A3.0 HIGH BURNUP FUEL MONITORING PROGRAM

The Prairie Island ISFSI provides for long-term dry fuel interim storage for High Burnup spent fuel assemblies, i.e., fuel assemblies with discharge burnups greater than 45 GWD/MTU, until such time that the spent fuel assemblies may be shipped off-site for final disposition. The cask system presently utilized at the Prairie Island ISFSI for the storage of High Burnup spent fuel is the Transnuclear TN-40HT which has a 40 fuel assembly capacity and is designed for outdoor storage. The first High Burnup fuel assembly was placed into storage operation at the Prairie Island ISFSI in April of 2013.

The Aging Management Review of the high burnup fuel spent fuel assemblies in a dry inert environment did not identify any aging effects/mechanisms that could lead to a loss of intended function. However, it is recognized that there has been relatively little operating experience, to date, with dry storage of high burnup fuel. Reference A5.8 provides a listing of a significant amount of scientific analysis examining the long term performance of high burnup spent fuel that provides a sound foundation for the technical basis that long term storage, i.e., greater than 20 years, may be performed safely and in compliance with regulations. However, it is also recognized that scientific analysis is not a complete substitute for confirmatory operating experience. Therefore, the purpose of the High Burnup Fuel Monitoring Program is to confirm that the High Burnup Fuel Assemblies' intended function(s) are maintained during the period of extended operations.

A description of the High Burnup Fuel Monitoring Program is provided below. Although the program is a confirmatory program, the description below uses each attribute of an effective AMP as described in NUREG-1927 for the renewal of a site-specific Part 72 license to the extent possible. In addition to the ten elements called for in NUREG-1927, the program includes an eleventh element, Toll Gate Assessments. This element is intended to provide periodic assessments of available information relative to the storage of high burnup spent fuel.

A3.1 Scope of Program

A3.1.1 NUREG-1927 Program Element

NUREG-1927 Program Element 1, Scope of the Program, (Reference A5.1) states "The scope of the program should include the specific structures and components subject to an AMR."

A3.1.2 PINGP Program Element

The High Burnup Fuel Monitoring Program relies upon the joint Electric Power Research Institute (ERPI) and Department of Energy's (DOE) "High Burnup Dry Storage Cask Research and Development Project" (HDRP) to monitor the condition of high burnup spent fuel assemblies in dry storage as a surrogate program for the high burnup fuel being stored at the Prairie Island ISFSI.

The HDRP is a program designed to collect data from a spent nuclear fuel dry storage system containing high burnup fuel. The program entails loading and storing a TN-32 bolted lid cask (the Research Project Cask) with intact high burnup spent nuclear fuel with four different kinds of cladding (including cladding types used at the Prairie Island Nuclear Generating Plant) at Dominion Virginia Power's North Anna Power Station. At the end of a long-term storage period, which may be up to 10 years or longer, the Research Project Cask will be transported to an off-site Fuel Examination Facility where the cask will be reopened and the fuel examined.

The scope of the High Burnup Fuel Monitoring Program includes those activities outlined in the "High Burnup Dry Storage Cask Research and Development Project Final Test Plan", February 27, 2014, (HDRPTP) prepared by the Electric Power Research Institute.

1) Monitoring temperatures inside and outside the cask.
2) Perform non-destructive and destructive examinations of sister rods to those in the Research Project Cask. These examinations include:
    a) Visual exams
    b) Cladding profilometry
    c) Rod internal pressure and content
    d) Hydride content and orientation
    e) Cladding mechanical testing
3) At the end of the long-term storage process, perform similar examinations of rods from the Research Project Cask.

A3.2 Preventive Actions

A3.2.1 NUREG-1927 Program Element

NUREG-1927 Program Element 2, Preventive Actions, (Reference A5.1) states "Preventive actions should mitigate or prevent the applicable aging effects."

A3.2.2 PINGP Program Element

The High Burnup Fuel Monitoring Program consists of temperature monitoring, non-destructive examinations, and destructive examinations of fuel rods to confirm there is no degradation of a high burnup fuel assembly that would result in a loss of their intended function(s). No preventive or mitigating attributes are associated with these activities.

A3.3 Parameters Monitored or Inspected

A3.3.1 NUREG-1927 Program Element

NUREG-1927 Program Element 3, Parameters Monitored or Inspected, (Reference A5.1) states "Parameters monitored or inspected should be linked to the effects of aging on the intended functions of the particular structure and component."

A3.3.2 PINGP Program Element

The parameters monitored by the High Burnup Fuel Monitoring Program are outlined in the HDRPTP. The principle aging effect being monitored is a change in material properties, e.g., ductility, of the cladding due to hydride reorientation. The intended functions of the fuel cladding that are being monitored include:

- Maintains a pressure boundary (PB)
- Provides structural/functional support (SS)

These functions combine to comply with regulations regarding the protection against degradation that leads to gross ruptures and the retrievability of the fuel.

The hydride reorientation aging mechanism is dependent upon the fuel cladding temperatures during the loading and storage operations. Hence the HDRPTP calls for monitoring of cask internal temperatures during loading and storage operations. These temperatures may then be used to infer the fuel cladding temperatures. The destructive examinations at the off-site Fuel Examination Facility will be used to determine the hydride content and orientation within the fuel cladding. The destructive examinations will also include fuel cladding ductility testing.

A3.4 Detection of Aging Effects

A3.4.1 NUREG-1927 Program Element

NUREG-1927 Program Element 4, Detection of Aging Effects, (Reference A5.1) states “Detection of aging effects should occur before there is a loss of any structure and component intended function. This includes aspects such as method or technique (i.e., visual, volumetric, surface inspection), frequency, sample size, data collection, and timing of new or one-time inspections to ensure timely detection of aging effects.”

A3.4.2 PINGP Program Element

The use of information from the surrogate program is an acceptable method to ensure that the potential aging effects of high burnup fuel are identified and managed prior to the loss of intended functions.

The HDRPTP calls for monitoring of cask internal temperatures during the initial cask drying process at one minute intervals. During the long-term storage period temperatures would be collected twice a day. These frequencies will provide data for thermal models during the larger temperature transients encountered during the drying process as well as cladding time at temperature taking into account daily and seasonal temperature fluctuations. This information will provide inputs to the evaluation of hydride reorientation and ductility testing.

The destructive examinations are intended to be performed after a long-term storage period which may be up to 10 years or longer. These examinations will provide a direct indication of the degree of hydride reorientation and ductility of the cladding.

The schedule for the HDRP as outlined in the final test plan calls for the Research Project cask to be loaded and placed in storage in 2017. Thus, information from the destructive examination of the fuel placed into storage would not be expected until after 2027. This schedule provides sufficient time to obtain, evaluate and take any necessary action prior to the high burnup fuel being stored at the Prairie Island ISFSI beyond 20 years. The “toll gate” assessments described in program element A3.11 assure that information from the HDRP and other relevant sources will be regularly conducted in a timely manner.

A3.5 Monitoring and Trending

A3.5.1 NUREG-1927 Program Element

NUREG-1927 Program Element 5, Monitoring and Trending, (Reference A5.1) states "Monitoring and trending should provide for prediction of the extent of the effects of aging and timely corrective or mitigative actions."

A3.5.2 PINGP Program Element

HDRPTP calls for submitting progress reports on a semi-annual basis while the Research Project Cask is in dry storage. It is expected that these reports will include trends of cask internal temperatures which may be used to infer the trend of the fuel cladding temperatures. As previously mentioned the hydride reorientation aging mechanism is dependent upon the fuel cladding temperatures during the loading and storage operations.

The destructive exams are scheduled to occur after a period of long-term storage and are expected to provide information on the extent of the hydride reorientation mechanism and its effect on the ductility of the cladding ductility prior to the high burnup fuel being stored at the Prairie Island ISFSI beyond 20 years.

A3.6 Acceptance Criteria

A3.6.1 NUREG-1927 Program Element

NUREG-1927 Program Element 6, Acceptance Criteria, (Reference A5.1) states "Acceptance criteria, against which the need for corrective action will be evaluated, should ensure that the particular structure and component intended functions are maintained under the existing licensing-basis design conditions during the period of extended operation."

A3.6.2 PINGP Program Element

When information from the ductility testing of the fuel in the Research Project Cask becomes available, an Action Request will be initiated within the NSPM Corrective Action Program to perform a Condition Evaluation. The Condition Evaluation will determine if the results of the ductility testing indicate the need for corrective action to ensure that the fuel cladding will continue to perform its intended functions under the existing licensing-basis conditions.

A3.7 Corrective Actions

A3.7.1 NUREG-1927 Program Element

NUREG-1927 Program Element 7, Corrective Actions, (Reference A5.1) states "Corrective actions, including root cause determination and prevention of recurrence, should be timely."

A3.7.2 PINGP Program Element

Northern States Power Company – Minnesota (NSPM) has a single Corrective Action Program that is applied regardless of the safety classification of the structure or component. The Corrective Action Program requirements are established in accordance with the requirements of the NSPM Quality Assurance Topical Report and 10 CFR 50, Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants.”

The Corrective Action Program procedures require the initiation of an Action Request for actual or potential problems including failures, malfunctions, discrepancies, deviations, defective material and equipment, nonconformances, and administrative control discrepancies, to ensure that conditions adverse to quality, operability, functionality, and reportability issues are promptly identified, evaluated if necessary, and corrected as appropriate. Guidance on establishing priority and timely resolution of issues is contained within the Corrective Action Program procedure.

All corrective actions for deviating conditions that are adverse to quality are performed in accordance with the requirements of the Quality Assurance Program which complies with the requirements of 10 CFR 50, Appendix B. Any resultant maintenance, repair/replacement activities, or special handling requirements are performed in accordance with approved procedures. Corrective actions provide reasonable assurance that deficiencies adverse to quality are either promptly corrected or are evaluated to be acceptable. Where evaluations are performed without repair or replacement, engineering analysis reasonably assures that the intended function is maintained consistent with the current licensing basis. If the deviating condition is assessed to be significantly adverse to quality, the cause of the condition is determined and an action plan is developed to preclude recurrence. Corrective actions identify recurring discrepancies and initiate additional corrective actions including root cause analysis to preclude recurrence.

As stated above, when information from the ductility testing of the fuel in the Research Project Cask becomes available, an Action Request will be initiated within the NSPM Corrective Action Program. Actions that are required to resolve inspection findings will be tracked to completion and trended within the Corrective Action Program.

A3.8 Confirmation Process

A3.8.1 NUREG-1927 Program Element

NUREG-1927 Program Element 8, Confirmation Process, (Reference A5.1) states “The confirmation process should ensure that preventive actions are adequate and appropriate corrective actions have been completed and are effective.”

A3.8.2 PINGP Program Element

The confirmation process is part of the NSPM Corrective Action Program and ensures that the corrective actions taken are adequate and appropriate, have been completed, and are effective. The focus of the confirmation process is on the follow-up actions that must be taken to verify effective implementation of corrective actions. The measure of effectiveness is in terms of correcting the adverse condition and precluding repetition of significant conditions adverse to quality. Procedures include provisions for timely evaluation of adverse conditions and implementation of any corrective actions required, including root cause evaluations and prevention of recurrence where appropriate. These procedures provide for tracking, coordinating, monitoring, reviewing, verifying, validating, and approving corrective actions, to ensure effective corrective actions are taken.

The Corrective Action Program is also monitored for potentially adverse trends. The existence of an adverse trend due to recurring or repetitive adverse conditions will result in the initiation of an Action Request.

A3.9 Administrative Controls

A3.9.1 NUREG-1927 Program Element 9, Administrative Controls

NUREG-1927 Program Element 9, Administrative Controls, (Reference A5.1) states "Administrative controls should provide a formal review and approval process."

A3.9.2 PINGP Program Element

The NSPM Quality Assurance Program, associated formal review and approval processes, and administrative controls applicable to this program and Aging Management Activities, are implemented in accordance with the requirements of the NSPM Quality Assurance Topical Report and 10 CFR Part 50, Appendix B. The administrative controls that govern AMAs at PINGP are established in accordance with the PINGP Administrative Control Program and associated Fleet Procedures.

A3.10 Operating Experience

A3.10.1 NUREG-1927 Program Element

NUREG-1927 Program Element 10, Operating Experience, (Reference A5.1) states "Operating experience involving the AMP, including past corrective actions resulting in program enhancements or additional programs, should provide objective evidence to support a determination that the effects of aging will be adequately managed so that the structure and component intended functions will be maintained during the period of extended operation."

A3.10.2 PINGP Program Element

It is recognized that there has been relatively little operating experience, to date, with dry storage of high burnup fuel. Hence this element is focused on the principle aging effect being monitored, e.g., ductility, of the cladding due to hydride reorientation.

Ductility tests performed at the Argonne National Laboratory

Reference A5.7 describes the results of tests performed by Argonne National Laboratory that examined the possible effects of hydride reorientation on high burnup fuel cladding. The tests involved cladding segments of high burnup spent fuel rods that were subjected to a temperature transient to simulate bounding drying and storage operations. After the temperature, the radial-hydride reorientation was characterized and ring compression tests were performed. Test results show that the trend of the data generated clearly indicates that failure criteria for high-burnup cladding need to include the embrittling effects of radial-hydrides for drying-storage conditions that are likely to result in significant radial-hydride precipitation.

The cladding material used in the test is the same as most of the high burnup fuel cladding stored at the Prairie Island ISFSI. While the burnup of the cladding segments was higher than that allowed to be stored at the Prairie Island ISFSI it is reasonably close. The temperature transient heated the cladding to 400 °C which corresponds to the cladding temperature limit for the fuel stored at the Prairie Island ISFSI. The cooldown rate was conservatively slower than what would be expected for the fuel stored at the Prairie Island ISFSI. For these reasons the cladding used in the ring compression test should be a reasonable representation of the potential condition of the cladding of the fuel stored at the Prairie Island ISFSI.

While the tests were performed on defueled irradiated fuel rod segments, there was no information in Reference A5.7 of the potential gap between the cladding and the fuel pellets. The size of this gap and the presence of the fuel pellets could have a significant impact on the ductility of a fuel rod to pinch type loads. Thus, the results of the ring compression tests may not be applicable to fuel rods in dry storage.

The ring compression test was used as a ductility screening test and to simulate pinch-type loading during cask transportation or cask drops from rod/grid-spacer and rod/rod mechanical interactions. This type of pinch load would occur when a cask is dropped horizontally or when a cask tips over. The current licensing basis for the cask stored at the Prairie Island ISFSI is that the loaded casks are always in the vertical position and cask tip over events are not credible. Thus, the results of the ring compression tests may not be applicable to fuel rods stored at the Prairie Island ISFSI.

A3.11 Toll Gate Assessments

A3.11.1 NUREG-1927 Program Element

It is understood that licensees will have formal operating experience assessment programs that evaluate the impact of applicable industry operating experience to their operation. Hence, NUREG-1927 does not include a separate program element for a formal periodic assessment of any new or additional information. When NUREG-1927 was finalized, the need to formally address degradation mechanisms characterized by little to no prior operating experience through future surrogate monitoring programs, such as the HDRP, was not anticipated. Given the unique nature of this confirmatory program, NSPM is electing to go beyond the guidance of NUREG-1927 and will periodically perform formal assessments of aggregated feedback from the HDRP, along with other information that may be available in the future at specific points in time during the period of extended operations. NSPM is aware that industry and NRC are engaged in public discussions about augmenting NUREG-1927 for this purpose and that the term “toll gates” has been coined to describe such intended periodic assessments. Accordingly, this element is being added to the program to describe specific periodic future assessments that will be conducted as part of this confirmatory program.

A3.11.2 PINGP Program Element

Formal evaluations of the aggregate feedback from the HDRP and other sources of information will be performed at the specific points in time during the period of extended operation delineated in the table below. These evaluations will include an assessment of the continued ability of the High Burnup Fuel Assemblies to continue to perform their intended function(s) at each point.

Toll Gate	Year*	Assessment
1	5	Evaluate, if available, information obtained from the HDRP loading and initial period of storage (during which the highest temperatures are likely to be observed) along with other available sources of information. If the HDRP cask has not been loaded at this point and no other information is available, move the next Toll Gate assessment forward 5 years.
2	15	Complete any outstanding evaluations from Toll Gate 1. Evaluate, if available, information obtained from the destructive examination of the fuel placed into storage in the HDRP along with other available sources of information. If the aggregate of this information confirms ability of the High Burnup Fuel Assemblies to continue to perform intended function(s) for the remainder of the renewal period, subsequent toll gate assessments may be cancelled. If the HDRP fuel has not been examined at this point and no other information is available, move the next Toll Gate assessment forward 5 years.
3	25	Complete any outstanding evaluations from Toll Gates 1 & 2 and evaluate any other new information. If the aggregate of this information confirms ability of the High Burnup Fuel Assemblies to continue to perform intended function(s) for the remainder of the renewal period, subsequent toll gate assessments may be cancelled. If the information is inconclusive, move the next Toll Gate assessment forward 5 years
4	35	Complete any outstanding evaluations from Toll Gates 1-3 and evaluate any other new information.

*Calculated from the effective date of the renewed license

At each of these toll gates, the impact of the aggregate feedback will be assessed and actions taken when warranted. The toll gates amplify the existing practice of continuously evaluating site-specific and industrywide operational experience for impacts on aging management. These evaluations will address any lessons learned and take appropriate corrective actions, including:

- Perform repairs or replacements
- Modify this confirmatory program in a timely manner
- Adjust age-related degradation monitoring and inspection programs (e.g., scope, frequency)

The above toll gates are not, by definition, stopping points. No particular action other than performing an assessment is required to continue cask operation. To proceed through a toll gate, an assessment of aggregated available operating experience (both domestic and international), including data from monitoring and inspection programs, NRC-generated communications, and other information will be performed. The evaluation will include an assessment of the ability of the High Burnup Fuel Assemblies to continue to perform their intended function(s) until the next toll gate is approached.

The above toll gates also represent formal opportunities for NSPM to take corrective actions, such as repairs or replacements, and to make adjustments to this program in support of operations through the period of extended operations. The evaluations and assessments will be retained as records within NSPM's record management system.

A5.0 References (Appendix A, Aging Management Program)

A5.1 NUREG-1927, *Standard Review Plan for Renewal of Spent Fuel Dry Cask Storage System Licenses and Certificates of Compliance*, March 2011.

A5.2 EPRI Report 1002882, *Dry Cask Storage Characterization Project, Final Report*, September 2002.

A5.3 Letter from D.A. Christian, Virginia Electric and Power Company to D.A. Cool (NRC), *Surry Independent Spent Fuel Storage Installation License Renewal Application*, dated April 29, 2002, ADAMS Accession Number ML021290068.

A5.4 Transnuclear Information Bulletin, April 2001.

A5.5 Letter from G. L. Stathes, Exelon Generation Company to Director Spent Fuel Project Office (NRC), *Submittal of Independent Spent Fuel Storage Installation (ISFSI) Cask Event Report*, dated December 01, 2010, ADAMS Accession Number ML110060275.

A5.6 American Concrete Institute, ACI 349.3R-96, *Evaluation of Existing Nuclear Safety-Related Concrete Structures*, January 1996.

A5.7 M.C. Billone, T.A. Burtseva, and R.E. Einziger, "Ductile-to-Brittle Transition Temperature for High-Burnup Cladding Alloys Exposed to Simulated Drying-Storage Conditions," in the Journal of Nuclear Materials, Volume 433, Issues 1–3, pages 431–448, February 2013.

A5.8 Letter from R. McCullum (NEI) to M. Lombard (NRC), dated March 22, 2013, "Industry Analysis and Confirmatory Information Gathering Program to Support the Long-Term Storage of High Burnup Fuel (HBF)," (ADAMS Accession No. ML13084A045).