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RIRP Issue Update: Chloride Induced Stress Corrosion Cracking of Spent Fuel Canisters

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Industry-NRC Meeting on SS Canister Degradation Issues
Rockville MD, 18 December 2012

Agenda

- Background
- EPRI Projects Related to ClSCC
- Elements of R&D Roadmap
- Voluntary Canister Inspections
- Summary

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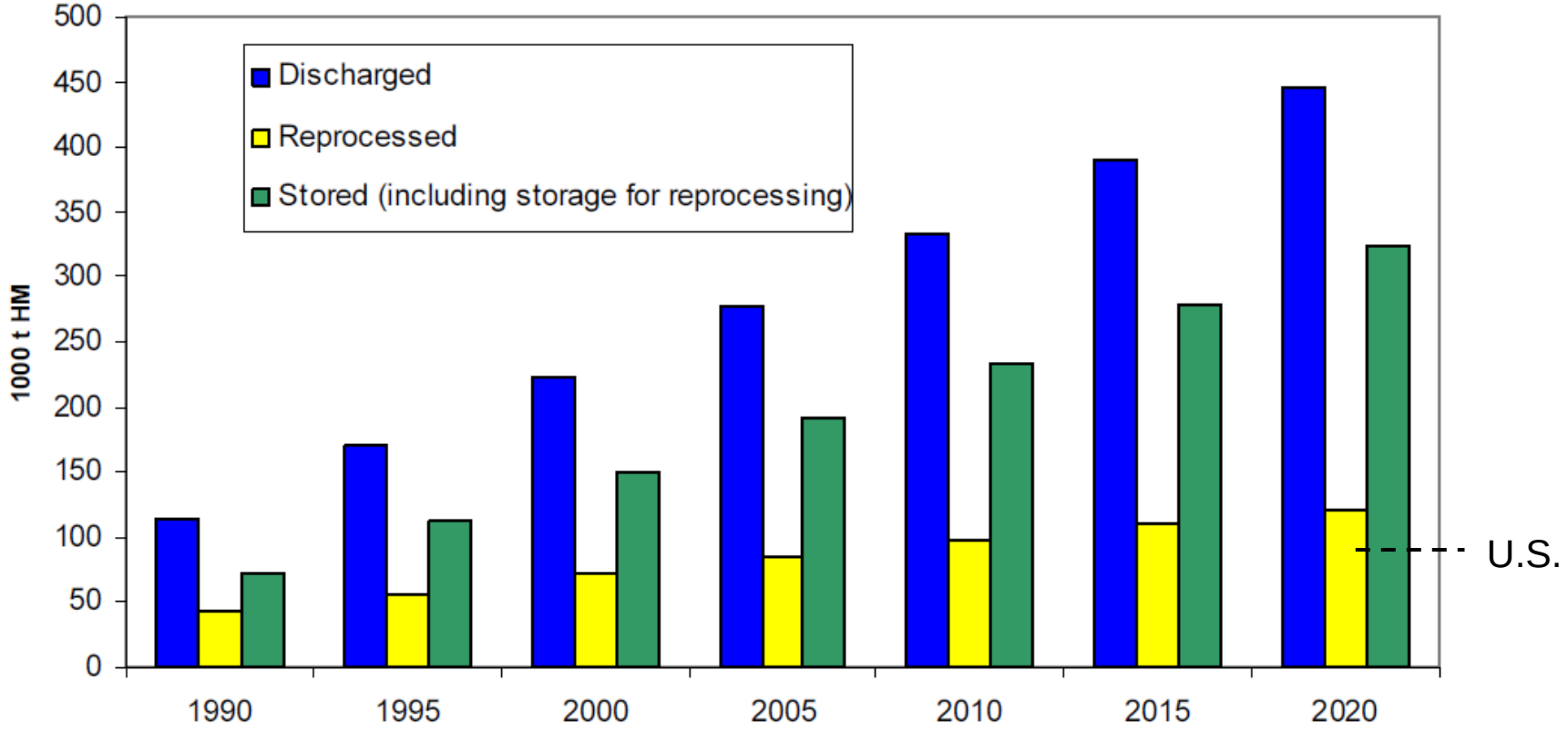
International Used Fuel Inventory in Storage by 2020: ~324,000 Metric Tons (~4x U.S. total)



Source: IAEA

400,000 MTU of used fuel would cover a football field about 45 yards deep.
[Coal ash from the equivalent amount of energy ~15,000 times more.]

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Cornerstones for Successful Extended Storage

- Ensure continued safe, long-term used fuel storage and future transportability
  - Fuel Integrity
  - Canister Integrity
  - Overpack Integrity
- Extended Storage Collaboration Program (ESCP) has identified gaps.
  - High burnup cladding: hydride effects (reorientation, embrittlement)
  - Welded stainless steel canisters stress corrosion cracking

High BurnUp Demo

Inspections

Aging Management

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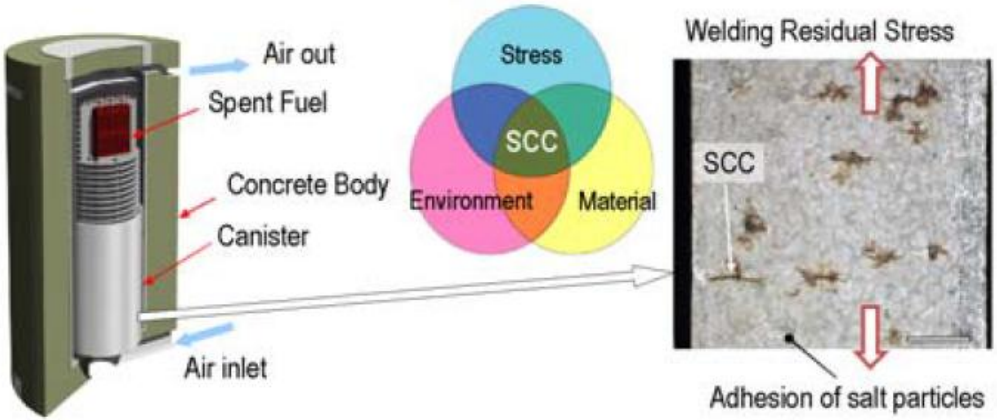
Stress-Corrosion Cracking (SCC) of SS Welded Canisters

For SCC you need:

- Austenitic stainless steels (e.g. 304, 316)
- Tensile stress (residual weld stress)
- Corrosive environment
  - Salts in the air
  - Deliquescence
    - Surface temperature
    - Humidity



SCC can occur *under conservative lab conditions*

What we don't know …
What are the conditions on actual canisters?

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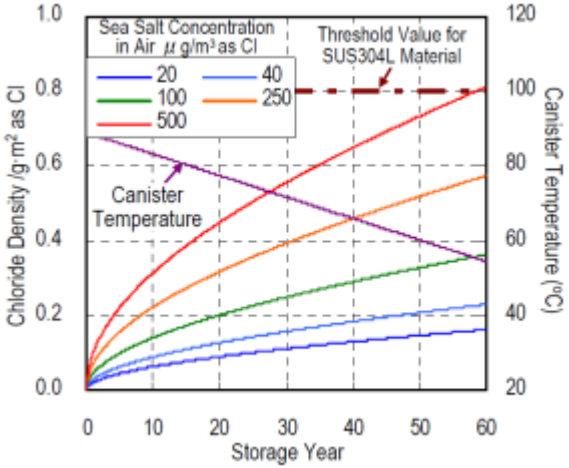
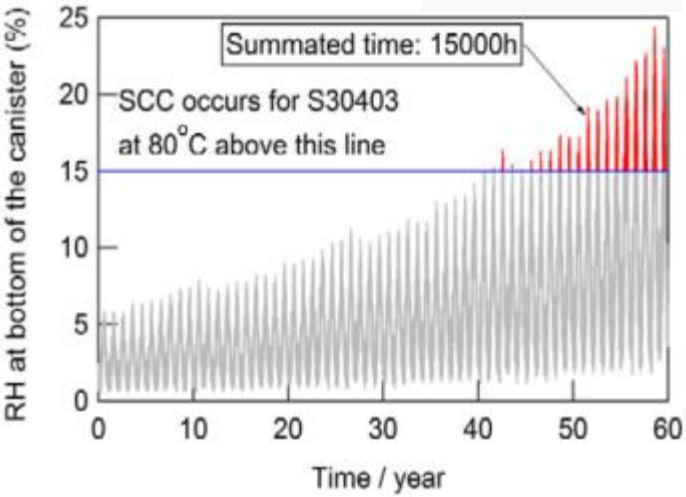
Voluntary Inspections

- Screening considerations for initial volunteers
  - 1,375 SS canisters in service as of 6/30/12
  - Canisters older than ten years: ~18% of US fleet
  - Canisters at coastal sites: ~21% of US fleet
  - Older than ten years *and* at a coastal site: ~5% of US fleet
- Initial Inspection plans: 3 coastal sites by end of 2013
  - Visuals
  - Surface contamination sampling
  - Atmospheric sampling





Gather data on actual canister conditions

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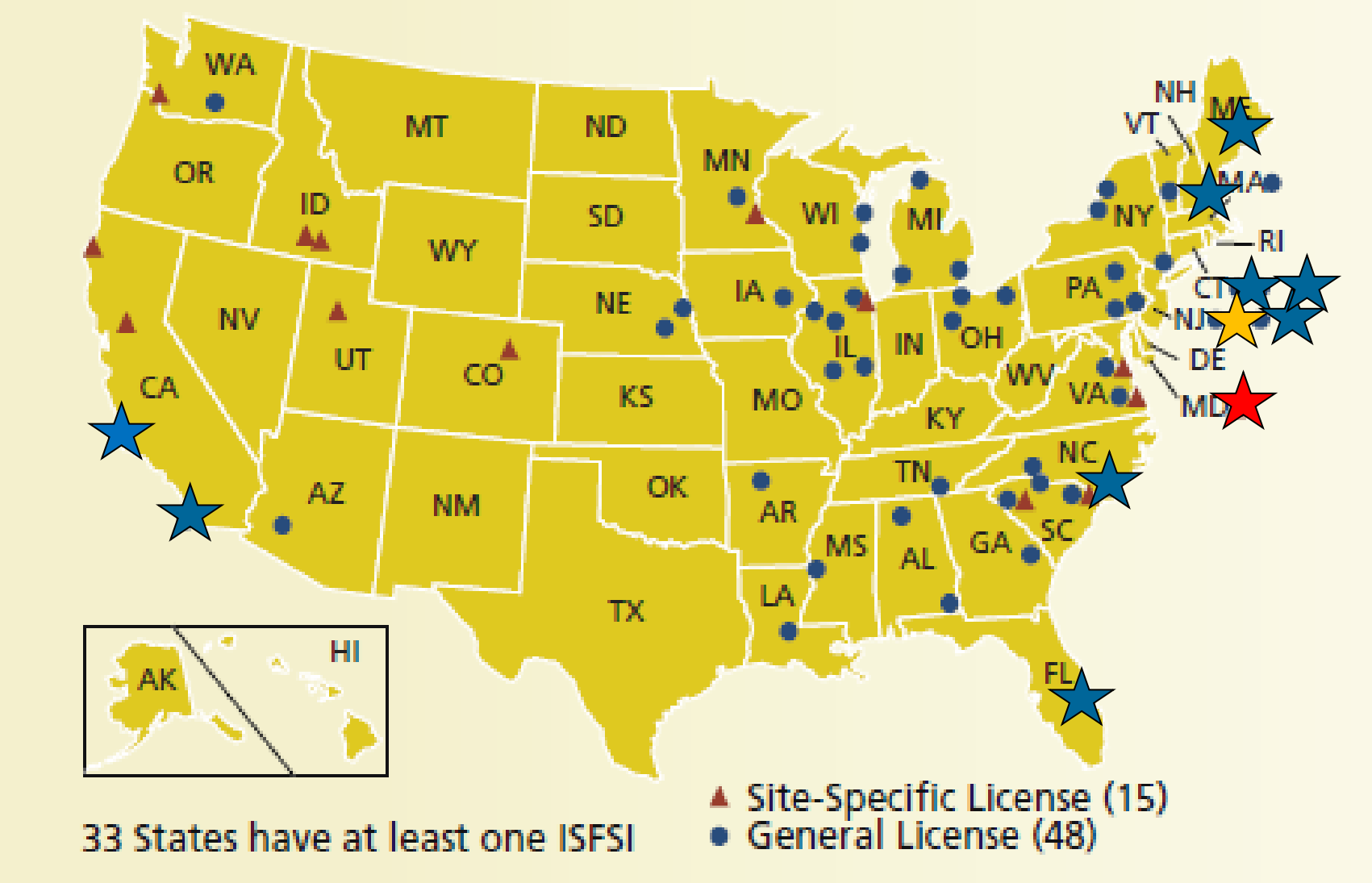
SS Canister Target Inspection Locations



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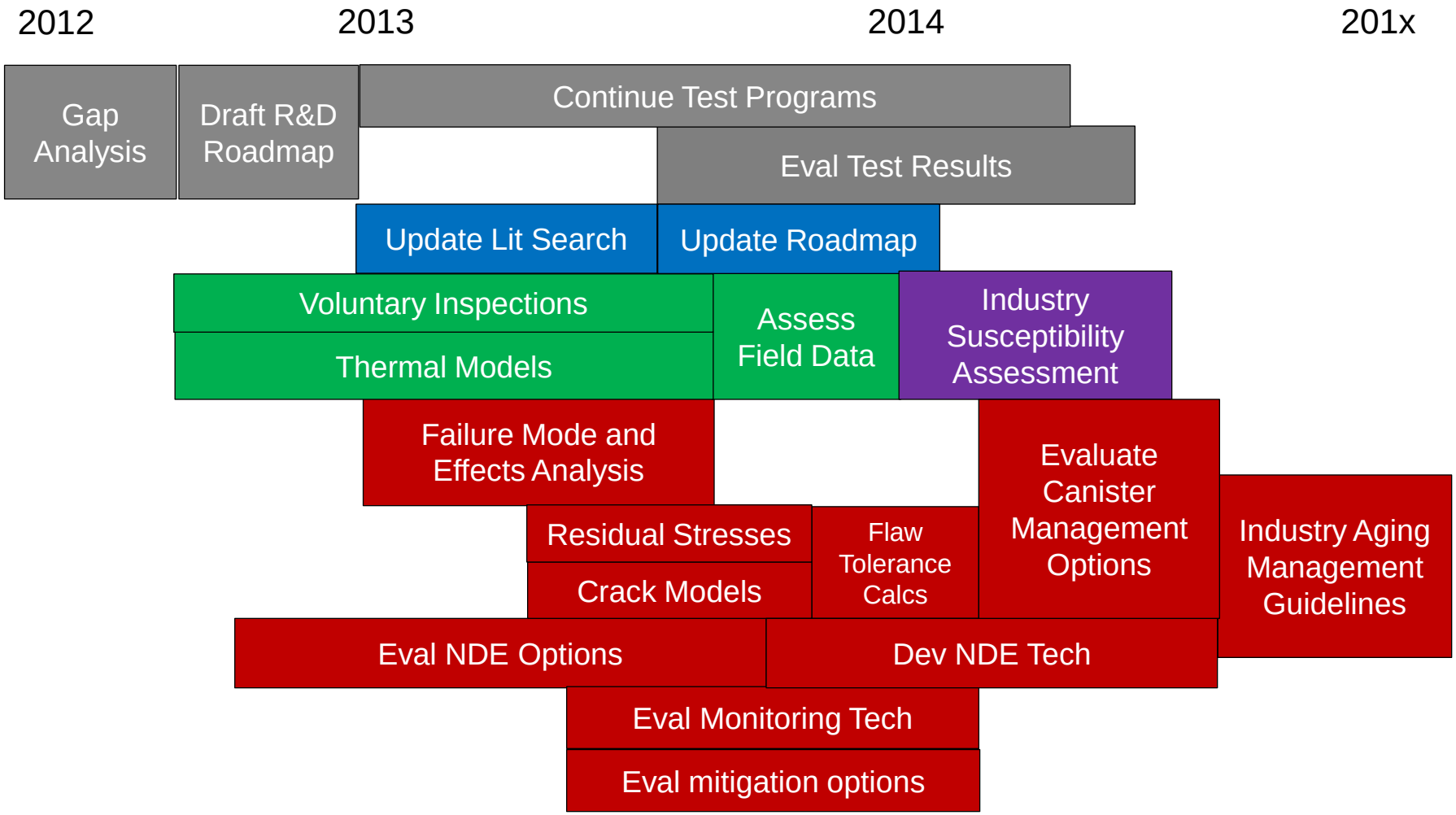
Project Overview for Aging Management Plan (draft)



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Failure Modes and Effects Analysis (FMEA) Approach

- Use existing FMEAs for reactor systems as a template
- Systematically identify credible failure modes for SS canisters
  - Focus on aging-related degradation
  - Incorporate results from gap analyses (DOE, NRC/CNWRA, NWTRB, EPRI, ESCP International Subcommittee)
- Identify range of potential effects for failure mode(s)
  - Loss of confinement: under what conditions?
  - If loss of confinement, what are the effects?

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Aging Management Plan

- Identified credible failure modes
- Understand residual stresses
- Have initiation and crack growth models
- Correlated the field conditions with lab testing
- Identified NDE options
- Identified mitigation options
- Determined appropriate inspection or monitoring

Decide the appropriate management strategy

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Elements of R&D Roadmap
Limitations of Current Knowledge

- Limited, conflicting laboratory data
  - Salt concentration
  - Temperature range
  - Relative Humidity range
  - Base metal vs. weld vs. heat-affected zone (HAZ)
- In-service body weld residual stresses
- Amount and composition of material deposited on the canister surfaces
- Canister surface temperatures

Recommend material procurement, further testing and modeling

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Sample Material Characteristics ("prototypic")

- Same material type
- Same welding technique(s) so residual stresses are prototypic
  - Weld filler material
  - Amount of heat (heat input, interpass temperature limit)
  - Number of passes
  - Same joint (weld prep) design
  - Same surface profile (reinforcement, grinding or lack thereof)
- Same base metal residual strains

EPRI working with cask fabricators to obtain samples

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Laboratory Experiments: Measurements Needed

- Surface salt/contaminant composition and concentration
- Visual inspections of the base metal, welds, and HAZ
- Destructive Examinations
  - Cut cross-sections to determine crack depth
  - Crack dimension and form
- Temperature
- Relative humidity

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Potential Laboratory Variable Permutations

- Base metal (2)
  - 304 and 316
- Weld processes
  - Weld passes: 2 kinds
  - Applied heat: 2 different amounts
- Surface salt composition (4)
  - Sea salt
  - $MgCl_2$;
  - NaCl
  - Sea salt with common soil clays
- Surface salt concentration (3)
  - 0.01 g/m^2;
  - 0.1 g/m^2;
  - 1 g/m^2
- Temperature (4)
  - 25, 35, 45, and 80C
- RH values (3)
  - ~15% for sea salt,
  - ~ 35% for $MgCl_2$ and
  - ~75% for Na Cl.

Further work needed to develop a prioritized testing matrix

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Laboratory Experiments: Who is or Will Be Doing Them?

- Completed or underway:
  - CRIEPI (completed)
  - CNWRA (underway)
- Additional organizations who could conduct additional experiments:
  - DOE UFD Program
  - NEUP programs
  - Others who have expressed some interest:
    - KAERI (Korea)
    - IAEA via contractors
    - ENRESA (Spain)

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Model Development

- Best estimate thermal models
- Prediction of residual stresses
- SCC crack initiation and propagation

Thermal Models

- PNNL
  - Completed: casks in long-term storage at INL
  - Ongoing: support for EPRI inspections
- Others in the future:
  - Cask vendors
  - DOE UFD Program
  - Other countries with welded SS canisters

SCC Crack Models (tentative)

- DOE UFD Program
- DOE NEUP (MIT)
- NRC/CNWRA
- EPRI

Propagation Models (tentative)

- DOE UFD Program
- DOE NEUP (MIT)
- NRC/CNWRA
- EPRI

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Degradation Model Development

- Correlations of canister surface salt/contaminant/organic temporal and spatial compositions and concentrations as a function of:
  - Cask system type
    - Horizontal versus vertical
    - Air flow patterns affecting deposition rates and locations
    - Other dimensions
  - Atmospheric characteristics
    - Time-averaged contaminant concentrations
  - Decay heat as a function of time (affects air flow velocity)

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Calvert Cliffs Canister Inspection

Keith Waldrop

NRC CISCC RIRP Meeting, Rockville MD

December 18, 2012

Inspection Schedule

June 25-28, 2012

- Day 1
  - Exterior concrete inspection
- Day 2
  - Final dry run
- Day 3
  - Visual from exit vents
- Day 4
  - Visual from front
  - Temperature
  - Dry surface samples
  - Wet surface sample

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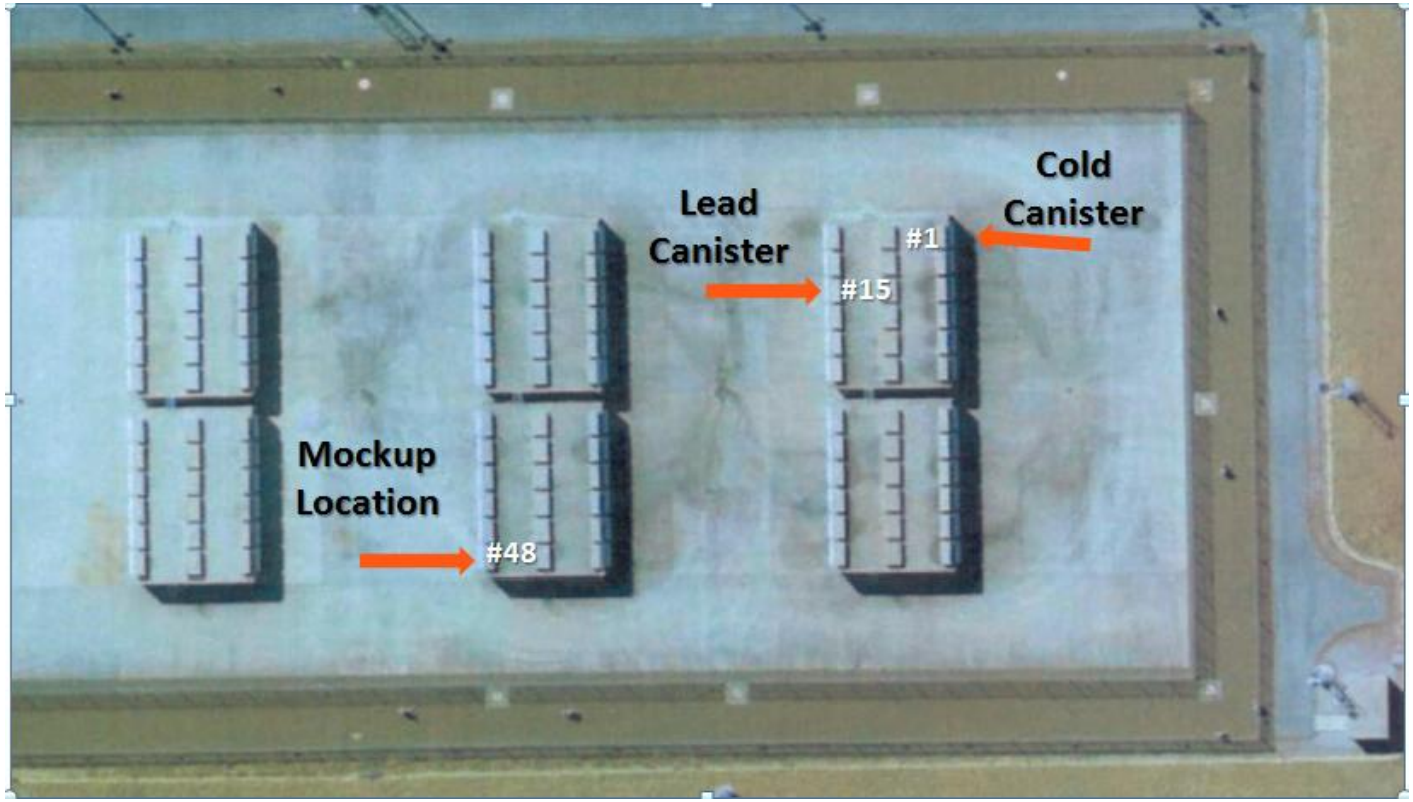
ISFSI Layout



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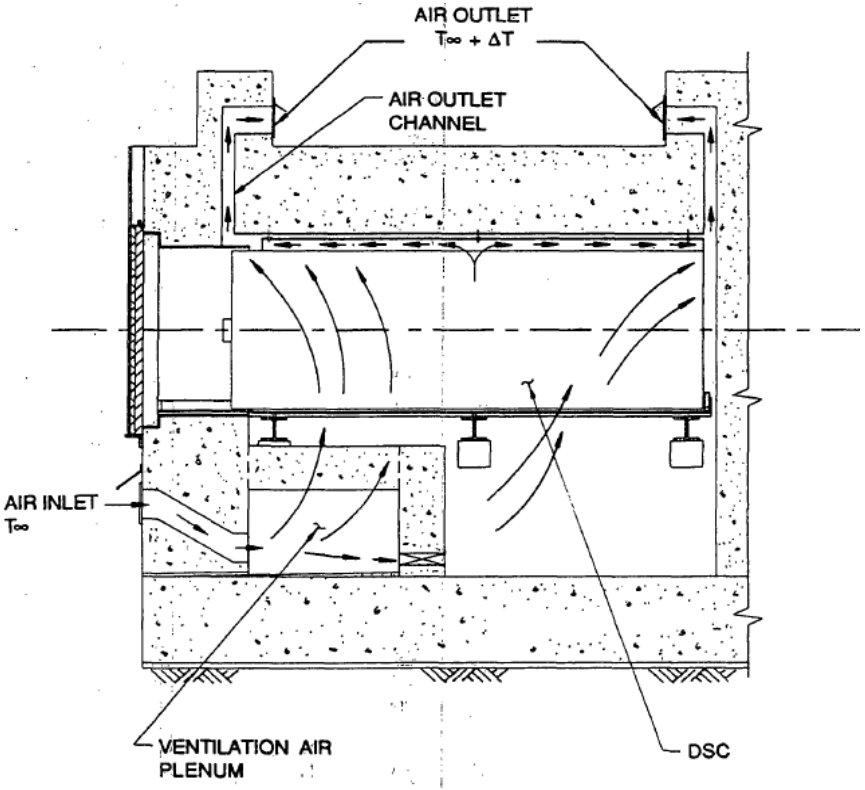
Inspection Access

Through outlet

- Visual

Through front

- Temperature
- Surface contaminants
  - Wet & Dry
- Tool to access canister side through small gap
- Temporary shielding



ADAMS Accession # ML110730769

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Calvert Cliffs Inspection

Visual

- Lower camera through rear roof outlet
- Stay to rear of HSM, away from high rad field
- Use Pan-Tilt-Zoom to view nearly all canister surface

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Calvert Cliffs Inspection

Canister surface temperature

- Canister bottom – immediately after door raised
  - Thermography
  - Thermocouple
- Several radial and axial locations
  - Thermocouple attached to end of extension tool
  - Rotate to contact surface and read temperature
  - Only on cold canister

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Calvert Cliffs Inspection

Surface samples

- Dry (scraping, brushing, vacuum)
  - Best for upper surfaces to collect “dust”
  - Insert tool, rotate to surface, turn on vacuum, scrape back and forth, rotate and remove tool
- Wet - SaltSmart™
  - Qualification testing for temperature and range of concentrations expected
  - Insert tool, engage SaltSmart™, deliver water, wait, disengage SaltSmart™, remove tool

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Calvert Cliffs Inspection - Results

Lead Canister

- Closure weld

- Dust on top surface

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Calvert Cliffs Inspection - Results

Lead Canister

- Evidence of dripping

- Lower surface – no dust

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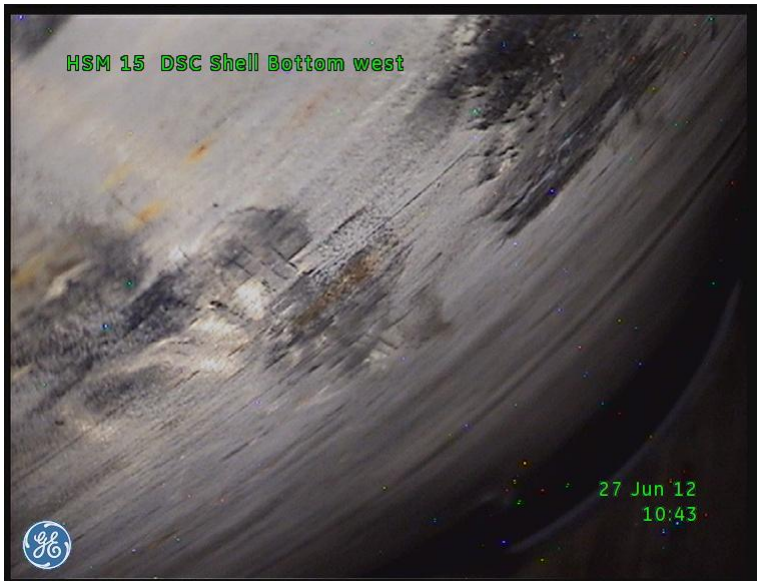
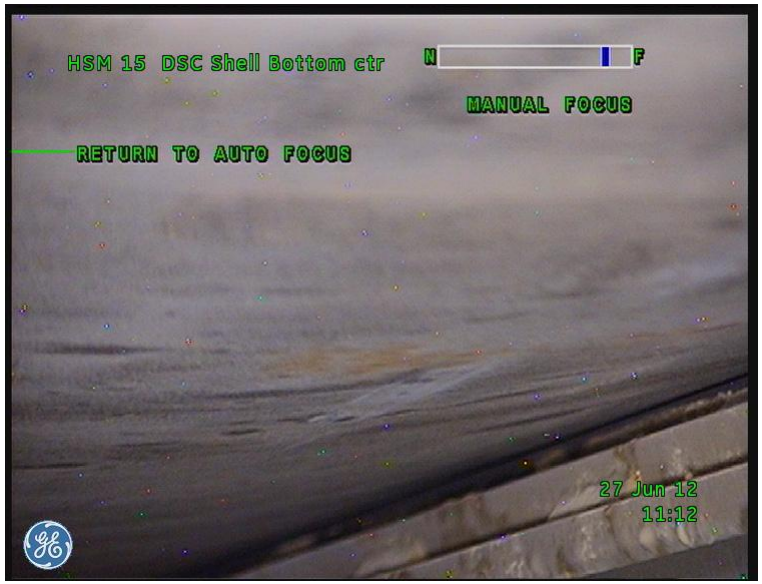
Calvert Cliffs Inspection - Results

Lead Canister

- Some discoloration
  - Possibly free iron contamination
  - Only on Lead Canister





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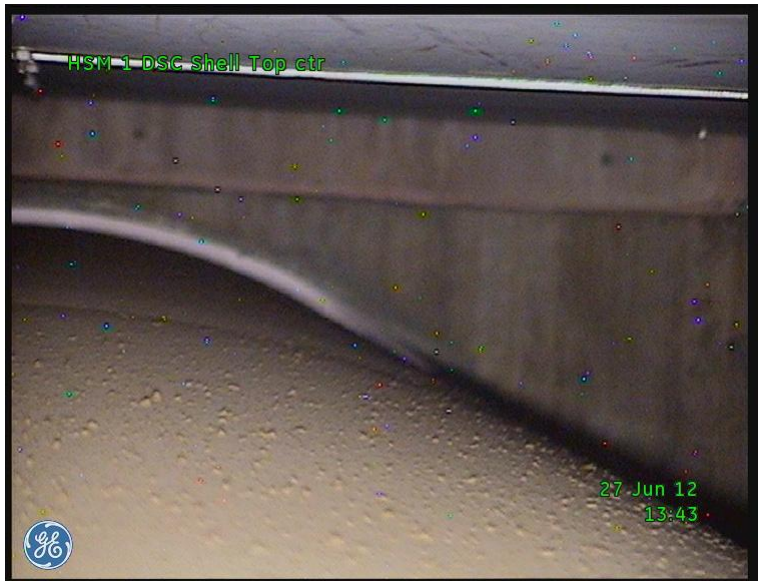
Calvert Cliffs Inspection - Results

Cold Canister

- Closure weld

- Dust on top surface



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Calvert Cliffs Inspection - Results

Temperatures

- Thermocouple only
- Lead Canister
  - 124 F at bottom
- Cold Canister
  - See table

Radial	Axial Distance From Bottom (in.)	Measured Temperature (F)
Under grapple ring	Under grapple ring	112
Top (12 o'clock)	0	115
Top (12 o'clock)	20	117
Top (12 o'clock)	40	119
Side (3 o'clock)	0	108
Side (3 o'clock)	20	109
Side (3 o'clock)	40	108
Side (9 o'clock)	0	104
Side (9 o'clock)	20	105
Side (9 o'clock)	40	108
Rail (5 o'clock)	0	106
Rail (5 o'clock)	20	107
Rail (5 o'clock)	40	108
Rail (7 o'clock)	0	105
Rail (7 o'clock)	20	106
Rail (7 o'clock)	40	106

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Calvert Cliffs Inspection - Results

Surface Samples

- Dry
  - 3 samples collected
    - 1 sample twisted and not useful
  - Awaiting analysis
- Wet
  - 1 sample collected
  - Evaluating result

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High BurnUp Demo

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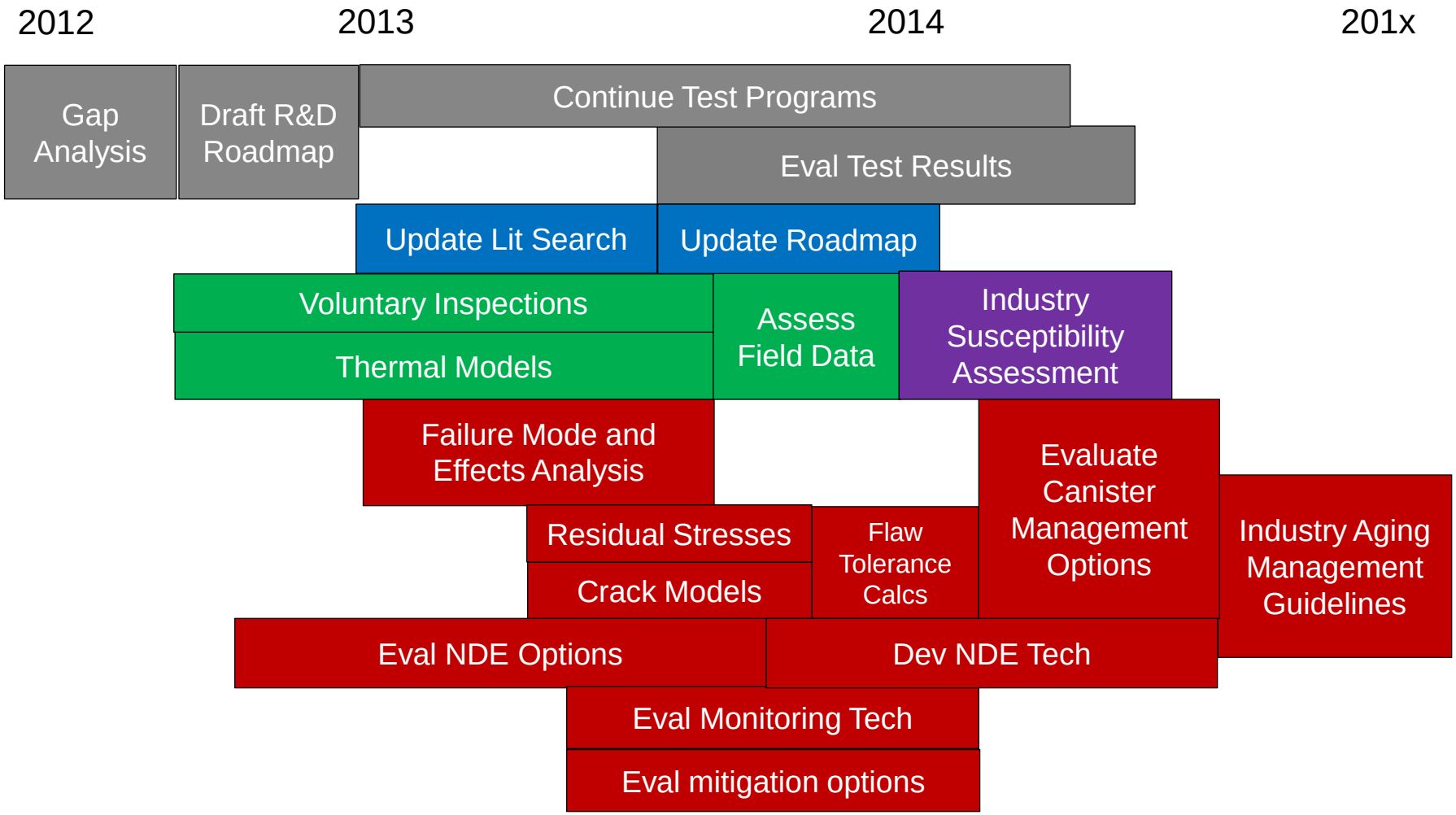

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