

DITOCO2030

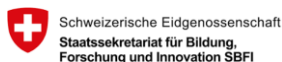


REPOSITORY DIGITAL TWIN CONCEPTS AND MODEL DEVELOPMENTS

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OUTLINE

15' Réka Szőke/Sergey Churakov: DITOCO2030/HERMES: Project aims and major achievements

10' Xavier Pintado/Pablo Cayon: DITOCO2030 WhitePaper recommendations and outlook

10' Gabriela Roman/Réka Szőke: Good practices and takeaways from interaction with end-users and stakeholders

25' Nikolaos Prasianakis: Surrogate models for acceleration of coupled codes

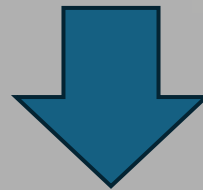
30' Interactive session with end-users participants

Moderators: Arto Laikari/Réka Szőke/Sergey Churakov:

Q&A/Live Pooling/Targeted questions/Open discussion

EURAD-2 DITOCO2030 project

NEXT-GENERATION **D**IGITAL **T**WINS TO SUPPORT **O**PTIMISATION, **C**ONSTRUCTION AND **O**PERATION OF SURFACE & SUBSURFACE RADIOACTIVE WASTE MANAGEMENT FACILITIES



Lay-out the path on how to close the R&D gap between the **currently fragmented digital twins (DT) of individual disciplines**, common data environments & decision-making platforms to **better understand the opportunities & limitations** of DT in their **deployment** in whole life cycle of waste management.

DRIVERS FOR THE DIGITAL TWINS

Why digital twins matter for nuclear assets and long-term operations

1

Economic efficiency

Optimize maintenance, minimize downtime and improve asset utilization.

2

Safety improvements

Enable real-time condition monitoring and faster emergency response optimization.

DIGITAL TWIN ADOPTION

A strategic enabler for asset performance, safety assurance and decision support

3

Regulatory compliance

Streamline analyses and verify conformity with high-fidelity models.

4

Long-term operation

Support predictive maintenance and structural health analysis to extend reactor life.

5

Technology advancement

HPC and AI expand decision support and improve operational effectiveness.

Together, these drivers make digital twins a core platform for safer, smarter and longer-lived nuclear infrastructure.

INSIGHTS from the White and Green Paper

"Why/how to change" & "What are the needs"?

Core message: build a federated, governed Digital Twin ecosystem - not a monolithic platform - to create a continuous digital thread across design, construction, operation and closure.

Why & how to change?

- **Fragmentation** across discipline: specific tools & disconnected data silos.
- **Terminology & scope alignment:** **no one DT definition**; misalignment creates governance & evidence gaps.
- Weak feedback loops **limit early deviation detection** between design assumptions & field reality.
- **Evidence is hard to trace & explain** consistently to regulators, stakeholders and future program teams.
- The result is **duplicated effort** (cost), this slows data handovers & reduced agility in decision-making
- **Trust must be built step-by-step:** regulatory & societal confidence **cannot be assumed** (it grows)
- **Limited Nuclear-Specific Case Studies**

What CAN/SHOULD a DT be?

- **Predictive model:** forecast system evolution.
- **Virtual representation**
- **Real-time sync:** Continuously updates with live sensor data.
- **Unified environment:** Combines computation + visualization
- **Decision support:** Synthesizes knowledge to guide operations.
- **Simulation engine:** Maps current → future states
- **Control loop:** Enables human actions & parameter optimization
- **Visualization:** Uses VR+ tools to communicate complex results.
- **History-aware:** Integrates past data for trend analysis and long-horizon predictions.
- **Repository digital twin (waste):** Detailed model of underground facilities spanning design, build, and operations.



What DITOCO2030 recommends?

- **Full compatibility** with industry standards & evolving project requirements
- **Compliance** with regulatory frameworks & requirements
- Treat DT as an **interoperable ecosystem** connecting BIM/GIS, monitoring data & multi-physics models through open interfaces & shared semantics.
- **Embed governance from the start:** data access, cybersecurity, provenance, versioning & traceability rules.
- **Focus on decision-critical use cases & requirements** rather than technology for its own sake.
- **Use DT to strengthen** safety-case communication, transparency & program continuity over long lifecycles.
- **Leverage cross-sector expertise** to apply digital technologies in nuclear waste management.
- **Facilitate knowledge transfer** from other sectors to improve technical and economic outcomes.
- **Promote collaboration** by engaging experts from various industries.
- **Disseminate findings** to keep stakeholders informed about project advancements.
- **Incorporate feedback** to refine strategies, address concerns.

KEEP end-users ENGAGED & AWARE!

Implementation pathway & call to action

Short/mid-term actions establish the foundation; long-term actions scale toward a Living Safety Case DT

Short / mid term

- **Mobilize** WMOs, TSOs and REs around a common governance & decision structure.
- **Prioritize** a small set of decision-critical use cases with KPIs, datasets, interoperability needs & acceptance criteria.
- **Define** a modular, technology-agnostic reference architecture with semantic backbone, integration, model/version management and visualization.
- **Deliver** an MVP as the geometric + info anchor, benchmark platforms and run auditable pilots.
- **Allow AI/LLM only under governance**, with provenance, cybersecurity controls and human oversight.

Long term + follow-on scope

- **Scale** to a Living Safety Case DT that continuously assimilates monitoring data for assessment, reporting & communication.
- Establish **shared benchmarking, validation & qualification** using common reference cases, comparable verification evidence.
- **Follow-on priorities:** shared semantics & governance, common requirements & datasets, vendor-lock-in mitigation, controlled engineering automation, reg.-shaped validation.

Decision for leadership: align on the first high-value use cases, launch the governed MVP, and build validation with TSOs/regulators from day one.

HERMES : BACKGROUND & AIMS

*WP-HERMES is RD&D project aiming at the development of high-fidelity numerical models for simulations of strongly coupled THMC processes in repository nearfield, repository design optimisation and interpretation of mock-up experiments using a combination of **physics-based models and accelerated computing** assisted with **machine learning and artificial intelligence**.*

High-fidelity simulations refer to **accurate and detailed model-based representations of real-world** systems, processes, or phenomena involving advanced computational models, precise data inputs, sophisticated computational algorithms and use of advanced High-Performance-Computing (HPC).

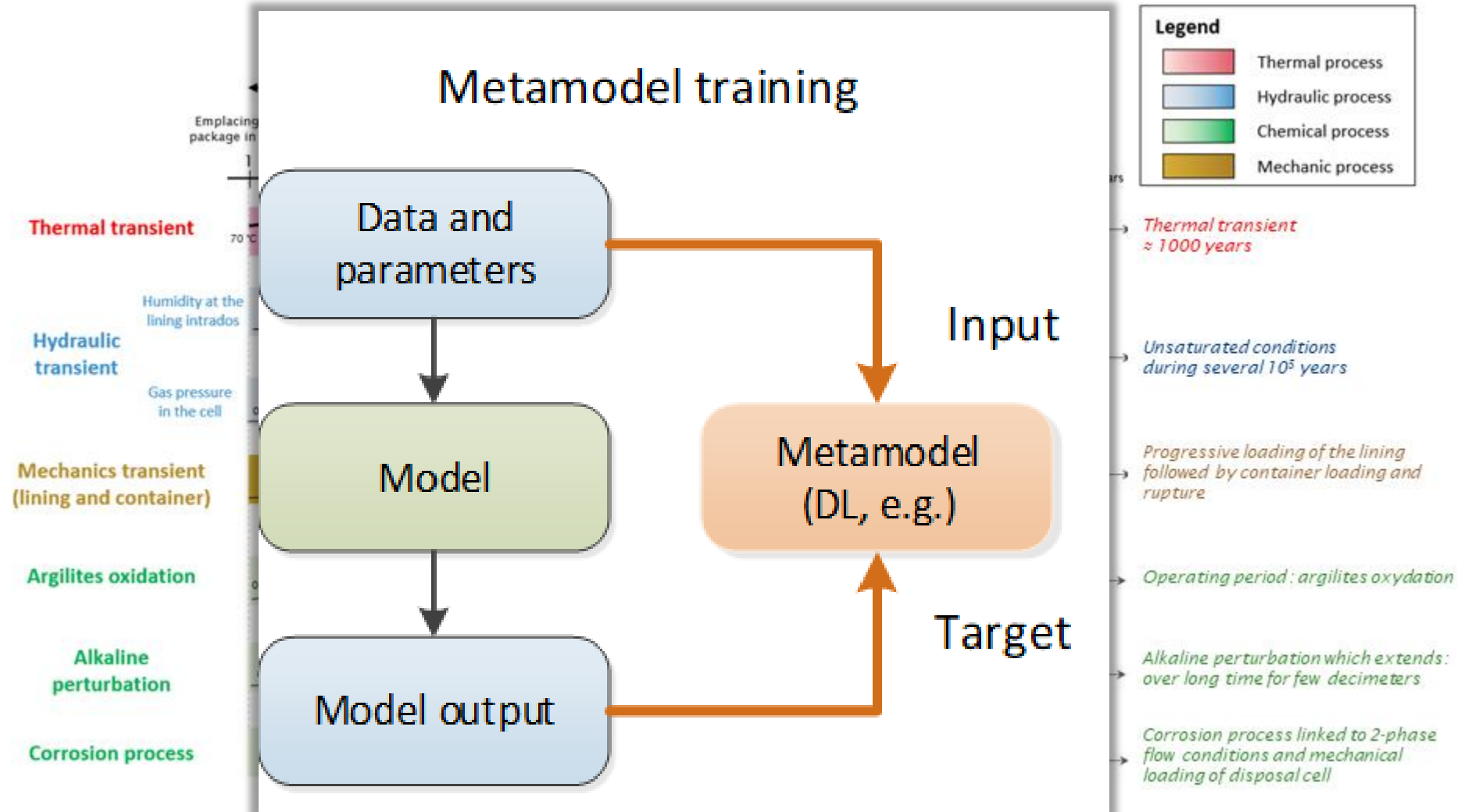
Detailed System representation:

- High resolution spatial representation of the system with its components and material properties
- Description of coupled physical phenomena, complex material behavior and system interactions
- Close match of real-world observations (monitoring data)

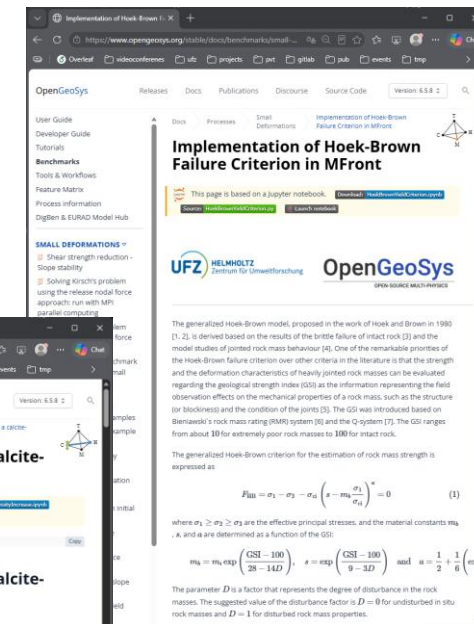
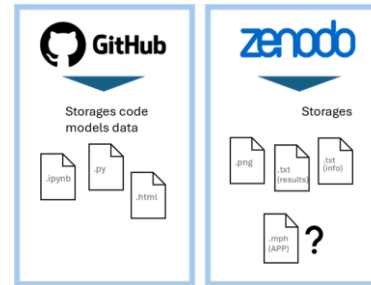
Computational Challenges

- High computational demands
- Handling of complex equations and large (in time & in space) datasets

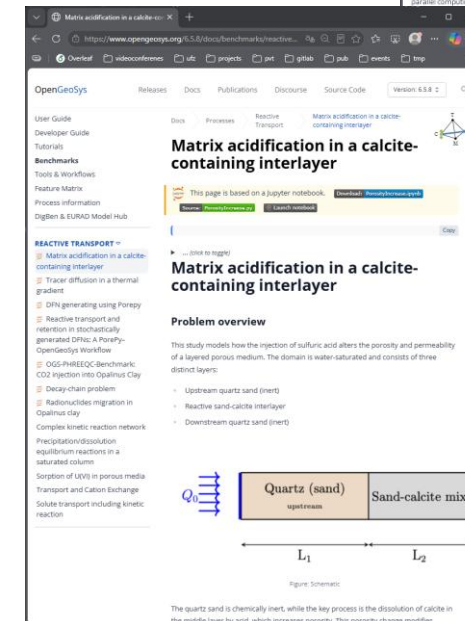
COUPLED PROCESSES



HERMES



- **F**indability
- **A**ccessibility
- Interoperability
- **R**euse of digital assets

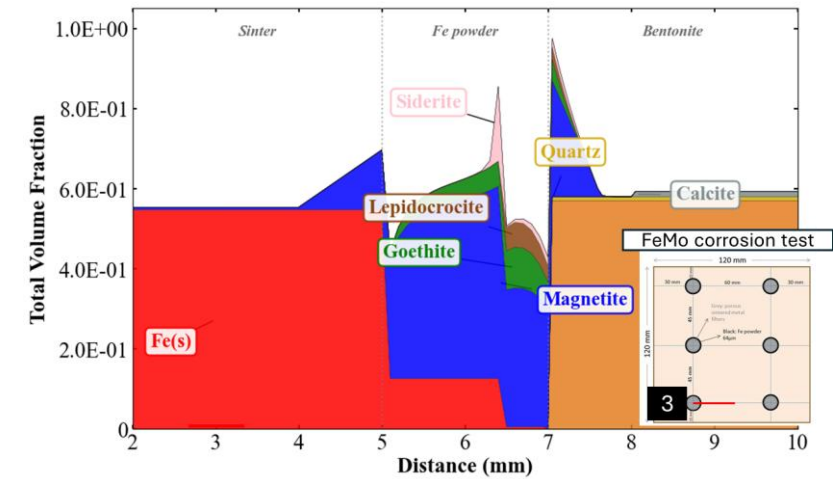
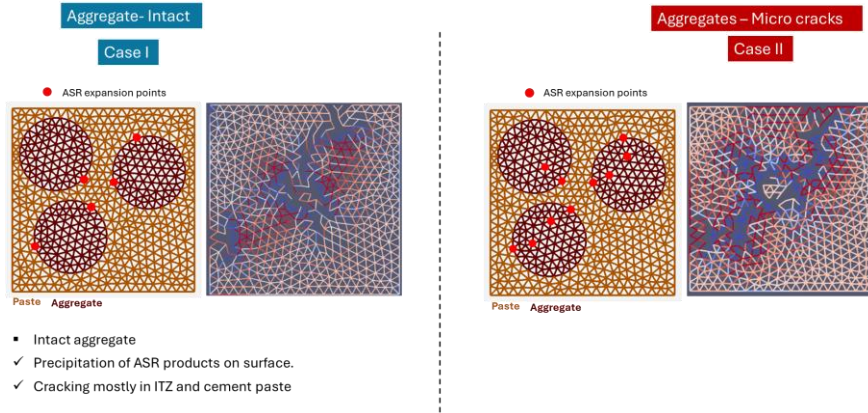


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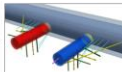
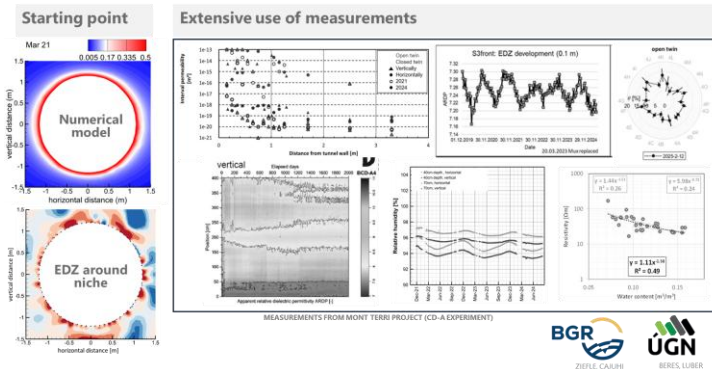
MULTISCALE MODELLING EXAMPLES

Lattice element model (Cracking)



EXPERIMENTAL VALIDATION OF DIGITAL MODELLING TOOLS, HIGHLIGHT: MONT TERRI PROJECT

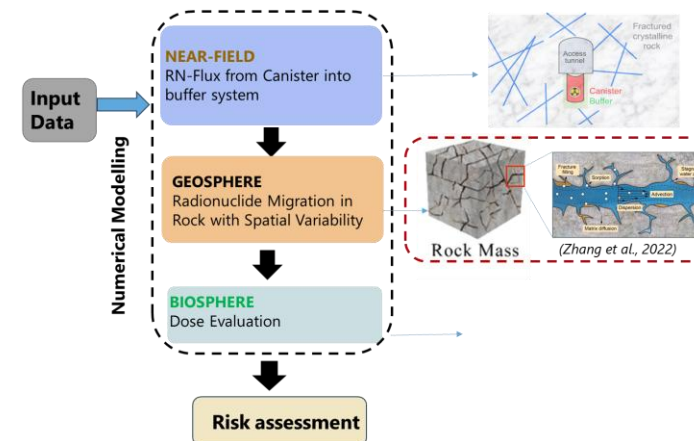
ENHANCING NUMERICAL MODELS VIA IMPROVED PARAMETER ESTIMATES FROM GEOPHYSICAL MEASUREMENTS



Aiming on

IMPROVEMENT OF MODEL APPROACHES BY COMBINING PHYSICAL AND DATA-DRIVEN MODELS

Motivation: Development of a Modelling Framework for Radionuclide Transport from a Deep Geological Repository



INTERACTIVE Q&A SESSION WITH END-USERS PARTICIPANTS

- Better understand needs from end users. New emerging questions and challenges.
- Confirm the reported gaps and discuss new opportunities.
- Threats and regulatory impact for AI-powered Digital Twins.
- Challenges and opportunities in management of large and sensitive datasets.
- Standardization integration and compatibility in data management.
- Any other emerging topics ...