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# Initial Results of High Burnup Dry Storage Cask Research Project at U.S.

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## 1. Introduction

For decades, low burnup fuel (<45 GWD/MTU) has been being placed into dry cask storage. The technical basis for dry storage of low burnup fuel was established through the many research. With the technical basis established, storage of high burnup fuel (> 45 GWD/MTU) in dry storage casks then began in 2004 in the US. Due to the expanded use of dry storage for high burnup fuel, its different characteristics compared to low burnup fuel, and the lack of data on the behavior of HBU fuel under actual dry storage conditions (vs. lab conditions), similar data on high burnup fuel from a demonstration cask were desired to support Independent Spent Fuel Storage Installation (ISFSI) license renewals as well as transportation licenses. Many organizations across the globe saw the need for such a high burnup demonstration cask. In 2013, the U.S. Department of Energy (DOE) initiated the High Burnup Dry Storage Cask Research and Development Project to design and implement a high burnup, large scale, long term, dry storage cask research and development project for spent nuclear fuel. Participants in the project include the host utility Dominion Energy Virginia; technology vendors Orano (formerly AREVA), Framatome (formerly AREVA), Westinghouse, and NAC International; and six DOE national laboratories. This paper is the cask and instrumentation used, the high burnup fuel loaded, the sister rods which were extracted to characterize the fuel before storage, as well as many of the considerations that went into these selections.

## 2. Cask and Instrumentation

### *2.1 Cask*

The cask selected for the High Burnup Research Project Cask was a bolted metal cask design. An existing TN-32B bolted metal cask (TN-32B-81) was used as the starting point.

### *2.2 Thermocouples*

To measure the temperature inside the cask, it is not possible to place a thermocouple directly on the fuel rod cladding to measure the cladding temperature directly. Instead, a thermocouple lance was inserted in a guide tube within an assembly. The objective for the thermocouples was to provide sufficient measurements to produce a complete 3-D distribution of temperature inside the cask. This was accomplished using seven radially distributed thermocouple lances, each with nine axially distributed thermocouples within each lance for a total of 63 thermocouples.

### *2.3 Fuel Selection*

Selection of what fuel to load, and where to locate each assembly in the cask, were important factors to consider in order to maximize the value of this single HBU cask demonstration. As a result, ZIRLO, M5, Zr-4 and low-tin Zr-4 were chosen. Earlier advanced cladding types (assemblies with a mixture of M4 and M5) were excluded.

### *2.4 Sister Rods*

The overall objective of this project is to understand the behavior of HBU fuel in dry storage, hence it is important to understand the fuel cladding properties before dry storage. To accomplish this, 25 fuel rods are undergoing nondestructive and destructive examinations to determine the baseline conditions (at time zero).

### *2.5 Roading*

All 32 assemblies had previously received a detailed visual inspection. Six poison rod assemblies, necessary to meet the criticality requirements for transportation, were preinstalled in the proper assemblies. Each of the 32 HBU assemblies were grappled by the fuel handling machine from their respective location in the spent fuel pool, moved into the cask pit and loaded into the designated location in the cask.

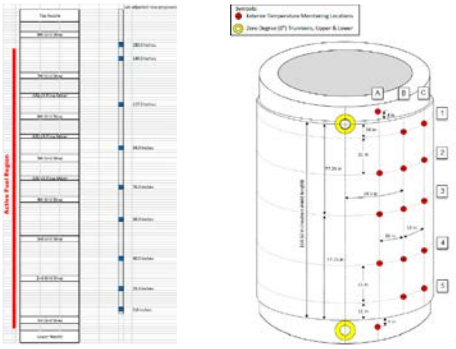
## 3. Results and Observation

### *3.1 Visual Inspection*

Prior to loading the cask, a detailed four-face visual examination was performed on every assembly. The inspection looked for any anomalies, which consist of fuel rod integrity anomalies, fuel rod bow, fuel rod growth, unusual oxides/crud/discoloration, damage, or debris. The visual inspections of the fuel assemblies for the HBU cask found no abnormal conditions.

### *3.2 Cask Temperature*

Both the internal and external temperatures were recorded. The internal temperatures were measured using seven thermocouple lances each with 9 axially spaced thermocouples inserted into a guide tube within the fuel assembly. The external temperatures were measured periodically at 15 locations on one side of the cask using an IR gun.



(a) (b)

**Figure 3-1 Temperature Measurement Locations**
**(a): Internal, (b): External**

The ambient temperature was also recorded using a thermocouple placed in the open space about halfway between the cask and the wall of the decon bay, and about a third of the way from the bottom of the cask. Ambient temperatures were also recorded by thermocouples internal to the data logger system. The data logger was located about 20 feet above the top. The peak measured temperature was 237°C and occurred in the center of the cask, slightly above the mid-plane. This peak temperature occurred about 8 hours after the start of vacuum drying and about 13 hours after the completion of draining. Following helium backfill, the steady state temperatures rose to 231°C (within about 6°C of the peak temperature under vacuum conditions)

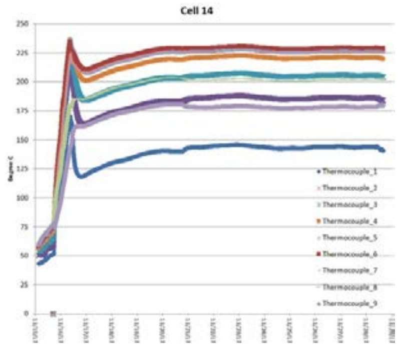


**Figure 3-2 Temperature vs. Time – Cell 14**

The axial profile was as expected. Without helium, it was generally symmetric about the mid-plane and dropped off sharply at the ends. With the introduction of helium, the axial profile slowly shifted to a slightly top peaked shape.

The cask was in the decon bay during the thermal soak period, cask surface temperatures were measured at 4 different times. The external surface temperatures were measured at 4 different times while the cask was in the decon bay: with water still in the cask, then about 4 hours, 5 days and 12 days after helium backfill. The external temperatures were about as expected. They generally followed the internal temperature profile with a lag time due to the thermal inertia.

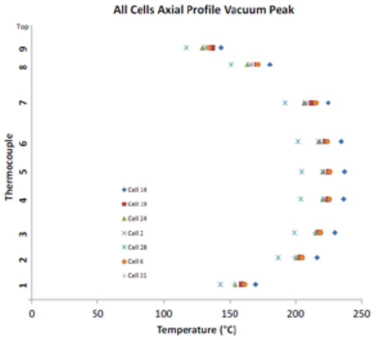


**Figure 3-3 Measured Temperatures during Vacuum Drying**

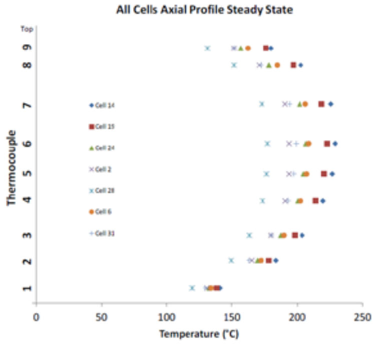


**Figure 3-4 Measured Temperatures at Steady State**

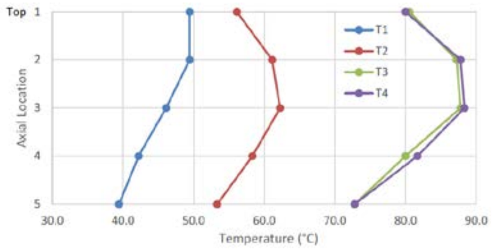


**Figure 3-5 External surface temperatures for column B at different times (T1-T4)**

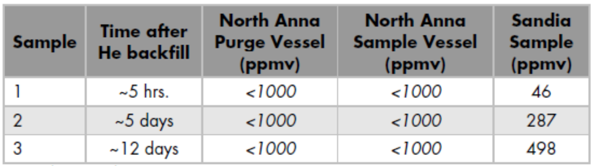
### *3.3 Cask Pressure*

The cask pressure was measured during the vacuum dryness test and after the helium backfill. The cask internal pressure during the pressure rebound test following vacuum drying increased 7.5 x $10^{-5}$ MPa (0.75 mbar) over the 30 minute period, from 5.5 x $10^{-5}$ MPa (0.55 mbar) to 1.29 x $10^{-4}$ MPa (1.29 mbar). The final pressure was still well below the required 4 x $10^{-4}$ MPa (4 mbar) and met the Technical Specification requirements.

### *3.4 Gas Sample*

Gas samples were collected at 3 separate times during the thermal soak period: about 5 hours after helium backfill, then about 5 days and 12 days after helium backfill. Each sample collection filled 3 sample containers: a North Anna Sample Vessel, a North Anna Purge Vessel, and a Sandia Sample Vessel. Gas samples were analyzed for fission gases, hydrogen, oxygen and water. The results of the gas sample analysis are shown in below table

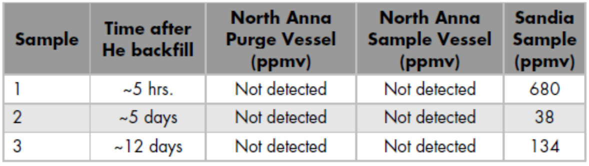
**Table 3-1 Measured hydrogen concentrations from gas sample analysis**



| Sample | Time after He backfill | North Anna Purge Vessel (ppmv) | North Anna Sample Vessel (ppmv) | Sandia Sample (ppmv) |
|---|---|---|---|---|
| 1 | ~5 hrs. | *<1000* | *<1000* | 46 |
| 2 | ~5 days | *<1000* | *<1000* | 287 |
| 3 | ~12 days | *<1000* | *<1000* | 498 |

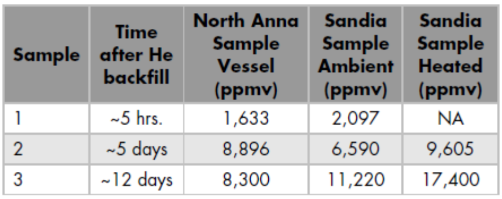
Note – All North Anna values were less than the MLD (0.1%).

**Table 3-2 Measured oxygen concentrations from gas sample analysis**



| Sample | Time after He backfill | North Anna Purge Vessel (ppmv) | North Anna Sample Vessel (ppmv) | Sandia Sample (ppmv) |
|---|---|---|---|---|
| 1 | ~5 hrs. | Not detected | Not detected | 680 |
| 2 | ~5 days | Not detected | Not detected | 38 |
| 3 | ~12 days | Not detected | Not detected | 134 |

**Table 3-3 Water concentrations from gas sample analysis**

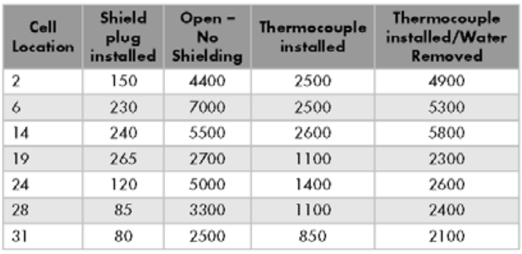


| Sample | Time after He backfill | North Anna Sample Vessel (ppmv) | Sandia Sample Ambient (ppmv) | Sandia Sample Heated (ppmv) |
|---|---|---|---|---|
| 1 | ~5 hrs. | 1,633 | 2,097 | NA |
| 2 | ~5 days | 8,896 | 6,590 | 9,605 |
| 3 | ~12 days | 8,300 | 11,220 | 17,400 |

### *3.4 Dose*

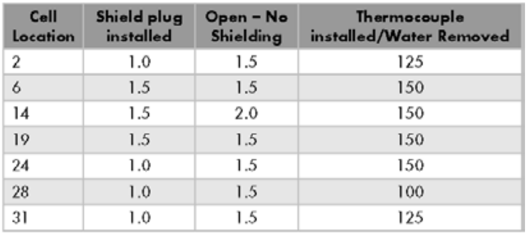
Through thermal modeling, confirmed by measurements, it has been discovered that HBU fuel is not getting. Before the water was drained from the cask, dose rates were measured at the thermocouple locations with the shield plug installed, with the thermocouple hole open directly to the fuel assembly below (no shielding), and with the thermocouple installed. Once the cask was ready to transport to the ISFSI, a final survey was performed before the cask was allowed to be taken to the ISFSI.

**Table 3-4 Measured gamma dose rates at thermocouple locations**



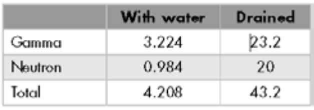
| Cell Location | Shield plug installed | Open – No Shielding | Thermocouple installed | Thermocouple installed/Water Removed |
|---|---|---|---|---|
| 2 | 150 | 4400 | 2500 | 4900 |
| 6 | 230 | 7000 | 2500 | 5300 |
| 14 | 240 | 5500 | 2600 | 5800 |
| 19 | 265 | 2700 | 1100 | 2300 |
| 24 | 120 | 5000 | 1400 | 2600 |
| 28 | 85 | 3300 | 1100 | 2400 |
| 31 | 80 | 2500 | 850 | 2100 |

**Table 3-5 Measured neutron dose rates at thermocouple locations**



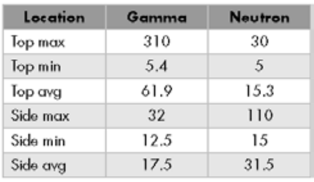
| Cell Location | Shield plug installed | Open – No Shielding | Thermocouple installed/Water Removed |
|---|---|---|---|
| 2 | 1.0 | 1.5 | 125 |
| 6 | 1.5 | 1.5 | 150 |
| 14 | 1.5 | 2.0 | 150 |
| 19 | 1.5 | 1.5 | 150 |
| 24 | 1.0 | 1.5 | 150 |
| 28 | 1.0 | 1.5 | 100 |
| 31 | 1.0 | 1.5 | 125 |

**Table 3-6 Measured dose rates on side of cask**



| | With water | Drained |
|---|---|---|
| Gamma | 3.224 | 23.2 |
| Neutron | 0.984 | 20 |
| Total | 4.208 | 43.2 |

**Table 3-6 Measured dose rates before transport**



| Location | Gamma | Neutron |
|---|---|---|
| Top max | 310 | 30 |
| Top min | 5.4 | 5 |
| Top avg | 61.9 | 15.3 |
| Side max | 32 | 110 |
| Side min | 12.5 | 15 |
| Side avg | 17.5 | 31.5 |

## 3. Conclusions

To validate the technical basis for dry storage of HBU fuel, and to provide data for extended storage of HBU fuel, DOE, EPRI, Orano (formerly AREVA), Framatome (formerly AREVA) and Dominion Energy have begun a large scale, long term, dry storage cask research and development project. Dominion Energy successfully loaded the High Burnup Research Project cask in November 2017 at their North Anna Power Station, and data collection has begun. The project is already yielding important results. Through thermal modeling, confirmed by measurements, it has been discovered that HBU fuel is not getting to the temperatures that could appreciably impact the mechanical properties of the cladding. Additional data will continue to be collected and analyzed, including data from the sister rods. The project is expected to continue for at least a decade with plans to open the cask after about 10 years of storage to examine the condition of the cladding after storage. The data from the project can be used for model validation and improvement, support license renewals and new licenses for dry storage facilities, support transportation licensing for HBU fuel, and input to future cask designs. These U.S. experiences are expected to help not only the adoption a dry storage facility for spent fuel but also the technical assessment of dry storage facility in Korea.

## REFERENCES

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