Extended Storage of High Burn-up Fuel Cask R&D Project – 16591

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ABSTRACT

Under contract by EPRI and DOE, AREVA Federal Services LLC (AFS) is leading a team consisting of AREVA Inc. and Dominion Virginia Power (Dominion) to develop and conduct a full-scale confirmatory Research project with HBU fuel. A test plan was developed using an existing AREVA Transnuclear (TN) TN-32 bolted storage cask with a modified, specially instrumented lid to be engineered and then loaded with multiple cladding types of HBU pressurized water reactor (PWR) UNF from Dominion's North Anna Power Station (this modified cask is identified as TN-32B). Seven specially designed thermocouple lances, each containing nine detectors, will be inserted into the designated fuel assembly guide tubes through the modified cask lid. The loaded cask with the monitoring system will be placed into dry storage on the existing North Anna Independent Spent Fuel Storage Installation (ISFSI) pad for a period of extended monitoring. In addition, design modifications to the lid have been incorporated to permit periodic gas sampling of the cask internals during the storage period on the ISFSI pad. The fuel selected for this research project ranges in average assembly burnup between 50 GWD/MTU to 67 GWD/MTU. The instrumentation used to collect the thermal data is very similar to incore thermocouple detectors used at nuclear power plants and is considered very reliable for this application. Prior to cask loading at North Anna, a series of "fit up" tests will be performed at the fabricator to ensure proper alignment, fit and function of the modified cask and related instrumentation and equipment.

INTRODUCTION

Presently, commercial nuclear reactors are producing primarily High Burn-up (HBU) spent/used nuclear fuel (UNF) which, after >5 years of cooling in a spent fuel pool, can be placed into dry storage systems. HBU is defined as greater than 45 gigawatt-days per metric ton uranium (GWd/MTU). Long-term storage and transportation of HBU UNF have been identified as configurations that would benefit from the collection of *in-situ* data, which can be utilized as confirmatory data for the demonstration of continued safe HBU fuel storage and transportation. In particular, a full-scale field demonstration of an instrumented storage cask loaded with HBU fuel would provide data likely confirming the expected and modeled behavior of the HBU UNF in the storage and transportation configurations. The Department of Energy (DOE) and Nuclear Regulatory Commission (NRC) have performed assessments focusing on long-term aging issues important to the performance of the structures, systems, and components of the dry storage systems for UNF. Some technical issues and research and data needs emerged from these assessments, many focused on the long term behavior of HBU UNF. Industry and DOE determined that a large scale cask research and development project using a commercially utilized and representative dry storage system loaded with HBU UNF and augmented by laboratory-scale experiments would be beneficial in addressing the technical issues identified in these assessments for the long term behavior of HBU UNF.

In 2012, DOE made the decision to solicit proposals from industry to develop a R&D Project using the science-based, engineering-driven approach outlined herein. The result of that solicitation process was the award of a contract to an industry team, led by Electric Power Research Institute (EPRI), to develop a Cask R&D Project using high burn-up UNF. The Test Plan for the Cask R&D Project is the subject of this paper.

Under contract by EPRI and DOE, AREVA Federal Services LLC (AFS) is leading a team consisting of AREVA Inc. and Dominion Virginia Power (Dominion) to develop and implement a test plan to conduct a full-scale confirmatory Research project with HBU fuel. A test plan was developed using an existing AREVA Transnuclear (TN) TN-32 bolted storage cask with a modified, specially instrumented lid to be engineered and then loaded with multiple cladding types of HBU pressurized water reactor (PWR) UNF from Dominion's North Anna Power Station (this modified cask is identified as TN-32B). Seven specially designed thermocouple lances, each containing nine detectors, will be inserted into the designated fuel assembly guide tubes through the modified cask lid. The loaded cask with the monitoring system will be placed into dry storage on the existing North Anna Independent Spent Fuel Storage Installation (ISFSI) pad for a period of extended monitoring. In addition, design modifications to the lid have been incorporated to permit periodic gas sampling of the cask internals during the storage period on the ISFSI pad.

Other than normal, onsite cask transfer from the plant to the ISFSI, no public transportation modes are necessary. All UNF assemblies to be used for the research project are currently stored in the North Anna Power Station spent fuel pool (SFP) and can be loaded into the cask using approved cask loading procedures. All of the fuel assemblies to be used in the research project will have burn-ups in excess of 50 GWd/MTU (average assembly burn-ups will range from 50 to 67 GWd/MTU) for each of the following three cladding types: standard Zircaloy-4, Zirlo™, and M5™.

With design and analysis support from AREVA TN and AFS, Dominion has developed and submitted to the NRC for review and approval, a license amendment request (LAR) to allow use of the cask at North Anna under its site-specific ISFSI license. The LAR includes all the basic design features of a TN-32B cask as well as the planned fuel payload, the analyses supporting the fuel payload, and the instrumentation and test.

Based on existing data, models, and experimental results, long-term safe storage of HBU UNF is possible and the information to be gained through this research project will help validate and solidify the technical bases for this argument. DOE, EPRI, NRC, and other U.S. and international organizations have collected data on low burn-up fuel over several decades, and on HBU fuel for over a decade, such that a database of low and high burn-up UNF properties already exists. Furthermore, DOE, EPRI, and several organizations outside the U.S. are continuing to collect high burn-up UNF data. Nevertheless, the NRC has asked applicants for dry storage system license renewals for information on the condition of HBU UNF after the initial 20 year licensing period. Thus, to support these license renewal activities for the extended storage of HBU UNF, the NRC supports the development of a HBU Research program to provide data confirming the data collected by DOE, EPRI, et al. Along these lines, NRC also provided some considerations for such a program [NRC 2013] to ensure appropriate support is provided to the license renewals.

In combination with the growing database on high burn-up UNF properties, a HBU Research program using high burn-up UNF — like that performed using low burn-up UNF — could provide considerable information and confirmation of analyses to address NRC's questions. The combination of the existing and future data and the results of the HBU Research program will:

- Confirm some of the bases for the development of aging management plans (AMPs) after the initial storage periods
- Provide confirmatory data for multiple high burn-up license renewal applications expected in the next decade, such as:

  2012: Prairie Island TN-40; Calvert Cliffs NUHOMS®
  2015: Transnuclear NUHOMS® 1004 design
  2020: NAC-UMS; Holtec HI-STORM designs

- Provide confidence in the ability to transport UNF prior to shipment to a consolidated storage, reprocessing/recycling, or permanent disposal facility.

DESCRIPTION AND DISCUSSION

Inventories of Used Nuclear Fuel

Due to continued delays in the introduction of reprocessing or permanent disposal in most countries that operate nuclear power plants, the need for longer-term storage of UNF is increasing worldwide. The figure below is a forecast of the U.S. inventory of UNF. At present, none of the UNF or the high-level radioactive waste (HLW) generated from reprocessing of UNF has been disposed, as no UNF or HLW permanent disposal facility exists. Hence, 100 percent of the UNF and HLW remain in storage. The original assumption was that UNF would be transferred from the pools to a reprocessing facility before the pools reached their capacity. However, changes in the economics and national policies regarding reprocessing resulted in much more limited deployment of reprocessing worldwide. For countries without access to reprocessing or a centralized storage facility, such as the U.S., nuclear utilities have been forced to continue onsite storage of growing inventories of UNF. Most utilities facing limited SFP storage capacity initially re-racked their pools to increase capacity and at present, the majority of the nuclear plants in the U.S. have re-racked their pools at least once. However there are limits to the re-racking that can be performed in the SFPs and many reactors have reached these limits and are now using dry storage for UNF. Since most of the UNF burned in the reactors are high burn-up fuel, the objective of this program is to collect confirmatory data for the long term storage of this UNF.

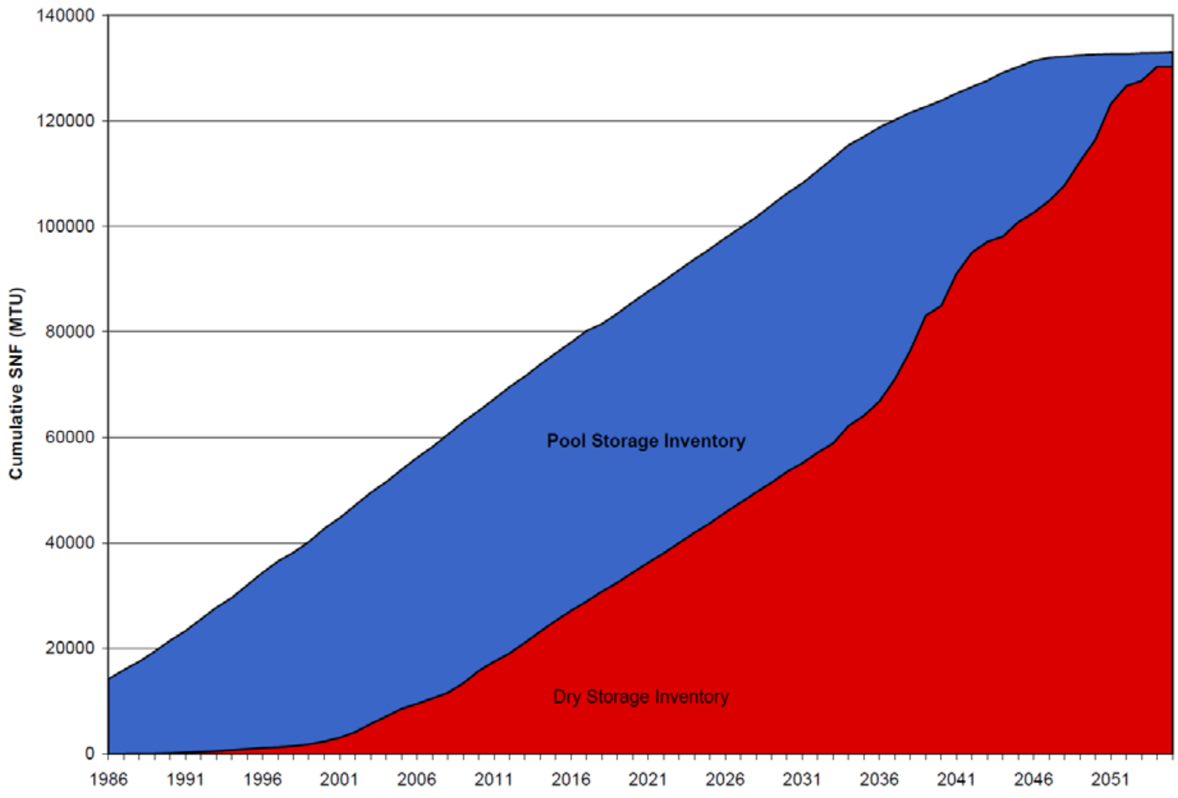

Fig. 1. Projected UNF Inventory in Wet and Dry Storage in the U.S. [1]

Project Overview

The HBU Cask R&D Project has been successfully underway since 2013, and is on track to complete its stated goals. Below are the key millstones and status for the project to date:

2013:

- Prepare the Draft Test Plan - *complete*
- Seek public comments on the Draft Test Plan - *complete*

2014:

- Establish the Final Test Plan - *complete*
- Complete the design of the modified bolted lid - *complete*
- Begin preparation of the storage Design and Licensing Basis Document (DLBD) - *complete*
- Complete title and liability transfer documents for sister rods - *complete*

2015:

- Extract sister rods from of the high burn-up assemblies - *complete*
- Complete the DLBD - *complete*
- Submit the storage license application to the NRC- *complete*
- Order long lead material in preparation for fabrication of hardware - *in progress*

2016:

- Begin modifications to the Research cask lid

- Fabricate all components needed for project (thermocouples, funnel guides)
- Address NRC requests for additional information
- Perform fit-up testing of the modified lid, Research cask, and instrumentation
- Ship the Research cask including the modified lid to North Anna

2017:
- Dominion will obtain storage license from NRC (tentative, pending NRC review)
- Perform dry runs
- Load the Research cask and begin temperature and gas data collection during the drying process
- Move the loaded Research cask to the North Anna ISFSI

2018:
- Continue taking periodic temperature measurements of the stored fuel
- Complete a limited number of calculations to support a future transportation license submittal

2018 to the end of the storage period:
- Continue taking periodic temperature measurements

End of the storage period:
- Without opening the cask, prepare the cask for transport to an offsite Fuel Examination Facility
- Ship the Research cask to the Fuel Examination Facility
- Open the Research cask and visually examine the fuel
- Extract high burn-up rods for subsequent examination
- Conduct non-destructive and destructive examinations of the rods at a national laboratory

Fuel Selection

The high burnup assemblies planned for demonstration purposes will range in average assembly burnup between 50 GWD/MTU to 67 GWD/MTU. Bear in mind that individual rod average burnups will be higher. The capability to load a full complement of 32 high burn-up fuel assemblies in accordance with the cask thermal analysis, criticality analysis, and regulatory requirements has been determined. It was determined that poison rods are needed to meet the regulatory criticality limits. The following criteria was used to select fuel assemblies to be used in the Research.

Cask:
- All fuel shall be intact – no structural defects or open holes;
- For those assemblies susceptible to bulge joint corrosion, those susceptible assemblies to be used in the project will have been repaired;
- The assemblies will be free of envelope violations that prevent the fuel assembly from being inserted into the cask cell (e.g., torn grid straps, debris, or assembly distortion), and unusual corrosion or crud;
- The combination of assemblies to be used in the Cask will not result in any cladding temperatures exceeding 400°C

Research Cask and Modified Lid

In order to obtain the desired thermal data, the TN-32B cask lid will be modified to accept seven thermocouple lances that will penetrate the lid. The lances are sealed with closure assemblies that are connected to the Cask's overpressure (OP) system. The OP system provides indication of the lid containment seal's integrity. The radial placements of the thermocouple detectors are shown in the figures below. The locations are based upon thermal modeling performed by the national labs, and correspond to the areas of greatest scientific value for confirmatory data used in the models.

Fig. 2. TN-32B Cask at Fabricator

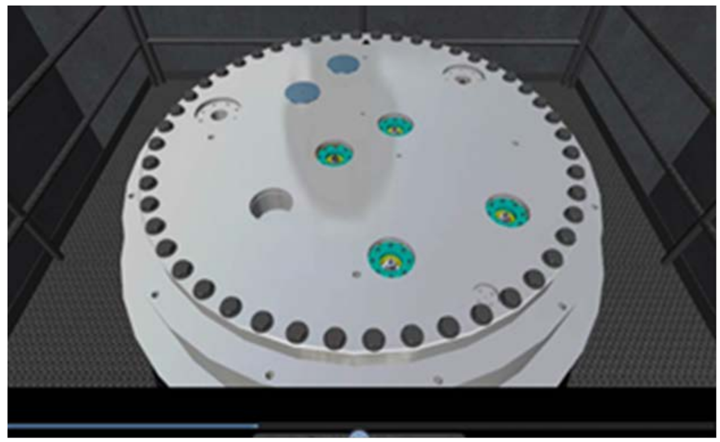

Fig. 3. Graphic of Modified Lid with Four Lances Inserted

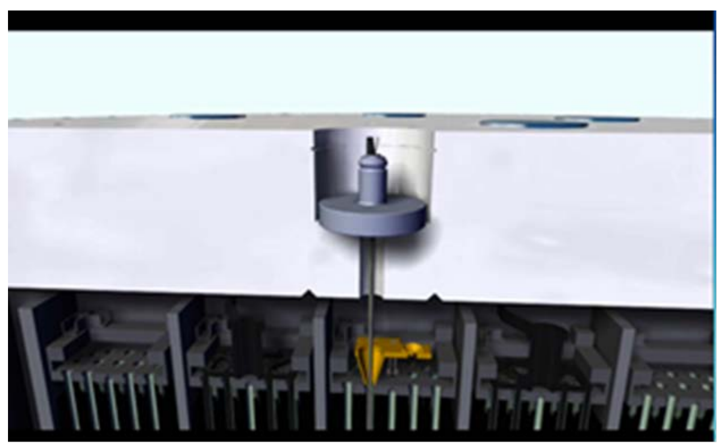

Fig. 4. Cross-sectional View of the Lance and Seal Assembly Inserted

The OP tank provides the monitoring gas pressure to the inter-seal space. Recognize that the TN-32B is a single lid cask and does not have a direct monitored penetration to the cask cavity. Instead, the pressure is monitored between the required dual metallic O-ring seals (much like any other bolted lid cask design). The inter-seal pressure on the TN-32B is maintained at a higher pressure than the cask cavity pressure such that if the inter-seal pressure (from the OP tank) decreases beyond a certain set point, an alarm is received indicating a potential problem with a seal. By Technical Specifications for the existing TN-32 casks at North Anna, the inter-seal pressure and the pressure switches undergo periodic surveillance at three-year intervals. This is expected to also be the case for the cask.

A data logger will be contained in a weatherproof box mounted on the side of the cask. The logger would digitally record temperature from the thermocouples at specified frequencies. The logger will be powered by battery with a solar collector to maintain the battery charge.

The design and selection of the instrumentation and supporting equipment for the project is based on many years of performance data at operating nuclear power plants as part of the station's in-core instrumentation. The temperatures, pressures, radiation doses, and other environmental conditions encountered during reactor operations are easily greater than those that the instrumentation will be subjected to in the Research Cask Project. Historical data from usage of similar equipment at numerous operating commercial nuclear power stations provides documented evidence indicating that a functional lifespan of at least 10 years is reasonable. After fabrication of the thermocouples, extensive testing and qualification of the instruments is performed to ensure it meets the required specifications. Testing and qualification of the instrumentation includes:

- Physical inspection
- Radiography
- Heat treatment (anneal)
- Hydrostatic testing
- Electrical testing

Placement of Instrumentation Into the Cask

A guide fixture will be used to ensure proper alignment and to avoid damage to either the fuel or the thermocouples. The figure below provides a conceptual means to aid in the insertion of the thermocouple lance into the guide tube. The guide will be designed for ease of installation using remote tooling. Prior to deployment at the North Anna Power Station, fit-up testing and training will be conducted to demonstrate that the equipment will function as designed and operators and technicians are proficient using the equipment. This evolution is very important to ensure the planned methodology, associated procedures, and training will result in a successful execution of this critical step. It is also important that the host site have confidence in the approach prior to deployment to their plant. As low as reasonably achievable (ALARA) considerations are also a major factor in the equipment design and operational procedures used for the installation of the thermocouple into the assemblies. Careful design and fit-up testing using proven ALARA techniques will minimize worker dose.

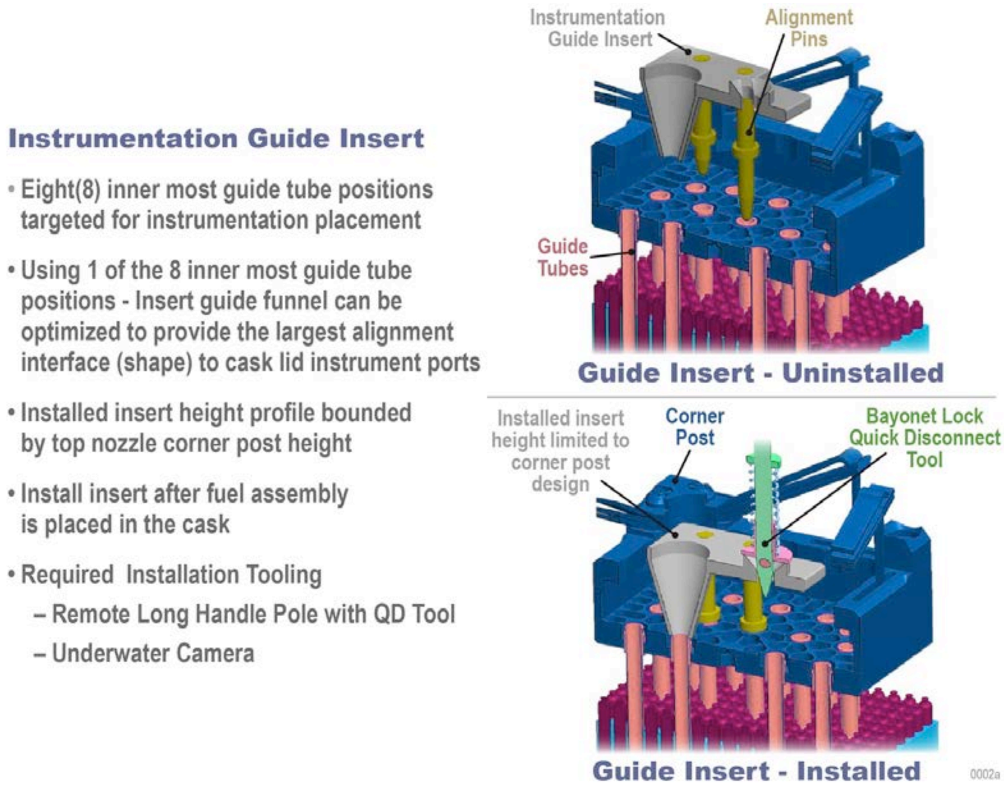

Fig. 5. Instrumentation Guide Insert Installation Diagram

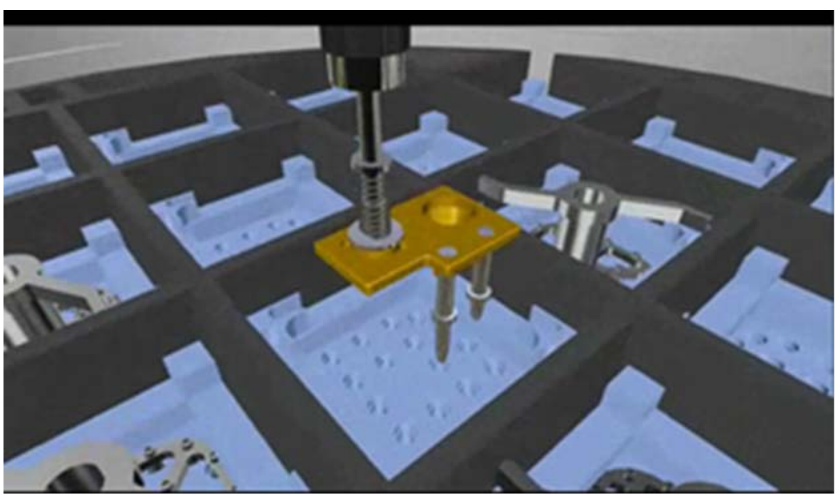

Fig. 6. Funnel Guide Being Lowered Into Position

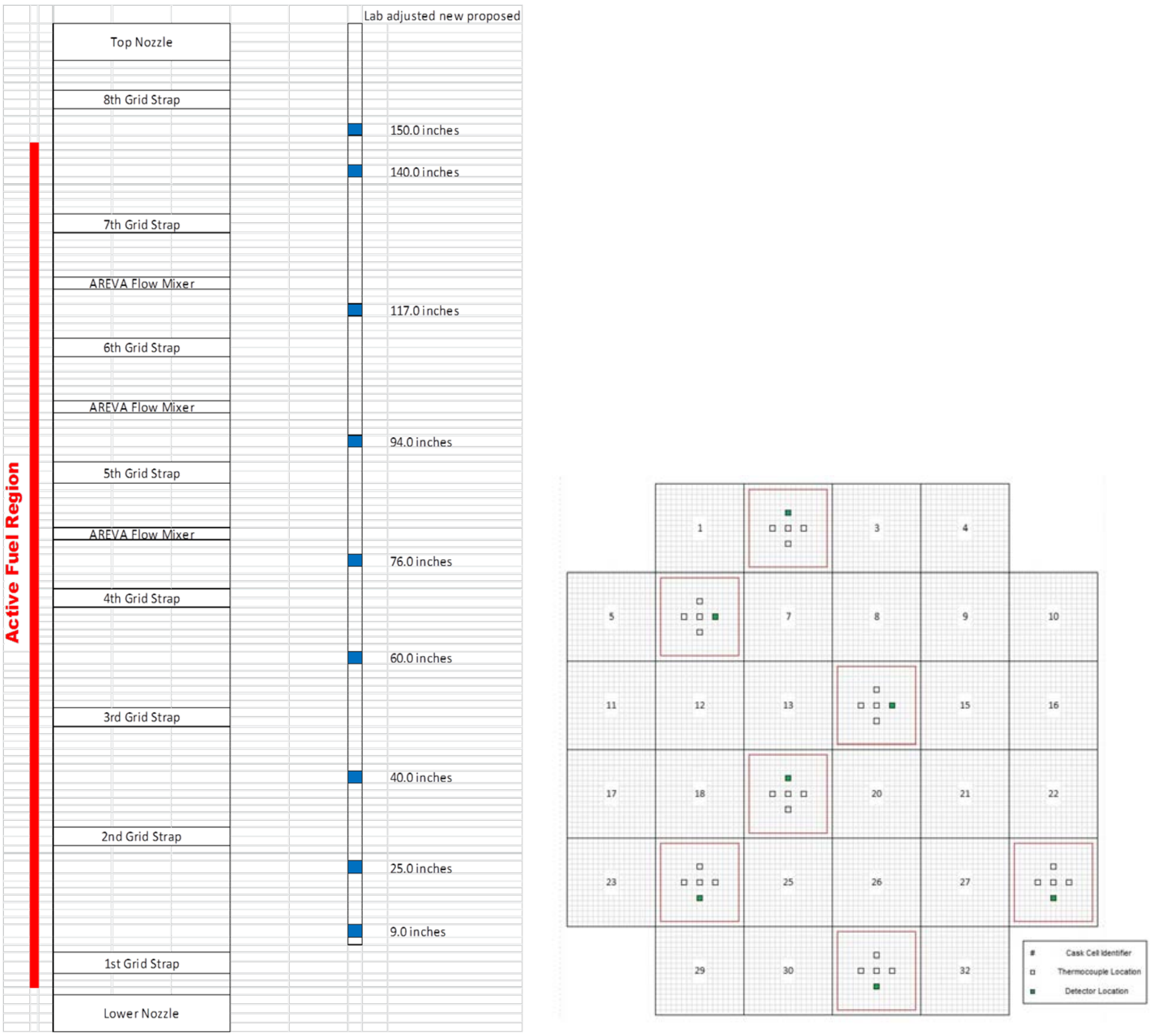

Fig. 7. Axial and Radial Locations of the Thermocouple Detectors

Planned Measurements

- A total of 63 thermocouples (e.g., 7 radial and 9 axial locations) – measurements will be recorded by the data logger system
- Site ambient conditions will be taken from the station's meteorological system
- Gas sampling and analysis during the first two weeks after cask drying and helium backfilling will be accomplished via grab samples and analysis at an onsite laboratory prior to moving the Research cask to the pad.

Frequency of Measurements

It is important to collect data with a frequency sufficient to accomplish the Research Cask Project objectives. While data collection frequency will vary depending on the rate of change of the variable during the period of the measurement, no need for continuous data collection is foreseen. The proposed data collection frequency and the rationale for the proposed data collection frequency are as follows:

Temperature Measurements

- During the initial cask drying process: every minute.
- Provide data for thermal models during the larger temperature transients during the drying process.
- Measure peak temperatures and time at peak temperature to support assessments of the degree of hydride reorientation.

During the long-term storage period, minimum of twice per day—preferably near the time of maximum and minimum daily ambient temperature.

Data collection at this frequency will also provide information on how cask gas (and indirectly, fuel cladding) temperatures are affected by daily and seasonal temperature fluctuations and other ambient conditions (rain, snow, and cloud cover).

Data collection at this frequency will provide information on high burn-up cladding time at temperature that will provide input to hydride reorientation, ductility recovery, and creep behavior.

Gas Pressure and Composition Measurements

- First two weeks: two times per week.
- Gas sampling in the first two weeks immediately following loading will provide the maximum data value as both potential rod failure and conversion of any residual water to the gas phase will likely occur either during or almost immediately after the cask drying process.
- Gas pressure measurements during the first two weeks will provide an indication that all seals and gas-sampling procedures are functioning as predicted.
- Long-term storage period: periodic cask cavity gas pressure sampling is contemplated but will require NRC approval.

Significant changes in gas composition, if they occur, will most likely occur during the first two weeks after drying. Furthermore, due to the design feature of maintaining a higher helium pressure between the inner and outer seals, no oxygen ingress into the cask cavity will be possible.

Detailed system operational procedures and associated training will be developed and implemented in accordance with the host site’s programmatic requirements. In addition, procedures and training requirements governing the inspection, maintenance, repair, and calibration requirements of the instrumentation and related equipment will also be developed and implemented. The project team has the ability to change the frequency of the temperature data collection throughout the course of the storage period.

CONCLUSIONS

This High Burn-up Cask R&D Project will provide important, confirmatory data to be used in conjunction with the modeling and experimental data that currently exist, along with additional modeling, separate effects testing, and small-scale testing that DOE has planned for the near future. With confirmatory data from the Cask R&D Project, the relevance of the present and future models and tests can be assessed. Assuming the validity of the relevant models, separate effects tests (SETs), and small-scale tests (SSTs) are confirmed by the Cask R&D Project, then a higher degree of confidence in these models and tests can be obtained. Lower cost models, and accelerated SETs and SSTs can explore a wider range of conditions that may occur for the range of fuel types and storage conditions currently in use, and planned for future storage followed by transportation. Hence, the Cask R&D Project will provide the platform for these models and tests to supply a large amount of data relevant to the assessment of the safety of long-term storage followed by transportation for HBU UNF.

REFERENCES

1. K. Waldrop, *Impacts Associated with Transfer of Spent Nuclear Fuel from Spent Fuel Storage Pools to Dry Storage After Five Years of Cooling, Revision1, #1025206, Final Report,* Figure 1-2 (2012).

ACKNOWLEDGEMENTS

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