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Increasing CANDU Operating Margins with CANFLEX Fuel

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ABSTRACT

The CANFLEX® fuel bundle is the latest design in the evolution of CANDU® fuel. Its 43-element fuel bundle assembly and its patented critical-heat-flux (CHF) enhancement appendages offer, over the range of operating conditions, 5 to 8% higher critical channel powers (CCP) than the standard 37-element bundle. The maximum linear-element rating in a CANFLEX bundle is 20% lower than that of a 37-element bundle, reducing the consequences of most design-basis accidents. It is fully compatible with operating CANDU reactors, designed to have hydraulic and neutronic characteristics that are similar to those of the existing fuel. This feature allows operators to introduce CANFLEX bundles during normal on-power refuelling

A rigorous verification process has been followed to qualify CANFLEX for use in a CANDU reactor. Extensive out-reactor testing combined with analysis has been used to show that CANFLEX meets the fuel design requirements. The design requirements, assessments and performance test results were documented in a Fuel Design Manual and were subject to an industry-wide formal Design Review. The final step prior to implementation was a demonstration irradiation in a power reactor. A 2-channel, 24-bundle demonstration irradiation of CANFLEX was started on 1998 September 03 at New Brunswick Power's Point Lepreau Generating Station. All 24 bundles have completed their planned irradiation. Several of the irradiated bundles have been examined to verify bundle integrity and condition. The post-irradiation examination data shows that the in-reactor performance of the CANFLEX fuel has met all design criteria and that it is fully compatible with existing CANDU reactors.

CANFLEX fuel development is part of an overall strategy on plant ageing, which recognized that certain processes were taking place within the heat-transport system which, if left unabated, could result in a decrease in the margin to fuel-sheath dryout. Because of the increase in CCP brought about by the improved CANFLEX design, it was recognized that this new fuel, when used in combination with other remedial actions, could counterbalance the adverse effects of aging within the heat-transport system.

This paper will report on the CANFLEX qualification program, the results of the demonstration irradiation and present the CANFLEX thermalhydraulic performance data. The paper will also discuss the various increases in safety margins with the use of CANFLEX fuel. Finally, it will show potential economic benefits of this new fuel concept and identify future developments and their potential economic impact.

INTRODUCTION

Since the early 1990's, Atomic Energy of Canada Limited (AECL) and the Korea Atomic Energy Research Institute (KAERI) have pursued a collaborative program to develop, verify, and prove a new fuel design that would introduce advanced fuel cycles into CANDU reactors and provide enhanced performance with natural uranium (NU) fuel to provide higher operating margins in existing CANDU reactors.

In 1998 September, New Brunswick Power (NBP), at the Point Lepreau Generating Station (PLGS), began a two-year demonstration irradiation of CANFLEX fuel bundles, as final verification of the CANFLEX design in preparation for full-core conversion. This document provides a summary of the CANFLEX qualification and performance assessment program and discusses the benefits existing plants can derive from using this fuel design.

CANFLEX BUNDLE DESIGN

The CANFLEX design is a 43-element fuel-bundle assembly offering improved operating and safety margins, compared with the standard 37-element fuel bundle, for operating CANDU reactors[1-7]. The CANFLEX bundle design includes critical heat flux (CHF) enhancement devices leading to 5 to 8% higher critical channel power (CCP) in a full-length fuel channel, compared with that of 37-element fuel bundles. The lower heat rating of the CANFLEX fuel elements at current bundle powers leads to lower fuel temperatures. Hence less free fission-gas inventory is produced under normal operating conditions compared with the free fission-gas inventory produced in standard 37-element fuel elements at a similar bundle power.

The CANFLEX bundle consists of 2 fuel element sizes: small-diameter elements in the outer and intermediate rings, and larger-diameter elements in the inner and centre rings (Figure 1). Special buttons are attached to the elements at 2 planes, to provide improved heat-transfer and hence CHF enhancement (Figure 2). To maintain compatibility of the new bundle design with the design of existing CANDU 6 reactor and fuel handling systems, the basic overall dimensions of the CANFLEX fuel bundle were designed to be the same as those of the 37-element fuel bundle. The small-diameter elements of the outer ring result in a slightly larger end-plate diameter compared with end-plate diameter of the standard 37-element bundle. Consequently, the bearing pad heights of the bundle are designed to be larger than those of the 37-element bundle. This feature makes the CANFLEX bundle fully compatible with the sidestop/separator assembly of the CANDU 6 fuelling machine. The sidestop/separator assembly is an important component in the fuelling machine. The fuel bundle dimensions must be compatible with this assembly.

CANFLEX fuel is designed to have hydraulic and neutronic characteristics that are similar to those of the existing fuel. This feature allows operators to introduce CANFLEX bundles during normal on-power refuelling. The fuel bundle, in all other respects, is designed to be equivalent to the 37-element bundle, to be "transparent" to all reactor systems. To verify this, tests were performed for pressure drop, bundle strength under a number of situations such as radial cross-flow, and a test of the long-term fretting performance.

CANFLEX QUALIFICATION AND PERFORMANCE ASSESSMENT

The CANFLEX bundle has undergone an extensive verification program [8,9]. The verification program has been conducted following the strategy laid out in the Design Verification Plan (DVP). The verification work consisted of analysis and testing, drawing on the capabilities of AECL's facilities in Canada and KAERI's facilities in Korea. The DVP identifies the performance requirements, specifies the test or analysis required to verify that the requirement is met, and identifies responsibility and procedures. All testing and analysis conformed to the quality standard CAN/CSA-N286.2 or equivalent [10]. The DVP called for preparation of a Test Specification, Test Procedure, Acceptance Criteria and identified the required documentation.

Thermalhydraulic Testing of CANFLEX to Establish Thermalhydraulics Performance Data

To fully characterize the thermalhydraulic performance of CANFLEX, CHF experiments were performed in Freon-134a in the MR-3 facility at CRL, on both the 37-element and the CANFLEX simulated fuel strings. The pressure-drop characteristics of the CANFLEX bundle were determined in both Freon tests and hot and cold water.

Full-scale CANFLEX bundle tests were performed to obtain licensing data in the high-pressure steam-water loop at theStern Laboratories [14,16]. The test string consisted of a 6-m-long, 43-element, bundle simulator. A wide range of steam-water flow conditions was covered in the CHF experiment: an outlet-pressure range from 6 to 11 MPa, mass-flow-rate range from 7 to 25 kg/s, and inlet-fluid-temperature range from 200°C to 290°C. Most of the data are directly relevant to analyses of the regional overpower trip (ROPT) set point in the reactor.

The dryout power enhancement of CANFLEX over 37-element fuel established from the water CHF testing, ranges from 8 to 18% for the range of conditions of interest at the same inlet-fluid temperature (Figure 3). Single and two-phase pressure-drop tests were performed at lower pressures and fluid temperatures, as well as at higher mass-flow rates (Figure 4). The pressure drop data corresponded closely to those previously obtained with a simulated string of 37-element bundles at the same test facility.

The water CHF and pressure drop data have been used to derive a CHF correlation and pressure drop loss coefficients for the NUCIRC [17] computer code. NUCIRC applies the correlations to the range of channel geometries, power shapes and operating conditions specific to a given reactor. Pre-release versions of NUCIRC with the CANFLEX correlations show that a typical CANDU 6 reactor will operate with 5 to 8% higher critical channel powers when fuelled with CANFLEX compared to the standard 37-element bundles. NUCIRC Version 2.01 which will contain the CANFLEX calculation options, is currently being verified and should be formally released late in fiscal year 2000/01.

Out-reactor Flow Testing

AECL and KAERI have subjected the CANFLEX fuel bundle to a set of out-reactor flow tests to simulate reactor conditions and verify that the design is compatible with existing reactor hardware. In addition to the heat transfer and pressure drop tests the following mechanical flow tests have been successfully completed:

- **Strength Test:** Strength tests showed that the fuel can withstand the hydraulic loads during refuelling, when the fuel string is supported only by the sidestops.. Post-test bundle geometry measurements showed no significant distortion.
- **Impact Test:** Impact tests showed that the CANFLEX bundle can withstand the bundle impact during refuelling.
- **Cross Flow:** Cross flow tests demonstrated that, during refuelling, when the bundle is in the cross flow region, the bundle withstands the flow-induced vibration for a minimum of 18 h.
- **Fuelling Machine Compatibility:** Fuelling machine compatibility tests showed that the bundle is dimensionally compatible with the fuel handling system.
- **Flow Endurance:** The 3000-h flow endurance test demonstrated that the CANFLEX bundle will maintain structural integrity during operation; fretting wear on the bearing pads, inter-element spacers and pressure tube will remain within design limits.

In-reactor Testing

CANFLEX bundles, AJK, AJM and AJN, were irradiated in the U-1 and U-2 loops in the NRU research reactor to demonstrate performance under expected in-reactor conditions. Typical power changes during refuelling and peak outer element midplane powers exceeding 70kW/m were used for the irradiation conditions in the NRU tests. For the high burn-up NRU irradiations, burn-ups of greater than 480MWh/kgU were achieved. Once the bundles were removed, detailed post-irradiation examinations (PIE) were performed. The irradiation in NRU reactor confirmed the performance of the CANFLEX bundles under in-reactor operating conditions.

Reactor Physics Testing and Analysis

The ZED-2 facility at CRL was used to measure the fine-structure, reaction rates, and reactivity coefficients for CANFLEX natural-uranium bundles, to validate the reactor physics lattice code WIMS-AECL [18]. The data showed excellent agreement with code predictions. A fuel management computer code was used to simulate reactor operation over 600 full-power days, to determine peak bundle powers, power changes during refuelling, burnups, and residence times. Various fuelling schemes were studied. Fuel performance requirements were established for NRU irradiation tests. The analysis showed that the CANFLEX bundle meets or exceeds all power requirements.

Structural Analysis

The CANFLEX design was analyzed for sheath strains, fission-gas pressure, end-plate loading, thermal behavior, sliding wear, element bow and end-flux peaking. The CANFLEX design met the performance requirements.

Formal Design Review

The Verification Program results were summarized in the Fuel Design Manual. This document captures all the design requirements and points to the individual analysis or test which shows that the requirement has been met. In 2000 February, AECL's Chief Engineer conducted a formal design review to assess the CANFLEX verification and qualification program, and the bundle's readiness for full-core

implementation. Industry experts from New Brunswick Power, Hydro Quebec, Ontario Power Generation, the two domestic fuel fabricators, and subject-area experts reviewed the CANFLEX Fuel Design Manual and other CANFLEX documentation. Reviewers provided written comments that the Design Team addressed. Closure was achieved for the majority of issues, however, a number of actions were assigned, including the completion of outstanding work, such as PIE of the DI bundles and completion of the thermalhydraulics licensing report.

CANFLEX DEMONSTRATION IRRADIATION

Demonstration Irradiation Plan

The final step in qualifying the fuel for full-core implementation was a demonstration irradiation in a power reactor. The principle objective was to show compatibility with all reactor systems rather than to establish CANFLEX performance data.

PLGS applied its standard process for special fuel irradiations for the CANFLEX demonstration irradiation [19]. This process involves preparation of an Information Report which is the basis on which both management and regulatory approvals are built. The demonstration irradiation plan called for Zircatec Precision Industries to manufacture 26 CANFLEX bundles to the Quality Assurance levels normally applied to 37-element fuel supplied to PLGS- 24 bundles for fuelling in PLGS and 2 for archiving. All configurations of CANFLEX bundles mixed with 37-element bundles in a single channel during transition and full-core refuelling were to be tested. The following objectives were set and applied to select candidate sites:

- Some fuel should be exposed to as high a power as possible within the allowable operating envelope.
- Some fuel should be exposed to as wide a power variation as possible within the allowable envelope.
- At least one channel should have normal dwell with a full CANFLEX fuel string.
- Some fuel should be exposed to normal fuelling-induced power ramps.
- At least one selected channel will be in the flow-assist-fuelling region.
- Some fuel should be exposed to high burnup within the allowable operating envelope.
- Some fuel should be exposed to long in-reactor residence time.
- Some fuel should be in an instrumented channel.
- Some fuel should be exposed to the largest amount of acoustic excitation that is possible.
- One high-powered channel and one low-powered channel were to be selected for CANFLEX fuelling.

On discharge and transportation to the bays, the CANFLEX bundles were to be visually examined. Two bundles would be selected and shipped to the Chalk River Laboratories (CRL) for PIE, consisting of:

- Visual examination, bundle and element profilometry;
- Disassembly and element profilometry;
- Gamma scanning;

- Fission-gas and void volume measurements;
- End-plate weld and button-weld strength tests;
- Metallography and ceramography;
- Chemical burnup analysis (high-performance liquid chromatography);
- Alpha, beta and gamma autoradiography; and
- Hydrogen analysis of sheath, button and end plate.

The demonstration irradiation will be fully documented, including station data and PIE reports.

CANFLEX Demonstration Irradiation Status

Once Atomic Energy Control Board (AECB) approval for the DI was secured in the late summer of 1998, PLGS fuel engineers selected channel S08 for the high-power channel and channel Q20 for the low-power channel (Figure 5-6). As part of the routine on-power fuelling in 1998 September, 8 CANFLEX bundles were fuelled into each of the two channels. In 1999 March, the low-power channel Q20 was refuelled and the first 4 DI CANFLEX bundles were discharged into the fuel bays. PLGS had planned a fuel-channel inspection in S08 during a summer maintenance shutdown, and it was decided to leave the CANFLEX fuel in the channel during the shutdown to demonstrate its compatibility with all maintenance handling systems and operations. Thus the high-power channel S08 was refuelled after reactor start-up in 1999 August, discharging 4 CANFLEX fuel bundles and establishing a full channel of 12 CANFLEX fuel bundles. In 2000 January, the final fuelling in Q20 was successfully completed, discharging 4 CANFLEX bundles and restoring the channel to full 37-element configuration. In 2000 February, S08 was refuelled, discharging 8 CANFLEX bundles. In 2000 August the last of the DI bundles was discharged thereby completing the irradiation of 24 CANFLEX bundles at PLGS.

The power history of bundles irradiated in the high power channel S08 (Figure 7) show a relatively high burnup of over 220 MWh/kgU, compared to a more standard burn-up of 175 MWh/kgU. From an operational perspective, the CANFLEX fuel behaved exactly as 37-element fuel would have: there were no significant differences in any monitored aspect of station behavior which could be attributed to CANFLEX fuel. During the above-mentioned summer shutdown, channel S08 underwent Spacer Location And Repositioning (SLAR) and Channel Inspection and Gauging Apparatus for Reactors (CIGAR) inspection. The fuel handling associated with these procedures was uneventful and the results of the CIGAR inspection did not indicate any unusual wear in the channel that was related to the use of CANFLEX fuel.

Irradiated Fuel In-bay Inspection

Of the 24 CANFLEX bundles irradiated, 20 bundles have been visually inspected in the fuel bays at Pt. Lepreau (the remaining 4 bundles discharged in August require 2 months of cooling before a full inspection can be made). The inspection team included fuelling experts from the station, a member of the CANFLEX design team and a member of the AECL fuel inspection group, who will conduct the PIE in the cells. The examination was done using an underwater periscope; photography was achieved using a

television camera attached to the periscope and digital imaging. The inspection team concluded that the bundles were in very good condition. All observations, photographs and irradiation data have been sent to the design team for review and disposition. The following summarizes observations and current status of disposition:

- Element Gap: Gaps were observed between adjacent elements. This led the inspection team to suspect spacer interlocking. Examination of the bundles during PIE found no evidence of interlocking as discussed in the next section. As had been observed in 37-element fuel bundles, the CANFLEX bundles were found to have element settling where limited distortions of some elements occurred due to a combination of applied loads, irradiation-induced creep and fabrication tolerances in the inter-element spacings. The design team awaits completion of the PIE to disposition this finding.
- Marks on the sides of CHF Buttons: Marks on the sides of a small fraction of the buttons raised concerns that material loss or corrosion was taking place during irradiation. Inspection of the two archive bundles held from the production run of the DI fuel, revealed CHF buttons that had features that appear similar to those seen in the bays at PLGS, i.e., an area with a raised periphery, at the side of some CHF buttons. Based on a comparison of the marks from the irradiated fuel and the unirradiated fuel, it was concluded that the features are an artifact of the fabrication and/or brazing process.
- Marks on End Caps: The inspection team saw scrape marks on some of the end-caps on some bundles. These appear to have been made when the side stops or separator feelers were inserted or withdrawn. Similar marks have been observed on 37-element bundles when side stops become worn. The design team concluded that the issue is not related to CANFLEX.
- Bearing Pad Wear: Some wear was observed on outboard bearing pads consistent with 37-element experience. All mid-plane pads of the CANFLEX bundles received very light wear. One mid-plane bearing pad showed higher wear on the CANFLEX bundle but a similar wear pattern was noted on one of the 37-element bundles inspected at the same time. The design team concluded that bearing pad wear was consistent with current irradiated fuel experience.
- Marks on one location on the end-plates: Marks were observed on the outer circumference of the end-plates. Similar marks were found on the archived bundles. It was traced to the manufacturing process which was used to fabricate the end-plates.

Full inspection reports have been prepared and the Design teams disposition of the findings will be documented for inclusion in the Demonstration Irradiation Report.

Post-Irradiation Examination

Two CANFLEX DI fuel bundles were shipped to CRL for post-irradiation examination (PIE) (Figure 8). Bundle FLX019Z, irradiated in Q20 position 8, was shipped to CRL on 1999 December 22. Bundle FLX019Z reached a calculated bundle burnup of 144 MWh/kgU and reached a peak outer-element linear power (OELP) of 38 kW/m. Bundle FLX007Z, irradiated in S08 position 8, was shipped to CRL on 2000 March 30 from PLGS. Bundle FLX007Z reached a calculated bundle burnup of 221 MWh/kgU and reached a peak OELP of 45 kW/m.

The visual and non-destructive examinations have been completed for both bundles and the destructive examinations are in progress. The following is a brief summary of the PIE results to date:

- No unusual features or anomalies were found visually.
- End-plate distortion was minor.
- Element settling was found; element settling has also been observed in the 37-element bundle in past PIE (Figure 9). No marks were found on spacers or elements to indicate spacer interlocking and no locked spacers were found. The spacers on one archived bundle were intentionally locked and the profilometry showed very different and distinct element bowing (Figure 10)
- Bearing and spacer pad wear was minor.
- Typical pellet-interface ridging was found for FLX007Z but it was not distinctive for the lower power bundle FLX019Z (Figure 11).
- Element gamma scans were normal and no Cs migration to the pellet-interface was evident (Figure 12).
- Fission gas volumes (1.4 to 1.7 ml at STP) and releases (less than 0.1%) were small.
- No unusual features or anomalies have been found in the metallographic and ceramographic examination of FLX019Z (e.g., typical fuel microstructure Figure 13).

The plant data, fuel-bay inspections, PIE and assessment work will be documented in a full report in 2001. This will conclude the demonstration irradiation program for the CANFLEX bundle.

INCREASING CANDU OPERATING MARGINS WITH CANFLEX FUEL

Implementing CANFLEX fuel in existing CANDU 6 reactors will increase the critical channel powers (CCP) by 5 to 8%. The actual CCP gain depends on individual channel conditions such as channel creep shape, power shape and local flow conditions. CCP is calculated using the computer code NUCIRC. The increase in CCP margin can be used by station operation to offset the margin reductions due to reactor ageing, such as the effect of heat transport system fouling and of diametral creep of the pressure tubes. Alternatively, the increase in margin could be utilized to increase the core power output, particularly in a new reactor.

The ~20% reduction in the linear element rating of the CANFLEX bundle (compared to the 37-element bundle) results in a substantial reduction of the fission product inventory in the fuel-to-sheath gap (i.e., gap-inventory). For example, at the same maximum bundle power, the iodine gap-inventory in the maximum-rated element in a CANFLEX bundle is estimated to be 3 times lower than the maximum-rated element in a 37-element bundle. This reduction provides several benefits. For accidents in which a number of fuel elements are predicted to fail and their fission product gap-inventory released, the radiological consequences will be reduced with the use of the CANFLEX bundles. This further enhances the safety performance of the reactor. The lower gap-inventory and lower power will also lead to lower activity burden in the heat transport circuit in the event of fuel failures during normal operation. While the performance of the CANDU fuel has been excellent, and the failure rate has been very low, on-power fuelling and failed fuel detection and location systems are designed to provide the means for an operator to

locate and remove defected fuel. The lower gap-inventory and lower power allows a longer action time for the operator. The lower gap-inventory will also reduce the radiological contamination in the heat transport circuit that arises from activity release from failed fuel. Consequently, the man-rem exposure during reactor maintenance is expected to be less, resulting in occupational health and cost benefits.

CANFLEX Implementation

AECL contracted Candesco to develop an implementation plan. The goal of the work was to identify the required scope of effort and define an optimized timetable for implementation of CANFLEX fuel in a CANDU 6 reactor. The approach taken was to define the program tasks required for implementation in detail and then, in consultation with the appropriate technical specialists within AECL's organization, to define the resource requirements for these tasks. Careful attention was paid to assumptions regarding the order of the tasks so that the resulting schedule was optimized in respect to elapsed time, while ensuring that it was still realistic.

The plan consists of the following main components:

- Regulatory interaction
- Finalizing design issues
- Safety and licensing
- Operational planning and implementation

Some basic assumption were made in defining this program plan. They are as follows:

- The utility implementing CANFLEX will perform all required modifications of Operating Manuals and/or operating procedures
- The utility implementing CANFLEX will develop the plan for managing the reduction in 37-element fuel inventories and provision of CANFLEX fuel in a timely manner
- The software tools needed to perform the licensing and design analyses with appropriate CANFLEX-specific models will be available.
- Code verification and validation will be addressed for tools used in safety analysis outside the context of this program

According to the plan, first loading of CANFLEX fuel in-reactor could take place within 20 months from the project start and trip setpoints could begin to be increased within 32 months from project start. The uncertainties on these time intervals are ±3 and ±6 months, respectively.

Economic Model of CANFLEX Implementation

To provide an economic basis for implementation, an economic model has been prepared to include all investments, effects on annual utility revenues and annual operating costs. Both the net present value (NPV) and internal rate of return are calculated for a range of implementation strategies and assumptions.

The economic model can assess the changes in revenue, operating costs, and investments that result from implementation of various plant-life-extension strategies available to offset the anticipated decline in reactor power due to ageing effects. The analysis includes all fiscal-year revenues, and all investment

costs are calculated to yield the annual projected cash flows. The differences between the cash flows are discounted to the decision date and are summed over the time period of application.

Implementation of CANFLEX fuel involves an initial investment in revising the safety analyses and operating procedures, leading to technical reviews and licensing submissions to obtain regulatory approval. The incremental costs of CANFLEX fuel are captured by the model. The resultant NPV quantifies the economic benefit of using a range of CANFLEX implementation strategies, to establish the sensitivity to various parameters. These various cases guide station management in selecting the most appropriate implementation strategy. Each station has unique and proprietary cost factors. The model accepts the reactor-specific costs as input assumptions and calculates the CANFLEX benefit. Current analysis using the latest thermalhydraulic performance data shows that the improvements in station revenue from the CANFLEX Mk4 bundle far outweigh the additional costs associated with its introduction and production. Each utility will implement CANFLEX according to its unique situation. AECL is working with utilities in Canada to determine implementation strategies for CANFLEX.

Safety Analysis And Licensing

At various stages of the CANFLEX fuel design, safety assessments were performed for key design basis accidents in a CANDU 6 reactor with 37-element fuel bundles replaced by CANFLEX bundles. These assessments were performed in order to provide interim feedback to design. The safety assessments identified the implications to the safety report when the CANFLEX fuel design is used in place of the existing 37-element bundles. This design-feedback process provides good assurance that there will not be unexpected impact of the design to safety.

Current operating licenses of Canadian reactors stipulate that only fuel of an approved design may be irradiated in the reactor. Use of any new fuel type in the reactor therefore requires regulatory approval. This approval depends on the existing safety report and supporting documentation to demonstrate that the change in fuel type does not compromise the safe operation of the reactor.

For the demonstration irradiation, a safety assessment was submitted to the regulators. The assessment showed that the presence of up to 24 CANFLEX fuel bundles in the core would not have a negative impact on the safe operation of the reactor. For full-core CANFLEX implementation, a separate licensing submission regarding full-core operation will be required. This licensing submission will also consider the transition between an all-37-element core and an all-CANFLEX core, since this process takes place over an extended period (about two years). The submission will cover all design basis accidents that will be affected by the change in the fuel types. As noted before, because the CANFLEX bundles have higher CCP performance and lower fission product gap-inventory compared to the 37-element bundles, larger safety margins are expected in most of the design basis accidents. It is also expected that the safety assessment in support of full-core CANFLEX implementation can also build extensively on the results of the assessment that was performed for the DI. AECL is working with CANDU utilities in Canada to establish the licensing program requirements for full-core implementation and the various roles and responsibilities.

CONCLUSIONS

CANFLEX fuel has been under development for over 10 years. CANFLEX fuel has been verified through extensive testing by AECL and KAERI and has been critically reviewed under a Formal Design Review. Results from the 20 CANFLEX bundles irradiated to date in PLGS verify the compatibility of this fuel type with existing reactor systems. The economic analysis based on the CHF-enhancement data indicates a significant payback to utilities operating CANDU reactors. The utilities now have an alternative fuel that can be deployed with confidence in CANDU design to provide a greater operating margin.

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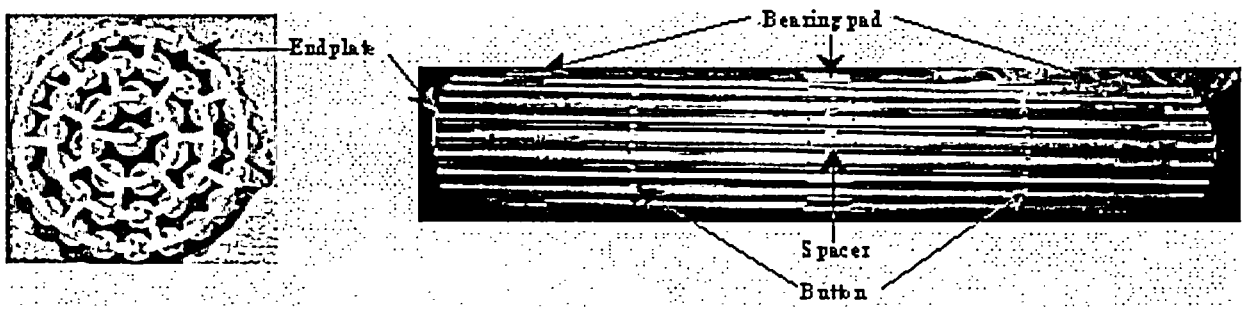
19. P.J. Reid, R.G. Steed, R.A. Gibb, R.W. Sancton, "A Standard Approach to Special Fuel Irradiations at Point Lepreau Generating Station", Proc. 19th Annual Conference of the Canadian Nuclear Society, Toronto, Ontario, Canada, 1998 October 18-21.

Acrobat Document

Figure 1: CANFLEX Design

CANFLEX (CANDU Flexible) Bundle



- CHF enhancement increases critical channel power by 5%-8%. Further improvements are possible
- 20% lower element ratings leads to lower Fission-product production
- Fully compatible with existing CANDU 6 reactors
- Fully qualified for use in CANDU 6 reactors

Figure 2: CANFLEX Pressure Drop Characteristics

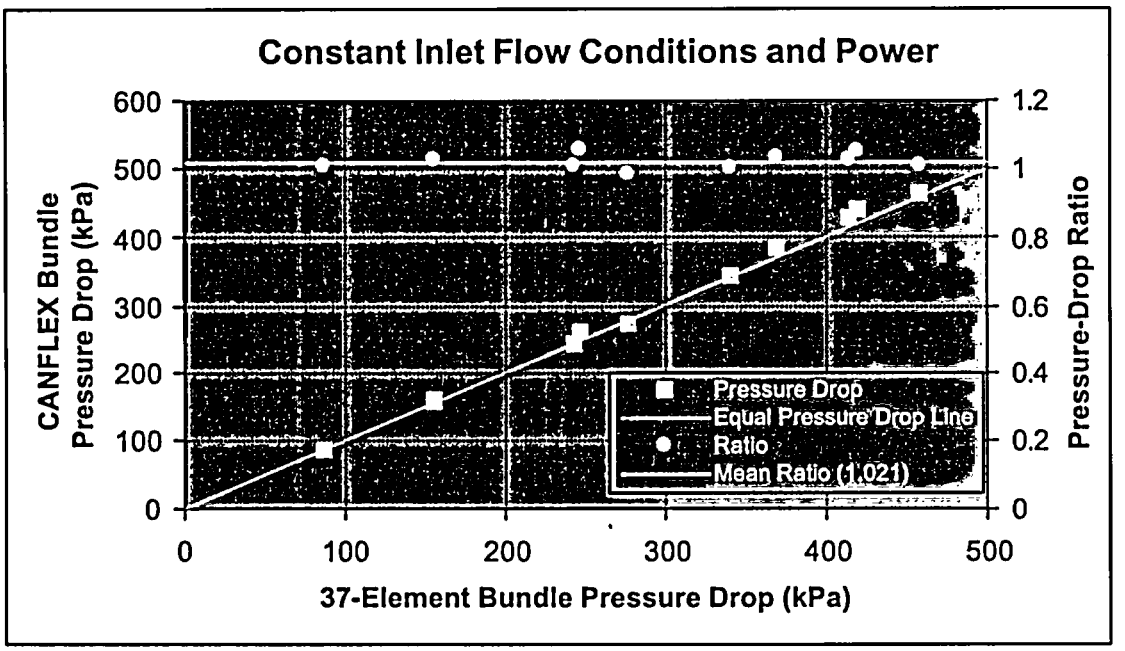


Figure 3: Dryout Power Enhancement of CANFLEX Relative to 37-Element

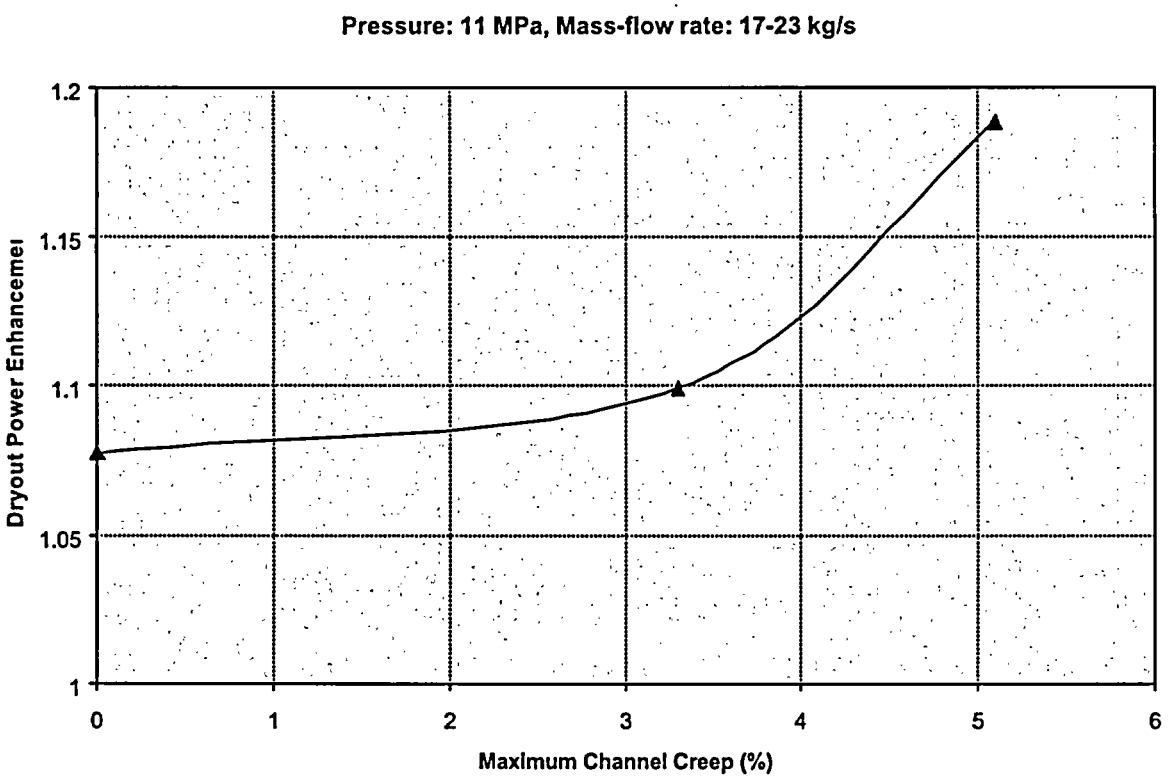


Figure 4: Fuelling History for High-power Channel

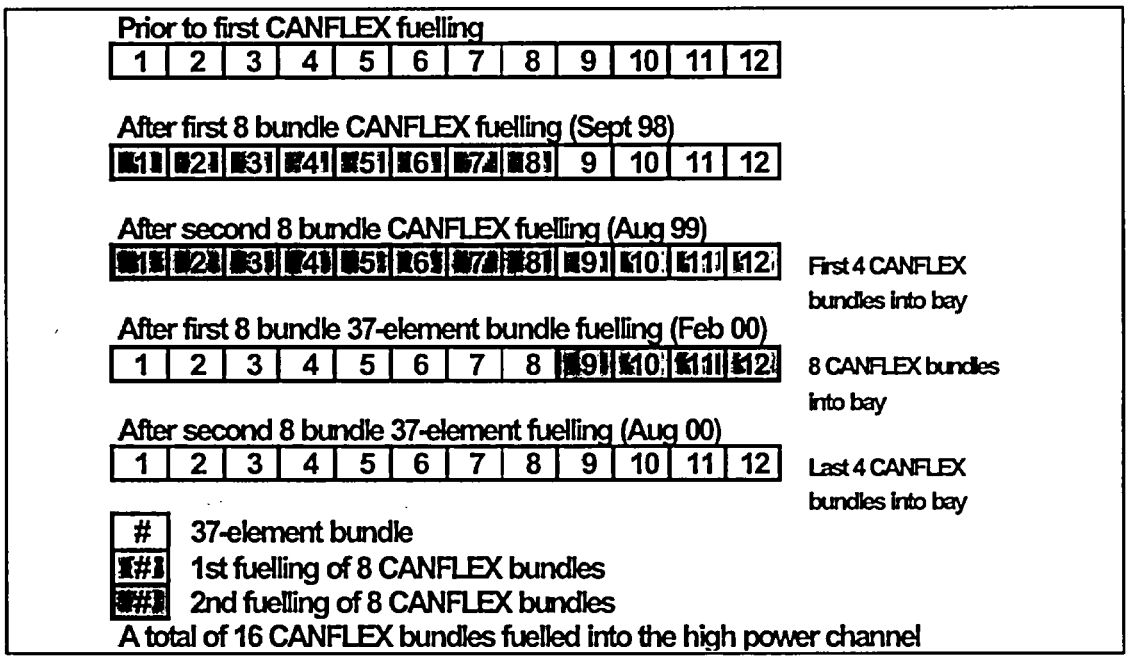


Figure 5: Power History for the DI CANFLEX Bundles in High-power Channel S08

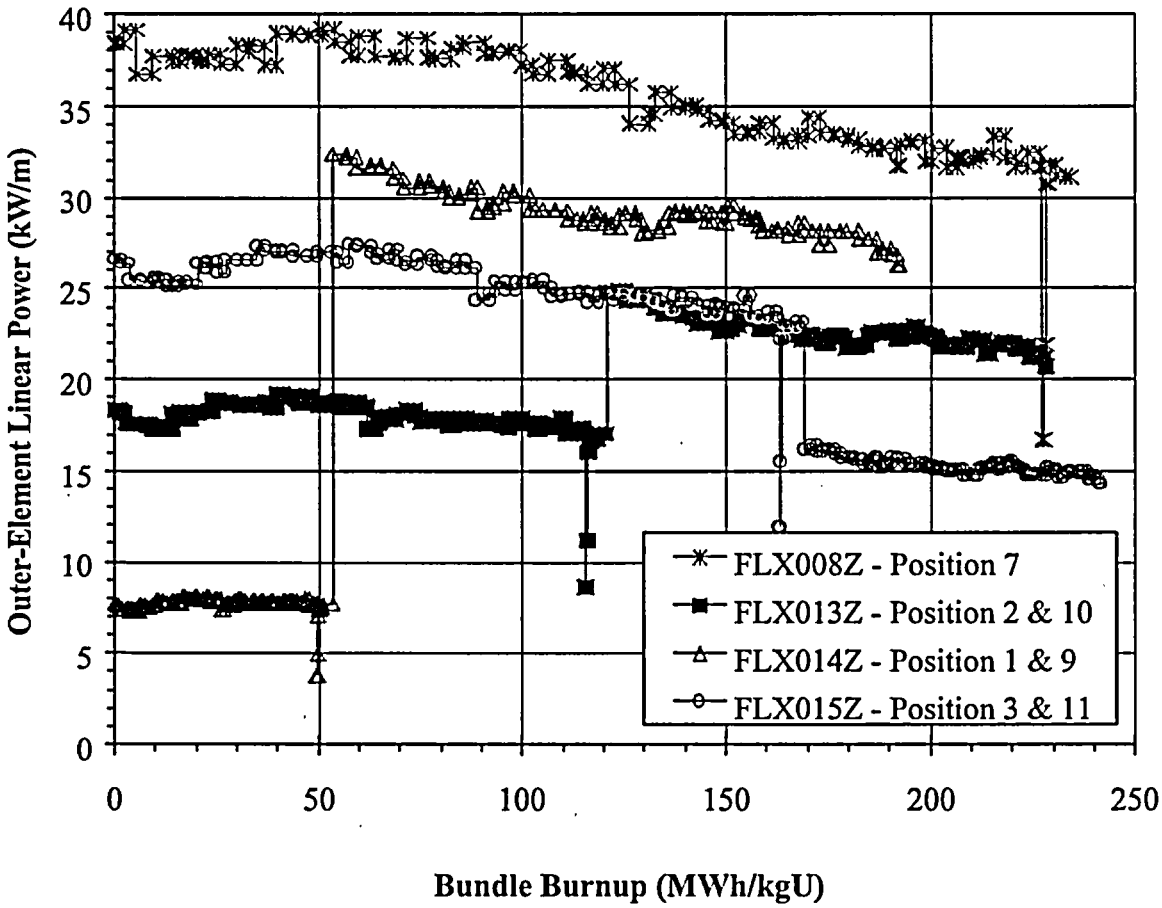


Figure 6: CANFLEX DI Element Diameter Profile

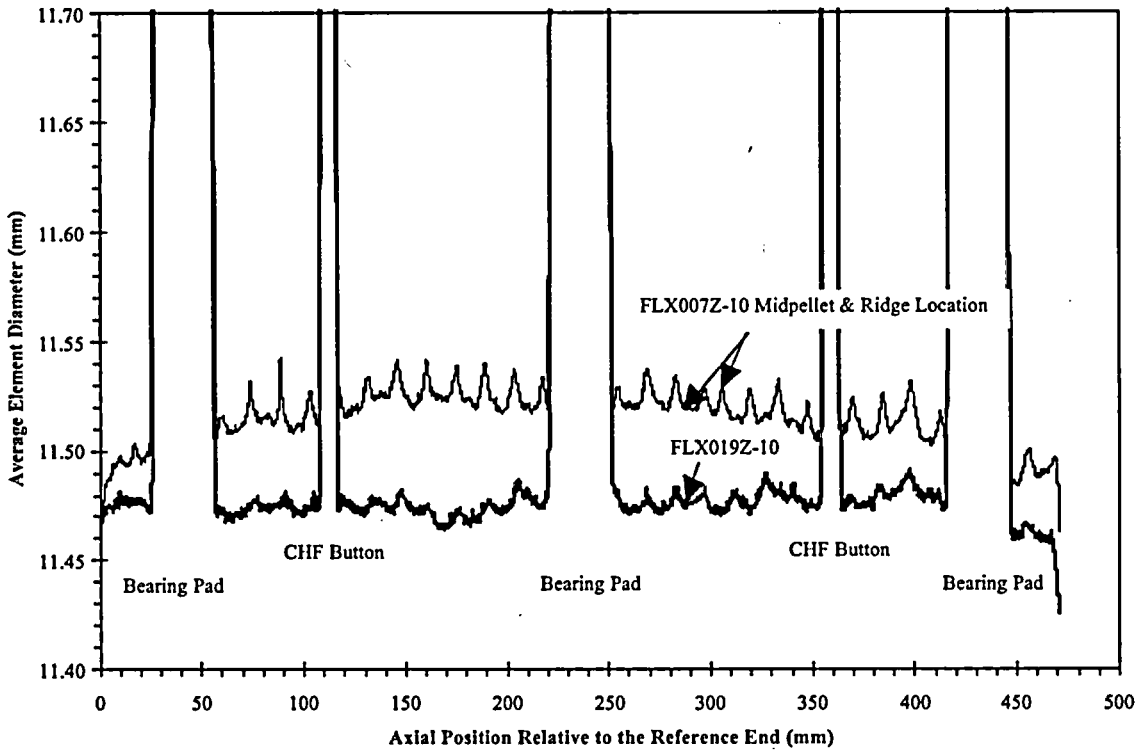


Figure 7: Gamma Scan Profile

Lepreau Canflex Bundle FLX007Z. Element 10. 2000 April 27.

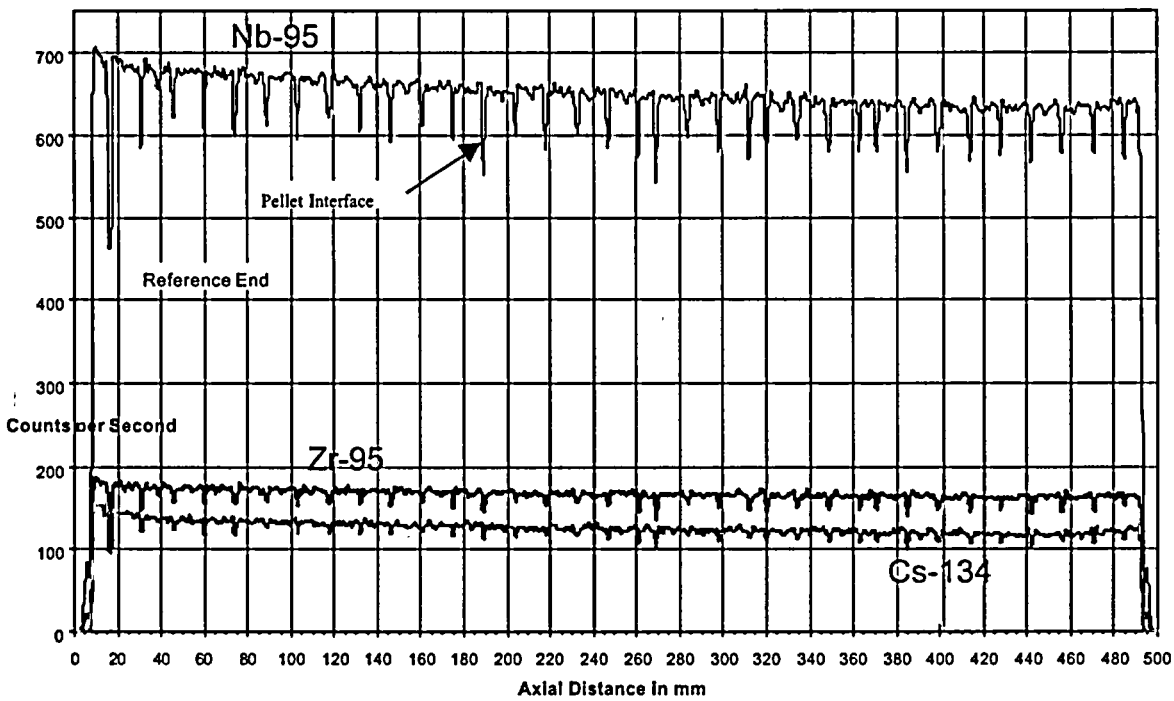
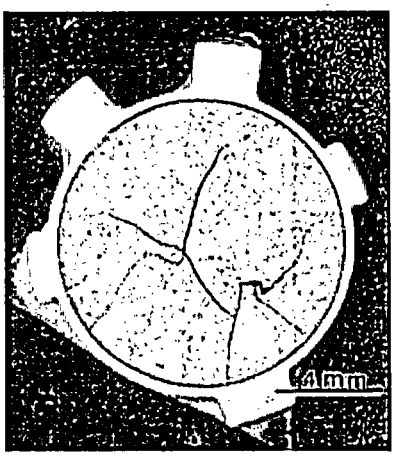
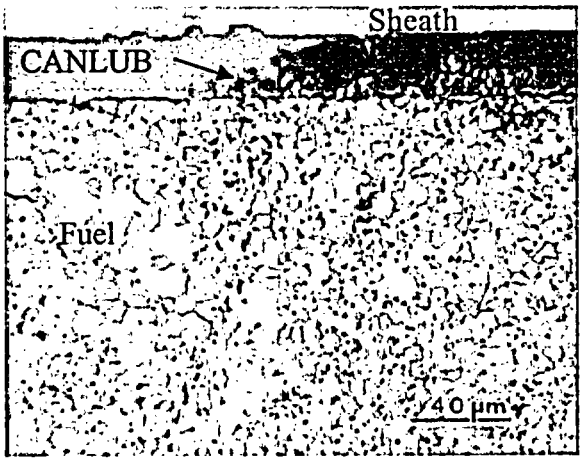


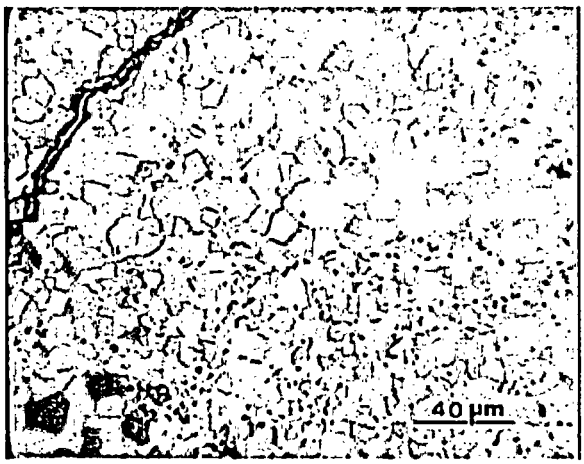
Figure 8: FIX019Z Element Fuel Microstructure Profile



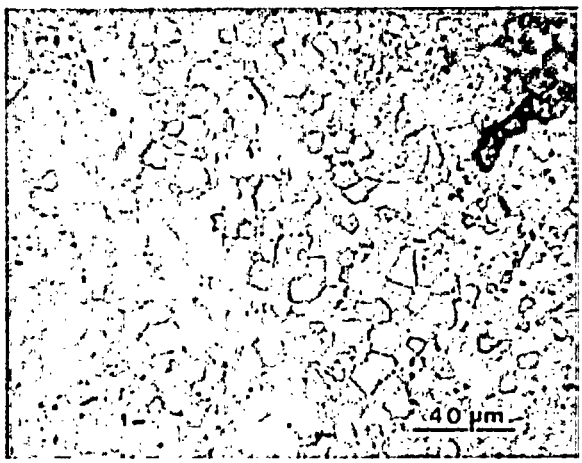
Macro Etched



Periphery



Mid-Radius



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