SAND2023-04967C

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PATRAM 2023
Proceedings of the 20th International Symposium on the Packaging and Transportation of Radioactive Materials
June 11-15, 2023
Juan-les-Pins, France

First Do No Harm:

A Wholistic Approach to Identifying Feasible Commercial Corros Mitigation Coatings for Use on Spent Nuclear Fuel Storage Can

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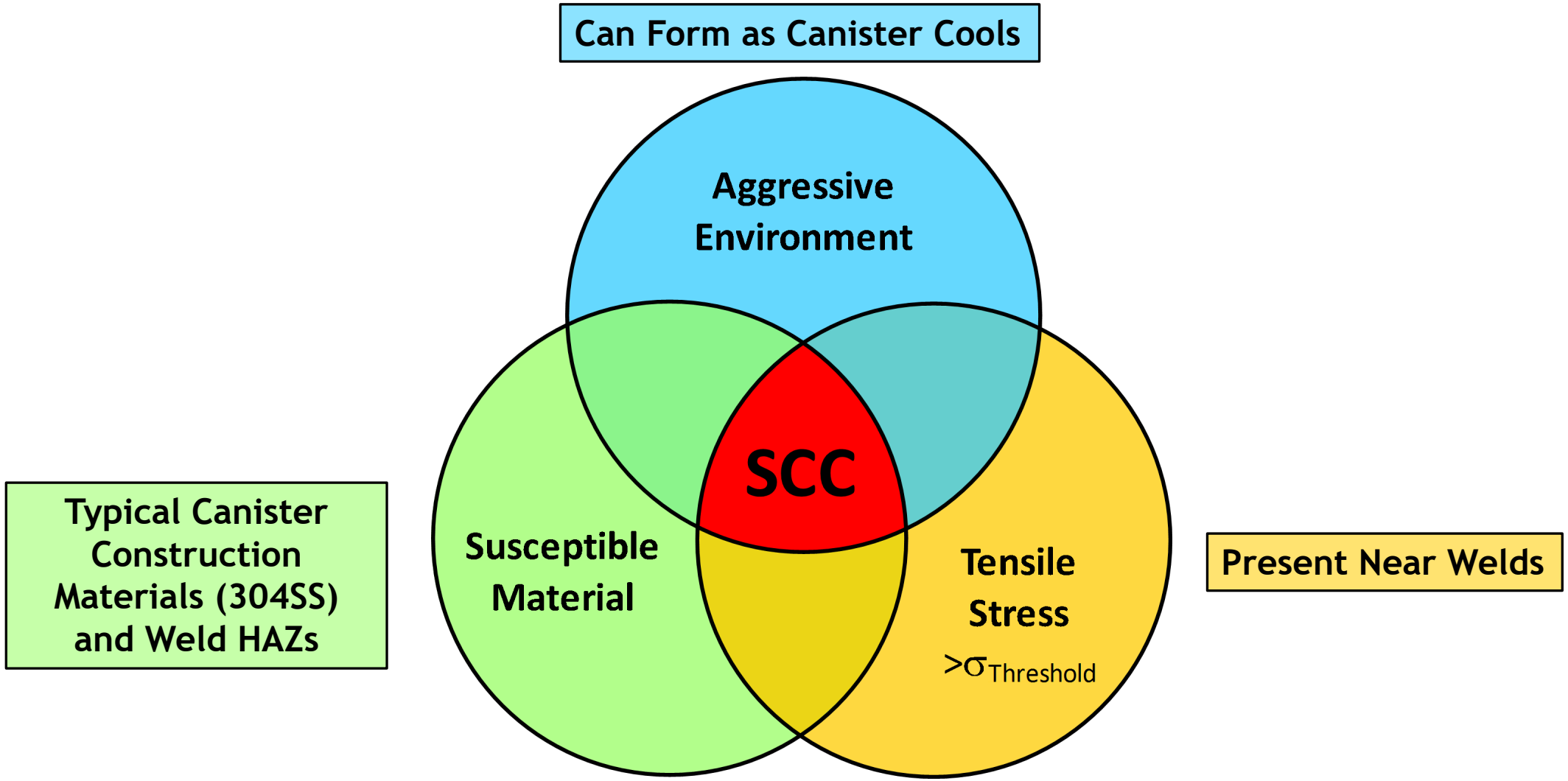
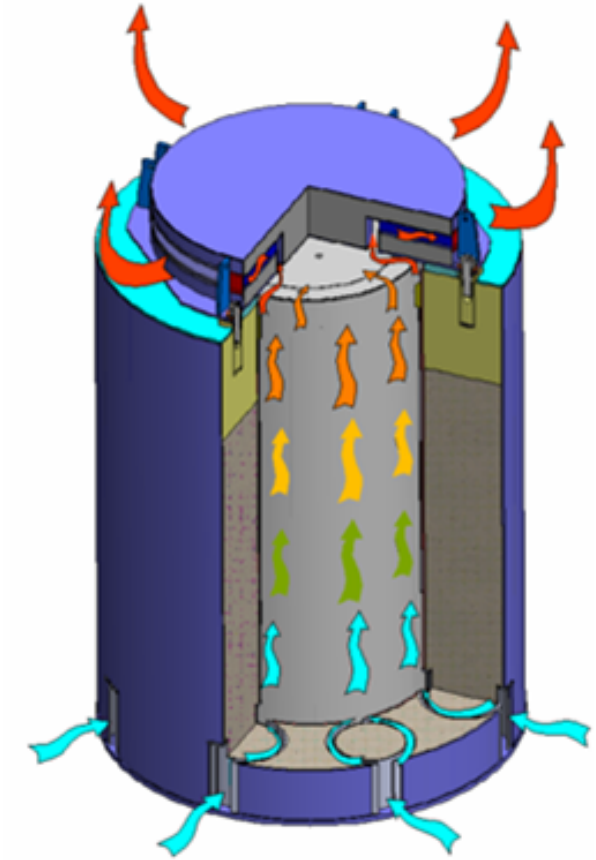
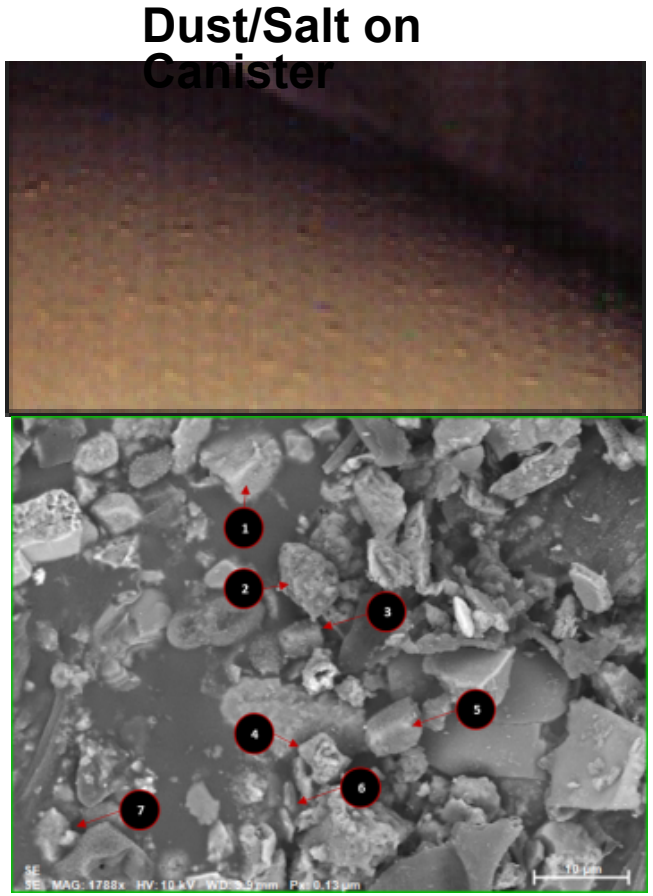
Conditions for SCC Exist in Interim Storage Environments



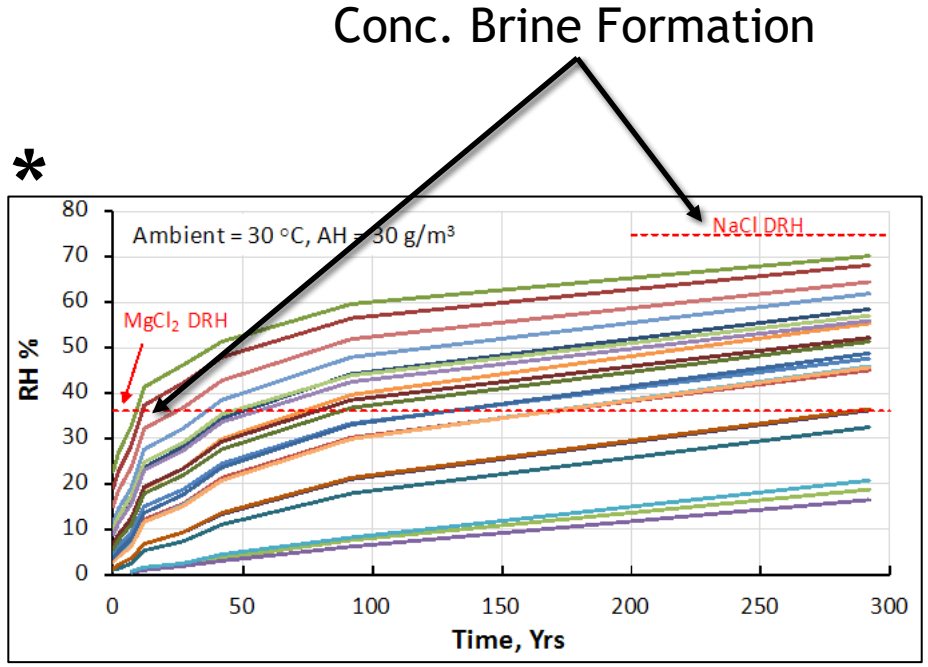
Precursor to possible SCC: Formation of Brine



Canister is passively cooled, convection pulls in ambient air (occurs in horizontal and vertical storage systems)



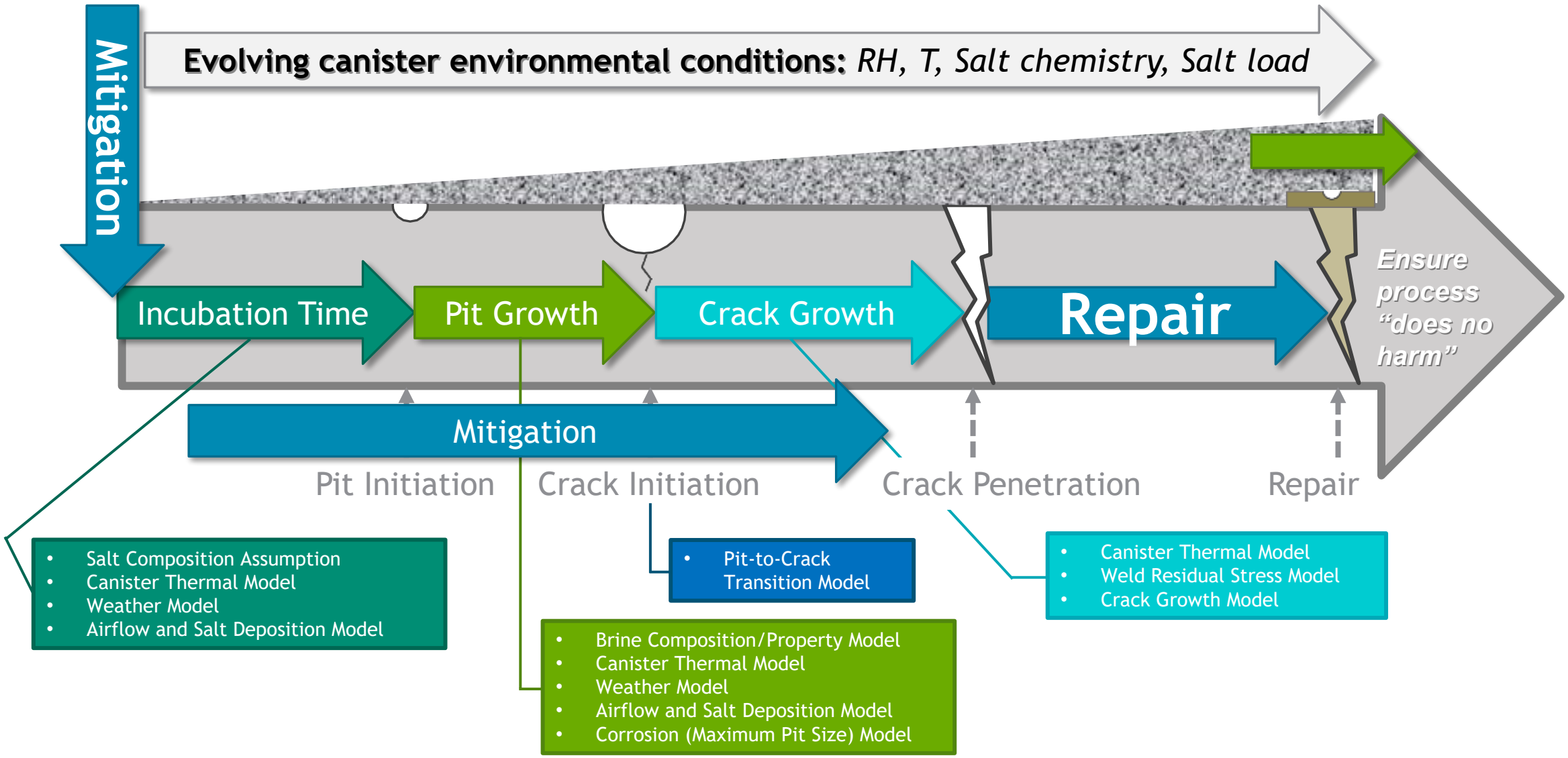
As canister cools, salt and dust is deposited on canister



Eventually, deliquescence occurs and brine forms on surface of canister.

*Figure assumes a seawater brine will deliquesce, actual chemistry will vary.

Corrosion Research Continuum



Sandia has ongoing research thrusts across entire canister corrosion continuum

Repair of SNF Canisters Has Challenges

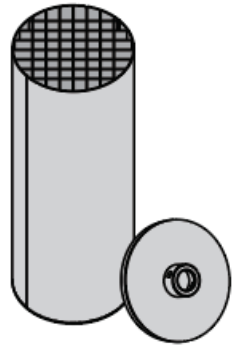
First Do No Harm:
Coating must not introduce additional hazards or risk to the storage system

WHEN a repair is performed determines **WHAT** conditions a coating will have to survive & **HOW** it can be applied

Ex Situ Prevention

Advantages
Unlimited Access
No radiological hazards
Full Coverage Coating

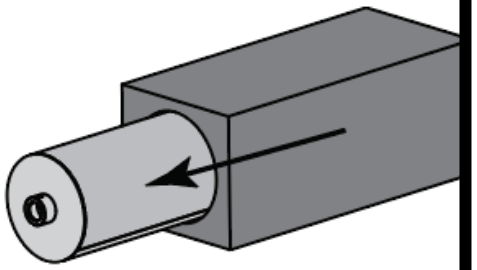
Challenges
Toughest Survability Reqs.
N/A for Existing Canisters



Ex Situ Repair

Advantages
Good Access
Full Coverage Repair
Applicable to Existing Canisters

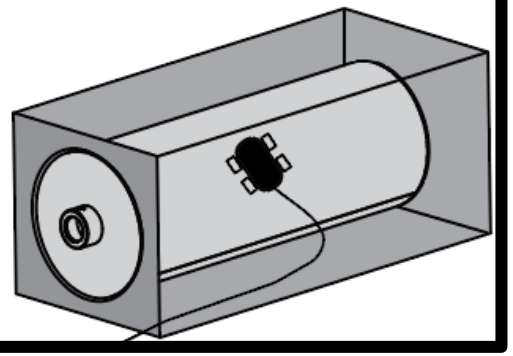
Challenges
Potential Exposure Risk
Additional Cost of Removal
Few Cleaning/Coating Options



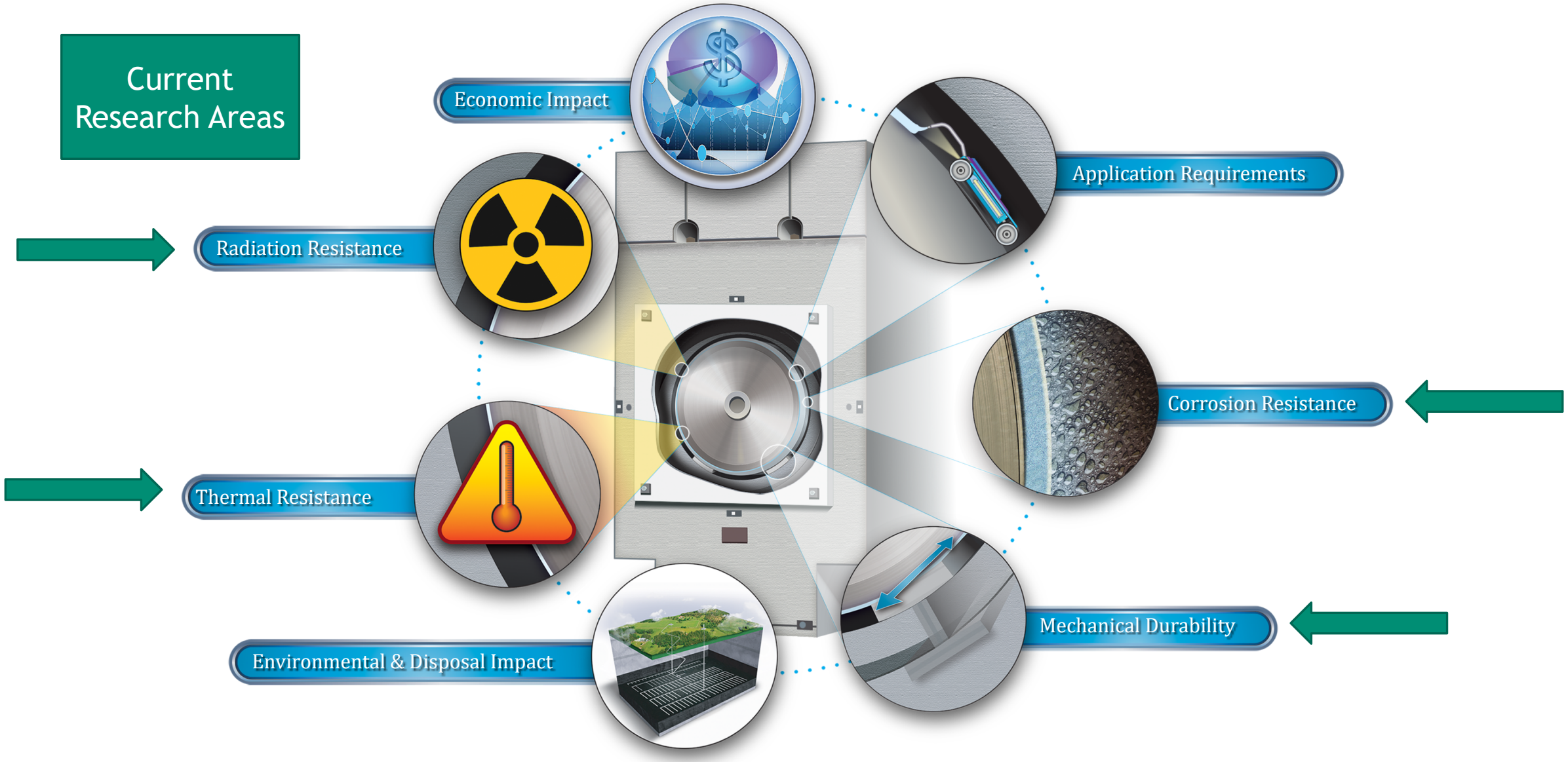
In Situ Repair

Advantages
Applicable to Existing Canisters
Low Exposure Risk
Lowest Survivability Reqs.

Challenges
Limited Canister Access
Few cleaning/coating options
Partial Coverage Repair

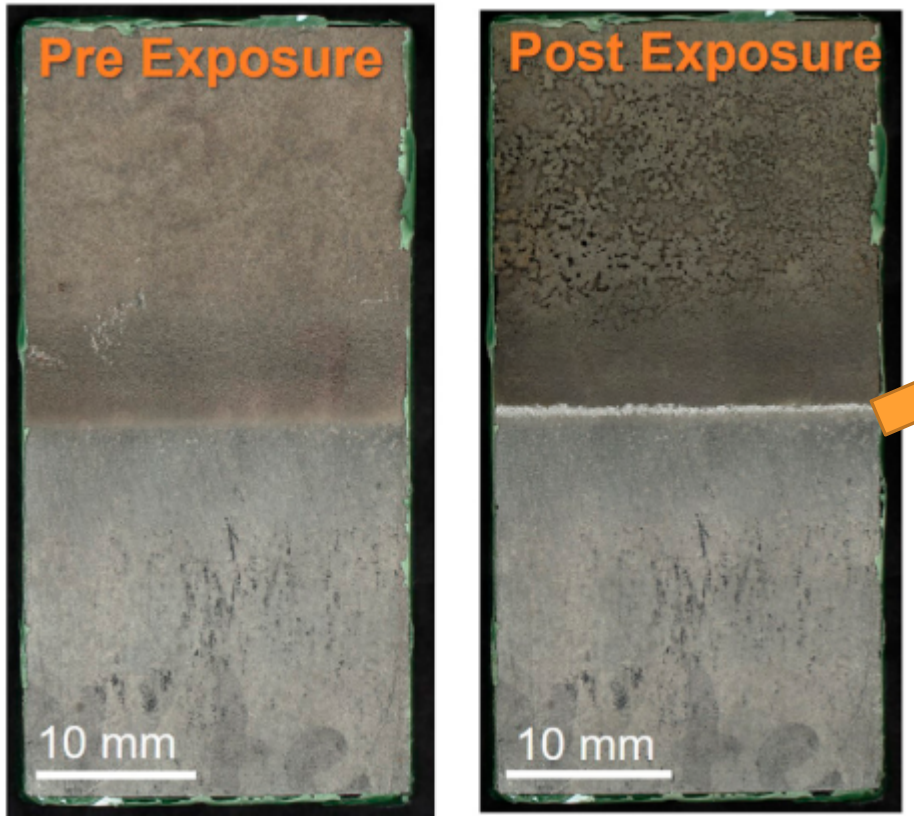


Wholistic Approach to SCC Mitigation and Repair

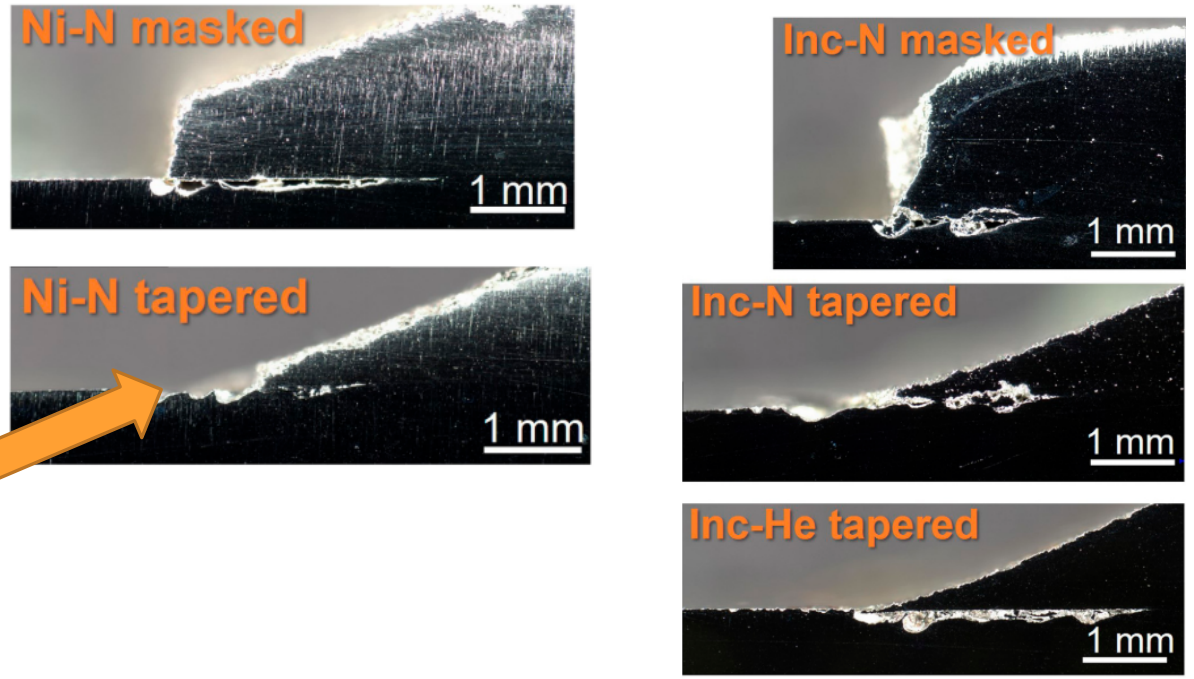


Previous Work - Cold Spray

Ni-N Tapered Pre/Post Ferric Chloride Exposure



Undercutting after Ferric Chloride Testing



In accelerated ferric chloride tests, factors such as the surface roughness, coating porosity, the interface type (tapered or masked) and the amount of deformation in the substrate influenced the corrosion behavior of the cold spray. Careful alloy selection did not eliminate corrosion in accelerated testing.

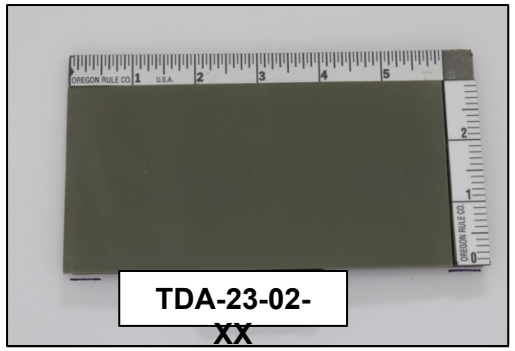
Karasz, E. K., Montoya, T. D., Taylor, J. M., Ross, K. A., & Schaller, R. F. (2022). Accelerated corrosion testing of cold spray coatings on 304L in chloride environments. *Frontiers in Metals and Alloys, 1*. doi:10.3389/ftmal.2022.1021000

Candidate Coatings

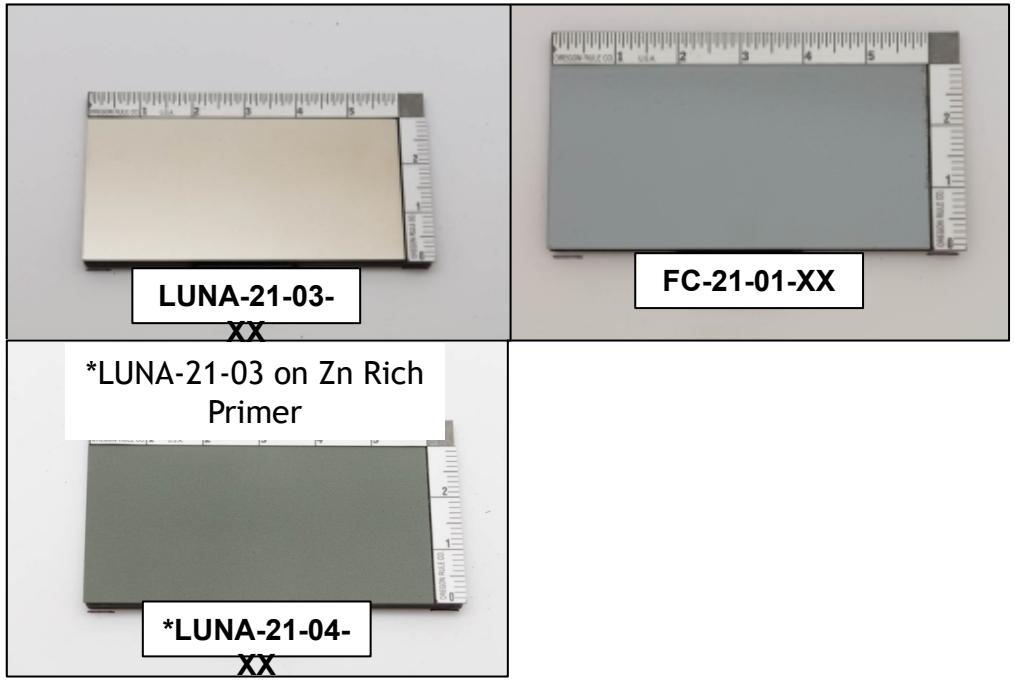
13 coating variants from 5 commercial coatings manufacturers.
Down selected to 8 variants in 2023.

Naming Convention
COATING-YEAR-VARIANT#-COUPON#

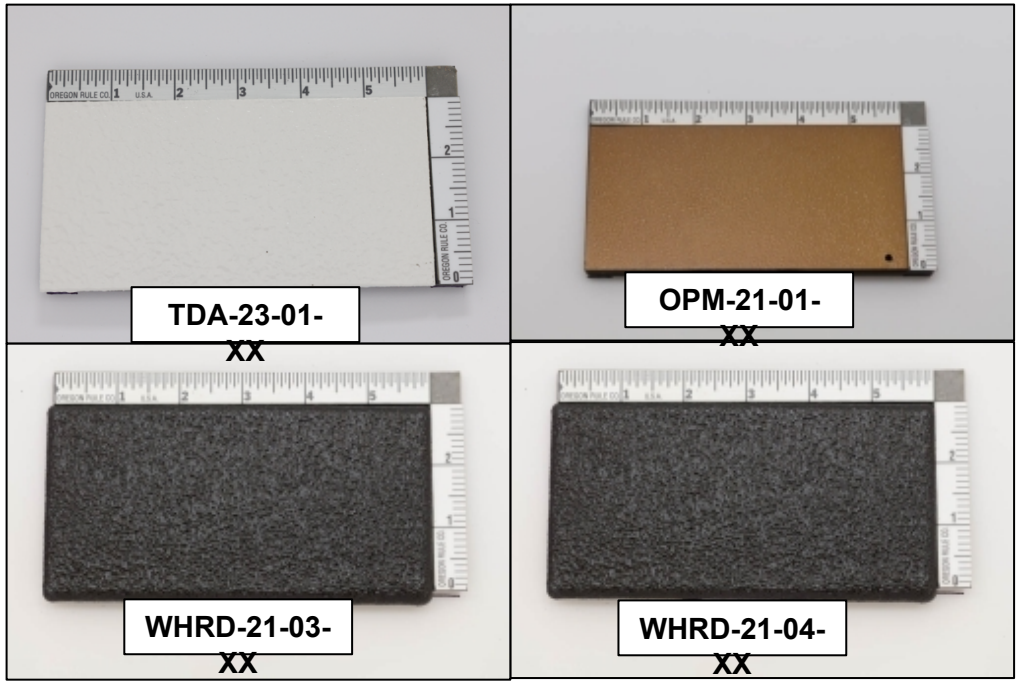
Bare Zn Rich Primer(1)



Ceramic Hybrid (3*)



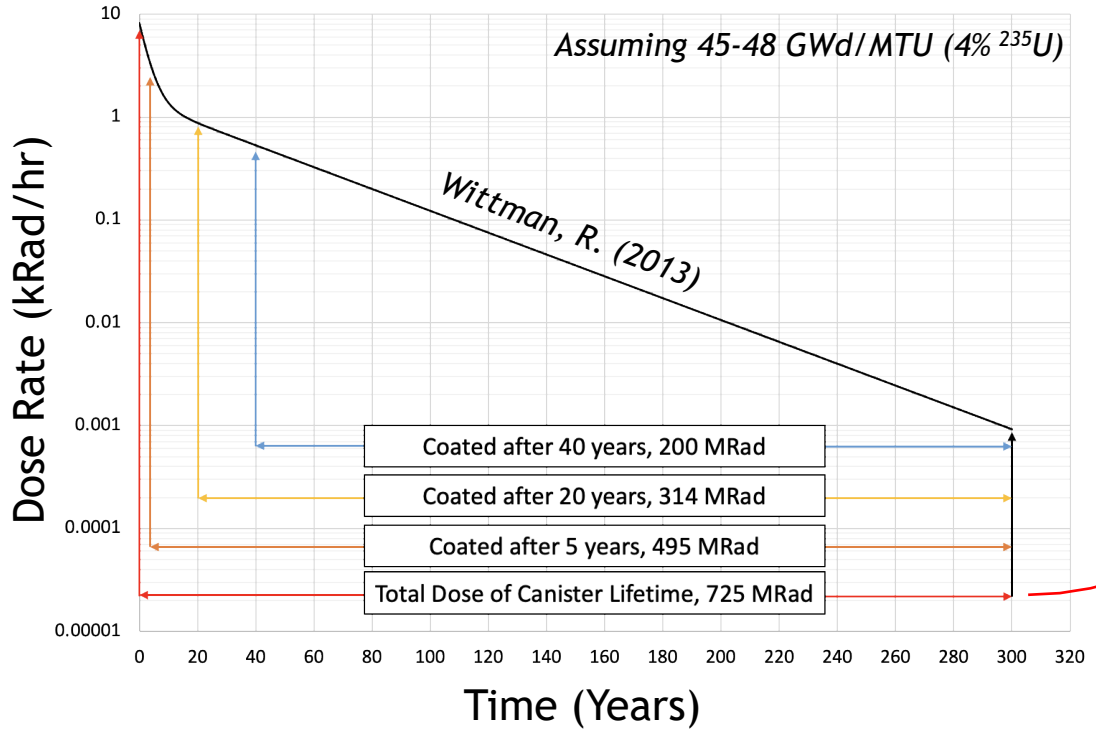
Polymeric (4)

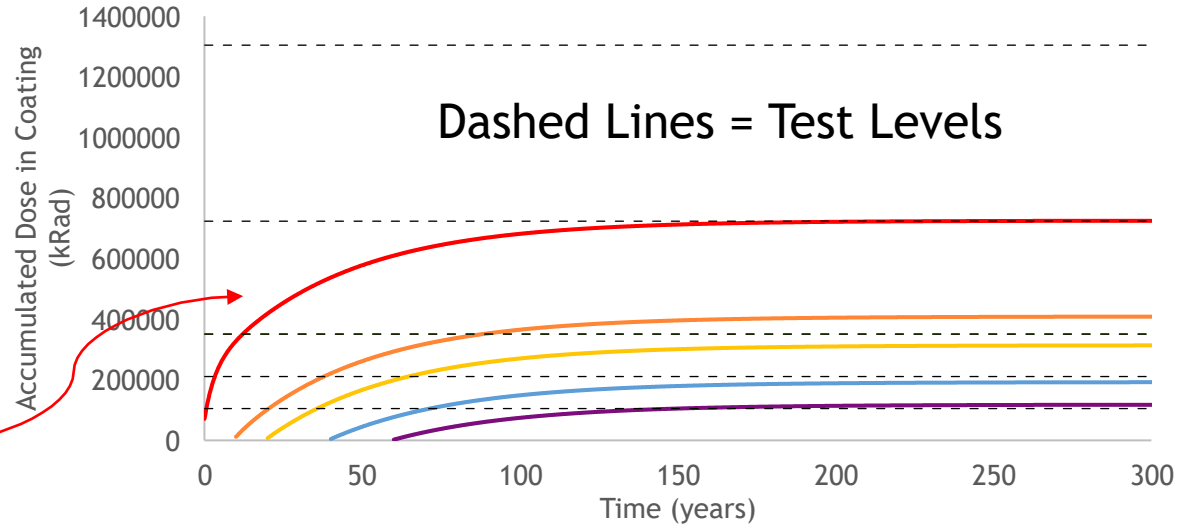


Knight, A. W. et al., FY21 Status Report: SNF Canister Coatings for Corrosion Prevention and Mitigation. 2021
M3SF-21SNN010207062

When to Repair?

WHEN coating is applied in canister lifetime ⟶ determines WHAT radiolytic dose it receives



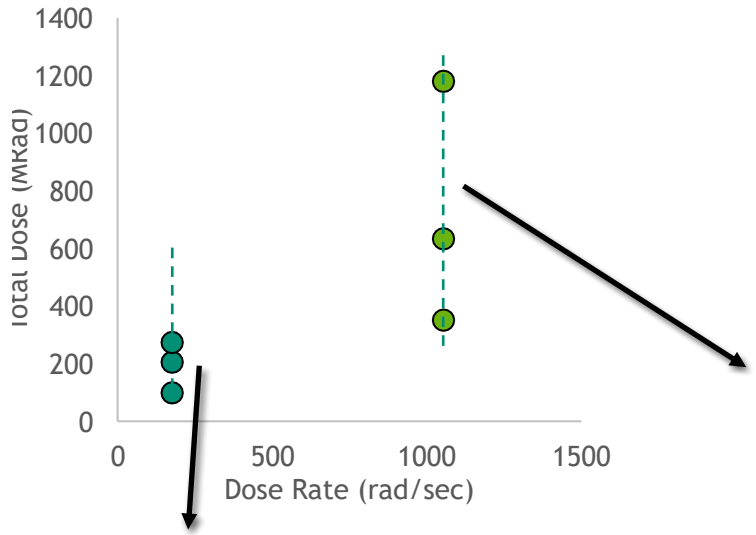


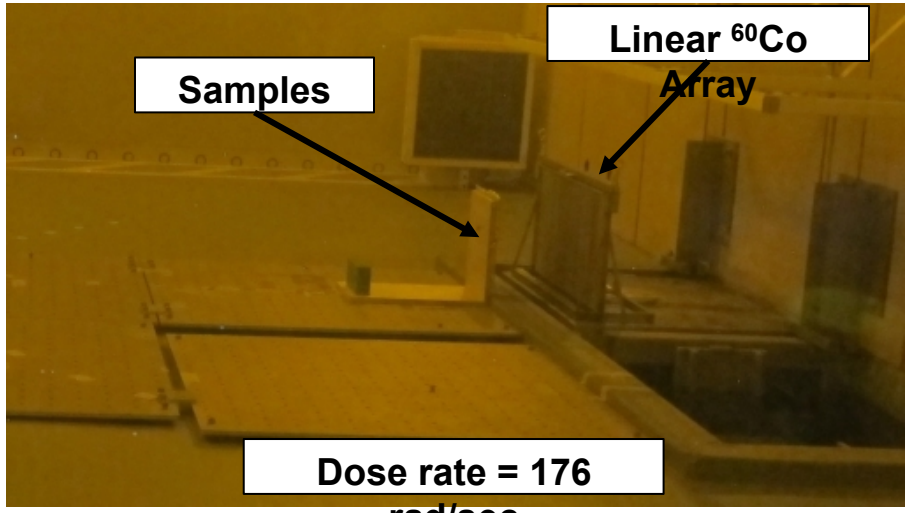
Other properties of coatings also play a role in determining when prevention or repair should be deployed (e.g. mechanical and thermal resistance)

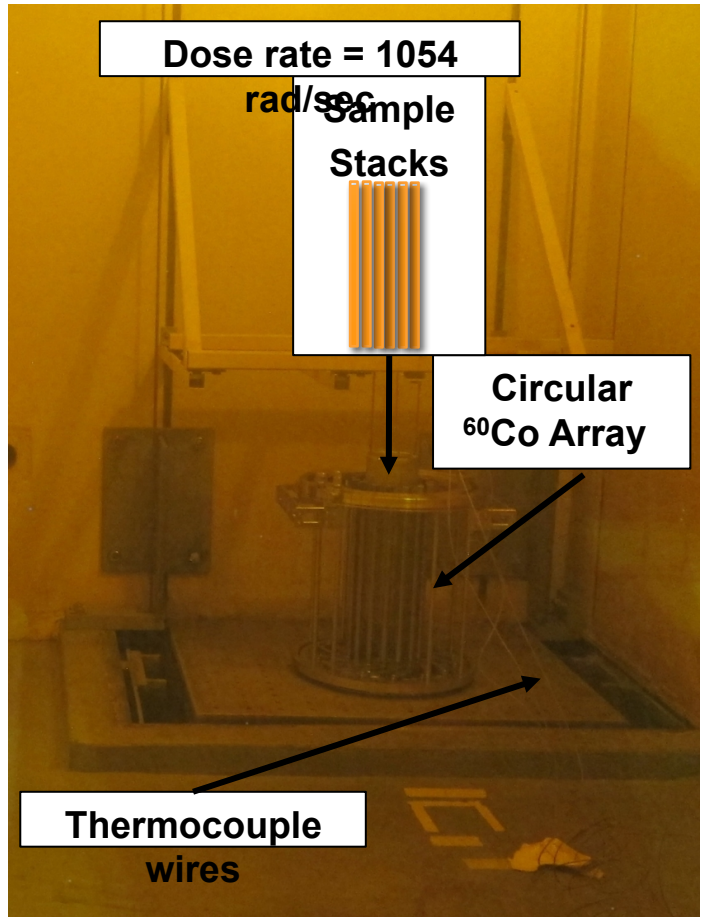
Radiolytic Exposure Setup & Design

Two dose rates (176 rad/sec & 1054 rad/sec) were used to achieve 5 different doses.

Wood Mounting Fixtures





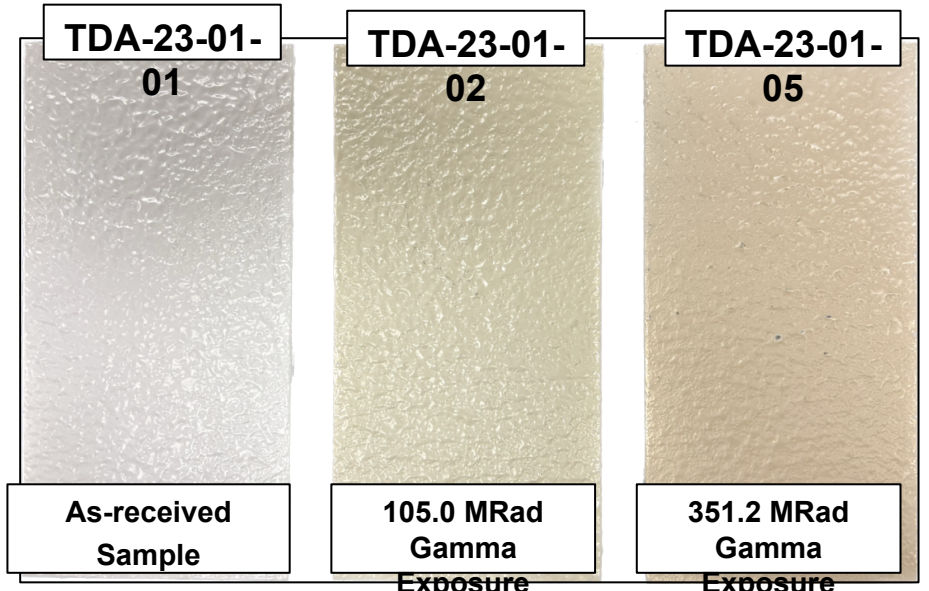


Putting Radiolytic Exposure In Perspective

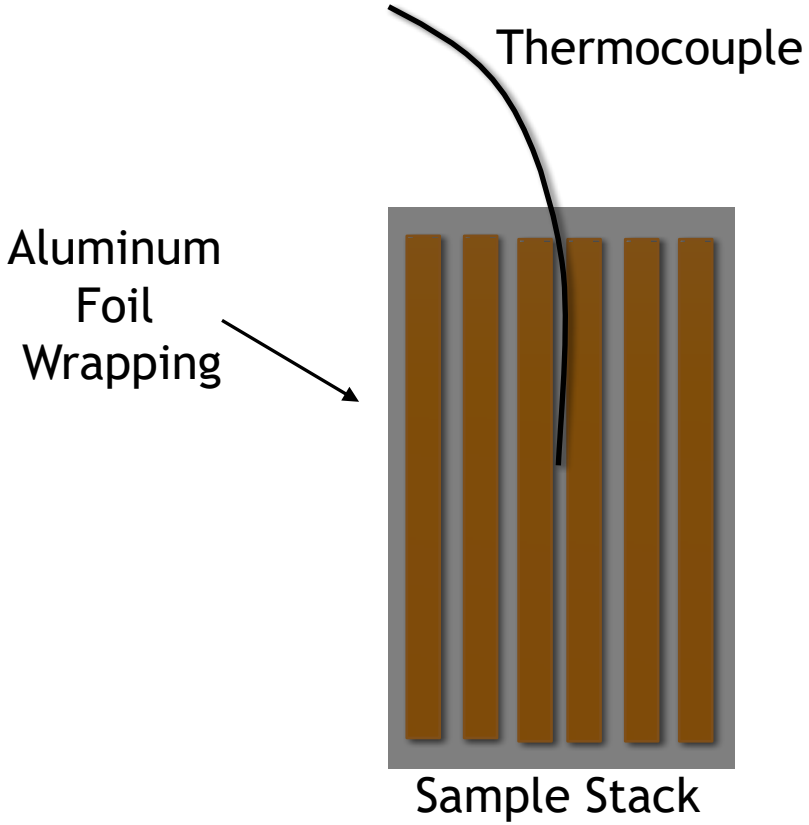
Two ways to think about coating doses:

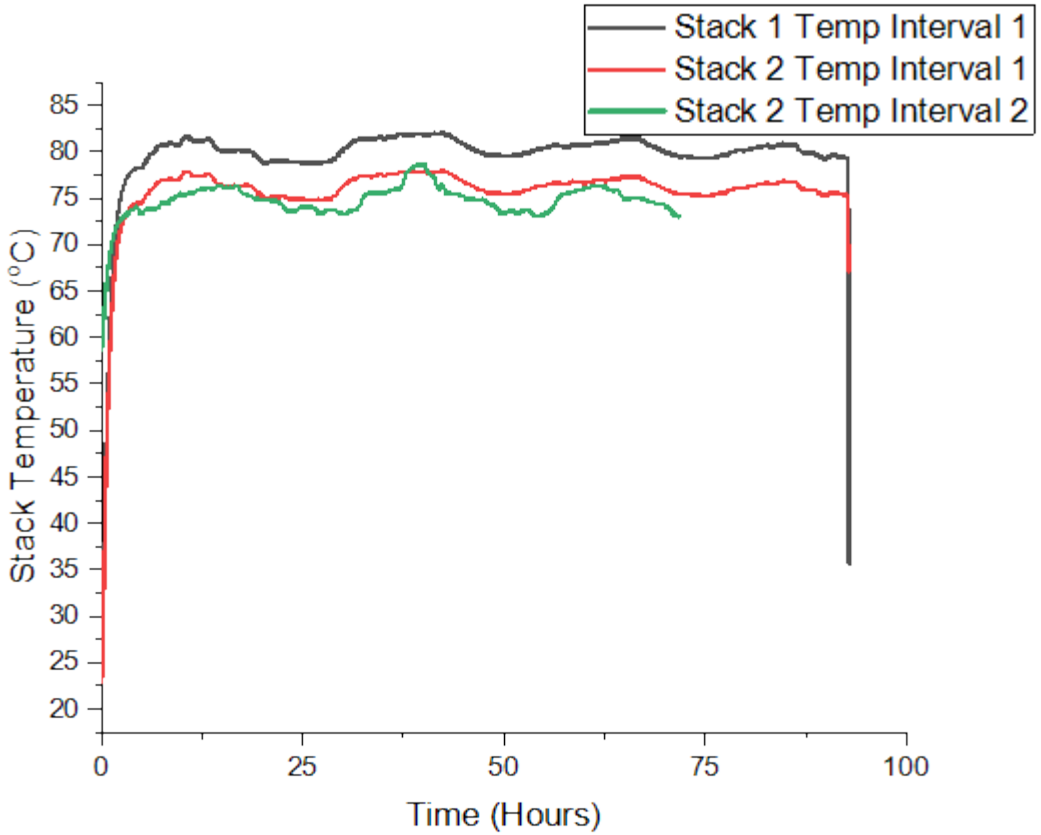
1.) Ex Situ Application (Prevention): If coated on a new canister, how long can coating survive before reapplication?

2.) In Situ Application (Repair): How long AFTER loading can I apply coating so it survives remaining storage lifetime



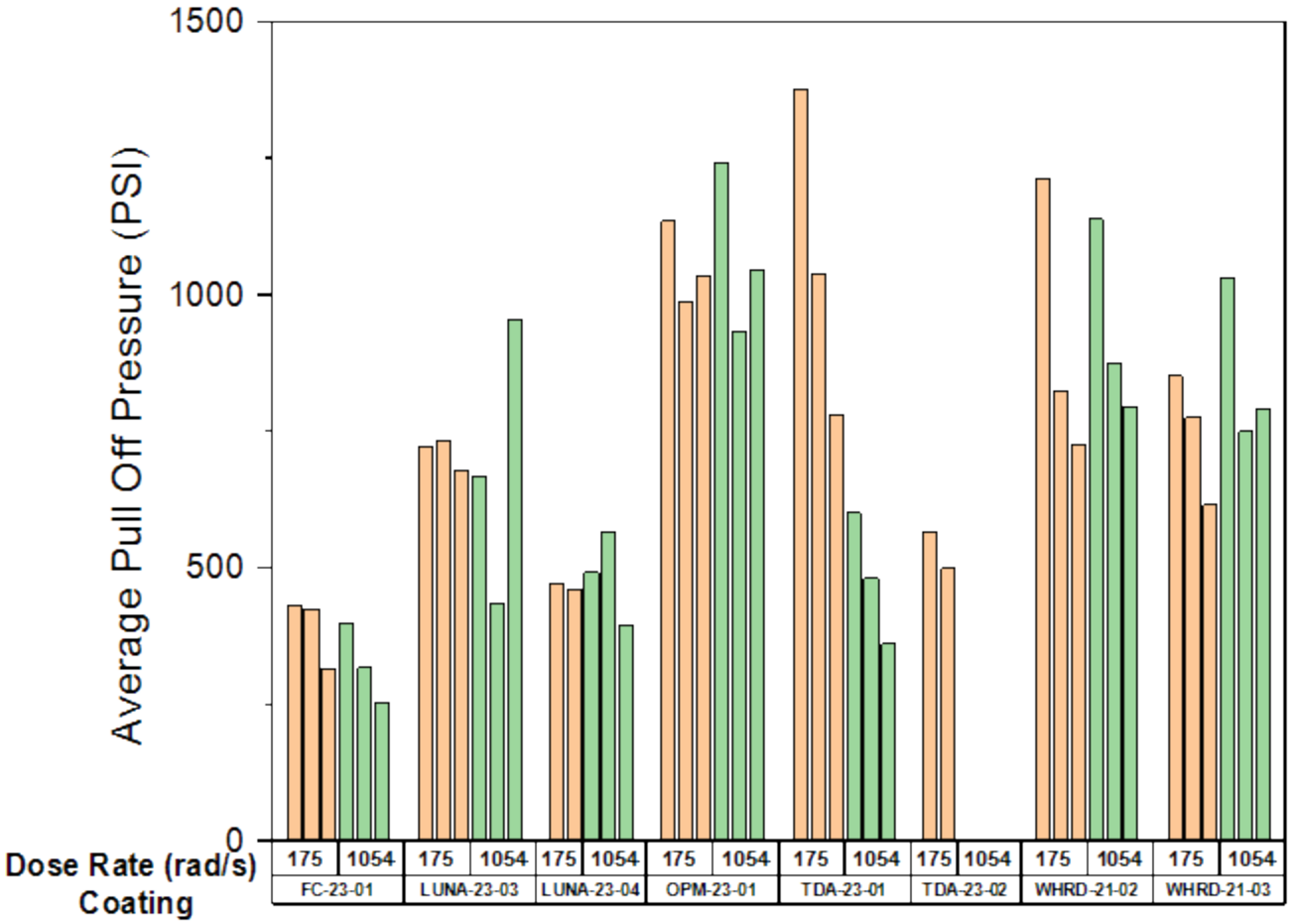
Self-heating in Shutter Array





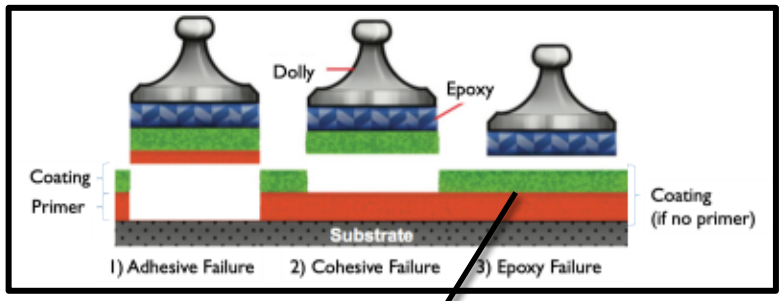
Coupons were stacked and layered in aluminum foil prior to loading in the shutter array. These stacks had a large volume which self-heated in the high flux of the shutter array.

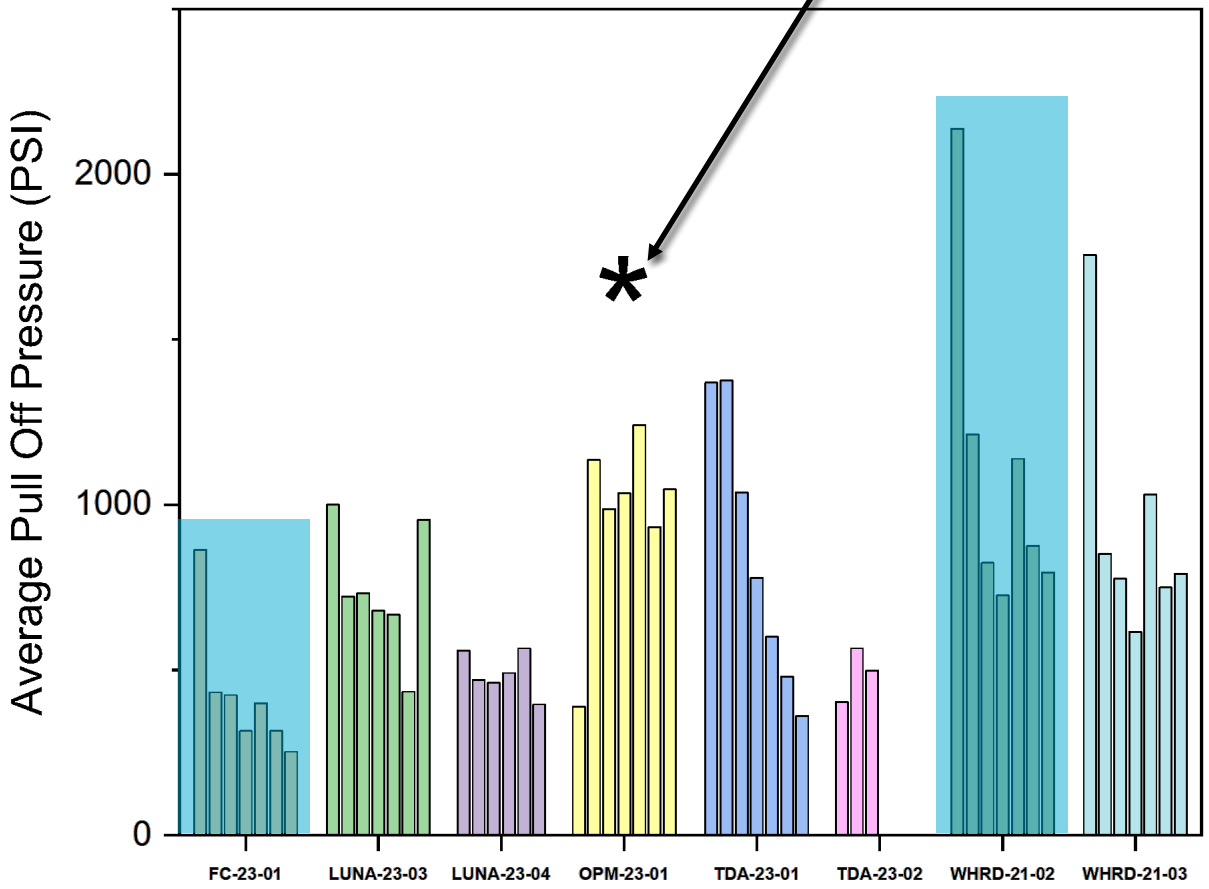
Radiolytic Dose Rate Vs. Adhesion

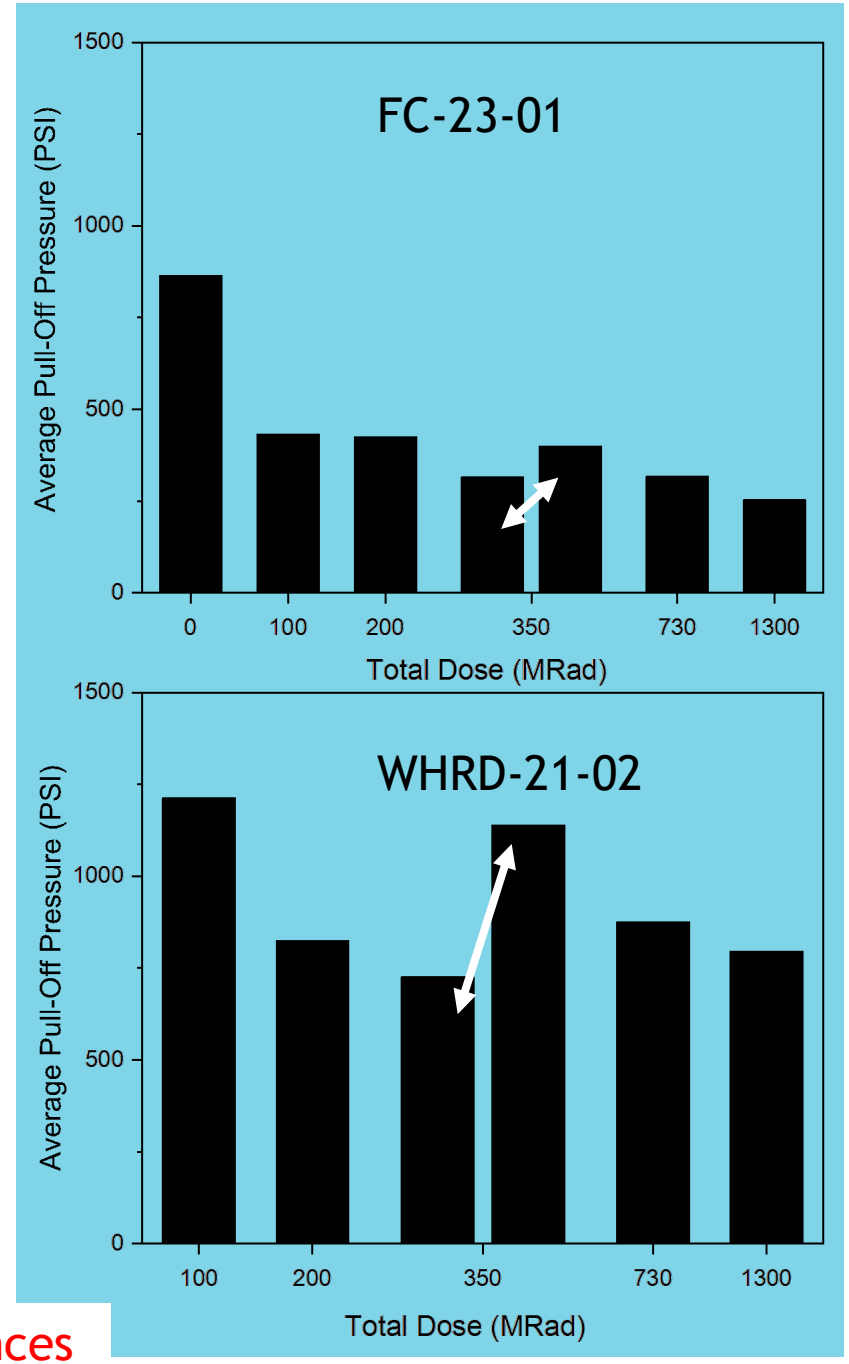


Actual max dose rate on loaded canister is 2-3 rad/s, used 175 rad/s and 1054 rad/s in these tests. Further investigation on implications of dose rate effects are ongoing.

Total Radiolytic Dose Vs. Adhesion

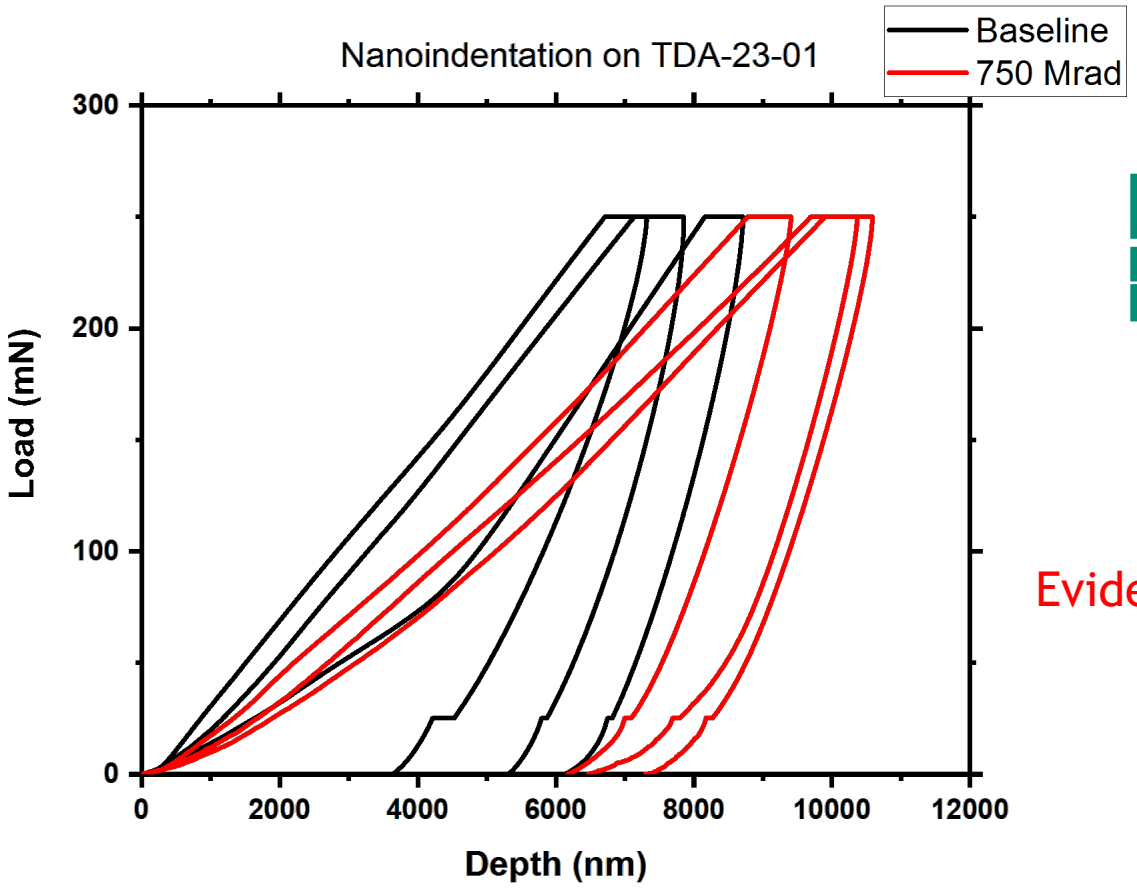






Discontinuity in trend at 350MRad may be due to temperature differences

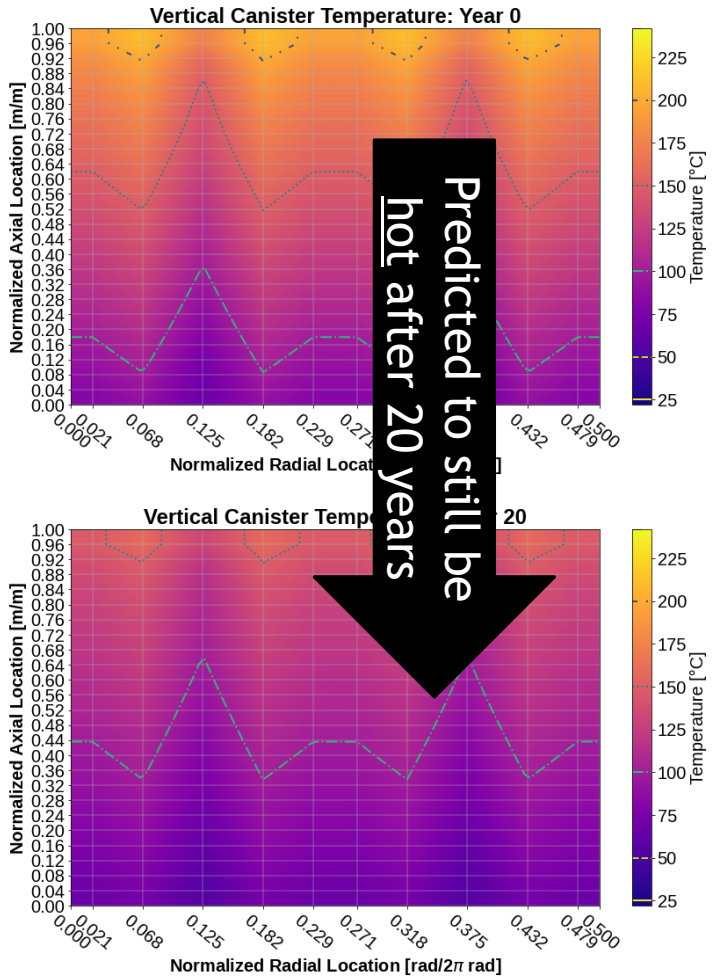
Radiolytic Exposure & Hardness



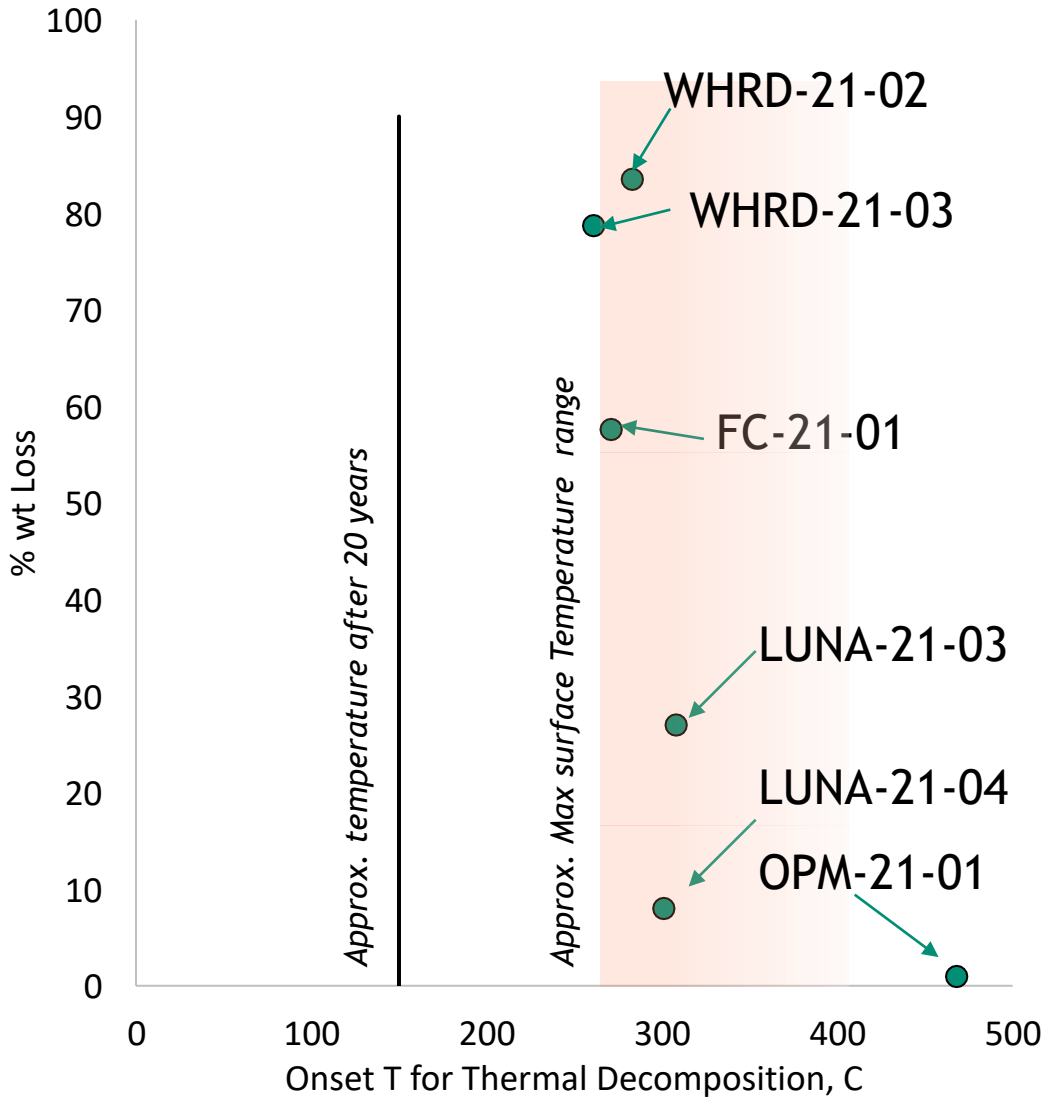
Coating	Dose (Mrad)	Dose Rate (rad/s)	Modulus (GPa)	Hardness (MPa)
TDA-23-01	0	0	4.68	362
TDA-23-01	750	1054	3.498	200

Evidence of softening of coating, may be due to chain scission.

Thermal Resistance



Gilkey et al (2022)



High temperatures over decades-long period is a challenge for any material system

Conclusions

Using coatings on SNF storage canisters is complicated and requires additional study.

Coatings must not create additional risks or problems during interim storage thus rigorous vetting is required before potential implementation.

Cold spray coatings are mechanically and radiologically robust but still require further research to optimize for this application, especially with regard to corrosion performance.

Some coatings exhibited color changes, mechanical softening and decreased adhesion after exposure to radiation (at accelerated dose rates).

The thermal resistance of the coatings is good in most cases in the conditions studied, but longer term studies are required.

Future Work & Analyses

Further investigation of long term thermal behavior of coatings such as outgassed components and thermo-mechanical properties.

Multifactor quantitative analysis to determine which coatings are best for each application scenario.

Realistic coating application tests on dusty/salty surfaces (cleaning processes, adhesion, etc.)