Issues and Countermeasures for Long-Term Storage of Spent Fuel by Dry Cask

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Issues for Long-term Storage
Concern of losing containment requirement

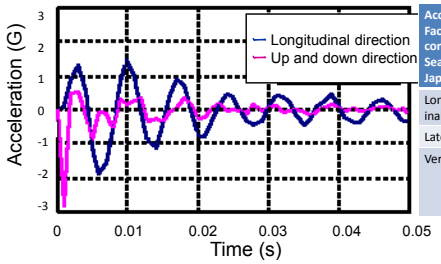
- Metal Cask Storage (Metal Gasket)
  - By mechanical vibration in transport before storage
  - By Tsunami attach
  - By stress relaxation (to be presented at PSAM 11)
- Concrete Cask Storage (Stainless Steel Canister)
  - By Stress Corrosion Cracking (SCC) (more to be presented at PSAM 11)

Mechanical vibration in transport
-Background-

- Transport casks receive mechanical vibration in transport, which may influence the containment performance of metal gaskets.

- Quantitative influence of such vibration has not been known, but is crucial for a post-transport storage.

Mechanical vibration in transport
-Measurement of acceleration in the vicinity of a cask trunnion in sea transport in Japan-



Acceleration Factors to be considered for Sea Transport in Japan	
Longitudinal	1.5g
Lateral	1.5g
Vertical	1.0g up, 2.0g down

Ref. Shirai, K. et al 2006 Annual Mtg of AESJ

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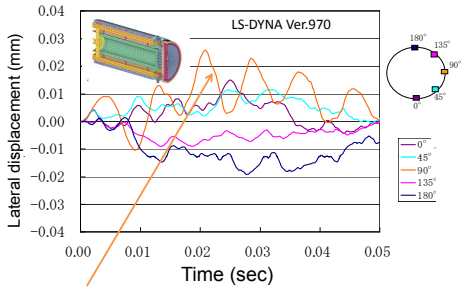
Mechanical vibration in transport
-Calculated Sliding displacement of Lid by the acceleration-



→The sliding(± 0.01mm) in 90 degree should be noted.

Ref. Shirai, K. et al 2006 Annual Mtg of AESJ

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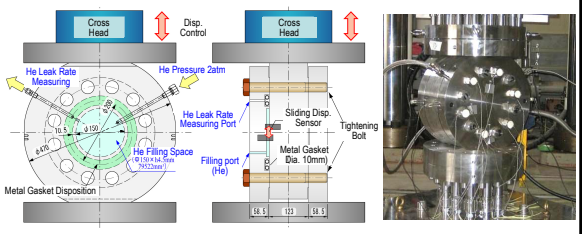
Mechanical vibration in transport
-Experimental Apparatus and Specimen-



Scale (1/10, 470ϕ) model of a cask lid with a metal gasket coated with Al, which was thermally aged at 180 ℃ for 20h simulating thermal history in transport before storage.

Ref. Saegusa, T. et al, Proc. PATRAM 2010

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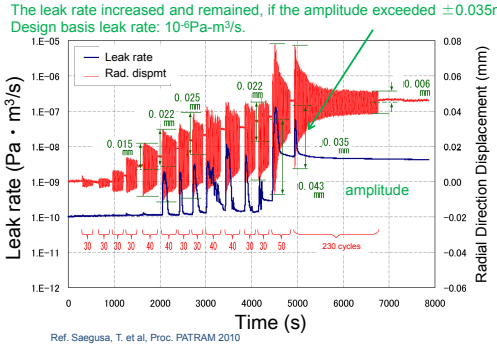
Mechanical vibration in transport
- Leakage under Cyclic Loading-

The leak rate increased and remained, if the amplitude exceeded ±0.035mm.
Design basis leak rate: 10^{-6}Pa-m³/s.



Ref. Saegusa, T. et al, Proc. PATRAM 2010

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Mechanical vibration in transport
-Summary-

1. The metal gasket is sensitive to the mechanical vibration or lateral sliding in transport.
2. It is recommended to confirm its containment performance after transport and before storage. Mechanical vibration in transport could change the containment performance of the cask and affect its ability to meet subsequent requirements.

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Tsunami Attack
-Dry Storage Cask in Fukushima NPP-

- As of March 11, the Fukushima PPT has stored 9 metal casks (408 BWR SF) in a building.
- The cask cooling function was not lost as the casks were cooled by natural air convection.
- The dose level within the cask building is not abnormally high compared to background radiation. The integrity of the sealing performance has not yet been verified directly through leakage tests.

Metal Cask before the Tsunami

Metal Cask after the Tsunami

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(From the 2nd Report from Japanese government to IAEA, Sept2011)

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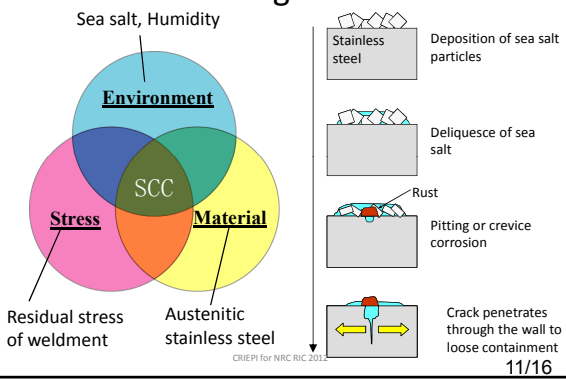
Stress Corrosion Cracking -Background-



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Countermeasures on SCC

a. Material
- Cr, Mo and N are beneficial alloying elements against chloride induced SCC.

b. Environment
- Measurement of salt concentration in the air at site is essential.
- Sea salt particle collection will help.

c. Stress
- Stress relaxation peening, LPB, etc. are effective.

d. Management
- Periodical inspection. Proper inspection period is derived from crack growth rate
- Monitoring

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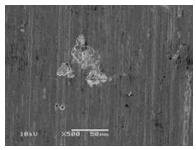
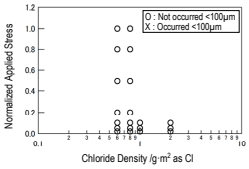
Countermeasures for SCC by b-1. Environment

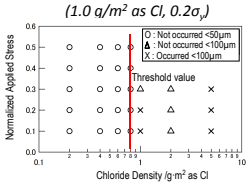
- Threshold Chloride Density for SCC Initiation is set to be 0.8g/m² as Cl.



(1.0 g/m² as Cl, 0.2σ_y)



(Specimen A for 2000hr, Hardness 305Hv)



(Specimen B for 5000hr, Hardness 247Hv)

Shirai, K. et al: CRIEPI Report N10035 (2011)

Countermeasures for SCC by b-2. Environment

Salt Deposition with Time: Results of Lab. & Field Tests

- Temperature dependence of the salt deposition
  $Q=\{5.07-0.022(T-30)\}\cdot(1.55t \times C/10000)^{1/2}$
- Temperature decay of the canister
  $T=-0.575X+89$

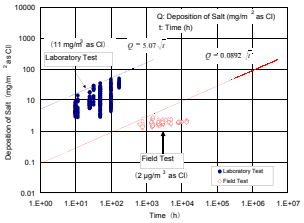
Q: amount of salt deposition

t: time (h)

C: salt concentration in the air (μg/m³ as Cl)

T: temperature of the canister surface (°C)

X: time (year)

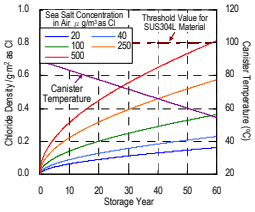


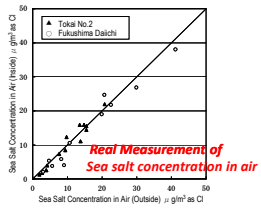
Wataru, M, K. et al: CRIEPI Report N09023 (2010)

Countermeasures for SCC by b-3. Environment

Prevention of the Initiation of SCC

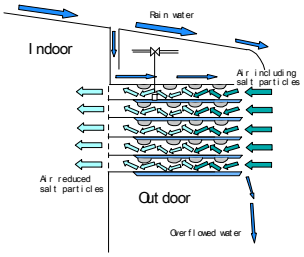
- Estimation of Deposition at High Temperature MPC
- Temperature decay of the canister during storage
- Prevention of the Initiation of SCC for more than 60years under an airborne salt concentration of 100μg/m³





Shirai, K. et al: CRIEPI Report N10035 (2011)

Countermeasures on SCC by b-4. Environment
Salt Particle Collection from Air



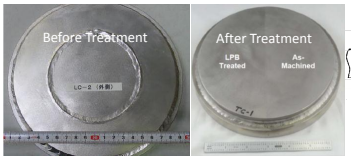
Salt particles will be absorbed on the surface of multiple trays attached at the air-inlet of the storage building or the concrete casks.

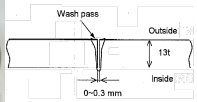
Salt Particle Collection Device

Takeda, H. et al: CRIEPI Report N08050 (2010)

Countermeasures on SCC by c-1. Relaxation of Residual Stress

- Tests of Relaxation of Residual Stress by
  - a. Zirconia Shot Peening (ZSP),
  - b. Laser Shot Peening (LSP), and
  - c. Low Plasticity Burnishing (LPB) .
- Specimen: S30403 circular plate of 100mm Φ x 13 mm in thickness . TIG weld and Laser-Beam weld

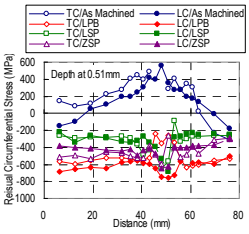


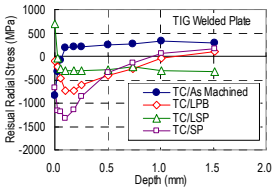


Shirai, K. et al: CRIEPI Report N10035 (2011)

[Example of Laser-Beam Welded Test Coupon]

Countermeasures on SCC by c-2. Relaxation of Residual Stress

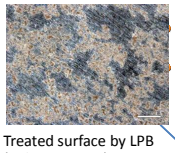




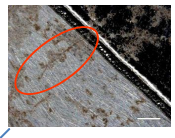
Measurement of Residual Stress Distributions showed tensile stress remains around the welded line in the as-welded specimens, whereas compressive stress remains in the peened specimens.

Shirai, K. et al: CRIEPI Report N10035 (2011)

Countermeasures on SCC by c-3. Relaxation of Residual Stress

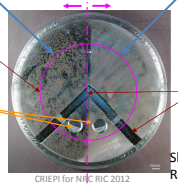


SCC Corrosion Test of S30403 stainless steel with weldment. Two photographs showed the effect of relaxation of the residual stress.



Treated surface by LPB (only corrosion)

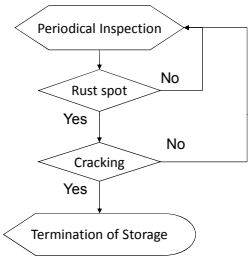
Non-Treated surface (SCC occurrence)



Shirai, K. et al: CRIEPI Report N10035 (2011)

Countermeasures on SCC by d.1 Management

Periodical inspection



Shirai, K. et al: CRIEPI Report N10035 (2011)

- Interval of inspection

  $\Delta T_i < \Delta T_p$

  ΔT_i : Interval of inspection

  ΔT_p : Time for through wall penetration by a crack initiated just after previous inspection

Crack growth behavior and crack growth prediction method must be clarified and established respectively

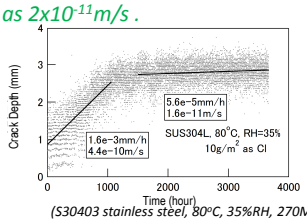
- Reliability of inspection

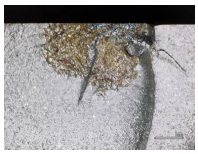
Development of reliable inspection method is out of scope in this program, will be a future work.

Countermeasures on SCC by d.2 Management

Crack Growth Test

- *4 Point Bending Test*
  - ✓ *Reverse Direct Current Potential Drop method*
  - ✓ *Potential drop was converted to crack depth, assuming half elliptical crack propagated.*
- *Crack Growth Rate was estimated as $2x10^{-11}$m/s .*





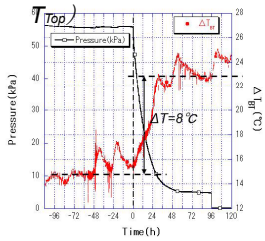
(S30403 stainless steel, 80°C, 35%RH, 270MPa, about 10g/m² as Cl of sea salt)

Shirai, K. et al: CRIEPI Report N10035 (2011)

Countermeasures on SCC by d.3 Management

Monitoring of He Leakage from Canister

$\Delta T_{BT} = (T_{Bottom} - T_{Top})$



ΔT_{BT} and Pressure

Leakage of Helium gas in the canister can be detected by monitoring ΔT_{BT}.

The changes of ΔT_{BT} is due to the change in the inner pressure and temperature profile resulting from the reduction of Helium convection in the canister. *T_{Bottom} increases whereas T_{top} decreases.*

Takeda, H. et al: Nuclear Eng. Design 238 (2008) 1220–1226

Conclusion

- Concern of losing containment requirement in Long-term Storage and countermeasures were addressed.
- Metal Cask Storage (Metal Gasket)
  Mechanical vibration in transport could change the containment performance for the subsequent storage. The containment should be checked before storage.
- Concrete Cask Storage (Stainless Steel Canister)
  SCC of normal stainless steel would be effectively prevented by relaxation of residual stress from weld and low chloride concentration in the air . The canister would better be monitored and inspected periodically.