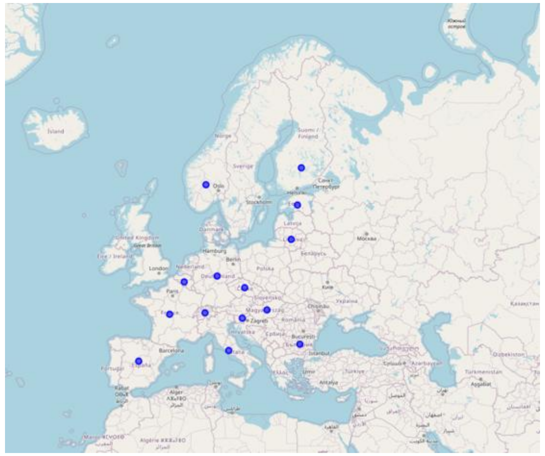
European Partnership
on Radioactive Waste Management

STRATEGIC STUDY DITOCO2030

TECHNICAL INSIGHTS AND LESSONS LEARNED



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NEXT-GENERATION DIGITAL TWINS TO SUPPORT OPTIMISATION, CONSTRUCTION AND OPERATION 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.