APT#79538

# Monitoring Helium Integrity in Welded Canisters

**Yung Y. Liu**

**INMM 30th Spent Fuel Seminar**

**Arlington, VA**

**January 12-14, 2015**



*Work supported by USDOE Used Fuel Disposition R&D And Nuclear Fuel Storage and Transportation*

ENERGY

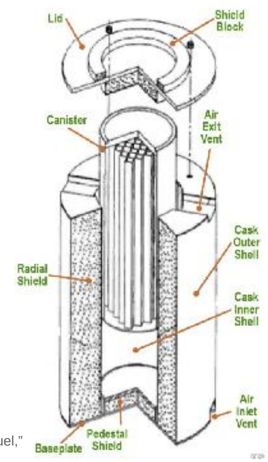
## Background

- 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.

1

# Outline

- Physical and Analytic Model[1]
- 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[2]
- Summary

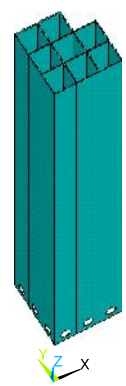


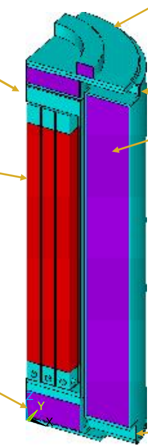

[1]J. Li, J and Y. Liu, "Thermal Performance of Dry Cask for High-Burnup Use Fuel," INMM-55th, Atlanta, GA, July 20-24, 2014.
[2]H. Tsai et al., "ARG-US Remote Area Modular Monitoring for Dry Casks and Critical Facilities," Ibid.

2

# ANSYS/Fluent Simulation – 1/4 Model

**Heat transfer mechanisms** include:
1) Conduction
2) Natural Convection




| | |
|---|---|
| **Contents:** | **32 HBU PWR 17x17** |
| **Heat load:** | **34 kW Total** |
| **Heat Dissipation** | |
| **Basket:** | **Stainless Steel** |
| **Fill Gas:** | **Helium** |
| **Seal:** | **Welded Closure** |
| **Cooling:** | **Air** |
| **Shielding** | **Concrete Oerpack** |

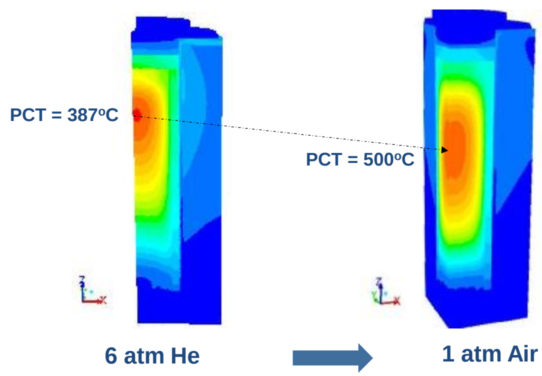
(Basket not shown for clarity)

3

## 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**

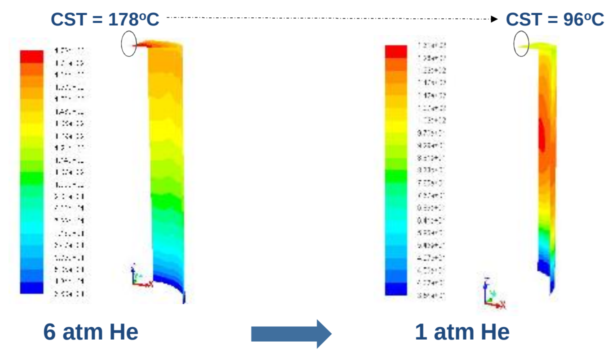





## Change in Canister Surface Temperature (CST) during leakage

- **When helium leaks, the canister top cools due to impeded convective heat transfer**
- **The ΔT is readily measureable according to ANSYS/Fluent analyses performed by ANL**

- **The 3D simulation results are consistent with experimental results from CRIEPI**



## Summary of canister helium leakage on PCT/CST

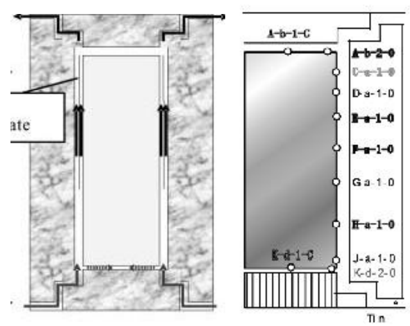
| Fill Gas / pressure (atm) | PCT (ºC) / (z/L) | CST (ºC) Canister center top |
|---|---|---|
| He / 6 | 387 / 0.85 | 178 |
| He / 1 | 462 / 0.54 | 96 |
| Air / 1 | 500 / 0.71 | 126 |

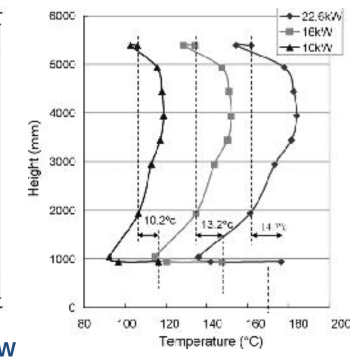
$$Nu = \begin{cases} 0.59Ra^{1/4} & 10^4 < Ra < 10^9 \\ 0.10Ra^{1/3} & 10^9 < Ra < 10^{13} \end{cases}$$

$$\rho = \frac{P \cdot M}{R \cdot T} \qquad Ra = Gr \cdot Pr = \frac{g\beta(T - T_\infty)\rho^2 l^3}{\mu^2}$$

6

## 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)**

*Takeda, H., M.., "Development of the Detecting Method of Helium Gas Leak from Canister," Nuclear *Engineering* and Design, Vol. 238, Issue 5, May 2008, pp. 1220–1226.

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

0.55 atm

**22.6 kW**

**Initial pressure: 56 kPa**

**Final pressure: 5 kPa**

**Leak rate: 0.486 Pa m³/s**

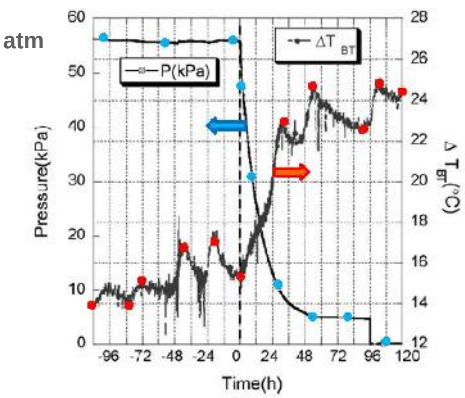



Fig. 12. Changes of $\Delta T_{BT}$ and pressure (case 1).

*Takeda, H., et al., ibid.

8

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

1.5 atm

**22.6 kW**

**Initial pressure: 151 kPa**

**Final pressure: 1 kPa**

**Leak rate: 5.16 Pa m³/s**

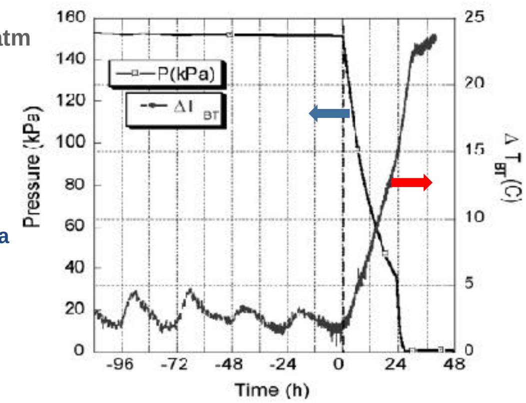



Fig. 15. Changes of $\Delta T_{BT}$ and pressure (case 2).

*Takeda, H., et al., ibid.

- CRIEPI experimental results corroborate ANL 3-D simulations

9

## 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

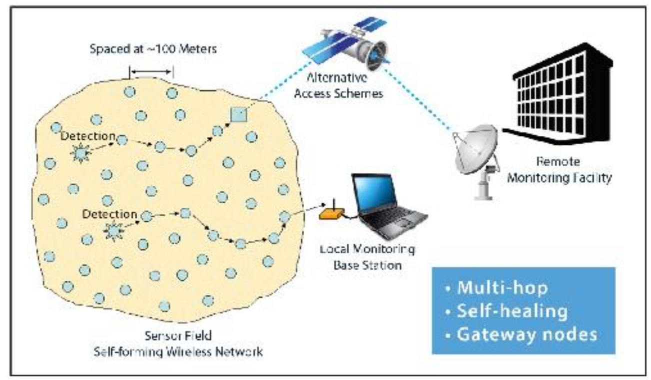
**Communication Packages**
- Wired Ethernet
- Cellular Modem
- Iridium Modem

http://embedsoftdev.com/embedded/wireless-sensor-network

Prototype RAMM units

10

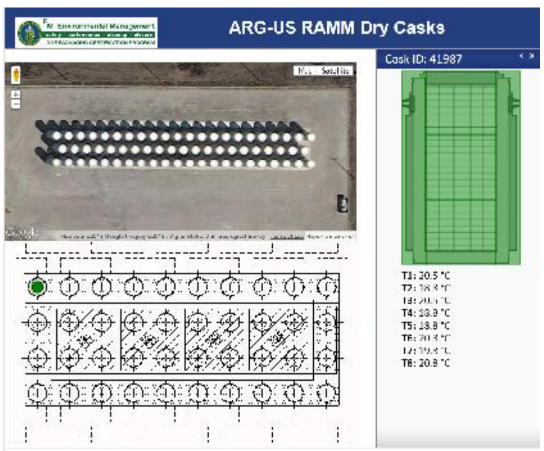
## RAMM forms a Wireless Sensor Network (WSN)




- 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

11

## ARG-US (“Watchful Guardian”) RAMM for dry cask monitoring




12

## 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, $N_2$, 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.**

13

## 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.**

| Vendor | System | Cask/Canister | Type[a] | Closure |
|---|---|---|---|---|
| EnergySolutions | FuelSolutions | VSC-24, W150 | C/O | Welded |
| General Nuclear Systems, Inc. | CASTOR | V/21, X/33 | Cask | Bolted |
| Holtec International | HI-STAR-100 | MPC-68, MPC-80 | C/O | Welded |
| | HI-STORM-100 | MPC-24, MPC-32, MPC-68 | C/O | Welded |
| NAC International, Inc. | S/T | NAC-I28 | Cask | Bolted |
| | MPC | MPC-26, MPC-36 | C/O | Welded |
| | UMS | UMS-24 | C/O | Welded |
| | MAGNASTOR | MAGNASTOR | C/O | Welded |
| Transnuclear, Inc. | NUHOMS | 52B, 61BT, 61BTH, 7P, 24P, 24PHB, 24PT, 24PTH, 24PT1, 32P, 32PT, 32PTH, 12T, HD | C/O | Welded |
| | TN Metal Casks | TN-24, TN-32, TN-40, TN-68 | Cask | Bolted |
| Westinghouse | MC-10 | MC-10 | Cask | Bolted |

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