Ca9105051

AECL-9194

ATOMIC ENERGY OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

IMPROVED LOCATIONS OF REACTIVITY DEVICES IN FUTURE CANDU REACTORS FUELLED WITH NATURAL URANIUM OR ENRICHED FUELS

Amélioration des postes de méccanismes de réglage de réactivité dans les futurs réacteurs CANDU à charge de combustible d'uranium ou de combustibles enrichis

P.G. BOCZAR and M.T. VAN DYK

Presented at The American Nuclear Society Topical Meeting on Advances in Reactor Physics and Safety, Saratoga Springs, New York, 1986 September 17-19

Chalk River Nuclear Laboratories

Laboratoires nucléaires de Chalk River

Chalk River, Ontario

February 1987 fevriér

ATOMIC ENERGY OF CANADA LIMITED

Improved Locations of Reactivity Devices in Future CANDU Reactors Fuelled with Natural Uranium or Enriched Fuels

by

P.G. Boczar and M.T. van Dyk

Presented at
the American Nuclear Society Topical Meeting on
Advances in Reactor Physics and Safety,
Saratoga Springs, New York, 1986 September 17-19

Atomic Energy of Canada Limited
Research Company
Reactor Physics Branch
Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada
KOJ 1J0

AECL-9194

1987 February

L'ÉNERGIE ATOMIQUE DU CANADA, LIMITÉE

Amélioration des postes de mécanismes de réglage de réactivité dans les futurs réacteurs CANDU à charge de combustible d'uranium naturel ou de combustibles enrichis

par

P.G. Boczar et M.T. van Dyk

RÉSUMÉ

On propose une nouvelle disposition de mécanismes de réglage de réactivité pour les futurs réacteurs CANDU*, laquelle améliore les caractéristiques du coeur de ceux-ci par les combustibles enrichis tout en permettant encore d'utiliser du combustible d'uranium naturel. On présente les calculs de physique de cette nouvelle disposition pour quatre types de combustible: l'uranium naturel, le mélange d'oxyde de plutonium et d'oxyde d'uranium (MOX) à taux de combustion de 21 MWd/kg et l'uranium légèrement enrichi (SEU) à taux de combustion de 21 ou 31 MWd/kg.

*CANDU - CANadian Deuterium Uranium. CANDU est une marque de commerce déposée auprès du US Patent and Trademark Office.

Improved Locations of Reactivity Devices in Future CANDU Reactors Fuelled with Natural Uranium or Enriched Fuels

P.G. Boczar and M.T. van Dyk

Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada
K0J 1J0

Abstract

A new configuration of reactivity devices is proposed for future CANDU* reactors which improves the core characteristics with enriched fuels, while still allowing the use of natural uranium fuel. Physics calculations for this new configuration are presented for four fuel types: natural uranium, mixed plutonium - uranium oxide (MOX) having a burnup of 21 MWd/kg, and slightly enriched uranium (SEU) having burnups of either 21 or 31 MWd/kg.

Introduction

The CANDU reactor is a safe, reliable and economical producer of nuclear-generated electricity. The choice of heavy water as coolant and moderator and close attention to neutron economy enables the CANDU reactor to be fuelled with natural uranium fuel, with the attendant benefit of low fuelling costs.

However, the excellent neutron economy also makes the use of enriched fuels in CANDU attractive. The uranium and logistical requirements and economics were recently evaluated for a wide range of advanced fuel cycles in CANDU(1). Slightly enriched uranium (SEU) having an enrichment of 1.2 wt.% and a burnup of approximately 21 MWd/kg improves uranium utilization by 30% over a natural uranium fuelled CANDU, i.e. 30% less mined uranium is required over the lifetime of the plant. Annual fuelling costs are reduced by 10 to 30% depending on burnup and the costs of natural uranium and enrichment services.

Excellent neutron economy in CANDU has also prompted interest in the use of mixed plutonium-uranium oxide (MOX) with the plutonium recovered from spent fuel from either a LWR (tandem fuel cycle), or from CANDU. While net uranium savings of 30% for the former, and 50% for the latter can be achieved relative to the use of natural uranium in CANDU, relatively high reprocessing costs and low uranium costs do not favour the economics of plutonium recycle at the present time.

* CANDU - CANadian Deuterium Uranium. CANDU is registered in the US Patent and Trademark Office.

The use of enrichment in CANDU does present some challenges. The current design, and in particular the configuration of reactivity control devices such as shutoff rods and adjuster rods, is based on the use of natural uranium fuel. This paper summarizes the incentives for relocating the reactivity devices in future CANDU reactors, and presents a configuration of reactivity devices which improves the performance with enriched fuels, while still allowing the use of natural uranium. This is but one of several improvements that could be made to future CANDU reactors to enhance the technical and economic characteristics of CANDU using enriched fuels. No attempt was made at an overall core or plant optimization.

Several fuel types were considered:

i) natural uranium (NU),
ii) slightly enriched uranium with 1.2 wt.% U-235 in heavy element, giving a burnup of about 21 MWd/kg (SEU-21),
iii) SEU with 1.7 wt.% U-235, giving a burnup of about 31 MWd/kg (SEU-31), and
iv) mixed plutonium-uranium oxide, with plutonium recovered from spent PWR fuel and diluted with natural uranium to give a total fissile content of 1.27 wt.%, and a burnup of about 21 MWd/kg (MOX-21).

Methodology

Fluxes and powers were calculated in three dimensions and two energy groups using a finite difference diffusion theory fuel management code. Cell-averaged cross sections as a function of burnup were calculated using WIMS-CRNL(2) for the enriched fuels, and a simpler cell code, POWDERPUFS(3), for natural uranium, to be consistent with earlier work. The presence of structural materials or reactivity control devices not modelled in the standard lattice cell was accounted for in the fuel management code by adding incremental cross sections to the cell-averaged cross sections at the locations occupied by these materials. These incremental cross sections were computed from a three-dimensional integral transport theory calculation in which the fuel and device were explicitly modelled.

The fuel management code allows for different degrees of complexity in the reactor model. In the time-average calculation, the cell-averaged cross sections are averaged over the dwell time of the fuel at each position in the core. The time-average calculation provides estimates of the average bundle and channel powers and fluxes throughout the core, as well as the average burnup and refuelling rates. Estimates of the actual maximum powers which would be encountered during reactor operation were made through a time-dependent refuelling simulation, in which the refuelling of specified channels at specified times was modelled. The time-dependent simulation was performed for all four fuels in the modified design, as well as for natural uranium in the reference case. The simulation was carried out for 90 full power days or until about 250 channels were refuelled, whichever came first. Flux calculations were performed at five day intervals. The channels refuelled and their order was exactly the same in all cases. The refuelling sequence is near-optimal for the enriched fuels, and is acceptable for natural uranium. The starting point in the simulation was a random distribution of channel ages (or fractional dwell time). The element power and power boost histograms arising from the simulations were used to assess the expected fuel performance. The calculational methodology is well established for the natural uranium fuelled CANDU(4).

CANDU-600 Reactor Model

The reactor model is based on the CANDU-600 design[5]. The reactor contains 380 horizontal fuel channels, arranged in a square lattice of 28.575 cm pitch. Each fuel channel consists of twelve 37-element fuel bundles inside a zirconium-niobium alloy pressure tube, cooled with D_2O. The pressure tube is thermally isolated from the Zircaloy calandria tube and the D_2O moderator by a gas annulus.

The reactor is refuelled on-line, in the direction of coolant flow, with adjacent channels refuelled in the opposite direction (bi-directional fuelling). An 8-bundle shift fuelling scheme is typically used throughout the core in the natural uranium fuelled CANDU-600, meaning that at each visit of the refuelling machine to a channel 8 fresh bundles are added to one end of the channel and 8 spent bundles are removed from the other end.

The fuel channels, moderator and reflector are contained within a cylindrical stainless steel calandria, which is notched at either end for mechanical reasons, as well as to eliminate D_2O from a region of the core where the effect of the radial reflector is minimal (Figure 1). Four large emergency discharge pipes located near the top and ends of the calandria protect against an over-pressurization of the moderator in the unlikely event of a pressure tube and calandria tube rupture.

Control of the reactor is achieved primarily through the use of vertically oriented reactivity devices which pass interstitially between the fuel channels in the unpressurized moderator. Twenty-one adjuster rods are arranged in three rows near the axial midplane of the core. The absorption properties of the adjuster rods can vary along their length or from rod to rod. The adjuster rods are normally in the core, and serve the following purposes: they provide 30 minutes xenon override capability in the event of a shutdown; they allow compensation for xenon transients resulting from a change in power level (power manoeuvering); the adjuster rods provide reactivity shim in the event that the fuelling machines are unavailable; and finally, their locations flatten the axial and radial power distributions with natural uranium fuel.

There are six light water filled zone control units, which provide bulk control of reactivity, as well as some spatial control of the flux and power distributions in the reactor core. The outer zone controllers are divided into two compartments, and the inner controllers into three for a total of 14 compartments.

The reactor can be shut down in an abnormal situation by inserting 28 shutoff rods, which are normally parked outside the calandria. Four mechanical control absorbers are used to shut down the reactor under normal conditions, and to override the increase in reactivity which results from the fuel temperature coefficient.

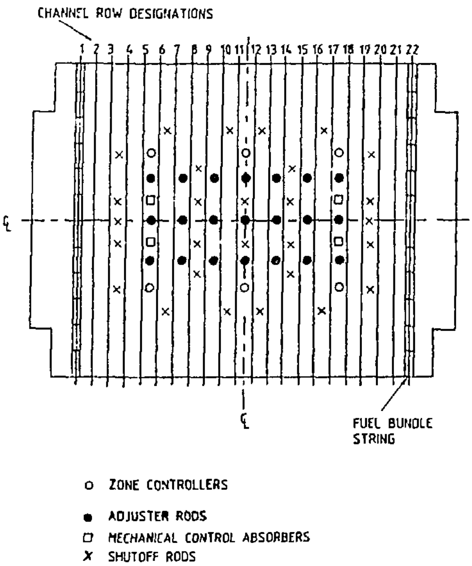


FIGURE 1: TOP VIEW OF CURRENT CANDU-600 CORE

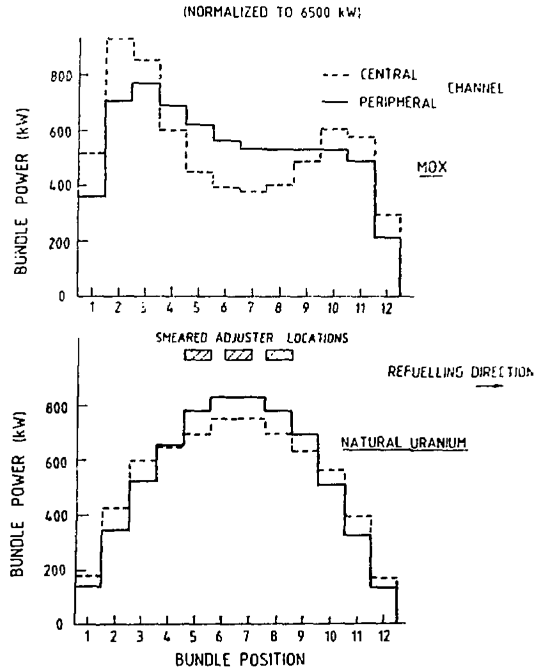


FIGURE 2: AXIAL POWER PROFILES IN CURRENT CANDU-600

The Reason for Repositioning Reactivity Devices

The positions of the reactivity devices in the current CANDU have been chosen on the basis of the power and flux distributions in the core with natural uranium fuel.

Figure 2 illustrates axial power profiles in the current CANDU for two fuel types: natural uranium with an eight bundle shift fuelling scheme and MOX-21 with a two bundle shift fuelling scheme. Two typical channels are shown - a central channel adjacent to the adjuster rods and a peripheral channel outside of the region of influence of the adjuster rods. With natural uranium fuel, the central location of the adjuster rods flattens the axial power profile, reducing the maximum bundle power for a given channel power.

With enriched fuel, it is necessary to reduce the number of bundles shifted during refuelling in order that limits on bundle and channel powers not be exceeded. With a two-bundle shift fuelling scheme with MOX-21 fuel, the axial power profile in the absence of adjuster rods peaks near one end of the channel, and decreases along the length of the channel. Although this axial power profile differs from that with natural uranium fuel, the shape is acceptable from the point of view of either fuel performance or the critical heat flux. The central location of the adjuster rods, however, produces a pronounced dip in the axial power profile near the center of the channel, which results in an increase in the maximum bundle power for a given channel power. As well, sizeable power boosts occur at the downstream end of the channel during refuelling (for example, when shifting from bundle position 8 to 10, or 9 to 11), which is undesirable from the standpoint of fuel performance. The reactivity worths of the shutoff rods and adjuster rods are also reduced.

In existing CANDU reactors, there are two ways of accommodating enriched fuels. One is to employ a fuel management scheme which makes the axial power profile in the absence of adjuster rods more like that with natural uranium fuel - peaked in the center of the channel. This is the basis of the so-called checkerboard fuelling scheme(6). Another option is to remove the adjuster rods altogether, and take advantage of the excellent axial power profile resulting from a two bundle shift fuelling scheme with medium burnup fuels. The advantages and disadvantages of each of these options will not be discussed here.

In future CANDU reactors, the locations of reactivity devices can be chosen to give good technical characteristics with both natural uranium and enriched fuels. With natural uranium fuel, the optimal location of the adjuster rods is near the axial midplane, while with enriched fuels, the optimal location is closer to the ends of the channel. In an earlier paper(7), a configuration of devices was identified which gave good axial power profiles for both natural uranium and medium burnup MOX fuels. However, the axial notch in the calandria and the emergency discharge pipes restricted the space available for devices near the ends of the channels. As a result, the shutoff rod worth with MOX fuel was about 50% lower than in the natural uranium reference case.

In the design proposed here, the size of the axial notch is significantly reduced and the emergency discharge pipes are moved closer to the channel ends allowing placement of a sufficient number of shutoff rods and adjuster rods near the channel ends. In the calculations, the axial notch was eliminated altogether, and the radius of the calandria reduced by about 13 cm to conserve the amount of heavy water in the moderator (Figure 3). This results in a burnup penalty of about 3-4% for natural uranium fuel, due to increased leakage. The optimal size of the notch has not yet been considered.

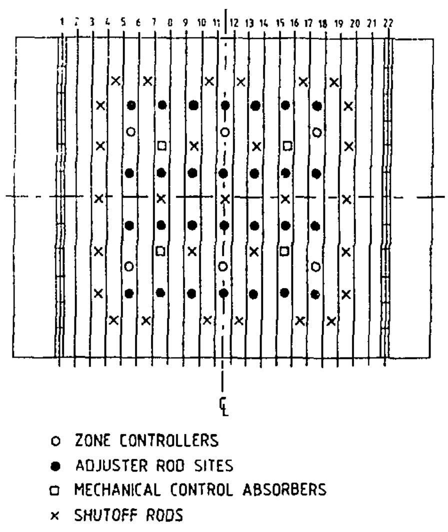
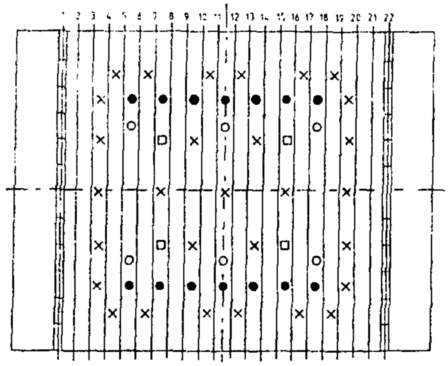
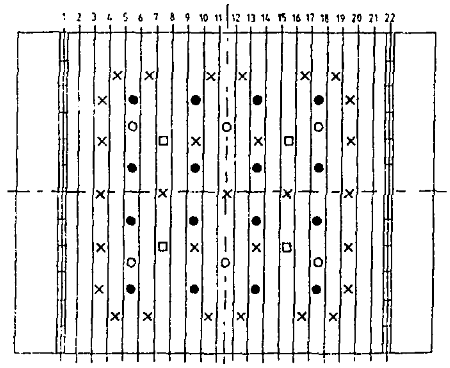


FIGURE 3: TOP VIEW OF MODIFIED CANDU-600 CORE

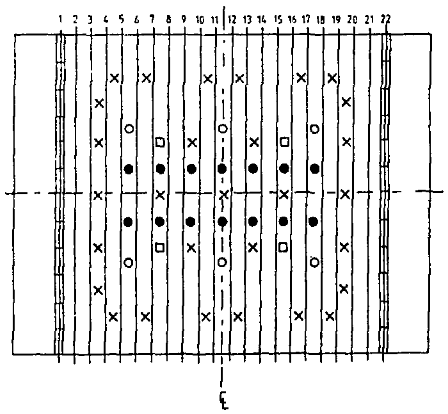
The six zone controllers occupy approximately the same locations as in the reference design. There are 29 shutoff rods, one more than in the current design. The number of mechanical control absorbers is the same as in the reference design, although their locations have changed. The 28 adjuster rod sites are arranged in four rows axially, and the number of adjuster rods employed would depend on the fuel type. For natural uranium only the inner two rows of adjuster rods near the axial midplane would be used (Figure 4A). For medium burnup SEU or MOX, there is a great deal of



C SEU-31



B SEU-21, MOX-21



○ ZONE CONTROLLERS
● ADJUSTER RODS
□ MECHANICAL CONTROL ABSORBERS
× SHUTOFF RODS

A NATURAL URANIUM

FIGURE 4: ADJUSTER ROD LOCATIONS IN MODIFIED CORE

flexibility in the number and locations of rods used: all 28 rods could be used; only the two outer rows of adjuster rods; or four rods in each of the rows, which is the configuration chosen here (Figure 4B). The relative strengths of the inner and outer rows of adjuster rods were chosen to give the desired axial power profile and reactivity worth. For high burnup fuel, only the outer two rows of adjuster rods would be used (Figure 4C). The adjuster rod sites which are not used would be plugged, or other devices could be used there. The calandria shell would be manufactured with holes for all of the adjuster rod sites regardless of the initial fuel. The repositioning of the reactivity devices would also require changes in some parts of the reactor building such as the reactivity deck, and the calandria vault. A cursory consideration of these changes indicates that the proposed layout is feasible, but a more detailed assessment would be required to confirm this.

Fuel Management Results

The results of the calculations are shown in Table 1 for the natural uranium reference case, and for the modified core with each of the four fuel types considered.

The average fuel irradiation was chosen to keep the reactor critical. For the enriched fuels, an allowance of about 2.5 mk was made for parasitic absorption in core materials which were not modelled explicitly, such as flux detectors, and structures at the periphery of the core. Hence, a target of 1.0025 was set for k_{eff}.
In the natural uranium model, only the structural material at the periphery of the core was neglected, and no allowance was made for this (for consistency with previous calculations) and so a target eigenvalue of 1.0000 was used.

Table 1: Physics Characteristics of Modified Core

	Reference	Modified Design			
	Natural Uranium	Natural Uranium	SEU-21	MOX-21	SEU-31
Number of Bundles Shifted	8	8	2	2	1
k_{eff}	0.9999	1.0000	1.0027	1.0026	1.0020
Average Discharge Burnup (MWd/kg)	6.5	6.1	20.6	20.6	31.6
Maximum Time-Average Channel Power (kW)	6525	6590	6310	6395	6180
Average Maximum Channel Power from Refuelling Simulation (kW)	6825	6895	6680	6864	6543
Channel Power Peaking Factor (CPPF)	1.08	1.08	1.13	1.16	1.13
Maximum Time-Average Bundle Power (kW)	815	775	730	735	835
Average Maximum Bundle Power from Refuelling Simulation (kW)	850	840	790	850	910
Average Refuelling Rate					
channels/day	2.3	2.4	2.8	2.8	3.6
bundles/day	18.2	19.0	5.6	5.6	3.6
Reactivity Decay Rate (mk/day)	-0.39	-0.37	-0.51	-0.51	-0.42
Time Between Consecutive Visits of Fuelling Machine to Same Channel (days)	167	160	137	137	105
Adjuster Rods Worth (mk)	17	18	9	8	11
Xenon Override Time (min)	30	32	30	30	43
Zone Controllers Worth (mk)					
full	7.0	7.8	6.9	6.1	5.5
nominal	4.1	4.7	3.5	3.5	3.2
Shutoff Rods Worth (mk)					
all rods in	82	66	65	63	67
best 2 rods missing	48	44	45	44	42
Mechanical Control Absorbers Worth (mk)	11	14	12	10	8

Note: $mk = 1000 \frac{(\Delta k)}{k}$

The lower burnup for natural uranium fuel in the modified design compared to the reference design is a result of greater radial and axial leakage, as well as greater adjuster rod worth. The calculated achievable burnup is sensitive to details of the model.

The maximum time-average channel power depends on the degree of radial flattening achieved through the use of the adjuster rods as well as through different radial burnup zones in the core. In the reference case, only two radial burnup zones were used, while three were used in the modified design. This enabled the achievement of a lower time-average maximum channel power in the modified design with enriched fuel. However even with three radial burnup zones, the maximum time-average channel power in the modified design with natural uranium fuel is slightly greater than in the reference. Thus, the radial flattening achieved with natural uranium fuel using only two rows of adjuster rods is not as great as with three rows of adjuster rods.

The average maximum channel powers from the refuelling simulation are greater than the maximum time-average powers because of the refuelling ripple. The maximum channel power usually occurs for a channel which has recently been refuelled. The average maximum channel powers are similar for natural uranium in the reference and modified designs, and for MOX in the modified design. For the medium and high burnup SEU fuels, the average maximum channel powers are lower than for the reference case by about 2% and 4% respectively.

The channel power peaking factor (CPPF) is a measure of the ripple in channel powers due to refuelling, and was computed from the results of the refuelling simulation in the following manner. At each flux calculation (done at 5 day intervals), the ratio of the instantaneous channel power to the time-average power for that channel was computed for every channel in the core. The CPPF is the largest value of this ratio for the high-powered channels (having an instantaneous power equal to at least 90% of the maximum power at that time) averaged over the number of refuelling steps. The CPPF is greater for the enriched fuels than for natural uranium, as the effect of the fewer bundles shifted does not completely compensate for the greater enrichment.

The maximum time-average bundle powers are about 10% lower for SEU-21 and MOX-21 than for natural uranium. However, when the effects of the refuelling ripple are taken into account through the time-dependent refuelling simulation, the advantage in maximum bundle power is reduced to 7% for the SEU-21 fuel, while the MOX-21 and natural uranium fuels in the modified design have approximately the same average maximum bundle power as natural uranium in the reference design. For the high burnup SEU-31 fuel the average maximum bundle power is about 8% higher than for natural uranium in the current design.

The refuelling rate in terms of channels per day and hence the number of channel closures, is about 20% greater for the SEU-21 and MOX-21 fuels, and 50% greater for the SEU-31 fuel, relative to the reference case. However, in terms of the refuelling machine utilization, this is more than compensated for by the reduction in the charge rate in bundles per day. There would be a reduction in refuelling machine utilization with the enriched fuels.

The last lines in Table 1 give the static reactivity worths of the control devices. The adjuster rod strengths (i.e., the incremental thermal absorption cross sections) have been chosen to provide at least 30 minutes xenon override time. With the SEU-31 fuel, the absorption of the adjuster rods was increased to provide additional power shaping.

The zone controller worths decrease as the "blackness" of the fuel increases, but the total worth is believed to be adequate in all cases. The nominal percentage fills for natural uranium are different from the enriched fuels.

While the total static shutoff rod worth is about 17 mk smaller in the modified core than in the reference, the design basis in the loss of coolant accident (LOCA) analysis usually assumes that the two most effective rods fail to drop into the core. The shutoff rod worth with the best two rods missing in the modified design is only marginally smaller than in the reference design, and is judged to be sufficient, although this would need to be confirmed by detailed dynamic calculations of a postulated LOCA.

The reactivity worth of the mechanical control absorbers has to be sufficient to override the reactivity increase following a hot shutdown, when the fuel temperature drops to that of the coolant. The reactivity change is largest for a core containing fresh fuel. While the reactivity coefficients have not been calculated in this study, previous calculations have shown that the magnitude of the fuel temperature coefficient for fresh fuel is about the same for natural uranium and SEU-21, and is lower for MOX-21. On this basis then, the worth of the mechanical control absorbers in the modified design appears to be sufficient for natural uranium, SEU-21 and MOX-21 fuels. More detailed calculations would be needed to establish the requirement for fresh SEU-31 fuel. However, the most likely scenario for the introduction of high burnup fuels in CANDU would probably involve a transition from a lower enrichment to a higher enrichment fuel, which would avoid a fresh core of the high enrichment fuel. In any event, more mechanical control absorbers can be added to the design if necessary.

Figure 5 shows relative time-average axial bundle power profiles in each of the cores, normalized to a bundle average of 1.0, along the channel which has the highest maximum bundle power. The new configuration of adjuster rods results in greater axial flattening for all but the SEU-31 fuel, relative to natural uranium in the reference design. The optimal location of the outer row of adjuster rods for the high burnup SEU fuel is about 12 cm closer to the channel ends. For the

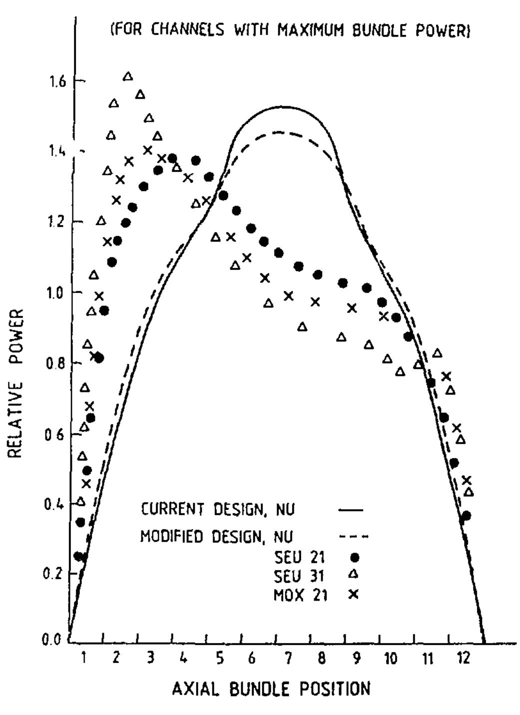


FIGURE 5: AXIAL POWER PROFILES IN MODIFIED CORE

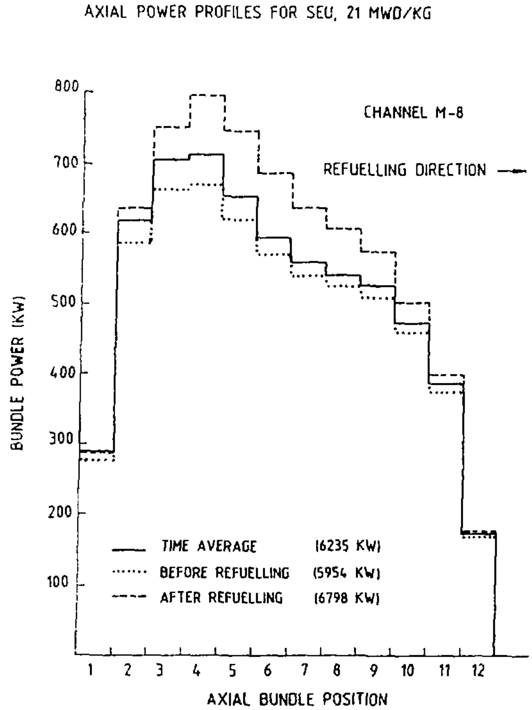
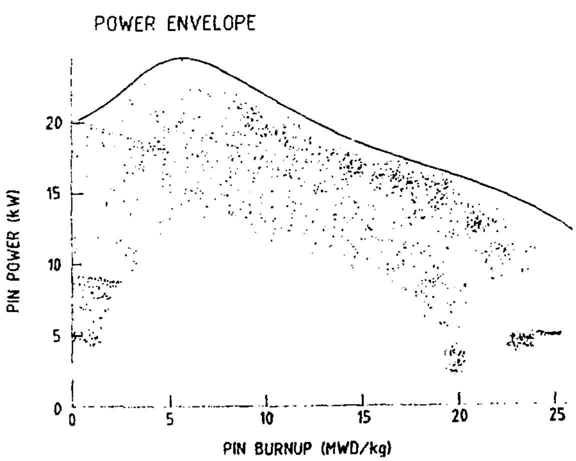


FIGURE 6: COMPARISON OF INSTANTANEOUS AND TIME-AVERAGE AXIAL POWER PROFILES FOR SEU-21

SEU-21 fuel, the axial power profiles with and without the adjuster rods are very similar. This reduces the perturbations in the power distribution resulting from inserting or withdrawing the adjuster rods. Consequently, load following capability should be improved, and the rise to full power after a shutdown can be achieved in a shorter time than with natural uranium fuel.

A typical evolution of the axial bundle power profile during burnup is illustrated in Figure 6. From the time-average axial power profile, boosts in the bundle power during refuelling would be expected only in shifting from position 1 to 3, and from position 2 to 4. However, by examining the power profiles immediately before and after refuelling, smaller power boosts are seen to occur in shifting from positions 3 to 5 through 7 to 9.



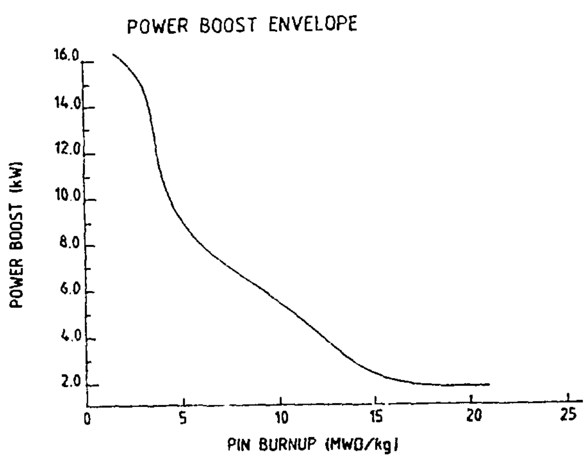


FIGURE 7: PIN POWER AND PIN POWER BOOST ENVELOPES FOR SEU-21

Figure 7 shows the pin power envelope and pin power boost envelope for the highest rated pin in the bundle resulting from the 90 day refuelling simulation for the SEU-21 fuel. (The ordinate can be converted to units of kW/m by dividing by the element length 0.48 m). The dots under the power envelope are calculated maximum pin powers for each of the bundles in the core at one point in the simulation. The envelopes for the other enriched fuels are similar. Analysis of these envelopes by fuel engineers indicates a very low probability of fuel failure based on current fuel performance data. This data is presently being extended to higher burnups. Note that enrichment grading or pin size grading could be used to lower the peak element power.

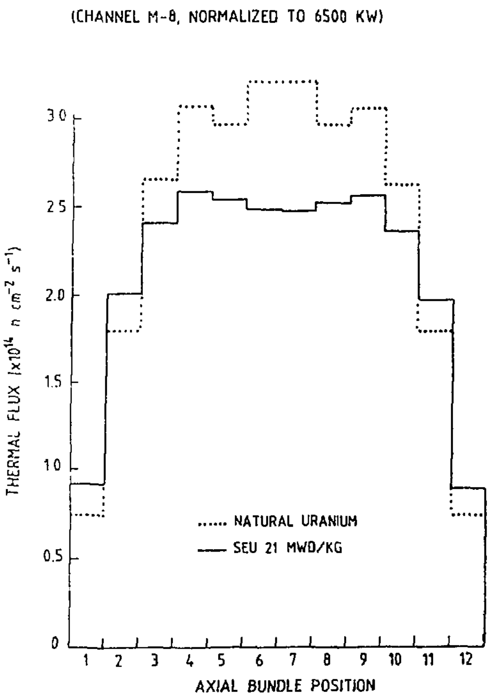


FIGURE 8: AXIAL CELL-AVERAGE THERMAL FLUXES

Finally, Figure 8 shows typical cell-average thermal axial flux profiles for natural uranium in the current design, and SEU-21 in the modified design, normalized to a channel power of 6500 kW. Because of the enrichment, the absolute value of the flux is smaller for SEU-21 than for natural uranium. Also, the axial flux profile is much flatter for the SEU fuel than for natural uranium.

Summary

The configuration of reactivity devices presented in this paper results in good core characteristics for a range of fuels, from natural uranium to high burnup SEU fuel. In order to accommodate sufficient numbers of adjuster rods and shutoff rods near the ends of the channels for the enriched fuels, the size of the axial notch in the calandria shell has been significantly reduced, and the emergency discharge pipes have been moved closer to the channel ends.

A simple fuel management strategy is employed for each of the fuels considered: an eight-bundle shift fuelling scheme throughout the core for natural uranium, a two-bundle shift fuelling scheme for medium burnup SEU or MOX, and a one-bundle shift fuelling scheme for high burnup SEU. The fuelling machine utilization is reduced with the enriched fuels.

Axial power profiles are acceptable for all the fuels studied. With SEU-21, maximum bundle and channel powers are lower than in the natural uranium reference case by 7% and 2% respectively. If enrichment grading or pin size grading were employed with the SEU-21 fuel to flatten the radial distribution of linear element rating across the bundle, then an increase in total reactor power may be possible relative to natural uranium, while maintaining the same operating margin.

The reactivity worths of the control devices with enriched fuel in the modified design are lower than with natural uranium in the reference design. However, the worths are judged to be sufficient.

References

1. J. Veeder and R. Didsbury, "A Catalogue of Advanced Fuel Cycles in CANDU-PHW Reactors", Atomic Energy of Canada Limited, Report AECL-8641 (1985).

2. J.V. Donnelly, "WIMS-CRNL, A User's Manual for the Chalk River Version of WIMS", Atomic Energy of Canada Limited, Report AECL-8955 (1986).

3. A.A. Pasanen, "Fundamentals of CANDU Reactor Nuclear Design", A Lecture Series given at Trieste 22 January - 28 March 1980", unrestricted Atomic Energy of Canada Limited Report, TDAI-244 (1980).

4. A.L. Wight, "Validation of OHRFSP Against Actual Operating Data from Pickering NGS A and Bruce NGS A", Proc. Canadian Nuclear Society Annual Meeting, Toronto, Canada, 1985 June 09.

5. "Technical Summary - CANDU Nuclear Generating Station", published by the Public Affairs Office, Atomic Energy of Canada Limited, CANDU Operations, Mississauga, Ontario, Canada.

6. P.S.W. Chan and A.R. Dastur, "A Checkerboard Fuelling Scheme for Increasing the Fuel Burnup of Existing CANDU's to LWR Levels", Proc. of the ANS Topical Meeting on Advances in Fuel Management, Pinehurst, NC, March 1986.

7. P.G. Boczar, "Physics Characteristics of a CANDU-600 with Repositioned Adjuster Rods Fuelled with MOX or Natural Uranium", Atomic Energy of Canada Limited, Report AECL-8839 (1985).

ISSN 0067-0367

To identify individual documents in the series we have assigned an AECL- number to each.

Please refer to the AECL- number when requesting additional copies of this document

from

Scientific Document Distribution Office
Atomic Energy of Canada Limited
Chalk River, Ontario, Canada
K0J 1J0

Price: A

ISSN 0067-0367

Pour identifier les rapports individuels faisant partie de cette série nous avons assigné un numéro AECL- à chacun.

Veuillez faire mention du numéro AECL- si vous demandez d'autres exemplaires de ce rapport

au

Service de Distribution des Documents Officiels
L'Energie Atomique du Canada Limitée
Chalk River, Ontario, Canada
K0J 1J0

Prix: A

649-87