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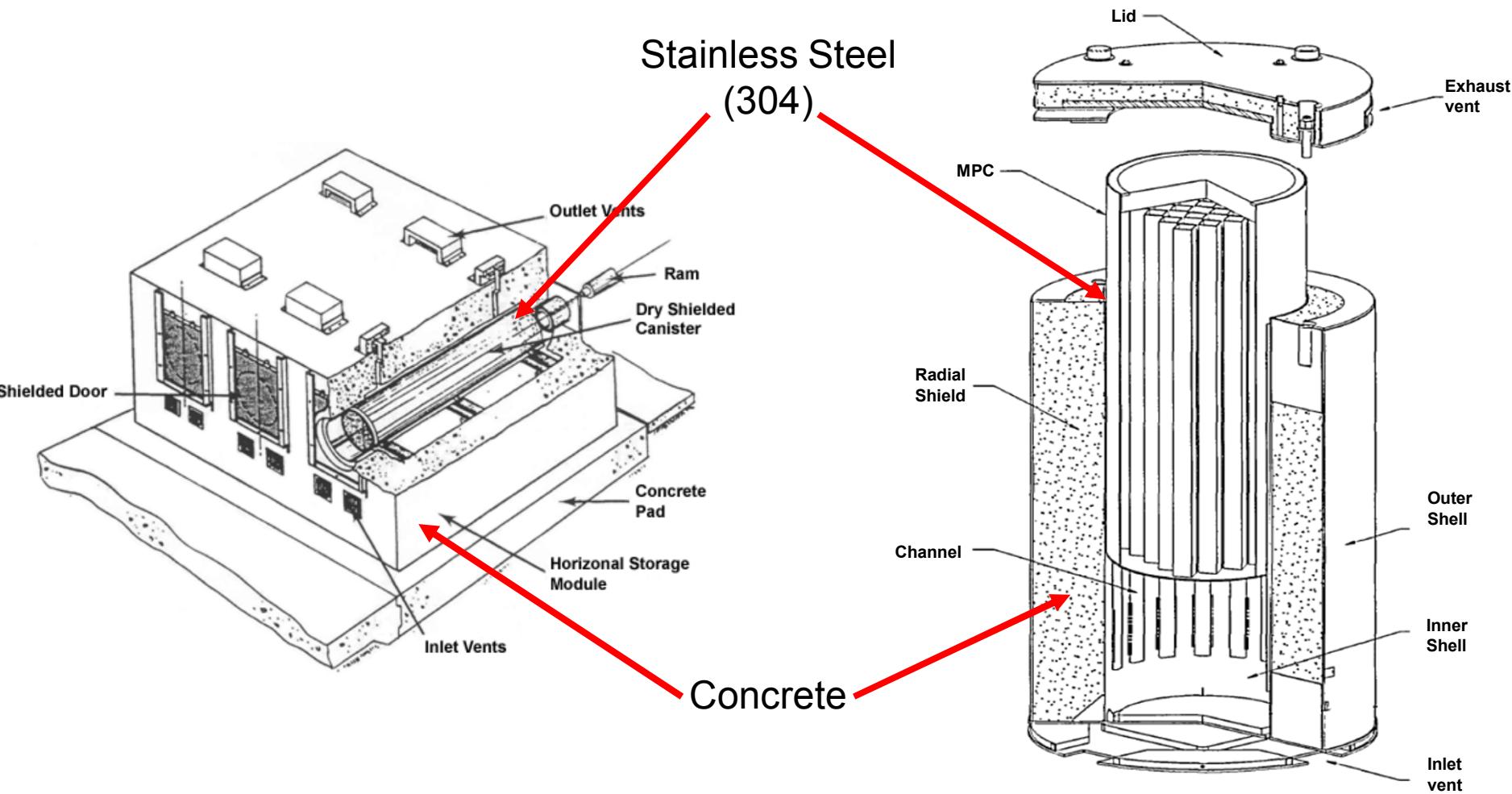
# Understanding the Surface Environment and its Impact on the Extended Performance of Interim Storage Containers for Spent Nuclear Fuel

D.G. Enos and C.R. Bryan



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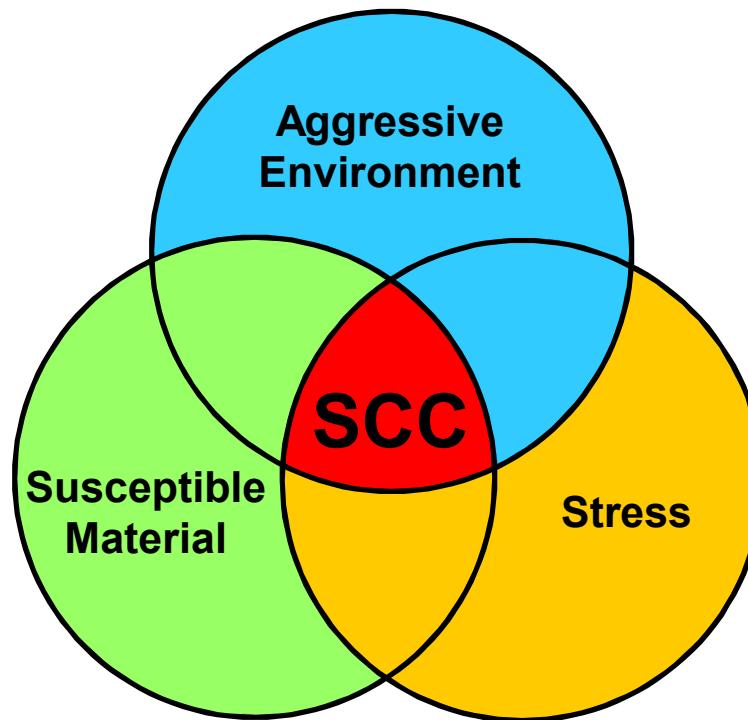
# Interim Storage Systems (Welded)



**Horizontal (e.g., Areva TN)**

**Vertical (e.g., Holtec)**

# Degradation mechanism of concern: Stress Corrosion Cracking (SCC)

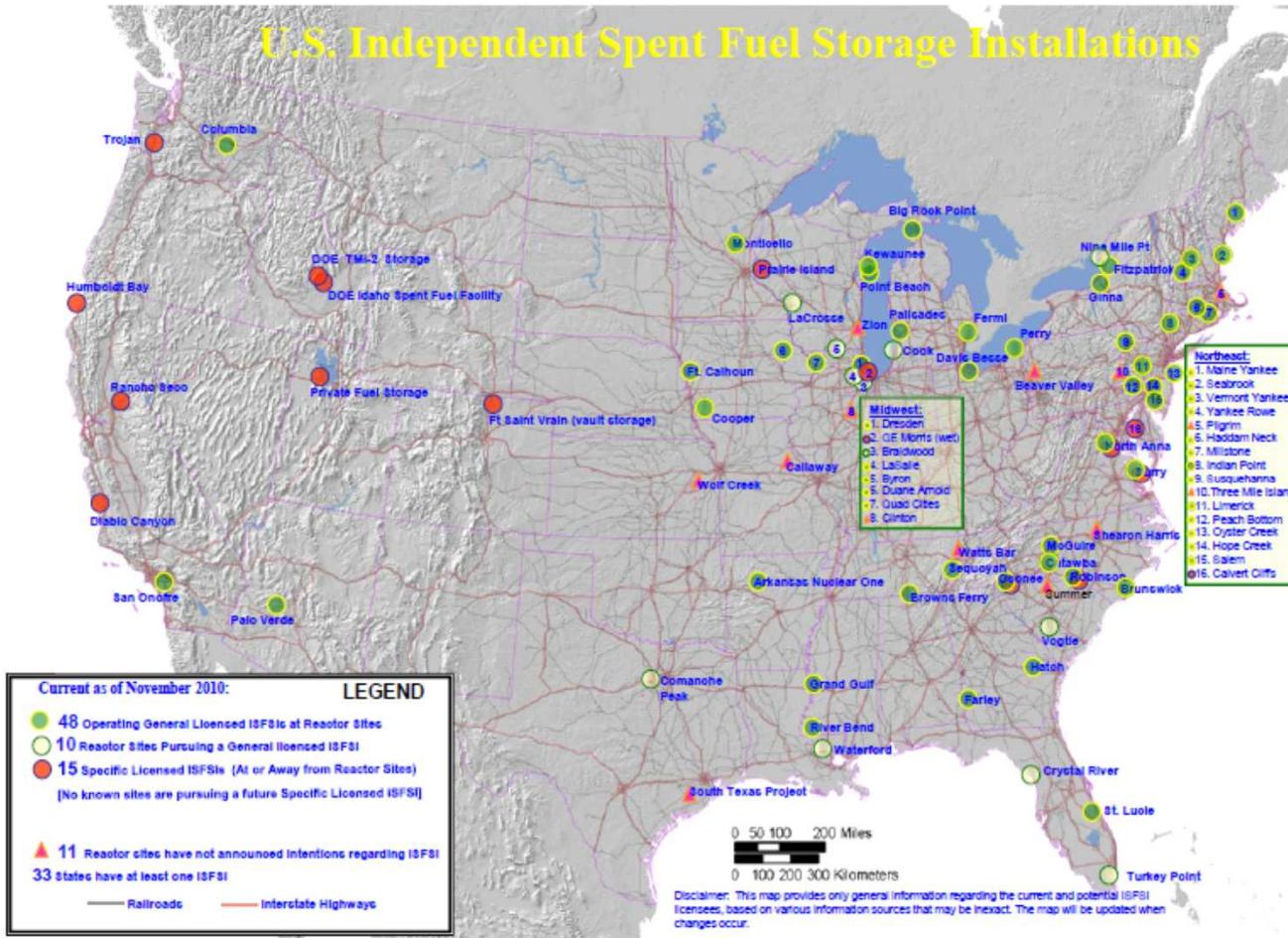


Questions that need to be answered:

1. Will a chloride bearing environment form on the surface of the containers?
2. Is the material of construction for fielded interim storage containers susceptible?
3. Is there a sufficiently large tensile stress to support crack initiation and propagation in fielded interim storage containers?

# Where are ISFSIs located?

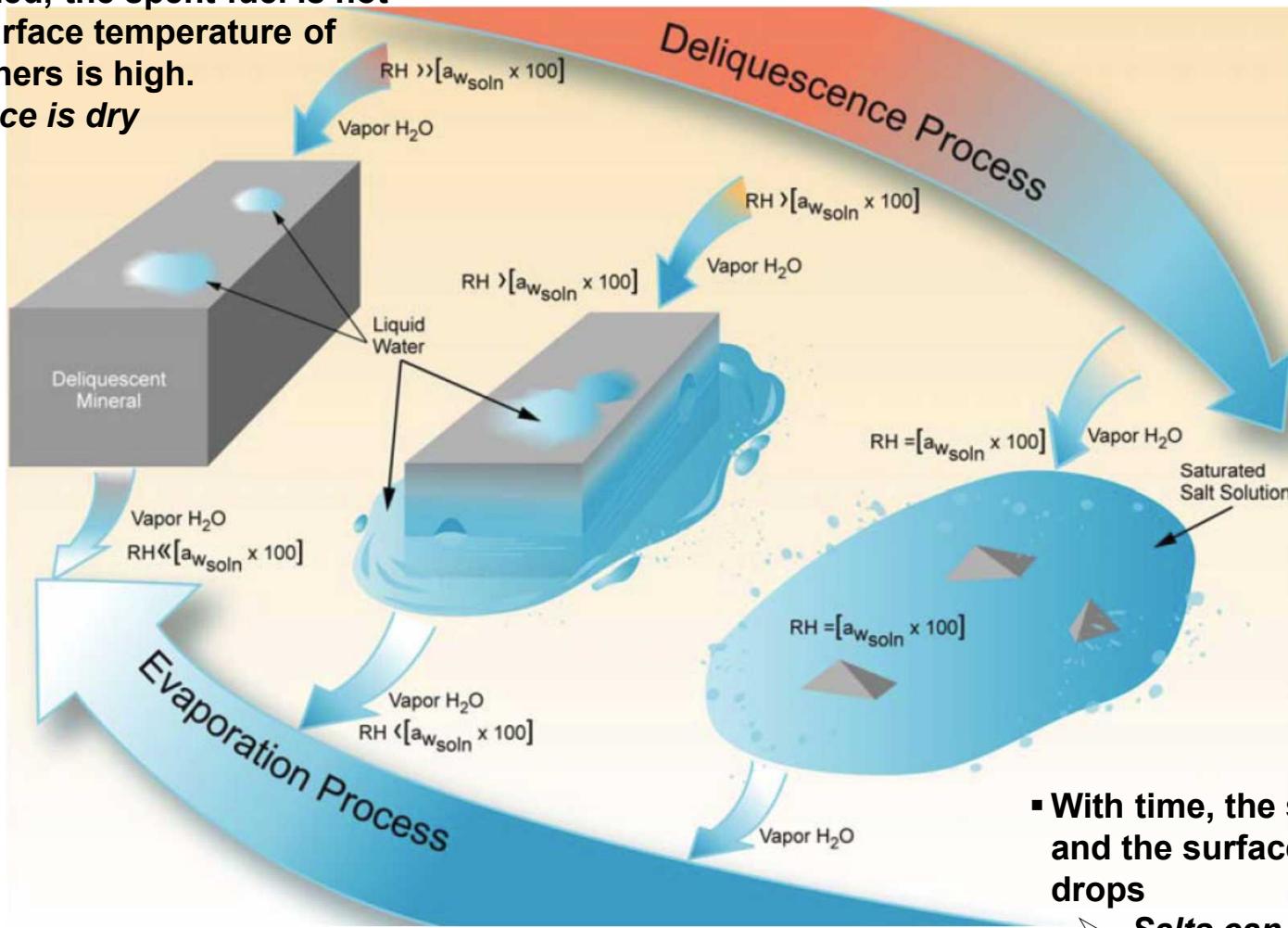
- Many interim storage sites are located in marine environments where significant deposition of marine aerosols is anticipated



# Development of an Aggressive Environment

- When loaded, the spent fuel is hot and the surface temperature of the containers is high.

- *Surface is dry*



- With time, the spent fuel cools and the surface temperature drops

- Salts can deliquesce

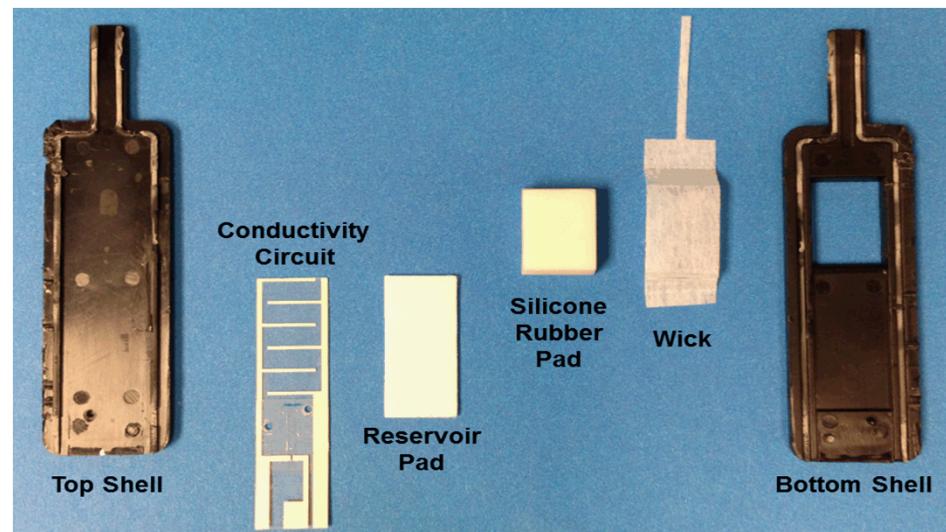
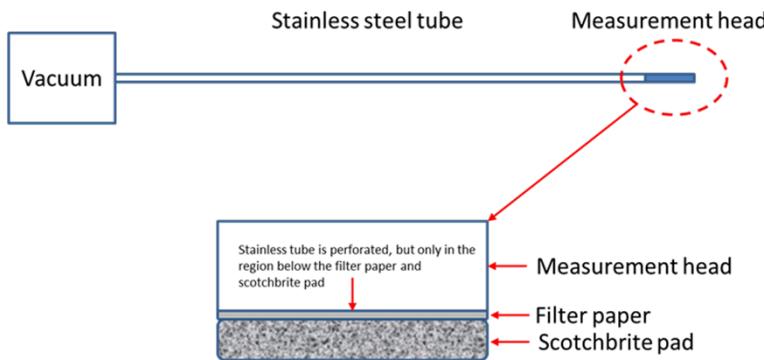
# Is there anything on the surface of fielded containers?

- EPRI has driven an effort to view and sample the dust on the surface of the containers at several ISFSI sites
  - Calvert Cliffs (with support from Areva TN) – Brackish water
  - Hope Creek (with support from Holtec) – Brackish water
  - Diablo Canyon (with support from Holtec) – Marine (Ocean)

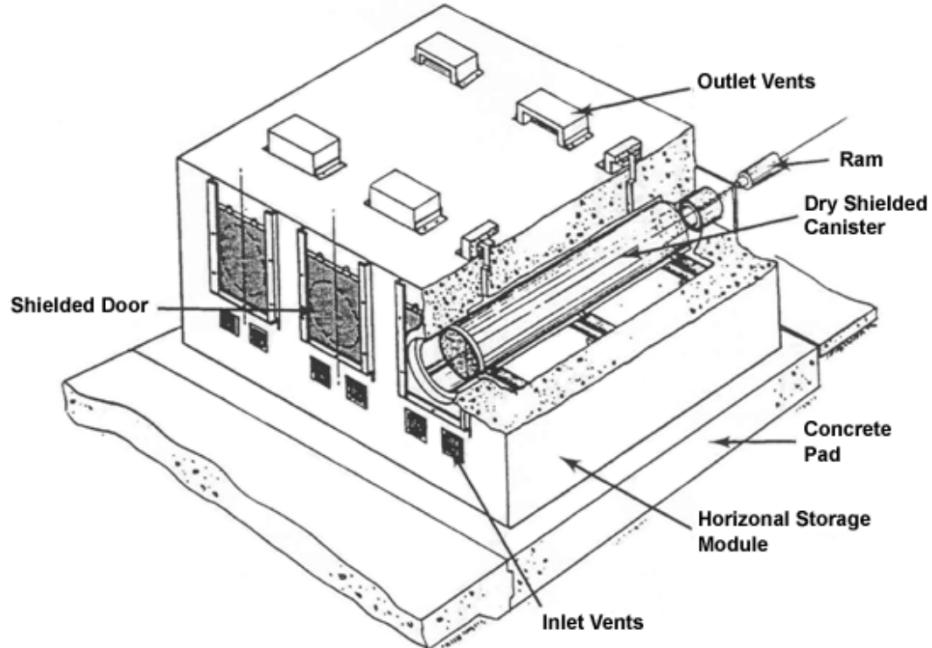


# Both wet and dry sampling techniques were employed

- Similar procedures were used at all three utilities
- Dry sampling was accomplished via an abrasive pad rubbed on the container surface
- Wet sampling was performed using a device known as the SaltSmart™



# Calvert Cliffs – Horizontal Storage System



# Calvert Cliffs

Water soluble salts:

- 30 minute leach with deionized water
- Cations:  $\text{Ca}^{2+} \gg \text{Na}^+, \text{Mg}^{2+}, \text{K}^+$
- Anions:  $\text{SO}_4^{2-} \gg \text{NO}_3^- > \text{Cl}^-$

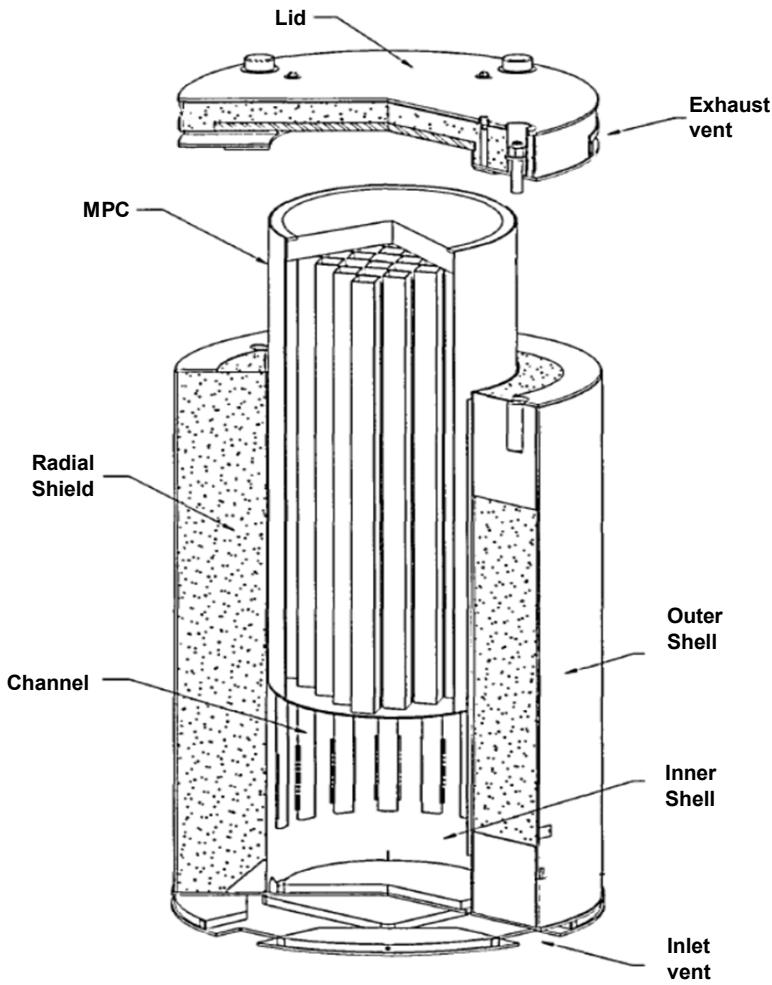
Salts do not appear to have a large marine component:

- Low  $\text{Na}^+$ ,  $\text{Cl}^-$ , high  $\text{Ca}^{2+}$ ,  $\text{SO}_4^{2-}$
- Conversion after deposition via particle-gas conversion reactions?  
Does not explain low Na
- Preferential deposition of deliquesced Ca-Cl salts, followed by conversion to sulfates and chloride-loss?

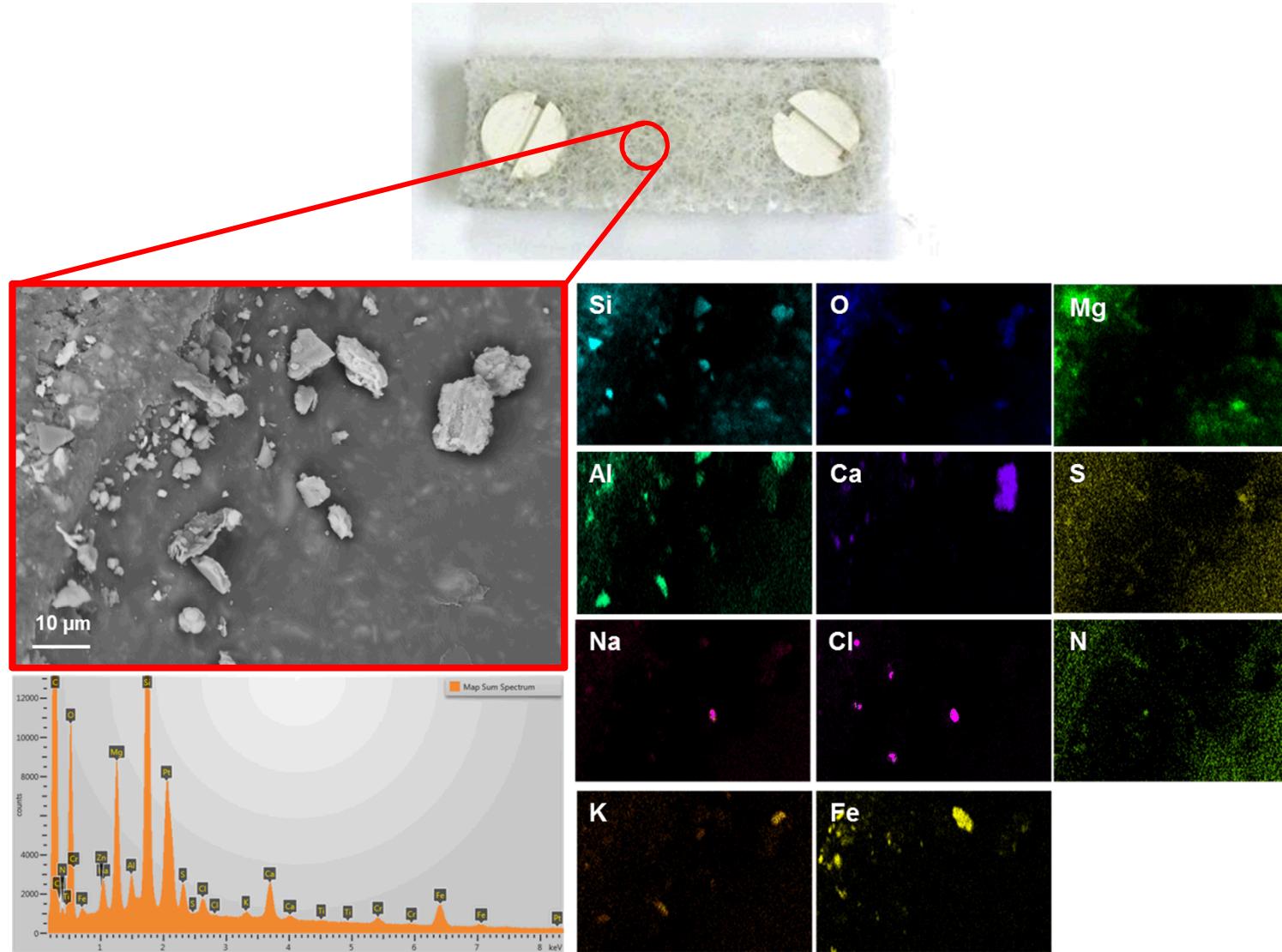
Ion	EPRI #1 filter	EPRI #1 pad	EPRI #4 filter	EPRI #4 pad
$\text{Na}^+$	19.2	14.8	n.d.	11.3
$\text{K}^+$	18.1	13.7	1.05	7.75
$\text{Ca}^{+2}$	77.1	20.6	24.1	153
$\text{Mg}^{+2}$	16.9	6.0	1.95	17.6
$\text{F}^-$	0.30	0.61	n.d.	n.d.
$\text{Cl}^-$	5.64	n.d.	n.d.	3.10
$\text{NO}_3^-$	21.3	9.09	4.34	14.2
$\text{SO}_4^{-2}$	89.7	51.5	48.0	291
$\text{PO}_4^{-3}$	6.68	2.05	0.45	n.d.
Total mass, $\mu\text{g}$	255	118	80	498

From: C.R. Bryan, D.G. Enos "Understanding the Environment on the Surface of Spent Nuclear Fuel Interim Storage Containers", SAND2013-8487C, October, 2013

# Hope Creek and Diablo Canyon – Vertical Storage System

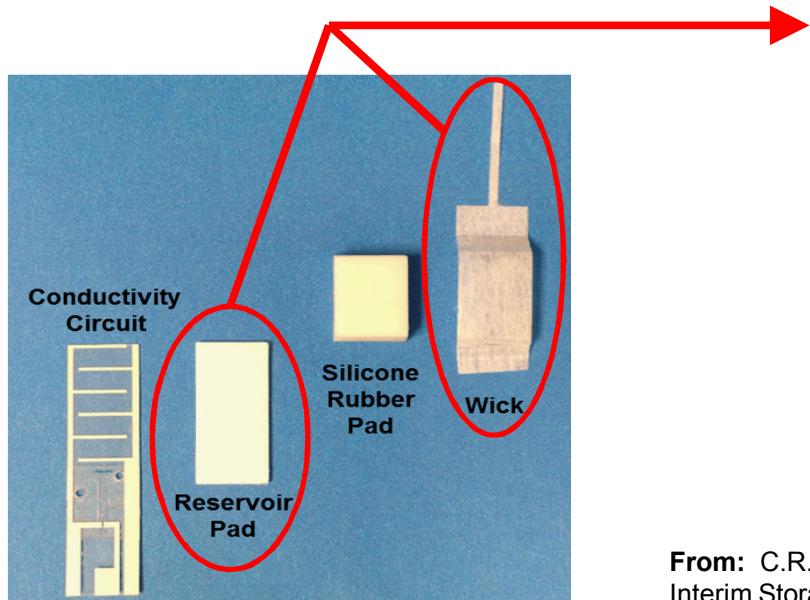


# Hope Creek



# Typical Wet Sample Results

- Solutions extracted from SaltSmart reservoir pads
- Complicating factors
  - Extraction efficiency in the field
  - Temperature effects
  - Pad to container contact patch variation

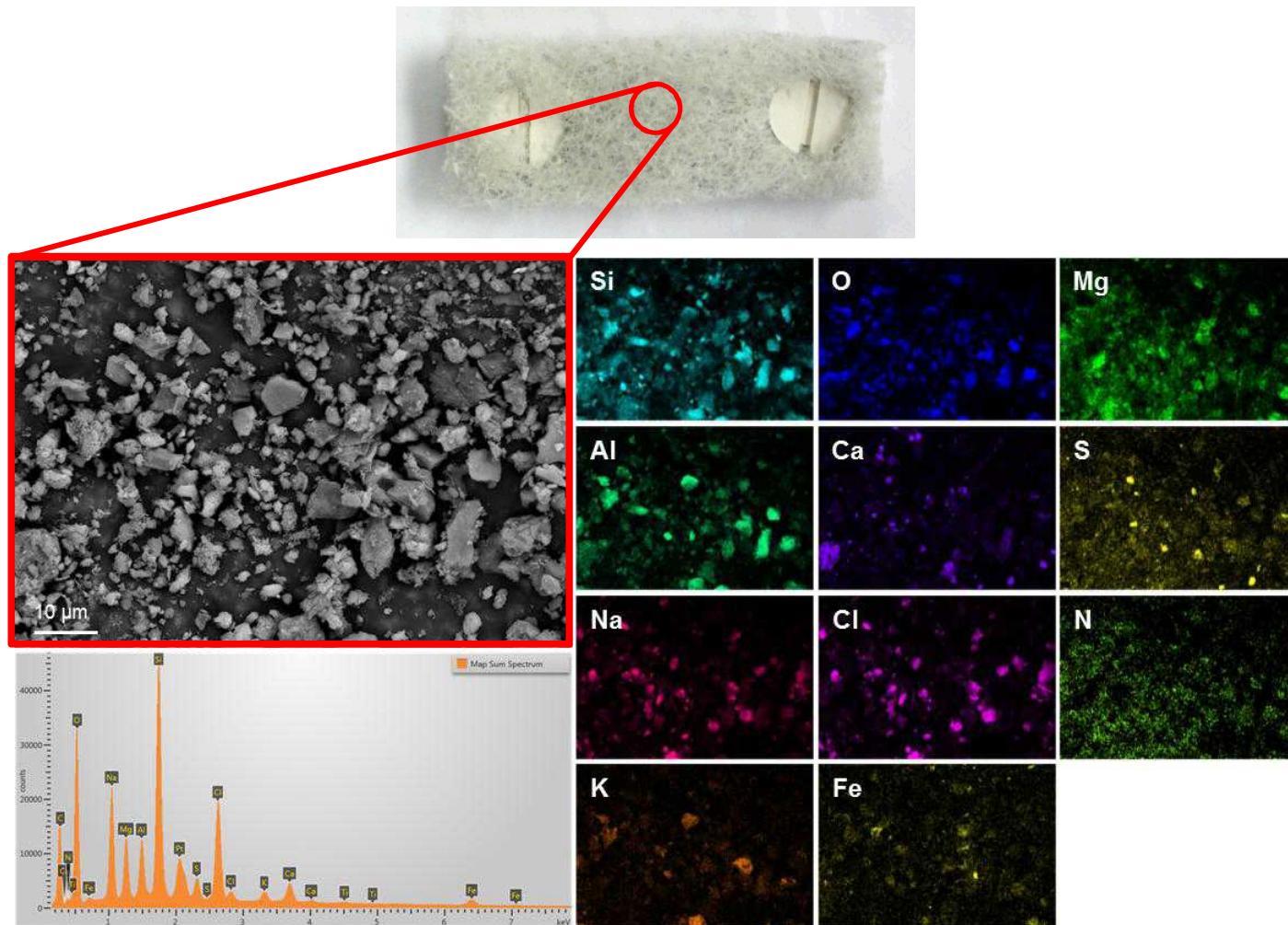


Example from Hope Creek

Sample #	Location	Depth (cm)	Temp (°C)	[Cl] (mg/m <sup>2</sup> )
144-008	Side	396	34	3
144-009	Side	229	47	2.9
144-010	Side	30	57	3.9
144-013	Top	0	59	14
144-014	Top	0	61	60
144-003	G.S	--	--	1.6
144-004	G.S	--	--	2.5
145-006	Side	396	21	7.3
145-007	Side	229	38	7.1
145-014	Side	30	55	4.1
145-013	Top	0	79	7.5
145-002	G.S	--	--	2.2
145-011	Blank	--	--	2.5

From: C.R. Bryan, D.G. Enos "Analysis of Dust Samples Collected from Spent Nuclear Fuel Interim Storage Containers at Hope Creek, Delaware and Diablo Canyon, California", SAND2014-16383, July, 2014

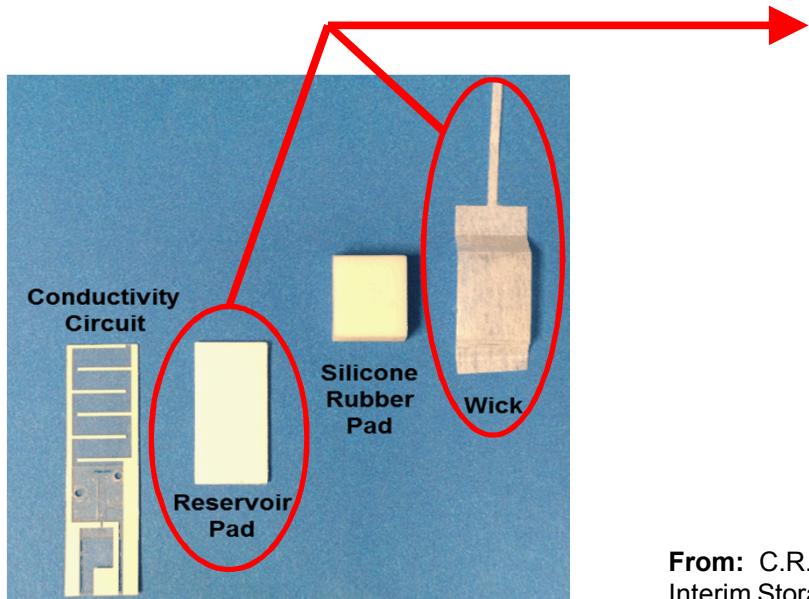
# Diablo Canyon



From: C.R. Bryan, D.G. Enos "Analysis of Dust Samples Collected from Spent Nuclear Fuel Interim Storage Containers at Hope Creek, Delaware and Diablo Canyon, California", SAND2014-16383, July, 2014

# Typical Wet Sample Results

- Solutions extracted from SaltSmart reservoir pads
- Complicating factors
  - Extraction efficiency in the field
  - Temperature effects
  - Pad to container contact patch variation



Sample #	Loc.	Depth (cm)	Temp (°C)	Cl <sup>-</sup> (mg/m <sup>2</sup> )
123-003	Side	426	49	4.8
123-004	Side	350	79	3.6
123-005*	Side	320	87	2
123-002	G.S.		—	58
123-010	Blank		—	25
170-007*	Side	320	81	4.2
170-008*	Side	289	84	2.9
170-009*	Side	274	87	2.5
170-002	G.S.	—	—	13
Blank	—	—	—	4.2
Blank	—	—	—	2.3
Blank	—	—	—	3.8
Blank	—	—	—	1.5

\*Wick adhered to silicone pad, and reservoir only partially saturated

**From:** C.R. Bryan, D.G. Enos "Analysis of Dust Samples Collected from Spent Nuclear Fuel Interim Storage Containers at Hope Creek, Delaware and Diablo Canyon, California", SAND2014-16383, July, 2014

# Is Localized Corrosion of Interim Storage Components a Legitimate Concern?

- Requirements for crevice corrosion or pitting
- Driven vs. atmospheric
- Implications of a thin electrolyte layer
- Evolution of brine chemistry on the container surface
- Is the parent material the right material to be considering?

# Is there going to be sufficient stress?

- Is there sufficient residual stress within the container wall to support propagation of a through-wall crack?
- Many complicating factors
  - Weld procedure (start/stop, technique, etc.)
  - Weld repairs

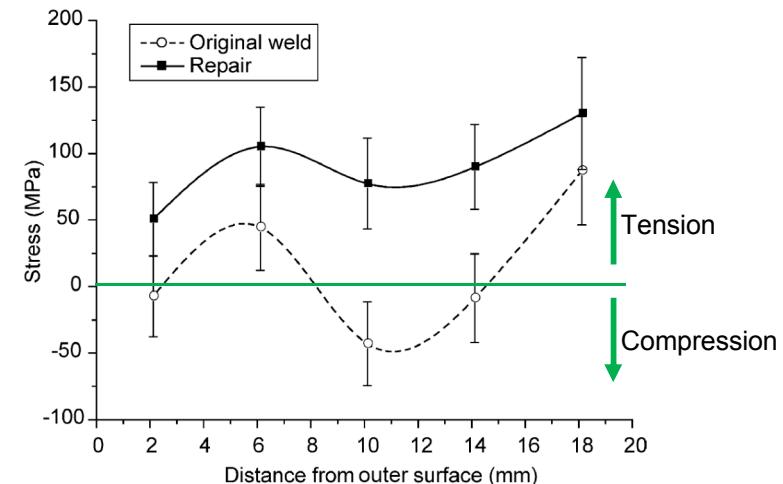
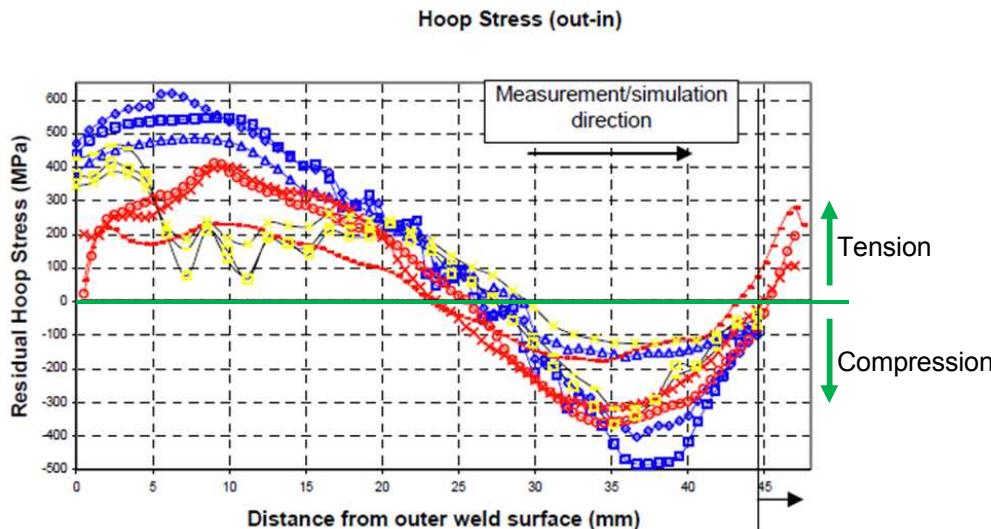
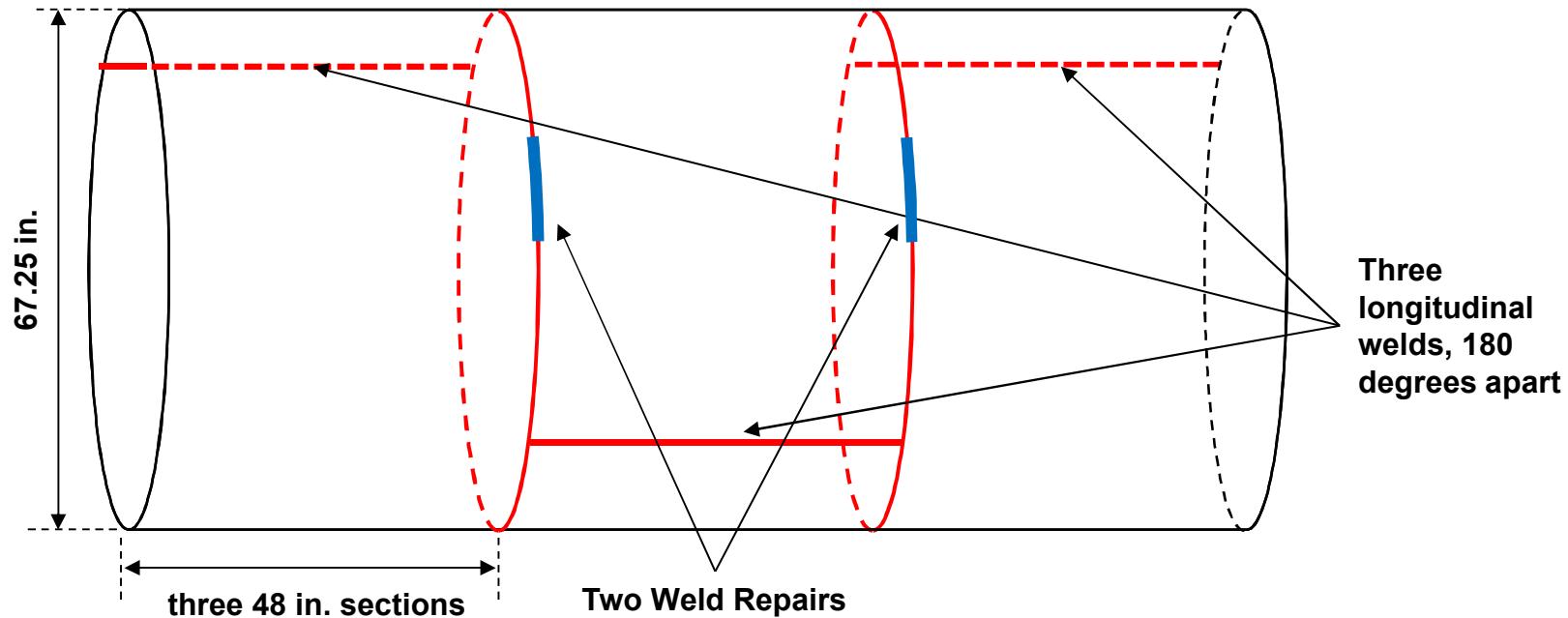


Fig. 14. Hydrostatic residual stress profile (17.5 mm from weld centre-line).

# Full Scale Mock-Up Assembled to Directly Measure Residual Stresses



- Wall material: 304 SS welded with 308 SS
- Wall thickness, overall diameter, weld joint geometry: standard geometry for NUHOMS 24P
- Welds:
  - Full penetration and inspected per ASME B&PVC Section III, Division 1, Subsection NB (full radiographic inspection)
  - Double-V joint design, Submerged Arc welding process

# Current Plans for the Mock-Up

- Mock up construction completed in September, 2014
- What are we going to measure?
  - Weld residual stress state (deep hole drilling, neutron diffraction, contour)
  - Extent of sensitization (electrochemical)
  - Baseline electrochemical testing
  - Stress corrosion cracking susceptibility
- How will the mock-up be sampled?
  - Material to be used in support of UFD work as well as NEUP activities where appropriate
  - Subdividing the mock-up will impact the stress state – will limit what can be done
  - Sample geometry that we need?

# Summary and Future Direction

- Large existing fleet of storage containers made from welded 304SS, located at both marine and inland sites
  - Material known to be susceptible to SCC
  - Chloride bearing salts likely in some locations
  - Residual stresses at welds could be significant and tensile in nature
- Moving Forward, research will focus on
  - Understanding potential brine chemistry on container surface
  - Quantifying residual stress state at welds and weld repairs in full scale mock-container
  - Exploring susceptibility of welded material to both localized corrosion and stress corrosion cracking initiation and propagation

# Acknowledgements

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## EPRI

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- Shannon Chu – CISCC Task group

## Industry

- Laszlo Zsidai (Holtec) – sampling at Hope Creek and Diablo Canyon
- Bill Bracey (Areva-TN) – sampling at Calvert Cliffs