Status Update for the Canister Deposition Field Demonstration

Spent Fuel and Waste Disposition

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ABSTRACT

This report updates the high-level test plan for evaluating surface deposition on three commercial 32PTH2 spent nuclear fuel (SNF) canisters inside NUTECH Horizontal Modular Storage (NUHOMS) Advanced Horizontal Storage Modules (AHSM) from Orano (formerly Transnuclear Inc.) and provides a description of the surface characterization activities that have been conducted to date. The details contained in this report represent the best designs and approaches explored for testing as of this publication. Given the rapidly developing nature of this test program, some of these plans may change to accommodate new objectives or requirements.

The goal of the testing is to collect highly defensible and detailed surface deposition measurements from the surface of dry storage canisters in a marine coastal environment to guide chloride-induced stress corrosion crack (CISCC) research. To facilitate surface sampling, the otherwise highly prototypic dry storage systems will not contain SNF but rather will be electrically heated to mimic the thermal-hydraulic environment. Instrumentation throughout the canister, storage module, and environment will provide an extensive amount of information for the use of model validation. Manual sampling over a comprehensive portion of the canister surface at regular time intervals will offer a high-fidelity quantification of the conditions experienced in a harsh yet realistic environment.

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ACKNOWLEDGEMENTS

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The authors would like to express their appreciation to Ned Larson of the DOE for his programmatic leadership and vision. We greatly acknowledge the contributions of Brady Hanson, Steve Ross, Sylvia Saltzstein, and Geoff Freeze to this project.

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ACRONYMS

AHSM	Advanced Horizontal Storage Module
CFD	computational fluid dynamics
CMM	coordinate measuring machine
DAQ	data acquisition
DCSS	dry cask storage system
DOE	US Department of Energy
DPI	dye penetrant inspection
DSC	dry shielded canister
ECA	eddy current array
FCRD	Fuel Cycle Research and Development
FY	fiscal year
HLZC	heat load zone configuration
ISFSI	independent spent fuel storage installation
NE	Office of Nuclear Energy
NUHOMS	NUTECH Horizontal Modular Storage
PHT	peak heater temperature
PM	particulate matter
PNNL	Pacific Northwest National Laboratory
PTB	power test board
PWR	pressurized water reactor
RMS	root mean square
SCC	stress corrosion crack
SCR	silicon controlled rectifier
SFWD	Spent Fuel and Waste Disposition
SNF	spent nuclear fuel
SNL	Sandia National Laboratories
TC	thermocouple
UFSAR	Updated Final Safety Analysis Report

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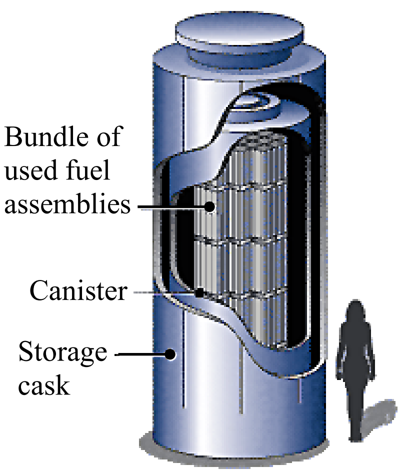
STATUS UPDATE FOR THE CANISTER DEPOSITION FIELD DEMONSTRATION

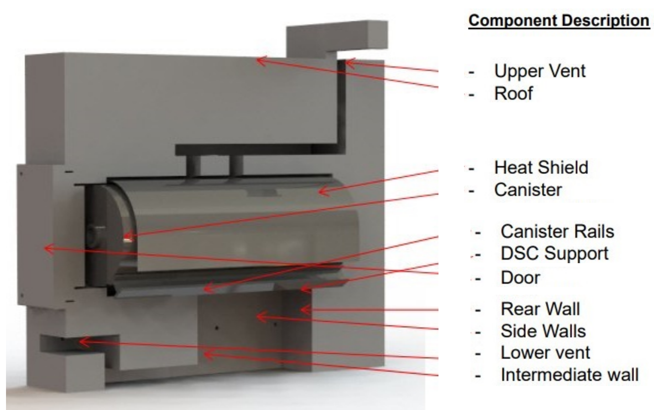
This report fulfills milestone M2SF-21SN010208033 in the Canister Deposition Field Demonstration work package (SF-21SN01020803). This work was sponsored under the Department of Energy's (DOE) Office of Nuclear Energy (NE) Spent Fuel and Waste Disposition (SFWD) campaign.

1 INTRODUCTION

Dry cask storage systems (DCSSs) for spent nuclear fuel (SNF) are designed to provide a confinement barrier that prevents the release of radioactive material, maintain SNF in an inert environment, provide radiation shielding, and maintain subcriticality conditions. SNF is initially stored in pools of water for cooling where the water also provides radiation shielding. As these pools get closer to capacity, dry storage systems are becoming the primary means of extended storage. After sufficient cooling in pools, SNF is loaded into a canister and placed inside a storage cask, where the canister is welded shut. The DCSS is then decontaminated and dried, and the system is moved to an on-site dry storage location. Figure 1.1 shows the major components of typical vertical and horizontal dry storage cask systems for SNF.



Source: https://www.nrc.gov/waste/spent-fuel-storage/diagram-typical-dry-cask-system.html



Source: https://twitter.com/Orano_usa/status/1174384799181692930/photo/1

Figure 1.1 Typical dry cask storage systems, vertical on left, horizontal on right.

Typically, the canisters are made of stainless steel. The dry storage system is designed with an open volume between the canister and the storage cask or vault. Rejection of the decay heat is accomplished by air flowing from air inlets at the bottom to outlets at the top via natural convection. This passively cooled design also allows dust from the environment into the system. These particulates may then collect on the surfaces of the canister. As the SNF cools, salts contained in the dust may deliquesce in the presence of moisture from the ambient relative humidity to form concentrated brines, which may contain corrosive species such as chlorides. These species can cause localized corrosion, called pitting. With sufficient stresses, these pits can evolve into stress corrosion cracks (SCCs), which could penetrate through the canister wall and allow communication from the interior of the canister to the external environment [Schindelholz, 2017].

1.1 Objective

This report provides an update to the previous high-level test plan for evaluating surface deposition on dry storage canisters [Lindgren *et al*., 2020] and a description of the surface characterization activities that have been conducted to date. The objective of the study is to measure the deposition of corrosive species (chloride salts) from marine coastal ambient air onto prototypic spent nuclear fuel (SNF) canisters. To facilitate surface sampling, the otherwise highly prototypic DCSS will not contain SNF but rather will be electrically heated to mimic the prototypic thermal environment.

The study will include three identical DCSSs. One system will represent a canister loaded with roughly the maximum allowed heat load, another will represent a canister loaded with one quarter of the maximum heat load, and the third canister will be used as an unheated control.

DOE NE-8 has provided three Orano (formerly Transnuclear Inc.) NUTECH Horizontal Modular Storage (NUHOMS) 32PTH2 dry shielded canisters (DSCs) and Advanced Horizontal Storage Modules (AHSMs) for use in the study (illustrated in Figure 1.2). The 32PTH2 canister is capable of holding thirty-two pressurized water reactor (PWR) assemblies. The three canisters were delivered to Sandia National Laboratories (SNL) on November 13, 2020. Figure 1.3 shows a photograph of the three canisters staged in the high bay of Sandia's Building 6630 where they will be fitted with electrical heaters and instrumented with thermocouples. The component weights for the 32PTH2 spent fuel canister are provided in Table 1.1. Discussions are ongoing to locate a suitable facility to host this long-term deposition study. An independent spent fuel storage installation (ISFSI) near a marine coastal environment would be ideal to provide harsh yet realistic conditions.

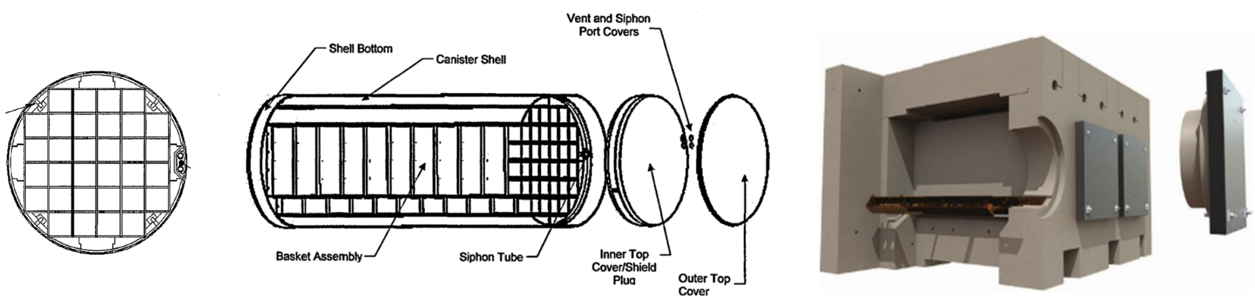


Figure 1.2 32PTH2 spent fuel canister (end view – left, side view – center) and Advanced Horizontal Storage Modules (AHSM – right).

Figure 1.3 Three 32PTH2 spent fuel canisters inside of Sandia's Building 6630 south high bay.

Table 1.1 32PTH2 spent fuel canister component weights [Transnuclear, 2017].

Component	Nominal Weight	
	Pounds	Kilograms
Canister shell	6,060	2,749
Outer top cover plate	2,140	971
Inner top cover plate	2,150	975
Top shield plug and support ring	6,430	2,917
Bottom end assembly	7,200	3,266
Grapple ring	75	34
Total canister assembly	**24,055**	**10,911**
Fuel compartments (32)	11,090	5,030
Aluminum/poison plates	4,920	2,232
Stainless steel plates	2,360	1,070
Small support rails	3,260	1,479
Large support rails	9,370	4,250
Total Fuel Basket	**31,000**	**14,061**
Basket fuel spacer	1,460	662
Total empty DSC (basket and canister)	56,515	25,635
Fuel assembly weight (32) @ 1610 lb/assembly	51,520	23,369
Total loaded DSC weight	**108,035**	**49,004**

The three canisters will be designed to simulate three decay heats.

1. 0 kW decay heat for control. Canister will be loaded with heater assemblies and insulation to perform as a backup if other systems fail. The control canister should be most susceptible to deliquescence due to having the coolest surface temperatures.
2. 10 kW decay heat to represent canisters that have been stored for a while and more susceptible to deliquescence than the higher-powered canister because of cooler surface temperatures.
3. 40 kW decay heat to represent a freshly loaded system with short cooled fuel. The decay heat will be decreased at various intervals to determine how concentration, composition, and location of deposits vary with decay heat and associated air flow velocities and patterns.

After some period of time, to be determined based on a combination of modeling and sampling at the host location, the canisters will be inspected for salt composition and concentration at various locations on the canister as described in Section 2.3.2.2.

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2 APPARATUS AND PROCEDURES

2.1 32PTH2 Canister and Advanced Horizontal Storage Module

The 32PTH2 canisters were selected for testing based on availability and suitability. These canisters were made available to the national laboratories by DOE NE-8 for research purposes. While the 32PTH2 is not the latest generation of canister designs, the technology contained in this system is representative of the domestic fleet of DCSSs, especially for horizontal storage.

2.1.1 Modifications

Modifications to certain components will be necessary to accommodate testing. Specifically, the canister lids and support ring will need to be altered for testing purposes. These modifications primarily include modifying the outer lid such that it is able to mechanically mount onto the support ring and excluding the shield plug and inner lid. Pass throughs for power, instrumentation, and the lifting lugs will also need to be considered. In addition, modifications to the AHSM will be needed. Insulative walls on the sides and rear of the AHSM will provide better boundary conditions for modeling and prevent the different powered canisters from influencing their neighbors. A rear hatch cut into the AHSM is also needed for cable management.

2.1.1.1 Lid Modification

The electric heaters that simulate the decay heat of spent fuel and the internal temperature sensors that monitor the thermal response will require penetrations in the top canister cover for signal and power wiring. Figure 2.1 illustrates some details of the prototypic top shield plug assembly. The outer top cover plate will be modified such that it can be mounted directly to the shield plug support ring and will serve as the only cover installed. Additional mounts to the support ring may be needed to secure the inner lid. The inner top cover and shield plug will not be installed. The top shield plug is not required because the heat source is not radioactive. In prototypic commercial application, both the inner and outer top cover plates are welded in place to produce redundant hermetic seals, which are also not needed for the proposed testing. The shield plug is nominally 14 cm (5.5 in.) thick ASTM A36 carbon steel, weighs about 2,900 kg (6,380 lbs.) and rests on a support ring welded to the inside circumference of the canister. Both the inner and outer top cover plates, or lids, are nominally 5 cm (2 in.) thick and weigh about 1,000 kg (2,200 lbs). The inner cover plate is made of 304 stainless steel and the outer cover plate is made of 316 stainless steel, the same material as the canister walls.

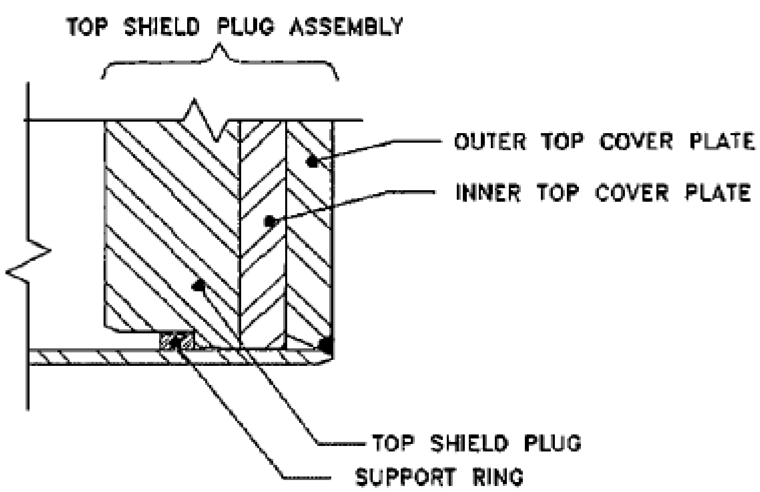

Figure 2.1 Detail of the top shield plug assembly for the 32PTH2 canister. Adapted from Figure B.3.1-1 [Transnuclear, 2016].

The top outer cover plate is intended to be installed and left in place through the duration of testing. Should maintenance and repair be required, the lid will be removeable with the canister in a horizontal orientation. To facilitate this operation, a lid lifting fixture was designed and constructed. Figure 2.2 shows the horizontal lid lifting fixture. The inner lid is pictured in these photographs. The notch on the right side of the inner lid (as pictured) is to accommodate the siphon tube and vent port chase. The same dimension notch will be cut into the outer lid. The outer lid was chosen for service because of its 316 stainless steel construction, which is much more resistant to chloride attack in marine environments.

Figure 2.2 Lid lifting fixture allows lid to be installed into canister horizontally.

The recessed space obtained by locating the outer cover on the shield plug support ring will allow approximately 10 cm (4 in.) of space below the top plane of the canister shell for junction boxes required for temperature sensor and heater power connections. This design feature ensures the junction boxes will not interfere with the canister installation into the AHSM. The installation of a thin insulation layer on the outer top cover plate is being considered to provide additional protection to the junction boxes and to simulate the conductive losses of the shield plug and inner cover plate. Further modeling is needed to determine if additional insulation on the outer cover plate will improve comparisons with prototypic canister temperatures.

2.1.1.2 AHSM modification

The concrete AHSM vault will also be modified to accommodate the testing. Some of the modifications are illustrated in Figure 2.3, Figure 2.4, Figure 2.5, Figure 2.6, and Figure 2.7. A rear hatch with dimensions of approximately 0.91 × 0.91 m (36 × 36 in.) will be cut in the back wall of the vault to gain access to the junction boxes recessed into the top of the canister. Internal and external temperature sensor and heater power wiring (see red and yellow junction box in Figure 2.4) will exit the vault through this access opening. Temperature sensitive thermocouple (TC) junctions will be made in a junction box outside the vault (see black and white junction box in Figure 2.4). In preparation for canister extraction and surface sampling, the connections going from the junction boxes to the data acquisition and heater power will be disconnected. The TC junction box is then moved from outside the vault to inside the canister next to the heater power junction box as illustrated in Figure 2.5. Also shown in Figure 2.4 and Figure 2.5 is rigid fireproof insulation (see blue and white structure) on the back exterior wall. The vault hatch will be sealed by the installation of hatch door as shown in Figure 2.6.

Additional modifications will be made to the three AHSMs to improve the quality of boundary conditions for model validation. Thermal breaks will be placed between adjacent vaults to keep the high-powered test from influencing the adjacent lower powered tests. These thermal breaks, or insulation, will be placed inside the rebar of specialized side shield walls prior to the pouring of concrete. These side walls will also be engineered to couple to the AHSMs on both sides. Figure 2.7 illustrates the placement of insulation in the external and internal side walls. This figure also demonstrates how dividers will be placed in the outlets to further limit thermal-hydraulic communication between the AHSMs.

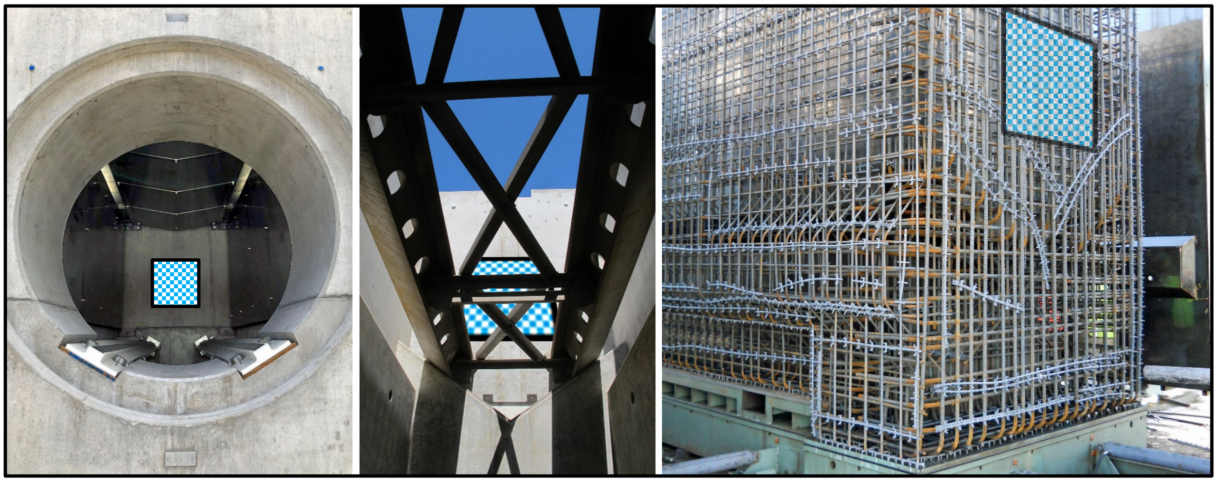

Figure 2.3 Different views of the AHSM showing location of conceptual rear hatch (shown as blue-white checker pattern).

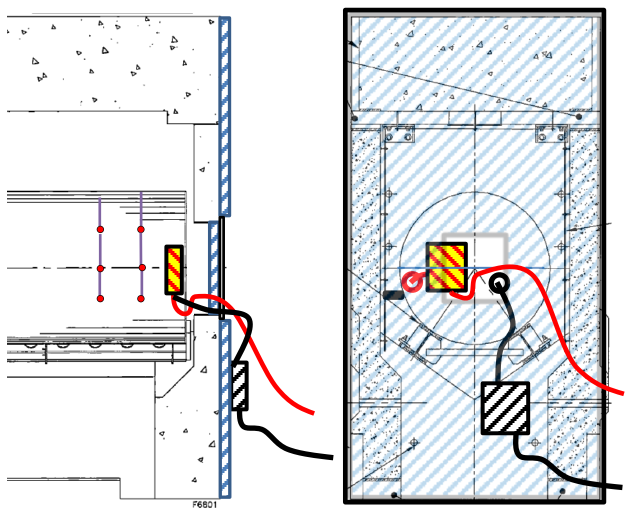

Figure 2.4 AHSM vault modifications (configuration for operations).

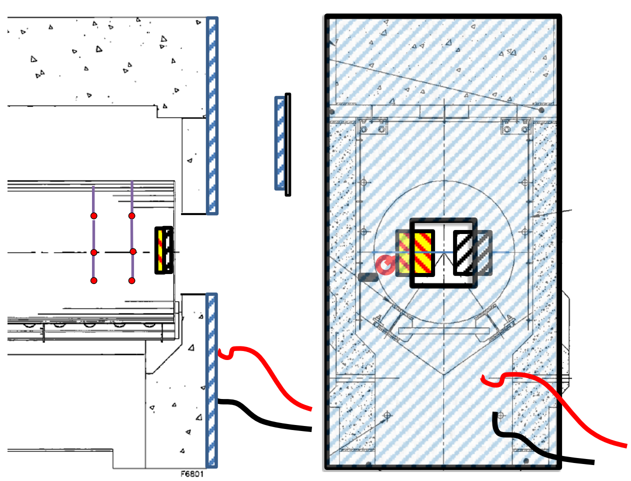

Figure 2.5 AHSM vault modifications (configuration for extraction).

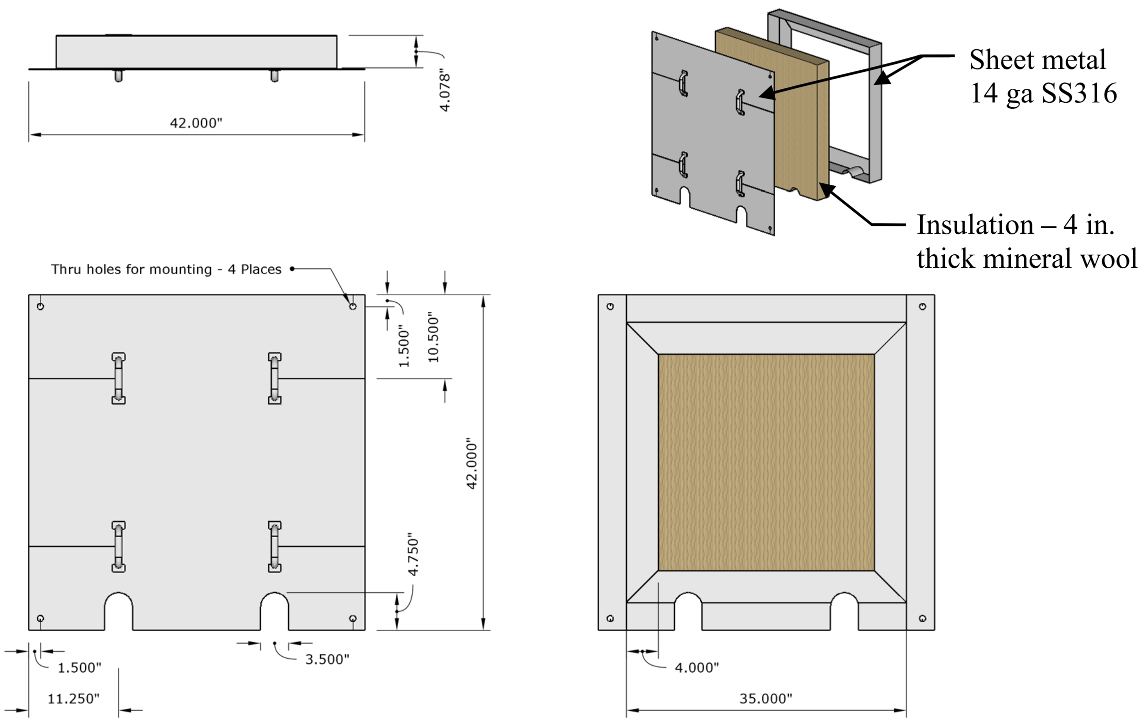

Figure 2.6 Vault hatch door.

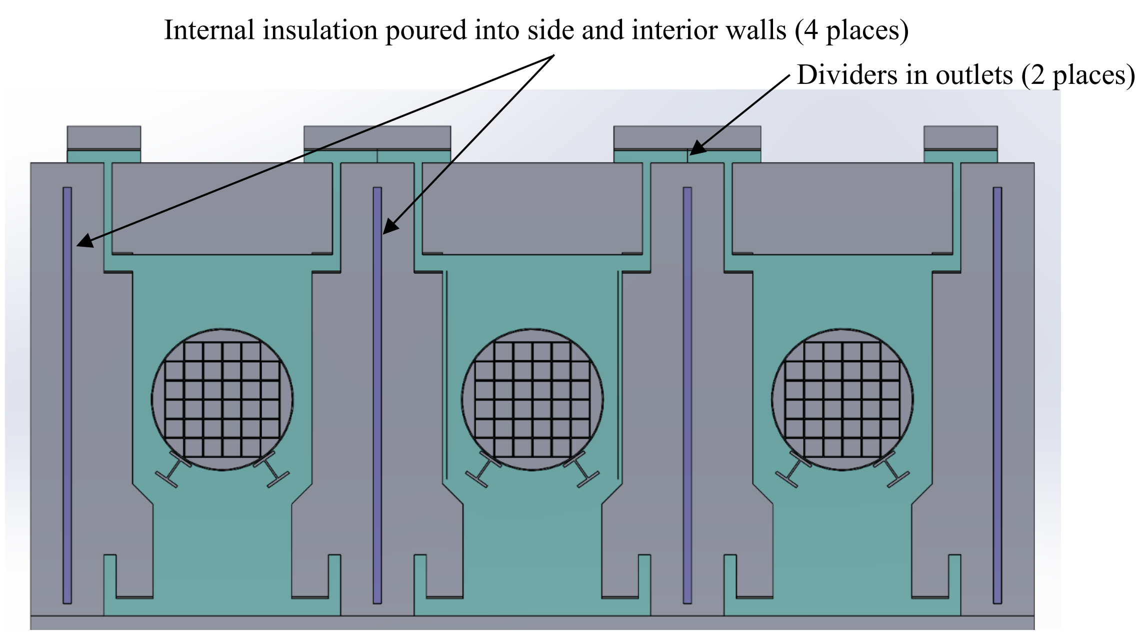

Figure 2.7 Insulation plan for side walls and outlet dividers for AHSM.

2.1.2 Canister Insertion and Extraction

Depending on the available facilities at the host site, a means for inserting and extracting the canister will need to be devised. As of this writing, a modified transfer skid is being explored in further detail and is the preferred choice. The modified transfer skid is shown in Figure 2.8. The transfer skid will not need the shielding transfer cask allowing access to most of the canister surface for sampling. The transfer skid will also incorporate custom support rollers to facilitate canister movement.

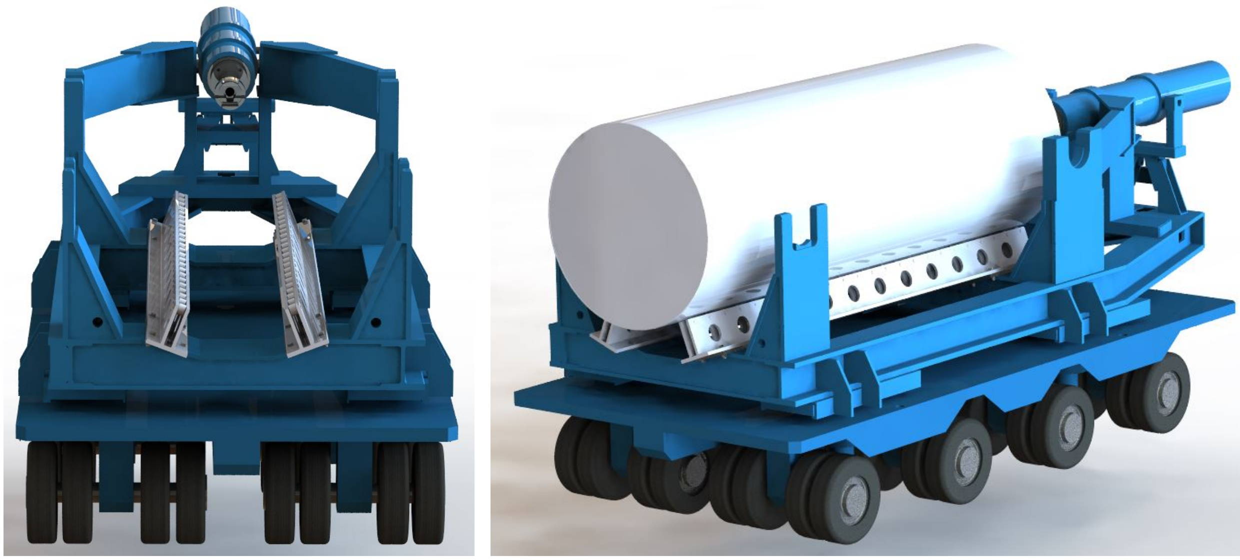

Figure 2.8 Modified transfer skid with custom support rollers.

2.2 Simulated Decay Heat

2.2.1 Power Control

In order to achieve a surface temperature distribution that accurately represents an analogous commercially loaded canister, the power loading pattern of the electric heaters will closely follow the power loading of spent fuel in the commercial canister. The 32PTH2 DSC is designed to store up to 32 fuel assemblies in the four arrangements shown in Figure 2.9. There are three distinct assembly power zones identified. Heat Load Zone Configuration (HLZC) #1 will be scaled to a total power of 10 kW or 40 kW. The heaters will be powered to mimic this loading pattern using Control Concepts Microfusion silicon-controlled rectifiers (SCRs). The total power delivered to each zone will be independently measured using Ohio Semitronics Power Test Boards (PTBs), which provide high-accuracy true root mean square (RMS) measurements for voltage, current, power, and power factor and are specifically designed to accommodate distorted and chopped waveforms typical of SCRs. Electrical power will be supplied using a 112.5 KVA, 480 V 3Ø → 208 V 3Ø, GE Guard II noise isolation transformer for clean power with demonstrated 120 dB common mode noise rejection and 60 dB transverse mode noise rejection. Similar power control systems have been used in previous studies with excellent results [Durbin and Lindgren, 2018; Pulido *et al.*, 2020].

	Zone 3	Zone 3	Zone 3	Zone 3	
Zone 3	Zone 2	Zone 2	Zone 2	Zone 2	Zone 3
Zone 3	Zone 2	Zone 1	Zone 1	Zone 2	Zone 3
Zone 3	Zone 2	Zone 1	Zone 1	Zone 2	Zone 3
Zone 3	Zone 2	Zone 2	Zone 2	Zone 2	Zone 3
	Zone 3	Zone 3	Zone 3	Zone 3	

Number of Fuel Assemblies	4	12	16	
	Zone 1	Zone 2(2)	Zone 3(1)	
HLZC #	Maximum Decay Heat/Fuel Assembly(3), [kW]	Maximum Decay Heat/Fuel Assembly(3), [kW]	Maximum Decay Heat/Fuel Assembly(3), [kW]	Maximum Decay Heat/DSC, [kW]
1	0.8	1.5	1.0	37.2
2	0.9	1.3	1.0	35.2
3	1.0	1.0	1.0	32.0
4	0.8	1.0	1.0	31.2

Notes:

(1) Damaged fuel assemblies, up to 16 damaged (balance intact), shall be placed in Zone 3 only.

(2) Zone 2 is for placement of up to 8 reconstituted fuel assemblies with irradiated stainless steel rods when stored in the Option 1 configuration (the four corner locations of Zone 2 are not allowed for storage of such assemblies). The Option 2 configuration for storage of up to 32 reconstituted fuel assemblies with irradiated stainless steel rods does not have any restriction on placement of fuel assemblies within the DSC. Option 1 and Option 2 are defined in Table B.2.1-1.

(3) Decay heat per fuel assembly shall be determined per Table B.2.1-7.

Figure 2.9 Heat Load Zone Configuration for the 32PTH2 DCS. From Figure B.2.1-1 [Transnuclear, 2016].

A power/instrumentation skid will provide a protected enclosure for power control, instrumentation interfaces, and data acquisition (DAQ). This unit is comprised of an insulated steel storage container (Width × Depth × Height = 8 × 10 × 8.5 ft.) with a top-mounted HVAC unit for climate control. To accommodate clearance and cable management, the final footprint on the ISFSI pad of the power/instrumentation skid is expected to be 10 × 15 ft. The primary power service requirements are estimated to be a total of 80 kW, which allows for continuous use of 50 kW for simulated decay heats (40 and 10 kW) and 15 kW for HVAC and instrumentation. This load represents 81% of the service capacity.

The DAQ system will be built for reliability and flexibility. A National Instruments PXI-e chassis is the leading candidate for scalable performance. Up to 608 total TCs are currently planned with 192 TCs per system (96 internal and 96 external including the AHSM) and 32 TCs for ambient and component temperatures.

2.2.2 Target Surface Temperatures

The objective of this field demonstration is to deploy an electric heater system that reproduces the surface temperature distribution obtained from an analogously loaded 32PTH2 spent fuel canister. The targeted surface temperatures were calculated by staff at Pacific Northwest National Laboratory (PNNL) via detailed computational fluid dynamics (CFD) modeling using STAR-CCM+ for the 10 kW and 40 kW cases. A summary of the results is presented in Table 2.1. The surface temperature profiles are shown in Figure 2.10 for the 40 kW case and in Figure 2.11 for 10 kW case.

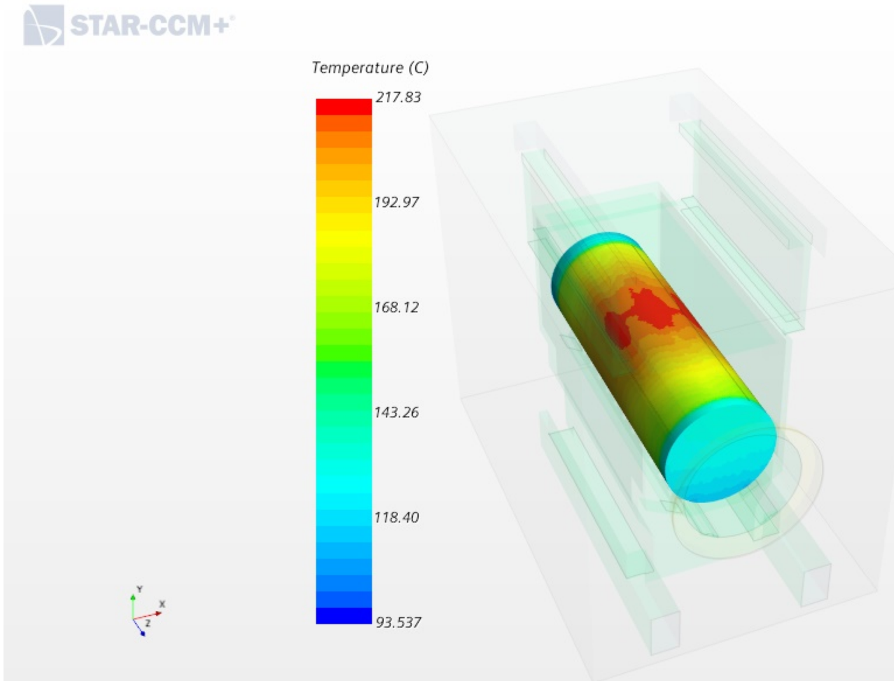

Figure 2.10 Surface temperature distribution of a 32PTH2 canister uniformly loaded with 40 kW of spent fuel.

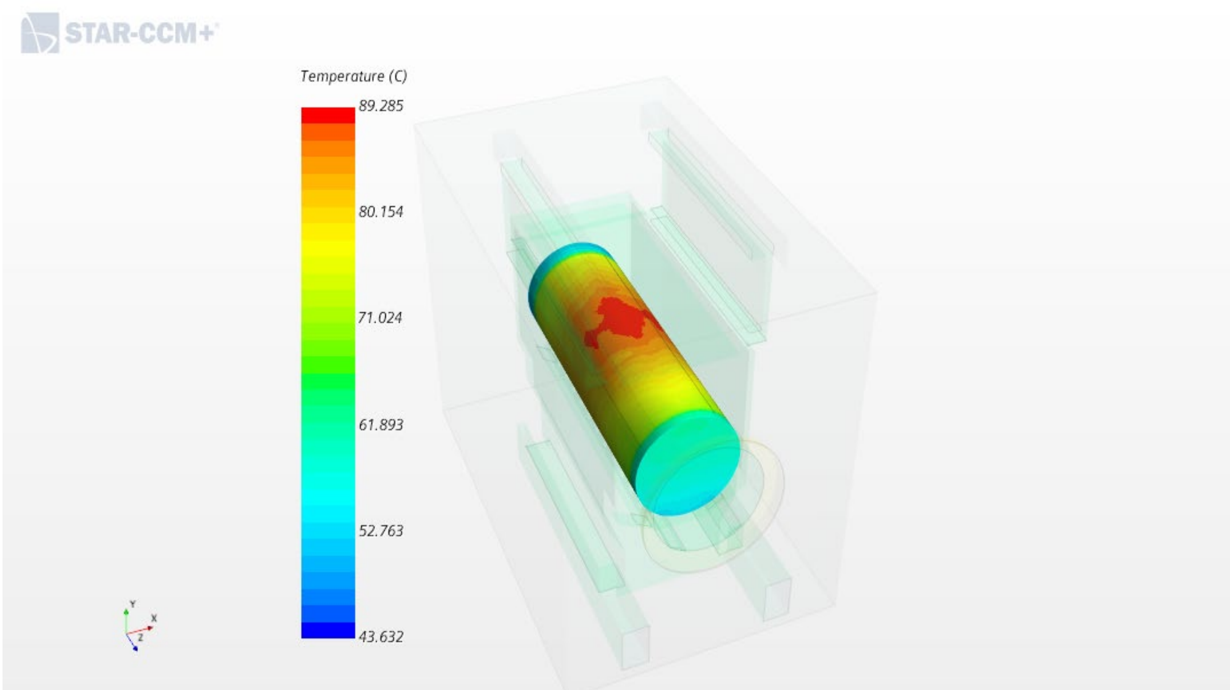

Figure 2.11 Surface temperature distribution of a 32PTH2 canister uniformly loaded with 10 kW of spent fuel.

Table 2.1 Calculated 32PTH2 spent fuel canister surface temperatures.

Model	32PTH2 Porous Media	32PTH2 Porous Media
Canister Fluid	Helium	Helium
Heat Load [kW]	10	40
Avg. Shell Canister Temp. [°C]	75	181
Max. Shell Canister Temp. [°C]	89	218
Min. Shell Canister Temp. [°C]	44	94
Standard Deviation Shell Canister Temp. [°C]	13	40
Avg. Top Lid Temp. [°C]	50	114
Max. Top Lid Temp. [°C]	53	124
Min. Top Lid Temp. [°C]	44	95
Standard Deviation Top Lid Temp. [°C]	2	6
Avg Bottom Canister Temp. [°C]	59	127
Max Bottom Canister Temp. [°C]	65	144
Min Bottom Canister Temp. [°C]	51	110
Standard Deviation Bottom Canister Temp. [°C]	7	25

2.2.1 Heater Design

The goalpost radiative style heater design shown in Figure 2.12 has been chosen for use in this study. The U-tube heater is centered on a stainless-steel C-channel backbone. Thermal radiation shields are located on each end of the heater assembly and produce more prototypic canister skin temperature profiles. This design provides near symmetric heat transfer into the fuel compartment.

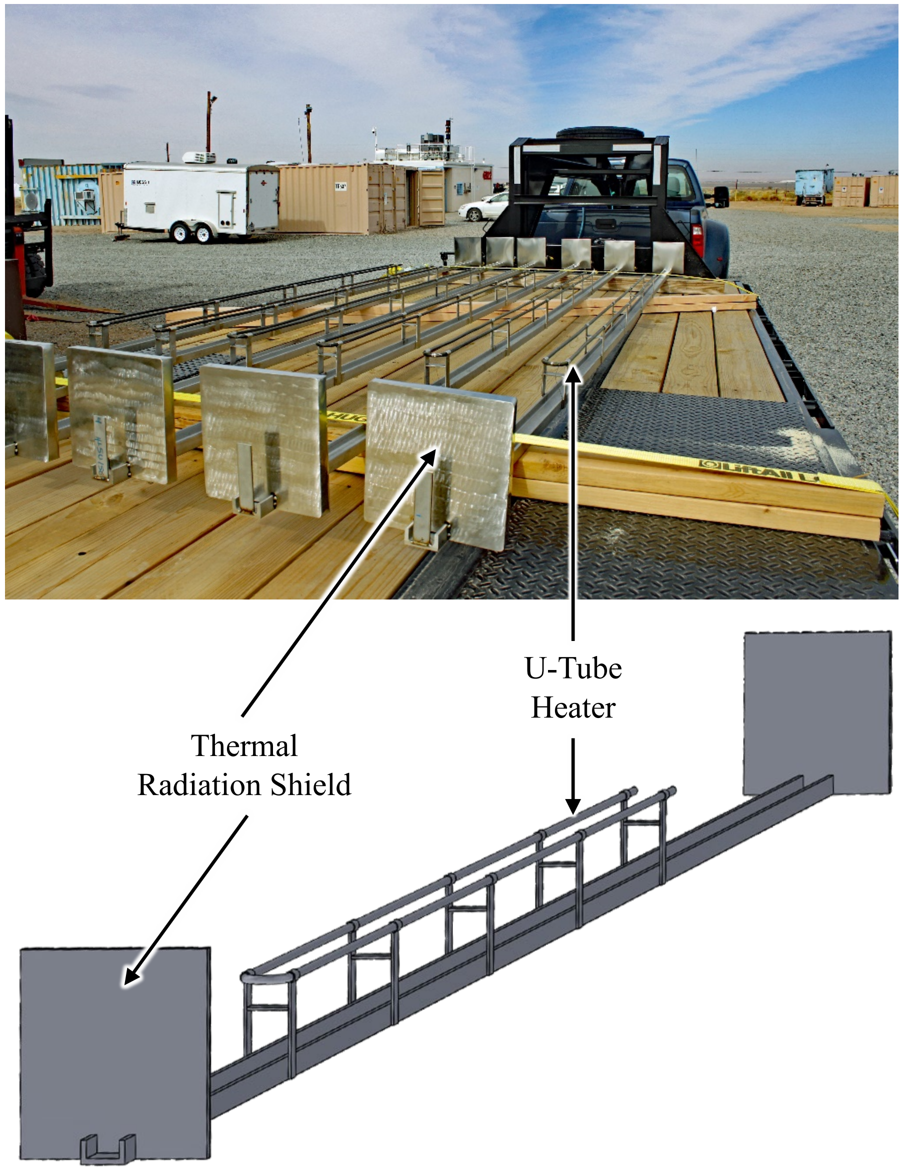

Figure 2.12 Goalpost radiative heater design with thermal radiation shields.

2.2.1 Preliminary Heater Testing

Preliminary *in situ* heater tests were conducted to check the adequacy of the proposed heater design. The heaters were placed in the basket in the locations shown in Figure 2.15. The red, blue, and green colors designate the power control circuit used. The basket locations are numbered serially starting in the upper left corner. Each heater is assigned a unique identifier (*e.g.* "HA" for heater "A").

With a total power of 9.60 kW applied, the transient peak heater temperature (PHT) and surface temperature at the four cardinal coordinates are shown in Figure 2.14. The PHT reached about 415 °C and as expected the highest surface temperature is on the top of the canister (180°) and the coolest is located at the bottom of the canister (0°). The temperatures on the sides (90° and 270°) are similar, indicating good symmetry. Due to the large mass of the canister, it took four days to reach steady state. Note that the boundary conditions for these preliminary tests represent natural convection into an open room which differs significantly from the confined natural convection boundary conditions found inside the Advanced Horizontal Storage Module.

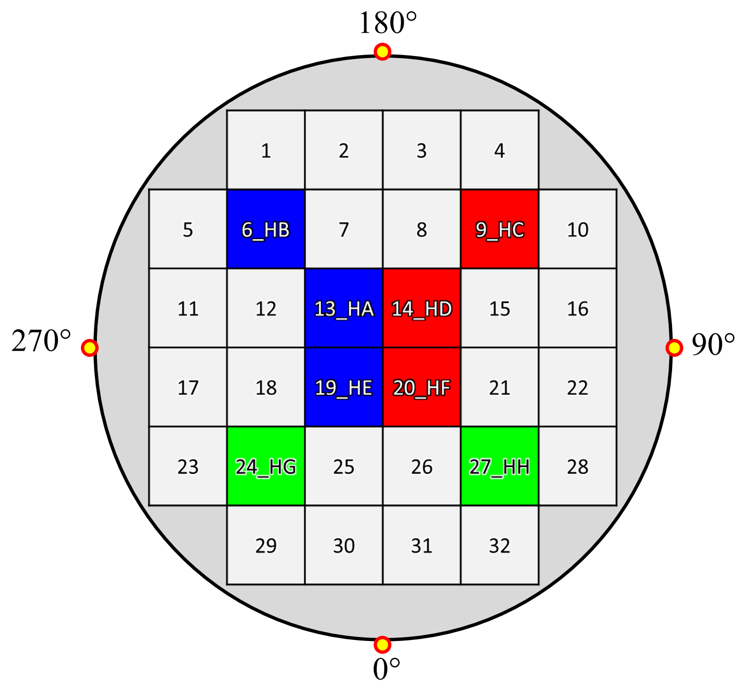

Figure 2.13 Heater location in the canister basket for the preliminary heater tests.

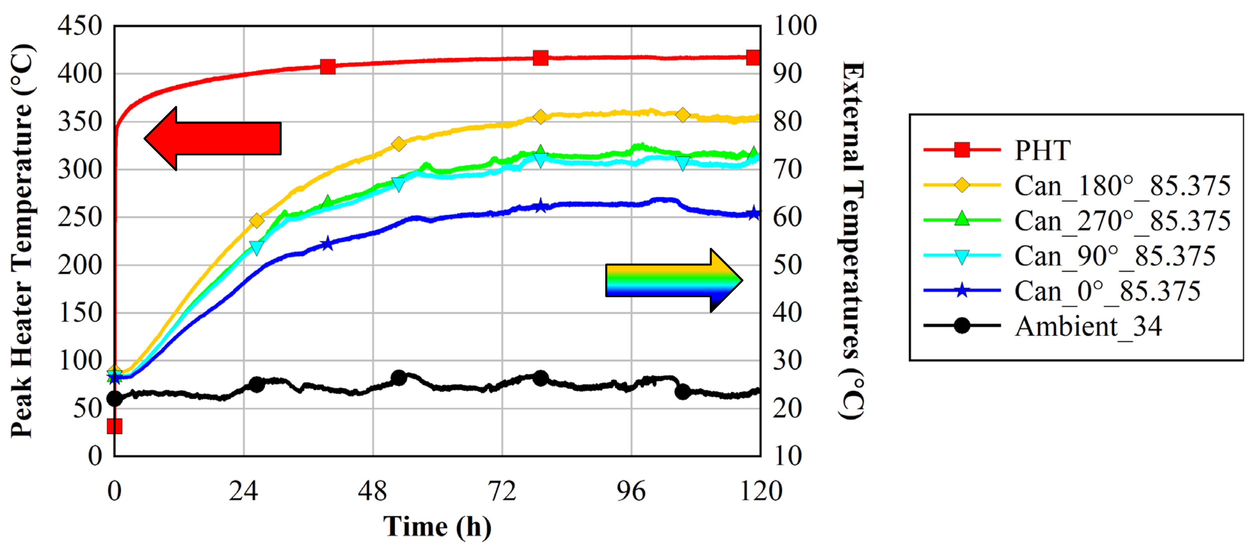

Figure 2.14 Transient peak heater temperature (PHT) and canister surface temperatures measured with 9.60 kW total applied power.

2.3 Instrumentation Plan

2.3.1 Internal Measurements

The interior of the basket will be instrumented with 1.0 mm (0.040 in.) type-K TCs. Because the internal surface of the basket is largely inaccessible, the internal TCs will be installed on the heater assembly that is positioned in each of the 32 basket storage cells. The exact number and location of these TCs will not be finalized until the heater assembly design is finalized. At a minimum, two to three TCs will be installed along the length of each heater assembly (with a practical maximum of 96 TCs per canister) and exit through penetrations in the top cover plate.

2.3.2 External Measurements

2.3.2.1 Thermocouples

The exterior surface of the canister will be instrumented with type-K TCs to provide a minimum of one temperature measurement for each surface sample location as shown in Figure 2.15. An equally important consideration is to make these temperature measurements in a manner that minimizes any flow disturbance of the naturally induced air flow over the canister surface carrying the particulates of interest. In order to minimize air flow disturbance on the surface of the canister, smaller type-K TCs with diameter of 0.81 mm (0.032 in.) will be used, and the sheaths will be routed just above the canister support rails as shown in Figure 2.16. The TCs will run straight longitudinally along the canister shell and then route perpendicularly along an arc to the location of interest. The TC sheaths will be passed out of the heated zone through the rear hatch in the AHSM. If any TCs and sample locations are located below the canister support rails, the traverse to the junction box at the back of the vault will be just below the support rail. Because the canister support rails already introduce a significant flow obstruction, the addition of a TC chase in the wake of the rails should not add any significant disturbances.

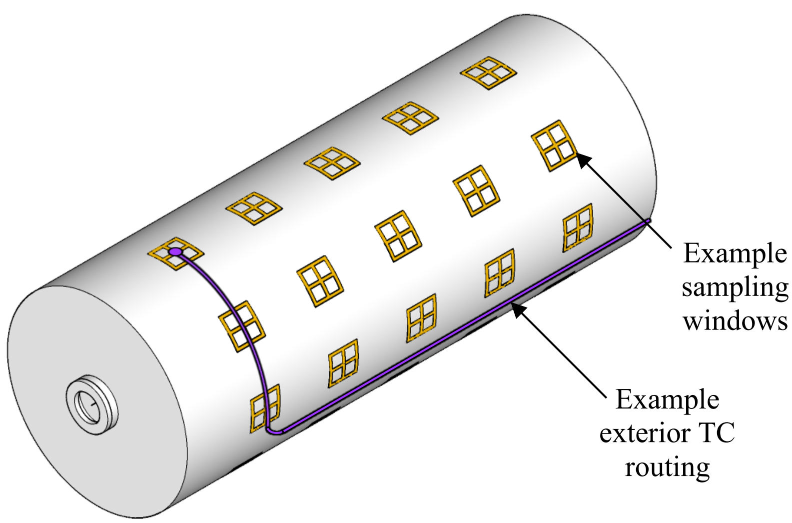

Figure 2.15 Canister exterior TC and sample collection locations.

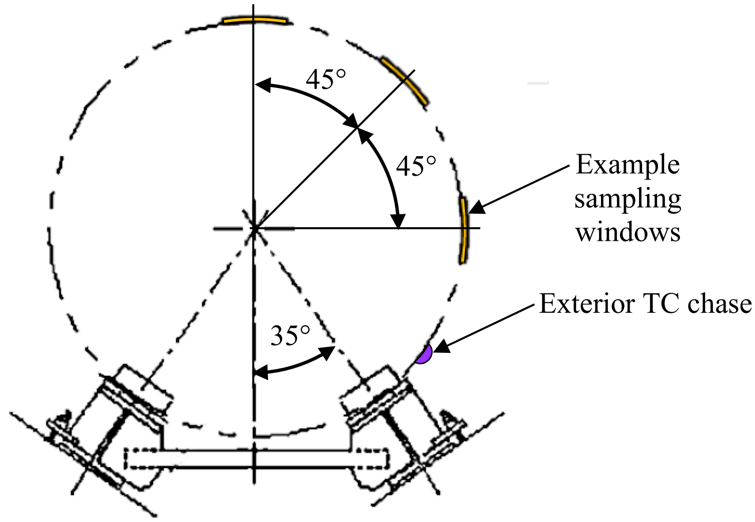

Figure 2.16 End view of the canister and support rails showing example sampling locations. Adapted from Figure B.3.1-7 [Transnuclear, 2016].

2.3.2.2 Surface Sampling

As described in detail in Bryan *et al.*, 2021, the area around each TC location on the exterior of the canister will be sampled on a periodic basis for surface deposits in a regular pattern as depicted in Figure 2.17. Each of the four colored squares represents a sampling location approximately 7.5 × 7.5 cm (3.0 × 3.0 in.) and two types of samples will be collected at each location – a dry sample and a wet sample during every sampling event (see Bryan *et al.*, 2021 for details). The central TC location is indicated by the purple circle in the center. Baseline thermal modeling indicates that a maximum temperature difference of 10 °C can exist between the extremes (corners) of the sample windows.

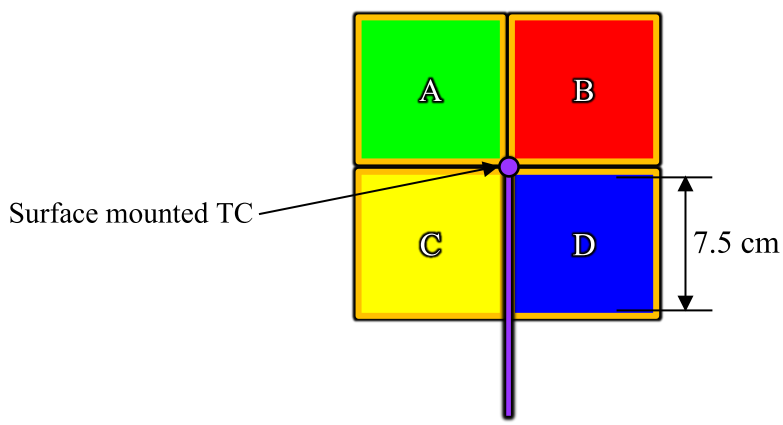

Figure 2.17 Surface deposition sampling pattern.

A possible sampling schedule for each location is summarized in Figure 2.18 [Bryan *et al.*, 2021] and was constructed to maximize the ability to collect cumulative undisturbed salt deposition and deposition rates over smaller intervals. The four sibling locations around the TC should provide comparable results due to close proximity. Specifically, at each sampling location on the canister, the first grid block (A) will be sampled during the first sampling campaign, one year into the test. During the second sampling campaign, grid block B will be sampled for the first time, and grid block A will be resampled. During each sampling campaign, a new grid block will be sampled, and some subset of the already sampled blocks will be resampled. Each newly sampled block provides cumulative dust and salt load information; resampled blocks provide yearly data [Bryan *et al.*, 2021].

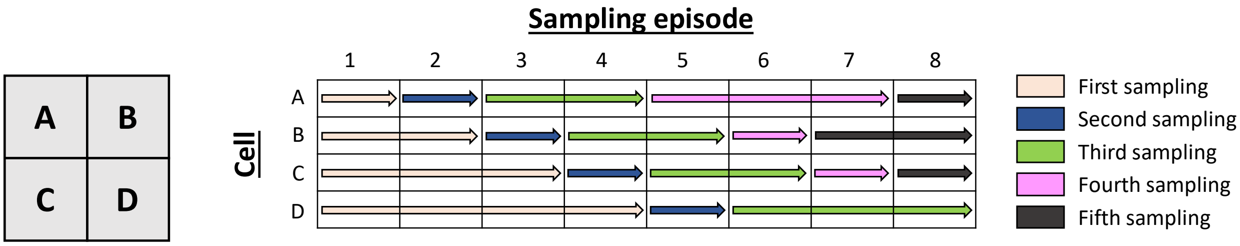

Figure 2.18 Sampling grid and possible sampling schedule [Bryan *et al.*, 2021].

2.4 Atmospheric Monitoring

Ambient monitoring will be conducted on or near the storage vaults. Continuous monitoring will include typical weather station parameters such as air temperature, absolute ambient pressure, wind speed and direction, humidity, and precipitation. Additionally, particulate matter (PM) sensors will be used to continuously monitor various size ranges of aerosols in the air. Deposition models require the particle composition and density (mass per m^3 air), as well as size distribution, for inputs. Periodically, on-site aerosol sampling will be conducted to characterize these parameters.

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3 SURFACE CHARACTERIZATION

Extensive surface characterization has been performed on all three of the canisters. Detailed high-resolution photomapping has been completed on the accessible two-thirds of the canister surfaces. Laser line surface scanning has also been completed on all three canisters producing a 3-D representation of the accessible two-thirds of the canister surfaces. The accessible welds on all three canisters have been characterized by eddy current array (ECA) to produce an impedance map that allows for flaw detection, material and coating thickness measurements, material identification, and establishing the heat treatment condition of certain materials. Finally, dye penetrant inspection (DPI) has been completed on the accessible welds of one of the three canisters. This low-cost method is widely used to locate surface flaws such as cracks, pits and porosity. Other than some minor porosity and pitting, the dye inspection did not reveal any indication of cracks.

3.1 Photomapping

Detailed photomapping of the upper two-thirds of the circumferential canister surface was performed with a 45-megapixel Canon R5 camera using a 50 mm low distortion lens. The lower one-third of the canister was not assessable due to the cradles and proximity to the floor. Conventional merging of all the photos into a single file would result in an unwieldy 8.1-gigapixel image. Rather, the images are converted to a deep zoom image tile set that consists of arrays of smaller file size images with increased resolution as the magnification is increased (similar to Google Maps). Figure 3.1(a) shows the camera alignment fixture with the cirfumferential and axial measuring tapes and indicates the overlapping camera field of views [Tanbakuchi, 2021]. Figure 3.1(b) shows the composite image of the canister surface while Figure 3.1(c) and (d) show examples of zoomed-in resolution of surface features.

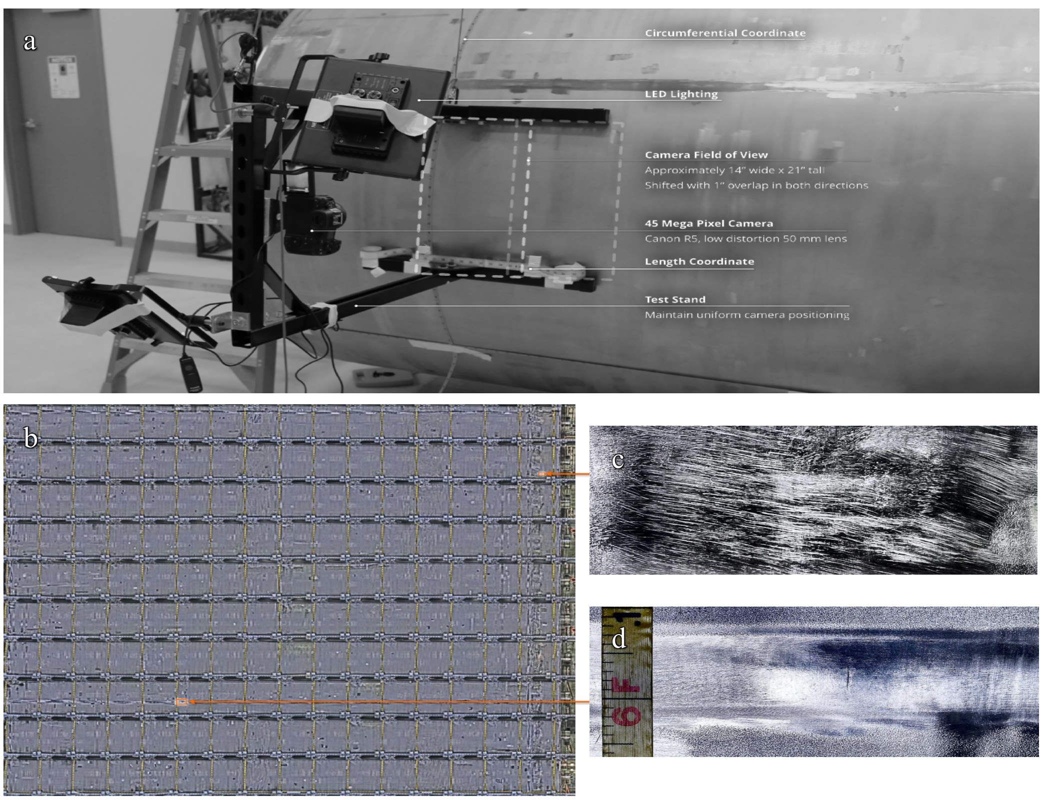

Figure 3.1 Detailed photomapping of the canister circumferential surface. (a) Camera alignment fixture showing the cirfumferential and axial measuring tapes and the overlapping camera field of views. (b) Composite image of the canister surface. (c&d) Zoomed in resolution of surface features.

3.2 Laser Line Surface Scanning

Laser line scanning is a non-contact method of measuring the shape of a 3-dimensional object. The hand-held probe creates a digital representation of the object by measuring the distance from the scanner to the laser beam that is projected onto the object. Figure 3.2 shows images of the non-contact laser scanning operation in progress using a FARO® 8-axis QuantumS coordinate measuring machine (CMM) for position data. The practical feature resolution is ~100 µm (0.004 in.).

Figure 3.2 Images showing the non-contact laser scanning in progress using an 8-axis Quantum^{S} coordinate measuring machine for position data.

A 3-D surface map of the upper two-thirds of the canister was generated. The lower one-third of the canister was not assessable due to the cradles and proximity to the floor. The data was referenced to a primitive cylinder to produce displacement differences shown in Figure 3.3 (a) and (b) with ± 3.2 mm (± 0.125 in.) on the legends.

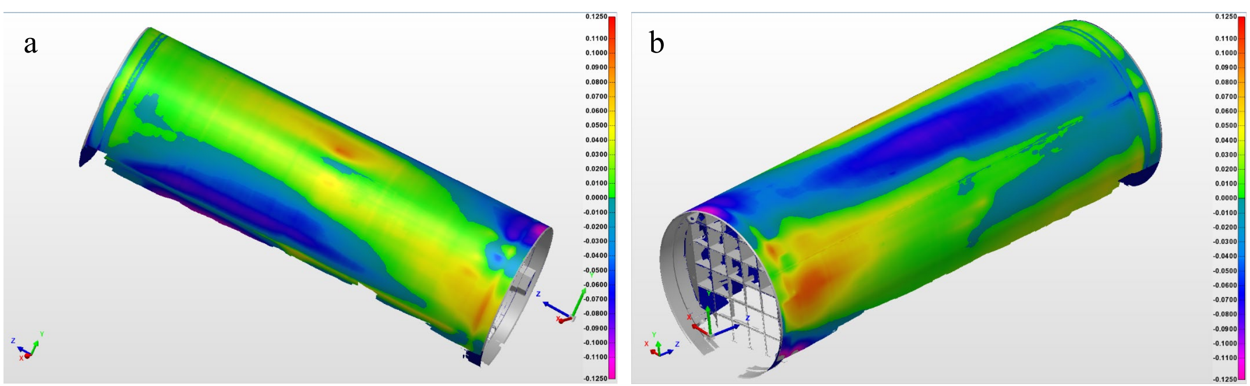

Figure 3.3 Displacement differences from primitive cylinder in inches.

3.3 WELD INSPECTIONS

3.3.1 Eddy Current Array

Eddy current array (ECA) is a nondestructive inspection technology that provides the ability to electronically drive multiple eddy current coils, which are placed side by side in the same contact probe assembly. The coils detect impedance change within the material to provide a method for flaw detection, material and coating thickness measurements, material identification and establishing the heat treatment condition of certain materials. Figure 3.4(a) shows the eddy current array testing in progress using an

Olympus Omniscan MX instrument with an SBB -051-150-032 probe. Figure 3.4(b) shows the color scale (right) impedance change within the material. The encoder resolution is 0.53 mm (0.021 in.).

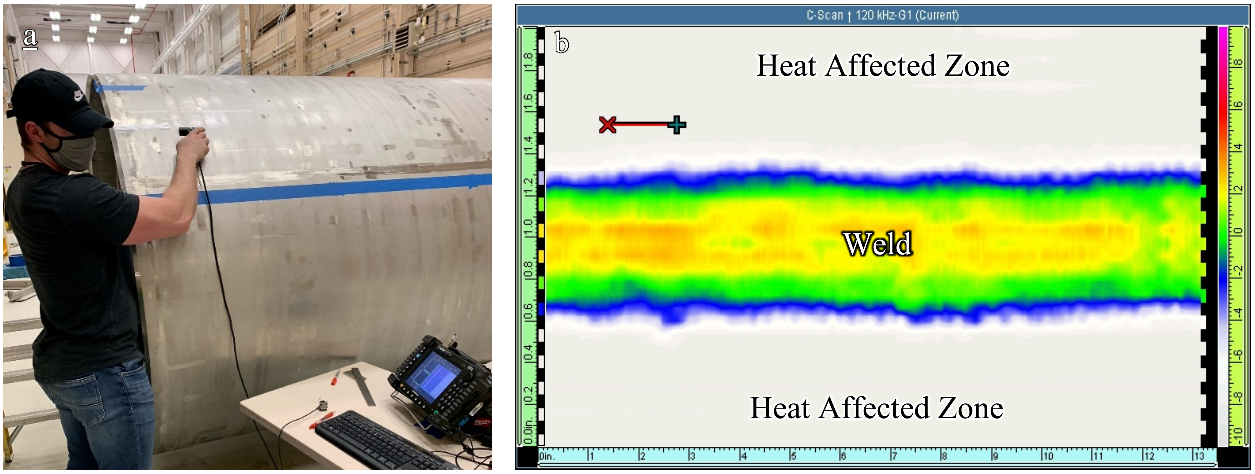

Figure 3.4 (a) Eddy current array testing in progress. (b) Impedance change within the material.

3.3.2 Dye Penetrant

Dye penetrant inspection (DPI) is a low-cost method widely used to locate surface flaws such as cracks, pits and porosity. Dye is applied to the welds and adjacent heat affected zones. Excess dye is removed and a powdered developer is applied over the treated area. The surface is then inspected with an ultraviolet lamp which causes any remaining developed dye to glow. Figure 3.5 (a) shows the dye penetrant applied to the welds on one region of the canister [Nelson and Schauble, 2021]. Figure 3.5 (b) shows a pit detected after the dye was developed and inspected with an ultraviolet light. Figure 3.5 (c) shows a photograph of the same pit and Figure 3.5 (d) shows the photo image and dye penetrant image superimposed. Other than some minor porosity, the dye inspection did not reveal any indication of cracks.

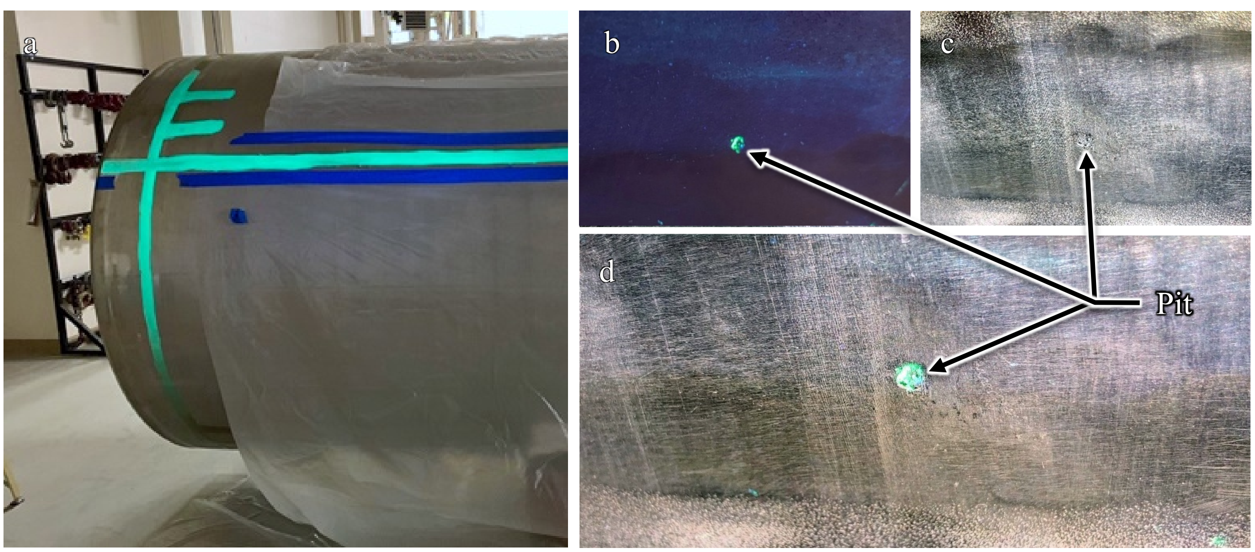

Figure 3.5 (a) Dye applied to welds and heat affected zones. (b) Pit detected when surface inspected with UV lamp. (c) Photo image of same pit. (d) Photo image and dye penetrant image superimposed.

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4 SUMMARY

This report provides an update to the previous high-level test plan [Lindgren *et al*., 2020] for evaluating surface deposition on three commercial Orano 32PTH2 spent fuel canisters housed in AHSMs and a description of the surface characterization activities that have been conducted to date. The goal of the testing is to collect highly defensible and detailed surface deposition measurements of dry canisters in a marine coastal environment to guide CISCC research. To facilitate surface sampling, the otherwise highly prototypic DCSS will not contain SNF but rather will be electrically heated to mimic the prototypic thermal environment.

The outer top cover plate will be modified such that it can be mounted directly to the shield plug support ring and will serve as the only cover installed. The inner top cover and shield plug will not be installed. The top outer cover plate is intended to be installed and left in place through the duration of testing.

The exterior surface of the canister will be instrumented with type-K TCs to provide a minimum of one temperature measurement for each surface sample location. Both wet and dry surface samples will be collected on a systematic basis.

The concrete AHSM vaults will also be modified to accommodate the testing. A rear hatch will be cut in the back wall of the vault to gain access to the junction boxes recessed into the top of the canister. Internal and external temperature sensor and heater power wiring will exit the vault through this access opening. Insulation will be added to the AHSMs to provide near-adiabatic boundary conditions for each system. A thermal break between adjacent vaults is particularly important to keep the high-powered test from influencing the adjacent lower powered tests. Insulating the exterior side and back walls serve as near-adiabatic boundary conditions and improve modeling validation.

Extensive surface characterization has been performed on all three of the canisters. Detailed high-resolution photomapping has been completed on the accessible two-thirds of the canister surfaces. Laser line surface scanning has also been completed on all three canisters producing a 3-D representation of the accessible two-thirds of the canister surfaces. The accessible welds on all three canisters have been characterized by ECA to produce an impedance map that allows for flaw detection, material and coating thickness measurements, material identification, and establishment of the heat treatment conditions of the canister shell. Finally, DPI has been completed on the accessible welds of one of the three canisters. This low-cost method is widely used to locate surface flaws such as cracks, pits, and porosity. Other than some minor porosity and pitting, the dye inspection did not reveal any indication of cracks.

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