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Integrated Plan for Addressing Potential Chloride-Induced Stress Corrosion Cracking of Austenitic Stainless Steel Dry Cask Storage System Canisters

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Status Update to NRC
April 4, 2013

Agenda

- Background/Objective
- Elements of R&D Roadmap
  - Failure modes and effects analysis
  - Literature survey
  - Voluntary inspections
  - Degradation models
  - Susceptibility Assessment Criteria
- Advisory Panel Formation
- Next Steps

Stress-Corrosion Cracking (SCC) of SS Welded Canisters

SCC requires 3 concurrent conditions:

1) Austenitic stainless steels (e.g. 304, 316)
2) Tensile stress (residual weld stress)
3) 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?

3

Objective

- Communicate details of EPRI's R&D plan to address potential chloride-induced stress corrosion cracking of austenitic stainless steel canisters in dry cask storage systems
- Discuss status of this effort and related programs underway

4

R&D Roadmap: SCC Susceptibility Assessment

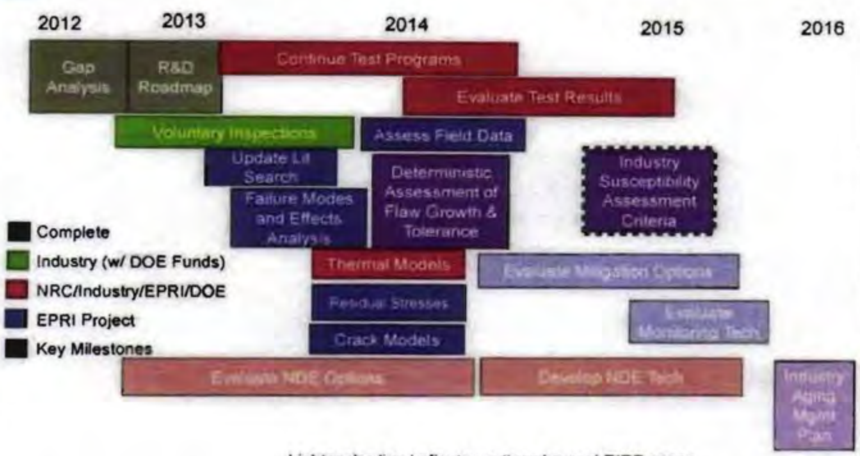
Process
To understand the phenomenon of SCC in the context of dry cask storage

Key Elements
- Voluntary inspections
- Failure modes and effects analysis
- Literature survey
- Degradation experiments and models

Goal
Methodology that identifies
- minimum conditions in environment and cask
- associated time scales

5

Project Overview to Address RIRP Action Items

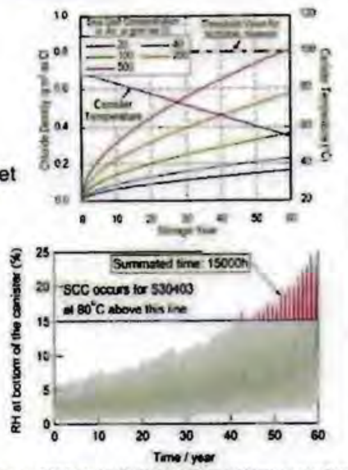


Lighter shading indicates actions beyond RIRP scope

6

Voluntary Inspections

- Initial screening considerations
  - 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 deposit sampling
  - Atmospheric sampling
  - Hope Creek ~ July/August
  - Diablo Canyon late September



Figures: SCC Evaluation Method of Multi-Purpose Canister in Long Term Storage. Central Research Institute of Electric Power Industry

Sample analysis results will be shared with NRC as part of response to RAIs, will also be published in an EPRI report

Failure Modes and Effects Analysis (FMEA) Approach (slide 1/2)

- Scope of this effort is limited to welded SS canister designs exposed to atmosphere
- Focus on aging-related degradation
- Industry will review at early and later stages in its development
- FMEA of Stainless Steel Canisters
  - Draft September 2013
  - Final December 2013
- Systematically identify credible failure modes for SS canisters
  - Incorporate results from gap analyses done by others
  - Existing design basis documents for volunteer plant will be reviewed and factored into the failure modes considered

Failure Modes and Effects Analysis (FMEA) Approach (slide 2/2)

- Identify range of potential effects for failure mode(s)
  - A Fault Tree Analysis (FTA) of the failure modes to evaluate combinations of initiating events
  - Frequency / probability of failure mode occurrence as a function of time
  - Consequences associated with the failure mode
  - Detection before the impact of the effect is realized
  - Consider both normal and accident conditions

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Literature Survey

- Review work relevant to chloride-induced SCC in 304 and 316 SS
- Seek to identify available information to better define the actual environmental conditions of ISFSIs in the US
- Identify knowledge gaps between the potential environmental conditions and the degradation data currently available
- Key Resources include:
  - PWROG : *Screening Criteria for ID and OD-Initiated SCC of Pressure Boundary Stainless Steel Components* (2011)
  - NRC: *Atmospheric Stress Corrosion Cracking Susceptibility of Welded and Unwelded 304, 304L, and 316L Austenitic Stainless Steels Commonly Used for Dry Cask Storage Containers Exposed to Marine Environments* (2010)
  - EPRI: *Effects of Marine Environments on Stress Corrosion Cracking of Austenitic Stainless Steels* (2005) #1011820

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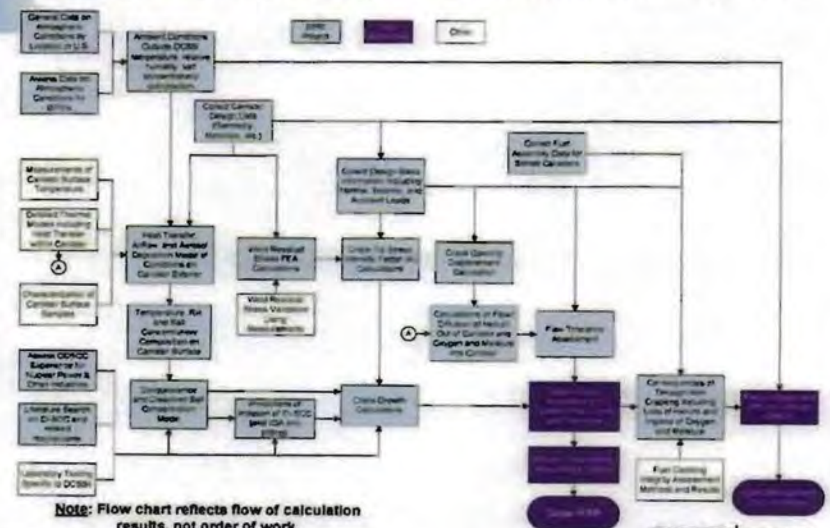
Industry Susceptibility Assessment Development



Note: Flow chart reflects flow of calculation results, not order of work.

Collaboration on Model Development

- Environment necessary for crack initiation (probability/time)
  - Best estimate thermal models – see below
  - SCC crack initiation models – see below
- Crack growth rate depends on Stress Intensity Factor
  - Prediction of residual stresses – EPRI and ESCP Participants
  - Propagation Models – see below
- Loads and failure modes (FMEA) input to determine flaw tolerance – EPRI

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

Degradation Models - Assess the Potential for Through-wall Crack Growth in the Canister Wall

- Probability that an environment necessary for crack initiation will exist
  - Primary basis: FMEA work
  - Considering variations in environmental conditions over time (salt concentration, relative humidity, temperatures)
- Crack growth rate
  - A function of crack tip stress intensity factor
    - Depends on the applied and residual stress state, weld residual stress analysis of closure welds will be performed
- Deterministic Assessment of Canister Flaw Growth and Tolerance
  - Draft January 2014
  - Final April 2014

13

Industry-wide Susceptibility Criteria

- Develop criteria to assess susceptibility of ISFSIs to canister degradation, potentially leading to a loss of confinement integrity
- Identify the associated time scales
- Interaction between relative humidity, salt concentration, and local temperature due to decay heat may combine to create a window of concern for susceptibility
- Industry Susceptibility Criteria
  - Draft December 2015
  - Final June 2015

14

Advisory Panel Formation

- Advisory panel will oversee development of susceptibility assessment methodology
- Beginning now and lasting through 2015+
- Follow-on work will develop an aging management plan
  - The aging management plan will guide industry activities including inspection schedules and potential application of mitigation techniques to canisters.

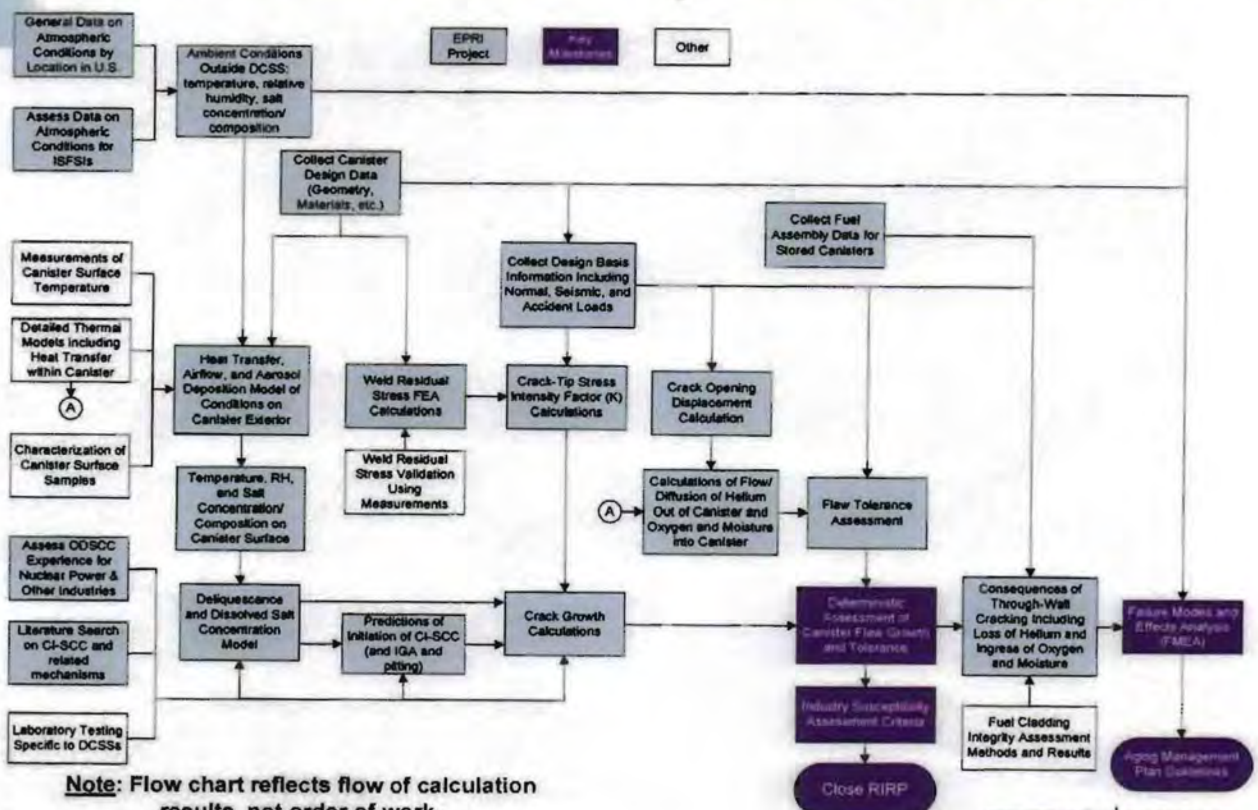
Advisory Panel Participants

- Arizona Public Service
- Constellation
- Exelon
- Nextera/Florida Power& Light
- Pacific Gas & Electric (PG&E)
- Public Service Electric and Gas Company (PSE&G)
- Three Yankees

- Transnuclear
- Holtec
- NAC

- Nuclear Energy Institute
- Structural Integrity Associates

Industry Susceptibility Assessment Development



Note: Flow chart reflects flow of calculation results, not order of work.

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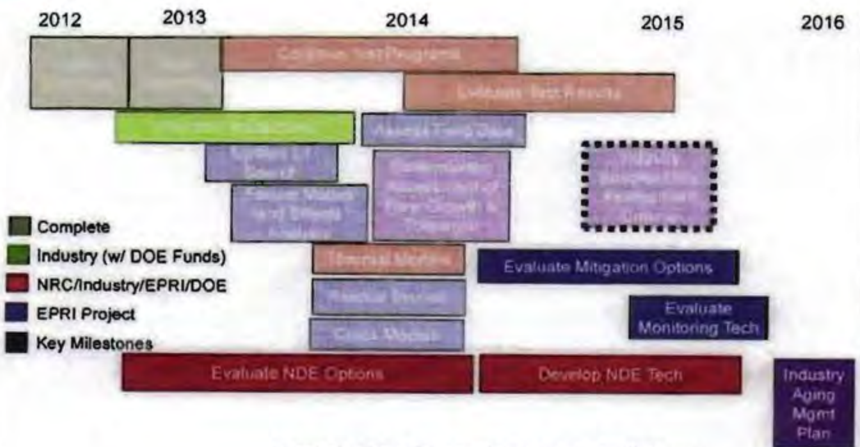
Project Continuation



Lighter shading indicates actions to complete RIRP scope

Aging Management Plan – Develop Options

- Stainless Steel Canister Confinement Integrity Assessment
  - Probabilistic models of environment and crack behavior applied to determine recommended inspection frequencies
- Simultaneous effort to identify, develop, evaluate:
  - NDE Technologies
  - Monitoring Technologies
  - Mitigation Technologies
- Publish guidance document early 2016

Utilities incorporate appropriate management strategy into site plans

Next Steps

- Key Publication Dates (Estimates)
  - FMEA of Stainless Steel Canisters
    - Draft 9/13
    - Final 12/13
  - Deterministic Assessment of Canister Flaw Growth and Tolerance
    - Draft 1/14
    - Final 4/14
  - Industry Susceptibility Assessment Criteria
    - Outline 5/14
    - Draft 12/14
    - Final 6/15
- Potential EPRI-NRC Meeting Dates and Topics
  - October 2013: FMEA of Stainless Steel Canisters
  - May 2014: Deterministic Assessment of Flaw Growth and Tolerance & Susceptibility Assessment Outline
  - Subsequent meetings will be planned ahead of key milestones (approximately every 6 months)
- Questions?

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USED FUEL STORAGE AND TRANSPORTATION ISSUE SCREENING FORM
Issue Number: N-10-01

Title: Dry Spent Fuel Storage Canister Chloride Induced Stress Corrosion Cracking

I. a. Problem Statement (Provide a clear, concise description of the issue.)

There is insufficient data to determine the minimum conditions (environmental and cask), and the associated time scales, necessary for potential initiation of stress corrosion cracking (SCC) in stainless steel dry spent nuclear fuel (SNF) storage canisters deployed at ISFSIs located in chloride atmospheres.

b. Background Information (Summarize industry events, licensing actions, inspection information, correspondence, and other documents germane to the issue. Attach documents as appropriate)

Austenitic stainless steels (304, 304L and 316L) used for confinement boundary in SNF storage canisters may be susceptible to SCC when exposed to a chloride atmosphere (References 1 through 4). Fog and spray aerosols from salt water bodies can contain high concentrations of chlorides that may deposit on canister surfaces, potentially leading to SCC. Degradation from this phenomenon may impact the ability of the storage system confinement boundary to perform its safety function over an extended operating period. SCC, if present, may also impact the future transportation performance (if the system or component is dual-purpose certified). The chloride induced SCC (CISCC) phenomenon has historically not been the subject of NRC review of applications for dry spent fuel storage system Certificates of Compliance, but has been the subject of some RAIs issued since 2012.

References 1 through 4 contain descriptions of laboratory experiments performed to simulate the CISCC phenomenon. However, the laboratory conditions do not accurately represent in-situ conditions at ISFSI sites. This difference between the laboratory and the in-situ conditions makes it impossible to determine the condition-based time scales under which SCC of stainless steel dry cask storage canisters could potentially occur.

References:

1. "Research Program on Stress Corrosion Cracking of Stainless Steel Canister for Concrete Cask," Central Research Institute of Scientific Power Industry (CRIEPI), Japan, January 16, 2007.
2. NUREG/CR-7030, "Atmospheric Stress Corrosion Cracking Susceptibility of Welded and Unwelded 304, 304L, and 316L Austenitic Stainless Steels Commonly Used for Dry Storage Containers Exposed to Marine Environments," USNRC, October 2010.
3. Report 1011820, "Effects of Marine Environments on Stress Corrosion Cracking of Austenitic Stainless Steel," Electric Power Research Institute, September 2005.
4. Report 1013524, "Climatic Corrosion Considerations for Independent Spent Fuel Storage Installations in Marine Environments," Electric Power Research Institute, June 2006.

II. Screening Criteria (Provide an explanation as to how the issue meets each of the screening criteria to be considered for generic issue resolution.)

1. Does the proposed issue involve spent fuel storage or transportation and affect multiple 10 CFR 71 and/or 10 CFR 72 regulated entities (provide basis)**?**
Yes. There are multiple ISFSIs located at sites in the United States which could potentially be classified as having chloride atmospheres.

2. Does the proposed issue warrant generic resolution (provide basis)**?**
Yes. A consistent approach is needed to determine what conditions define a chloride atmosphere in the context of chloride induced SCC of austenitic stainless steel and over what time frame SCC could cause deleterious effects to the SNF canister's confinement boundary.

3. Does the issue warrant engagement between the industry and NRC (provide basis)?

Yes. The NRC believes industry involvement would provide a better understanding regarding the extent of the condition and/or provide additional data to address salt deposition and potential degradation due to CISCC. This effort would inform future licensing requirements for spent fuel storage systems.

4. Will generic resolution of the issue produce tangible benefits (provide basis)?

Yes. The beneficial outcomes of resolving this issue using this protocol are a consistent licensee and CoC holder approach to addressing the issue and a stable, predictable licensing and inspection protocol.

5. Is the issue already adequately covered by another process (provide basis)?

No. This issue has not reached a level of urgency or safety significance to qualify it for the NRC's generic safety issue process because testing is inconclusive (laboratory conditions do not accurately represent in-situ conditions at ISFSI sites), actual conditions (atmosphere and cask) vary from site to site and from model to model and cask to cask; and actual field data is insufficient. Since there is not an immediate safety concern, use of this protocol permits a deliberate yet timely approach to understanding the issue and creating the necessary tools for licensing and implementing prevention and mitigation strategies, as necessary.

POC: Are all screening criteria satisfied ("Yes" responses to questions 1-4 and "No" to question 5) **?**

Yes __X__ **No**______

III. Success Criteria (Describe the criteria to be used to define success for resolving this issue.)

Acquire and document data to determine:

1. The minimum conditions (cask and environment) necessary for potential initiation of CISCC.
2. The time scales under which CISCC could occur, based upon actual atmospheric and cask conditions.

IV. Date: 01/31/2013

USED FUEL STORAGE AND TRANSPORTATION ISSUE RESOLUTION PLAN

Issue Number: N-10-01

Title: Dry Spent Fuel Storage Canister Chloride Induced Stress Corrosion Cracking

I. Summary of Resolution Plan

Industry and NRC will interact in public meetings and through letters to achieve the following:

Acquire and document data to determine:

1. The minimum conditions (cask and environment) necessary for potential initiation of CISCC.
2. The time scales under which CISCC could occur, based upon actual atmospheric and cask conditions.

II. Actions and Due Dates

ACTION	RESPONSIBLE PARTY	DUE DATE
1. Public meeting to discuss the data acquired in NRC and EPRI research	NRC/Industry	Completed – 3/14/2011
2. Industry develop draft criteria for the minimum conditions defining a chloride atmosphere under which SCC of canister confinement boundary made of austenitic stainless steel (304, 304L, 316L) could occur (e.g. relative humidity, chloride concentration in air, distance from salt water, cask surface temperature), and a method for determining the condition based time scale under which CISCC could occur (e.g. screening criteria)	Industry	Completed – February 2012
3. Public meeting for industry to present plans for acquiring field data.	NRC/Industry	Completed – 2/14/2012
4. Public meeting for 1) NRC to present technical data and regulatory questions, and 2) Industry to present conceptual screening criteria identifying the minimum conditions necessary for potential initiation of CISCC and a method for determining the condition based time scale under which CISCC could occur.	NRC/Industry	Completed – 4/12/2012
5. Perform pilot acquisition of field data (e.g. cask surface temperature, relative humidity, chloride content, and atmospheric parameters) at Calvert Cliffs Nuclear Station. This pilot will demonstrate the feasibility of acquiring certain data, be used to inform development of a more robust program, and provide useful data for addressing information gaps. which will support the basis of the condition based time scales under which SCC could occur; future plans to acquire field data will be based in part on the need for information to inform the screening criteria	EPRI/Industry	Completed – 6/27&28/2012
6. Public meeting to provide update on industry's plans/actions including: 1) proposed update to RIRP resolution plan, 2) R&D Roadmap, and 3) pilot data acquisition results and plans for future	Industry/NRC	Completed – 12/18/2012

inspections. Discussion to obtain NRC feedback on industry's plans. NRC update of related activities.		
7. Develop an draft R&D roadmap (referred to as Master Plan at 4/12/2012 meeting) for acquiring data necessary to fill-in gaps for understanding the condition based time scales under which SCC could occur. R&D Roadmap will start with the gaps identified in the Conceptual Screening Criteria, and will identify R&D being performed by industry, NRC, DOE, and others; as well as how/when this R&D is projected to result in data sufficient to close the RIRP.	EPRI/Industry	April 2012 – 1/31/2013
8. Submit draft R&D Roadmap for NRC feedback.	EPRI/Industry	January 31, 2013
9. Submit proposed update to RIRP screening form and resolution plan (Revision 2) to NRC, which incorporates feedback from public meeting.	NEI/Industry	Completed – 01/31/2013
10. Provide comments on proposed update to RIRP screening form and resolution plan for industry to incorporate. OR If NRC agreement on proposed forms, RIRP screening form and resolution plan Revision 2 are finalized.	NRC	March 2013
11. If NRC comments on proposed screening form and resolution plan, incorporate and finalize RIRP resolution plan Revision 2.	NEI/Industry	April 2013
12. Provide comments on draft R&D Roadmap.	NRC	April 2013
13. Finalize R&D Roadmap, incorporate NRC comments.	EPRI/Industry	May 2013
14. Collect/consolidate data per R&D Roadmap (including EPRI acquisition of actual canister data). Evaluate/update conceptual screening criteria as additional data becomes available. Monitor all R&D and update Roadmap as necessary. Assess when sufficient data exists to resolve RIRP.	EPRI/Industry	TBD – Based upon R&D Roadmap
15. NRC sponsored research at SwRI/CNWRA may result in data relevant to this RIRP.	NRC	As appropriate.
16. Periodic NRC/Industry public meetings to: 1) present updates on R&D and discuss development of data sufficient to close RIRP (including updates to conceptual screening criteria), 2) exchange information to increase the value of R&D activities (e.g. industry provide NRC with weld data for typical canisters), 3) discuss whether the RIRP resolution plan needs to be updated, and 4) discuss whether sufficient data exists to close the RIRP.	NRC/Industry	As appropriate. (e.g. every 6 months). Tentatively: March and September every year for as long as identified in R&D Roadmap
17. Finalize, and send to NRC, a screening process with criteria defining the minimum conditions (cask and environment) necessary for initiation of CISCC and a method for determining the condition based time scale under which SCC could occur (e.g. screening criteria) that can be used by ISFSI licensees to evaluate the potential	NEI/EPRI/Industry	30 days after the public meeting that 1) identifies that sufficient R&D has been completed to close the RIRP, and 2) discusses a draft final Screening Criteria.

for CISCC to occur on canisters at their site.		
15. NRC review and provide written comments on ISFSI CISCC screening criteria	NRC	60 days after receipt of Industry's Screening Process
16. Industry finalize ISFSI CISCC screening criteria based upon NRC feedback, and field data from actual casks	Industry	30 days after receipt of NRC comments
17. ISFSI owners use screening to identify CISCC-susceptible ISFSIs and time scales	Industry	60 days after finalizing screening criteria
18. Public meeting to discuss screening results, and closure of RIRP. Identify whether entire issue can be closed, or if another process is appropriate to continue to address issue.	NRC/Industry	30 days after ISFSI owners performing screening of their site
19. Submit proposed RIRP closure form to NRC.	NEI/Industry	30 days after public meeting
20. Provide comments on proposed closure form for industry to incorporate. OR If NRC agreement on proposed closure form, RIRP closure form is finalized.	NRC	60 days after submission
21. Finalize RIRP closure form (if necessary to address NRC comments).	NEI/Industry	30 days after public meeting

III. Date: 01/31/2013