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The Plan for a Long-term Storage Demonstration Test of Heavy Water Reactor Spent Fuel

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1. Introduction

Worldwide, as the dry storage of used nuclear fuel becomes increasingly prevalent, the focus of nations is shifting towards the long-term integrity maintenance of dry storage systems. The International Atomic Energy Agency (IAEA) conducts Collaborative Research Programs (CRPs) for the demonstration tests of used nuclear fuel. The participating countries in the IAEA joint research aim to enhance the acceptability of the safety of dry storage systems for used nuclear fuel. Therefore, for our country, which must prepare for large-scale dry storage of used nuclear fuel, technological development in this regard is essential. In line with this, the Korea Hydro & Nuclear Power (KHNP) is collaborating with the Canadian Nuclear Laboratories (CNL) on a project called 'Used Nuclear Fuel Long-Term Storage and Demonstration Test Technology (SSDT).' This project is scheduled to be conducted from around 2021 to 2027.

2. CNL'S Capabilities & Experience

CNL is a globally recognized combined Environmental Remediation Management (ERM) organization and premier Nuclear Science and Technology (S&T) Laboratory that has led support of the CANDU fleet for decades. CNL's capabilities range from decommissioning, to environmental remediation, waste management, long-term operations research and development, safety & licensing, and engineering. These capabilities are underpinned by the S&T laboratory as a technical authority and source of cross-cutting CANDU subject matter expertise. CNL has specific capabilities and experience relating to the SSDT Project Plan. CNL has a long history of dry storage spent fuel expertise. CNL has operated multiple CANDU prototype and test reactors at the Chalk River, Douglas Point, Gentilly, and Whiteshell sites, and has managed spent fuel and performed R&D for these sites. CNL also has a strong history of commercial R&D in the areas of spent fuel.

2.1 History of CNL's Long Term Dry Storage Experiments (DSE)

Among CNL's most prominent work in this area are the long term dry storage experiments ("Long Term DSE") which began at the CNL Whiteshell site in the 1970s. The Long Term DSE consists of three experiments, containing multiple bundles of spent fuel from the CANDU Pickering and Bruce reactor stations: (1) Easily Retrievable Basket (ERB), (2) Controlled Environment Experiment 1 (CEX-1), and (3) Controlled Environment Experiment 2 (CEX-2).

The DSE were started in the late 1970s and early 1980s to evaluate how spent fuel changes as a function of time in dry storage. Baseline Post-Irradiation Examination (PIE) was completed prior to placement in dry storage. Interim PIE was completed every 5-10 years via retrieving individual storage baskets in the Whiteshell Shielded Facilities (SF), opening the bolted lids on the baskets, retrieving the desired fuel, re-bolting the lid, and returning the baskets to the Whiteshell Concrete Canister Storage Facility (CCSF).

The main objective of the DSE is to assess the length of time that Zircaloy-clad UO2 fuel from multiple CANDU power reactors can be safely stored in dry conditions. The objective of this PIE campaign is to determine if any measurable changes to fuel condition attributable to time in dry storage occurred via detailed non-destructive and destructive PIE of select DSE fuel elements and comparison to measurements made on previously-examined DSE sister fuel elements (i.e., from the same irradiated fuel bundle).

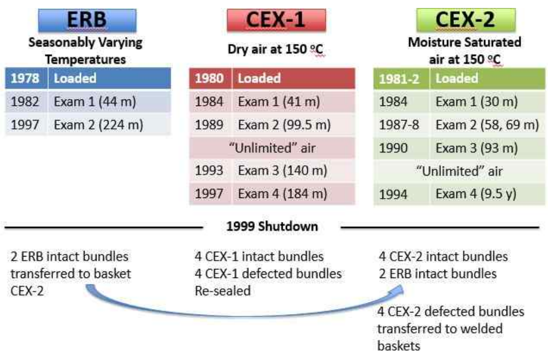

Fig. 1. Long Term DSE Pre & Post 1999 Shutdown Status – ERB, CEX-1, CEX-2

It has now been more than 20 years since the last PIE of DSE fuel. PIE now would more than double the length of storage time since the last PIE. This represents the longest dry stored CANDU fuel experiment in the world and is the longest running experiment of this type in the world. Performing PIE on this spent fuel can be used to represent spent CANDU fuel from CANDU stations across the world to provide data for safe long-term storage, transportation, and eventual disposal of spent CANDU fuel.

In terms of the irradiation conditions, the Pickering and Bruce fuel in the DSE is representative of typical power and burnup in a CANDU-6. The storage configuration of the DSE canisters is deemed to be representative of CANDU fuel dry storage conditions.

2.2 PIE Plan

Under current plans, CNL will be transporting all spent fuels from Whiteshell to Chalk River, over a distance of approximately 2,000 km, from 2022 to 2025 as part of decommissioning the Whiteshell site. By end of 2025, all the fuels will have been removed from Whiteshell and shipped to Chalk River in their current storage baskets. In Chalk River, the transported fuels will go into similar concrete silos, and will be stored in dry storage until retrieved and processed as required to meet disposal requirements planned in the 2030s.

In order to perform PIE of the long term DSE fuel before the 2030s, the DSE fuel of interest must be removed from its current storage basket. During previous PIE campaigns, the capability to remove fuel bundles from their storage baskets was provided by the Whiteshell hot cells. Due to accelerated decommissioning of the Whiteshell site, including the hot cells, it will not be possible to use this facility. Instead, a capability to remove fuel bundles from their storage baskets will need to be developed at the Chalk River hot cells after it arrives from Whiteshell in its current storage basket.

Of the long term DSE, the CEX-1 basket is the most readily accessible, contains fuel with the most previous PIE data, and continues to contain its original eight experimental bundles. It contains both intact and intentionally-defected fuel stored in air heated to 150℃ until 1999 when it was then exposed to seasonally-varying temperatures, thus providing a variety of options for bundle selection with significant historical data available. It is therefore recommended as the primary candidate for PIE in this scope of work.

2.3 Scope of Work

CNL is therefore proposing to retrieve fuel from the CEX-1 basket at Chalk River (Activity 1) and to perform detailed non-destructive and destructive PIE of the fuel (Activity 2). The CEX-1 basket has two compartments, each with a bolted lid. One side has four intact bundles and one side has four intentionally defected bundles. It has been assumed two defected bundles and one intact bundle will be utilized for this work.

2.3.1 Activity 1

CNL will ship the CEX-1 basket to Chalk River as part of decommissioning the Whiteshell site, separately from this project.

For this project, CNL will procure a new flask and associated transfer equipment from a third party. The new flask will be small and light enough to place the CEX-1 basket into a Chalk River hot cell. The flask will be opened and the CEX-1 basket removed. The CEX-1 basket will be opened and the desired fuel bundles removed. As both intact and defected fuel bundles are desired, the CEX-1 basket will need to be flipped in order to access both ends. The reverse process will then be used to return the CEX-1 basket to storage at Chalk River.

There are no complete bundles in CEX-1, but there are several partial bundles with detailed PIE history from one or more fuel elements having been removed for previous PIE. These partial bundles will provide valuable information regarding the integrity of bundles and endplates, while also being easily matched against historical data from the same bundles.

2.3.2 Activity 2

Once the fuel arrives at Chalk River, the proposed PIE includes both non- destructive and destructive examination. A variety of analyses are envisioned to evaluate corrosion reactions of spent fuel and integrity of fuel cladding, these activities are outlined below. As indicated below, certain types of analyses are relevant only to defected fuel.

Table I: Options for PIE Tests

PIE Activity	*Defected Fuel*	*Intact Fuel*
Non-Destructive Examinations		
*Fuel Receipt & Identity Verification**	*1*	*1*
*Bundle Visual Examination & Sectioning**	*1*	*1*
Element Visual Examination	*22*	*22*
Fuel Element Weighing	*2*	*2*
Profilometry	*6*	*3*
Gamma Scanning	*4*	*2*
*Torque Testing***	*~30*	*~30*
Gas Puncture, Void Volume and Fission Gas Analysis	*1*	*4*
Destructive Examination Phase 1		
Ring Tensile Testing	*20*	*20*
Metallography and Ceramography	*5*	*5*
Hot Vacuum Extraction Mass Spectrometry (H/D Analysis)	*30*	*30*
Destructive Examination Phase 2		
SEM/X-Ray Diffraction	*3*	*-*
X-Ray Photoelectron Spectroscopy	*3*	*-*
Coulometric Titration (O/U Ratio)	*3*	*-*

3. Conclusions

In South Korea, dry storage facilities for spent nuclear fuel of the pressurized water reactor type have been in operation since the early 1990s. To renew the operating license for such facilities, it is necessary to demonstrate the integrity of the storage system and the spent nuclear fuel throughout the storage period. To achieve this, an initial characterization examination of the spent nuclear fuel must be conducted before implementing dry storage, verifying the integrity and identifying any potential defects.

To facilitate this, KHNP is planning Post-Irradiation Examination (PIE) tests in collaboration with Canada's CNL for the long-term integrity assessment of pressurized water reactor spent nuclear fuel.

For all the available fuel elements, CNL currently has data from approximately t=0 yr to t=20 yr, based on PIE completed on the long term DSE prior to Whiteshell site shutdown in 1999.

The additional data from performing this scope of work at approximately t=40 yr can be correlated with historical trends for the intact and defective fuel, and used to draw better conclusions about dry-stored CANDU fuel behavior from t=0 yr to t = 40 yr. The resultant PIE report will outline the

Results of the currently proposed PIE work as well as results from previous examinations, drawing conclusions where appropriate for trends observed on the dry stored fuel over the last ~40 years. This data can be used to develop a model to attempt to predict trends beyond 40 years, if desired.

The data obtained from the Post-Irradiation Examination (PIE) tests conducted by CNL will be utilized to support the renewal of the operating license for domestic dry storage facilities for spent nuclear fuel.

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