OPTIMISATION OF CANISTER DESIGN AND LIFETIME ASSESSMENT

State of the Art and plans within the EURAD CONCORD WP

20/9/2022 • N. Diomidis

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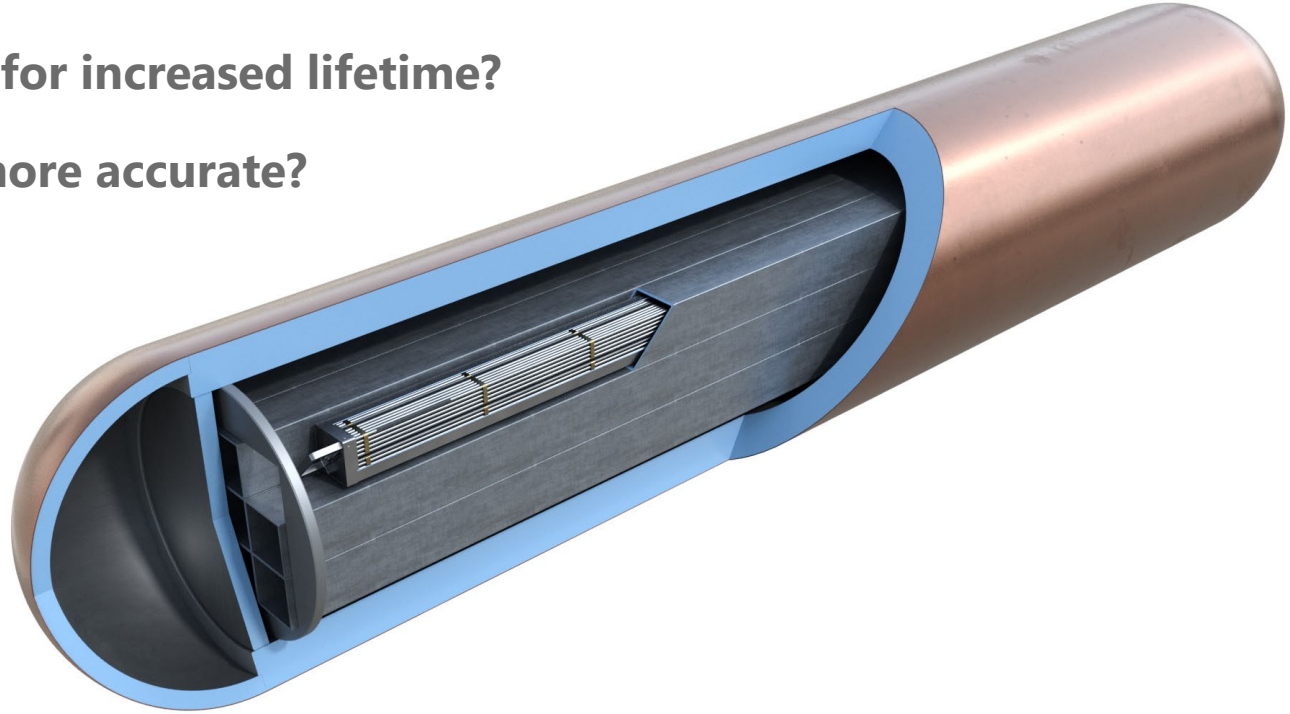
DISPOSAL CANISTERS FOR SF & HLW

- Complete containment for a certain period of time
- Focus given to the end of containment: canister lifetime.

- How can canister design be optimised for increased lifetime?
- How can lifetime prediction become more accurate?



HOW DO CANISTERS FAIL?

- **When the environmentally induced degradation of the materials exceeds a threshold, which typically depends on the mechanical stress**
  - Fracture and environmental degradation mechanisms depend on material and environment

- **E.g.:**
- **Plastic collapse of metallic canister after excessive wall thickness loss due to corrosion**
- **Fracture initiating in a weld defect of a hydrogen-embrittled steel canister**
- **Increase of porosity due to preferential leaching of ceramic materials or seals**
- **Accelerated corrosion in a through-coating defect, forming a deep pit leading to stress intensification.**

CANISTER CONCEPTS

WMO	Canister concept	Estimated or target lifetime (yr)	Nominal buffer dry density (g/cm^3)	Max canister temperature (°C)	Time to full nearfield saturation (yr)	Maximum surface absorbed dose rate (Gy/hr)	Expected mechanical loads (MPa)
SKB	Copper-cast iron	$>10^6$	1.6	95	Few tens to a few thousand	0.2	15 50 (glacial)
Posiva	Copper-cast iron	$>10^6$	1.55	95	Few tens to a few thousand	0.3	14 50 (glacial)
Andra	Carbon steel	>500	No buffer	90		10	
Ondraf-Niras	Carbon steel	Several thousand	Cementitious buffer	100	5-10 up to a few thousand	25	8
Nagra	Carbon steel	10,000	>1.45	~120	A few centuries	0.2	22-29 max
SURAO	Carbon Steel	10,000	1.4	95	100	0.3	20
NWMO	Copper coated steel	$>10^6$	1.6	85	50-5,000 depending on host rock type	0.8	15 45 (glacial)
NUMO	Carbon steel	>1,000	1.6	100	<1,000 Host-rock dependent	0.006-0.011	11 (hard rock)

TREATMENT OF COPPER CORROSION IN LIFETIME PREDICTION

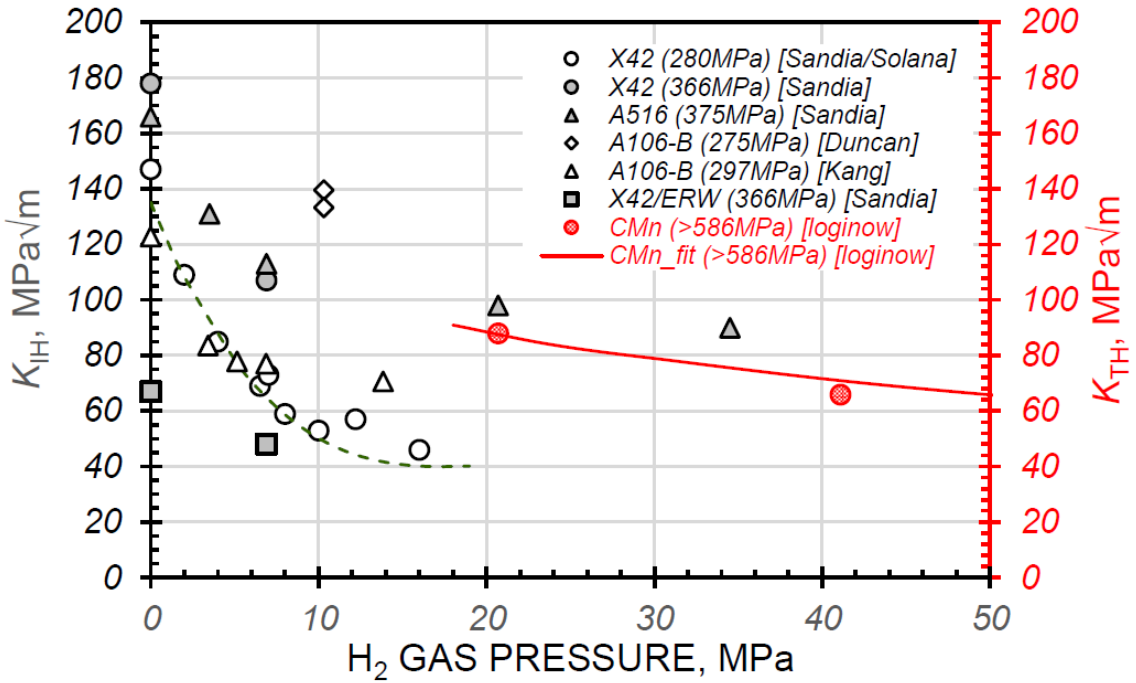
	SKB	Posiva	Nagra	NWMO
Oxic corrosion	Allowance	Allowance	Allowance	Allowance
Radiolysis	Allowance	Allowance	Allowance	Allowance
Remotely produced sulfide	Mass transport (intact and eroded buffer)	Mass transport (intact and eroded buffer)	Mass transport	Mass transport
Microbial activity prior to buffer saturation	Allowance (SR-Site)	Excluded by Reasoned Argument	Excluded by Reasoned Argument	Excluded by Reasoned Argument
SCC	Excluded by Reasoned Argument	Excluded by Reasoned Argument	Excluded by Reasoned Argument	Excluded by Reasoned Argument
…….				

TREATMENT OF STEEL CORROSION IN LIFETIME PREDICTION

	Andra	Ondraf-Niras	Nagra	NUMO
γ-radiation	Limit dose rate to 10 Gy/hr	No effect for dose rate of 25 Gy/hr	Limit dose rate to <1 Gy/hr	Limit dose rate to 3 Gy/hr
Anaerobic corrosion	Empirical corrosion rate	Empirical corrosion rate	Empirical corrosion rate	Empirical corrosion rate
Localised corrosion		Exclude by Reasoned Argument	Depth-dependent PF	Depth-dependent PF
SCC	Specify resistant material	Exclude by Reasoned Argument	Exclude by Reasoned Argument	Exclude by Reasoned Argument
……..				

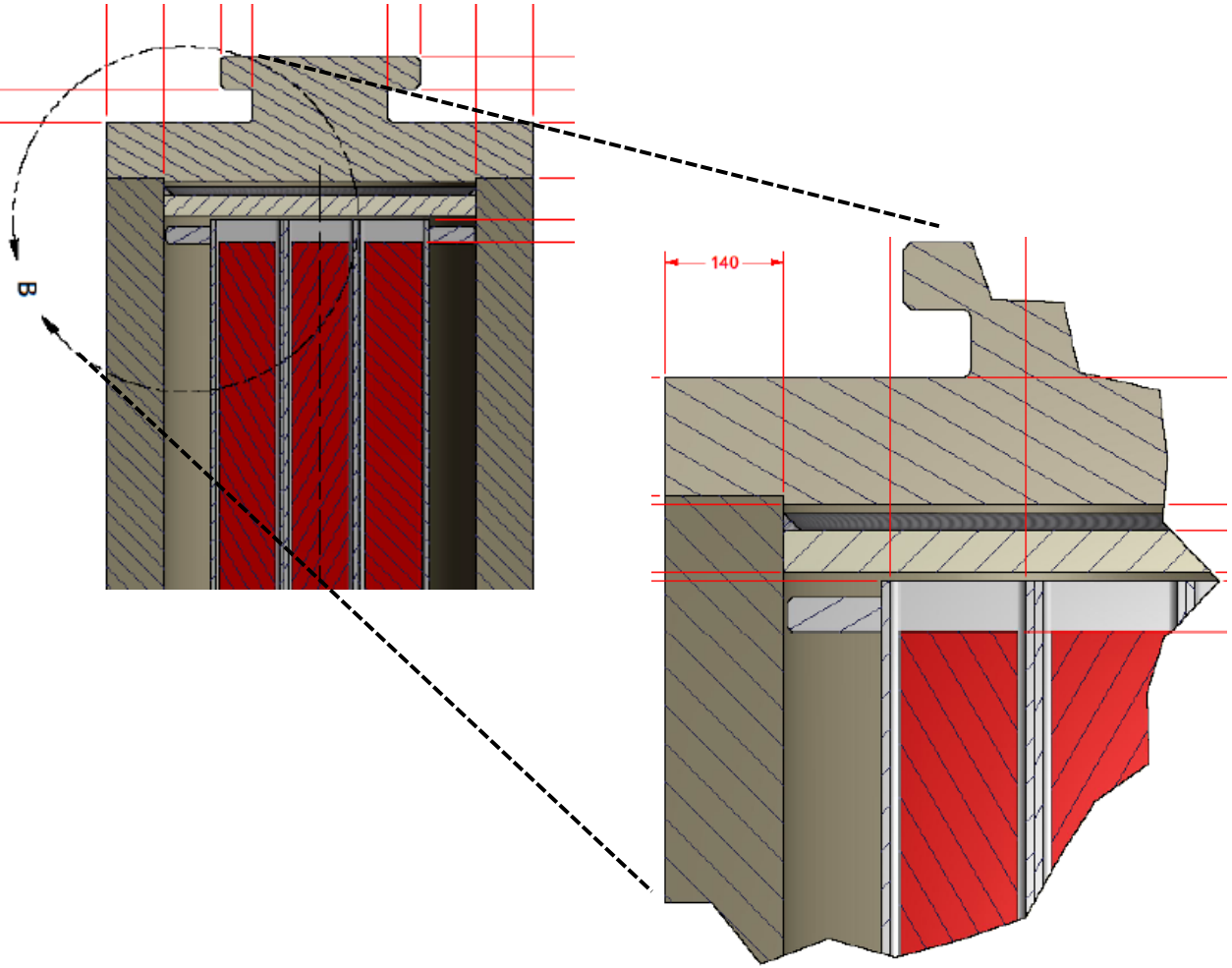
DESIGN CONSIDERATIONS: CANISTER MATERIALS & PROPERTIES

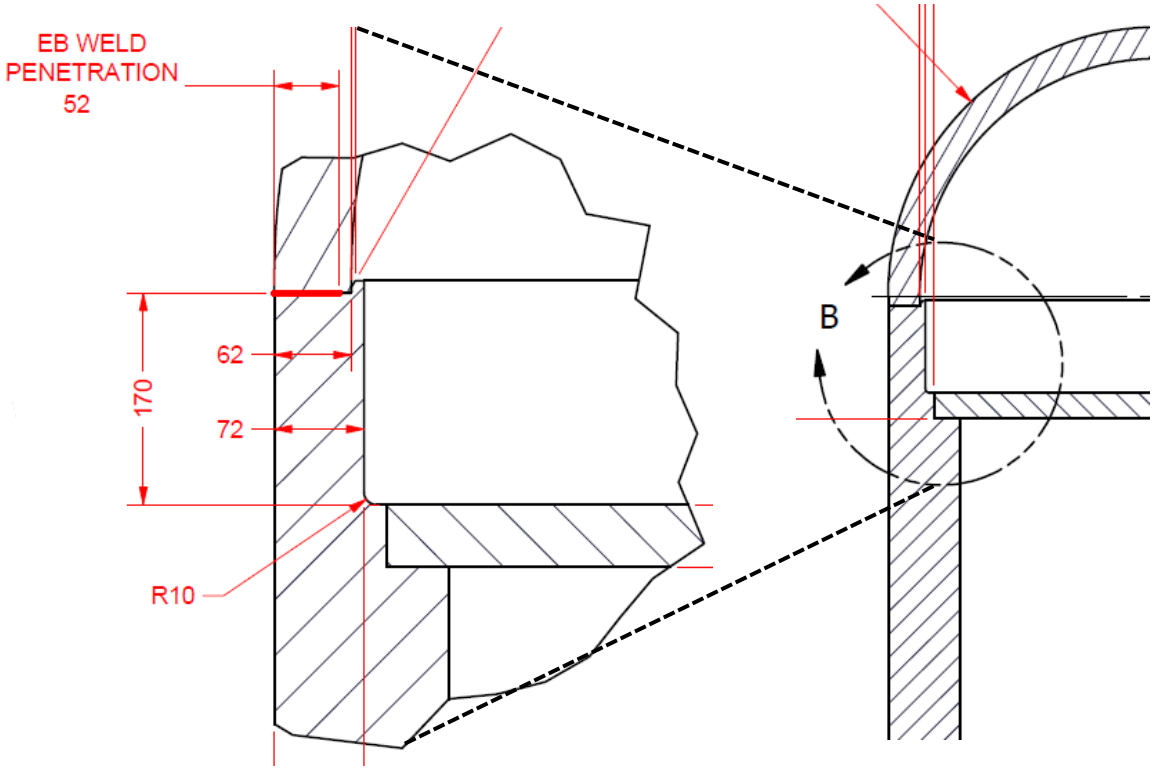
- A wide range of options limited by manufacturing capability at scale and knowledge of (long-term) properties



- Andra's work on SCC-resistant steels

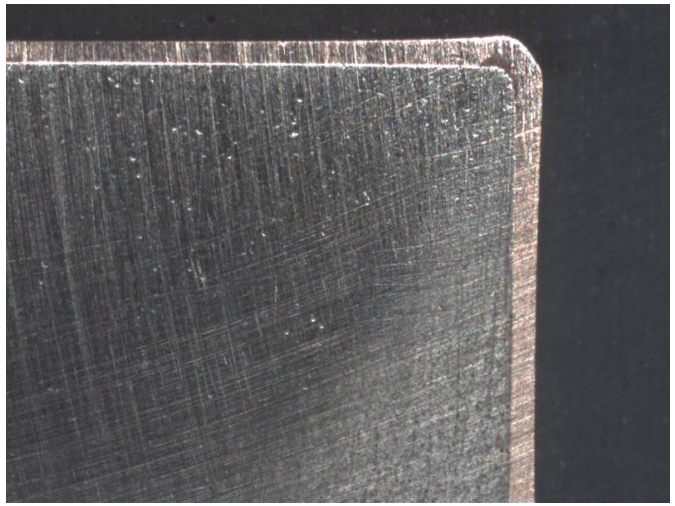
DESIGN CONSIDERATIONS: PHYSICAL DIMENSIONS AND SHAPE

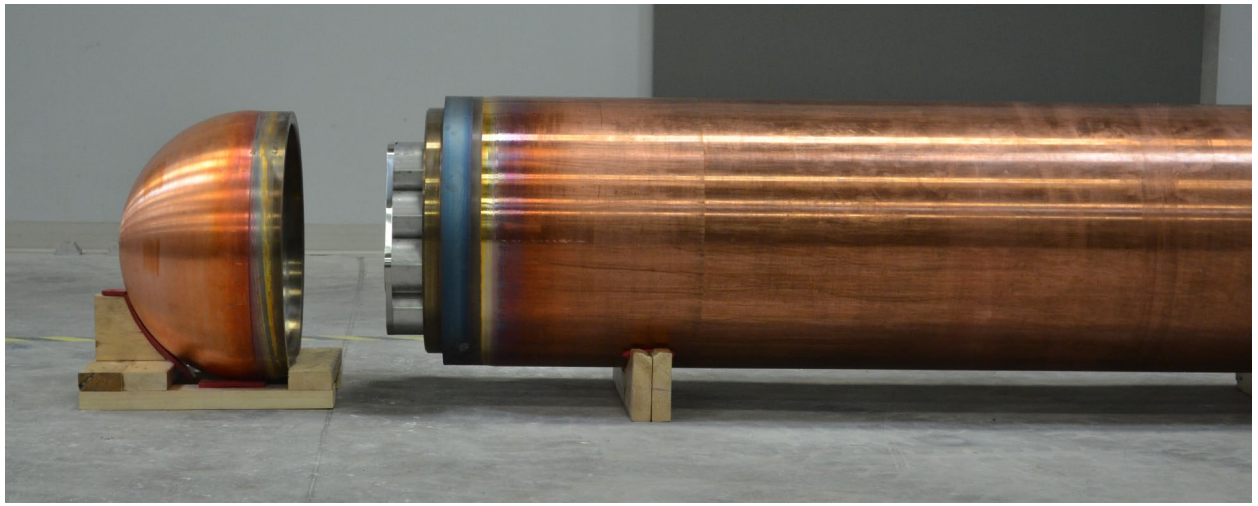




DESIGN CONSIDERATIONS: MANUFACTURING PROCESS

- **Coatings:**
  - Efficient way for producing dual material canisters with various benefits (and “new” challenges)
  - 10 years of work by NWMO to develop Cu coatings and demonstrate their feasibility
  - Development of Cu coated canister concepts in Switzerland and Japan.
  - The door is open for the (re-)evaluation of other coating materials & processes

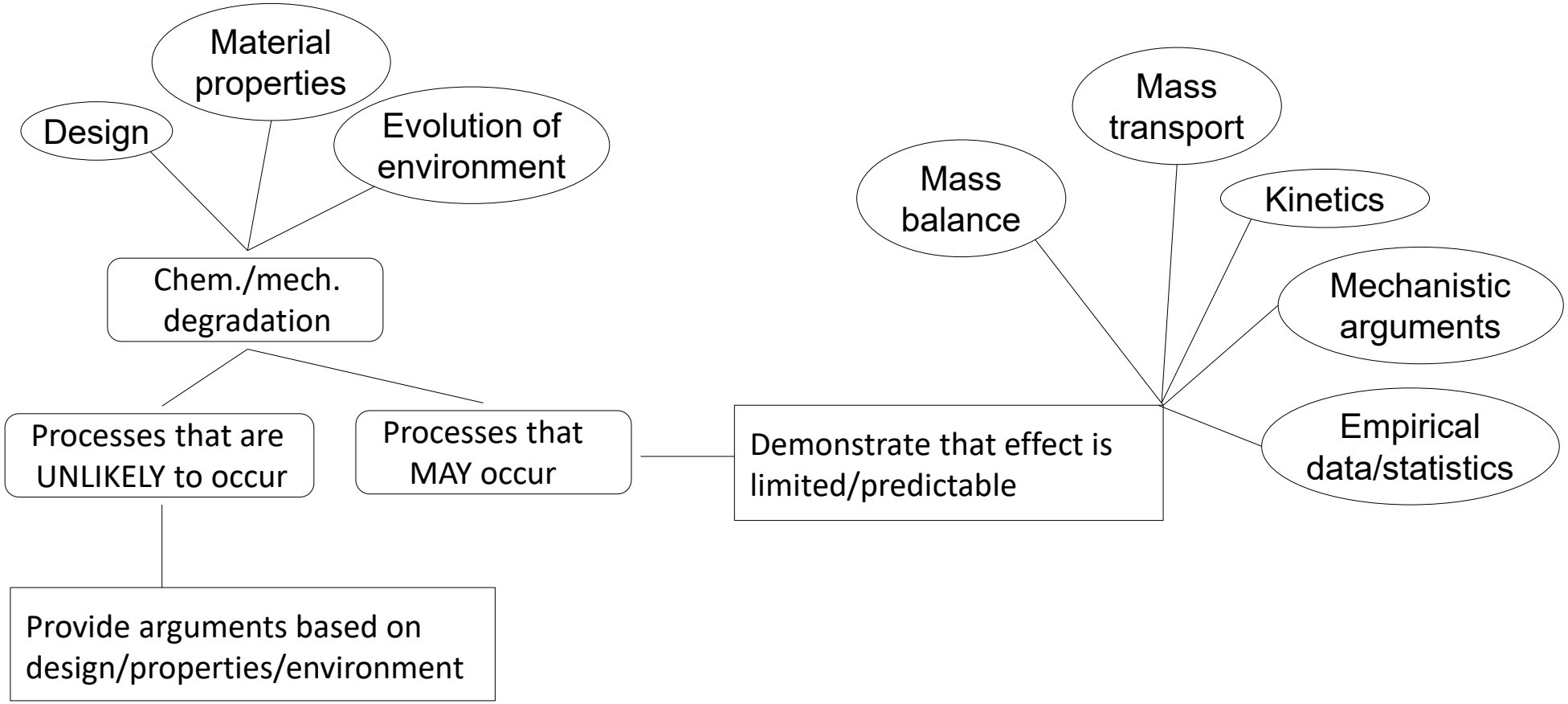




DESIGN CONSIDERATIONS: OTHER AREAS OF POTENTIAL OPTIMISATION

- Operational aspects
- Inventory & canister loading
- Cost & procurement

LIFETIME PREDICTION CONSIDERATIONS



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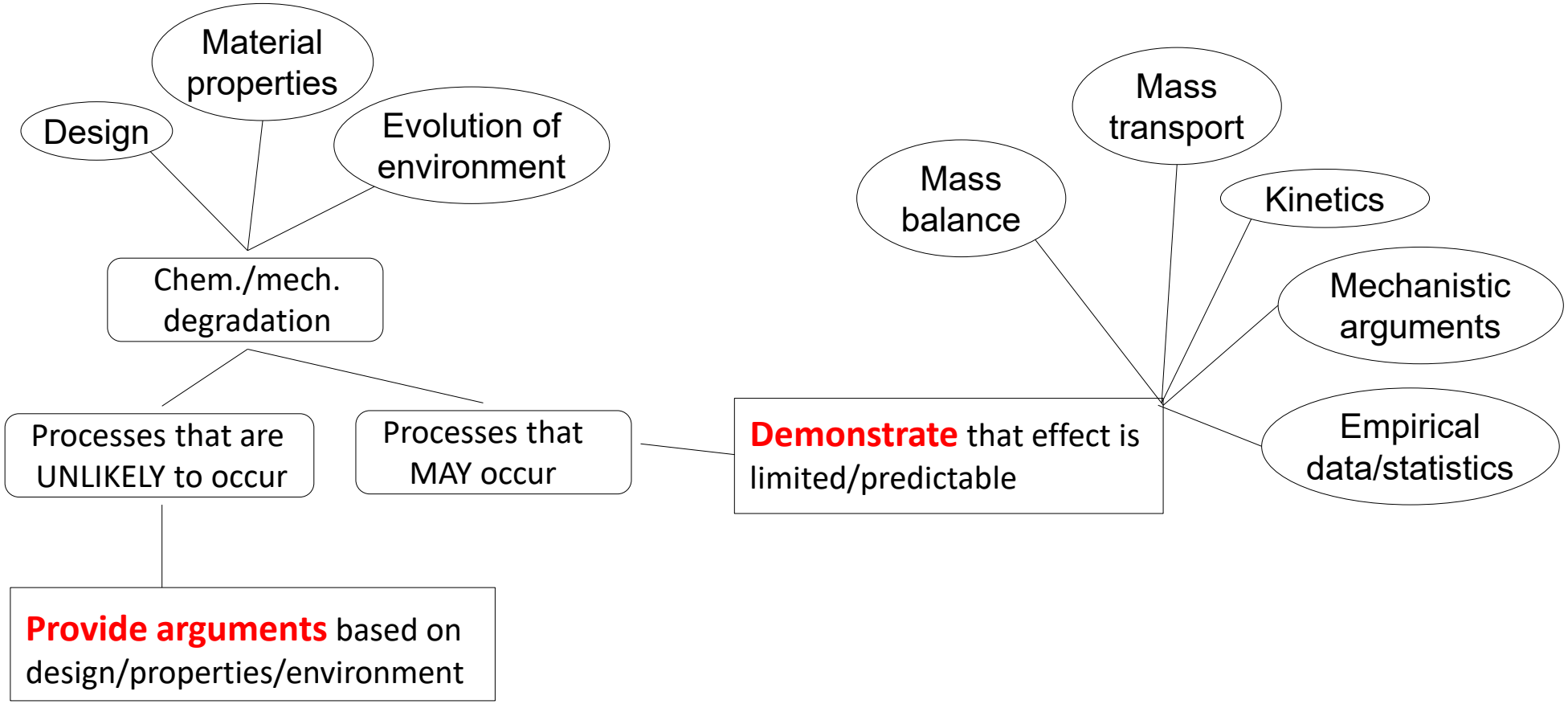

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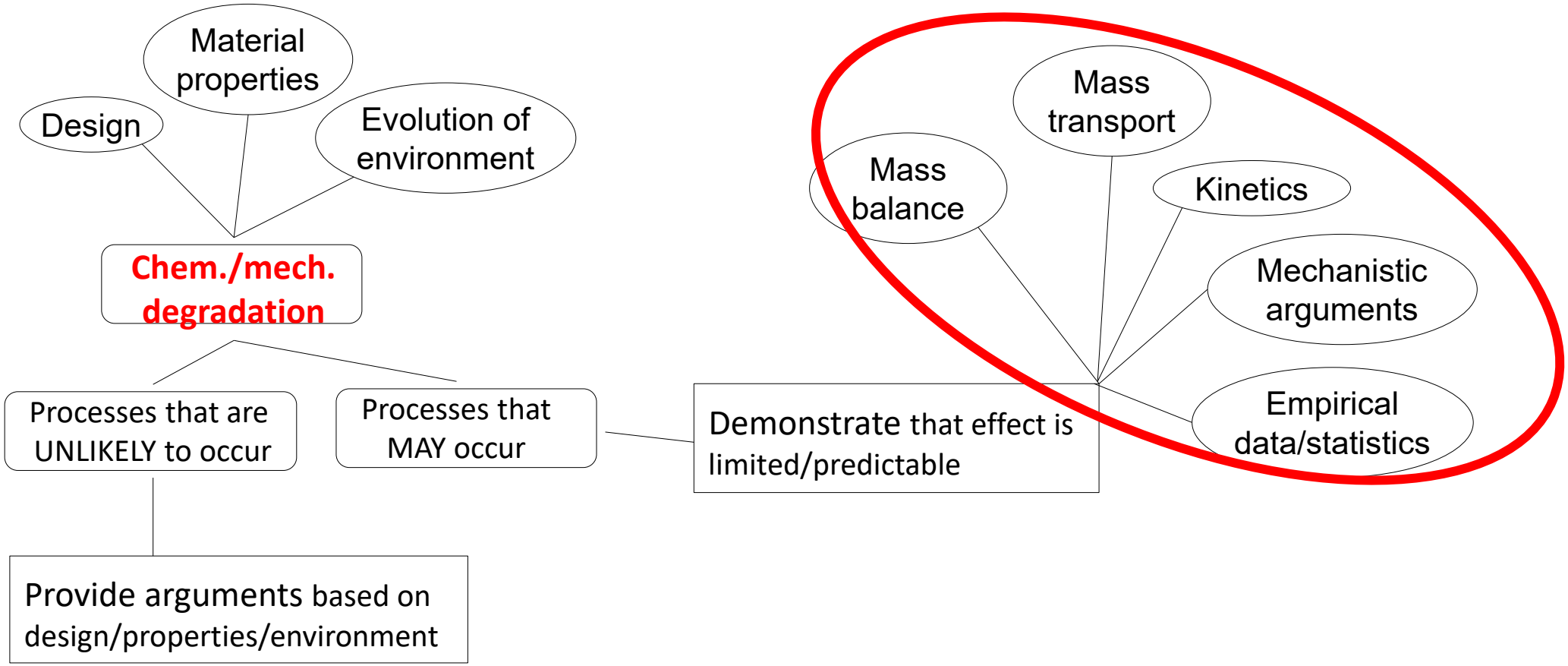
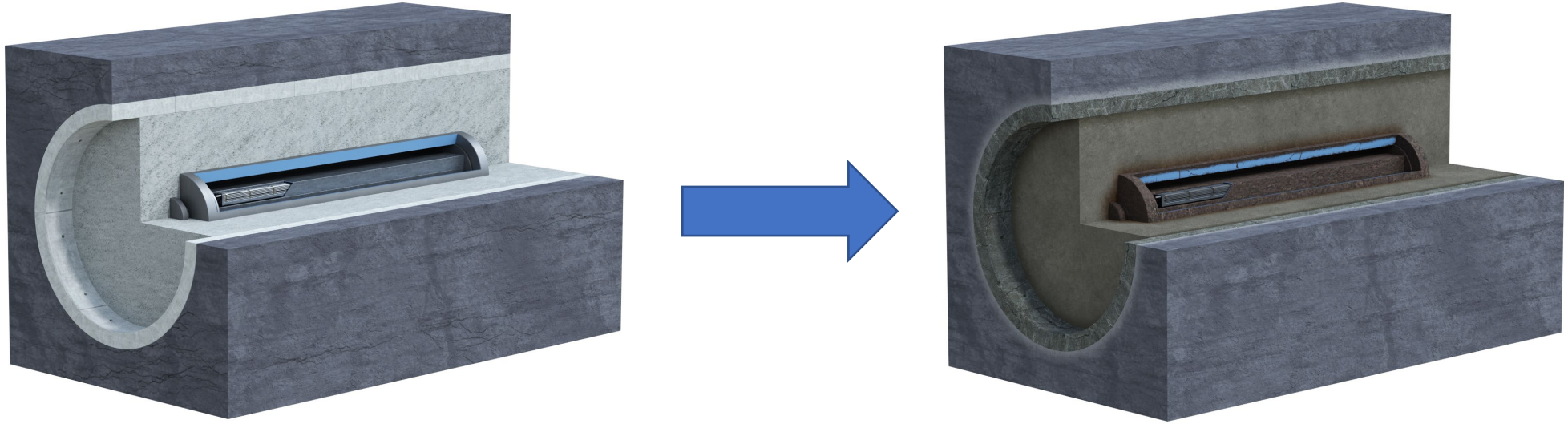


MOTIVATION FOR WP CONCORD

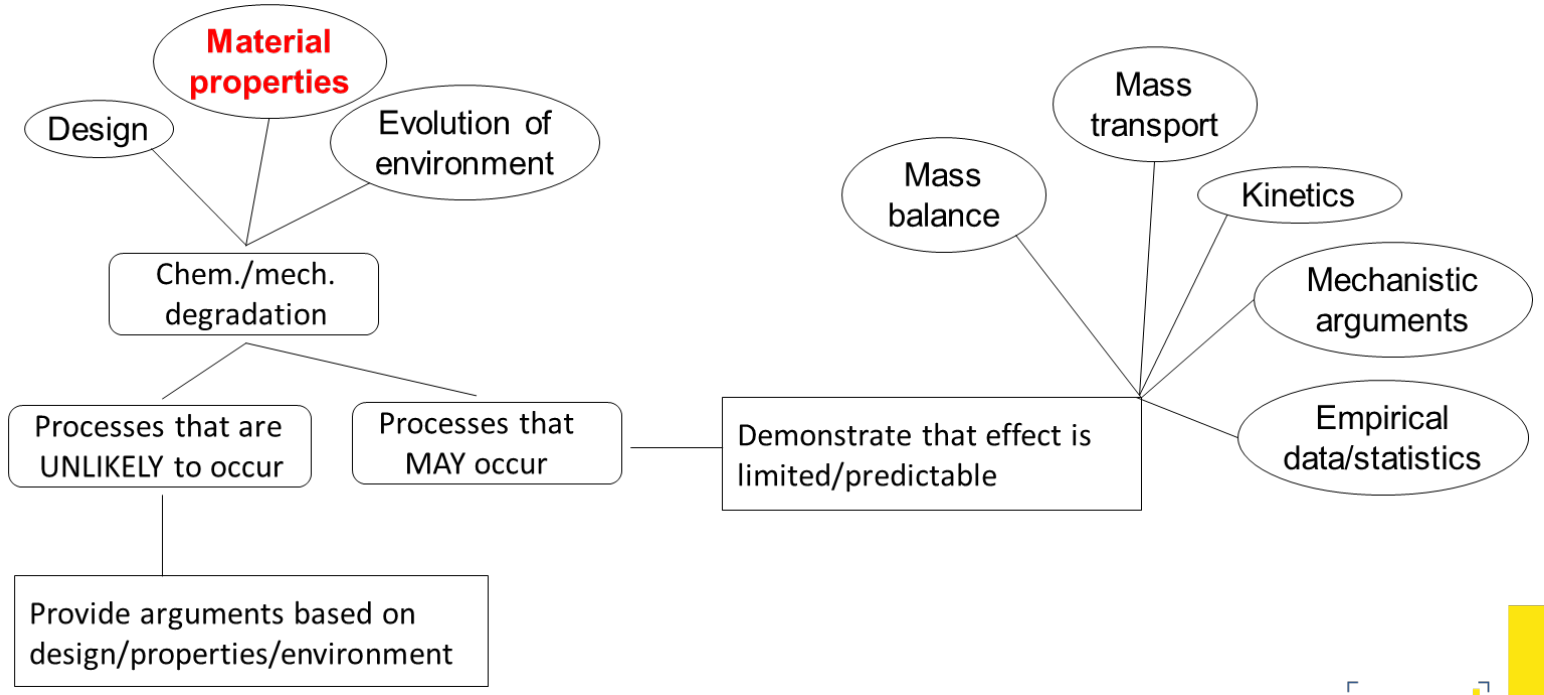
Long-lived disposal containers for SF/HLW have been shown to be feasible and safe.

- **Can they be optimised?**
- **Can the prediction of their lifetime become more accurate and robust?**



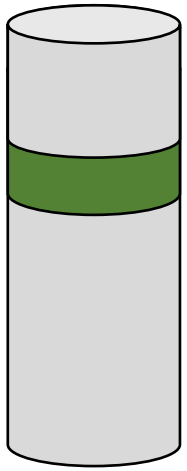
AIMS OF WP CONCORD - 1

Explore the potential of novel container materials for the optimisation of container performance within the EBS

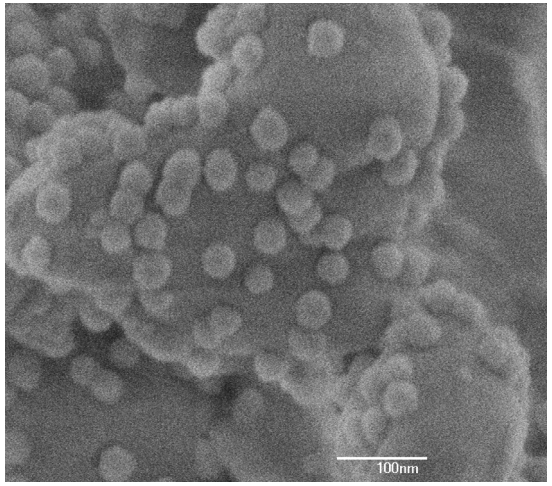


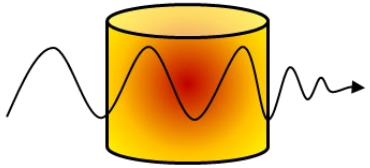
CANISTER MATERIALS: CERAMICS

- **Optimisation of sealing material for silica-alumina canisters:**

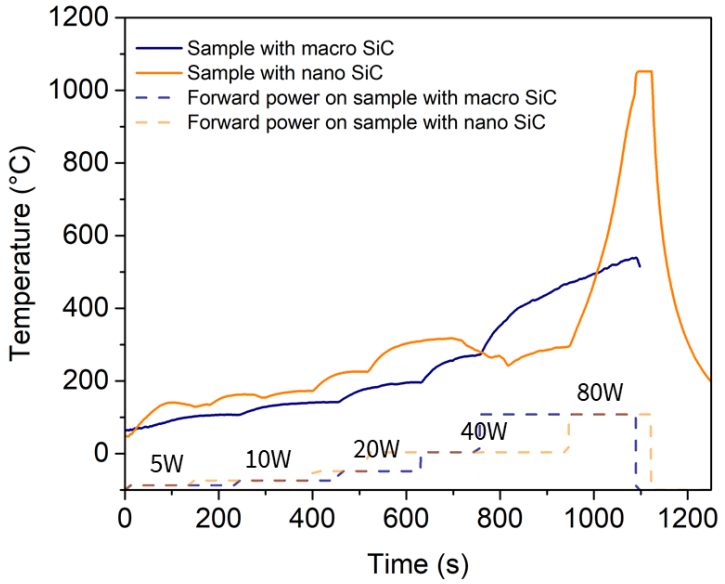


Sealing material



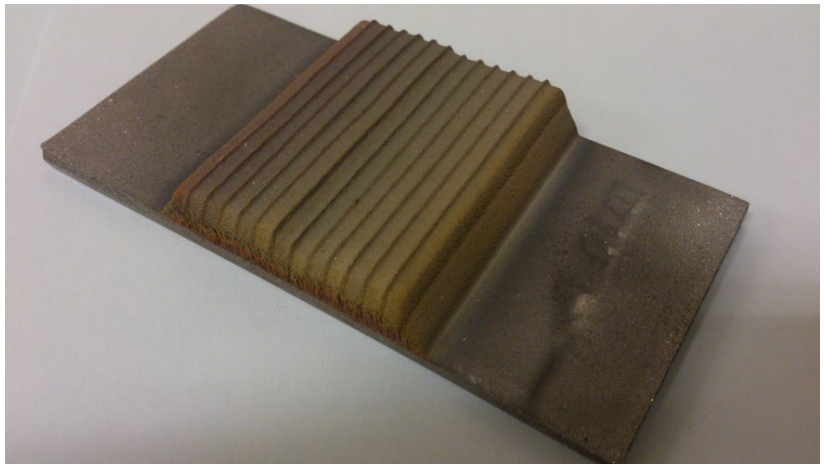


Microwave heating



CANISTER MATERIALS: METALLIC COATINGS

- **Optimisation of established techniques**
  - Cold spray Cu vs. Cu/Al_2O_3

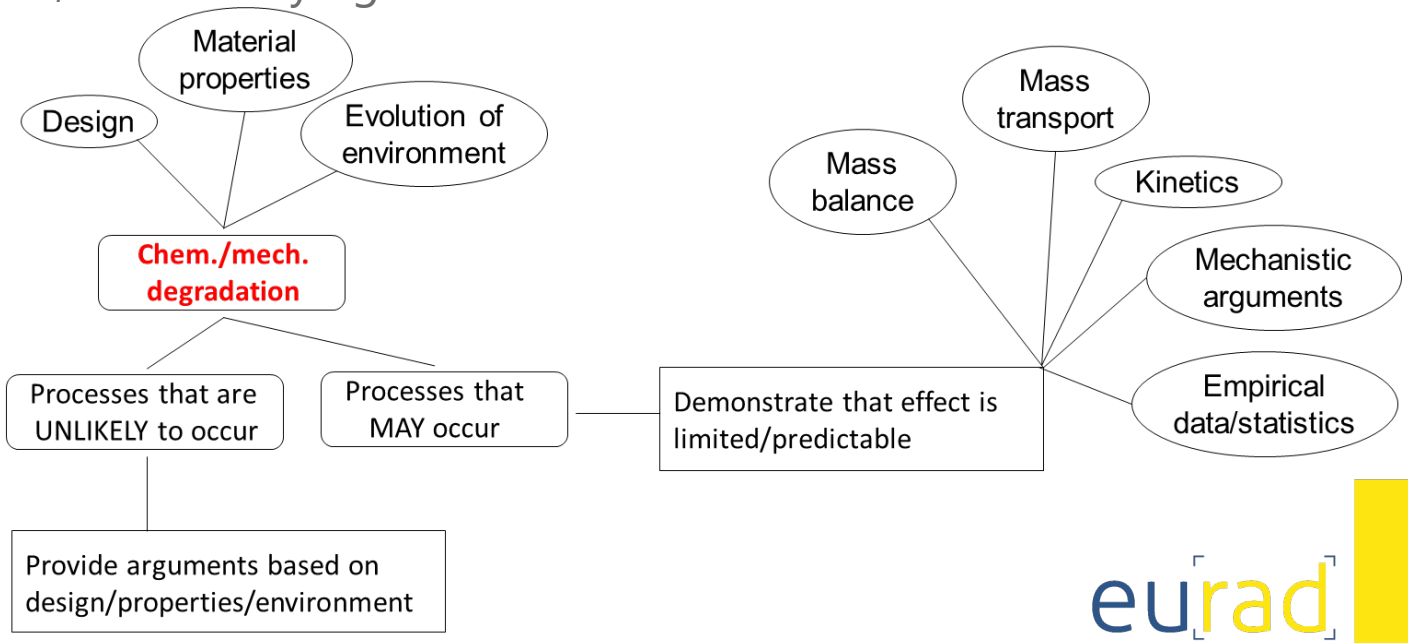


- **Alternative techniques and materials**
  - PVD of Ti, Cr, Cu

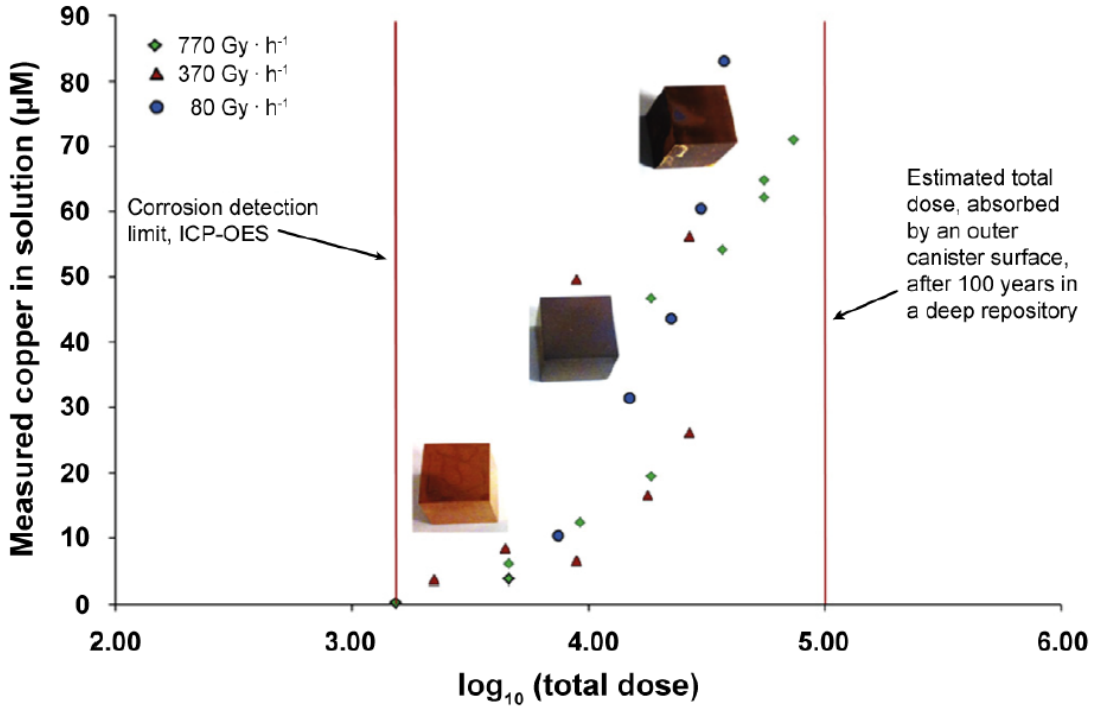
AIMS OF WP CONCORD - 2

Deepen the understanding of coupled interfacial processes influencing container performance under repository-relevant conditions, with a focus on:

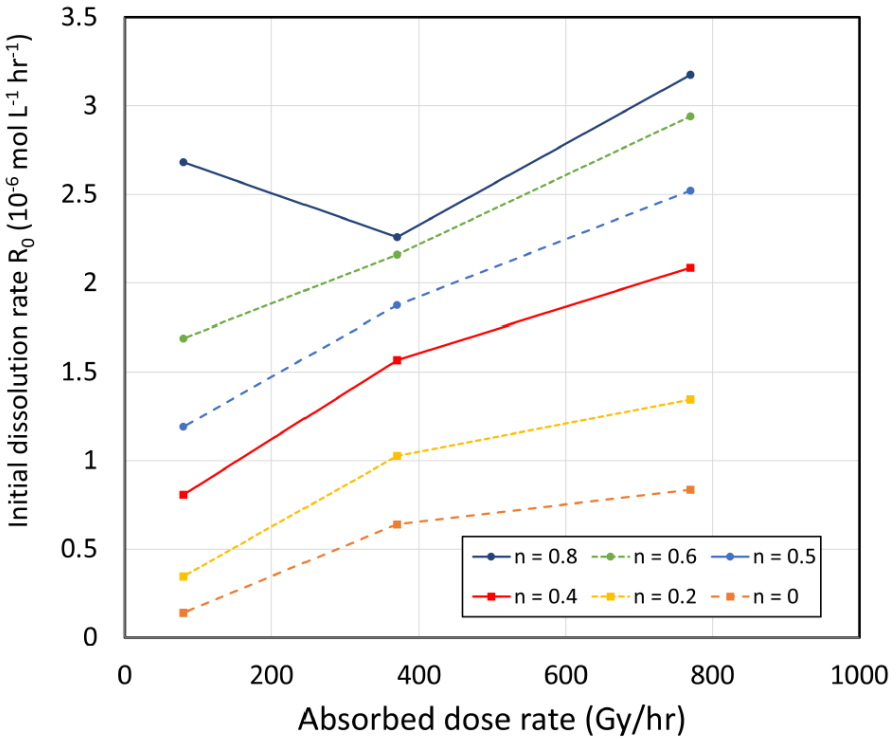
- irradiation-accelerated corrosion,
- microbially-influenced corrosion
- degradation during nearfield transients, and at varying scales.



COUPLED PROCESSES: IRRADIATION-ACCELERATED CORROSION



or?



COUPLED PROCESSES: IRRADIATION-ACCELERATED CORROSION

Duration of experiment (Hrs)	Dose Rate (Gy h^{-1})								
	0.0	0.1	0.2	1	2	10	20	100	1000
	Total irradiation dose (kGy)								
1	0 (S, C)								1 (S)
10	0 (S, C)							1 (S)	10 (S)
100	0 (S, C)					1 (S, C)		10 (S, C)	100 (S)
1,000	0 (S, C)			1 (S,C		10 (S, C) + 2 with ben (S,C)		100 (S, C)	
5,000	0 (S, C)		1 (S, C)		10 (S)		100 (S)		
10,000	0 (S, C)	1 (S, C)		10 (S,C)		100 (S, C)			

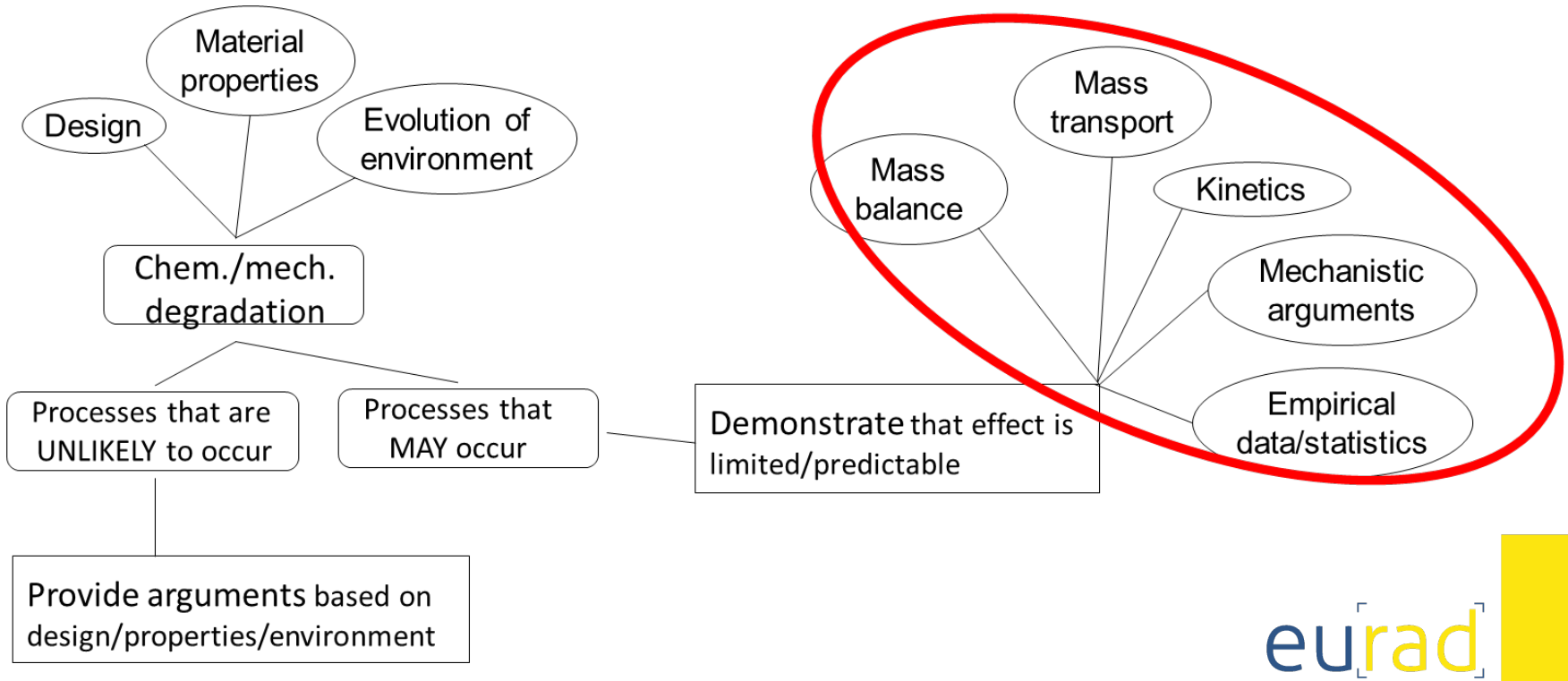
S: steel. C: copper. Number in cell: total dose (kGy)

Sealed under Ar

Head space for H_2

AIMS OF WP CONCORD - 3

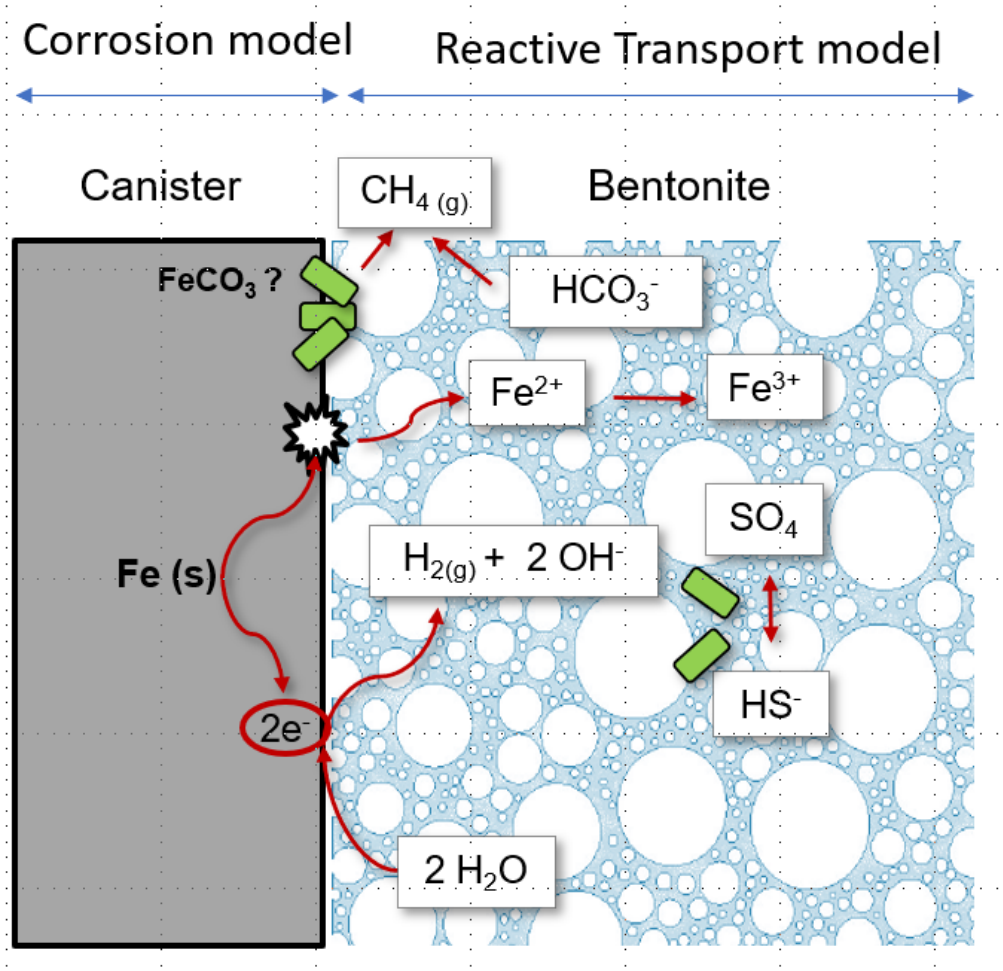
Support performance assessment by demonstrating mechanistic understanding and by developing predictive models.



MODELLING & PA

- **Pairing of modellers with experimental teams for interpretation of results**
  - Model experiments based on pre-existing models

- **Integration for lifetime prediction by**
  - Extending models to repository scales
  - Integrating new knowledge from ConCorD
  - Provide underpinning argumentation and refined modelling tools for performance assessment



CONCLUSIONS & OUTLOOK

- **Several aspects of SF/HLW disposal canisters have optimisation potential**
- **Progress in science and technology is expected to lead to increased canister lifetimes and reduced uncertainties/conservatism**
- **Our confidence in make long-term predictions can increase through improved scientific understanding and modelling tools**
- **EURAD WP ConCorD will:**
  - Explore the potential of novel materials and processes for the optimisation of long-term container performance
  - Assess whether and how irradiation influences the corrosion of canister materials under disposal conditions
  - Improve the understanding of the role of microbes in corrosion in the context of nuclear waste disposal
  - Study canister material corrosion during redox, hydraulic, and thermal nearfield transients
  - Synthesize newly acquired knowledge into a form applicable for container performance assessment

THANK YOU FOR YOUR ATTENTION

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