BUNDESGESELLSCHAFT FÜR ENDLAGERUNG

URS RETREAT

Uncertainty assessment in the representative preliminary safety analysis in the German site selection procedure

PHILLIP KREYE, DEPARTMENT OF SAFETY ASSESSMENT

17.04.2023, Annweiler am Trifels

GZ: SG02301/11-3/19-2023#8 | Objekt-ID: 9695616

TOPICS

BUNDESGESELLSCHAFT FÜR ENDLAGERUNG

01 THE GERMAN SITE SELECTION PROCEDURE

02 THE REPRESENTATIVE PRELIMINARY SAFETY ASSESSMENTS

03 RADIONUCLIDE TRANSPORT MODELLING AND UNCERTAINTY

04 DATA MANAGEMENT

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THE GERMAN SITE SELECTION PROCEDURE

01

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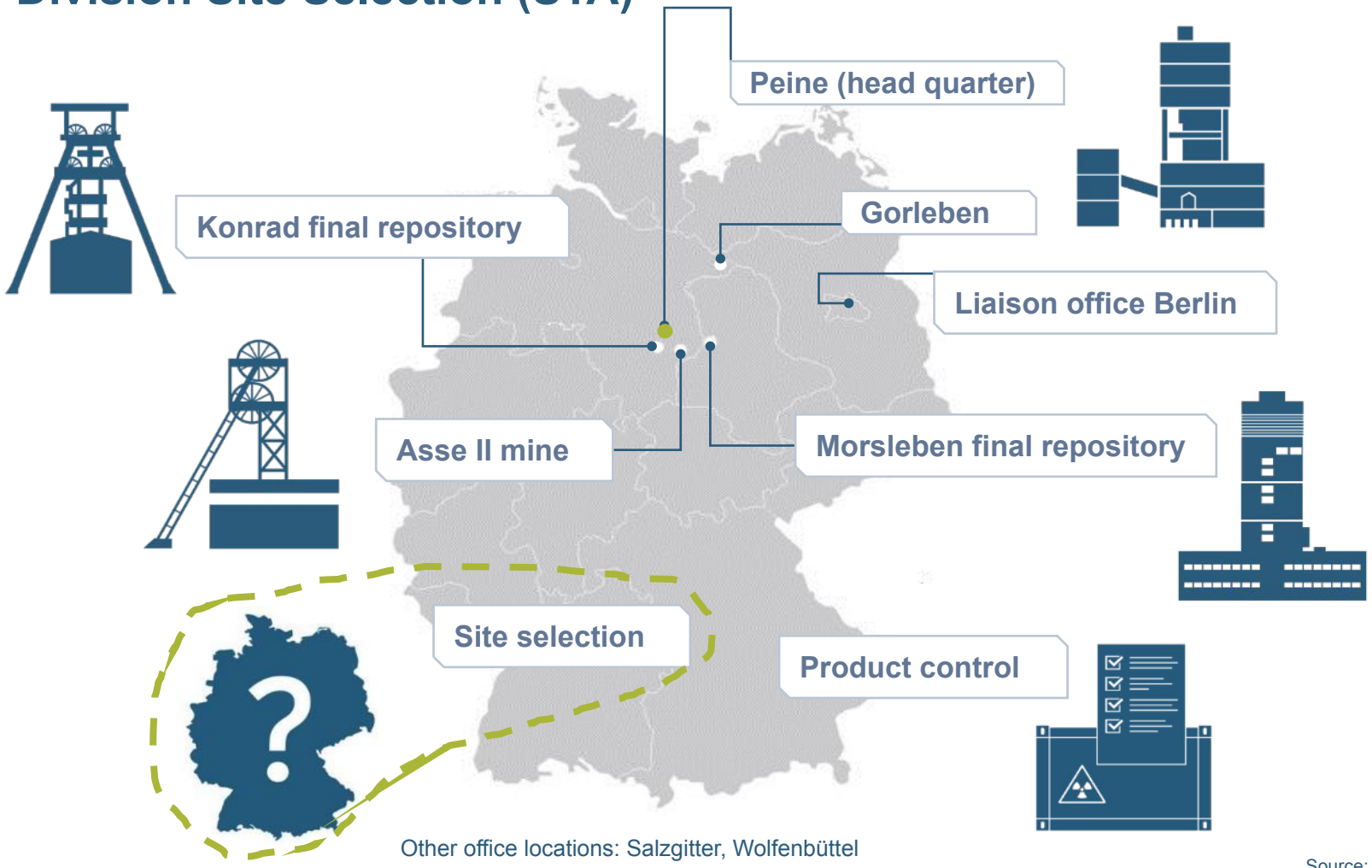
Division Site Selection (STA)



Source: BGE

Short profile STA
Division manager: Lisa Seidel
Approx. 100 employees
5 departments: - Project management (VM) - Site selection (ST) - Safety investigation (SU) - Exploration (EK) - Repository planning (EP)

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SITE SELECTION PROCESS

Specific Requirements in Germany

- Find most-suitable site (not just any suitable site)
- Three host rocks
- 1 million years
- Heterogeneous data availability, lack of digitalisation
- Transparency, traceability and involvement of the public
- Many different stakeholders

Source: BGE

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HOST ROCKS IN GERMANY

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Crystalline rock

heat-conductive, robust,
but brittle

Rock Salt

heat-conductive, ductile and
practically impervious,
but water-soluable

Claystone

sorptive, low permeability,
but thermally vulnerable

Source: BGE

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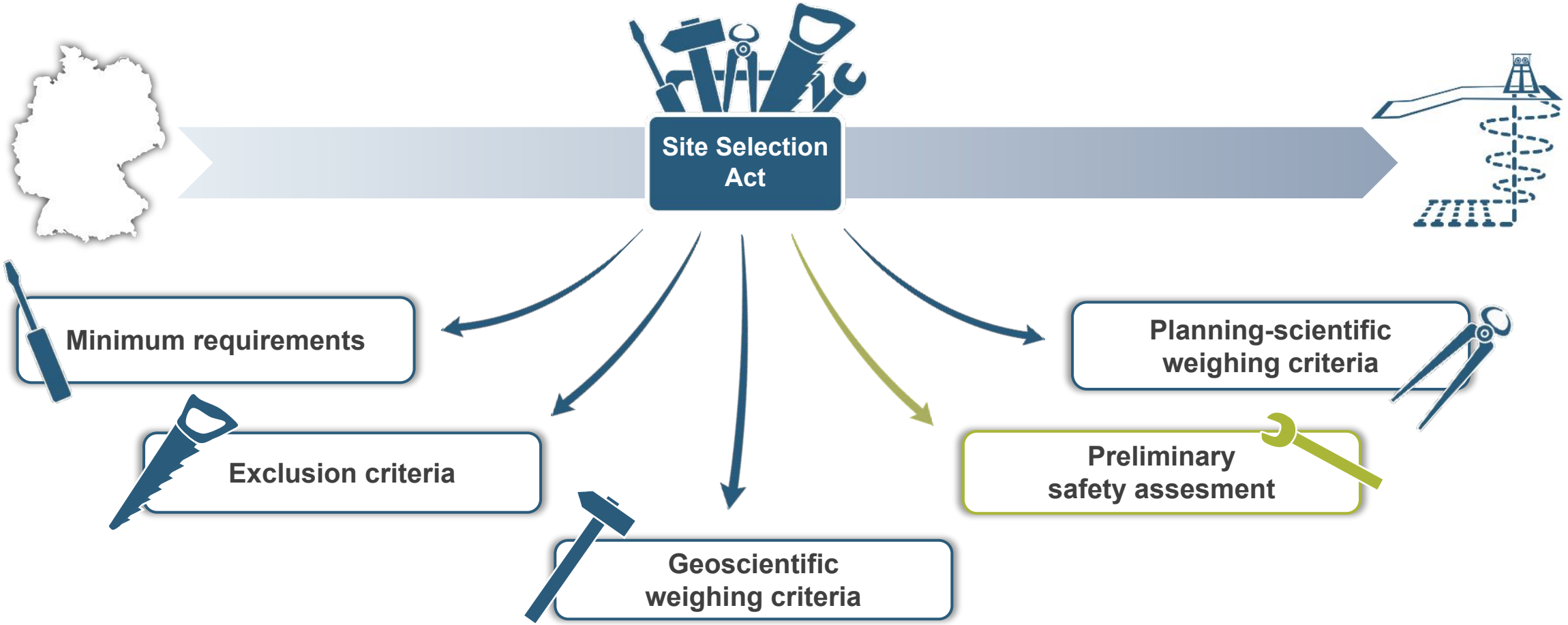
THE SITE SELECTION PROCEDURE (1/2)



Source: BGE

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THE SITE SELECTION PROCEDURE (2/2)

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Sub-areas Interim Report 28 September 2020

Decision on surface exploration (section 15, StandAG)

Decision on underground exploration (section 17, StandAG)

Site decision

Phase I | **Phase II** | **Phase III**

Step 1
Identification of sub-areas (section 13, StandAG[1])

Step 2
Identification of siting regions for surface exploration (section 14, StandAG)

Surface exploration

Proposal for underground exploration (section 16, StandAG)

Underground exploration

(section 18, StandAG)
Final site comparison and site proposal (section 19, StandAG)

Application of exclusion criteria (AK) (section 22, StandAG)

Application of minimum requirements (MA) (section 23, StandAG)

Application of geoscientific consideration criteria (geoWK) (section 24, StandAG)

If necessary, planning-scientific weighing criteria (planWK) (section 25, StandAG)

Preliminary safety analyses (vSU) (section 27, StandAG)

representative | further-developed | comprehensive

Source: BGE

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SUB-AREAS INTERIM REPORT (STEP 1, PHASE I)

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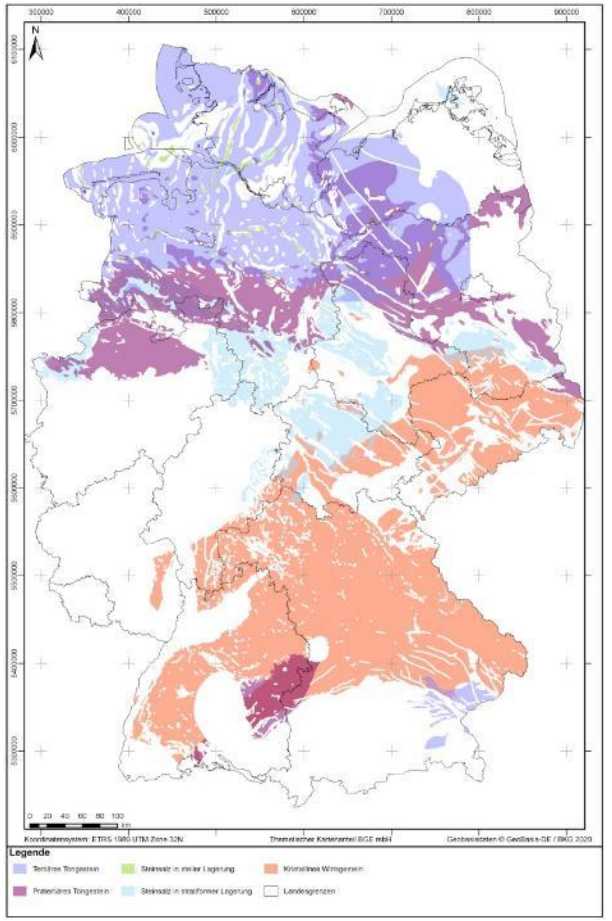
Host rock	Number of identified areas	Number of sub-areas	Areas of sub-areas (in km²)
Claystone	**12**	**9**	**129,639**
Rock salt, of which			
• **stratiform deposit**	23	14	28,415
• **steep deposit**	139	60	2,034
Rock salt total	**162**	**74**	**30,450**
Crystalline host rock	**7**	**7**	**80,786**
Total	**181**	**90**	**240,874**
Share of federal territory			Roughly 54%



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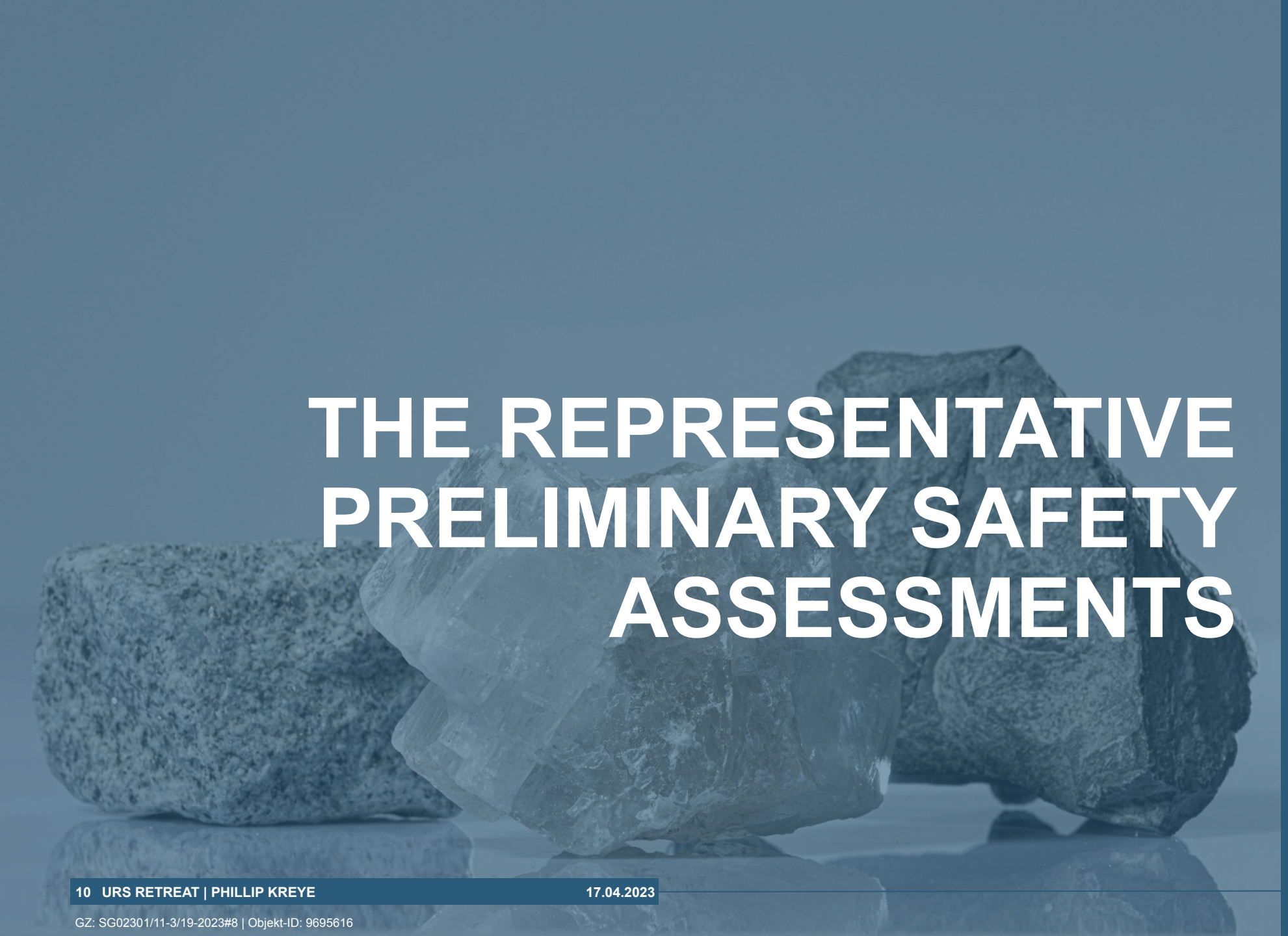

THE REPRESENTATIVE PRELIMINARY SAFETY ASSESSMENTS

02

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REPRESENTATIVE PRELIMINARY SAFETY ASSESSMENTS (rvSU)

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For each UR (section 3)

Section 5 Geosynthesis

Section 6 Preliminary **safety concept;** preliminary **design** of repository; **optimisation** of repository system

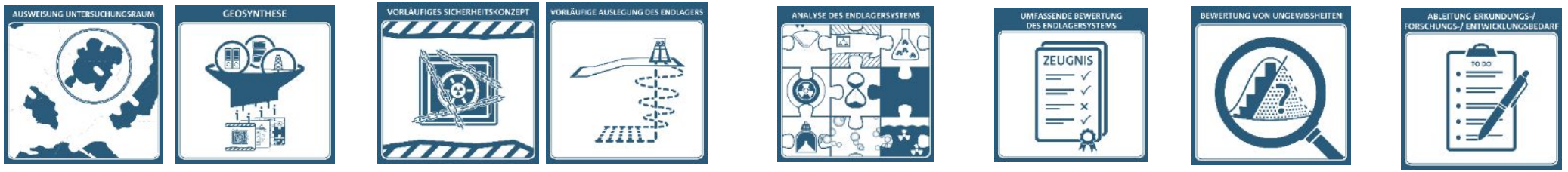
Section 7 Analysis of repository system

Section 10 Comprehensive **evaluation** of repository system

Section 11 Evaluation of **uncertainties**

Section 12 Derivation of **exploration, research** and **development** requirements

Radionuclide transport calculations



Source: BGE

Source for the various sections: EndlSiUntV

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QUANTITATIVE ASSESSMENT OF THE RADIONUCLIDE TRANSPORT

Section 7 EndlSiUntV; Section 4 EndlSiAnfV

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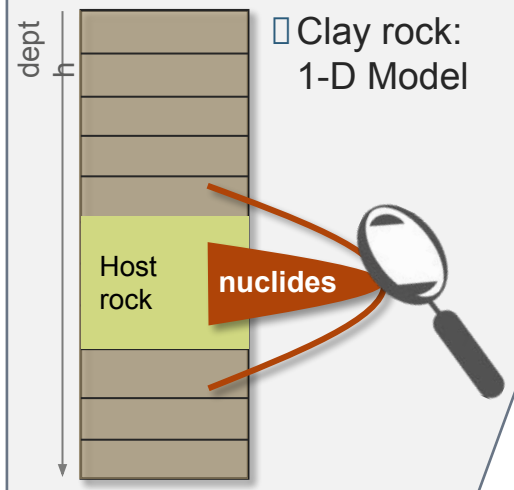
Calculation of radionuclide transport



- Clay rock: 1-D Model

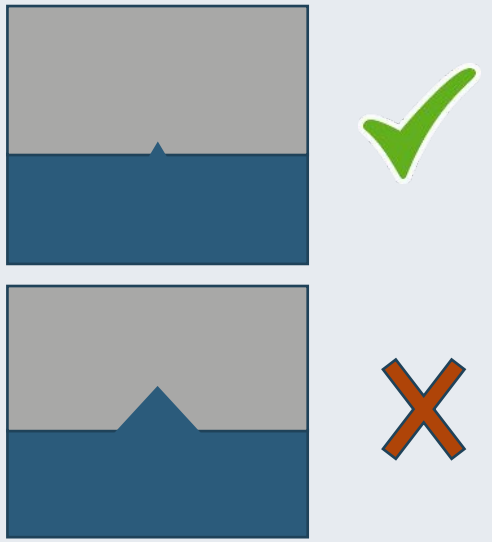
Regulatory requirements

- **In total,** no more than a fraction of **10^{-4}** and
- **Annually**, no more than a fraction **of 10^{-9}**

Both of the mass and the number of atoms of all originally emplaced radionuclides

From the area of the essential barriers

Assessment



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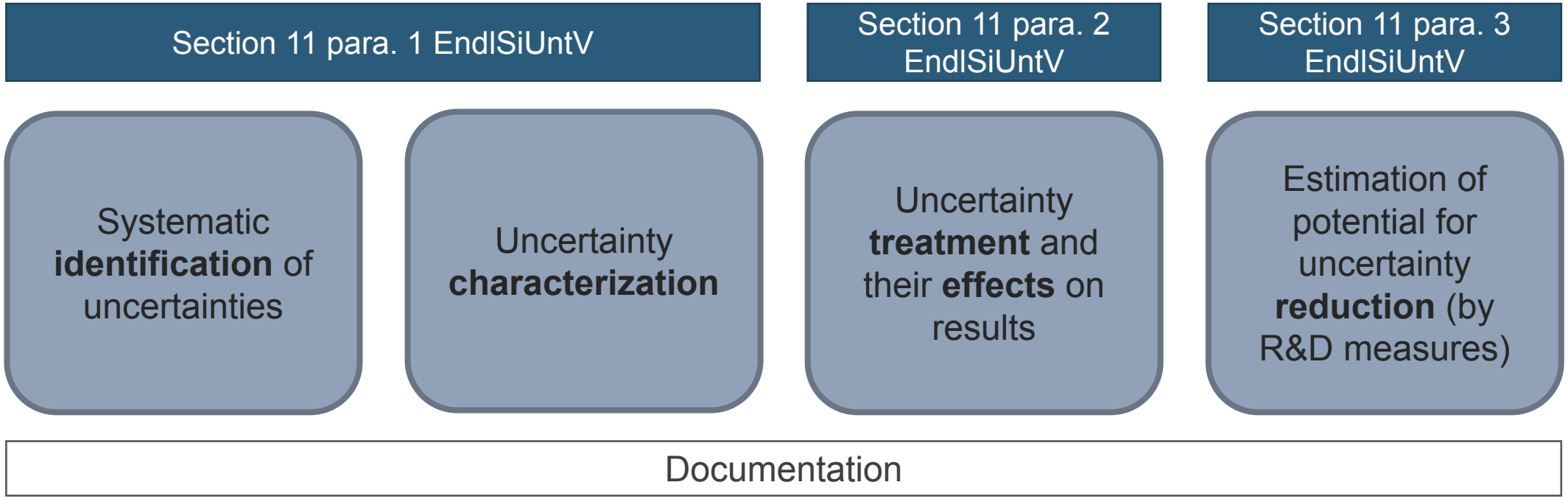
UNCERTAINTY ASSESSMENT

Section 11 EndlSiUntV



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RADIONUCLIDE TRANSPORT MODELLING AND UNCERTAINTY

03

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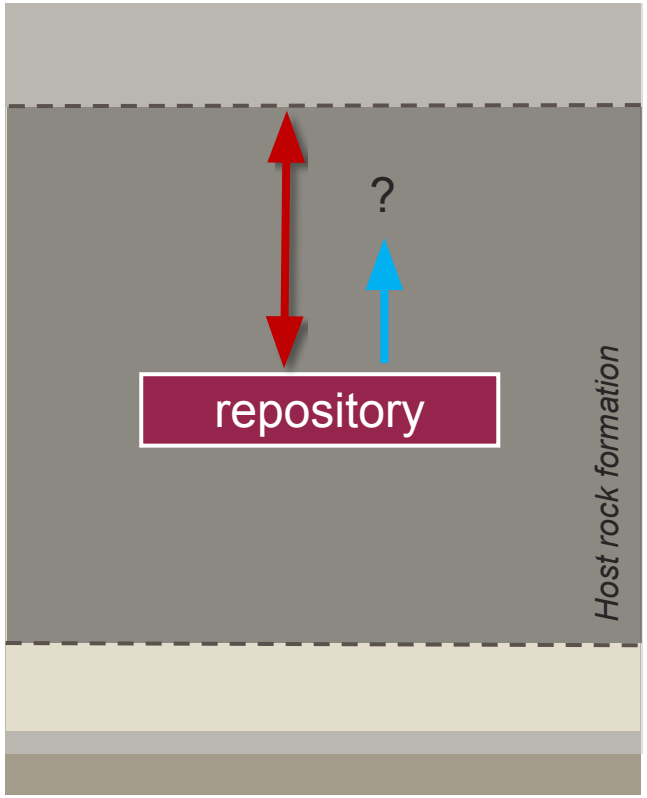
MODELLING OBJECTIVE

For modelling radionuclide transport in Claystone

- Area ~1/3 of Germany
- Short runtime
- Preliminary estimate of containment
- Spatial differentiation
  - By using different criteria



barrier extent d_{min}

transport length d_{1Ma}

Successful containment criteria
release fraction:
< fraction 10^{-4} overall
< fraction 10^{-9} annually
over 1 mill. years
(by mass and amount)

Source: BGE

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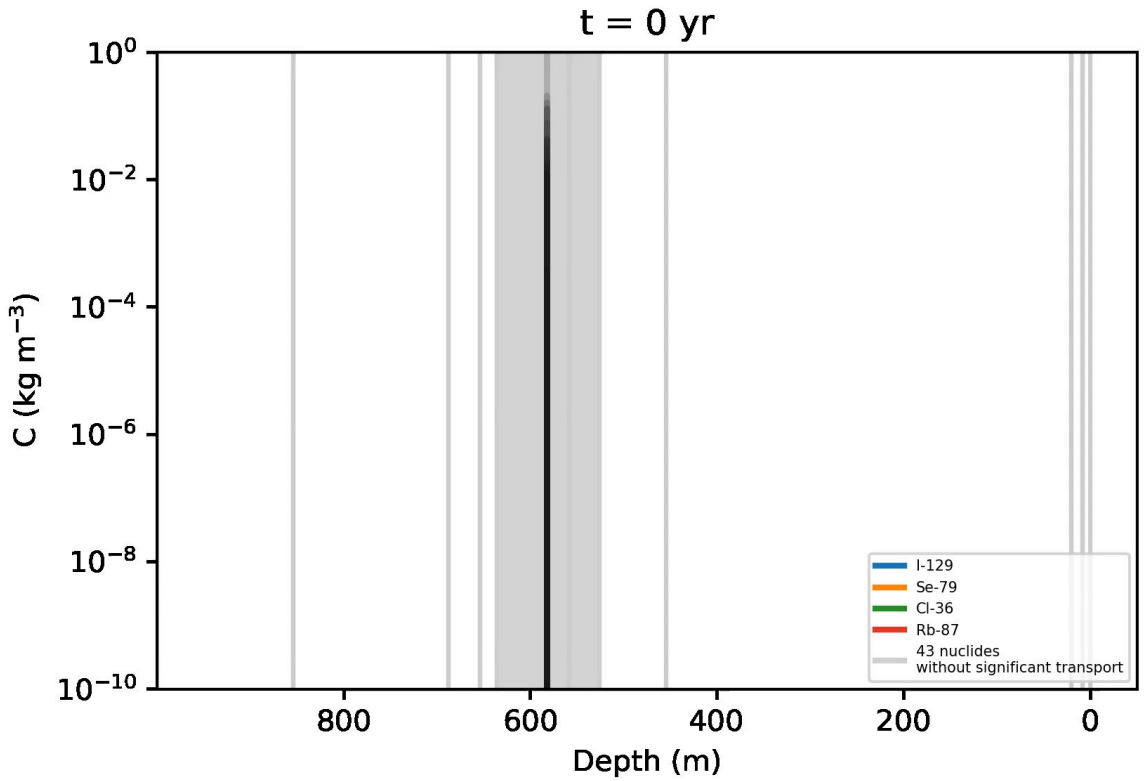
TransPyREnd

- 1D transport code
- Diffusion, advection and sorption
- Radioactive decay (simplified nuclide scheme)
- Finite differences, Crank-Nicolson method
- In-house development (Python)
- Open-source release imminent
- Public (Behrens et al. 2023)

$$\phi R_i \frac{\partial c_i}{\partial t} = \frac{\partial}{\partial x}\left(D_{e,i}\frac{\partial c_i}{\partial x} - q c_i\right) + \sum_j \phi\, c_j R_j \lambda_{j,i} - \phi c_i R_i \Lambda_i$$



i – Index of species
j – Index of another species
$\lambda_{j,i}$ – Decay rate of nuclide j to i (s^{-1})
Λ – Total decay rate of nuclide i (s^{-1})
q – Darcy velocity (m s^{-1})
ϕ – Effective porosity (-)
c – Concentration (mol m^{-3})

Source: BGE

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UNCERTAINTY QUANTIFICATION

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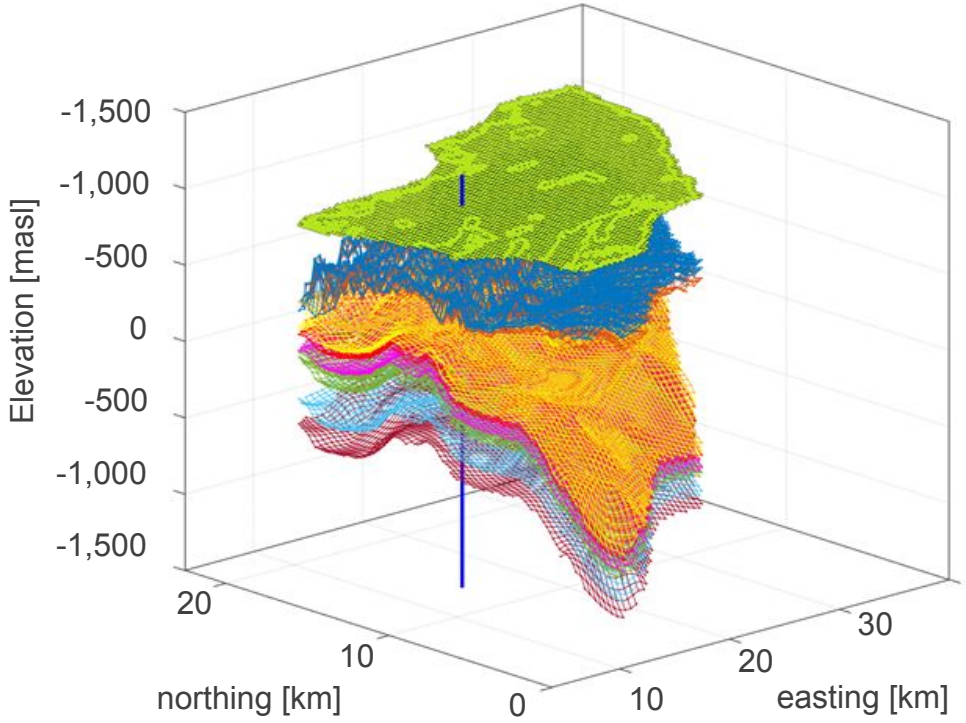
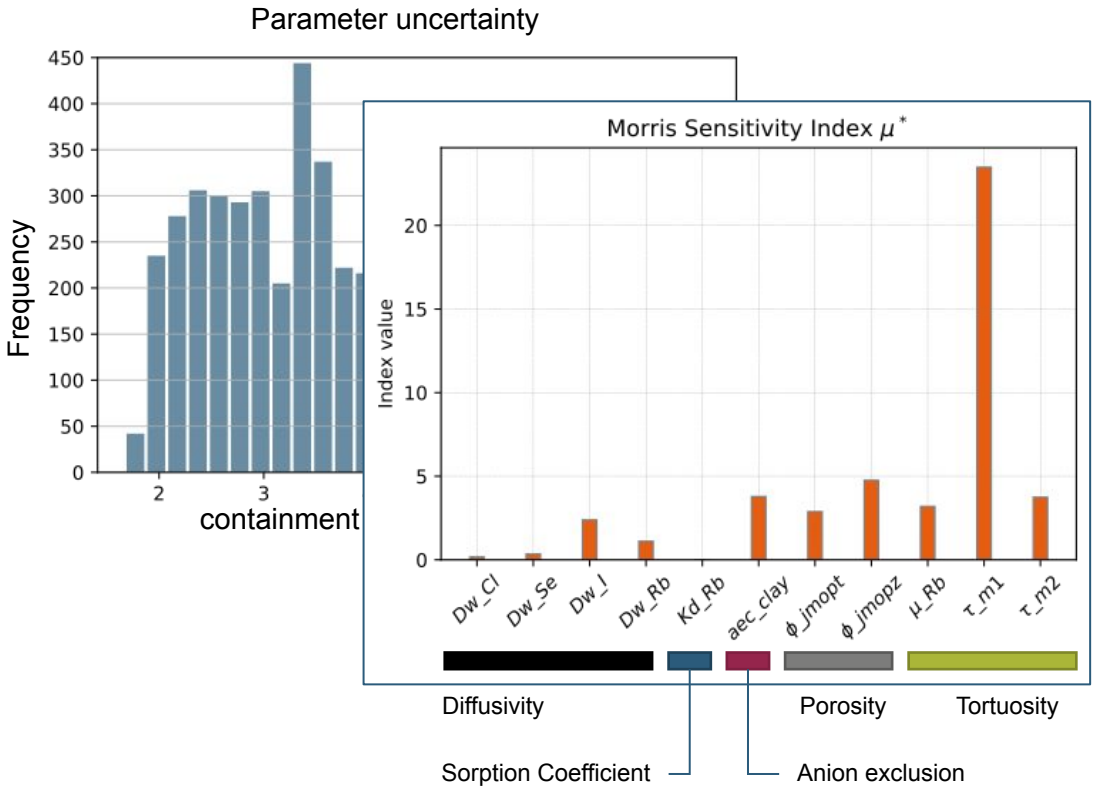
Geological Model



Transport Model



Source: BGE

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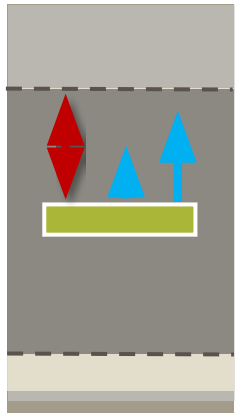
CRITERIA I_M AND I_{M_GEO}
Assessment of safety

Spatial differentiating criteria
Transport calculations for the entire investigation area

$$I_M = d_{min}/d_{1Ma}$$ → *Legal requirement: 10^{-4}- limit fulfilled? (yes/no)*

$$I_{M\_Geo} = d_{min}/d_{1Ma(Geo)}$$ → *Evaluation of the geology*



Source: BGE

transport distance d_{1Ma}

transport distance $d_{1Ma(Geo)}$

maximum permitted transport distance d_{min}

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CRITERIA I_R AND I_L
Assessment of robustness

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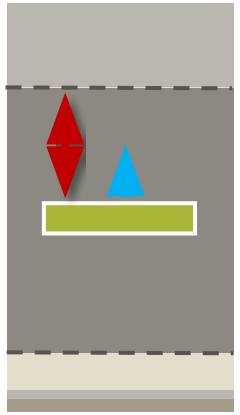
Criteria for best investigation areas

Multiple transport calculation with variation of the input parameters at selected profiles

$$I_R = P(I_M > 1) \quad \Rightarrow \quad ratio\ of\ runs\ with\ I_M > 1$$

$$I_L = 1 - \frac{1}{n}\sum_{i=1}^{n}\left(\frac{d_{1Ma_i}}{d_{min}}\right)^2 = 1 - \frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{I_{Mi}}\right)^2$$

⇒ *inclusion of the distribution function of all transport distances*



Source: BGE

transport distance d_{1Ma}

maximum permitted transport distance d_{min}

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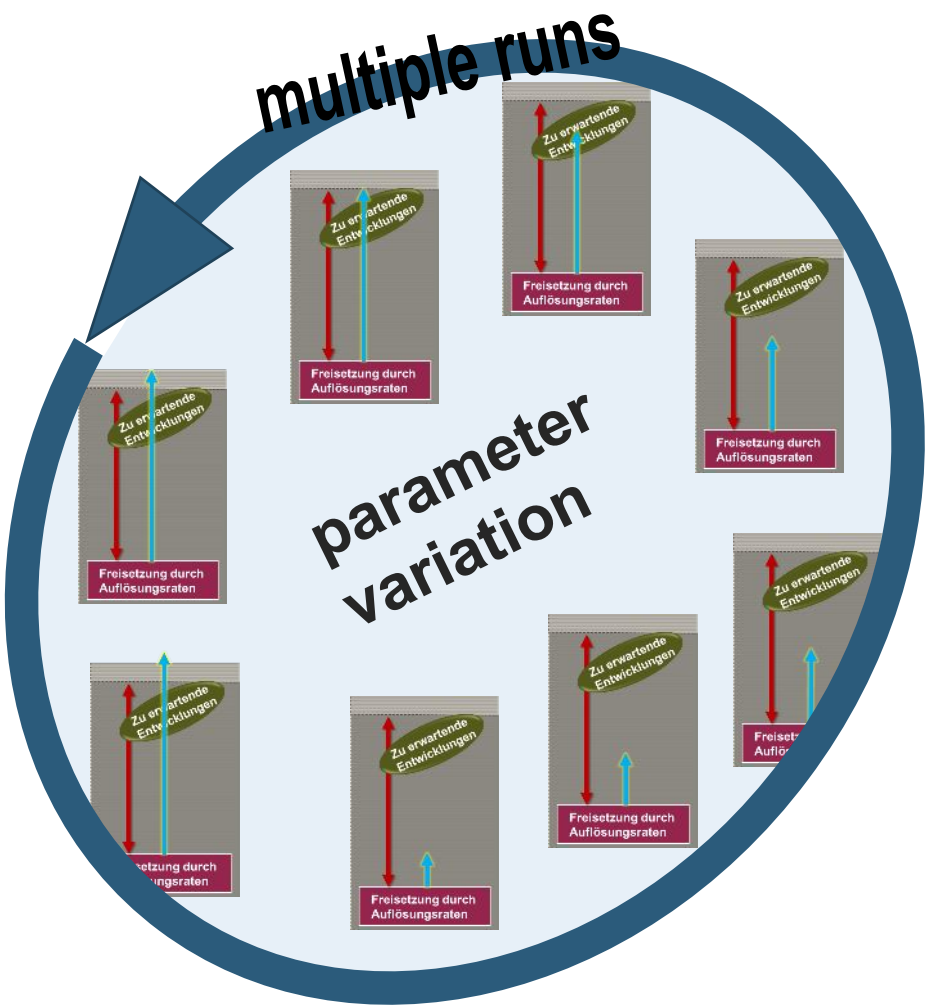
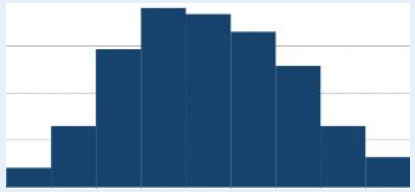
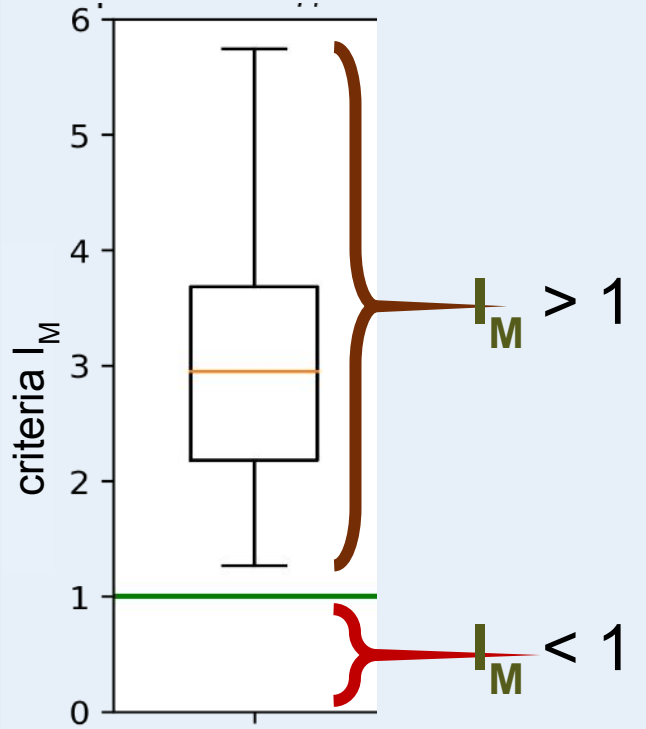
CRITERIA I_R





There are thousands of values of I_M for the same profile (within the investigation area)

$$I_R = P(I_M > 1)$$



In this example is $I_R = 1$, since all I_M are greater than 1.

Source: BGE

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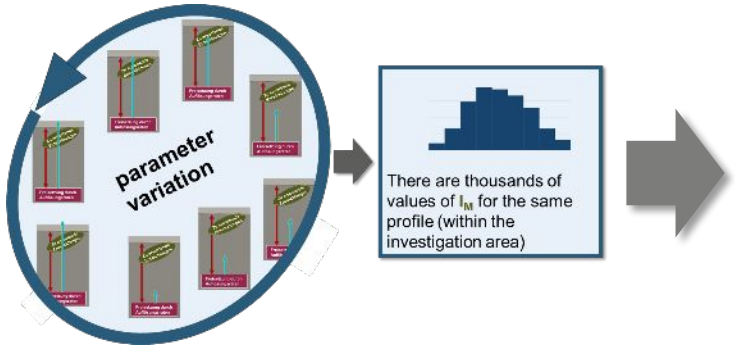
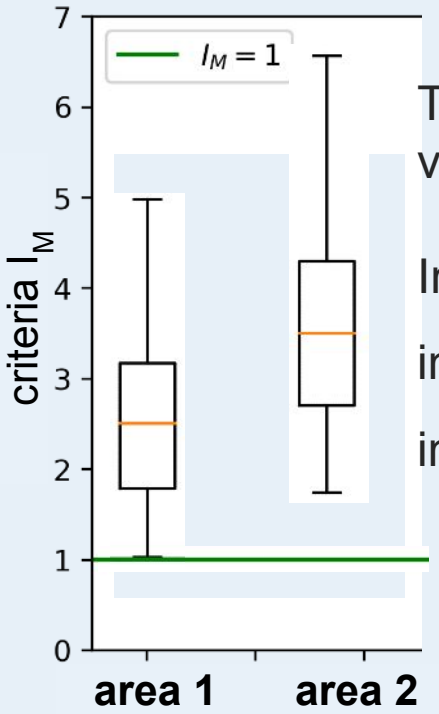
CRITERIA I_L

$$I_L = 1 - \frac{1}{n}\sum_{i=1}^{n}\left(\frac{d_{1Ma_i}}{d_{min}}\right)^2 = 1 - \frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{I_{Mi}}\right)^2$$





The criteria I_L assesses the distribution function of the I_M values

In this example:

investigation area 1 → I_L = **0,75**

investigation area 2 → I_L = **0,86** (better)

Source: BGE

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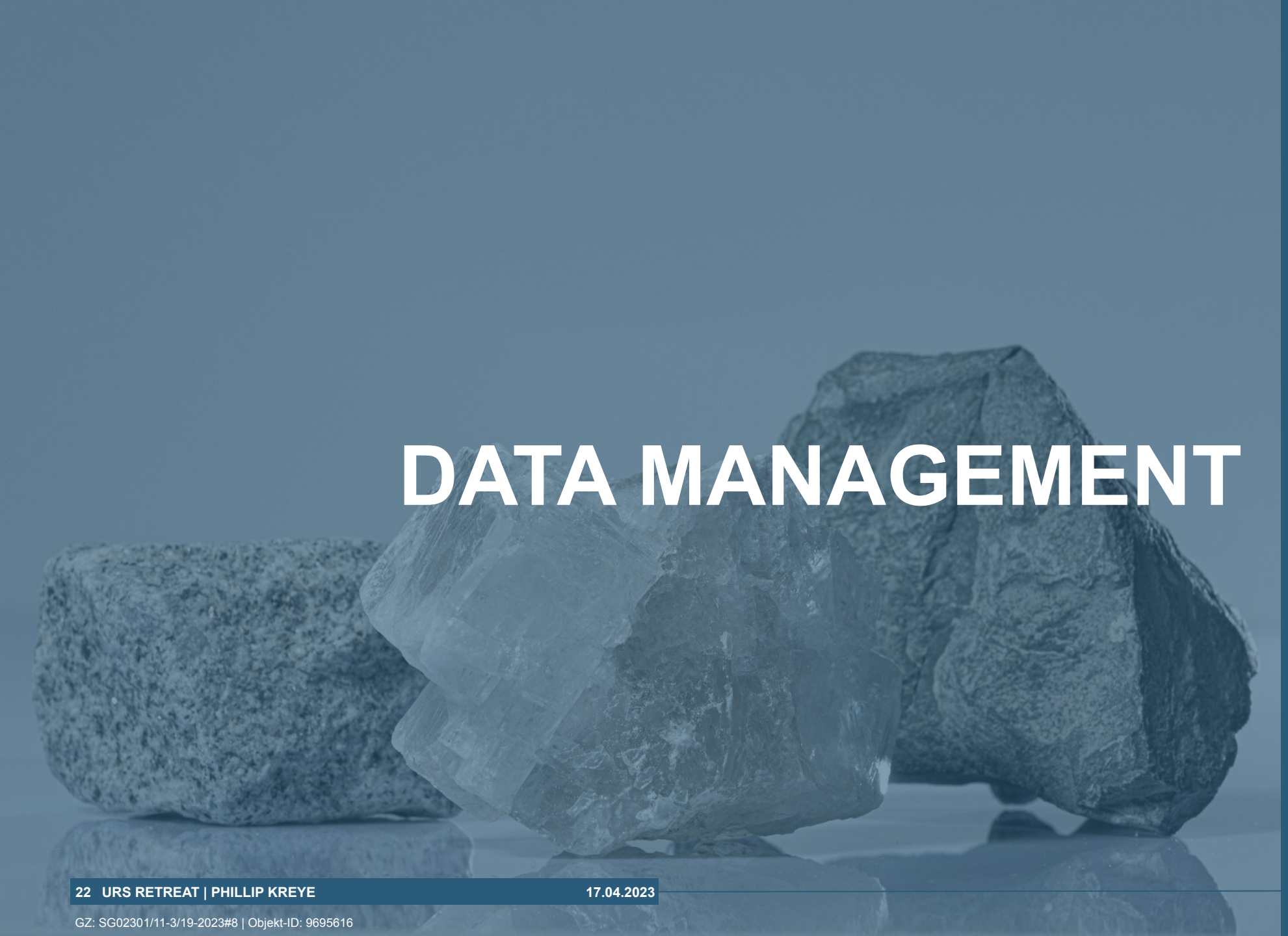

DATA MANAGEMENT

04

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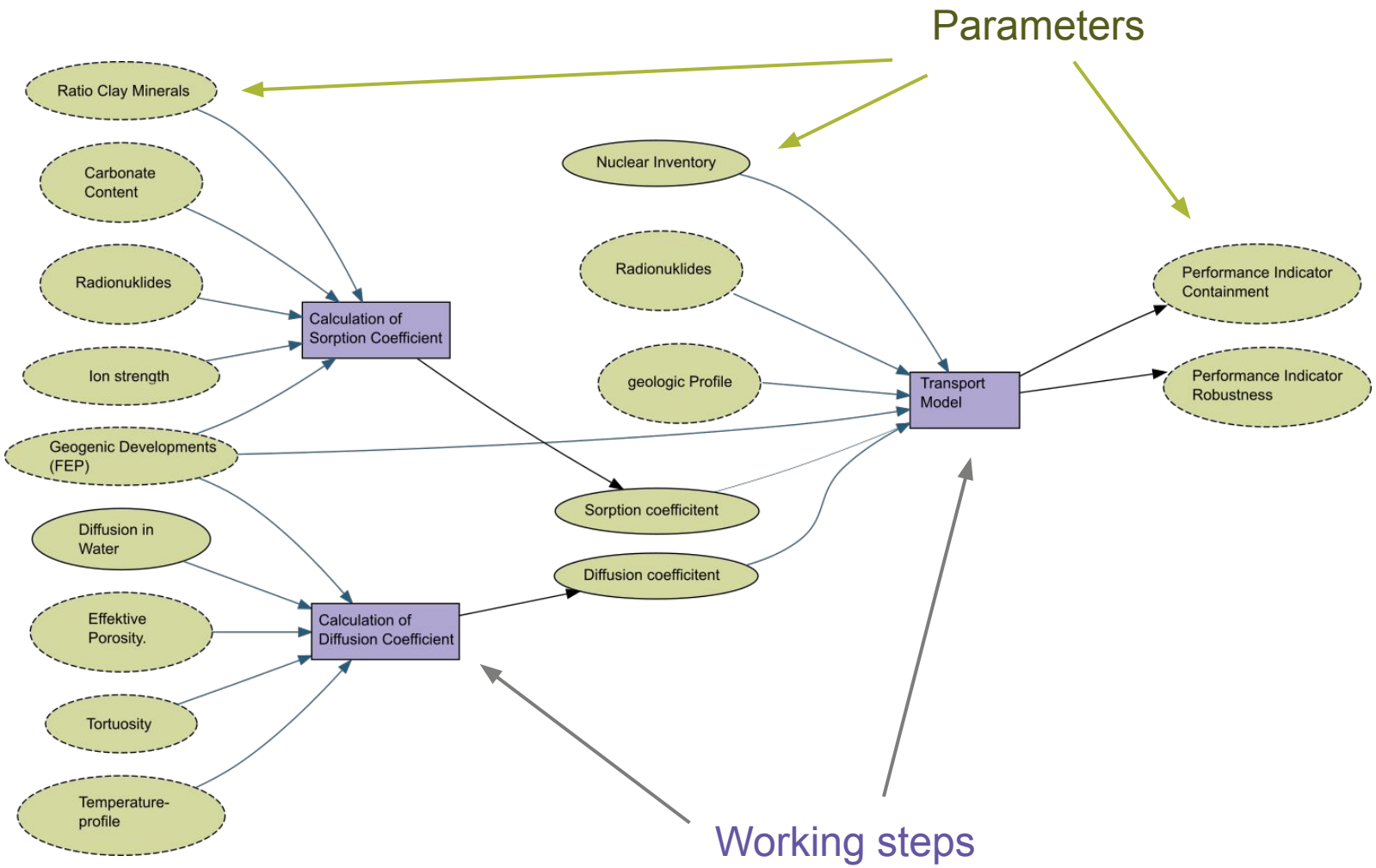
PARAMETER CASCADE



Source: BGE

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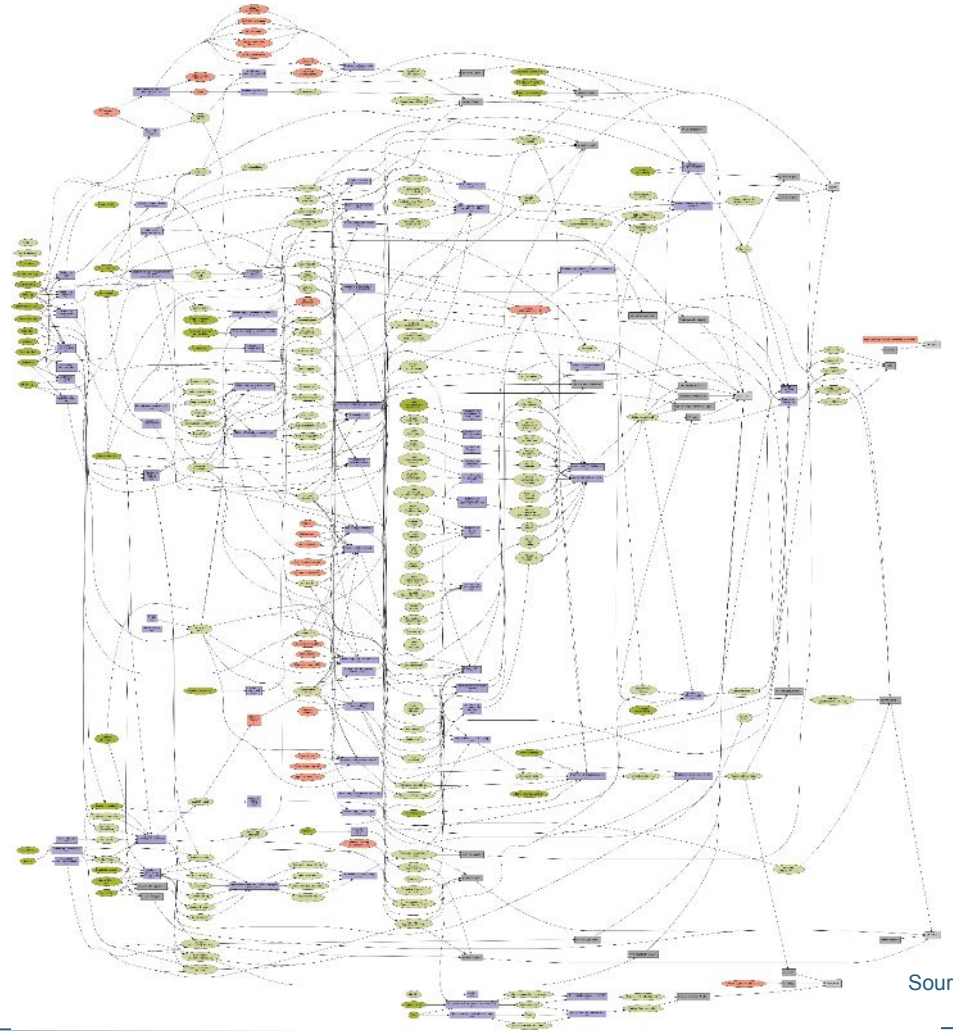
PARAMETER CASCADE

Dataflow Diagram of the Entire Process

- 80+ work steps and 200+ parameters
- Complexity from interconnectivity
- Challenge:
  - Monitor uncertainty and estimate impact
  - Trace source and intermediate information



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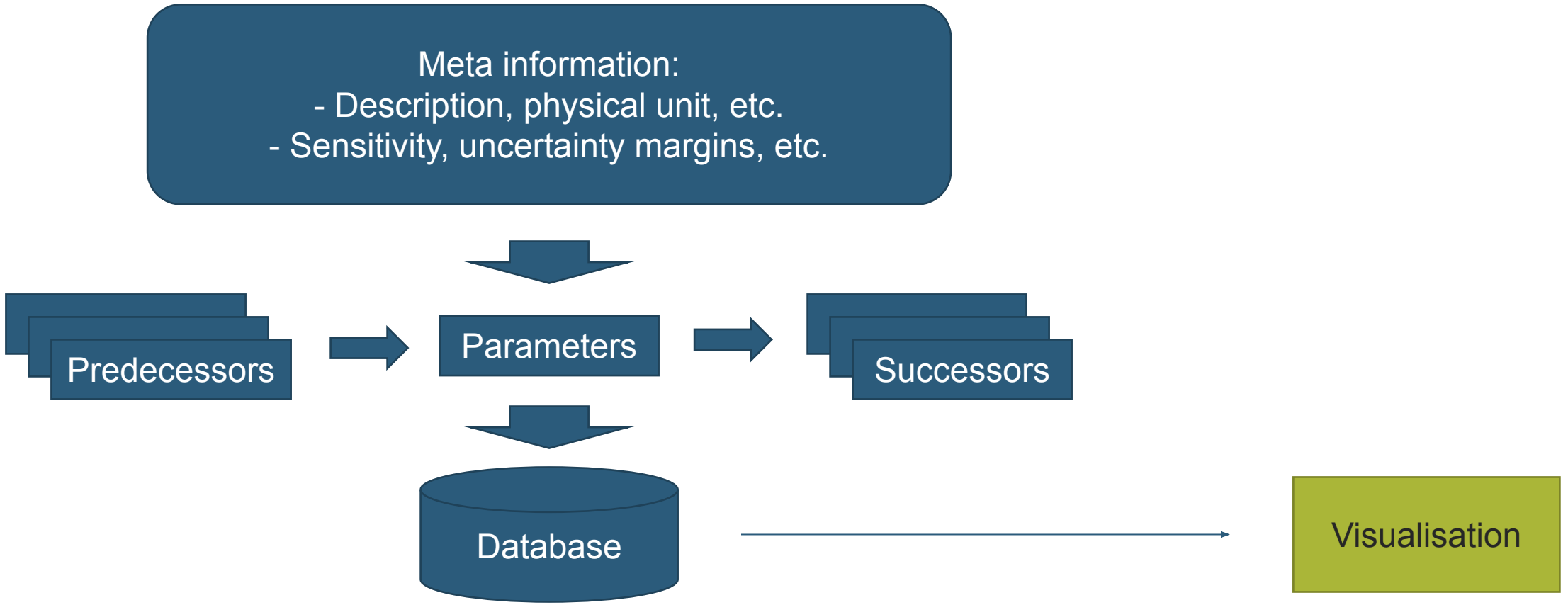
SOFTWARE

Database



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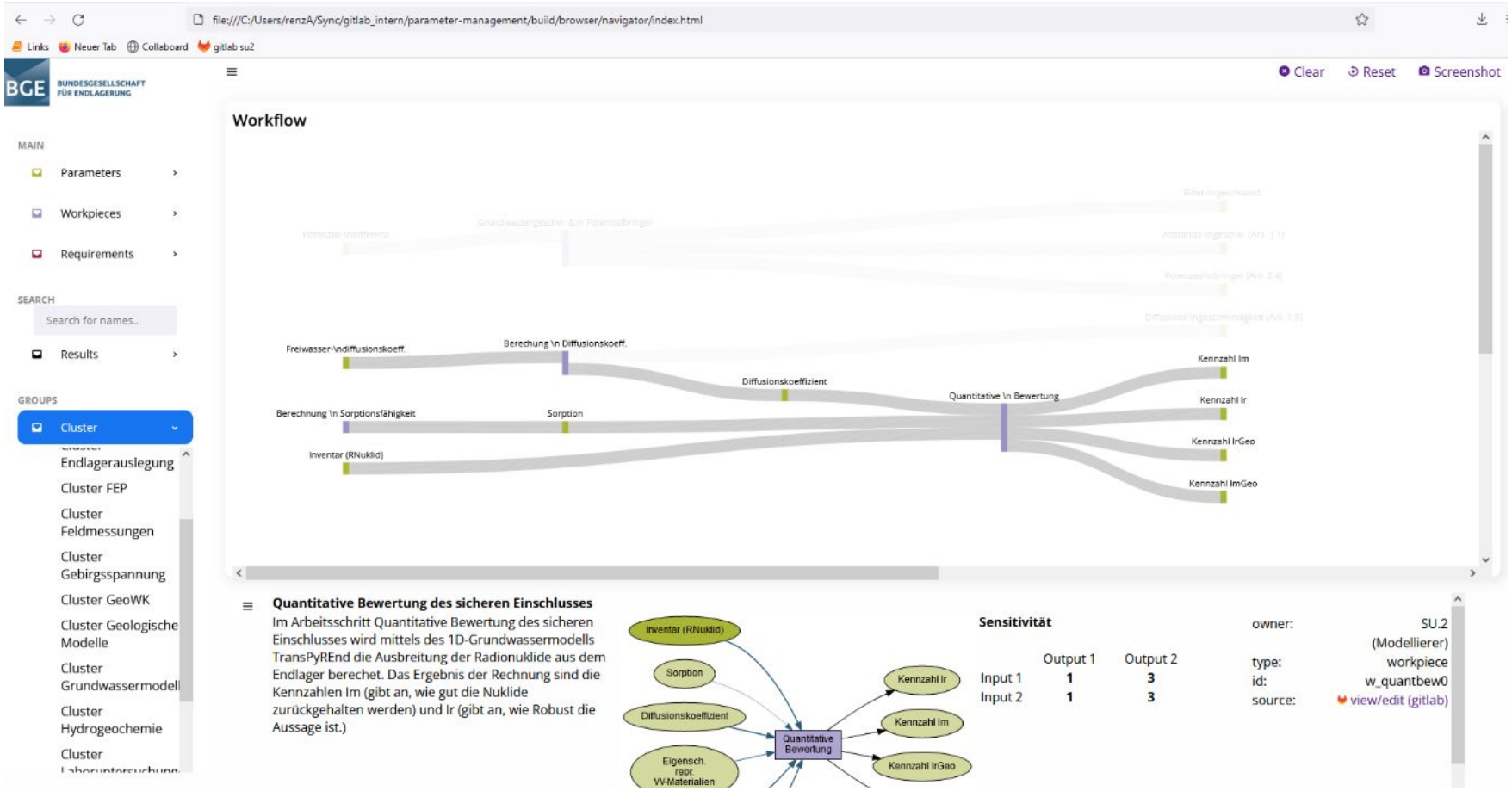
INTERACTIVE NAVIGATION SOFTWARE



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ABBREVIATIONS

AK	exclusion criteria
geoWK	geoscientific consideration criteria
MA	minimum requirements
planWK	planning-scientific weighing criteria
R&D	research and development
rvSU	representative preliminary safety analyses
STA	site selection
UR	investigation area
vSU	preliminary safety analyses

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LITERATURE

- Behrens, C.; Luijendijk, E.; Kreye, P.; Panitz, F.; Bjorge, M.; Gelleszun, M.; Renz, A.; Miro, S.; Rühaak, W. (2023): TransPyREnd: a code for modelling the transport of radionuclides on geological timescales. Adv. Geosci., Bd. 58. S. 109–119. ISSN 1680-7359. DOI: https://doi.org/10.5194/adgeo-58-109-2023
- Repository Safety Investigation Ordinance (EndlSiUntV) of 6 October 2020 (Federal Law Gazette Part I, p. 2094, 2103)
- Repository Safety Requirements Ordinance (EndlSiAnfV) of 6 October 2020 (Federal Law Gazette Part I, p. 2094, 2103)
- Repository Site Selection Act of 5 May 2017 (Federal Law Gazette Part I, p. 1074), last amended by Article 1 of the act of 7 December 2020 (Federal Law Gazette Part I, p. 2760)

BUNDESGESELLSCHAFT
FÜR ENDLAGERUNG

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