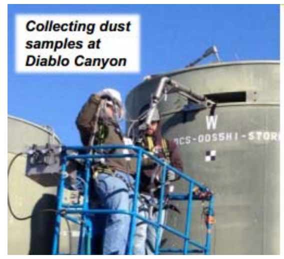
Diablo Canyon: conditions for stress corrosion cracking in 2 years



A limited 2014 surface inspection found sea salt crystals on a Diablo Canyon Holtec dry storage canister that had been loaded with fuel for only two years. Two canisters were inspected, ranging from 2 to 3.5 years in service with heat load of 15 to 20 kW at time of loading. The inspection was limited to temperature and surface contaminants and was performed while the steel canisters were inside the concrete cask, due to radiation and damage concerns. Temperatures were low enough to trigger the corrosive environment needed for stress corrosion cracking initiation – much sooner than expected. [1, 2] Canister measured temperatures ranged from 49°C (120°F) to 118°C (245°F). Calculated temperatures ranged from 60°C (140°F) to 105°C (221°F). Lid – measured temperatures ranged from 87°C (188°F) to 97°C (207°F). [3]

Salt deliquescence can occur on interim storage containers only over a small part of the temperature and relative humidity (RH) range that the storage containers will experience. A reasonable maximum possible absolute humidity is 40-45 g/m3 for sea salts. This corresponds to a maximum temperature of deliquescence of ~85ºC. [4]

Crack initiation at the higher end of the temperature range (up to 80°C) is likely to occur sooner than at ambient temperatures.

> *Most austenitic stainless steels vessels and piping plant experience with SCC [stress corrosion cracking] suggests that incidence of SCC rises dramatically when temperatures exceed 55-60ºC. Stainless steel items operating above these temperatures are definitely candidates for preventative measures. Stainless steel equipment operating below 55-60ºC will not be totally immune to SCC. (Occasional failures have been reported on ambient temperature equipment after 10-15 years of service).*
>
> *An increase in temperature generally aggravates the conditions for SCC, other conditions being equal. Cracking is more likely to occur at 80ºC proceeding about four times faster at this higher temperature in "wicking" tests compared with 50°C. In tests lasting 10,000 hours each, the maximum chloride concentration to initiate SCC was determined to be about 400 ppm at 20°C and 100 ppm at 100°C. These parameters however will vary with the nature of the specific chloride involved. For example, SCC has been reported at temperatures as low as -20°C in methylene chloride, where the aggressive species was almost certainly hydrochloric acid itself, formed by hydrolysis.*[5]

The Electric Power Research Institute (EPRI) sample inspection of Diablo Canyon canisters and a few other facilities' canisters provided the first look at canister conditions. However, it was limited and not intended to find stress corrosion cracks. It was a visual look at canister condition for signs of gross change or unexpected condition, and an initial data collection to understand the actual canister conditions important to CISCC [Chloride-induced stress corrosion cracking] regarding temperature and surface compositions data only**.** It was not perfect and not the final step.[6]

A July 2010 UK report by R. Parrott and H. Pitts is extremely educational on the challenges and limitations of inspecting for stress corrosion cracking in stainless steel components. It addresses components other than loaded spent fuel dry storage canisters. (There is no current inspection method for loaded canisters.) However, the method they recommend as the most reliable is not even possible with loaded spent fuel dry storage canisters. See UK report for details.[7]

Dr. Hira Ahluwalia, materials and corrosion engineer, stated in an article

> *Visual identification prior to failure is difficult due to the typical tightness of stress-corrosion cracks…Typically, evidence of corrosion, such as accumulations of corrosion products, is not observed, although stains in the cracked region may be apparent. Stress-corrosion cracks tend to originate at physical discontinuities, such as pits, notches and corners. Areas that may possess high-residual stresses, such as welds or arc strikes, are also susceptible.*[8]

In addition to footnoted references, see following reports and *SanOnofreSafety.org* website.

Calvert Cliffs Stainless Steel Dry Storage Canister Inspection Report, 2014
http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001025209

Data Report on Corrosion Testing of Stainless Steel SNF Storage Canisters, D.G. Enos, et al, Sandia National Laboratories, September 30, 2013, SAND2013-8314P [Calvin Cliffs]
http://www.energy.gov/sites/prod/files/2013/12/f5/CorrosionTestStainlessSteelSNFStorContainer.pdf

EPRI Chloride Induced Stress Corrosion Cracking of Spent Fuel Canisters, December 18, 2012 slide presentation. *http://pbadupws.nrc.gov/docs/ML1302/ML13022A316.pdf*

NRC Fourth Request for Additional Information for Renewal Application to Special Nuclear Materials License No. 2505 for the Calvert Cliffs Site Specific Independent Spent Fuel Storage Installation (TAC NO. L24475), June 23, 2014 *http://pbadupws.nrc.gov/docs/ML1417/ML14175B035.pdf*

Outside Diameter Initiated Stress Corrosion Cracking Revised Final White Paper, PA-MSC-0474, October 13, 2010, Ryan Hosler (AREVA), John Hall (Westinghouse) (includes San Onofre and others).
http://pbadupws.nrc.gov/docs/ML1104/ML110400241.pdf

NDE to Manage Atmospheric SCC in Canisters for Dry Storage of Spent Fuel: An Assessment, DOE, PNNL-22495, September 2013 *http://pbadupws.nrc.gov/docs/ML1327/ML13276A196.pdf*

EPRI Failure Modes and Effects Analysis (FMEA) of Welded Stainless Steel Canisters for Dry Cask Storage Systems, December 2013, includes dates U.S. casks first loaded.
https://sanonofresafety.files.wordpress.com/2013/06/epri2013-12-17failure-modes-and-effects-analysissscanisters.pdf

Stress Corrosion Cracking, Corrosion Morphology photos
http://abduh137.wordpress.com/2008/01/20/corrosion-morphology/

---

[1] *Understanding the Environment on the Surface of Spent Nuclear Fuel Interim Storage Containers*, Charles R. Bryan, David G. Enos, Sandia National Laboratories, June 2014 *http://psam12.org/proceedings/paper/paper_468_1.pdf*

[2] FY14 *DOE R&D in Support of the High Burnup Dry Storage Cask R&D Project*, William Boyle, DOE, NWTRB Meeting, August 6, 2014 (slide 12) *http://www.nwtrb.gov/meetings/2014/aug/boyle.pdf*

[3] *Update on In-Service Inspections of Stainless Steel Dry Storage Canisters*, EPRI, Keith Waldrop, Senior Project Manager, Presented by John Kessler, Program Manager, NEI-NRC Meeting on Spent Fuel Dry Storage Cask Material Degradation, January 28, 2014 (Diablo slides 17-19) *http://pbadupws.nrc.gov/docs/ML1405/ML14052A430.pdf*

[4] *Data Report on Corrosion Testing of Stainless Steel SNF Storage Canisters*, Sandia Lab, September 30, 2013.
http://www.energy.gov/sites/prod/files/2013/12/f5/CorrosionTestStainlessSteelSNFStorContainer.pdf

[5] *Cracked: The Secrets of Stress Corrosion Cracking*, Hira Ahluwalia, President of Material Selection Resources Inc. (MSR) *http://csidesigns.com/flowgeeks/cracked-the-secrets-of-stress-corrosion-cracking/*

[6] *Update on In-Service Inspections of Stainless Steel Dry Storage Canisters, EPRI, Keith Waldrop, Senior Project Manager*, presented by John Kessler, Program Manager, NEI-NRC Meeting on Spent Fuel Dry Storage Cask Material Degradation, January 28, 2014 (Diablo slides 17-19) *http://pbadupws.nrc.gov/docs/ML1405/ML14052A430.pdf*

[7] *Chloride stress corrosion cracking in austenitic stainless steel – recommendations for assessing risk, structural integrity and NDE based on practical cases and a review of literature*, UK, R Parrott BSc PhD MIMMM CEng, H Pitts MEng PhD, July 2010 *http://www.hse.gov.uk/offshore/ageing/stainless-steels.pdf*

[8] Stress Corrosion Cracking, Dr. Hira Ahluwalia *http://csidesigns.com/flowgeeks/stress-corrosion-cracking/*