EUROPEAN JOINT PROGRAMME FOR THE INTEGRATION OF RADIATION PROTECTION RESEARCH CONCERT

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Conceptual model uncertainty in radioecology

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Bundesamt für Strahlenschutz

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 662287.

What is radioecology?

"Radioecology is a highly multidisciplinary scientific discipline situated at the crossroads between environmental radioactivity, whether natural or man-made, and its consequences on both, man and the environment. It deals with radioactivity as a stressor requiring risk assessment, but also as a tracer of biogeochemical and ecological processes. "

http://www.iur-uir.org/en/

Radioecological models are needed for

- Prognostic assessments (e.g. regulatory purposes)
- Assessments for radioecological emergency preparedness and response
- Low activity levels in the environment (e.g. measurements not feasible)

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Conceptual model uncertainty

- Definition
  - Deals with simplifications needed to translate a conceptual model into mathematics (EPA, 2009; EPA, 2014)
  - Refers to incomplete understanding and simplified representations of modelled processes as compared to reality (Refsgaard *et al.*, 2007)

→Neglecting conceptual model uncertainty may lead to uncertainty bands that are not sufficiently wide (Engeland, 2005)

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Quantification of conceptual model uncertainty

Given a model and available experimental data several strategies are possible (Refsgaard *et al.*, 2006):

1. Use a split-sample approach for calibrating and validating the model and increase the range of parameter uncertainty to implicitly account for conceptual model uncertainty.
2. *Estimate the total uncertainty of the model output with statistical analysis of the residuals and subtract the parameter uncertainty from total uncertainty.*
3. Carry out a process-sensitivity analysis.
4. Use advanced statistical tools such as Multi-model inference, Bayesian Model Averaging and Generalised Likelihood Uncertainty Estimation.

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Conceptual model uncertainty in radioecology

Conceptual model uncertainty is present (examples):

- When using simplifying empirical parameters, e.g. transfer factor soil-plant, soil-mushroom, soil-cow milk etc.
- When deliberately excluding relevant processes.
- When assuming that the system is in an equilibrium state whereas this is not the case (dynamic process).
- When the source term is oversimplified, e.g. hot particles are neglected.

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Conceptual model uncertainty in radioecology

Conceptual model uncertainty is present (examples):

- Wh… …empirical parameters, e.g. transfer factor soil-plant, soil-…

Example 1: Wild boar meat contamination with radiocaesium

- When excluding relevant processes e.g. resuspension.
- W… …is in an equilibrium state whereas this is not the case (dynamic p…

Example 2: Interception of wet deposited radionuclides

- When the source term is oversimplified, e.g. hot particles are neglected.

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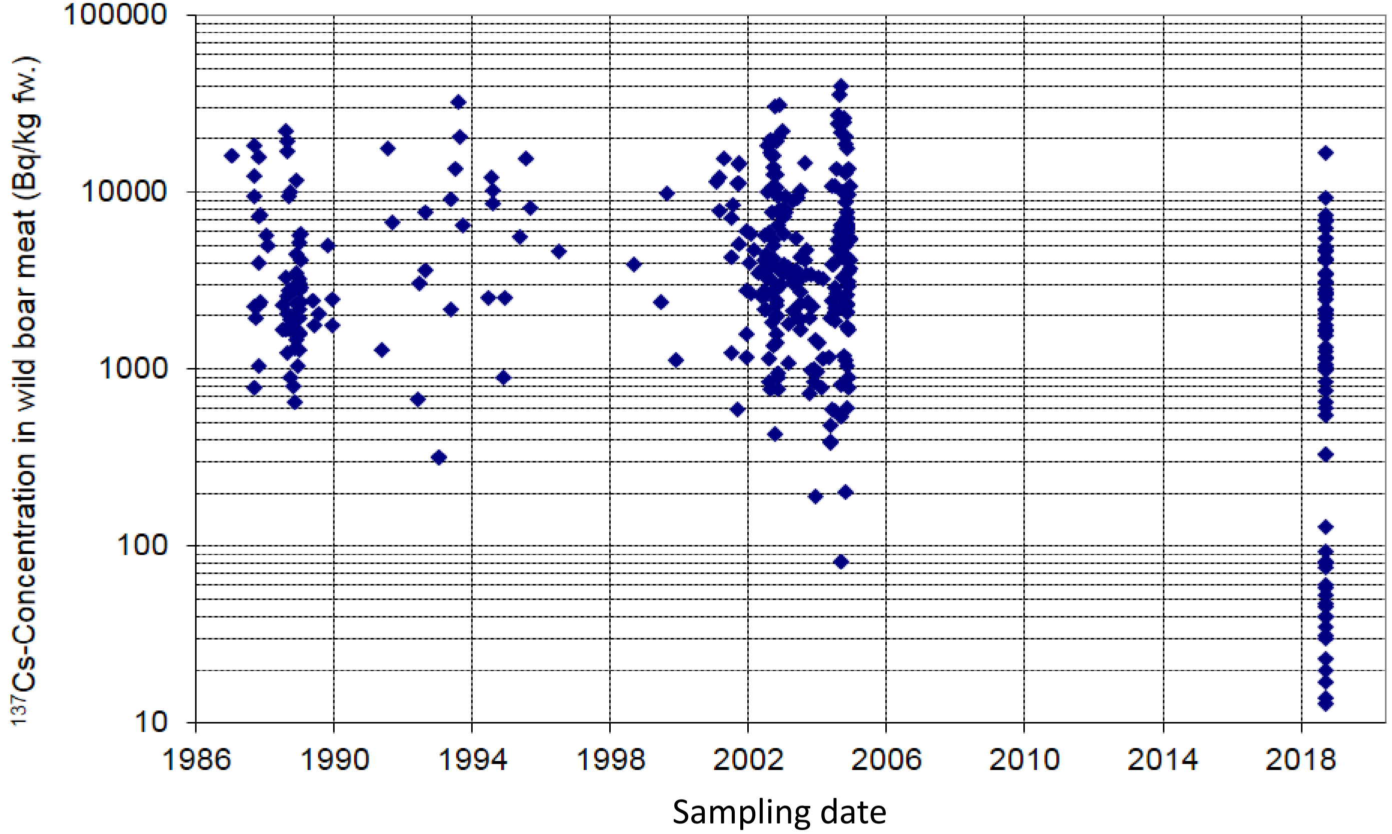
Example 1: Wild boar contamination with radiocaesium



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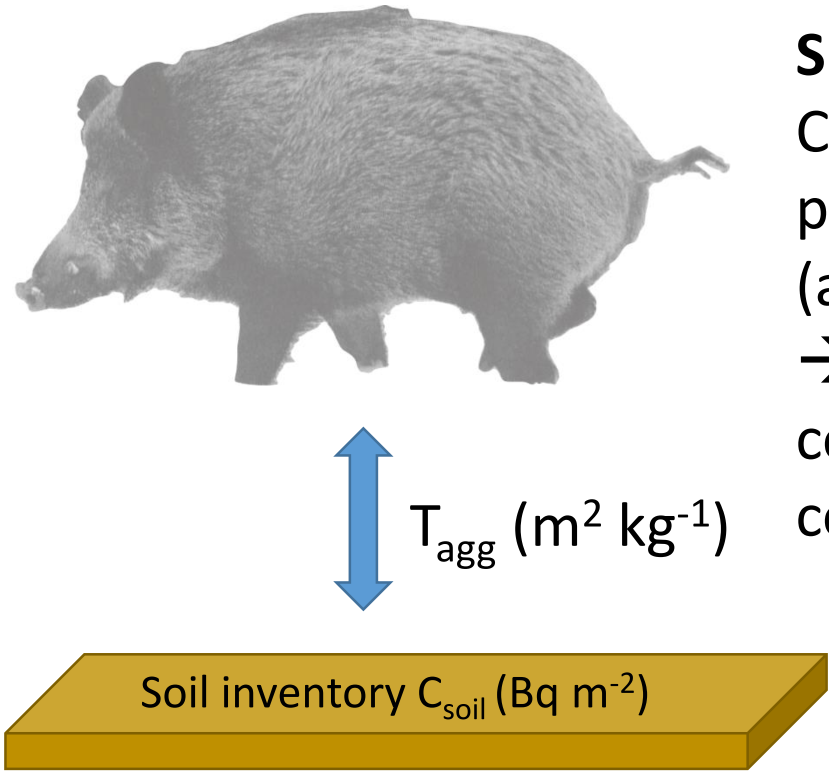
Wild boar contamination with radiocaesium



Simplified model:

Contamination of wild boar meat is proportional to soil contamination (aggregated transfer factor model)

→ Stochastic uptake of highly contaminated food items is not considered!

$$C_{wboar} = T_{agg} \cdot C_{soil}$$

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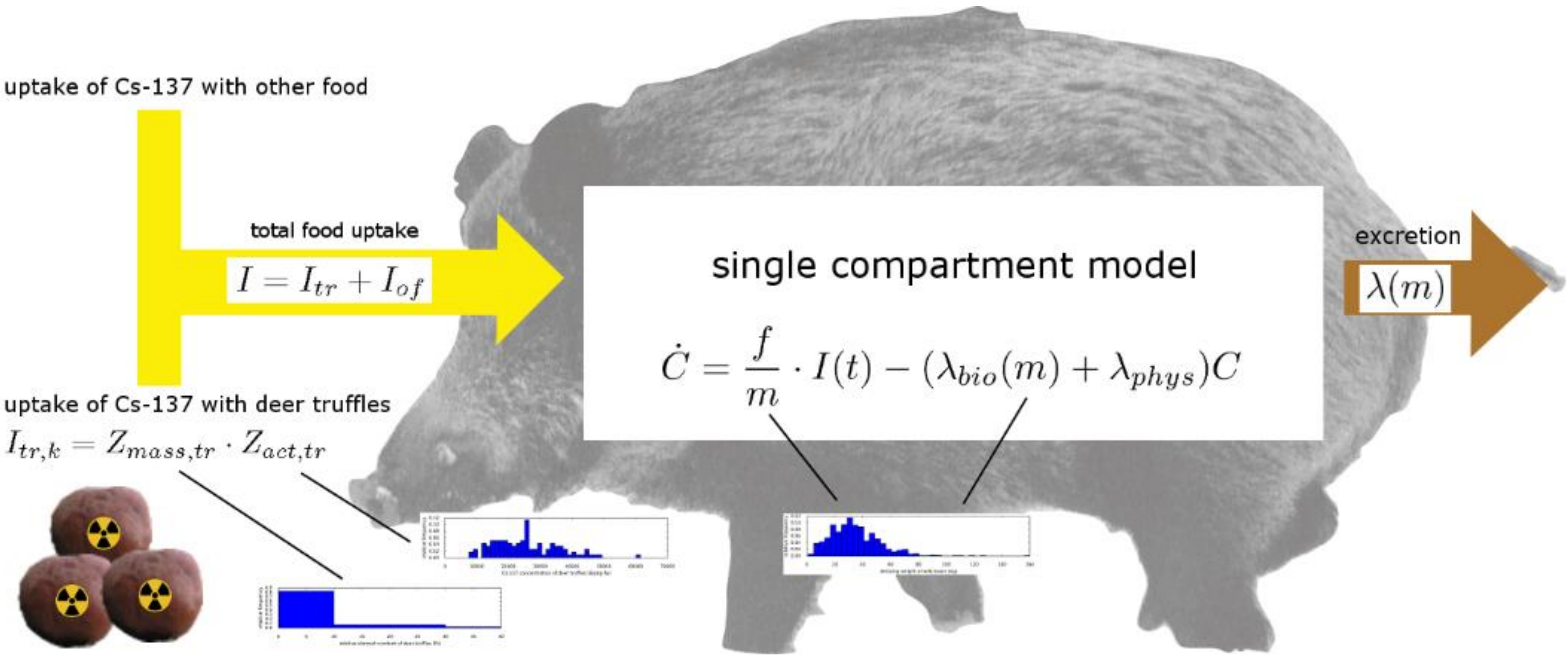
Process-based model for wild boar contamination

Process-based model: Stochastic uptake of highly contaminated food items is considered.
→ Model gives a probability distribution for the radiocaesium contamination of wild boars



Hartmann et al., IRPA 2017 Conference

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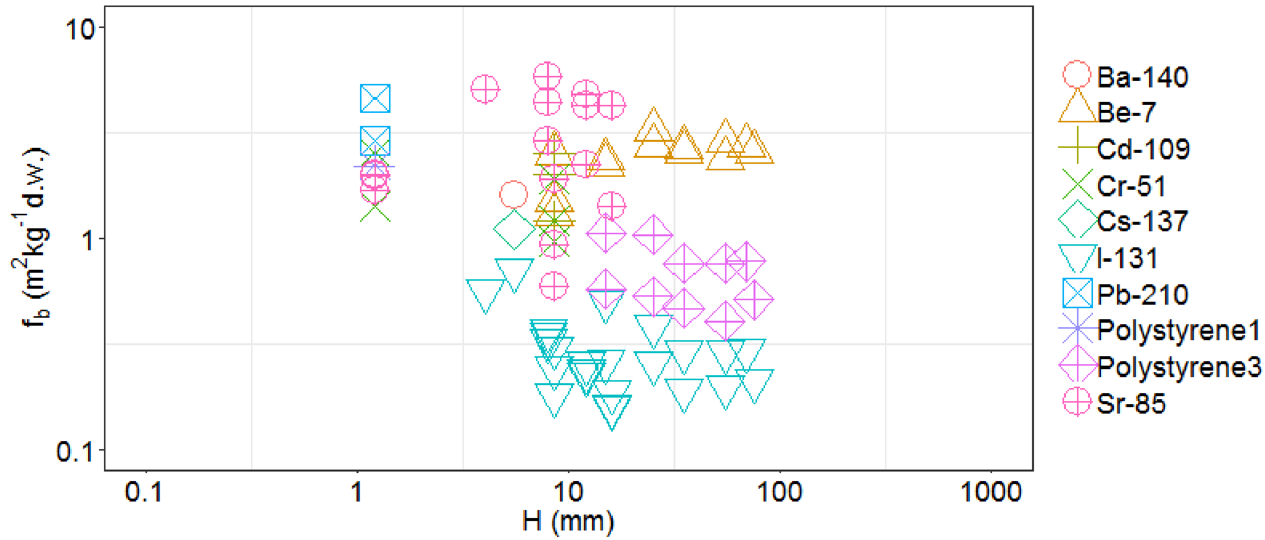
Example 2: Interception of wet deposited radionuclides by vegetation



$$f_B(H, I, E, LAI, W, \ldots) = \frac{A_{plant}/A_{total}}{B}$$

- H amount of rainfall (mm), I rain intensity, E evaporation rate (mm h^{-1})
- LAI Leaf area index, W plant water storage (mm)
- A_{plant} amount of pollutant retained on plant (e.g. Bq)
- A_{total} total amount of pollutant deposited onto soil-plant system (e.g. Bq)
- B standing biomass density (kg d.w. m^{-2})

Data available from laboratory experiments 1970-2014: variety of plants, different radioactive/inert substances, different rainfall conditions.

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Process-based models for interception of wet deposited radionuclides

Gonze and Sy (2016)* developed two process-based models:

1. Equilibrium model (EM): balance between drainage and absorption mechanisms depends on total capacity to mobilise deposited substances → absorption instantaneous and reversible
2. Kinetic model (KM): balance between drainage and absorption mechanisms depends on kinetic rates of these → kinetic and irreversible process

Bayesian approach to quantify parameter uncertainty and carry out residual analysis (model performance testing) is used.

** M. -A. Gonze, M. M. Sy (2016) Science of the Total Environment 565, 49-67*

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Quantification of conceptual uncertainty for EM and KM models

Build upon Gonze and Sy (2016) and deduce from 95% confidence interval of model output and 95% confidence interval of propagated parameter uncertainty → 95% confidence interval of conceptual model uncertainty

In practice: quantify difference between model output with propagated parameter uncertainty and residual S and model output with propagated parameter uncertainty only.

Main assumptions:

- Contributions to uncertainty are additive.
- Data available are representative.

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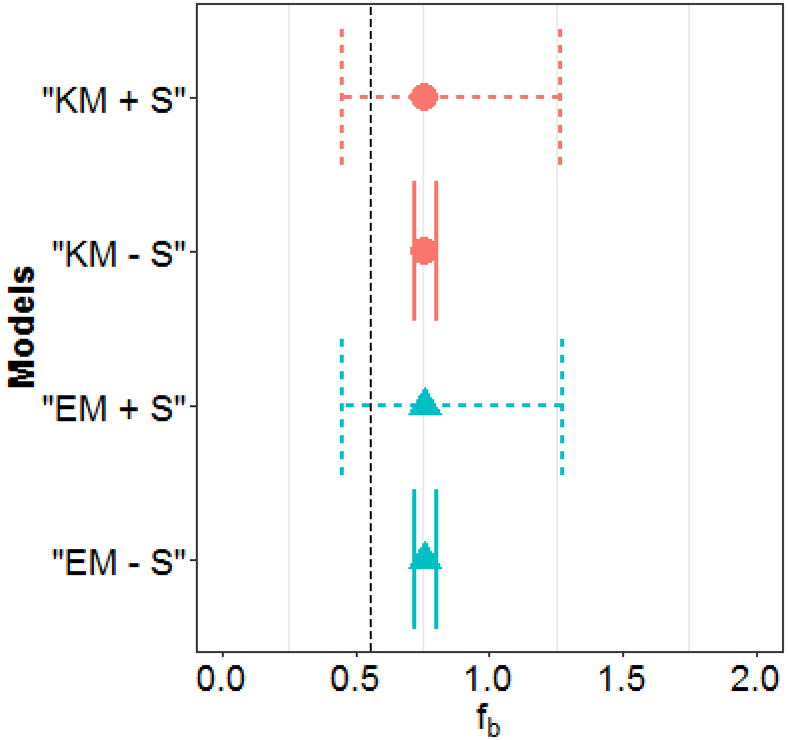
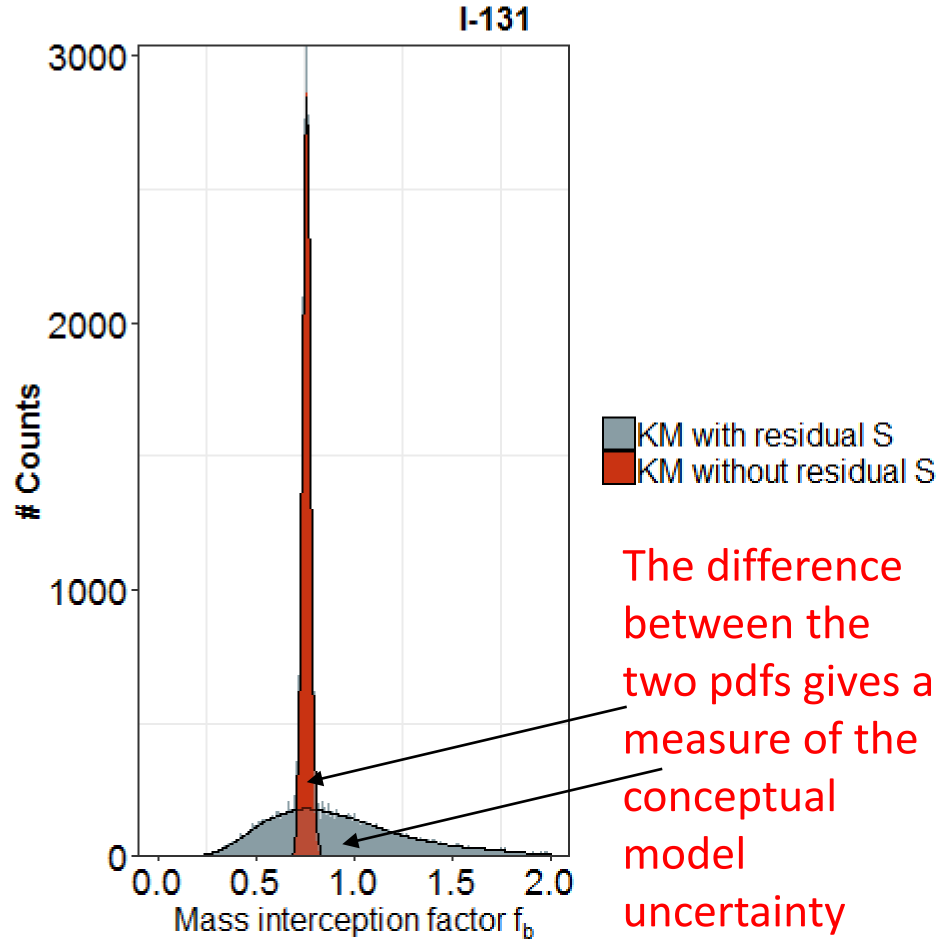
Results for iodine

For I-131 EM and KM model perform identically because iodine is a non-interacting substance.





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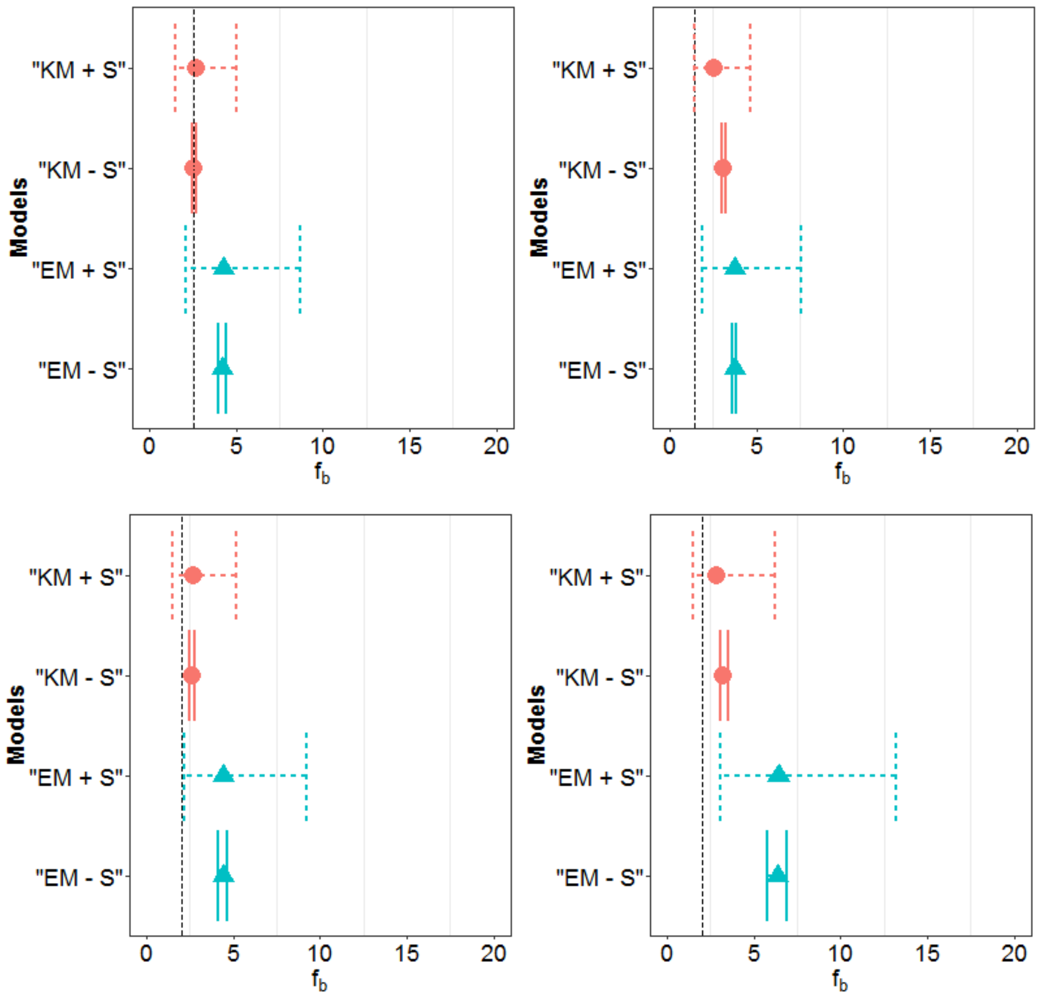
Results for beryllium and strontium

- 4 data points as example: 2 Be-7 (top) and 2 for Sr-85 (bottom).
- For these elements EM and KM model perform differently.



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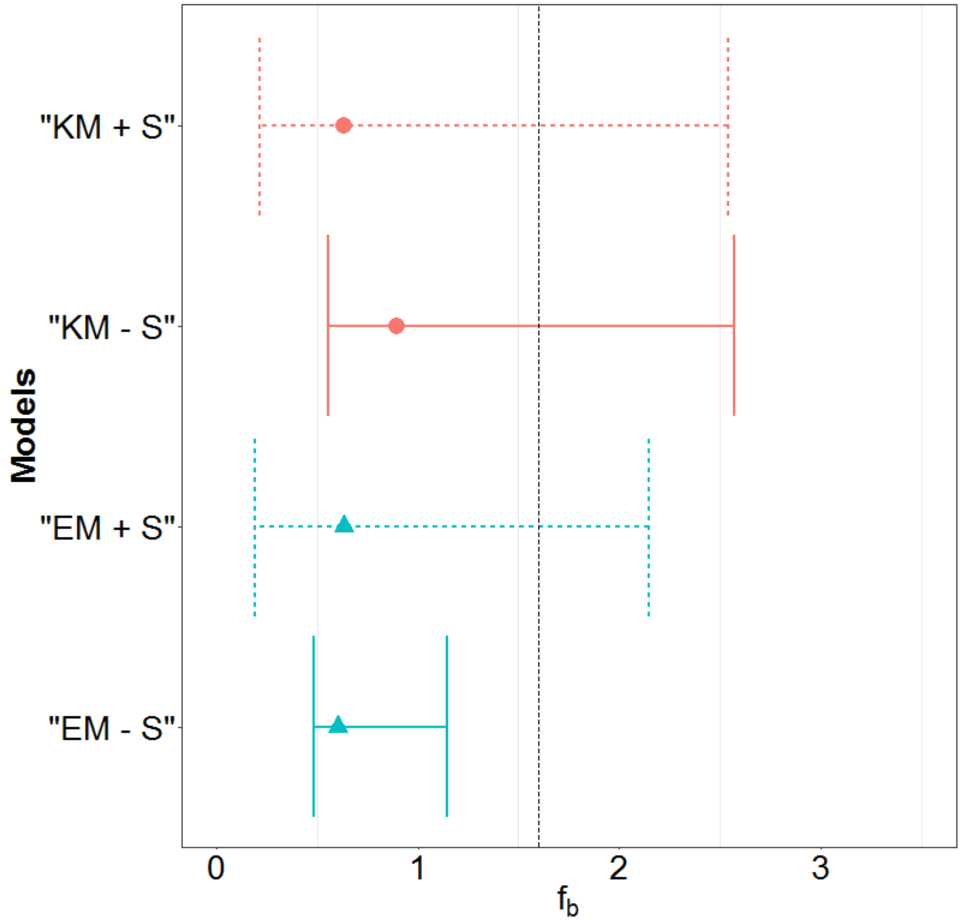
Results for caesium

- One data point available for predictions.
- Conceptual uncertainty for EM model is larger than for KM model.



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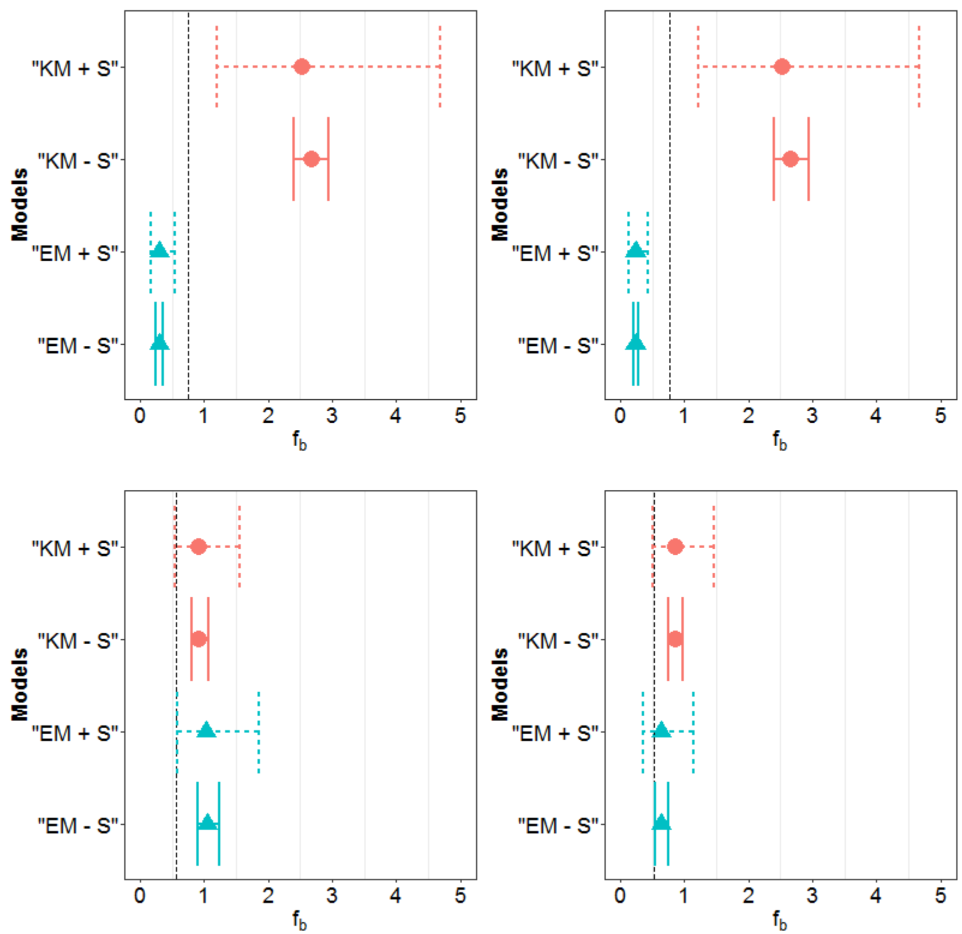
Results for polystyrene

- 4 data points as example.
- For these elements EM and KM model perform differently.



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Conclusion

- Considering all the data points conceptual model uncertainty is larger for EM model than for KM model. However, this depends on the underlying experimental data, namely type of element (valence) and experimental conditions (e.g. intermittent rain).

- Some variability, e.g. plant type, remains included in the residual S.

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Discussion

- Data unavailability and non-representativeness restrict the possibility to quantify the conceptual model uncertainty.
- The assumption of uncertainties being additive is often used to quantify the various uncertainty contributions.
- The quantification of propagated parameter uncertainty is often a pre-requisite for determining the conceptual model uncertainty.
- Other uncertainty sources are neglected (e.g. measurement uncertainty) but may play a role.

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Thank you!

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Equilibrium model (EM)

$$f \approx \begin{cases} 1-p & \text{if } T \leq T_S \\ \dfrac{(1-p)}{T \times \lambda} \times [1-(1-\lambda \times T_S) \times \exp(-\lambda \times (T-T_S)] & \text{if } T > T_S \end{cases}$$

where:

$$\lambda = \frac{D_S}{LAI \times (L + CR)}$$

- p free throughfall coefficient
- T_s saturation time
- D_s drainage rate at saturation
- LAI single-sided leaf area index ($m^2\ m^{-2}$)
- L specific foliage storage (mm)
- CR concentration ratio
- T exposure time

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Kinetic Model (KM)

$$f \approx \begin{cases} 1-p \quad \text{if } T \leq T_S \\ \dfrac{(1-p)}{T \times \lambda} \times \left[\dfrac{D_S}{LAI \times L} \times Ts + \dfrac{\alpha}{LAI \times L} \times T + \left(\dfrac{D_S}{\alpha + D_S} - \dfrac{D_S}{\alpha + (1-p) \times I} \right) \times (1 - \exp(-\lambda \times (T - T_S))) \right] \quad \text{if } T > T_S \end{cases}$$

where:

$$\alpha = \frac{J}{K} \times LAI$$

$$\lambda = \frac{\alpha + D_S}{LAI \times L} \quad .$$

- I rainfall intensity (mm h^{-1})
- J/K absorption velocity (mm h^{-1})
- p free throughfall coefficient
- T_s saturation time
- D_s drainage rate at saturation
- LAI single-sided leaf area index (m^2 m^{-2})
- L specific foliage storage (mm)
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