LESSONS LEARNED AND INSIGHTS FROM STRATEGIC STUDIES

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AGENDA OF THIS SESSION

- Technical insights / lessons learned from the StSt
- General views on the role of StSt

POLLING

- Join by Web: **PollEv.com/sckcena444**

What is the first thing on your mind what a strategic study should be – in 1 word

Nobody has responded yet.

Hang tight! Responses are coming in.

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

Do StSt meet their objectives?

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

StSt should lead to an R&D programme

YES

0%

NO

0%

DEPENDS ON TOPIC/OBJECTIVES

0%

TECHNICAL PRESENTATIONS

- OPTI
- DITOCO
- DITUSC
- CLIMATE
- ASTRA
- FORSAFF

STRATEGIC STUDY OPTI

Technical insights and lessons learned

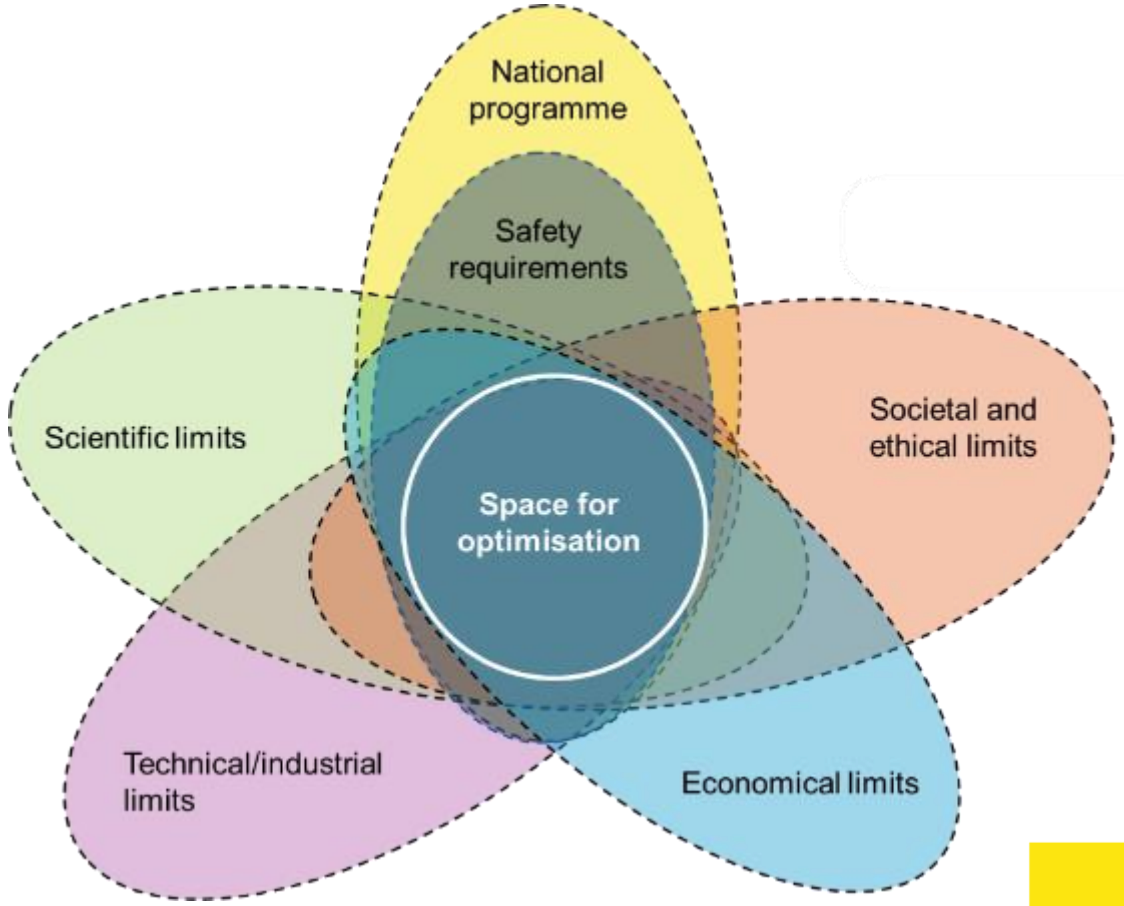
Co-funded by the European Union under Grant Agreement n° 101166718

HLW REPOSITORY OPTIMISATION INCLUDING CLOSURE

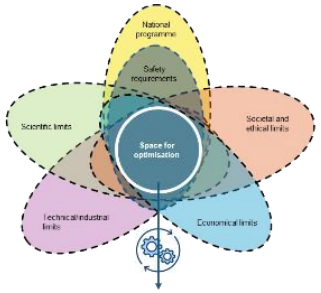
- Optimisation is a continuous and iterative process throughout the entire repository lifecycle
- The objective is to achieve the highest practicable level of protection and safety
- Optimisation takes place within prevailing circumstances, including regulatory, technical, geological, economic and societal constraints
- The overlap creates the space for optimisation
- Repository optimisation requires balancing multiple and potentially competing objectives through transparent decision-making
- Interactions between repository components necessitate a holistic, system-level approach supported by multi-criteria assessment

PREVAILING CIRCUMSTANCES

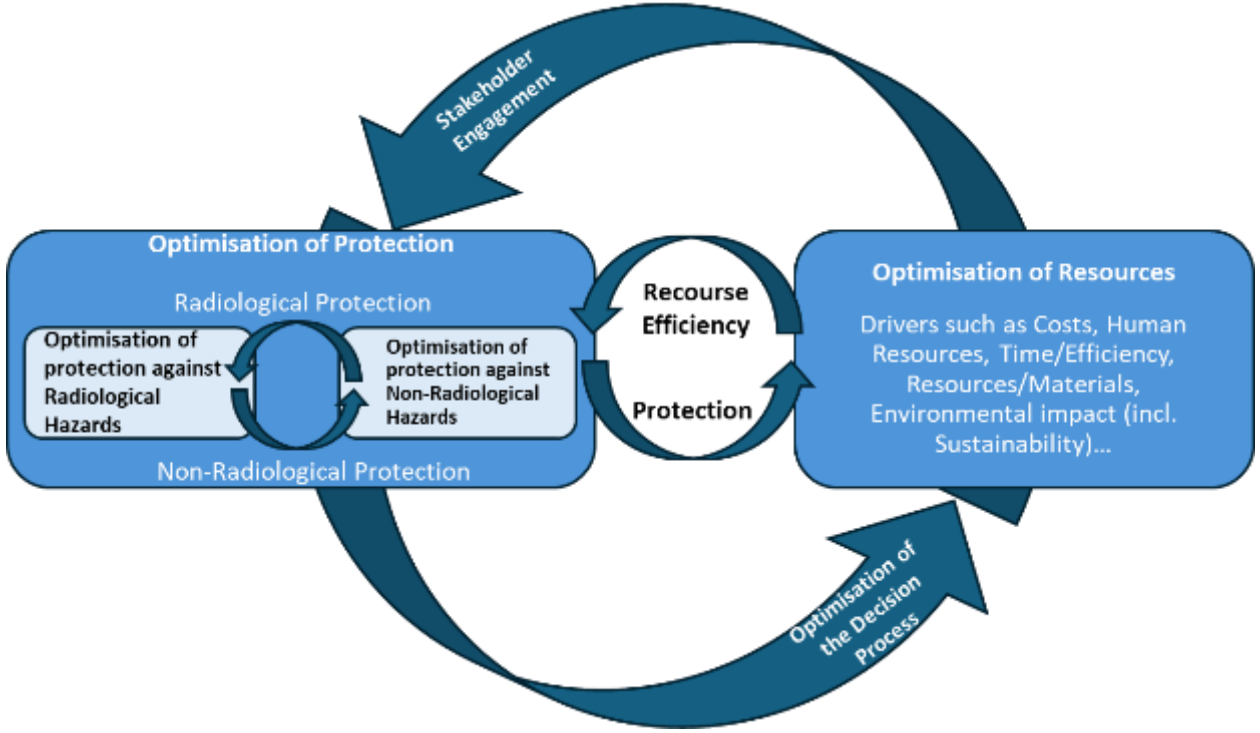
- Optimization is always aimed at achieving the best possible level of protection through a continuous iterative process, taking account of the **prevailing circumstances**
- The prevailing circumstances include, in particular, non-technical factors such as costs, societal considerations, human resources, and the national and international political context
- Each factor affecting the optimization of the GDF is associated with its own relevant circumstances
- These circumstances continue to evolve over time



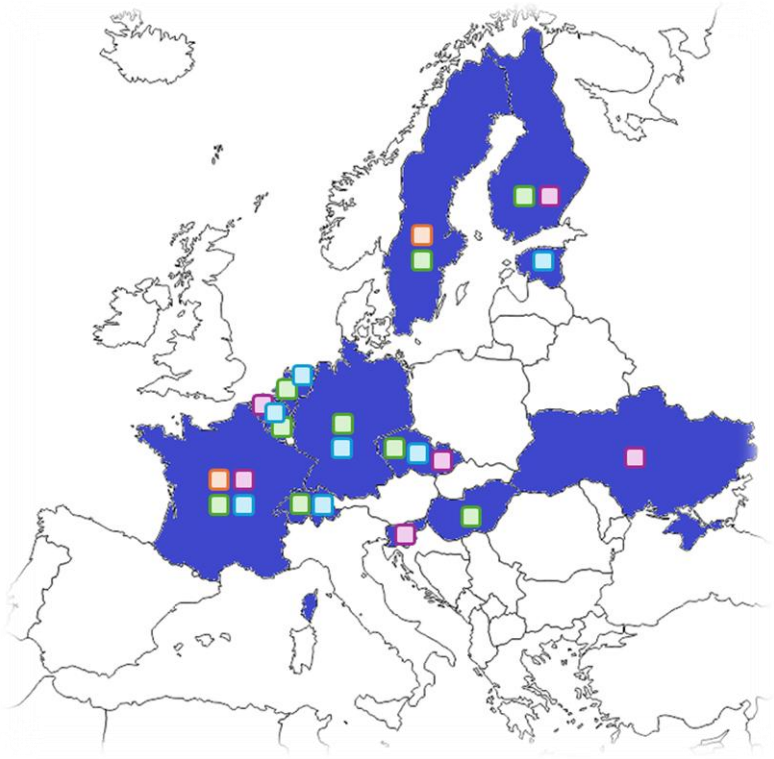
OPTIMISATION PROCESS



- All prevailing circumstances constrain the space for optimisation within which the optimisation process can be carried out
- The process may relate to
  - (a) the optimisation of protective measures and resources
  - (b) the decision-making process
- The optimisation of one component of a GDF, or even of a specific property of a component, may affect other components
- Such interactions require a holistic approach to optimization
- The potential impacts of optimisation options on the overall GDF are assessed and compared iteratively using multi-criteria analyses



HLW REPOSITORY OPTIMISATION INCLUDING CLOSURE - OPTI



THANK YOU FOR YOUR ATTENTION!

CSO

NTW NUCLEAR TRANSPARENCY WATCH

WMO

BGE BUNDESGESELLSCHAFT FÜR ENDLAGERUNG

Posiva

PURAM

nagra.

ONDRAF/NIRAS

COVRA

SKB

ANDRA

SÚRAO

TSO

SÚRO

BEL V

SSTC NRS

IRSN INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

VTT

EIMV ELEKTROINŠTITUT MILAN VIDMAR

RE

TU Delft

LIÈGE université

EURIDICE

sck cen

ÚJV

CTU CZECH TECHNICAL UNIVERSITY IN PRAGUE

TARTU ÜLIKOOL UNIVERSITAS TARTUENSIS

KIT

PAUL SCHERRER INSTITUT PSI

eurad 2

STRATEGIC STUDY DITOCO2030

TECHNICAL INSIGHTS AND LESSONS LEARNED

Speaker: Réka Szőke *reka.szoke@ek.hun-ren.hu*
Prepared: DITOCO2030 Board of Management

Co-funded by the European Union under Grant Agreement n° 101166718
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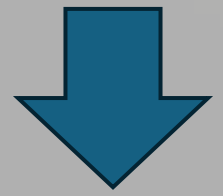
EURAD-2 DITOCO2030 project

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

DIGITAL TWIN ADOPTION

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

1 Economic efficiency

Optimize maintenance, minimize downtime and improve asset utilization.

2 Safety improvements

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

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.

WP 18 - DEVELOPMENT AND IMPROVEMENT OF THERMODYNAMIC UNDERSTANDING FOR USE IN NUCLEAR WASTE DISPOSAL SAFETY CASE – LESSONS LEARNT

S. Brassinnes (ONDRAF/NIRAS), X. Gaona (KIT)

Co-funded by the European Union under Grant Agreement n° 101166718

OBJECTIVE

To assess current thermodynamic understanding in support of the Radioactive Waste Disposal Safety Case : data gaps analysis and identification of priorities for possible future R&D programmes

TECHNICAL INSIGHTS ON OUTCOMES (1/3)

- Thermodynamics is **foundational** to the Safety Case
  - To ensure scientific credibility and defensibility of long-term safety assessment
- Current approaches are **robust**
  - Existing Safety Cases remain valid and defensible.
  - Conservative assumptions / bounding scenarios / sensitivity analyses
- Requires **robust, transparent and consistent** TDBs
  - Multiple TDBs are complementary, not redundant
- **No "show-stopper"** gaps — but data limitations remain
  - Must be prioritized (Safety relevance / Impact on model predictions / Regulatory needs / Feasibility)
  - Repository conditions and national programmes needs strongly influence priorities of national TDB programs
  - Uncertainties / limited predictive capability / over-conservative results
- **Combined approaches** to fill data gaps
  - Experimental work: most reliable but resource-intensive
  - Estimations: necessary but uncertain
  - Artificial Intelligence/ Machine Learning: promising but requires validation

TECHNICAL INSIGHTS ON OUTCOMES (2/3)

- Strong need for **European/international coordination and harmonization**
  - Align priorities, pool resources and avoid duplication
- **EURAD-2** = facilitator (not to develop a new TDB)
  - Identify stakeholder needs
  - Foster collaboration
  - Support targeted R&D
  - Ensure knowledge transfer
- **Strong call to action** for the EURAD community (move from analysis to implementation)
- Pragmatic, **stepwise roadmaps** are proposed (short term and long term: should be incremental, coordinated, and impact-driven)
- **Six high-impact scientific priorities**
  - Cement topics, including new materials, interphase with zeolites and solid-solution formation,
  - Redox processes of key components,
  - Ternary and quaternary complexation (carbonate, silicate, organics),
  - Thermodynamic database methodologies,
  - High-salinity systems,
  - Temperature-dependent thermodynamics.

MORE DETAILS ARE TO FOUND IN PROJECT DELIVERABLES :


EURAD-2 Deliverable 18.1 – DITUSC Green Paper

portance

European Partnership
on Radioactive Waste Management

Deliverable 18.1: DITUSC Green Paper

Work Package 18

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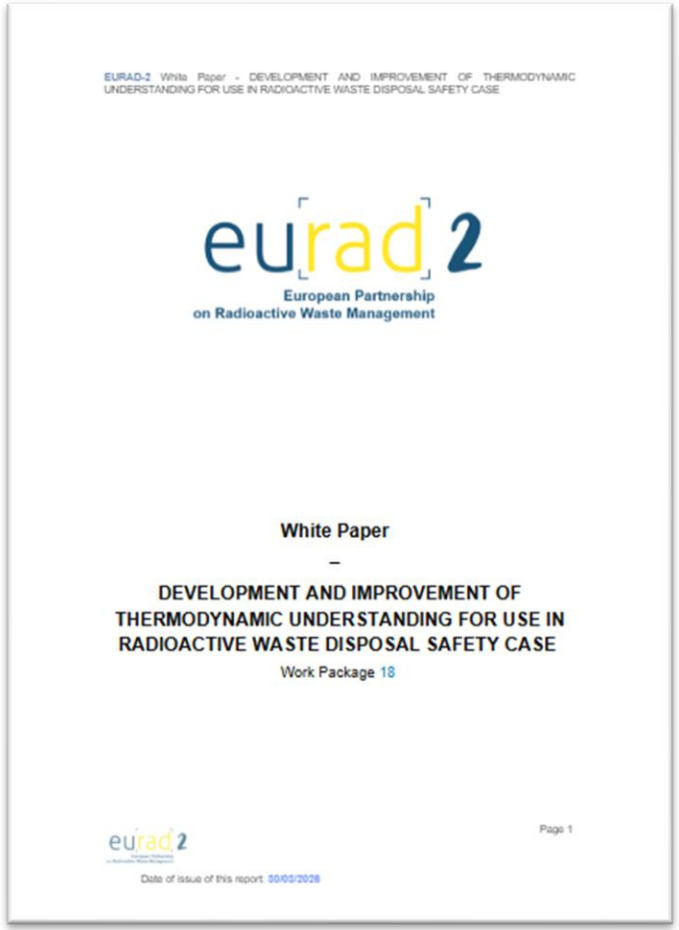
EURAD-2 White Paper - DEVELOPMENT AND IMPROVEMENT OF THERMODYNAMIC UNDERSTANDING FOR USE IN RADIOACTIVE WASTE DISPOSAL SAFETY CASE

European Partnership
on Radioactive Waste Management

White Paper

–

DEVELOPMENT AND IMPROVEMENT OF THERMODYNAMIC UNDERSTANDING FOR USE IN RADIOACTIVE WASTE DISPOSAL SAFETY CASE

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EURAD-2 Deliverable 18.4: Outcome/impacts report to Member States & End Users
OFFICIAL

European Partnership
on Radioactive Waste Management

Deliverable 18.4: Outcome/Impacts Report to Member States & End Users

Work Package 18

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Lesson: the relevant climate question changes with facility type, lifecycle phase and timescale.

CONSTRUCTION AND OPERATION

Mainly concerned with extreme weather and infrastructure performance, disrupt operations, compromise surface barriers, site access, and worker safety.

- Heavy rainfall
- Flooding
- Heatwaves
- Desertification
- Erosion
- Coastal hazards

POST-CLOSURE

Focus on system evolution, barrier performance and exposure pathways, ultimately affecting the safety case.

- Infiltration
- Groundwater flow
- Landscape evolution
- Sea-level change
- Permafrost/glaciation

Lesson: climate information becomes useful only when it is translated into decision-relevant inputs.

Climate science
projections · observations

Climate scenarios
timescales · states · extremes

Safety-relevant parameters
recharge - sea level - rainfall

System response
FEPs - barriers - hydrogeology

Safety decisions
design - licensing - review

Where CLIMATE repeatedly found the methodological gap

Scale & extremes

Climate-model output exists, but safety assessment often needs different spatial and temporal scales, especially for infrequent extremes.

Century to millennium gap

Near-term projections and geological-scale scenarios are stronger than the intermediate time window for some concepts.

Uncertainty propagation

The key is not to eliminate uncertainty, but to make assumptions traceable and carry uncertainty into system response and decisions.

Lesson: Harmonize the logic. Common language and proportionality improve transparency and comparability.

Shared European framework

1	**Scenario logic**	How climate futures are selected and bounded
2	**Translation rules**	How climate variables become safety inputs
3	**Uncertainty treatment**	How uncertainty is documented & propagated, with possible support of ICS
4	**Monitoring & review**	How new observations trigger reassessment

Proportionate National Implementation regarding existing and future facilities

A	**Facility type**	surface - near-surface - DGR
B	**Climate context**	Climate - coast
C	**Programme maturity**	screening structured scenario assessment, possibly bridging gaps in stakeholder involvement
D	**Regulatory context**	national requirements and licensing stage

Lesson: Integrating technical work, knowledge transfer and stakeholder engagement from the start makes Strategic Studies more effective.

Connect disciplines early

RWM experts, climate scientists, modellers, regulators and civil society need a sustained interface. The goal is access to expertise not to recreate climate science inside RWM.

Design outputs from the start

Define the role, audience and boundaries of the White Paper, Synthesis Report, Domain Insight and other products early, with clear ownership in the tasks that generate the evidence.

Treat knowledge transfer as core work

Training should be planned early, audience-first and interactive not as a final summary of the WP.
Knowledge products should remain useful after the project ends.

Integrate technical and societal learning

Civil-society interaction improved the framing of scenarios, communication and future research needs.

ASTRA

Alternatives RWM strategies (ASTRA)

FORSAFF

Waste management for SMRs and future fuels (FORSAFF)

DEFINITION OF STST AS IN GRANT AGREEMENT

- Strategic Studies (StSt)
  - Actions consisting of enabling experts and specialists to network on methodological/ strategical issues and advance significant challenges that are common to various National Programmes and that are in direct link with scientific and technical issues.

- Complementary to RD&D and in support to the implementation of the Member States' national programmes, EURAD-2 shall, based on the lessons learned from EURAD(-1), further give the opportunity to participants and expert contributors to network on methodological and strategic issues and challenges that are common to various national programmes and in direct links with scientific and technical issues:
  - **Share knowledge and discuss common methodological/strategical challenging issues (strategic studies) that are in close link with scientific, technical and societal aspects on RWM and that are common to various national programmes;**
  - Identify the contribution of past/on-going RD&D projects to the resolution of these issues;
  - Identify any emerging topics for collaboration that could be addressed within a European Programme;
  - Take into account emerging science and technology as well as research priorities originating from other programmes (e.g. results from Horizon Europe projects, H2020 projects or IAEA outputs).

LESSONS LEARNED FROM EURAD(-1) AND PREDIS

Strategic Studies	Unfocused/ too wide scope for Strategic Studies. Lack of engagement.	Strategic Studies revised as short sprints (max 2 years) to focus on outcome benefits, then re-evaluate the need of a future WP on similar topic.

GOOD PRACTICES TO REPLICATE

- Interactive workshops and discussions on common challenges and needs
- Cross-organisational collaboration
- End-user and civil society involvement
- Knowledge sharing and networking

CHALLENGES ENCOUNTERED

- Scope was unclear
- “Merging” issues
- Focus lacking
- Differences in expectations
- Tight timelines
- Administrative burden
- Uneven partner engagement
- Budget and travel constraints
- Misalignment with Wave-2 timing

SCORING OF THE OUTPUT

- **Quality of output varies**
  - StSt ≠ KM activity
- **Difficulties**
  - Translating findings into R&D topics
  - Recommendations towards different actors
  - Considering constraints in timing and budget – be realistic

LESSONS LEARNED AND RECOMMENDATIONS

- Successful Strategic Studies depend on
  - clear expectations
  - clear scope
  - SMART objectives
  - strong leadership (strategic vision)
  - active participation
  - careful partner selection
  - early and balanced stakeholder involvement
  - collaboration and integration across tasks
  - good communication

- Discouple StSt from future funding

VIEW OF THE BUREAU

- **Role of a StSt: different views**
  - Not only prepare future R&D
  - Also networking on strategic issues
  - Not all StSt must lead to R&D WP
- **StSt should be tailored to needs of the programmes**
- **Expectations of a StSt: different view – make clear from start**
- **Objectives of individual StSt: must be clear from start**
- **Tailor to fit:**
  - Large sample of participants vs. focused group of experts
  - Select the right people!
  - Consider top-down approach (select partner based on value)
- **Better define tasks and roles in StSt (top-down approach)**
- **Dissemination:**
  - Too limited – white papers must reach target audience
  - Large differences between StSt
  - Need to capture all work done – use correct format
  - EURAD is not only about writing papers, Also discussions, knowledge exchange, … are very important

VIEW CSOFF

- **Strategic studies are a valuable instrument for addressing specific topics**
  - clear objective = white papers and position papers
- **White papers ≠ scientific writing.**
  - Need expertise in writing
  - Defining a focused set of clear, actionable measures
  - Review of outcomes should start in the draft stage
- **Budget:**
  - Substantial but funding was distributed across a large number of partners
  - Future: smaller budgets and limited number of carefully selected partners
  - Shorter timeframes

- **Overall, the instrument should become more focused, agile, and dynamic.**

SUMMARY

✅ **Strategic Studies are a valuable EURAD-2 instrument**

- Facilitate networking and knowledge exchange on common strategic challenges.
- Support national programmes beyond purely RD&D objectives.

✅ **Success depends on clear focus and expectations**

- Well-defined scope, SMART objectives, and expected outputs are essential.
- Strong leadership and active stakeholder engagement are critical.

✅ **Strategic Studies should be tailored to their purpose**

- Not every study needs to lead to a future RD&D Work Package.
- The format, participant profile, and expected outcomes should fit the specific strategic question.

✅ **Future Strategic Studies should be more agile and impactful**

- Smaller, focused expert groups.
- Earlier review and stronger dissemination of outputs.


CLEAR OBJECTIVES
Define well-scoped, SMART objectives that drive impact and clarity.
TARGETED EXPERTISE
Engage the right experts with the knowledge and experience needed to deliver results.
Focus Strategic Studies
on delivering
actionable strategic guidance
through
EFFECTIVE COLLABORATION
Foster cross-organisational collaboration and open knowledge sharing to co-create solutions.
MEANINGFUL ENGAGEMENT
Actively involve end-users and stakeholders to ensure relevance, buy-in, and real-world impact.
WITH END-USERS AND STAKEHOLDERS
Ensuring our studies deliver value and support better decisions for radioactive waste management programmes.