New Fuel for Advanced Heavy Water Reactors

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1. Introduction

A redesign of the PHWR Fuel Element (FE) to be used in all argentine nuclear power plants has been proposed (1). This new FE presents several characteristics aimed to an improved in-core performance and economical benefits derived from the unification of most of the fabrication processes that today constitute two different production lines: one for Embalse NPP Candu type fuel and another for Atucha I.

Atucha I and Embalse, the two operating NPPs in Argentina, are PHWRs of different conception. Atucha I (357 Mwe) is of pressure vessel type and the FEs are full-length assemblies (530 cm of active length) with 36 uranium rods in the cluster and a support one in the outer ring. Embalse (648 Mwe) is a Candu pressure tube reactor fluelled with the well known 37 rod / 50cm length fuel bundles, twelve of which are loaded in each channel.

The more relevant changes in the proposed design are an increased subdivision of the fuel material in 52 rods and a 100cm long bundle. The combined features give the adequate channel pressure drop.

The optimization of the design from the neutronic point of view is here considered by means of cell and whole reactor calculations and special consideration is given to the FE behaviour with regard to the void coefficient.

2. Fuel element

Table 1 resumes some data of the new bundle (CARA), together with the standard Atucha I and Embalse bundles. CARA design fits directly Embalse's requirements of FE external radius, uranium content and active lengh. Six fuel bundles must be loaded per channel instead of twelve. In the case of Atucha I, it increases considerably the in-core inventory, and requires a kind of "spacer" to compensate the difference in channel diameter. Moreover, five fuel bundles must be somehow tied together to make a full-length assembly and the active length is so reduced from 530 to 500cm.

Table 1: Fuel element data (mm&kg)

	Atucha I-standard	Embalse-standard	CARA
Number of rods	36	37	52
Pellet diameter	10.8	12.15	10.09
Clad ext. diameter	11.9	13.11	10.86
Radius outer ring	45.10	43.31	44.41
uranium load	174.5	19.0	38.0

3. Calculations

Neutronic calculations have been performed for Atucha I with the standard FE, and the proposed CARA design. Additionally, a third alternative was considered for both reactors, a 48 rod bundle obtained by eliminating the central 4 rods and keeping the remaining characteristics of the CARA design. The reason for this is that one can consider "a priori", for such a rod-dense design, that the self-shielding of the internal ring of fuel is very high and that an internal D_2O "moderator" can compensate for the multiplication loss, increasing the inner rods thermal utilization, with obvious fuel and material saving. Further, the central free-rod zone can be used profitably in the Atucha I case, where five bundles have to be assembled together to form a full-length element. A central hollow tube could be an option for this purpose and could also be beneficial to the void coefficient as will be shown.

The 48 rod alternative also improves the internal power distribution, even if in this respect the increase in fuel subdivision leads to a lower mean power density and thus less PCI concerns.

Cell and core calculations have been performed with WIMS-D4 code (2) and PUMA code (3) in the "time average" option with the purpose of determining output burnup and channel powers with the new fuel designs.

The core active height had to be modified in the 52 and 48 rod options from 530cm to500cm and this was done cutting the lower part of the core so that the relative position of the upper active part and the control rods, which are inserted from the top, is mantained.

Figure 1 displays a cross section of the reactor core with its 253 channels.

In Figure 2, the maximum channel powers for all cases are shown compared with the thermalhydraulic limits. As usual the natural uranium case presents a slight overpower in the central channels. All other FEs containing 0.85% U_{235}, exhibit a similar behaviour: lower values in the central zone and higher in the periphery. No channel overpower was observed and linear power densities remained always lower than the maximum allowed for stationary operation: 530w/cm.

Table 2 : Atucha I: Results of the reactor calculations

Fuel Element	Composition	Peaking Factor	Exit Burnup (Mwd/ton)
standard	natural uranium	1.9	6000
standard	SEU	1.71	12100
CARA-52 rods	SEU	1.69	13400
CARA- 48 rods	SEU	1.69	13300

The exit burnup figures for the CARA designs improve the corresponding tothe standard FE in about 1000Mwd/ton for the SEU case.

4. Void Coefficient

In reference 4 the void coefficient of the standard 37 rod FE of the Candu cell was studied, concluding that an inhomogeneous composition consisting of 2% enrichment in the two outer rings of rods and a mixture of depleted uranium and 1% Dy in the seven internal rods, allowed a similar neutronic performance than the standard homogeneous 37 rod FE with 0.85% enrichment, but giving a negative void coefficient in the relevant burnup range.

The analysis was made extensive to the Atucha cell and to the new fuel designs. The composition is chosen to match the standard FE 0.85% enrichment burnup performance. Table 3 shows some results, ai indicates the different rings of rods, Udep indicates depleted uranium 0.3%.

Table 3: Void Coefficient for standard FE

Cell	Composition	Void Coeff. (pcm)
Embalse	a1/a2 Udep + 1% Dy a3/a4 2%U235	-420
Embalse	a1/a2 Udep + 0.3% Dy a3/a4 1.5%U235	372
Atucha	a1/a2 Udep + 0.7% Dy a3/a4 2%U235	-1260
Atucha	a1/a2 Udep + 0.3% Dy a3/a4 1.5%U235	-242

There is a shift of void coefficient values in both cells. Atucha I needs less enrichment and poison content to achieve negative values. Table 4 reproduces the coefficient for the new FEs in the Atucha cell.

Table 4. Atucha I: void coefficient for new FEs

Nr. of rods	Composition	Void Coeff. (pcm)
48	a1 Udep + 0.6% Dy a2/a3 2%U235	238
48	a1 Udep + 0.75% Dy a2/a3 2.2%U235	73
48	a1 Udep + 1.1% Dy a2/a3 2.5%U235	-197
48*	a1 Udep + 0.6% Dy a2/a3 2%U235	-114
52	a1 Udep + 1.5% Dy a2/a3/a4 1.5%U235	-72
52	a1/a2 Udep + 0.4% Dy a3/a4 2%U235	-90

* With a central hollow void tube, $\phi = 2.4$cm

In general, it can be said that the new designs require more enrichment than the standard cell to reverse the void coefficient sign. In the 48 rod case, a hollow void tube can help: the same composition as case 1 but with the void tube in the cluster center , reverses the coefficient sign.

5. Conclusions

The proposed CARA design shows a superior neutronic performance than the standard PHWR FEs currently used in Atucha I and Embalse NPPs.

A variant of the CARA FE consisting in the elimination of the central four rods, leaving 48 rods and a central free space, is strongly recommended because it saves materials (less uranium, less sheaths) with no loss of burnup. The central D_2O zone allows a better utilization of the inner rods and compensates the diminished uranium loading.

In Embalse no differences in core physics are expected except the beneficial decrease in linear power density. In Atucha I besides the lower power density, a higher exit burnup appears as a consequence of the higher uranium inventory. The exit burnup figures have been calculated with cell and reactor models and the result is that similar fuel management schemes as the proposed for Atucha I for the SEU standard FE case can be used with CARA, both in the 52/48 rod version.

It has been shown that all fuel element designs give place to a negative void coefficient with an adequate combination of enrichment and absorbers.

Special atention was devoted to the Atucha cell were less enrichment and less absorbers than in the Candu cell are necessary to reverse the void coefficient sign in the standard FE case.

Both 52 rod and 48 rod designs require somewhat more enrichment and poison to reach the same effect. In the latter case, a central void hollow tube can reverse the sign of this coefficient without change of cell composition. As said, this tube could be used as a kind of support rod to assemble five CARA bundles for the Atucha case.

REFERENCES

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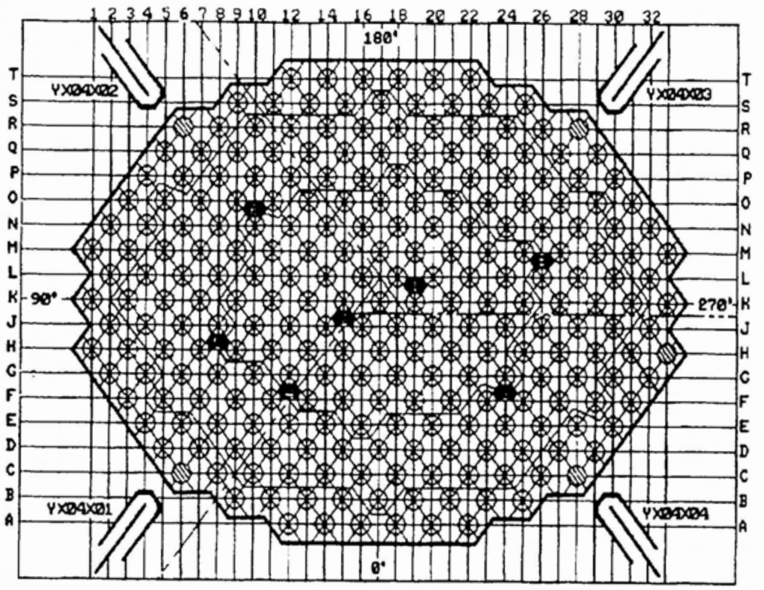

Figure 1

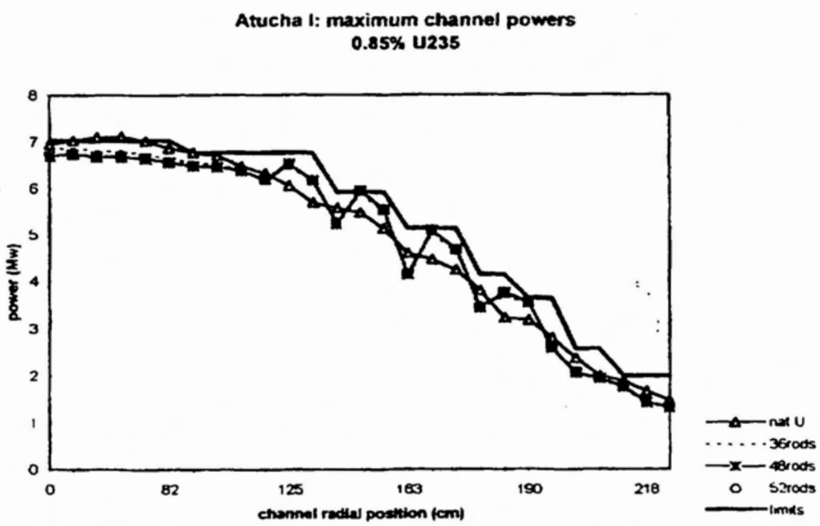

Figure 2