Alternative coatings as corrosion barriers for SF/HLW disposal canisters

N. Diomidis

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Nagra's canister development strategy

- The time to repository implementation is long (~2055): maximum advantage should be taken of developments elsewhere
  - Options should remain open until ~2035 (Application for repository construction license in ~2045).

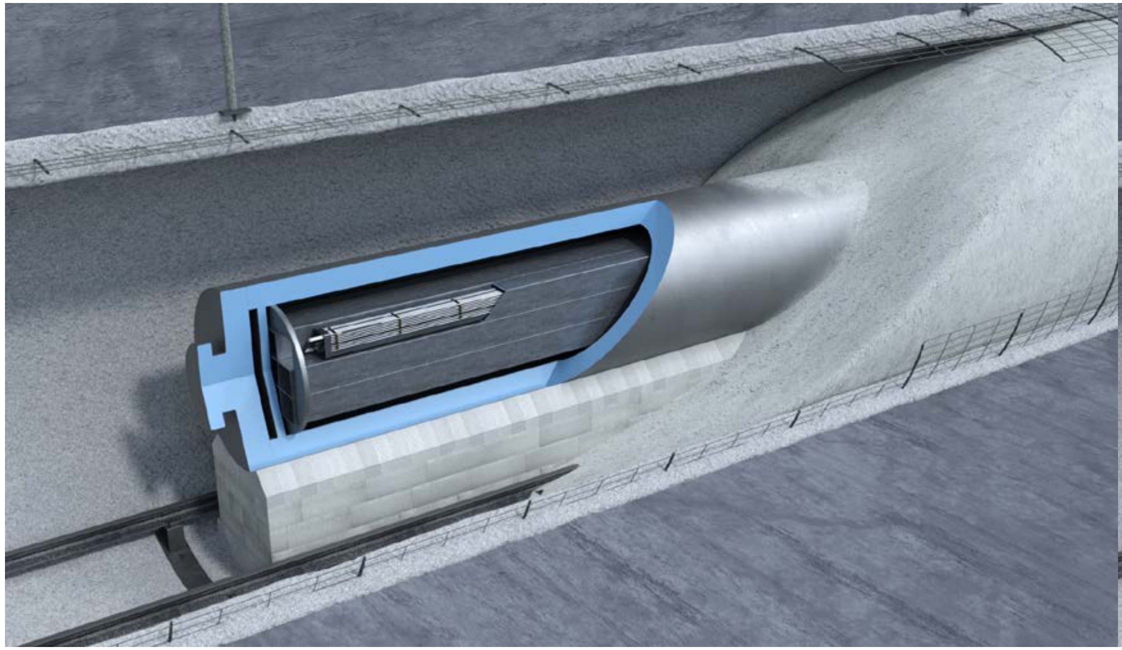
- Main objectives for general license application (RBG) (~2024):
  - Ensure that a **broad range of options** is adequately considered
  - Demonstrate **feasibility** of materials choices and concepts
  - Provide evidence that **operational** and **long-term safety** can be assured

Main candidate canister concepts in Switzerland

Carbon steel canister

Lifetime: **10’000** years

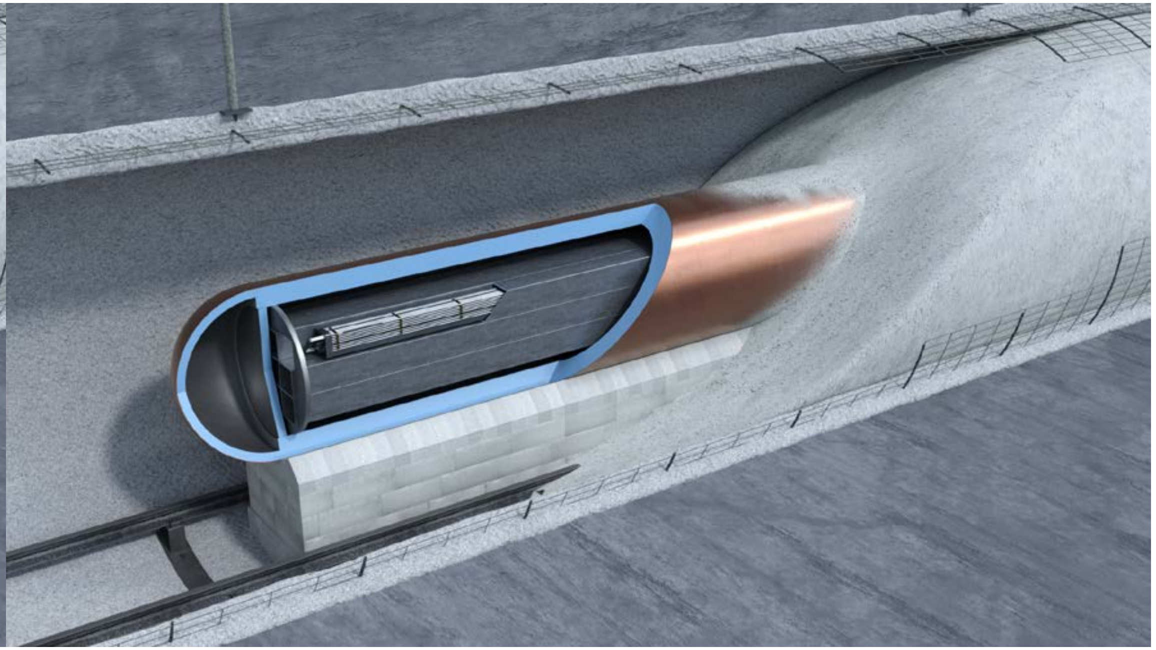
Reference concept for RBG



Copper-coated canister

Lifetime: **100’000** years

Main **alternative** for RBG



- Selection was the outcome of a broad options study (NAB 14-90)

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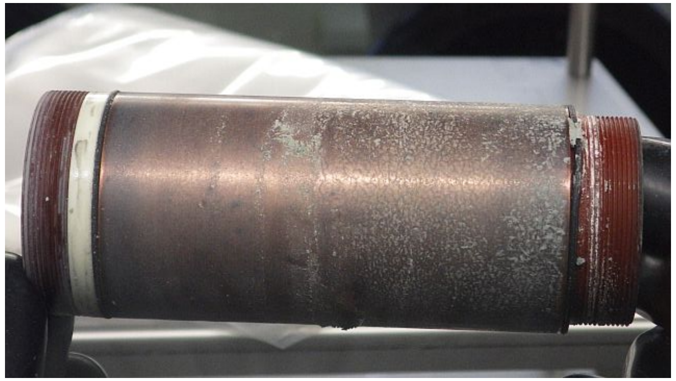
Copper-coated SF/HLW disposal canister

- Collaboration with NWMO on Cu coating development since 2012
  - Electrodeposition & cold spray coatings: full scale prototypes
  - Detailed benchtop electrochemical studies
  - Exposure to porewater simulants with Cl^-, HS^- etc.

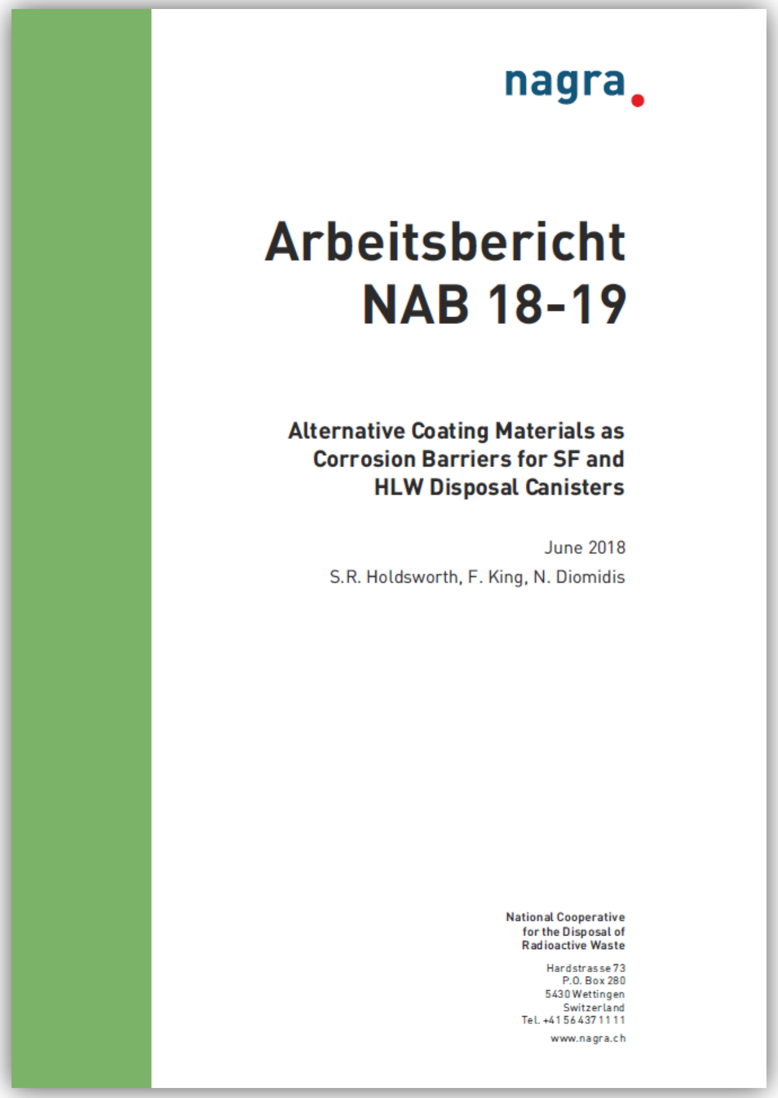


- Long-term *in-situ* corrosion experiments in Swiss URLs

- Cu's Achilles' heel: MIC
  - **What if** bentonite emplacement density cannot be guaranteed?
  - Bentonite blocks can be QC'd on he surface, but granular bentonite not.

Assessment of Ni, Ti & ceramics for coating a steel substrate

- Suitability and international experience
  - Rad waste and other industries
- Mechanical integrity
  - Tensile strength, fracture toughness, creep
- Resistance to environmental damange
  - General corrosion, localised corrosion, MIC, environmentally-assisted cracking, effect of irradiation, galvanic
- Coating solutions – manufacturing at scale
  - Outer shells, plating, spraying, weld overlay,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Arbeitsbericht
NAB 18-19

Alternative Coating Materials as Corrosion Barriers for SF and HLW Disposal Canisters

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S.R. Holdsworth, F. King, N. Diomidis

National Cooperative for the Disposal of Radioactive Waste

Hardstrasse 73
P.O. Box 280
5430 Wettingen
Switzerland
Tel. +41 56 437 11 11
www.nagra.ch

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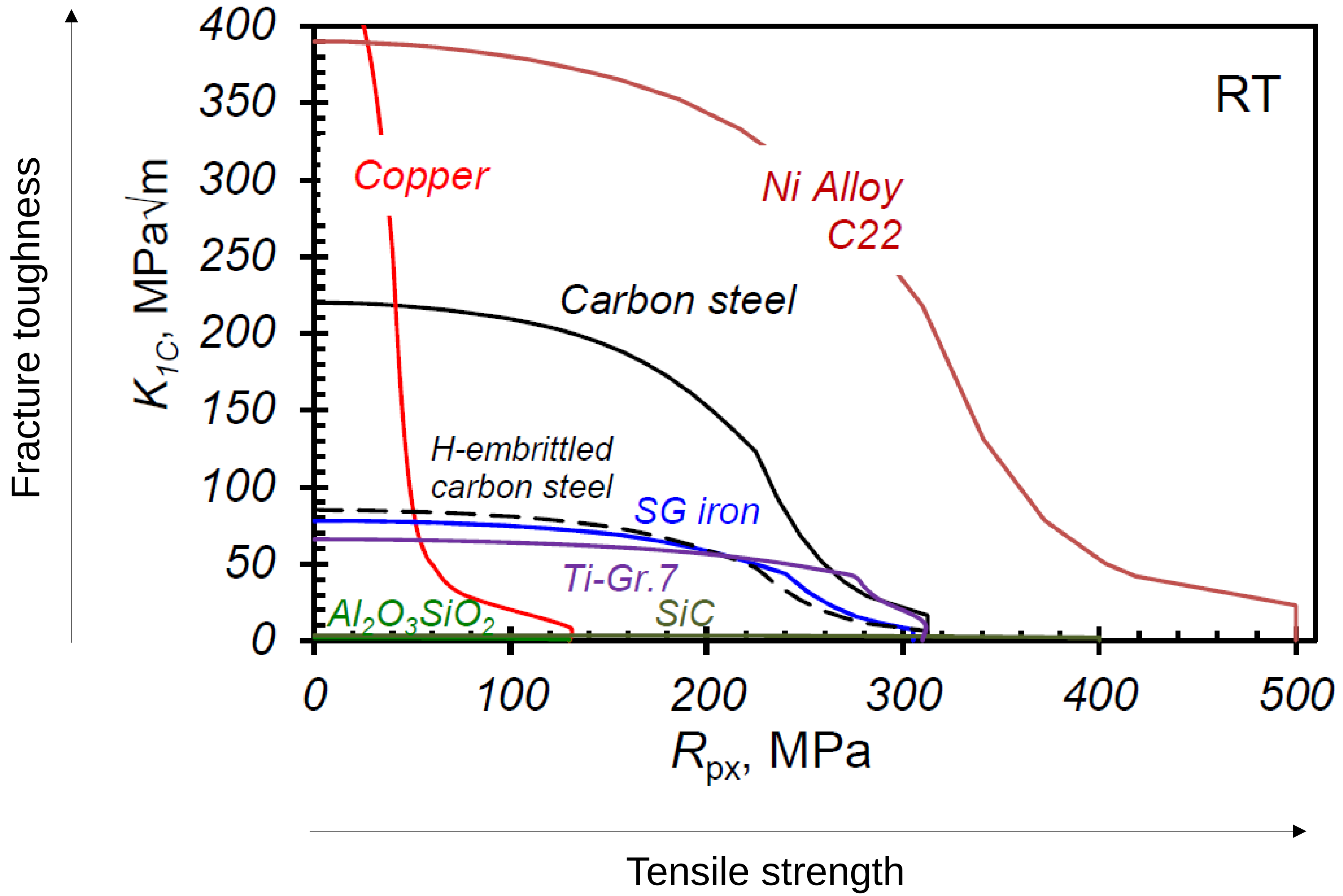
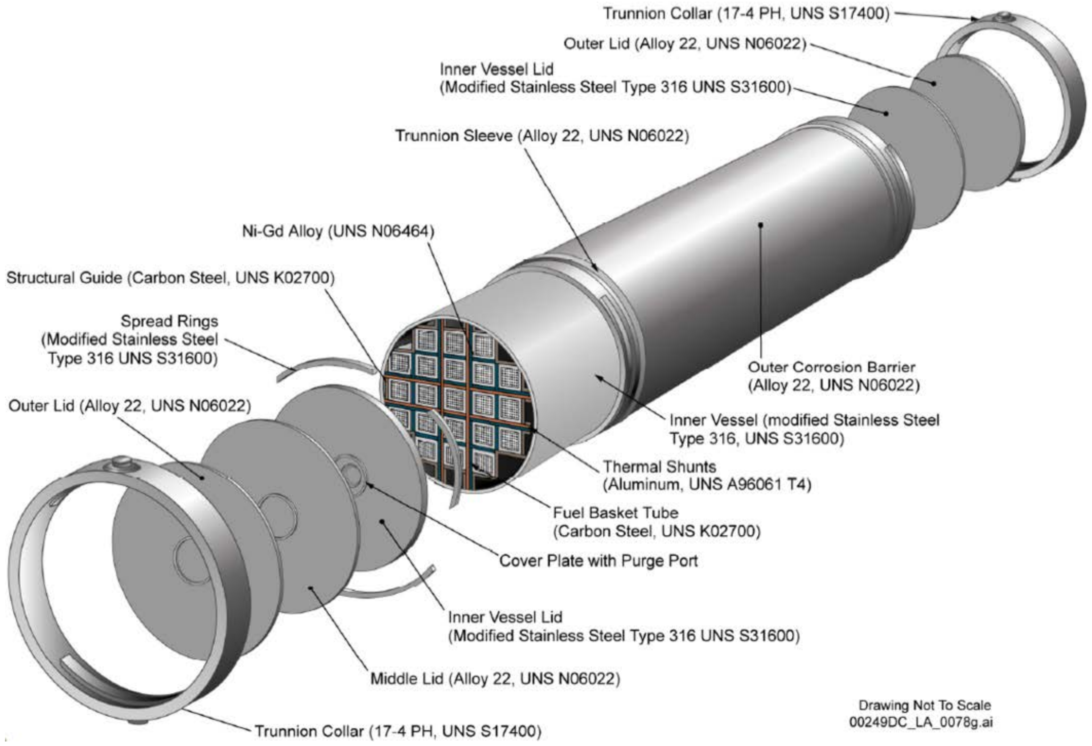
Overview of mechanical properties of candidate materials



Ni alloys I

- Yucca Mountain (C-22) & Canada, Belgium, Germany (backup, no detailed designs)

- NiCrMo (+Co/W?) alloys can provide very good corrosion resistance
- Localised corrosion (e.g. by S) is main concern for thin coatings: high PREN e.g. C-4, C-22, C-276
- General corrosion ~10’s nm/yr
- Immune to SCC and HIC in repository
- Susceptible to MIC (enhancement of general corrosion by empirical factor ≤2 in YMP)
- Enhancement of general corrosion by irradiation x4 for 10-100 Gy/hr (not for 1 Gy/hr)



Ni alloys II

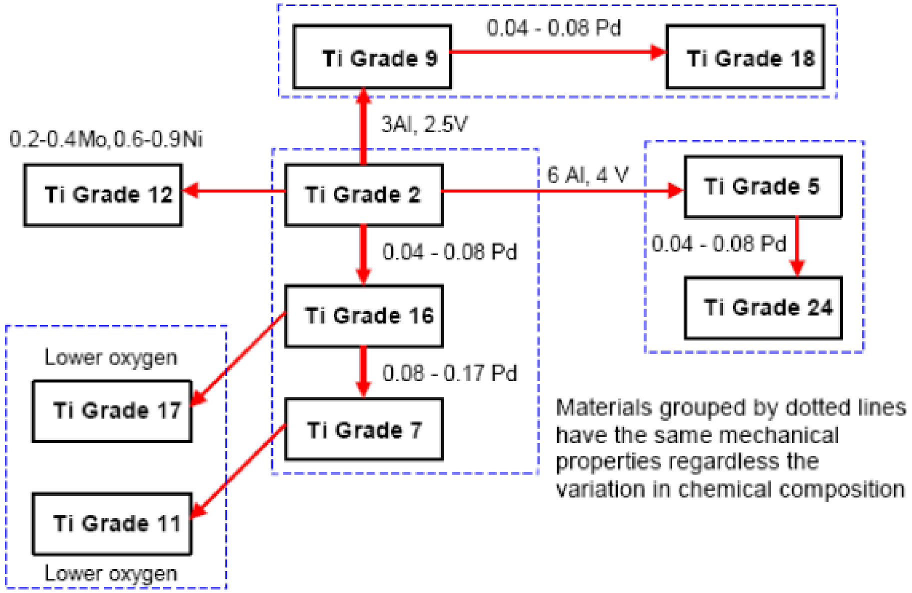
- Cladding big steel pressure vessels with Ni alloys is standard industrial practice (petrochemical & food industries)

- Outer shells (like YMP) feasible, final seam weld does not need PWHT, thickness and metallurgical condition are uniform, no risk of creep
- Different types of thermal spray and weld overlay processes possible
- The optimum solution in terms of metallurgical quality and cost appears to be provided by laser cladding an alloy such as C276 for which off the-shelf powder is readily available.
- HVOF can be an alternative method providing high metallurgical quality

Ti alloys I

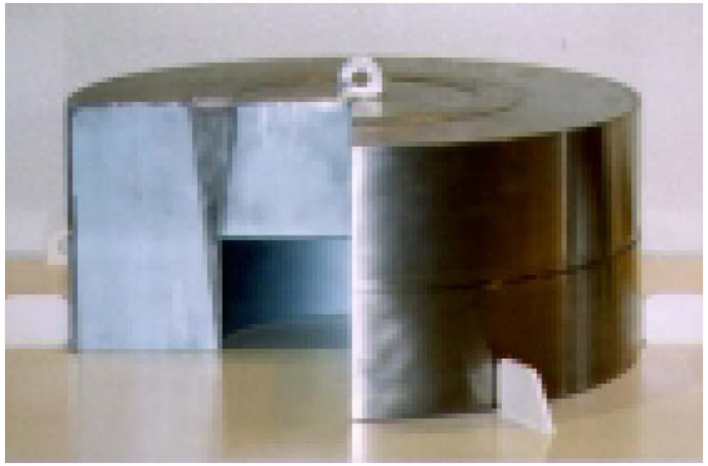
- AECL (Ti Gr.2), Japan, Sweden, YMP drip shields (Ti Gr.7)

- Very low general corrosion ~1nm/yr
- Extremely resistant to pitting, Pd alloys resistant to crevice corrosion
- Immune to MIC
- Very resistant to SCC (immune under repository conditions)
- Susceptible to HIC (slow H2 absorption during general corrosion)
- No effect of irradiation on corrosion properties
- Susceptible to creep at room temperature
- Embrittlement due to Fe contamination: no welding or thermal coating processes



Ti alloys II

- Most promising way of manufacturing is the Japanese solution of a shrunk-on out sleeve
- The flat ends were explosive-bonded and welded.
- Cold spray is a promising alternative coating method, porosity levels to be confirmed

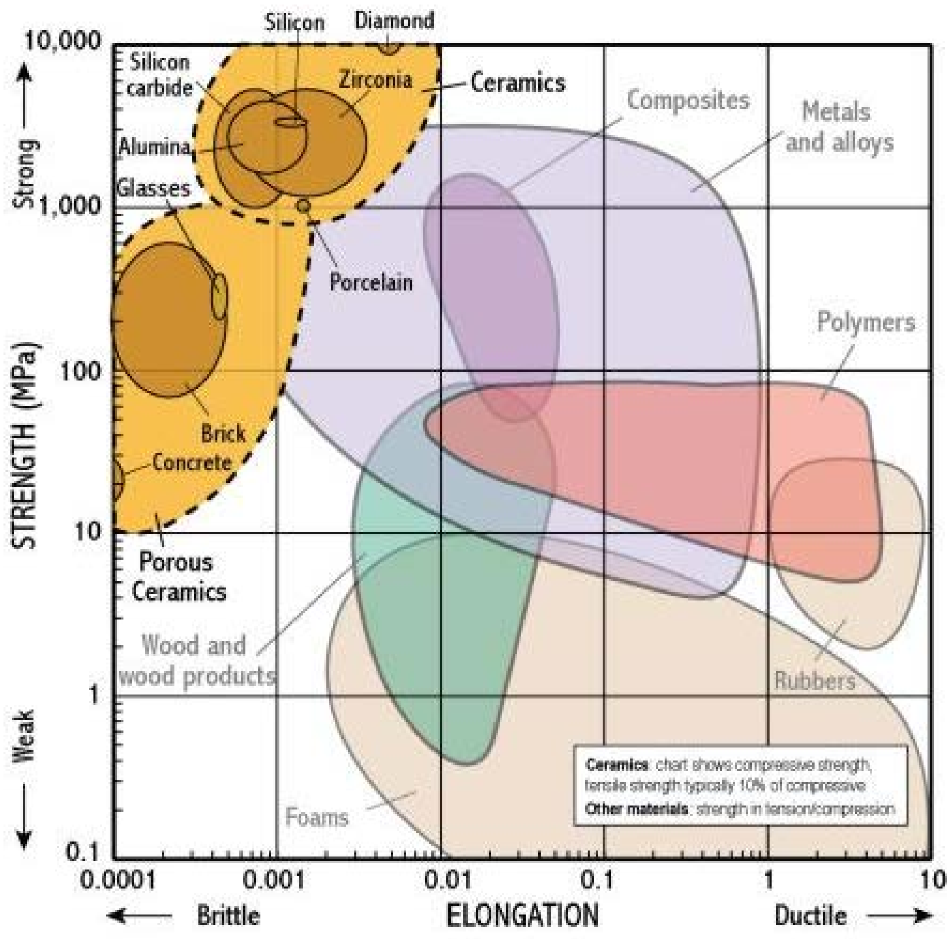


Ceramics I

- Considered in Sweden, France & Germany but as bulk materials

- Coating challenges:
  - Mechanical properties, Weibull modulus
  - Porosity (<2%)
  - Uniform thickness (>3mm)
  - CTE (<10^{-6} /°C vs. substrate)

- General not immune to environmental damage
  - Weight change, intergranular corrosion, leaching
  - Generally immune to MIC



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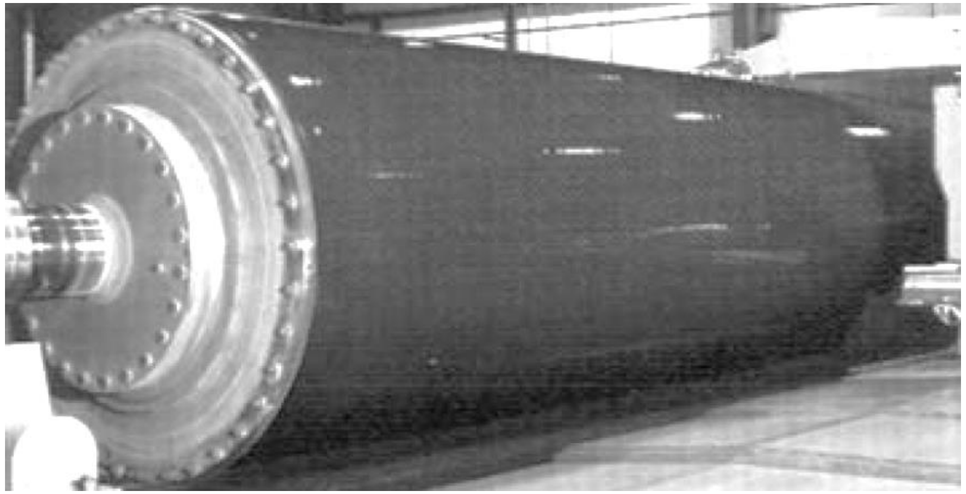
Ceramics II

- Thermal barrier coatings (aerospace, land-based turbines), automotive, paper & printing



- Numerous thermal spray techniques used
  - Plasma, DGUN, combustion, HVOF

- Final sealing, coating repair and inspection to be

Evaluated

- Strongest candidates:
  - ZrO_2-Y_2O_3 (YSZ)
  - Al_2O_3-TiO_2 graded multi-layer coating

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Conclusions

- Long-term corrosion data and natural/archaeological analogues are lacking for all materials
- Ni
  - Widely used for corrosion protection, mature manufacturing technology
  - Resistant to MIC but not immune.
  - Uncertainties on mechanisms and rates would be eliminated by the use of a different material
- Ti
  - Immune to MIC
  - Very low general corrosion, high resistance to irradiation, certain alloys immune to localised corrosion
  - But creep at room temperature and embrittlement by Fe and H_2
  - H2 embrittlement unavoidable, but predictable
- Ceramics
  - Less mature than metallic coatings
  - Issues with inherent brittleness, CTE mismatch, large thickness and low porosity needed
  - Promising materials exist, research investment required

thank you
for your attention