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POST-IRRADIATION EXAMINATION OF THE 37M FUEL BUNDLE AT CHALK RIVER LABORATORIES (AECL)

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ABSTRACT – The modified 37-element (37M) fuel bundle was designed by Ontario Power Generation (OPG) to improve Critical Heat Flux (CHF) performance in ageing pressure tubes. A modification of the conventional 37-element fuel bundle design, the 37M fuel bundle allows more coolant flow through the interior sub-channels by way of a smaller central element. A demonstration irradiation (DI) of thirty-two fuel bundles was completed in 2011 at OPG's Darlington Nuclear Generating Station to confirm the suitability of the 37M fuel bundles for full core implementation. In support of the DI, fuel elements were examined in the Chalk River Laboratories Hot Cells. Inspection activities included:

- Bundle and element visual examination
- Bundle and element dimensional measurements
- Verification of bundle and element integrity
- Internal Gas Volume Measurements

The inspection results for 37M were comparable to that of conventional 37-element CANDU fuel. Fuel performance parameters of the 37M DI fuel bundle and fuel elements were within the range observed for similarly operated conventional 37-element CANDU fuel. Based on these Post Irradiation Examination (PIE) results, 37M fuel performed satisfactorily.

Introduction

Life Management is imperative to maintain the safe, reliable and economic operation of CANDU reactors. As CANDU reactors age, pressure tubes experience irradiation assisted creep, resulting in flow bypass over the top of the fuel bundle. This has an effect on conventional 37-element fuel sub-channel cooling and critical heat flux (CHF) performance [1]. In 2010, Ontario Power Generation (OPG) began the demonstration irradiation (DI) of a modified 37-element fuel (37M) design at OPG's Darlington Nuclear Generating Station, which featured a smaller 11.5 mm (nominal) diameter centre element to improve bundle CHF in ageing pressure tubes [1]. Design changes made to the 11.5 mm diameter centre element included a reduction in the endcap dimensions and taller spacer pads.

The 37M DI bundles were discharged in 2011 and 2012 and examined in the Darlington irradiated fuel bays. Elements were removed from 37M bundles with bundle burnups in the typical operating envelope and were shipped to Chalk River Laboratories (CRL) for post-irradiation examination (PIE). An intact 37M bundle was subsequently shipped to CRL for PIE. The maximum bundle powers were between 600 kW and 800 kW (approximately 50 kW/m maximum outer element linear power).

Elements in a 37M bundle are numbered from 1 to 37 as shown in Figure 1. Element 37 is the 11.5 mm diameter centre element. At CRL, the bundle end with the manufacturer monogram on the endplate is referred to as the "Reference End" (RE) while the opposite non-monogram end is referred to as the "Non-Reference End" (NRE).

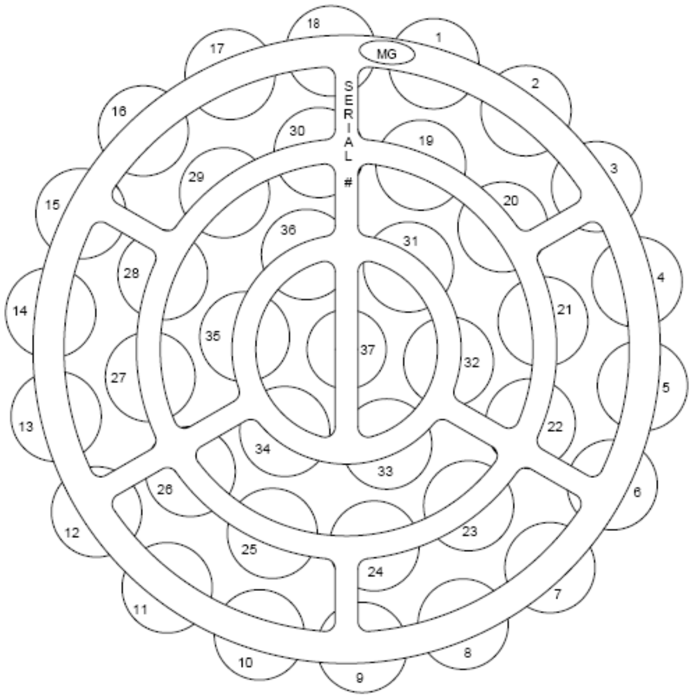


Figure 1 Element Numbering System and 37M RE Endplate Layout

1. Examination of the Intact 37M Bundle

The 37M bundle was shipped to CRL inside the Irradiated Material Transport (IMT) flask in 2011 and unloaded in AECL's Universal Cells Facility for examination. The 37M bundle was initially examined in the intact condition to assess its performance as a complete bundle. Disassembly of the bundle, required to assess the performance of individual fuel elements, was completed using a specialized milling apparatus.

1.1 Bundle visual examination

The 37M bundle and its endplates were visually examined using several inspection techniques and equipment (i.e., stereomicroscope, modified telescope and a radiation tolerant video camera). The bundle was found to be in good condition (Figure 2). Figure 3 shows an end-on examination which showed no interlocking spacer pads (interlocking spacers can affect a bundle's ability to compress during a fuelling operation). The bearing pad wear patterns and depth were typical of conventional 37-element fuel.

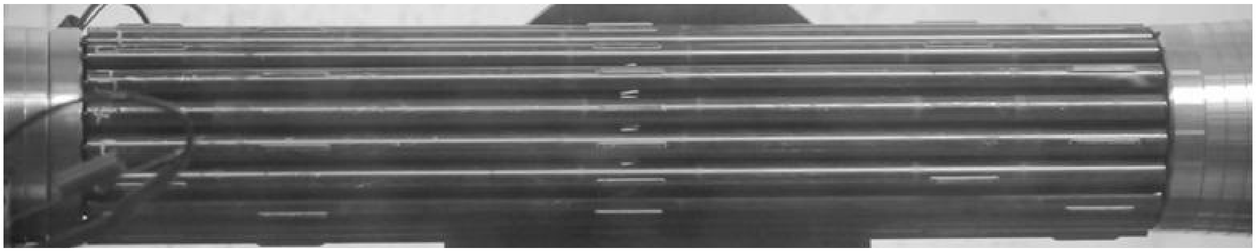


Figure 2 Intact 37M Bundle Mounted in the Profilometer Collets

Following visual examination, the intact bundle was subjected to dimensional mensuration using a profilometer, which included bundle-element bow, element length-over-endplate and endplate distortion measurements. Bundle-element bow represents the axial deformation of the bundle by measuring displacement relative to the ends of each element. A positive bow is away from the centre of the bundle, while a negative bow is toward the centre of the bundle. Figure 4 shows a map of the outer element bow pattern. The 37M bundle conformed to the shape of the pressure tube, with elements bowing outward at the 3 and 9 o'clock positions, while the elements at the 12 o'clock position bowed inward (i.e., 12 o'clock position represents the top of the pressure tube). The elements at the 6 o'clock position (i.e., Elements 13 and 14) generally have little bow. The bundle-element bow was comparable to previous measurements for conventional 37-element bundles ([2], [3]).

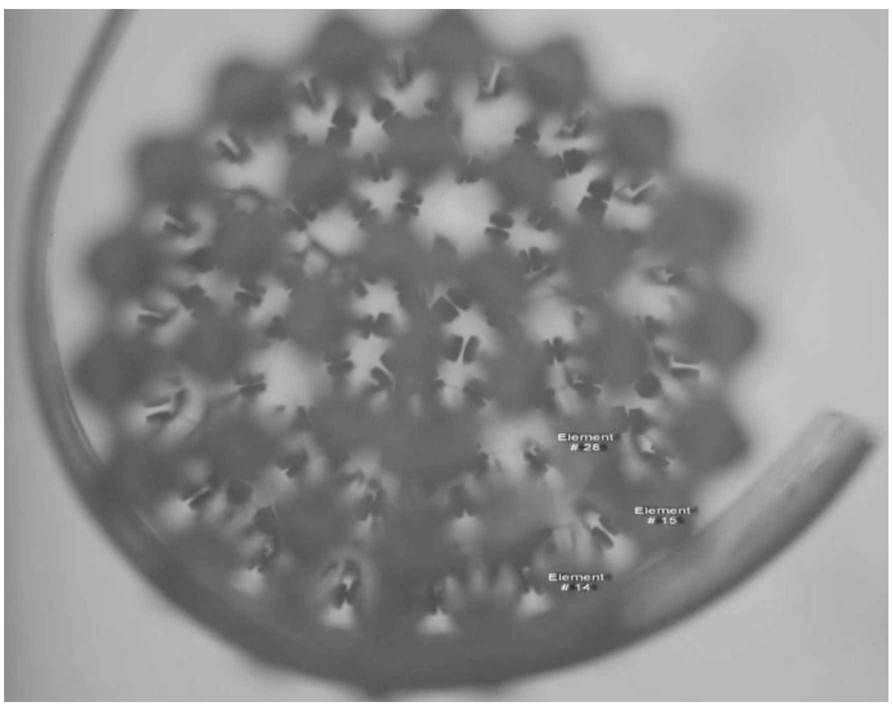


Figure 3 Inspection for Interlocking Spacer Pads

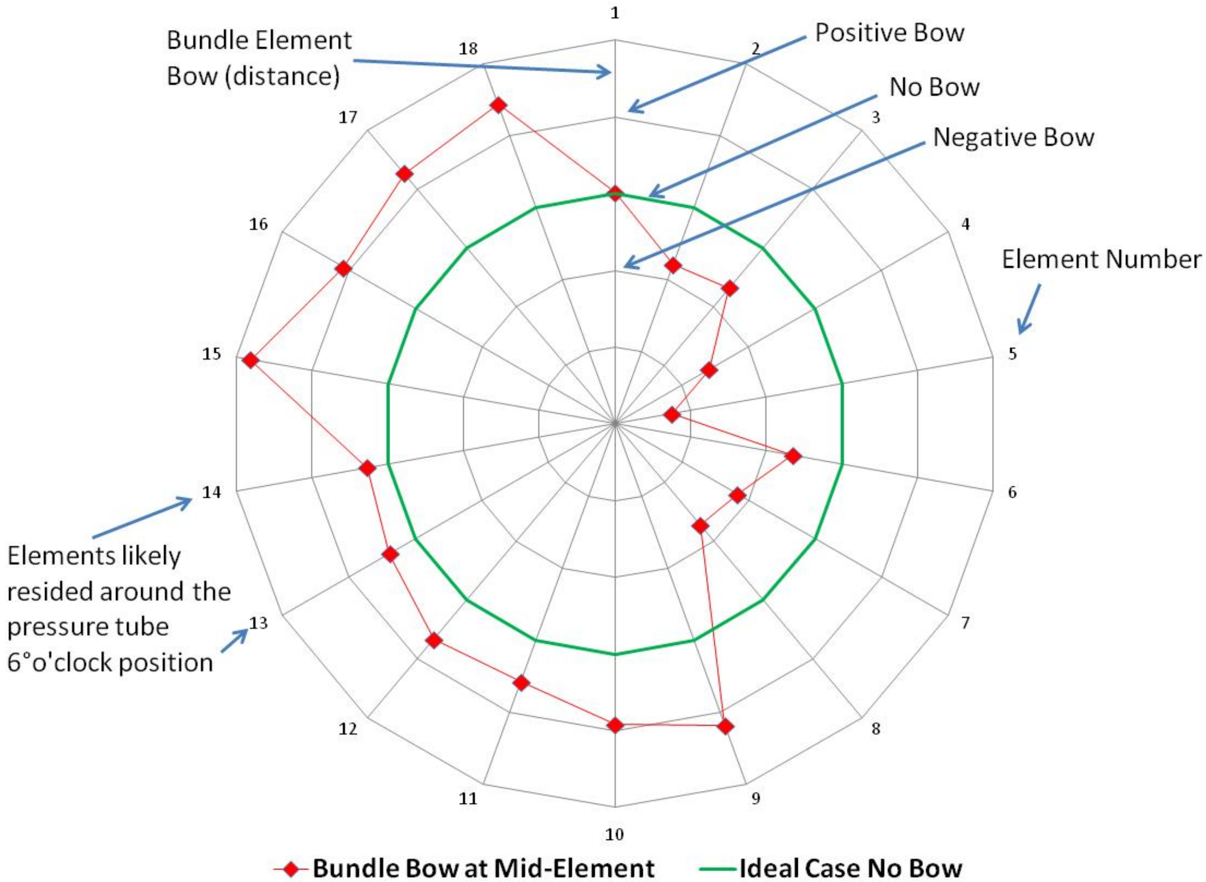


Figure 4 Bundle Bow Map

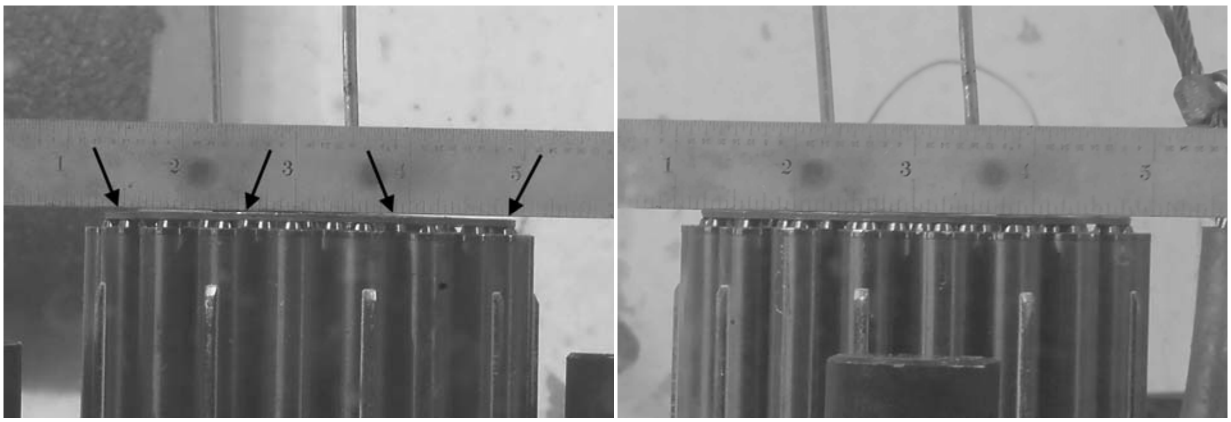
1.2 Bundle mensuration

The length-over-endplate apparatus measures the endplate-to-endplate post-irradiation bundle length with respect to a calibrated standard. Lengths were recorded and averaged at locations where 36 outer, intermediate and inner elements were welded. The average bundle length was within the design specifications.

Endplate distortion is a measurement of the deformation that an endplate undergoes during irradiation. A large deformation can result in endplate cracking or loss of endplate integrity. The endplates were visually checked for distortion by placing a straight edge against the endplate, as shown in
Figure 5. Fuel bundles in Darlington Nuclear Generating Station reactors are supported against the coolant flow using a latching system that contacts the downstream bundle at outer element positions. This results in slight deformation of the endplates, which support intermediate, inner and centre elements. The downstream reference endplate was domed (as expected;
Figure 5). The upstream NRE endplate was dished. The endplate distortion was within the range observed for conventional 37-element bundles irradiated at the Darlington Nuclear Generating Station.

1.3 Bundle dissassembly

The 37M bundle was placed in a supporting “clamshell” apparatus to maintain bundle integrity during the milling process. Endplate webs were cut such that the assembly welds (i.e., endcap-to-endplate welds) remained intact for incipient crack and torque testing.



RE Endplate (Arrows Show Gap Resulting from Endplate Doming) | NRE Endplate (Measurements Confirmed Dishing)

Figure 5 Endplate Visual Observations

2. Examination of Elements from the 37M Bundle and Elements Shipped from Other 37M Bundles

Detailed element examinations were completed on the 37 elements from the disassembled 37M bundle and disassembled elements from other 37M bundles. All elements were visually examined under a stereomicroscope and their diameters were profiled. Selected elements were subjected to endplate assembly weld torque testing. The internal gas volumes of twelve disassembled elements were measured.

2.1 Assembly weld torque testing

The assembly weld torque strength was measured by rotating the endplate material with a torque wrench while an element was mechanically restrained in a test fixture. All the measured torque strengths met the assembly weld torque specification.

2.2 Visual examinations

<u>2.2.1 Elements from the disassembled 37M bundle</u>

Elements from the disassembled 37M bundle were visually examined in four axial planes. The elements were in good condition. Most elements had marks, scrapes and scratches, consistent with normal handling. Minor deposits/stains were observed on some of the elements, comparable to what has been observed during past irradiated fuel PIE.

The observed sliding wear on the bearing pads for the outer elements was lighter for elements 1 through 9, which indicated that these elements resided in the top half of the pressure tube. This was in agreement with the bow measurements, which indicated that elements 13 and 14 resided at the bottom of the pressure tube.

The inner and intermediate elements were in very good condition. As expected, there were fewer handling mark, scrapes, and scratches observed in these two rings (compared to the outer elements). The 11.5 mm diameter centre element (element 37) was also in very good condition.

Spacer pad wear had no indication of spacer pad interlocking or excessive wear from vibrations and was below the design limit.

2.2.2 Disassembled elements from other 37M bundles

Several outer elements, each from different 37M bundles, were visually examined in four axial planes. In general, the outer elements were in good condition with scratches and scrapes typical of normal in-bay and hotcell handling. Typical sliding wear was observed on the bearing pads. Intermediate, inner and centre elements were also examined and found good condition. The sheath and endcaps on the smaller centre elements appeared comparable to the outer, intermediate and inner elements. Spacer pads had wear depth well below the design limit. The assembly welds were observed free of defects.

2.3 Element mensuration

All elements from the 37M bundle and the disassembled element shipment were measured using a using a profilometer. Element diameters were measured in three orientations to a precision of ± 0.01 mm. Residual sheath strain was calculated using fuel manufacturing data and the measured diameters. Element centre-line bow was measured as the displacement from a straight line drawn from each end of the element. Outer element bow between bearing pad was measured as the displacement from a straight line drawn between the bearing pads.

2.3.1 Sheath diameter, strain and ridging

All elements in the 37M bundle exhibited pellet ridging, except for the centre element. Figure 6 to Figure 9 show diameter profile examples of the outer, intermediate, inner and centre elements. Similarly, the centre elements from the disassembled element shipment did not exhibit sheath ridging. Some outer, intermediate and inner elements from the lower powered bundles had no ridging (as expected). The average residual sheath strains are within the range observed for conventional 37-element fuel. The mid-pellet residual sheath strains were within the expected operating envelope [4]. Pellet interface ridge heights were within the range of that observed in similarly operated conventional 37-element fuel.

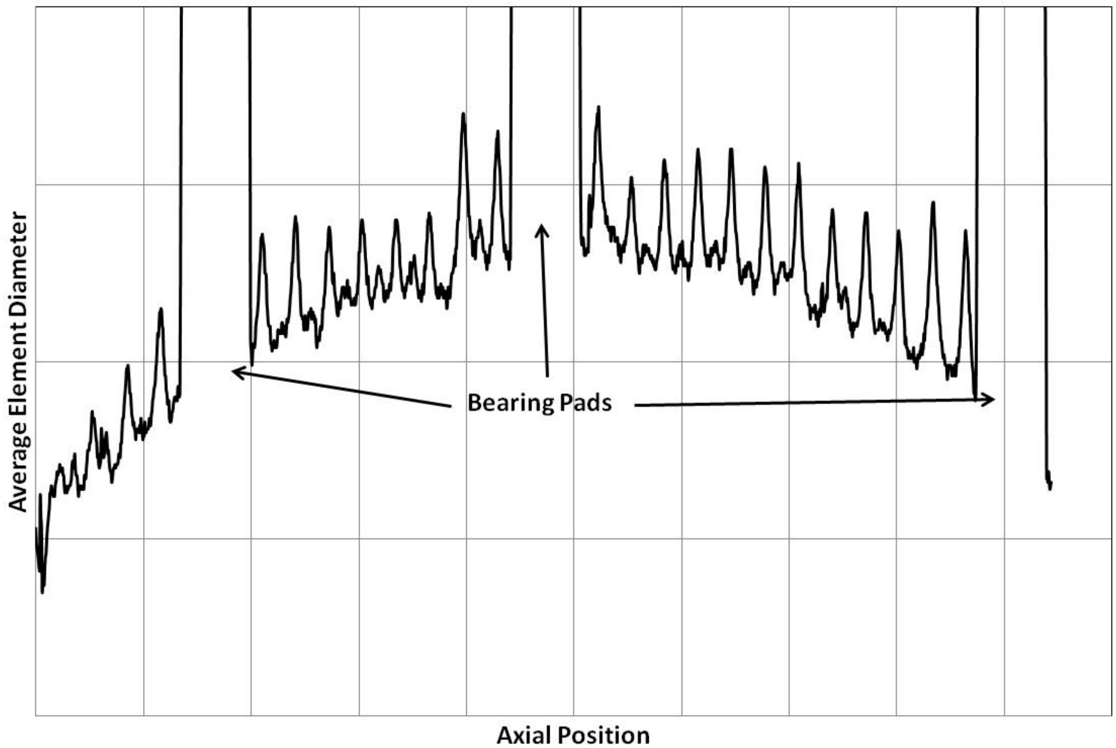


Figure 6 Example of Outer Element Average Diameter Profile

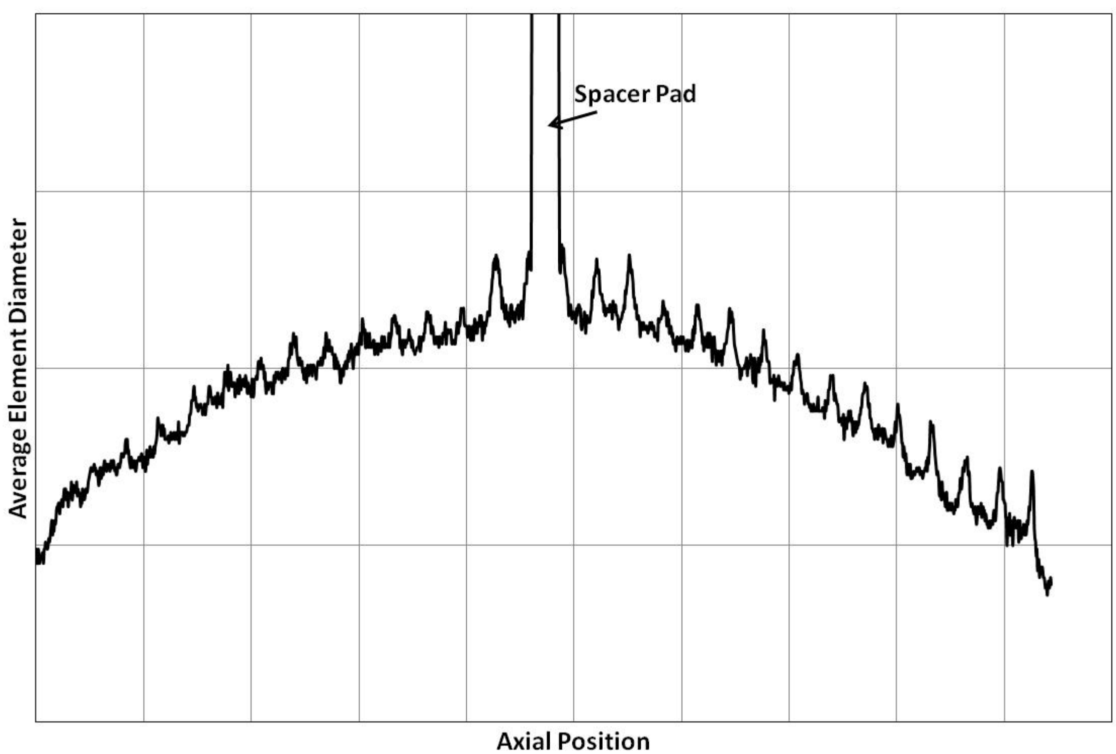


Figure 7 Example of Intermediate Element Average Diameter Profile

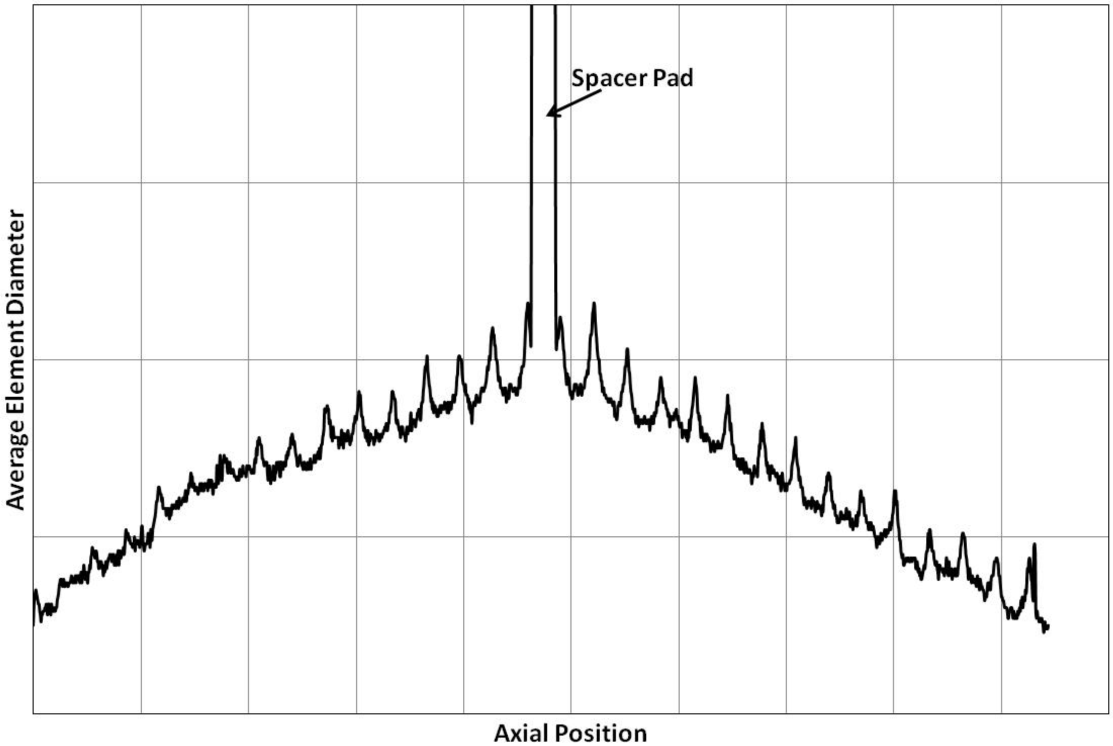


Figure 8 Example of Inner Element Average Diameter Profile

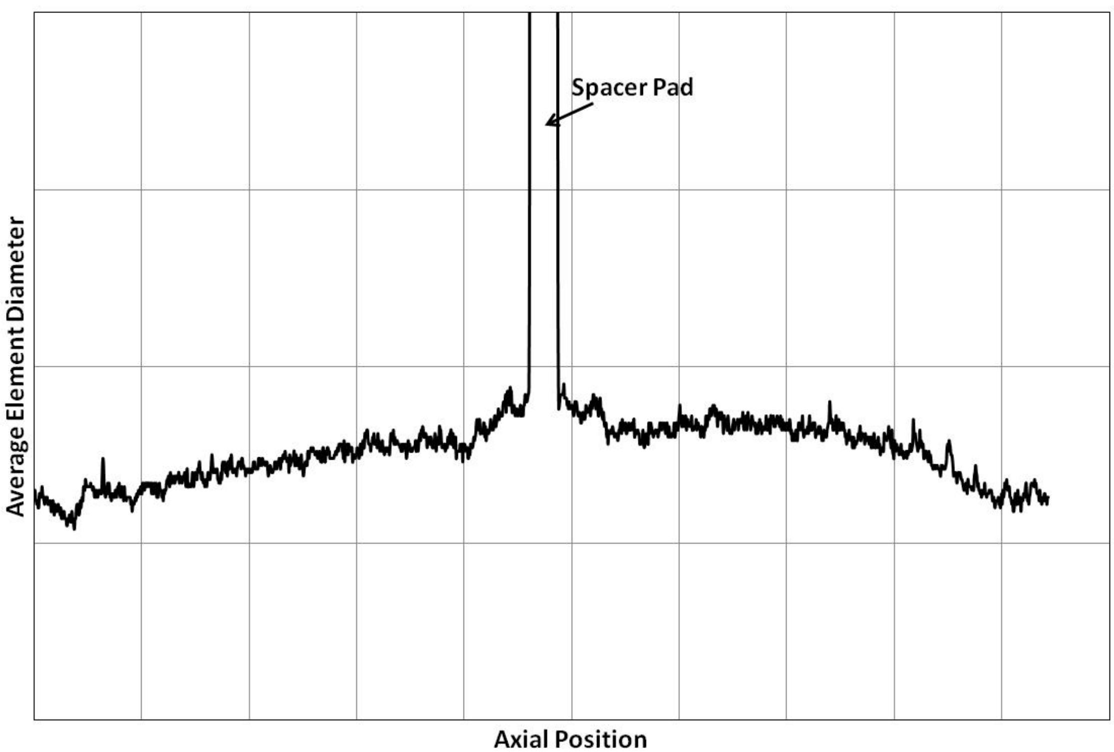


Figure 9 Centre Element Average Diameter Profile

2.3.2 Element bow

The element centre-line bow was measured at three orientations (i.e., 0º, 120º and 240º). The 0º orientation corresponds to the bearing pad plane for the outer elements and reference spacer pads for the intermediate, inner and centre elements. The largest deviation from the centre-line was comparable to that previously observed in conventional 37-element fuel.

The element bow between bearing pads was comparable to that previously observed in conventional 37-element fuel.

2.4 Element internal gas volume

The gas volumes for twelve 37M elements were measured using CRL's' custom-built FCV1000 equipment. The FCV1000 calculates the volume of gas in an element by puncturing the element in a vacuum and measuring the resulting pressure rise into a known volume. As expected, the centre (11.5 mm diameter) elements had the lowest gas volumes. The gas volumes were typical of fuel that operated to similar burnups and powers [5], and were well below the OPG operating limit [5].

3. Conclusions

One 37M DI bundle and disassembled elements from four 37M DI bundles were examined at CRL. The fuel performance parameters for the 37M fuel were within the range observed for similarly operated conventional 37-element CANDU fuel, including endplate distortion, bundle-element bow, spacer pad/bearing pad wear, residual sheath strain and element fission gas volumes. The 11.5 mm diameter centre elements fuel performance were found within the range observed for elements of that size [6]. Based on these Post Irradiation Examination results, 37M fuel performed satisfactorily.

4. References

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