Monitoring Helium Integrity in Welded Canisters

Yung Y. Liu

INMM 30th Spent Fuel Seminar
Arlington, VA
January 12-14, 2015

Background

- Over 80% of dry cask storage systems (DCSSs) in the U.S. employed welded stainless-steel canisters, stored either horizontally or vertically, inside a concrete module or overpack.
- Maintaining and confirmation of canister integrity is crucial in aging management of the DCSSs for extended long-term storage and subsequent transportation of used fuel.
- Monitoring the conditions of the canister from within is exceptionally challenging.
- In this presentation, we describe an approach to verify canister integrity by surveillance from outside, combining
  - 3D simulation of thermal performance of a dry cask, and adapting
  - Remote Area Modular Monitoring (RAMM), developed by Argonne for DOE Packaging Certification Program, for critical facilities including DCSSs.
Outline

- Physical and Analytic Model
- Analytical and Experimental Results
  - Effects of basket material and fill gas
  - Effects of He leakage on temperatures
- Remote Area Modular Monitoring (RAMM) for Dry Casks
- Summary

Change in Peak Cladding Temperature (PCT) during leakage

- PCT will increase due to reduced convective heat transfer
- Air ingress can cause cladding corrosion and hydrogen generation
- Helium leak detection is “arguably” the most important step, i.e., detection of aging effect, for a successful AMP

<table>
<thead>
<tr>
<th>Pressure</th>
<th>PCT (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 atm He</td>
<td>387°C</td>
</tr>
<tr>
<td>1 atm Air</td>
<td>500°C</td>
</tr>
</tbody>
</table>

Change in Canister Surface Temperature (CST) during leakage

- When helium leaks, the canister top cools due to impeded convective heat transfer
- The ΔT is readily measurable according to ANSYS/Fluent analyses performed by ANL
- The 3D simulation results are consistent with experimental results from CRIEPI

<table>
<thead>
<tr>
<th>Pressure</th>
<th>CST (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 atm He</td>
<td>178°C</td>
</tr>
<tr>
<td>1 atm He</td>
<td>96°C</td>
</tr>
</tbody>
</table>
Summary of canister helium leakage on PCT/CST

<table>
<thead>
<tr>
<th>Fill Gas / pressure (atm)</th>
<th>PCT (°C) / (z/L)</th>
<th>CST (°C) Canister center top</th>
</tr>
</thead>
<tbody>
<tr>
<td>He / 6</td>
<td>387 / 0.85</td>
<td>178</td>
</tr>
<tr>
<td>He / 1</td>
<td>462 / 0.54</td>
<td>96</td>
</tr>
<tr>
<td>Air / 1</td>
<td>500 / 0.71</td>
<td>126</td>
</tr>
</tbody>
</table>

\[ N_u = \begin{cases} 0.59Ra^{1/4} & 10^4 < Ra < 10^5 \\ 0.10Ra^{1/2} & 10^5 < Ra < 10^8 \end{cases} \]

\[ N_u = \frac{P - M}{R \cdot T} \quad Ra = Gr \cdot Pr = \frac{6P(T_2 - T_1) \mu^2}{\mu^2} \]

Experimental results with a mockup cask by CRIEPI* (1/3)

21 heater assemblies: 22.6, 16 and 10 kW (0, 20, 40 years of storage)

Experimental results with a mockup cask by CRIEPI* (2/3)

- Initial pressure: 56 kPa
- Final pressure: 5 kPa
- Leak rate: 0.486 Pa m$^3$/s
- 0.55 atm

Fig. 12. Changes of $\Delta T_{BT}$ and pressure (case 1).

Experimental results with a mockup cask by CRIEPI* (3/3)

- Initial pressure: 151 kPa
- Final pressure: 1 kPa
- Leak rate: 5.16 Pa m$^3$/s
- 1.5 atm

Fig. 15. Changes of $\Delta T_{BT}$ and pressure (case 2).

- CRIEPI experimental results corroborate ANL 3-D simulations

* Takeda, H., et al., ibid.
Remote Area Modular Monitoring (RAMM) for dry cask monitoring - Patent Pending

**Sensor Suite**
- Type K Thermocouples
- Gamma and Neutron Detectors
- Electronic Loop Seal
- Accelerometer
- Video, Motion and Heat
- Others

**Communication Packages**
- Wired Ethernet
- Cellular Modem
- Iridium Modem

[Prototype RAMM units](http://embedsoftdev.com/embedded/wireless-sensor-network)

RAMM forms a Wireless Sensor Network (WSN)

- Wired Ethernet underlay, Power-over-Ethernet (PoE); auto-switching to WSN when wired assets are lost
- 2.4 GHz (IEEE 802.15.4) wireless - long range, low power; redundant gateways (wired, cellular, Iridium)
- Versatile modular external sensors expansion based on ARG-US RFID with proven performance

[Diagram of RAMM network](http://embedsoftdev.com/embedded/wireless-sensor-network)
ARG-US ("Watchful Guardian") RAMM for dry cask monitoring

**Summary**

- ANSYS/FLUENT 3-D simulation of thermal performance of a vertical dry storage cask provided insights on temperature profiles (PCT/CST).
  - Heat load (34, 20, 10 kW)
  - Fill gas (He, N₂, air, Ar, Xe, Kr)
  - Fill gas pressure (1 – 6 atm)
  - Basket material (SS, Al-1100)
- Results show canister helium leakage should be readily detectable – by monitoring the external surface temperatures of the canister.
- These findings are consistent with results from CRIEPI experiments with mockup canisters/casks.
- Benchmark tests with actual canisters/casks, using "multiple" RAMMs or other conventional means, are highly desirable.
**Acknowledgments**

This work is supported by the Used Fuel Disposition Campaign (UFDC) R&D and Nuclear Fuel Storage and Transportation (NFST) Project, Office of Nuclear Energy, and DOE Packaging Certification Program, Office of Packaging and Transportation, Office of Environmental Management under Contract DE-AC02-06CH11357.

Dr. Yung Y. Liu  
Manager, Packaging Certification  
and Life Cycle Management Group  
Nuclear Engineering Division  
Argonne National Laboratory  
9700 S. Cass Ave., Bldg. 221  
Argonne, IL 60439  
630-252-5127  
yyliu@anl.gov

---

**Summary of Dry Cask Storage Systems Currently in Use in the U.S.**

<table>
<thead>
<tr>
<th>Vendor</th>
<th>System</th>
<th>Cask/Canister</th>
<th>Type*</th>
<th>Closure</th>
</tr>
</thead>
<tbody>
<tr>
<td>EnergySolutions</td>
<td>FuelSolutions</td>
<td>VSC-24, W150</td>
<td>C/O</td>
<td>Welded</td>
</tr>
<tr>
<td>General Nuclear Systems, Inc.</td>
<td>CASTOR</td>
<td>V-21, X-33</td>
<td>Cask</td>
<td>Welded</td>
</tr>
<tr>
<td>Holtec International</td>
<td>HI-STAR-100</td>
<td>MPC-68, MPC-80</td>
<td>C/O</td>
<td>Welded</td>
</tr>
<tr>
<td></td>
<td>HI-STORM-100</td>
<td>MPC-24, MPC-32, MPC-68</td>
<td>C/O</td>
<td>Welded</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C/O</td>
<td>Welded</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TN Metal Casks</td>
<td>C/O</td>
<td>Bolted</td>
</tr>
<tr>
<td>Westinghouse</td>
<td>MC-10</td>
<td>MC-10</td>
<td>Cask</td>
<td>Bolted</td>
</tr>
</tbody>
</table>

* C/O = metallic canister with overpack; Cask = self-contained metallic cask without overpack.