DITOCO WHITE PAPER

Results, recommendations and outlook

Deliverable 15.5 , Strategic Guidelines for the Development of a Standardized Digital Twin Design in Radioactive Waste Management

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WHY THIS WHITE PAPER?

GREEN PAPER (2025)
Digital Twins and their gaps in the Radioactive Waste Management domain , state of the art, landscape and shared gaps across end-users.

THIS WHITE PAPER (D15.5)
Translates the diagnosis into strategic guidelines: near-term foundations, a long-term horizon and a call to action for the sector.

WHY NOW

RISING DEMAND FOR SAFE NUCLEAR STORAGE

TECHNOLOGICAL DEVELOPMENT PACE

INCREASING ADOPTION ACROSS SECTORS

LEVERAGE WMO EXPERTIZE AND TARGET OF NEEDS

Information exists, but it is not connected

Engineering models, monitoring records, safety evidence, geoscientific and operational data are produced in separate systems, by different disciplines, for different purposes.

Continuity, not storage

Facilities are developed and assessed over decades. Data must remain usable and meaningful as teams, software, institutions and regulations change.

Early maturity in RWM

Digital twins are not yet a mature answer for the sector. The foundations have to be agreed before any large-scale deployment can be credible.

The question is not what a digital twin could eventually do, but which common foundations the sector must put in place now.

SCOPE OF THE PROJECT AND DEVELOPMENT PROCESS

GAP ANALYSIS
The Green Paper diagnosis taken as the starting point

EVIDENCE BASE
Digital twin use cases reviewed in RWM and in other industries

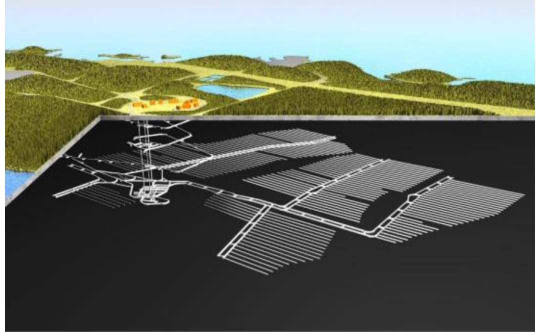
CONSOLIDATION
Iterative review within Task 5 and DITOCO WorkPackage Team.

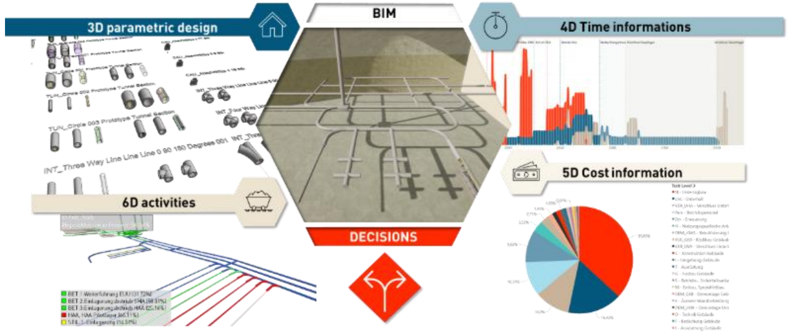
STRATEGIC GUIDELINES
Near-term steps, long-term horizon and call to action

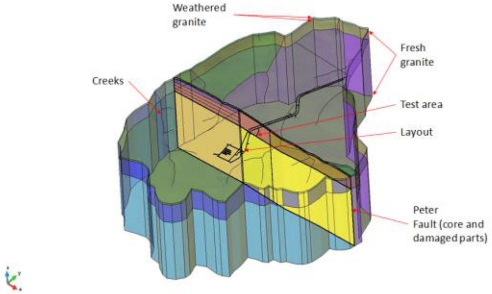
WHAT THE PROCESS WAS DESIGNED TO PRODUCE

- A reference base that translates industry experience and lessons learned into a form the RWM community can reuse.
- A strategic orientation document , not a technical implementation manual and not a fixed implementation plan.
- A shared basis for discussion with the community: some answers given, some questions left deliberately open.

Method: build on what has already been demonstrated elsewhere, rather than re-inventing baseline capability inside the nuclear sector.







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DITOCO White Paper milestones

Travel / in-person event
Workshop / meeting
Presentation
Webinar

2024
2025
2026

23 Oct 2024
Kick-Off EURAD-2

2 Jul 2025
EURAD-2 DITOCO2030 T3 & T4 workshop meeting

21 Aug 2025
EURAD-2 DITOCO T3 + T4 meeting

8 Sep 2025 EURAD-2 Annual Meeting
10 Sep 2025 DITOCO-HERMES Joint Session
12 Sep 2025 DITOCO2030 Annual Meeting
29 Sep 2025 From Concept to Practice: Stakeholder/End-user Perspectives on Digital Twins for Radioactive Waste Facilities

29 Oct 2025
10122 DITOCO - WAVE II - PITCHING

14 Jan 2026
- From Gaps to Integration
- Shaping the future of Digital Twins

20 Apr 2026 DITOCO Annual In-Person Meeting
23 Apr 2026 DITOCO - white paper presentation

15 Jul 2026
- Wihte Paper for Knowledge Mananagement Review

9 Sep 2026 DITOCO White Paper Results, recommendations and outlook
8-10 Sep 2026 EURAD-2 Annual Event n.º 2

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CURRENT LIMITATIONS AND THEIR IMPACT

CURRENT LIMITATION	IMPACT DIMENSION
Design decisions rely on standalone models, without consistent feedback loops during construction or operation	**COST** Duplicated effort in design and construction; higher maintenance cost
Monitoring data from sensors are poorly linked to predictive models, limiting adaptive management	**SAFETY** Anomalies detected late; long-term behaviour harder to predict
Knowledge continuity between design, construction, operation and closure is not guaranteed	**KNOWLEDGE** Loss of critical know-how and contextual data between phases
Standardized data formats and interoperability protocols between organisations and tools are missing	**TIME** Redundant validation and manual transfer; longer licensing
No “digital thread” links design to long-term safety assessment	**CONFIDENCE** Weaker traceable evidence for regulators and the public

The challenge is technical and organisational: without shared foundations, even good digital tools stay isolated and underused.

MATURITY: WHERE THE SECTOR STANDS TODAY

DEMONSTRATED DIGITAL-TWIN CAPABILITY ACROSS THE FACILITY LIFECYCLE

DESIGN & PRE-CONSTRUCTION	CONSTRUCTION	OPERATION & MAINTENANCE	CLOSURE & LONG-TERM SAFETY CASE
DEMONSTRATED	PRIORITY GAP	PRIORITY GAP	LONG-TERM AMBITION
Use cases available; lessons already extractable	4D/5D control, reality capture, as-built continuity	Predictive maintenance, monitoring-to-model feedback	Living, continuously enriched safety case

Design and site characterization Digital tools already in use

Construction Only Olkiluoto, Finnish nuclear repository is under construction. Skill transfer and lessons learnt from civil construction projects

Operation and extension Great potential for development. New procedures such as waste encapsulation, real time monitoring conditions and simulation of multiple scenarios. Posiva requested procedure validation prior to start the operation and waste disposal into the facilities.

Closure and long-term safety case Long-term ambition

Recommendation

Existing use cases concentrate on pre-construction stages. The next demonstration effort should therefore emphasize construction and operation, where added value is expected but has not yet been shown, and where a return on investment can actually be measured.

Digital twins are not a mature answer for RWM. They are a credible direction , provided the sector closes the construction and operation gap first.

TARGET VISION AND RECOMMENDATIONS

1. **Integrated data governance framework and open-source ontology**
   FAIR-aligned rules, metadata conventions and API-based integration , not a single central database. Shared terminology for waste packages, barriers, geology and sensor data.

2. **Modular, technology-agnostic reference architecture**
   Data backbone, BIM/GIS and simulation models, integration layer, AI model manager and visualisation interface, on mandated open standards (OPC UA, IFC/BIM-ISO, OGC).

3. **High-value, limited-scope pilot projects**
   A construction-oriented twin (4D/5D on a tunnel section, updated by laser scanning and site records) and an operation-oriented twin (predictive maintenance of a critical handling asset).

4. **Digital information platform for model validation**
   Federate data, geometry and simulation models in a traceable environment: model registry, validation dataset catalogue, cross-validation pipelines and auditable scorecards.

5. **Lifecycle Integration Framework: design to operation and maintenance**
   A complete digital thread with end-to-end traceability, from initial design assumptions through field execution to operational performance.

The sequence matters: agree requirements and semantics before choosing a platform, and keep architecture ownership with the WMOs.

OUTLOOK: CAPABILITY AND ASSURANCE MUST ADVANCE TOGETHER

Short Term
Better access to what already exists

- **Integrated access to federated information**
- Natural-language interrogation: “what changed, and why”
- Automated evidence retrieval with source references
- Immersive visualisation for training and stakeholder communication

Mid Term
From information to assisted engineering

- Generative optioneering for engineering alternatives
- **Anomaly triage from monitoring signals**
- Predictive and adaptive decision support
- **Automation of recurrent verification workflows**

Long Term
Reduced computational burden, shared frameworks

- **Qualified AI surrogate models for complex THMC simulations**
- More responsive digital twin workflows
- Reusable frameworks shared across WMOs
- Dynamic, continuously enriched safety case

VALIDATION, QUALIFICATION AND TRACEABILITY REQUIREMENTS GROW WITH CAPABILITY

AI and LLM functions are capabilities to be demonstrated under governance , provenance, reproducibility and human-in-the-loop control , not proven autonomous solutions.

FROM RECOMMENDATIONS TO THE SECOND WAVE

WHITE PAPER

Strategic direction, common principles and recommendations. Answers given, questions deliberately left open.

SECOND WAVE

An executable demonstration, not a deployment:

- agreed requirements and prioritised use cases
- geometrical and data model MVP as the twin's anchor
- priority data-source integrations and THMC surrogate investigation
- platform benchmark and governed AI/LLM proof of concept
- immersive visualisation and stakeholder validation

SCALE-UP DECISION

Validated outcomes, business case, WBS, cost factors and roadmap , evidence a WMO can take to a decision gate.

HOW THE RECOMMENDATION FAMILIES ARE PICKED UP

Requirements and semantics
Common DT requirements and a shared semantic backbone, aligned with EURAD KM assets

Pilots and lifecycle integration
Prioritised use cases executed on a representative MVP testbed

Platform and validation
Benchmark, selection framework and a qualification pathway shaped with TSOs

Governance and business case
Data access, cybersecurity, impact narrative and scale-up roadmap

The White Paper defines the direction; the Second Wave produces the evidence for implementation.
The White Paper can also be a guidance in tasks related to DT in WPs related to data management like ECOFRAME and STRATA-AI and with simulations of complex geometries like GEOSCALE and MOGARE (Second Wave) and not only HERMES but also ANCHORS Subtask 4.2 corresponding to the First Wave.

NEXT STEPS AND DECISIONS

1. **Mobilise the Consortium and put governance in place from day one**
   Core preparation team across WMOs, TSOs and research entities · named deliverable owners · lean steering and technical/KM structures · baseline rules for data access, confidentiality and cybersecurity

2. **Converge on decision-critical use cases and consolidate requirements**
   Structured prioritisation workshops · SMART objectives and KPIs · required datasets, interfaces and interoperability needs · explicit acceptance criteria

3. **Approve the MVP, the security perimeter and the benchmark criteria**
   Representative geometric and information model · anonymised, mock or synthetic data where access is restricted · reusable platform evaluation framework to minimise vendor lock-in

4. **Make the scale-up gate explicit from the beginning**
   Success KPIs · validation and qualification pathway with early TSO and regulator input · business case, cost drivers, capability gaps and adoption roadmap

IF ACTION IS NOT TAKEN NOW, DIGITAL TWIN EFFORTS WILL REMAIN FRAGMENTED, COSTLY TO INTEGRATE AND DIFFICULT TO QUALIFY FOR NUCLEAR APPLICATIONS.

Q&A

Thank you!

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