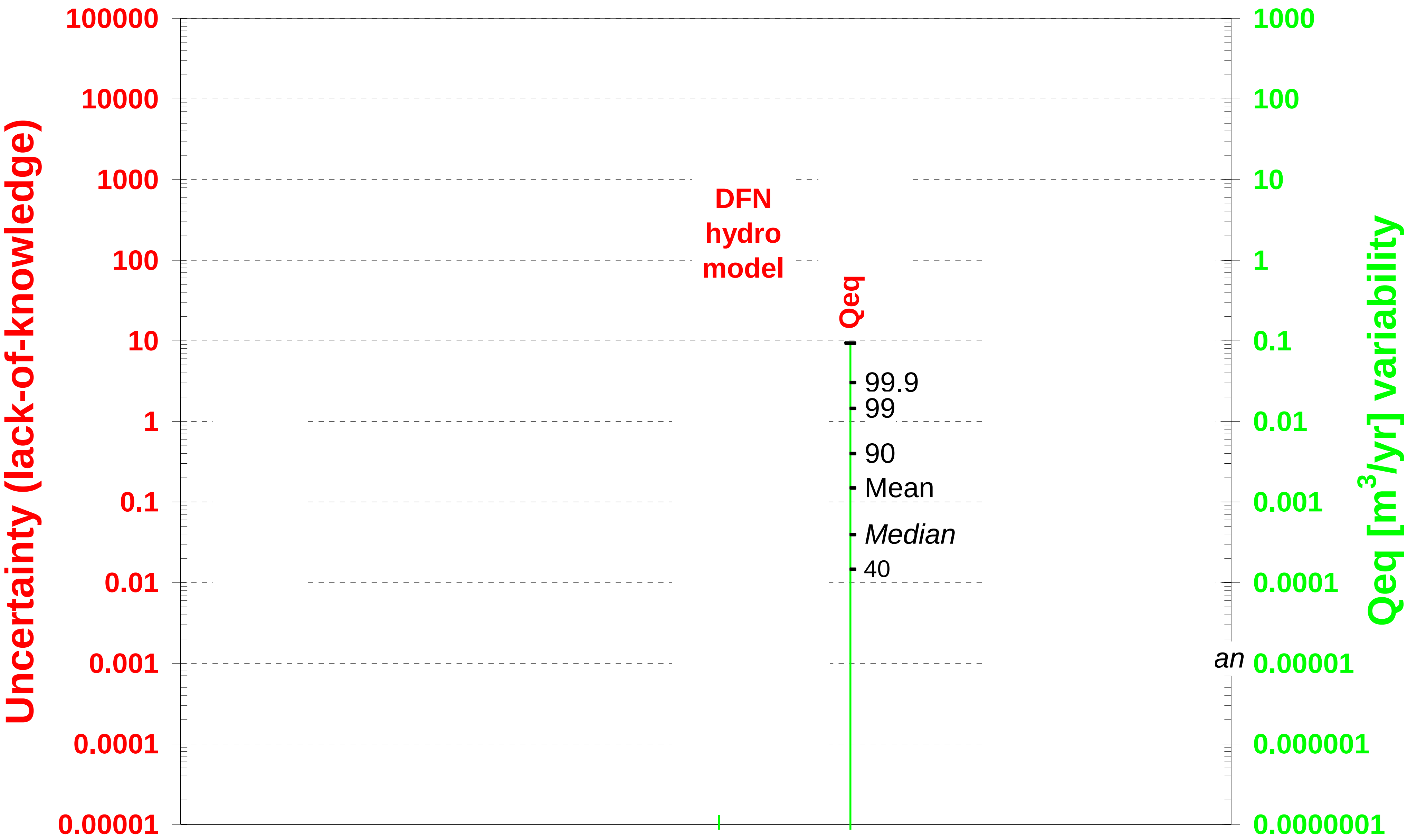
$$t_{DetrimentalBufferLoss} = \frac{M_0}{Erosion\ rate} = \frac{M_0}{FracTime \cdot EroConst \cdot Q_{eq}}$$

- Multiplicative factors, can be compared on log-scale

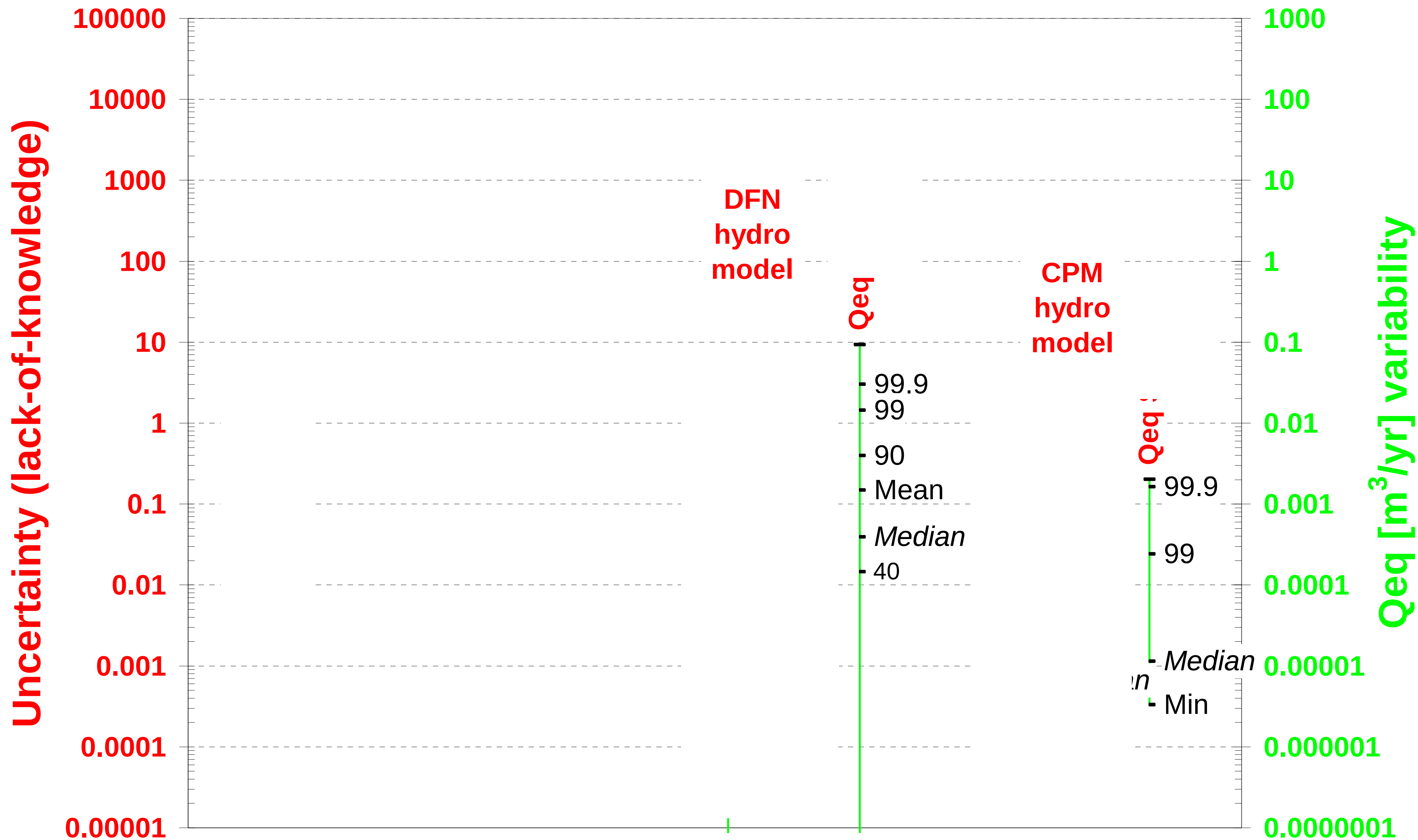
Erosion uncertainties



Erosion uncertainties



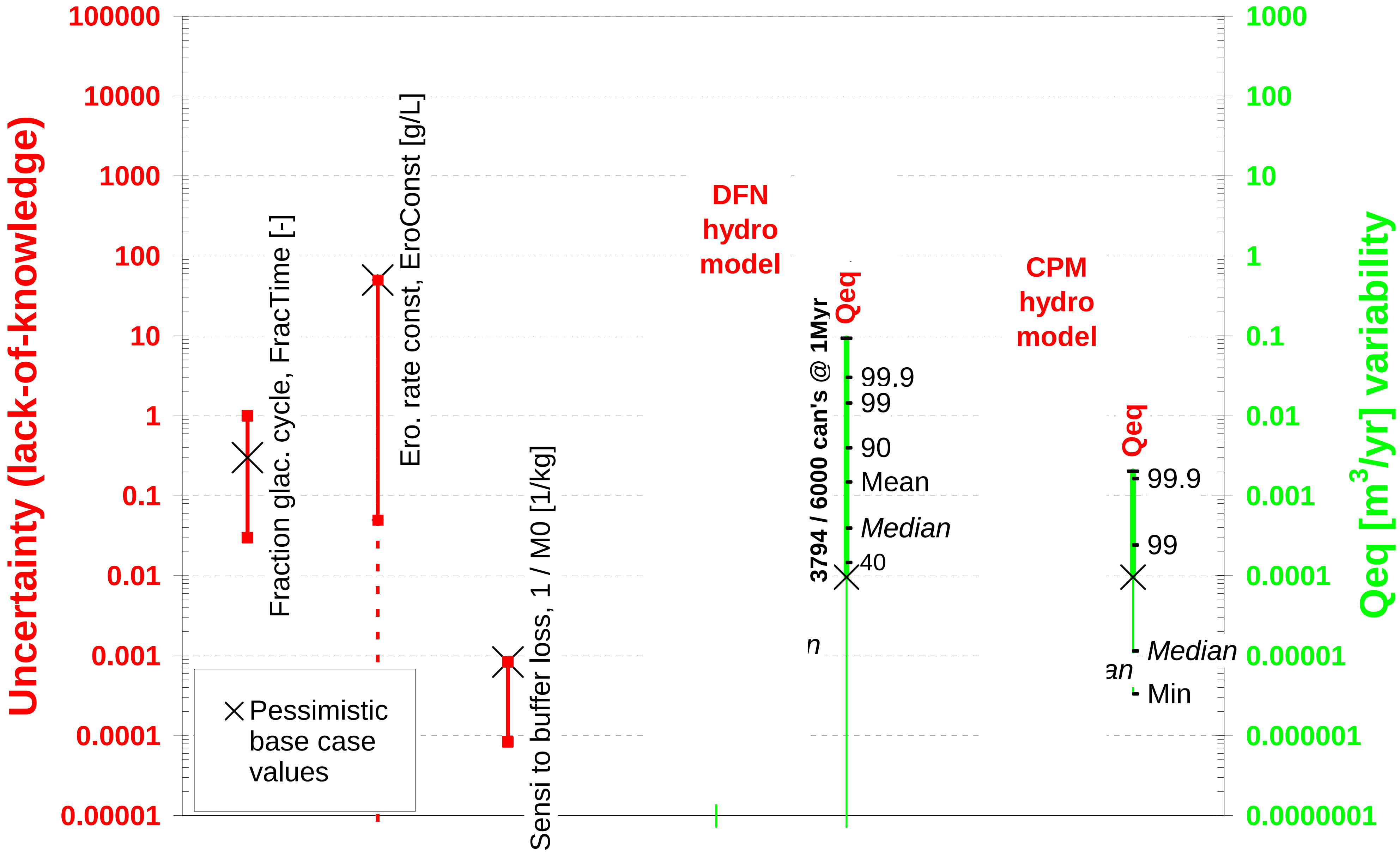
Erosion uncertainties



Handling of uncertainties related to erosion

- Epistemic uncertainty
  - Given as intervals (uniform distributions)
  - Approach: Select pessimistic value for compliance demonstration
- Aleatory uncertainty
  - Given as calculated distributions reflecting variability over canister positions
  - Approach: Use distribution to calculate # affected canisters

Erosion uncertainties



Factors affecting corrosion

- Corrosion geometry, area of canister affected, *Area*
  - Pessimistically derived area in SR-Can
  - Difficult to conceive of a lower value, i.e. a more concentrated attack
  - Could be higher, but not likely much higher
- Concentration of corroding agents in groundwater, $[HS^-]$
  - Reasonable value in SR-Can $[HS^-] = 10^{-6}$ M
  - Cautious value in SR-Can $[HS^-] = 10^{-5}$ M
  - Pessimistic value in SR-Can $[HS^-] = 10^{-4}$ M for 10% of deposition holes
- Groundwater flow rate, *U*
  - Three conceptual models in SR-Can
  - Large spatial variability over ensemble of deposition holes
  - Spalling does not affect flow rate

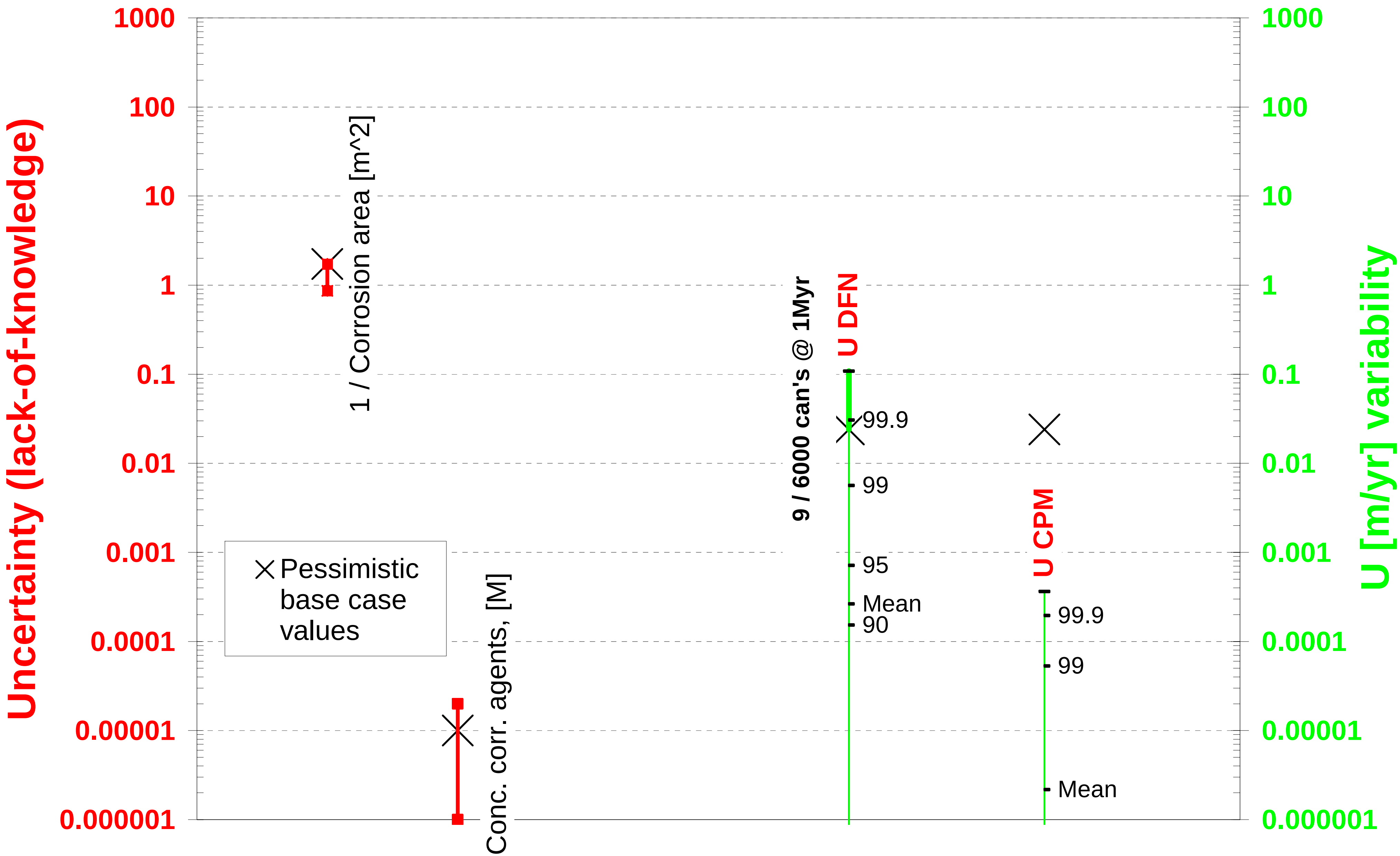
Model for corrosion

- Simple model to calculate time required to cause canister failure due to corrosion

$$t_{Corrosion\ failure} \propto \frac{Area}{U\left[HS^{-}\right]}$$

- Multiplicative factors – can be compared on log-scale

Corrosion uncertainties



Sensitivities to radionuclide release and dose

- Full probabilistic calculation
- > 40 uncertain variables, but only few important for dose at (e.g.) 10^6 years
- All dose results dominated by Ra-226

Methods for sensitivity analyses

- Several methods applied to results of probabilistic calculation
- Standardised rank regression, SRRC
  - Established method for determining sensitivity of output to input uncertainties for non-linear but monotonic models
- Conditional mean value
  - Method to identify variables related to high (or low) dose results
- Classification tree
  - Method to identify variables related to user defined classes, e.g. high (or low) dose results
- Tailored regression model, building on process insight
- All yield similar results regarding important uncertain parameters

Tailored regression model

- Builds on mathematical description of modelled processes
- Release rate of Ra-226 to biosphere determined by product of
  - Release rate from fuel to geosphere, *NFRate*
  - Transmission of Ra-226 through geosphere, *T*
- Release rate of Ra-226 from fuel to geosphere essentially determined by product of fuel dissolution rate *DFuel* and time elapsed since onset of release, *t*,
  - *NFRate* = constant·*DFuel*·*t*
- Transmission depends complexly on all uncertain factors relating to geosphere transport
  - However, only few are important:

$$T \propto \exp\left(cF^{0.5}\left(K_d D_e\right)^{0.25}\right)$$

Tailored regression model

Thus

$$DoseRa226 = Constant \cdot (Dt)\exp\left[cF^{0.5}(K_d D_e)^{0.25}\right]$$

or

$$\log(DoseRa226) = Constant + \log(Dt) + cF^{0.5}(K_d D_e)^{0.25}$$

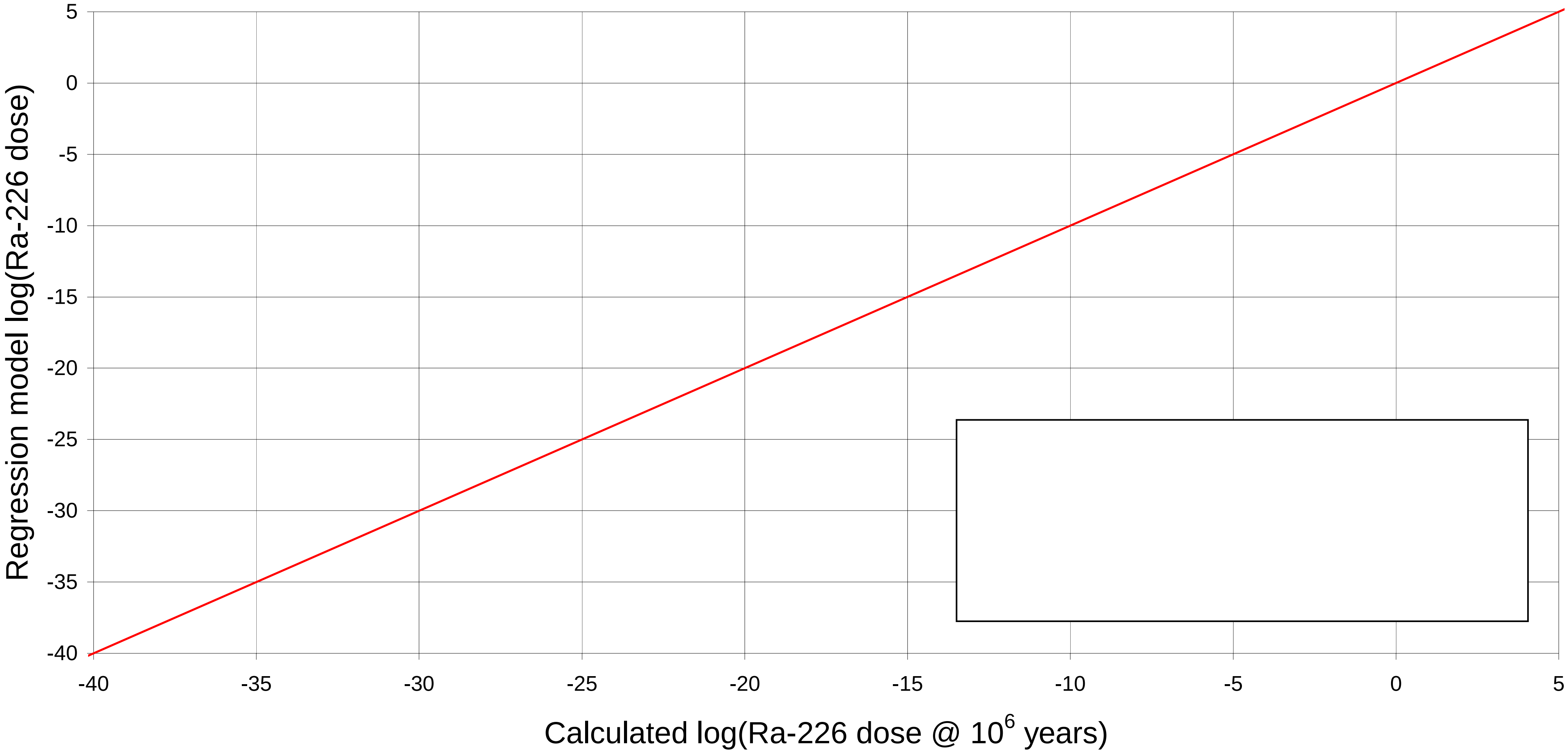
i.e.

$$\log(DoseRa226)$$

is suited for linear regression on

$$\log(Dt) \quad \text{and} \quad F^{0.5}(K_d D_e)^{0.25}$$

Tailored regression model(s)



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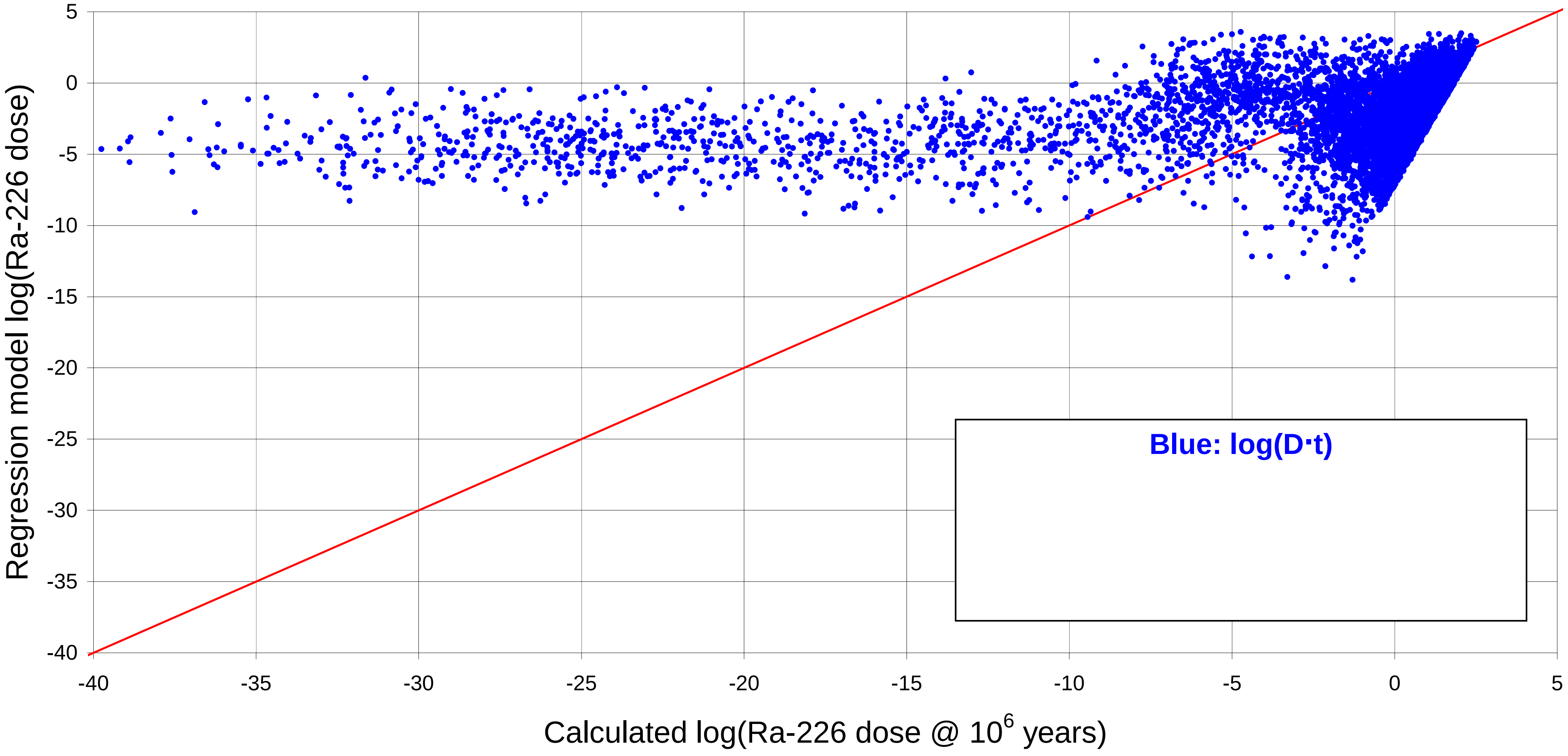

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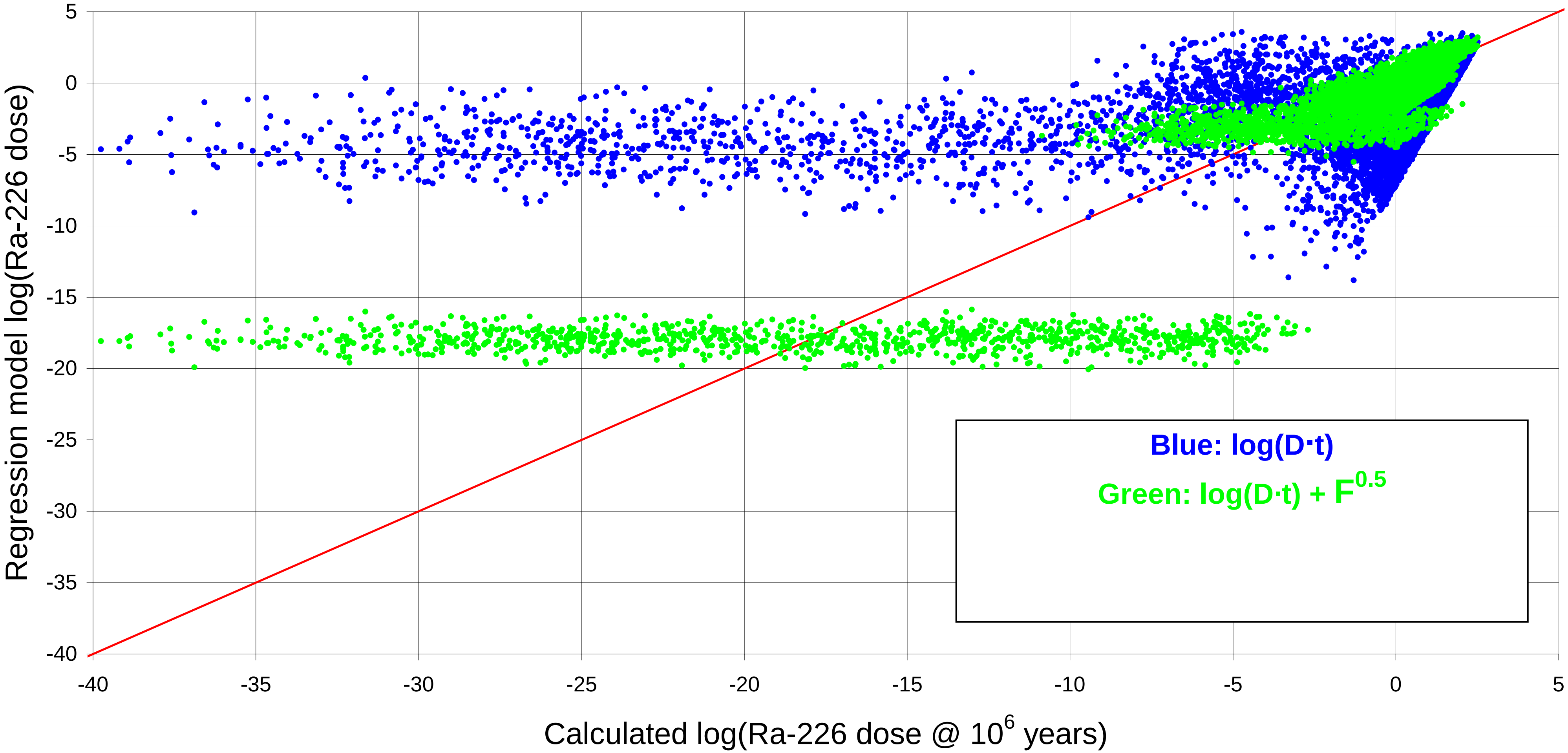

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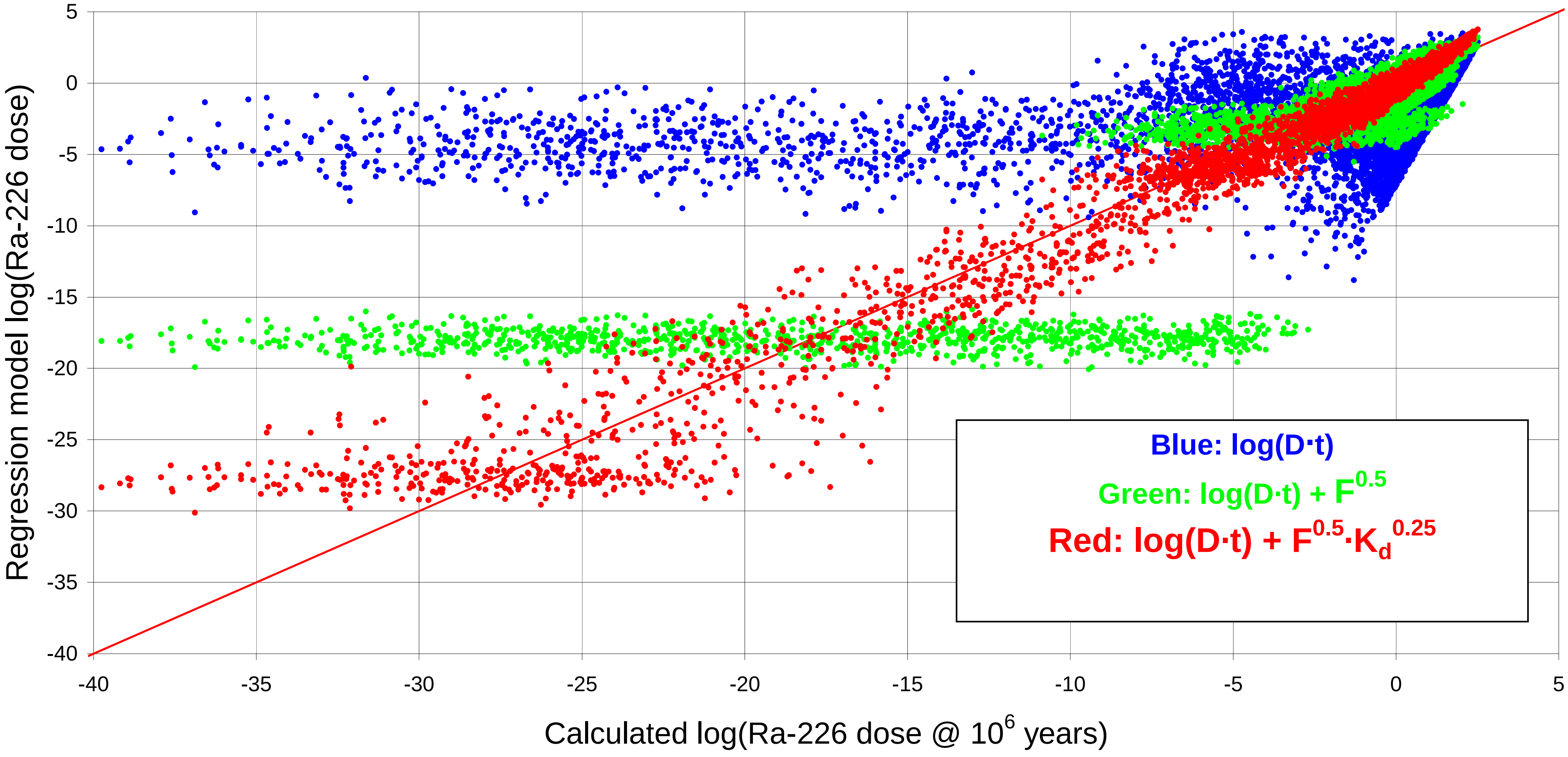

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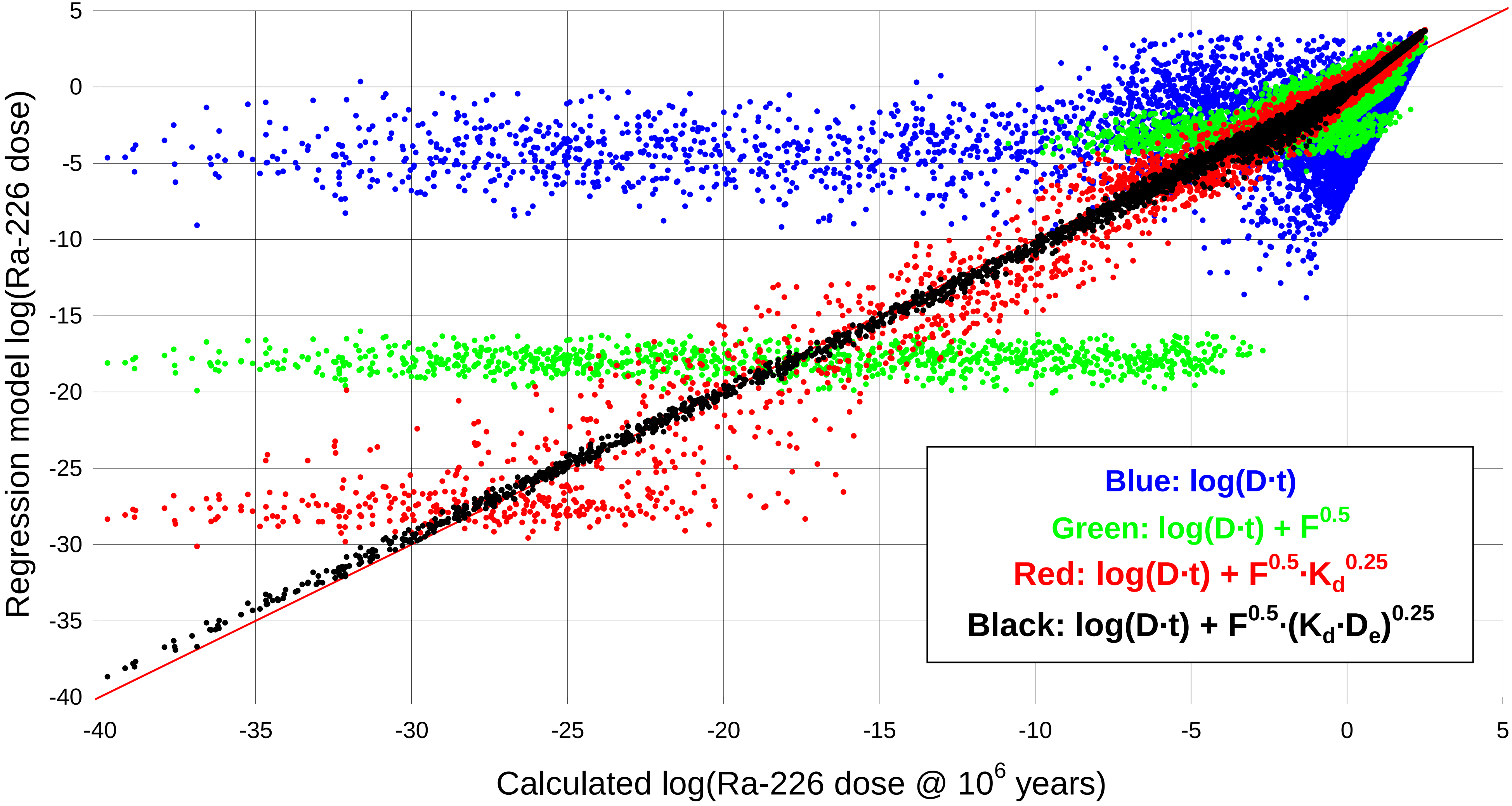

Conclusions

- Three separate and consecutive phenomena
  - Sensitivity analysis can thus be disaggregated in three steps
- First two modelled by simple multiplicative factors and with input uncertainties as intervals for lack-of-knowledge and distribution for variability
  - Allows simple diagram representation of sensitivity analysis results
- Third as traditional probabilistic transport calculation
  - Several methods yield same important parameters
  - Mathematical process models may be used to construct tailored regression model