STATUS OF THE DEMONSTRATION IRRADIATION PROGRAM OF THE NEW FUEL BUNDLE CANFLEX-NU IN KOREA

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ABSTRACT

In the late part of 1999, the Korea Electric Power Corporation has initiated a program to use CANFLEX-NU(Natural Uranium) fuel in theWolsong Generating Station(WGS) - #1 which has been operating since 1983, because the CANFLEX could be used to recover some of a CANDU heat transport system operation margins that had decreased due to ageing. The Korea Ministry of Science and Technology (MOST) has recognized the successful demonstration irradiation of 24 CANFLEX bundles at the Pt. Lepreau Generating Station in Canada, as final verification of the CANFLEX design in preparation for full core conversion. Therefore, MOST has pushed and gave a financial support to a KEPRI/KAERI Joint Industrialization Program of CANFLEX-NU Fuel, which will be conducted for 3 years from 2000 November, to validate CANFLEX-NU fuel bundle performance in direct conditions of relevance under the Korean licensing requirements as well as to evaluate the fuel fabrication capability, and to produce a safety analysis report for the full-core implementation.

The economic benefits of CANFLEX-NU fuel are directly dependent on the thermalhydraulic performance. Switching from the existing 37-element fuel to the CANFLEX fuel will be largely driven by the economic benefits to be realized. Showing a positive result in the economic evaluation as well as successfully demonstrating the CANFLEX fuel irradiation in WGS-#1, the full-core implementation of the fuel at the WGS-#1 in Korea will proceed by starting the licensing process at around 2003 April because the safety report for the full-core conversion will be ready by 2003 March.

This paper describes the status of CANFLEX-NU fuel industrialization program in Korea, as well as the fuel design features. It summarizes the plan of CANFLEX-NU fuel demonstration irradiation at the WGS- #1 in Korea and the status of documentation for the demonstration irradiation as well as for the CANFLEX-NU full-core implementation.

1. INTRODUCTION

As a prime example of the results that can be achieved through collaborative ventures between Canada and Korea, the Korea Atomic Energy Research Institute (KAERI) and the Atomic Energy of Canada Limited (AECL) have pursued, since 1991, a collaborative program to develop, verify, and prove the new fuel bundle design, CANFLEX[1]-NU(Natural Uranium)[1] fuel which could likely counterbalance the adverse effects of ageing within the CANDU[2] heat transport system.

CANFLEX fuel has been verified through extensive testing by KAERI and AECL and has been critically reviewed under a Formal Design Review. KAERI prepared the CANFLEX-NU fuel design report for use of CANFLEX bundles in Korea and submitted it to the Korea Institute of Nuclear Safety (KINS) on 1996 July, to obtain approval of the fuel design and fabrication method, as part of the Korean licensing process. This approval was obtained from the Korea Ministry of Science and Technology (MOST) on 1999 August 6.

Following the Government approval of the CANFLEX-NU fuel design and fabrication method in Korea as well as the successful DI (Demonstration Irradiation) of CANFLEX-NU fuel in the Point Lepreau Generating Station (PLGS), the Electric Power Research Institute (KEPRI) and KAERI are jointly conducting a 3-year Industrialization Program for the use of CANFLEX-NU fuel in a CANDU 6 Wolsong Generating Station (WGS).

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1 CANFLEX® (CANDU Flexible Fuelling) is a registered trademark of Atomic Energy of Canada Limited(AECL) and Korea Atomic Energy Research Institute(KAERI).

2 CANDU®(Canada Deuterium Uranium) is a registered trademark of Atomic Energy of Canada Limited(AECL)

In this paper, the first will shortly describe the design features of CANFLEX fuel bundle. The rest of the Sections will describe the industrialization program of CANFLEX-NU fuel in Korea, covering the plan of the fuel DI in WGS-#1, the status of licensing documentation for the DI, the schedule of the DI and the full-core implementation.

2. DESIGN FEATURES OF CANFLEX FUEL BUNDLE

The 43-element CANFLEX fuel bundle assembly and its critical-heat-flux(CHF) enhancement appendages [1], as shown in Figure 1, offer higher operating and safety margins than current fuel, while maintaining full compatibility with operating CANDU reactors. It enables a higher power to be realized before CHF occurs, leading to a net gain in critical channel power (CCP) typically of 6 to 10% over the existing 37-element NU fuel. The greater element subdivision and the use of two element sizes lower the peak linear-element rating, and a more balanced radial power distribution [1, 2, 3]. The maximum linear element rating in a CANFLEX bundle is 20 % lower than that of a 37-element bundle, reducing the consequence of most design-basis accidents. Therefore, the bundle is well suited for the use of advanced fuel cycles, particularly those that can attain high fuel burnup. The higher operating and safety margins offer the potential of reactor power uprating, which would further increase the economic competitiveness of the CANDU reactor.

CANFLEX fuel has been designed to have hydraulic and neutronic characteristics that are similar to those of the existing fuel. This feature provides the operators with the ability to introduce CANFLEX bundles during normal on-power refuelling. No hardware changes are required to switch to CANFLEX fuel because CANFLEX fuel is fully compatible with existing fuel handling equipment [4]. Fuel channels containing both CANFLEX and 37-element fuel, in any combination that can occur with normal fuelling, have improved or unchanged operating margins. Transition to CANFLEX fuel can be gradual with no waste of existing fuel.

In addition, CANFLEX[1] also enables the introduction of advanced fuel cycles [5] such as slightly enriched uranium (SEU), recycled uranium (RU) and other fuel cycles into CANDU reactors, and provides enhanced performance relative to natural uranium fuel by providing higher operating margins in existing CANDU reactors. The CANFLEX-RU offers lower fuelling costs and provides a means to raise reactor power within a fixed core size. The use of RU from PWR reactors promises to be more economical than SEU or natural uranium. The use and economics of RU are being assessed in the collaborative programs with AECL and British Nuclear Fuel Plc. (BNFL).

3. THE STATUS OF CANFLEX-NU FUEL INDUSTRIALIZATION PROGRAM IN KOREA

Because of the increase in critical channel power with CANFLEX, the Korea Electric Power Corporation (KEPCO) headquarter and WGS-#1 site recognized that it could use CANFLEX to recover some of the heat transport system operation margins that had decreased due to ageing. WGS-#1 as the first CANDU-6 nuclear power plant in Korea has been commercially operating since 1983 April. Since the late part of 1999, KEPCO has announced a program in Korea to prepare for a DI of CANFLEX-NU fuel in WGS-#1 and potentially implement the CANFLEX-NU full core. The Korea Ministry of Science and Technology (MOST) has recognized the successful DI of 24 CANFLEX bundles at PLGS in Canada, as final verification of the CANFLEX design in preparation for full core conversion. Therefore, MOST has pushed and gave a financial support to a KEPRI/KAERI Joint Industrialization Program of CANFLEX-NU Fuel, which will conducted for 3 years from 2000 November, to efficiently utilize the CANFLEX fuel technology developed by KAERI and AECL jointly, where KAERI's works has been conducted under the Korea's national program of the mid- and long-term nuclear R & D programs since 1992.

3.1 The DI(Demonstration Irradiation) Plan

KEPCO intends to perform a DI of 24 CANFLEX-NU fuel bundles in WGS-#1, while maintaining a minimum risk and maximum flexibility of the reactor operation. The purpose of this DI is: ① to validate CANFLEX-NU fuel bundle performance in direct conditions of relevance under the Korean licensing requirements, while limiting the risk, ② to evaluate the fabrication capability in Korea, and ③ to provide the rationale for the decision to perform the full-conversion of CANFLEX-NU fuel in WGS-#1.

The DI plan called for the KEPCO Nuclear Fuel Co. Ltd. (KNFC) to manufacture 26

CANFLEX-NU fuel bundles (24 fuel bundles for fuelling in WGS-#1 and 2 for archival purpose) to the Quality Assurance levels normally applied to the 37-element fuel supplied to WGSs. All configurations of CANFLEX-NU fuel bundles mixed with the 37-element bundle in a single channel during transition and full-core refuelling are going to be tested. As taken for the DI of 24 CANFLEX-NU fuel bundles in PLGS [6], the following DI objectives are set and applied to select candidate sites: ① some fuel should be exposed to as high a power as possible within the allowable operating envelope, ② some fuel should be exposed to as wide a power variation as possible within the allowable operating envelope, ③ at least one selected channel should have normal dwell with a full CANFLEX fuel string, ④ some fuel should be exposed to normal fuelling-induced power ramps, ⑤ at least one selected channel should be in the flow-assist-fuelling region, ⑥ some fuel should be exposed to the high burnup within the allowable operating envelope, ⑦ some fuel should be exposed to the long in-reactor residence time, and ⑧ some fuel should be in an instrumented channel. The DI will be fully documented, covering the station data report.

As CANFLEX-NU fuel bundles are discharged and transported to the bays, they will be visually examined. Figures 2 and 3 show projected fuelling histories of the fuel bundles for WGS - #1 high and low power channels, respectively, during the DI. The first fuelling of the CANFLEX bundles in WGS-#1 is planned in around 2000 October immediately after KINS review of the safety assessment report for the DI of 24 CANFLEX-NU fuel bundles at WGS-#1 as mentioned in the next Section. The post-irradiation examinations (PIE) of the CANFLELEX-NU bundles irradiated in WGS-#1 are not initially planned in the period of this 3 year Industrialization Program, because the overall schedule of the DI program is too tight to cover the PIEs by 2003 March as well as a shipping cask for the transportation of the irradiated bundles from WGS site to KAERI PIEF (Post-Irradiation Examination Facility) is not available in Korea. Therefore, KAERI intends to perform the PIEs right after the completion of this Industrialization Program, by calling for 2 bundles to be shipped to the KAERI PIEF for PIE as follows: ① a bundle from the high-power channel that has received highest burnup, and ② a bundle from the lower-powered channel that has seen longer residence times. The PIE will consist of visual examination, bundle profilometry, disassembly and element profilometry, gamma scanning, fission-gas and void volume measurements, end-plate weld and appendage-weld strength tests, metallography and ceramography, chemical burnup analysis, alpha, beta and gamma autoradiography, and hydrogen analysis of sheath, appendage and end plate.

3.2 Documentation for the DI

As mentioned above, on 1999 August, KAERI obtained the Korean Government (MOST) approval of CANFLEX-NU fuel design and fabrication method for the use of the fuel in WGSs, as part of the Korean licensing process. The major prerequisite for the DI at the WGS-#1 is the preparation of an appropriate safety analysis for the reactor, which covers the major features of the license under which that particular reactor operates. With extensive discussions and interactions with KEPRI, KAERI had prepared the safety analysis report for the DI. With extensive discussions and interactions with WGS-#1 site, AECL and/or KNFC, KAERI has prepared other prerequisite documents such as the operational considerations and irradiation requirements, the fuel design drawing and technical specifications, and a general guideline of the fuel manufacture, handling and PIEs for the DI.

In the safety assessment for the DI of 24 CANFLEX-NU fuel bundles at the WGS-#1, the focus was on establishing the behaviour of CANFLEX fuel relative to the 37-element fuel. Hence, as presented in the safety assessment documents for the DI of 24 CANFLEX-NU fuel bundles at PLGS [7], these was not comprehensive re-analyses of the postulated accident scenarios, but an examination of the expected difference in accident consequences because of the 24 CANFLEX-NU fuel bundles in two channels. Even when an explicit assessment was performed, the approach was to select one or two representative cases and then to compare the relative behaviour. The accident scenarios expectantly subjected to fuel failure were selected for the safety assessment [8]: large LOCA (Loss-Of-Coolant Accident), large break LOCA with LOECC (Loss Of Emergency Core Coolant), feeder breaks, end fitting failure, flow blockage, pressure tube rupture, and so on. The CANFLEX bundle has a smaller cross-sectional area than the 37-element bundle does, thus resulting in the potential for more void to form. Therefore, the power pulse that is attributable to void of the channel may be greater in magnitude for the CANFLEX bundle relative to the 37-element fuel. The differences in power pulses between a CANFLEX channel and a 37-element channel are only a consideration for large break LOCA and loss of regulation accidents and have no effect on the small break LOCA analysis, pressure tube rupture analysis, flow blockage analysis, the end fitting failure analysis. The lower maximum linear element ratings for CANFLEX bundles compared to 37-element bundles at the same bundle power leads to that any adverse consequences with the CANFLEX bundles for the accident scenarios that are not expected to result in any fuel failure are not expected, and therefore, the postulated accidents such as small break LOCA, loss of Class IV power, loss of HTS pumps in the primary circuit, loss of feed-water, steam-line breaks, and so on are not analyzed for this safety assessment. In the single channel analyses for the explicit assessments, behaviour for an all-37-element channel was compared to that for an all-CANFLEX channel. For mixed strings, the impact on key safety results would be intermediate between these two cases, due to the very similar behaviour thermal hydraulic and neutronic behaviour of the two bundle types. Explicit assessments used the computer codes and analysis methods which were employed in the safety analyses for the WGS-2, 3, and 4 Final Safety Report [9], because computer programs used in about 20 year ago for the WGS-#1 Safety Report [10] are not available or have been upgraded at this time and also the analysis methods and assumptions has been updated since about 20 year ago. When individual channels were considered, channel O06 with a channel power of 7.3 MW and a peak bundle power of 935 kW was the basis of the simulations.

3.3 CANFLEX-NU Full-Core Implementation in WGS-#1

The CANFLEX-NU Fuel Industrialization Program called for the Korea Power Engineering Company Inc. (KOPEC) to prepare a safety analysis report for the full-core conversion of CANFLEX-NU fuel in WGS-#1 by 2003 March. KOPEC intends to present the safety analyses on postulated accident scenarios as listed in Table 1 for the full-core implementation, where the input parameters for the safety analyses, which are based on the CANFLEX-NU fuel design as shown in Table 2, will be provided by KAERI. At this moment, KEPCO identified the detail work-scope based on the postulate accident scenarios shown in Table 1, and then is getting ready for CATHENA model report on the detailed fuel channel model, multiple average channel model, secondary side model, above header model, ECCS model, slave channel model, trip coverage analysis model as well as for the initial fission product inventory.

The Fuel Industrialization Program called for KEPRI to conduct an economic evaluation for the full-core conversion of CANFLEX-NU fuel in WGS-#1 also by 2003 March. This economic evaluation will be performed starting from 2001 December. The decision on the full-core conversion will be processed in this program. Successfully demonstrating the irradiation of CANFLEX fuel in the WGS-#1, it will lead the way towards the full-core implementation of CANFLEX-NU fuel in the reactor.

4. CONCLUSIONS

CANFLEX fuel has been under development for over 10 years. CANFLEX-NU fuel is a prime example of the benefits that can be achieved through collaborative ventures between Canada and Korea. Following the successful approval of the CANFLEX-NU design and fabrication method by Korean Government (MOST) as well as the successful DI of CANFLEX-NU fuel in PLGS, MOST has pushed and financially supported a KEPRI/KAERI CANFLEX-NU Joint Industrialization Program for 3 years from 2000 November to cover a DI of 24 CANFLEX-NU fuel bundles in WGS-#1 and the safety analyses for the full-core conversion of the fuel in the reactor.

The economic benefits of CANFLEX-NU fuel are directly dependent on the thermalhydraulic performance. Therefore, switching from the existing 37-element fuel to CANFLEX-NU fuel will be largely driven by the economic benefits to be realized. If KEPCO has a positive result from the economic evaluation as well as the successful DI of CANFLEX-NU fuel in WGS-#1, the full-core implementation of CANFLEX-NU fuel at the WGS-#1 in Korea will proceed by starting the licensing process immediately from around 2003 April because the safety report for the full-core conversion will be ready by, at least, 2003 March.

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Table 1. List of the Postulated Accident Scenarios in the Safety Analysis for the CANFLEX-NU Full-Core Conversion in WGS-#1

● Large break LOCA (LBLOCA) ● LBLOCA with containment system failure ● LBLOCA with ECCS failure ● Small break LOCA (SBLOCA) ● SBLOCA with containment system failure ● SBLOCA with ECCS failure ● Pressure tube rupture (PTR) ● PTR with containment system failure ● PTR with ECCS failure ● Channel flow blockage (CFB) ● CFB with containment system failure ● CFB with ECCS Failure	● End fitting failure (EFF) ● EFF with containment system failure ● EFF with ECCS Failure ● Steam line break (SLB) ● SLB with containment system failure ● SLB with ECCS Failure ● Feed-water system failure ● Loss of Class IV power ● HT Pump seizure ● Loss of reactivity control ● Loss of P & I control ● Loss of secondary pressure control ● Loss of shutdown cooling ● Loss of end shield cooling ● Pipe break in HT auxiliary system

Table 2. List of Input Parameters of the Safety Analysis for the CANFLEX-NU Full-Core Conversion in WGS-#1

● Physics parameter for time averaged core ● Channel thermalhydraulic parameter for time averaged core ● Physics parameter for equilibrium core ● Physics parameter for transition core ● Bundle relative element linear power ● Bundle relative element burnup	● SDS1 & SDS2 reactivity data ● Point nuetronic data ● Reactivity change by coolant density, fuel temperature, coolant temperature ● Liquid zone controller reactivity ● Mechanical control absorber reactivity ● Adjuster reactivity

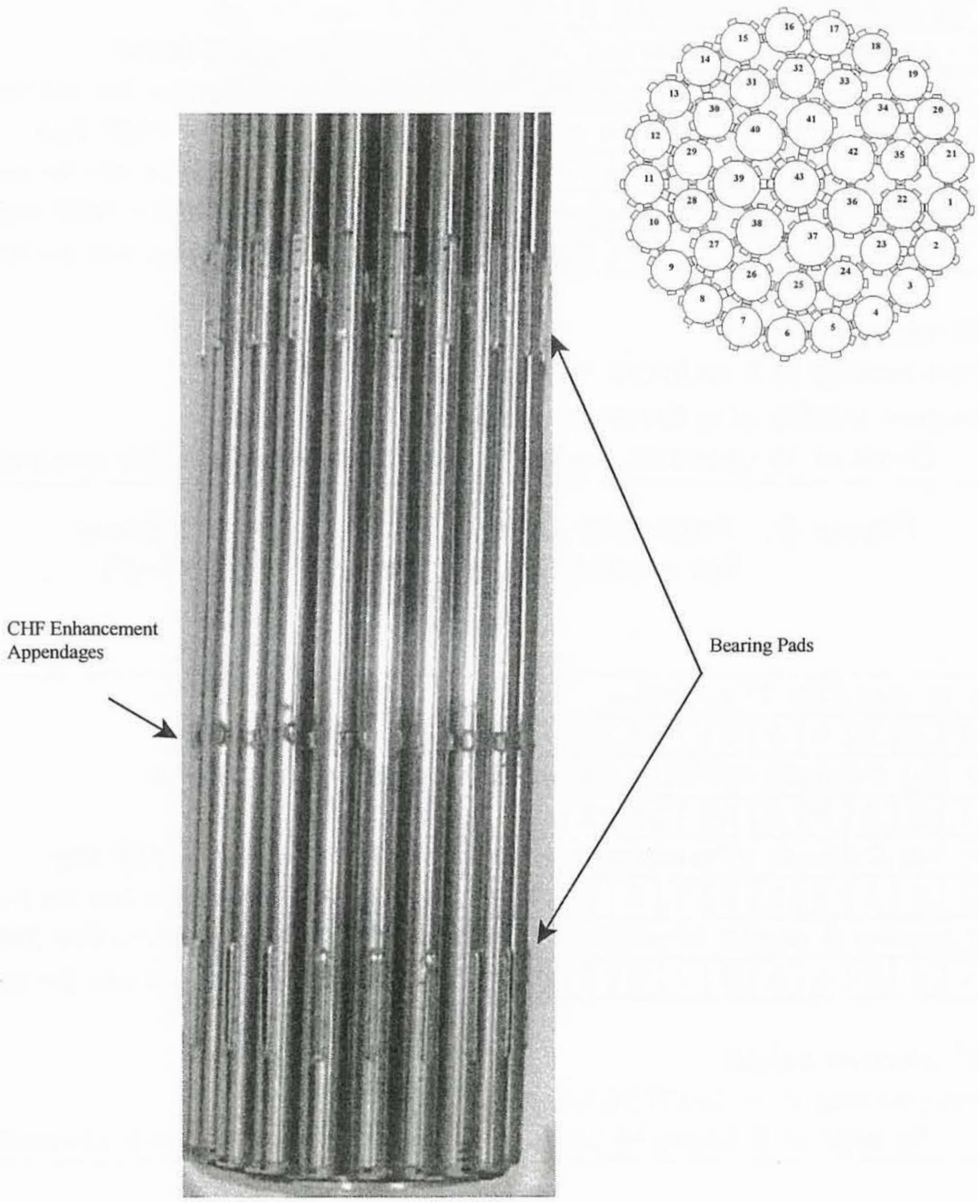

Figure 1. CANFLEX 43-Element Bundle

Prior to first CANFLEX fuelling

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |

After first 8 bundle CANFLEX fuelling(0 months):~2001 October

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |

After second 8 bundle CANFLEX fuelling(~6 month):~2002 March

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | ⇒4 CANFLEX bundles into the bay

After first 8 bundle 37-element bundle fuelling(~12 month):~2002 Sept.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | ⇒8 CANFLEX bundles into the bay

After second 8 bundle 37-element bundle fuelling(~18 month):~2003 March

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | ⇒4 CANFLEX bundles into the bay

| # | 37-element bundle

| # | First fuelling of 8 CANFLEX bundles

| # | Second fuelling of 8 CANFLEX bundles

(Total of 16 CANFLEX bundles will be in the bay from this channel)

Figure 2. Projected CANFLEX-NU Fuelling History for a High-Power Channel in WGS-#1

Prior to first CANFLEX fuelling

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |

After first 8 bundle CANFLEX fuelling(0 months):~2001 October

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |

After first 8 bundle 37-element bundle fuelling(~8 month):~2002 May

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | ⇒4 CANFLEX bundles into the bay

After second 8 bundle 37-element bundle fuelling(~16 month):~2003 Jan.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | ⇒4 CANFLEX bundles into the bay

| # | 37-element bundle

| # | First fuelling of 8 CANFLEX bundles

(A total of 8 CANFLEX bundles fuelled into the low power channel)

Figure 3. Projected CANFLEX-NU Fuelling History for Low-Power and Flow Instrumented Channel in WGS-#1