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Status of the Development of CANFLEX 0.9% SEU

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ABSTRACT

Atomic Energy of Canada Ltd. (AECL) participates in international collaboration programs on slightly enriched uranium (SEU) with the Korean Atomic Energy Research Institute, British Nuclear Fuel plc. and most recently with Nucleoelectrica Argentina S. A. (NASA). In Argentina, NASA has successfully converted Atucha I from natural uranium to 0.85% SEU. Significant fuel cycle cost reductions were realized, and NASA wishes to explore similar concepts to reduce operating costs of its Embalse reactor. This collaboration covers the first phase of a 3-phase program. If the study confirms the feasibility and benefits of SEU, then the program could move onto a demonstration irradiation and, potentially, full-core implementation of SEU fuel at Embalse.

This paper will provide an overview of the CANFLEX® 0.9% fuel concept. Reactor physics assessment of the conversion of a natural uranium core to an enriched core will be presented. The feasibility of conducting a demonstration irradiation of SEU fuel in a reactor core of natural uranium fuel will be covered. Preliminary assessments of the safety and licensing implications will be summarized.

INTRODUCTION

The use of 0.9% slightly enriched uranium (SEU) fuel offers significant benefits to CANDU® reactor operators. SEU fuel improves fuel cycle economics by increasing the fuel burnup, which enables large cost reductions in fuel consumption and in spent fuel disposal. SEU fuel offers enhanced operating margins that can be applied to offset aging effects, or to increase reactor power. These benefits can be realized using existing fuel production technologies and practices, and with almost negligible changes to fuel receipt and handling procedures at the reactor. The application of SEU is an important element in AECL's Next Generation reactor design.

Since the early 1990's, AECL and the Korean Atomic Energy Research Institute (KAERI) have pursued joint development of the CANFLEX® fuel bundle. Since 1994, AECL and British Nuclear Fuel plc (BNFL) have pursued an exchange of information co-operation program in SEU and recycled uranium (RU). In 2000, AECL and Nucleoelectrica Argentina S. A. (NASA) agreed to a collaborative program to study the feasibility of converting Embalse to SEU, in order to realize reduced operating costs and to provide a strategy for increasing reactor power.

A unique feature of the CANDU reactor design is its ability to use alternative fuel cycles other than natural uranium (NU), without requiring major modifications to the basic reactor design. These alternative fuel cycles, which are collectively known as advanced fuel cycles, utilize a variety of fissile materials, including SEU from enrichment facilities, and RU or plutonium obtained from the reprocessing of the spent fuel of light-water reactors (LWR). While the choice of a particular advanced fuel cycle depends on economics and resource conservation, as well as political considerations, the SEU fuel cycle is generally considered as the first logical step beyond the NU fuel cycle.

This paper provides early results of the physics and safety assessments concerning the converting of an operating CANDU 6 reactor from NU to SEU.

CANFLEX 0.9% SEU REFERENCE DESIGN

The CANFLEX design has been chosen as the fuel carrier for SEU. The maximum element linear-power rating of the CANFLEX fuel elements is 20% lower than that for 37-element bundles, leading to lower fuel temperatures. As a result, 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 lower fission-gas inventory results in lower element gas pressure, which enables higher burnups and reduces the consequences of most design-basis accidents.

Previous studies of CANDU SEU fuel cycles have shown that the optimal enrichment is between 0.9 wt% ^{235}U and 1.2 wt% ^{235}U. 0.9% SEU is chosen as the reference enrichment level for this study, because

- most of the benefits of the SEU fuel cycle are achieved between 0.9% and 1.0%,
- 0.9% SEU is below the threshold at which criticality considerations would have significant impact on fuel fabrication and fuel handling,
- the refuelling scheme is uniform 2- or 4-bundle shift, and transition from NU to SEU in a current CANDU can be easily accomplished with 0.9% SEU, and
- the neutronic properties of 0.9% SEU fuel are similar to those of the RU fuel, which is expected to be cheaper than equivalent SEU fuel.

RU, which is available as a by-product of conventional reprocessing of LWR fuel, can be considered as a subset of SEU. The fissile content of RU is nominally between 0.9% ^{235}U and 1.0% ^{235}U, depending on the initial fissile content and the discharge burnup of a particular batch of spent LWR fuel.

The reference fuelling scheme for CANFLEX 0.9% SEU fuel bundles is a 4-bundle shift where possible, and a 2-bundle-shift for the central channels. Since the fuel burnup for 0.9% SEU is twice that of NU fuel, the 4-bundle shift is equivalent to the current 8-bundle shift in fuelling rates, but 2-bundle shift would require a significantly higher fuelling rate. Alternate duty cycles are being assessed to reduce fuelling machine usage. Strategies are being explored to limit or eliminate the need for using 2-bundle shifts.

The reference design uses 0.9% enrichment in all 43 elements. Alternatively RU from spent PWR fuel can be considered as a lower-cost source of enrichment. The enrichment can be varied to tailor the burn-up, in order to address the specific needs of the application.

CANFLEX 0.9% SEU FEASIBILITY STUDY

CANFLEX is an appropriate vehicle for introducing SEU, because it reduces linear-power element ratings, thereby reducing fuel temperatures and gas releases, and facilitating the achievement of extended burnups. CANFLEX also provides a greater critical channel power margin than the 37-element bundle. The CANFLEX Mk-IV fuel bundle design has been qualified for the NU application.

The principle issues that must be considered with the use of SEU in CANDU are

- higher burnups, resulting in (1) longer residence time, (2) potential for higher fission gas production, and (3) greater decay heats in the spent fuel, all requiring design analysis and assessments.
- higher reactivity of the fuel, which requires different on-power fuelling schemes, resulting in different axial flux shapes that must be established through physics assessments, and that must be balanced with the duty-cycle for the fuelling machines. Bundle power, channel power and thermalhydraulic performance must be maintained.

The feasibility of transitioning the core from NU to SEU with no loss of reactor power, while maintaining safety and fuel performance standards, must be considered. To implement the fuel, it must be qualified; therefore, consideration must be given to a power reactor demonstration irradiation of SEU in a NU core. Finally, the overall economic impact of SEU on the capital and operating costs must be defined, as this will be the primary driver in switching to a new fuel type. Early work has concentrated on the reactor physics assessment and safety assessment, as presented in the following sections.

FEASIBILITY OF CONDUCTING A DEMONSTRATION OF CANFLEX SEU FUEL IN AN EXISTING CANDU 6 NU CORE

It is prudent to demonstrate the performance of SEU bundles under operating reactor conditions, prior to beginning the full-scale conversion from NU fuel to SEU fuel. This demonstration can be accomplished by irradiating a few SEU bundles in an operating reactor for a significant period of time. The discharged SEU fuel bundles would be examined closely in post-irradiation examination (PIE) hot cells, in order to confirm that the SEU fuel performance is within design specifications.

The demonstration irradiation (DI) of SEU bundles in a reactor currently operating with NU fuel requires careful planning, because the reactivity of the SEU fuel is significantly higher than that of the NU fuel. Hence, the presence of fresh SEU fuel could cause some local power peaking effects at the beginning of the DI. However, by choosing the appropriate channels and fuelling schemes for the DI, these local power perturbations can be mitigated. A reactor physics simulation of the DI of several SEU bundles in an operating CANDU 6 reactor has been conducted by using the RFSP-IST [4] and WIMS-AECL [5] codes to demonstrate that both the SEU fuel and the NU fuel can operate within current operating and safety limits during the DI period. An instantaneous fuel burnup distribution in a typical CANDU 6 core was used as a starting point of the DI simulation.

Channels L03, L11 and L20 in a CANDU 6 reactor have been identified as good candidates for the DI. Channels L03 and L20 are located outside the adjuster rod region, while L11 is a central channel inside the adjuster rod region. These channels are chosen primarily because of their moderate channel powers in the NU reactor. The fuel management scheme chosen for the DI channels is a 4-bundle shift with 0.9% CANFLEX SEU fuel for the first visit, and a 2-bundle shift with 37-element NU fuel for subsequent visits at the same channel. Hence, each DI channel contains four SEU fuel bundles. These SEU bundles are pushed through the channel using 2-bundle-shift NU fuel at 50 FPD intervals. All the SEU fuel bundles are discharged from the reactor after 300 FPD with an average discharge burnup of 13 MWd/kg.

In channel L03, the maximum channel power and maximum bundle power during the simulation period are 6.4 MW(th) and 890 MW(th), respectively, when the four SEU bundles are in the central locations, i.e., bundle positions 5,6,7 and 8 of the channel. Under these conditions the maximum element rating is below 47 kW/m, and the maximum element boost power is below 25 kW/m at a burnup of about 3.0 MWd/kg. Similar results are observed in the other two DI channels. There were no significant axial power distortions in the NU channels adjacent to the DI channels during the entire DI period when the SEU bundles were in different axial locations in the DI channels. The results of the DI simulation indicate that the DI of 12 SEU bundles can be carried out in an operating CANDU 6 reactor without affecting the reactor operation, and without posing a risk to either the SEU or the NU fuel.

Figure 1 shows the channel powers in the DI channel L03 and its NU neighbour K03, during the DI period. The corresponding maximum bundle powers are shown in Figure 2. Channel L03 has been refuelled six times using 2-bundle-shift NU fuel, and channel K03 has been refuelled twice using 8-bundle-shift NU fuel during this period. The maximum channel and bundle powers are all within operating limits.

PHYSICS ASSESSMENT OF THE TRANSITION TO AND OPERATION OF A 0.9% SEU-FUELLED CORE

The RFSP-IST and WIMS-AECL codes were used to simulate the transition from NU to 0.9% SEU in an operating CANDU 6 reactor. The starting point of the RFSP transition simulation corresponds to an actual reactor core configuration and fuel burnup distribution from an operating CANDU 6 reactor, with a full core of 37-element NU bundles. All these NU bundles are replaced by CANFLEX 0.9% SEU bundles using on-power fuelling over a simulation period of 726 FPD.

Fuelling Scheme For the Transition. The fuelling scheme used is a 4-bundle shift for the first introduction of the SEU fuel in a channel, and 2-bundle shifts with SEU fuel for all subsequent fuelling in the same channel. The refuelling simulations are carried out at intervals of 2 FPD, using both bulk and spatial control options with distributed xenon properties. The fuelling schemes for the transition study have been chosen for the following reasons:

- Using 2-bundle-shift fuelling at the beginning of the transition would give a very small increase in reactivity, because of the relatively low neutron flux levels at these positions at the ends of the channels. This would require the fuelling of more than 6 channels per FPD at the onset, resulting in excessive demand on the fuelling machine.

- The maximum distortion of the axial bundle power profile occurs in the period when there is a mixture of 4 SEU and 8 NU bundles in different channels in the reactor. It is highly desirable to get over this period as fast as possible.
- The use of a 4-bundle-shift fuelling scheme at the onset results in reasonable fuelling machine usage and acceptable axial bundle power profiles. However, the 4-bundle-shift scheme cannot be used for subsequent fuelling in the same channel, because the refuelling power ripple becomes excessive.
- The combination of a 4-bundle shift for the first introduction of the SEU fuel in a channel and a 2-bundle shift for all subsequent fuelling in the same channel appears to give the best results in terms of fuelling machine usage, axial bundle power profiles, and refuelling power ripples.

The fuelling rate is about 11.2 bundles per FPD for the first 100 FPD, and gradually declines to the equilibrium fuelling rate of about 8.8 bundles per FPD after 500 FPD.

Acceptance Requirements. The channels to be refuelled in each time step were carefully chosen to meet the following conservative requirements over the entire simulation period:

- the maximum channel power should not exceed 6.9 MW(th),
- the maximum bundle power should not exceed 850 kW(th),
- the average zone control level should remain between 30% and 70%, and
- individual zone control levels should remain between 10% and 90%.

CANDU 6 reactors are currently licensed to operate at a maximum channel power of 7.3 MW(th) and maximum bundle power of 935 kW using 37-element fuel bundles. The requirements used in the transition simulations are within these limits, with large conservative margins. Furthermore, the CANFLEX design could potentially allow an increase in these limits.

Bundle and Channel Powers. Although the simulation period covered 726 FPD, the maximum channel power, maximum bundle power and fuelling rate became relatively stable after 500 FPD, when most of the NU bundles had been discharged from the core. At 726 FPD, it is estimated that the reactor will have been operating at equilibrium SEU core conditions for a significant period of time.

Figure 3 shows the maximum channel power as a function of FPD in the transition simulation. The power is kept between 6.7 MW(th) and 6.9 MW(th) essentially for the entire simulation. The maximum channel power was below 6.7 MW(th) for a few cases, but it was never allowed to exceed 6.9 MW(th), a self-imposed conservative requirement. However, thermalhydraulic assessments may be required for those channels with significant axial power distortions to determine the appropriate CCP limits.

During the first 150 FPD of the transition, the presence of four or six SEU bundles at the up-stream end of the fuel channels created very significant distortions in the axial power profile. However, by keeping the maximum channel power below 6.9 MW(th), it was possible to keep the maximum bundle power at or below 850 kW(th), similar to the situations in the current NU reactor. The axial bundle power profile in the equilibrium SEU core is naturally flatter than that in an equilibrium NU core. As the transition progressed, more NU bundles were replaced by SEU bundles. The maximum bundle power began to decrease steadily, until the axial bundle

power shape approached that in an equilibrium SEU core. The variation of maximum bundle power as a function of FPD in the transition is shown in Figure 4. At 726 FPD, the maximum bundle power is about 800 kW, significantly lower than that in an equilibrium NU core.

The axial bundle power distributions at different stages during the transition in channel L03 are shown in Figure 5. This channel is outside the adjuster rod region, and it was refuelled eight times within this period. The introduction of the first four SEU bundles produces a severe axial power distortion. However, as more SEU fuel bundles are introduced at later stages, the distortion subsides. The axial power shape approaches the smooth inlet-skewed equilibrium SEU power shape after FPD 300. This flattened inlet-skewed power shape is a consequence of the simple 2-bundle-shift scheme used with SEU fuel. It is more desirable than the centre-peaked NU power shape, because it gives higher critical channel power (CCP) margins. Adjuster rods are not required, nor are they desirable for shaping the axial power profile in an SEU core. They can cause significant axial power distortions during the transition.

Figure 6 shows the axial bundle power distributions in Channel L11 at different stages during the transition. This channel is inside the adjuster region and it is also close to two zone controllers. Channel L11 was refuelled 8 times in this period. It can be seen that the axial power shape in channel L11 is already distorted before this channel is refuelled the first time. This distortion is created by the introduction of SEU fuel bundles in the adjacent channels. The introduction of the first 4 SEU bundles in L11 produces a severe double-humped axial power distortion. Introduction of SEU bundles in neighbouring channels at this time would further increase the axial power distortion in Channel L11. However, as more SEU fuel bundles are introduced in Channel L11 at later stages, the distortion decreases slowly. A smooth, but still double-humped axial power shape prevails after FPD 500. Because the SEU bundle power profile is naturally flat, the adjuster rods over flatten the axial power shape in an SEU core, creating an undesirable double-humped axial power shape.

Performance of Fuel Elements in Transition Core. The severity of the double-humped axial power distortion in inner-region channels suggests that a small number of fuel elements could be subjected to high power ratings and high power boosting during the transition. The outer elements in the NU 37-element bundles are most susceptible to excessive power boosting when they are pushed from bundle positions 7 and 8 (from inlet-end) to positions 9 and 10 during refuelling. The analysis of all outer elements in the NU 37-element bundles found no cases where both the normal power rating threshold and the power boost threshold were exceeded. The analysis concluded that the overall risk of fuel failure should be minimal. However, there were a small number of elements whose power boost ratings exceed the SCC threshold. All the elements in the three inner fuel rings are below the SCC defect threshold curves for normal operation and for power boost. Hence, there is no risk of fuel defect for these elements.

The NU elements are subjected to high operating powers and high refuelling power boosting only during the first 150 FPD of the transition, when the axial power shape is severely distorted. Furthermore, only the NU fuel elements in the inner core region are at risk. Therefore, several methods can be deployed to ensure good fuel performance:

- Raise the central adjuster rods (banks 6 and 7) before the start of the transition, and keep them locked out of the core until the equilibrium SEU core condition is reached. It should be noted that with SEU fuel, adjuster rods are not needed to flatten the flux and power

distributions. Hence, if they are not needed for another purpose, they can be removed altogether.

- Fuel the channels in the inner 10-by-10 square with CANFLEX NU bundles before the start of the transition, if the locking out of the central adjuster rods is not an option. The lower element rating in the CANFLEX design will keep the NU fuel element ratings below the SCC defect thresholds.
- Monitor the axial channel power shape carefully, especially during the first 150 FPD. The element ratings can be kept below the SCC defect thresholds by refuelling the inner channels judiciously.

The element ratings of all the CANFLEX SEU fuel elements for nominal power operation during the transition are significantly below the SCC defect threshold. The power boost ratings for all CANFLEX SEU fuel elements in the inner three fuel rings are also below the SCC power boost defect threshold curve. The power boost ratings of a very small number of ring-4 SEU fuel elements are slightly above the SCC defect threshold curve. Because the normal power ratings of all the CANFLEX SEU fuel elements are significantly below the SCC defect threshold curve, there is negligible risk of fuel failure for the CANFLEX SEU fuel.

The results of the RFSP simulations suggest that the reactor appears to operate at conditions similar to those in an equilibrium SEU core after 500 FPD. Therefore, power and burnup distributions for the period after 500 FPD are used to assess SEU fuel element ratings and power boost ratings in an equilibrium SEU core. Figure 7 shows the linear element rating for the ring-4 elements in the CANFLEX SEU fuel bundles for the period after 500 FPD. The power boost ratings for these fuel elements due to refuelling operations are shown in Figure 8. The results show that all the SEU CANFLEX fuel elements operate at power ratings and boost ratings significantly below the SCC defect threshold curves. Therefore, fuel failure for SEU CANFLEX fuel is not expected in an equilibrium SEU core.

Physics Summary Comments. Although this study shows that no change in the reactor operating procedure or hardware is required for the transition from an equilibrium NU core to an equilibrium SEU core, it is clear that the adjuster rods are not desirable during the transition. The option of locking some of the central adjuster rods out of the core during the transition period, even permanently, should be given serious consideration.

CANFLEX 0.9% SEU SAFETY IMPLICATIONS

The implementation of CANFLEX SEU fuel in a CANDU 6 reactor would have an overall beneficial effect in terms of safety margins during postulated reactor accidents. The main reason for this benefit is the reduction of more than 20% in the outer element linear powers of the fuel bundle, compared with the outer elements of a 37-element NU bundle. The effect of this reduction in element linear powers is that fuel temperatures, sheath temperatures and fission product release will all be lower for most design basis accidents. The higher fuel burnup would mean that the total inventory of long-lived fission products would be greater for CANFLEX-SEU fuel than for 37-element fuel; however, the distribution of the fission products would be different. Because of the lower fuel temperatures, the concentration of fission products in the fuel-to-sheath gap, as well as the grain boundaries, would be lower for CANFLEX-SEU fuel.

The effects of the above features of CANFLEX-SEU fuel upon the consequences of various postulated accidents in a CANDU reactor are outlined below.

Large Break Loss of Coolant Accident (LOCA). During a postulated LOCA, it is expected that the resultant power pulse within a CANFLEX-SEU core will be marginally greater than the power pulse within a CANFLEX-NU core, which, in turn, is greater than the power pulse within a 37-element fuelled core. The increase in the power pulse will be more than offset by the reduction in the outer element linear powers. The lower initial fuel temperatures will result in lower peak fuel centerline temperatures, thereby increasing the margins to fuel centerline melting. In addition, lower fuel temperatures will result in lower fuel string axial expansion, increasing channel integrity margins. Similarly, peak sheath temperatures of CANFLEX-SEU are expected to be lower than the peak sheath temperatures of 37-element fuel. The lower fuel and sheath temperatures will result in lower fission product release to the fuel-to-sheath gap, which will lead to fewer fuel failures and lower doses during a postulated large break LOCA. Because of the lower sheath temperatures, pressure tube temperatures will also be lower, resulting in less pressure tube/calandria tube contacts, and thus providing greater safety margins for channel integrity.

Large Break LOCA with Loss of Emergency Core Cooling (LOECC). In this postulated severe accident the CANFLEX-SEU bundle design could result in the potential for greater hydrogen generation within the containment structure, relative to the 37-element fuel. The higher burnup fuel will contain a greater long-lived fission product inventory than the current 37-element design, resulting in greater long-lived fission product release during a postulated LOCA/LOECC event. However, the inventory of short-lived fission products will be lower, since this inventory is strongly dependent upon element linear powers. A consequence of a flatter axial power profile is lower peak bundle powers within the channel—if low enough, then the elements could reach peak sheath temperatures that are below the metal/water reaction threshold, thus mitigating the production of hydrogen.

Small Break LOCA. The lower element linear powers, lower bundle powers, and an inlet skewed axial power distribution will all lead to greater margins with respect to fuel dryout during a postulated small break LOCA. This would substantially decrease the chances of fuel and channel failures.

Single Channel Events. For postulated single channel events, such as the complete channel flow blockage and feeder stagnation break, the lower element linear powers and peak bundle powers would result in a delay of channel failure for CANFLEX-SEU fuel, compared with 37-element fuel. The result would be marginally more molten material being generated at the time of pressure tube rupture. For the feeder off-stagnation break and end-fitting failure accidents, the two key parameters are fuel temperatures, and fission product content and distribution. The higher fuel burnup for SEU fuel will result in more long-lived fission products than would be found in 37-element fuel. However, the lower element linear powers would result in lower overall fuel-to-sheath gap and grain boundary inventories of fission products. This would mean that the initial release of fission products from SEU fuel would be lower. However, the long-term release may be greater, simply because of the greater total inventory of fission products compared with 37-element fuel. The mitigation measures would be the lower fuel temperatures of CANFLEX-SEU fuel that would reduce the oxidative release of fission products from the fuel matrix.

CONCLUSIONS

The CANFLEX 0.9% SEU fuel design has been established, and the fuel qualification and feasibility of applying it in existing CANDU 6 reactors is underway. The results of a 726 FPD RFSP simulation show that it is feasible to convert an existing CANDU 6 reactor from a full core of NU 37-element fuel to a full core of 0.9% SEU CANFLEX fuel, by on-power fuelling. The maximum channel power, the maximum bundle power, and the operating range of the zone controllers are all within the limits established for the current NU reactor. There is no risk of fuel failure for the SEU CANFLEX fuel elements in the transition core and in the equilibrium core. The results of DI simulations show that 12 SEU bundles can be irradiated in an operating CANDU 6 reactor without adversely affecting the reactor operation. The implementation of CANFLEX-SEU fuel into a CANDU 6 reactor would have an overall beneficial effect in terms of safety margins during postulated reactor accidents.

REFERENCES

1. I.J. HASTINGS, A.D. LANE and P.G. BOCZAR, "CANFLEX - An Advanced Fuel Bundle for CANDU", Int. Conf. Availability Improvements in Nuclear Power Plants, Madrid, Spain, 1989 April 10-14, and also AECL Report, AECL-9929 (1989).
2. A.D. LANE, G.R. DIMMICK, J.H.K. LAU, H.C. SUK, C.H. CHUNG and C.B. CHOI, "CANFLEX: A New CANDU Fuel Bundle with Expanded Operating Capabilities", Proc. 11th KAIF/KNS Annual Conference, Seoul, Korea, 1996 April 11-12.
3. B. ROUBEN, "Overview of Current RFSP-Code Capabilities for CANDU Core Analysis", Transactions of the American Nuclear Society, TANSAO 72, 339, 1995.
4. J.V. Donnelly, "WIMS-CRNL, A User's Manual for the CRNL Version of WIMS", AECL-8955, January 1986.

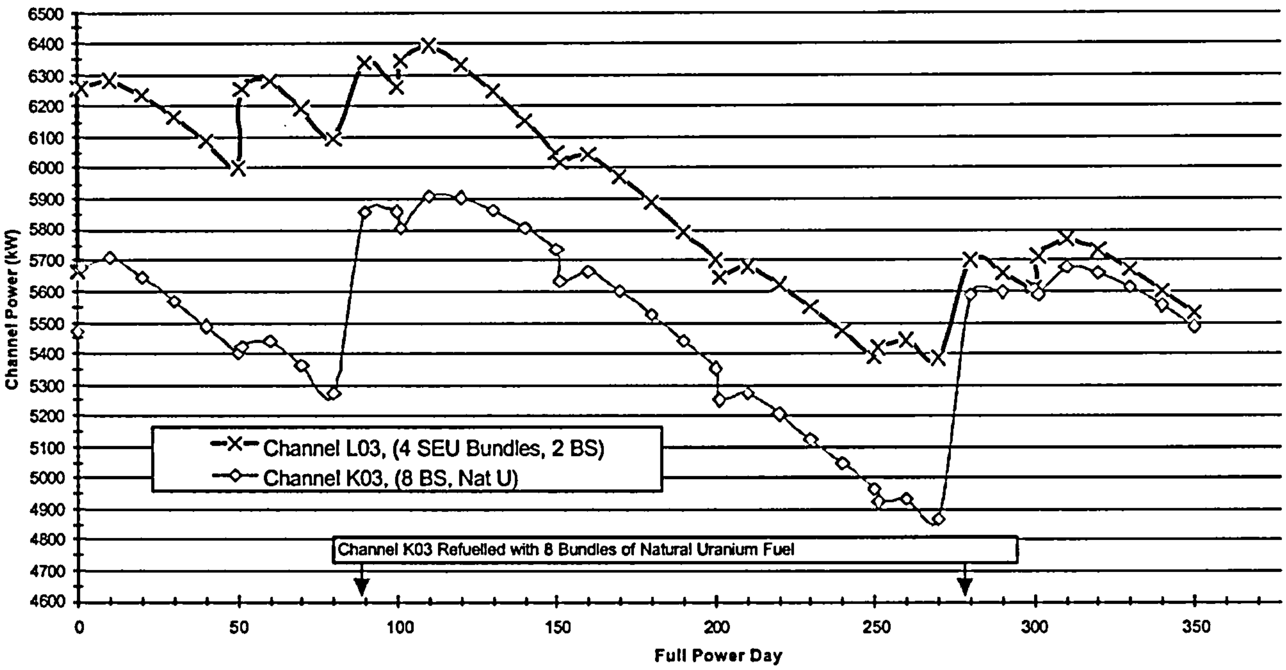

FIGURE 1. CHANNEL POWERS VS. FULL POWER DAY IN L03 AND K03 DURING DI SIMULATION

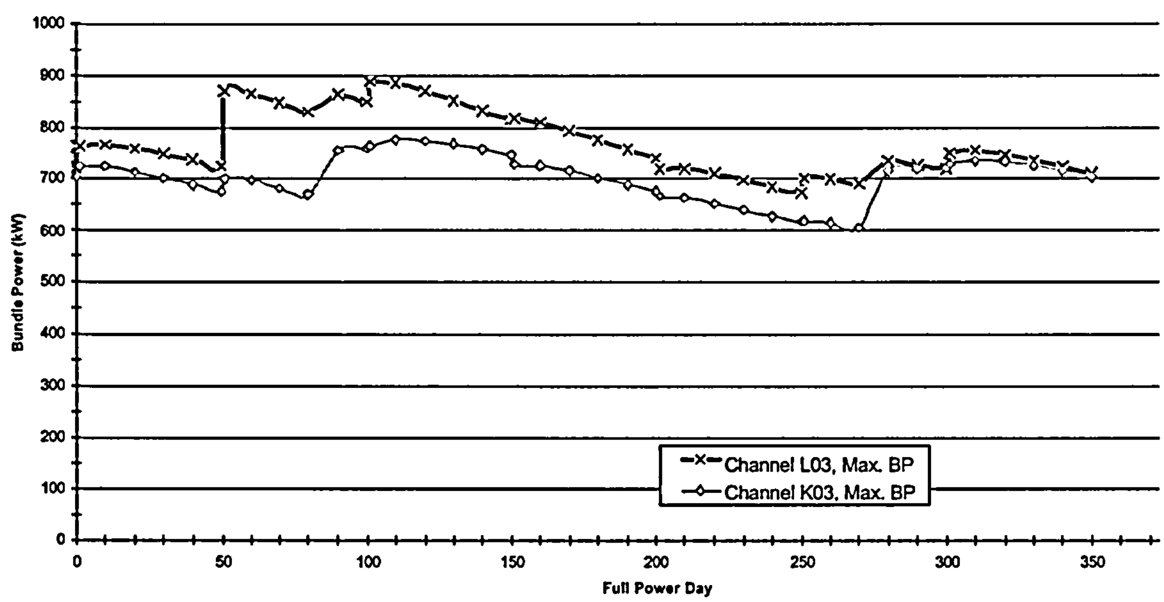

FIGURE 2. MAXIMUM BUNDLE POWERS VS. FULL POWER DAY IN L03 AND K03 DURING DI

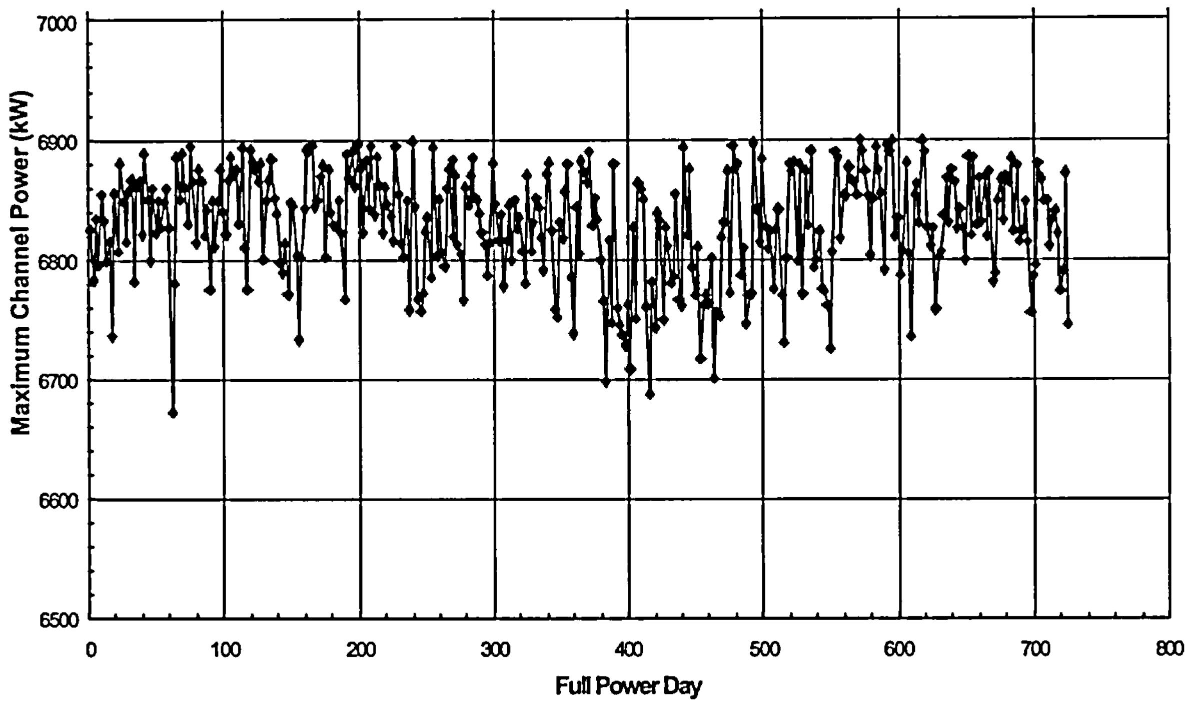

FIGURE 3. MAXIMUM CHANNEL POWER VS. FULL POWER DAY IN C6 NU/SEU TRANSITION CORE

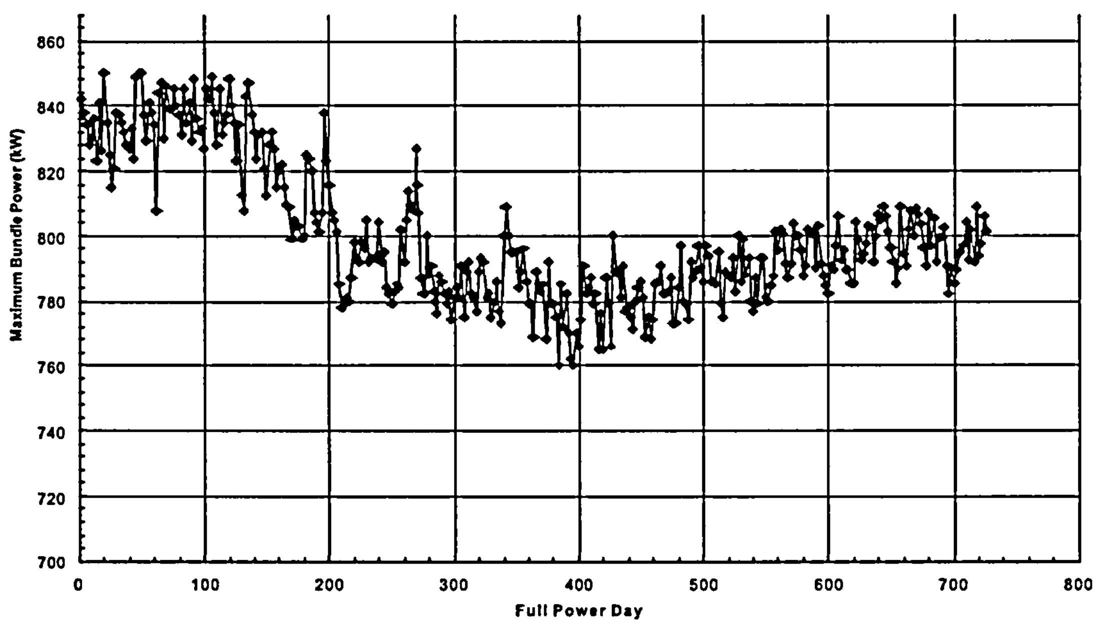

FIGURE 4. MAXIMUM BUNDLE POWER VS. FULL POWER DAY IN C6 NU/SEU TRANSITION CORE

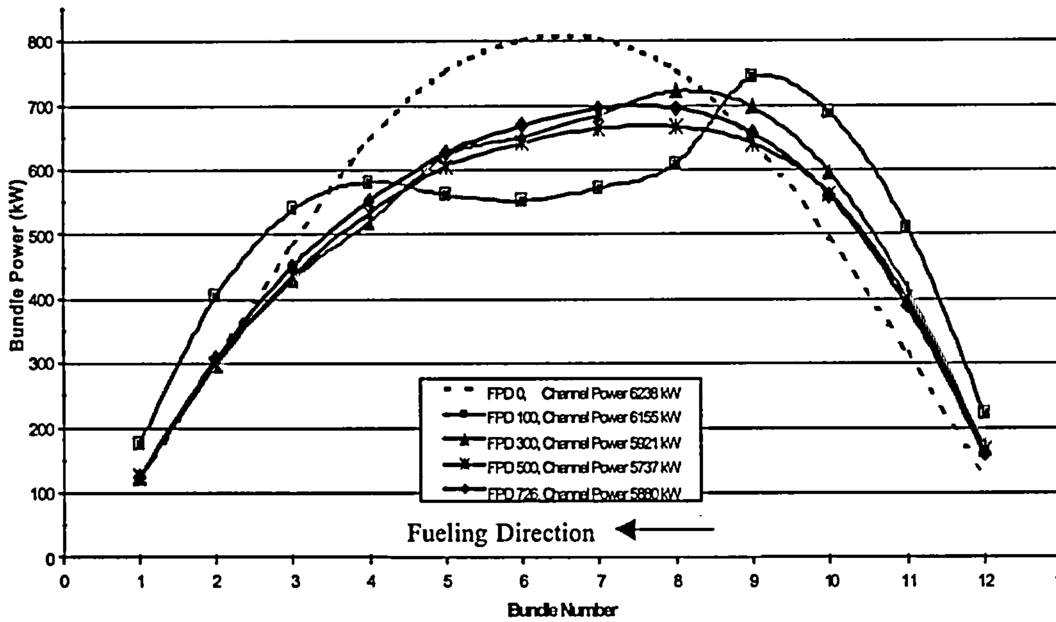

FIGURE 5. BUNDLE POWER DISTRIBUTION IN CHANNEL L03 DURING TRANSITION

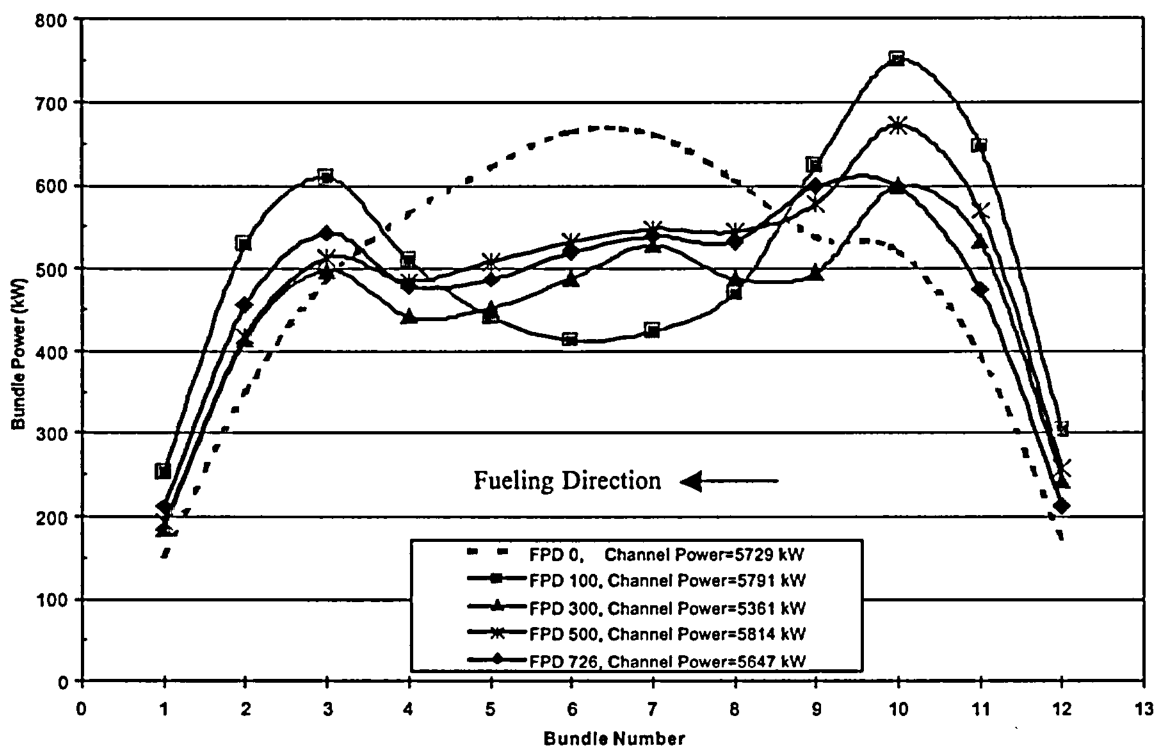

FIGURE 6. BUNDLE POWER DISTRIBUTION IN CHANNEL L11 DURING TRANSITION

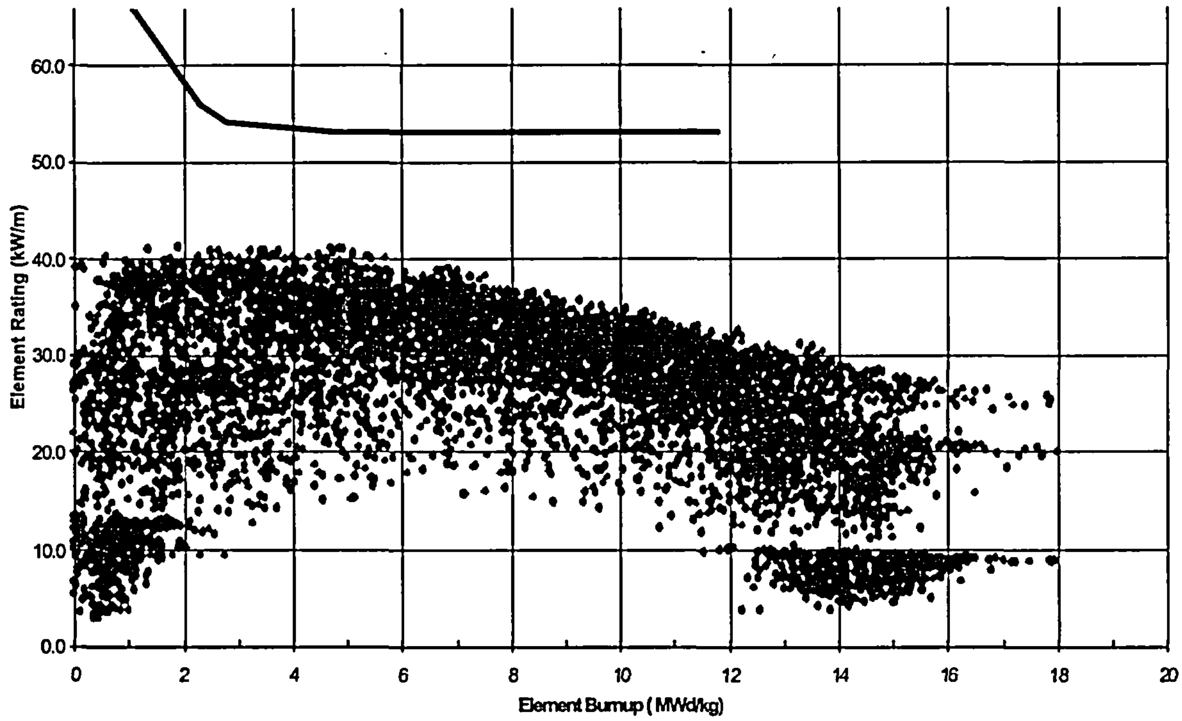

FIGURE 7. SEU (CANFLEX BUNDLE) RING 4 ELEMENT RATING VS. BURNUP

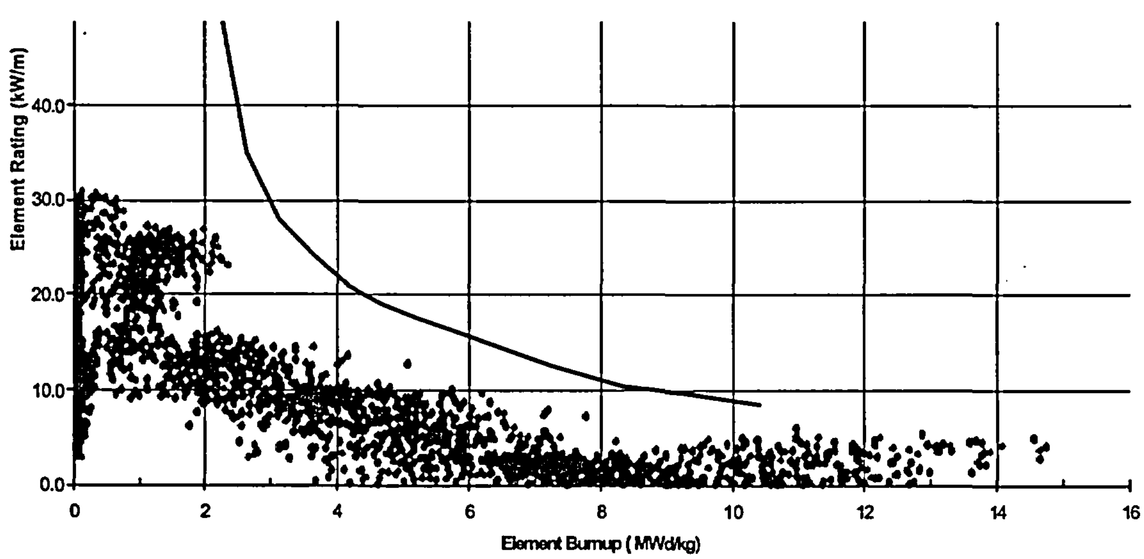

FIGURE 8. SEU (CANFLEX BUNDLE) RING 4 ELEMENT BOOST VS. BURNUP