

Dry Fuel Storage System Aging Management

EPRI Susceptibility Rankings and Relevant Experience



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Outline

- Background
- Site and Canister Ranking Methodology
- Latest Research
- Next Steps
- Conclusion and discussion



Background

Brief History of Milestones

2012 – NRC Information Notice 2012-20

- Several incidents of CISCC observed in “in austenitic stainless steel components that were exposed to atmospheric conditions **near salt-water bodies.**” – Songs, St. Lucie, Turkey Point, and Koeberg
- Letter states “**no immediate safety concern** has been identified with currently approved licenses”

2015 – EPRI issued Technical Report 3002005371 – Susceptibility Assessment Criteria for CISCC of Welded Stainless Steel Canisters for Dry Cask Storage Systems

2020 – Code Case N-860 approved by ASME

2024 – NRC DG-3058 (RG 3.78) published in the Federal Register

Multiple organizations continue to evaluate CISCC in DFSs experimentally, analytically, and operationally (inspections of in-service systems)

- To date, no inspections have resulted in additional actions beyond trending



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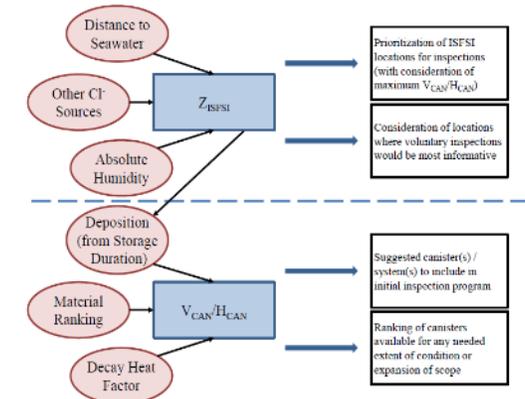
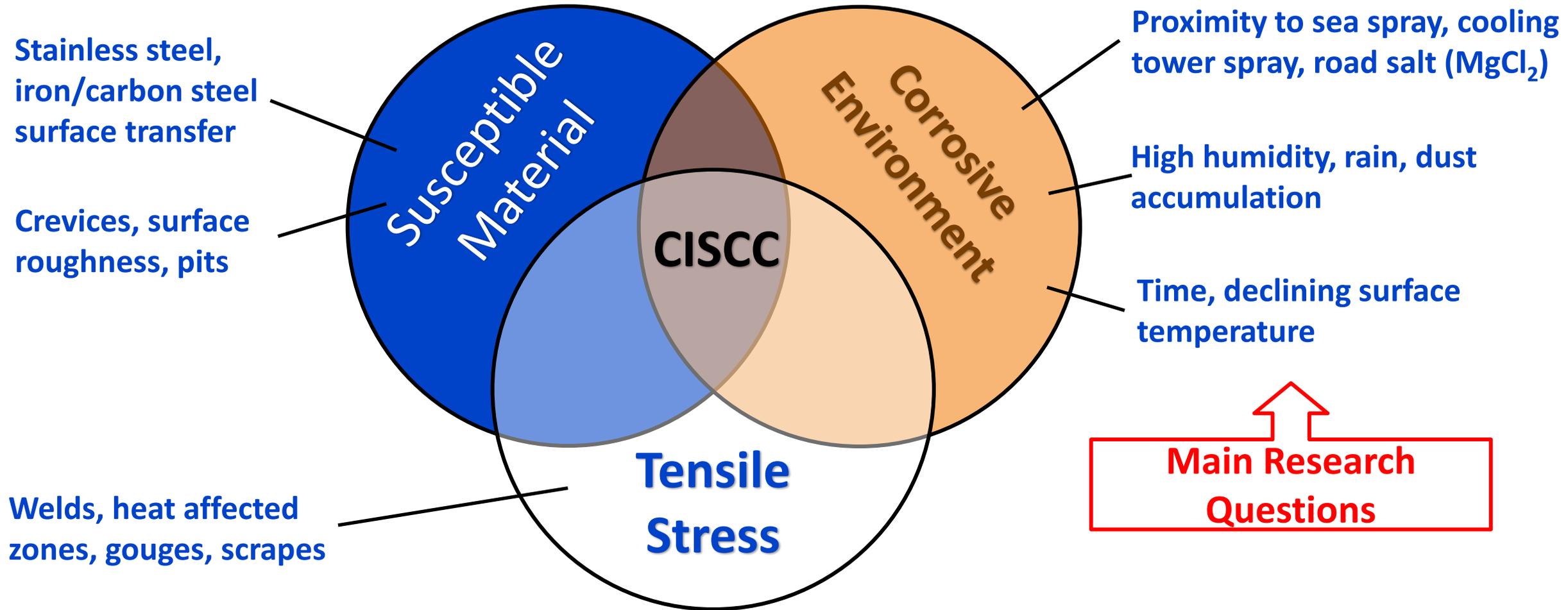


Figure 6-1
Summary of Susceptibility Assessment Criteria

The Central Aging Issue for SS Canisters: CISCC*



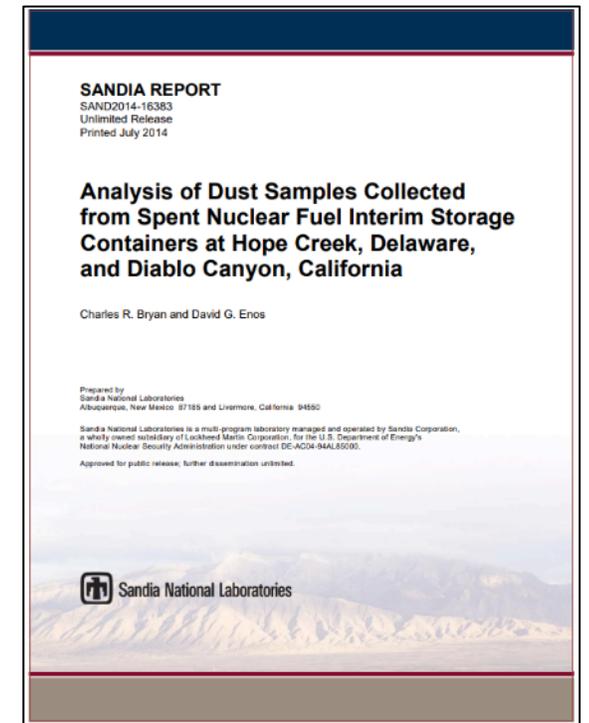
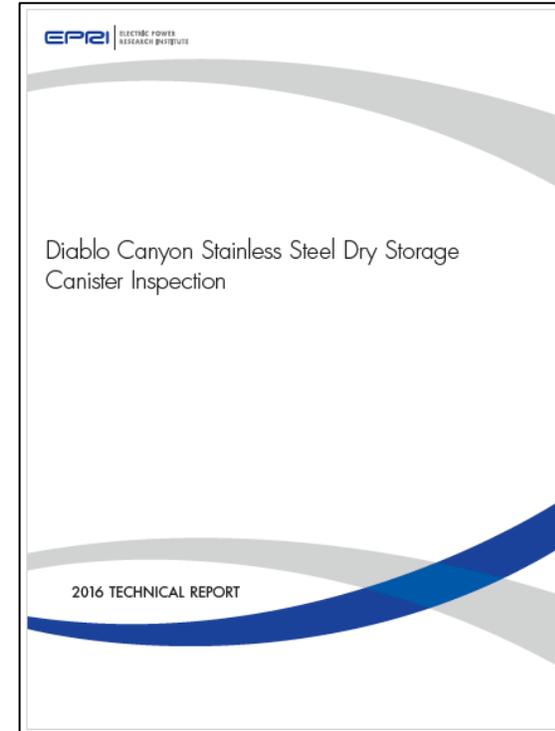
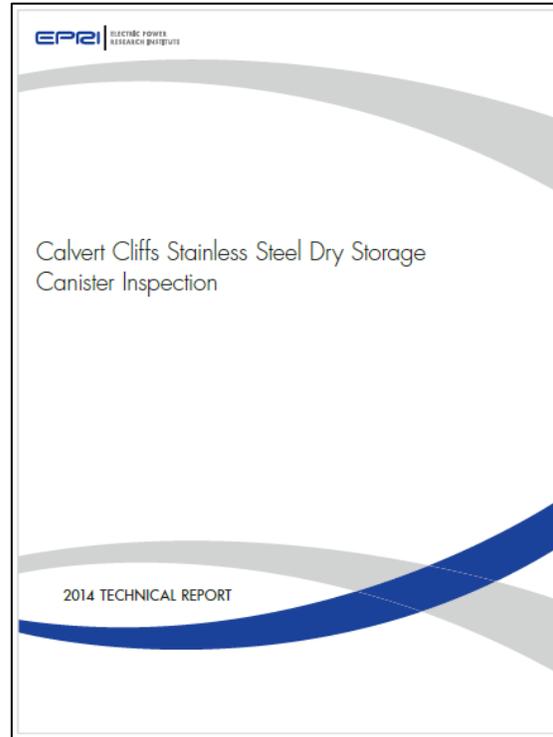
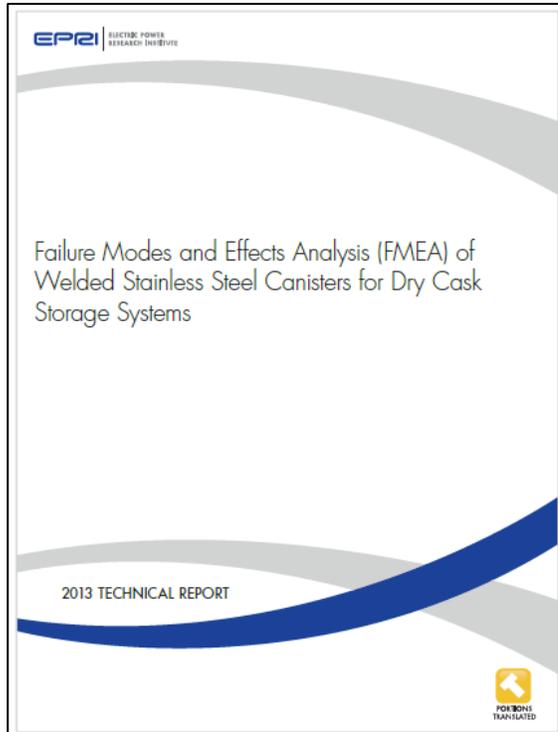
* Chloride Induced Stress Corrosion Cracking

Research Framework

A guide to coordinated, collaborative research leading to an end-point



Confirmatory Early Technical Evaluations and Inspection Results



Early work confirmed CISCC as leading potential degradation phenomenon and lower potential susceptibility at inland sites



Susceptibility Rankings
EPRI Technical Report 3002005371, 2015

Site Susceptibility Ranking

- Site susceptibility quantified by calculating a “Z” ISFSI ranking factor that can range from 1 to 10:

$$Z_{ISFSI} = Cl_{starting} + Cl_{adj} + AH_{adj}$$

where:

- Z_{ISFSI} = relative CISCC susceptibility ranking
- $Cl_{starting}$ = initial ranking based on marine aerosol
- Cl_{adj} = adjustment factor for local sources of chloride
- AH_{adj} = adjustment factor to account for differences in susceptibility due to climate

- Z_{ISFSI} is a measure of Cl content potentially available to accumulate on the canister without regard to Cl molecule type or conditions inside the overpack

Application of Ranking Methodology

- US ISFSI Sites with $Z_{ISFSI} > 3 = 11$

Absolute Humidity (g/m ³)	Elevation (m)	Dist. to Marine Shore (km)	Cooling Tower?	< 1km to Cooling Tower?	Tower Saline? (0=No, 1=Low, 2=High)	Salted Road within 200m?	Cooling Tower Rank	Ocean Rank	Salted Road	Elevation	AH	SUM	Z ISFSI	Age (yr)
7.9	220	500	Y	Y	0	N	1	1	-	-	-1	1	1	9
6.9	190	≥1000	N	-	-	N	-	-	-	-	-1	0	1	22
8.2	185	≥1000	N	-	-	N	-	-	-	-	0	1	1	13
7.5	270	≥1000	Y	Y	0	N	1	1	-	-	-1	1	1	14
9.5	35	125	N	-	0	N	-	-	-	-	0	1	1	32
8.5	220	≥1000	N	-	-	N	-	-	-	-	0	1	1	8
6.7	135	330	Y	Y	0	N	1	1	-	-	-1	1	1	22
10.8	250	420	N	-	-	N	-	-	-	-	0	1	1	12
7.7	190	≥1000	N	-	-	N	-	-	-	-	-1	1	1	12
8.7	280	≥1000	N	-	-	N	-	-	-	-	0	1	1	14
7.6	180	700	Y	Y	0	N	1	1	-	-	-1	1	1	29
7.8	180	700	Y	Y	0	N	1	1	-	-	-1	1	1	10
7.2	180	360	N	-	-	N	-	-	-	-	-1	0	1	22
7.4	310	≥1000	N	-	-	N	-	-	-	-	0	1	1	18
7.3	85	390	N	-	-	N	-	-	-	-	-1	0	1	14
8	46	23	N	-	-	N	-	-	-	-	0	1	1	20
5.2	1500	210	N	-	-	N	-	-	-	-	-1	0	1	25
7.8	30	40	N	-	-	N	-	-	-	-	-1	0	1	16
7	185	≥1000	N	-	-	N	-	-	-	-	-1	0	1	15
7	185	≥1000	N	-	-	N	-	-	-	-	-1	0	1	12
7.2	200	≥1000	N	-	-	N	-	-	-	-	-1	0	1	12
8.2	220	≥1000	N	-	-	N	-	-	-	-	0	1	1	14
7	10	30	N	-	-	N	-	-	-	-	-1	1	1	22
9.6	230	270	N	-	-	N	-	-	-	-	0	1	1	20
9.6	230	270	N	-	-	N	-	-	-	-	0	1	1	11
7.5	290	≥1000	Y	Y	0	N	1	1	-	-	-1	1	1	16
7.2	80	350	Y	Y	0	N	1	1	-	-	-1	1	1	12
9.5	95	160	N	-	-	N	-	-	-	-	-1	1	1	16
10.2	250	340	N	-	-	N	-	-	-	-	-1	1	1	34
10.2	250	340	N	-	-	N	-	-	-	-	-1	1	1	29
7.8	190	≥1000	Y	Y	0	N	1	1	-	-	-1	1	1	31
7.8	190	≥1000	Y	Y	0	N	1	1	-	-	-1	1	1	8
7.3	290	210	Y	Y	0	N	1	1	-	-	-1	1	1	21
7.6	190	600	Y	Y	0	N	1	1	-	-	-1	1	1	12
7	190	≥1000	N	-	-	N	-	-	-	-	-1	0	1	20
7.7	185	≥1000	N	-	-	N	-	-	-	-	-1	0	1	19
10.8	70	140	N	-	-	N	-	-	-	-	0	1	1	35
10.8	70	140	N	-	-	N	-	-	-	-	0	1	1	20
11.1	130	210	N	-	-	N	-	-	-	-	-1	1	1	8
11.4	10	35	N	-	-	N	-	-	-	-	0	1	1	17
7.3	220	170	Y	Y	0	N	1	1	-	-	-1	1	1	25
7.3	220	170	Y	Y	0	N	1	1	-	-	-1	1	1	25
8	15	80	N (was before ISFSI)	-	-	N	-	-	-	-	0	1	1	22
6.3	77	135	N (was before ISFSI)	-	-	N	-	-	-	-	-1	0	1	16
8.9	331	950	N	-	-	N	-	-	-	-	0	1	1	Future
7	350	160	N	-	-	N	-	-	-	-	-1	0	1	22
7.3	180	≥1000	N	-	-	N	-	-	-	-	-1	0	1	10
10.8	110	600	N	Y	0	N	1	1	-	-	0	2	2	21
11	180	Y	Y	Y	0	N	1	1	-	-	0	2	2	19
11	180	Y	Y	Y	0	N	1	1	-	-	0	2	2	9
9	210	Y	Y	Y	0	N	1	1	-	-	0	2	2	9
10.5	11	Y	Y	Y	0	N	1	1	-	-	0	2	2	17
10	11	Y	Y	Y	0	N	1	1	-	-	0	2	2	11
10	11	Y	Y	Y	0	N	1	1	-	-	0	2	2	23
10	11	Y	Y	Y	0	N	1	1	-	-	0	2	2	21
8	120	Y	Y	Y	0	N	1	1	-	-	0	2	2	16
8.2	65	Y	Y	Y	0	N	1	1	-	-	0	2	2	13
8.6	55	135	Y (co-located fossil)	Y	0	N	1	1	-	-	0	2	2	23
10.5	220	500	Y	Y	0	N	1	1	-	-	0	2	2	20
10.5	220	500	Y	Y	0	N	1	1	-	-	0	2	2	8
11	180	180	Y	Y	0	N	1	1	-	-	0	2	2	Future
8.3	90	170	Y	Y	0	N	1	1	-	-	0	2	2	Future
11.6	70	130	Y	Y	0	N	1	1	-	-	0	2	2	11
13.9	4	80	Y (co-located fossil)	N	0	N	-	-	-	-	-1	2	1	13
9.4	220	500	Y	Y	0	N	1	1	-	-	0	2	2	8
13.8	45	130	Y	Y	0	N	1	1	-	-	1	3	3	19
12.3	50	250	Y	Y	0	N	1	1	-	-	1	3	3	18
12.9	40	110	Y	Y	0	N	1	1	-	-	1	3	3	23
8.8	3	50	Y	Y	1	N	2	1	-	-	0	3	3	18
13.4	30	135	Y	Y	0	N	1	1	-	-	1	3	3	19
8.8	3	50	Y	Y	1	N	2	1	-	-	0	3	3	14
7.3	8	3.7	N	-	-	N	-	-	-	-	-1	4	4	16
13.5	9	15	N	-	-	N	-	-	-	-	-2	4	4	Future
12.7	6	2.5	N	-	-	N	-	-	-	-	-1	6	6	14
8.3	6	3	N	-	-	N	-	-	-	-	0	6	6	22
9	95	0.5	N	-	-	N	-	-	-	-	-1	7	7	15
7.9	7	0.25	N	-	-	N	-	-	-	-	-1	7	7	9
8.4	7	0.12	N	-	-	N	-	-	-	-	0	8	8	19
9.7	6	0.12	N	-	-	N	-	-	-	-	0	8	8	21
14.6	3	1.5	Y (co-located coal)	Y	2	N	3	5	-	-	-1	9	9	7
16.7	6	0.07	N	-	-	N	-	-	-	-	-2	9	9	6
16.4	5	0.4	N	-	-	N	-	-	-	-	-2	10	10	16
17.4	2	0.4	Y (co-located gas)	Y	1	N	2	8	-	-	-2	12	10	13

Representative data for illustration only

Column Items

- Absolute Humidity
- Elevation
- Dist. to Marine Shore
- Cooling Tower
- Salted Road within 200m?
- Age

$1 \leq Z_{ISFSI} \leq 3$ (60 ISFSIs)

$4 \leq Z_{ISFSI} \leq 7$ (6 ISFSIs)

$8 \leq Z_{ISFSI} \leq 10$ (5 ISFSIs)

Canister Susceptibility

- Canister susceptibility quantified by calculating a ranking factor that can range from 1 to 10:

$$H_{CAN} = Deposition + Material + Heat_{horiz}$$

where

H_{CAN} = current relative CISCC susceptibility ranking of the canister

Deposition = factor accounting for accumulated deposits

Material = factor based on canister shell material

$Heat_{horiz}$ = factor accounting for deliquescent area

$$V_{CAN} = Deposition + Material + Heat_{vert}$$

where

V_{CAN} = current relative CISCC susceptibility ranking of the canister

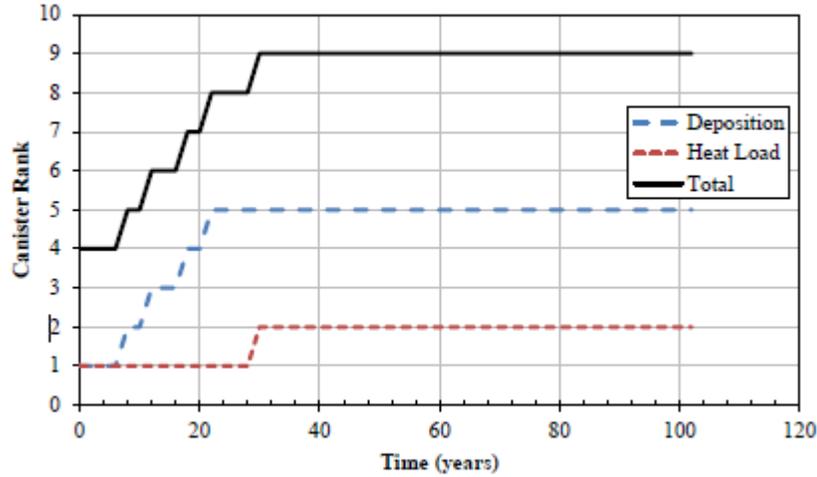
Deposition = factor accounting for accumulated deposits

Material = factor based on canister shell material

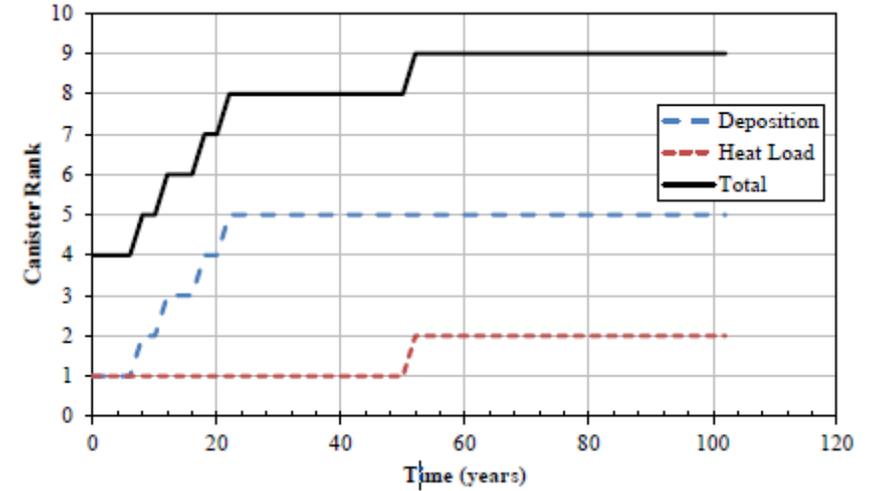
$Heat_{vert}$ = factor accounting for deliquescent area

- Canister Susceptibility makes use of best available data to predict specific susceptibility of a canister(s) on an ISFSI pad accounting for expected deposition rate, material of construction, heat load, and other factors.

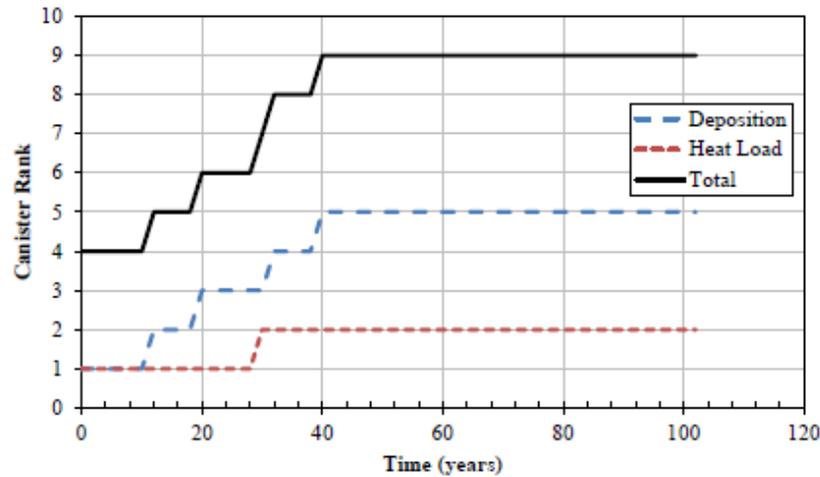
Canister Susceptibility Examples



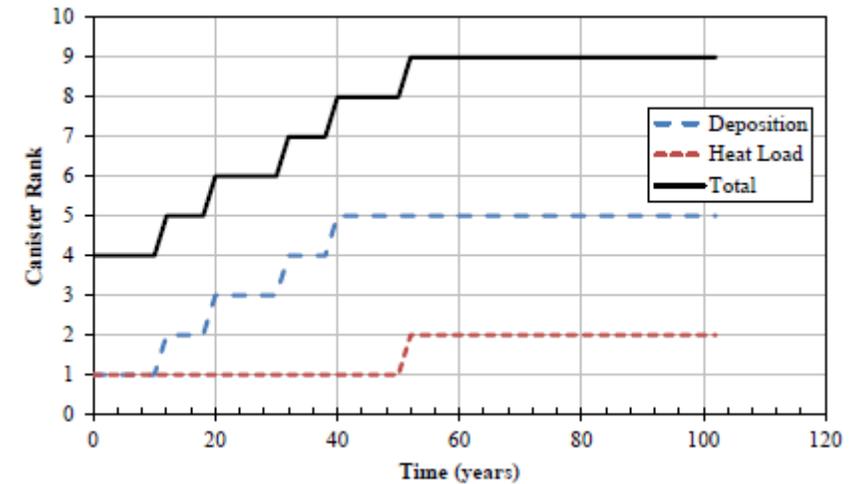
Horizontal Canister Ranking Example, Loaded at 15.1 kW with a Z_{ISFSI} of 8



Vertical Canister Ranking Example, Loaded at 15.1 kW with a Z_{ISFSI} of 8



Horizontal Canister Ranking Example, Loaded at 15.1 kW with a Z_{ISFSI} of 5



Vertical Canister Ranking Example, Loaded at 15.1 kW with a Z_{ISFSI} of 5

Canister ranking changes with Storage Duration and depends on Deposition which depends on Z_{ISFSI}



Latest Research

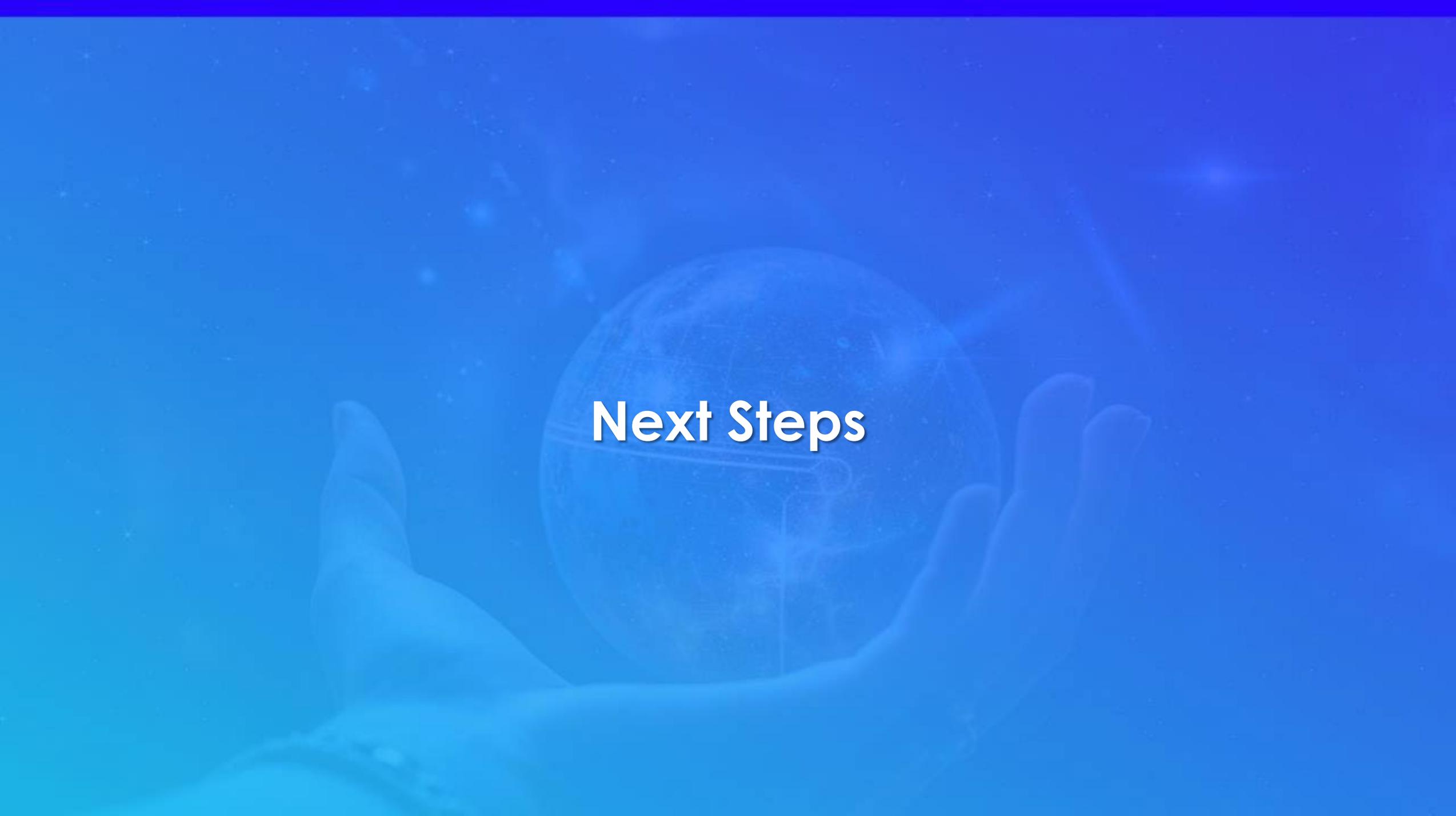
US National Laboratory Research

- PNNL and SNL have done substantial work on accelerated corrosion of Stainless Steels in the presence of Chlorides. Results can be summarized as follows.

	More typical of Inland site	More typical of Marine site	
	Environment		
Material	NaCl	MgCl ₂ ¹	MgCl ₂ + NO ₃
304 ²	Orange	Orange	Orange
304L ³	Green	Orange	Green
316L	Green	Orange	Green

1. Realistically, NO₃ will be present wherever MgCl₂ is present
2. No 304 canisters identified in service at marine sites
3. Represents vast majority of in-service canisters

The Cl molecule, SS type, and the presence of NO₃ are important factors

The image features a blue-tinted background with a central graphic of a globe held in two hands. The globe is semi-transparent and shows a grid of latitude and longitude lines. The hands are also semi-transparent and appear to be supporting the globe from below. The text "Next Steps" is written in a bold, white, sans-serif font, centered over the globe.

Next Steps

EPRI ESCP Aging Management Working Group Meeting

Objectives:

1. Evaluation of the current status of the aging management research - what has been done to date and what can be concluded from the results.
2. Development of a roadmap for the next 2 years to conclude key items.

Working Group Meeting:

1. Participation by invitation only. List of invited guests developed with input from Subcommittee and Task group leads. Number of registered attendees: 35
2. Attendees include participants from utilities (5), vendors (3), regulator (4), DOE (2), National laboratories (7), NEI (1), university (2), EPRI (5), and others.



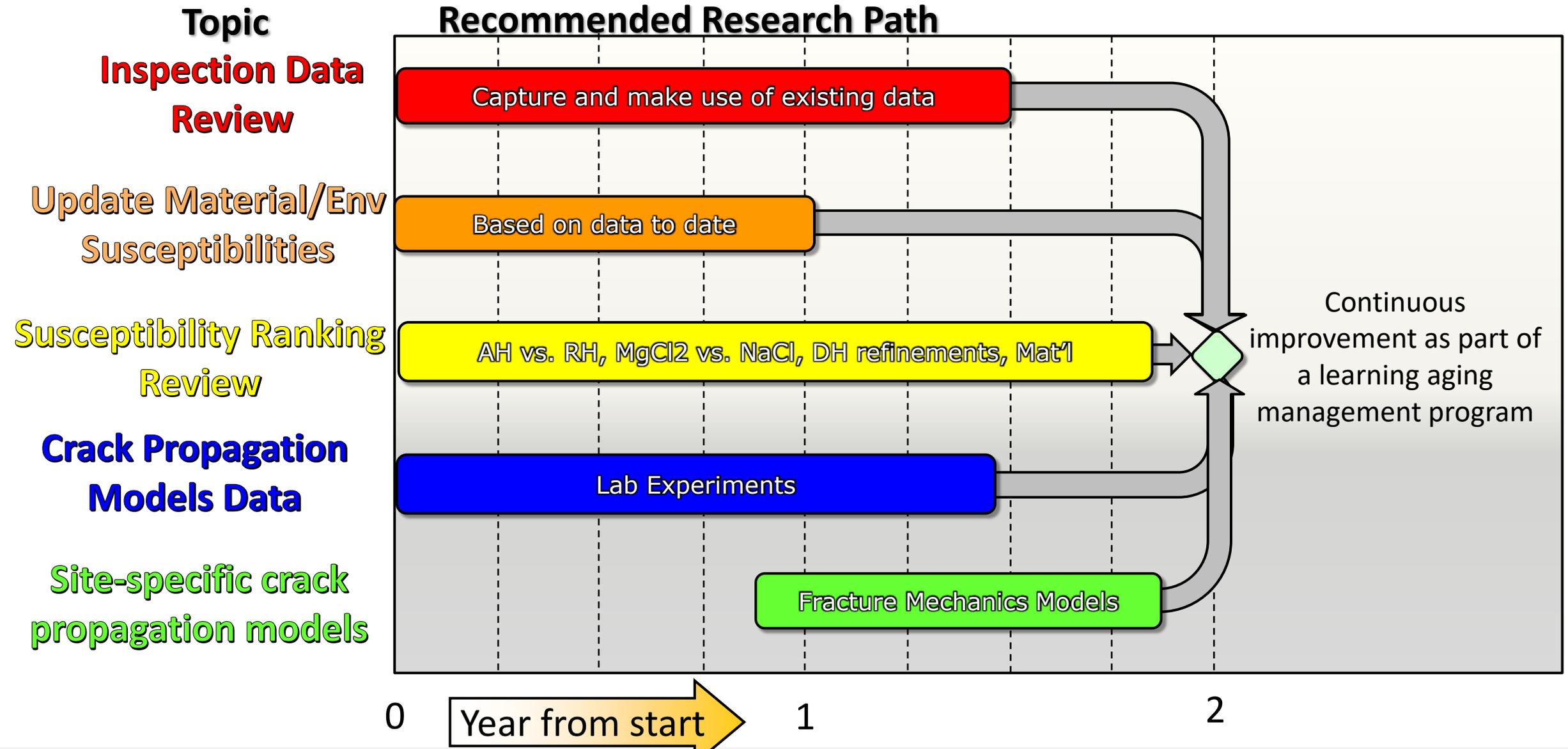
Documentation of what has been done in the past >10 years and development of roadmap for closure of key items within the next 2 years were the key objectives

General Consensus from the Working Meeting on Aging Management

- EPRI, NRC, and ASME Dry Storage System aging management documents create a conservative approach based on available information at the time they were issued.
- Risk of CISCC at inland sites is low.
- Improvements can be made on specific topics based on a learning approach as recommended in 2017 EPRI Technical Report 3002008193.
 - EPRI will publish a roadmap to describe the recommended next steps based on the outcome of the working meeting

Understanding of Dry Storage Canister Aging Management is Improving

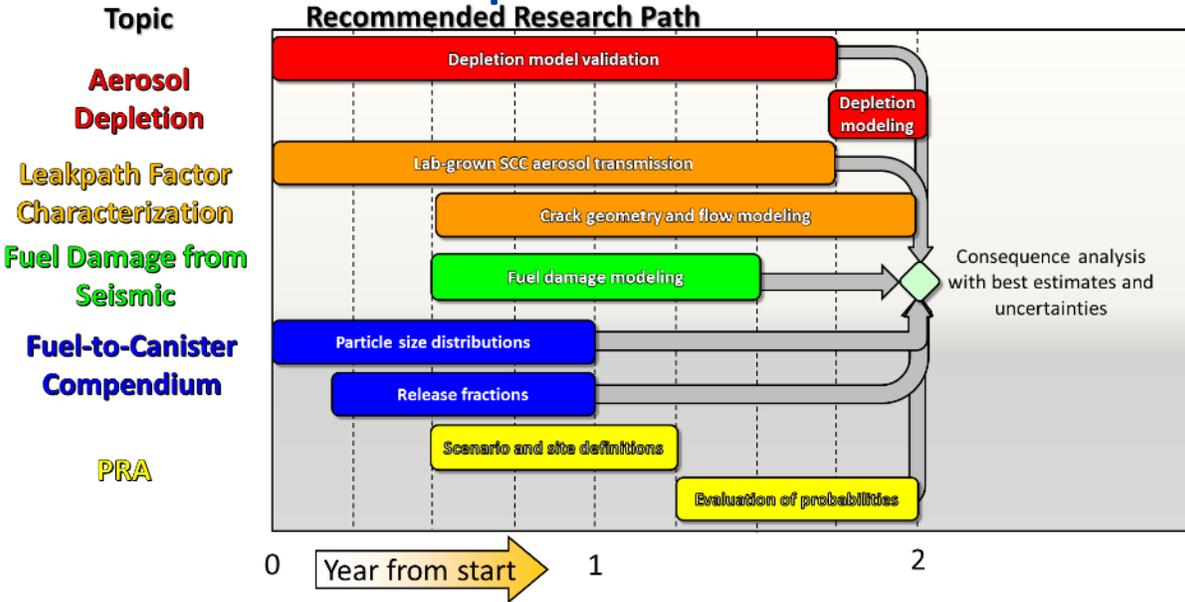
Aging Mechanisms – Recommended Two Year Plan



2-Year Roadmaps for All Aging Management Pillars

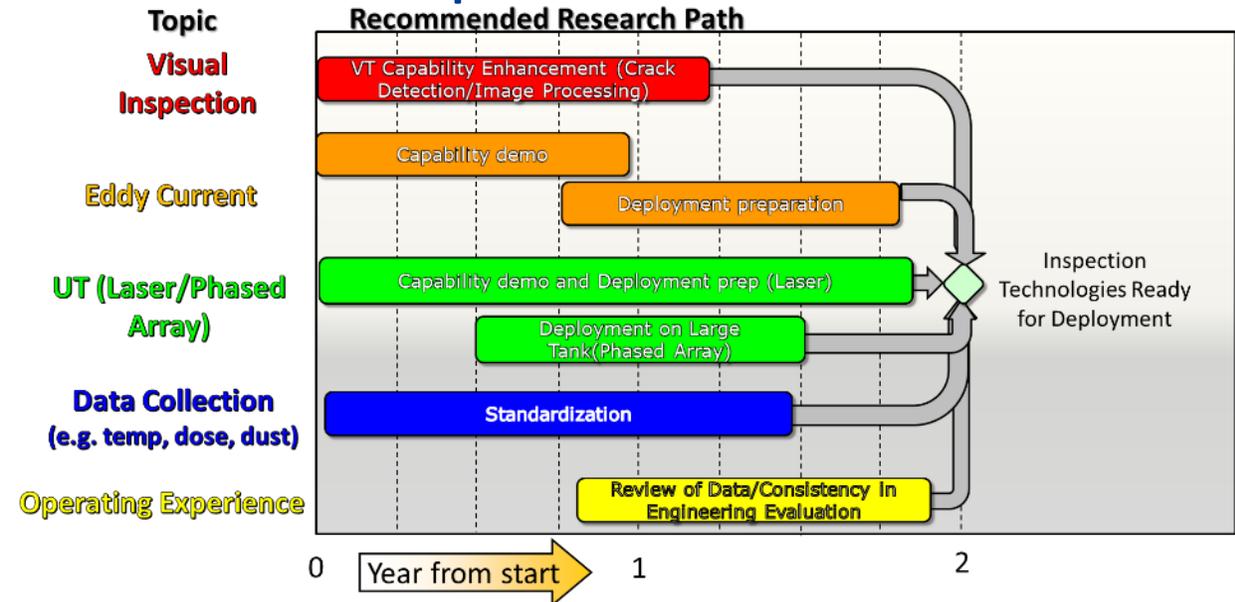
Consequence

Recommended Research Path



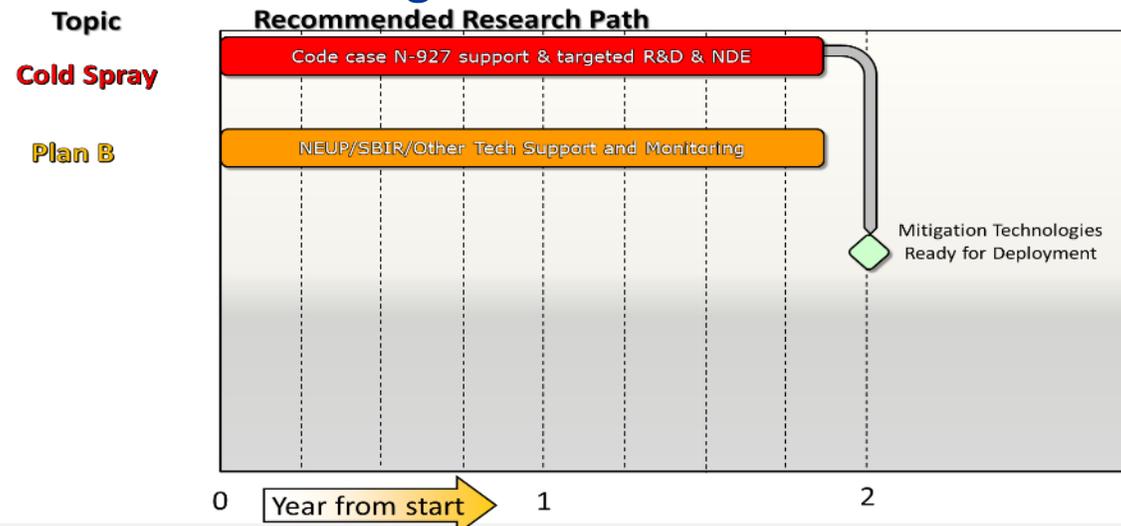
Inspection

Recommended Research Path



Mitigation

Recommended Research Path





Conclusions & Discussion

Data Driven Conclusions

- Initial concern for stainless steel aging management was targeted at marine sites.
 - Subsequent research and operating experience is validating that inland sites have much lower potential to be impacted by CISCC.
- Greater understanding of the Cl molecules, materials, and inhibitors has been developing over the past several years.
 - These results also support the conclusion that inland sites are less susceptible to CISCC.
- As learning continues, there may be data to support further reductions in inspection frequency at near marine sites.
- Significant progress has been made in the areas of inspection and mitigation with research expected to wrap-up in ~2yrs

DISCUSSION



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