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SLIGHTLY ENRICHED URANIUM FUEL FOR A PHWR

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Abstract

An improved fuel element design for a PHWR using slightly enriched uranium fuel is presented. It mantains the general geometric disposition of the currently used in the argentine NPP's reactors, replacing the outer ring of rods by rods containing annular pellets. Power density reduction is achieved with modest burnup losses and the void volume in the pellets can be used to balance these two opposite effects. The results show that with this new design, the fuel can be operated at higher powers without violating thermohydraulic limits and this means an improvement in fuel management flexibility, particularly in the transition from natural uranium to slightly enriched uranium cycle.

1. INTRODUCTION

It is widely known that the use of slightly enriched uranium (SEU) in PHWR reactors, originally designed to operate with natural uranium (NU), presents economic advantages derived from the fact that less uranium is required for producing the same amount of energy. Several studies related with this alternative fuel cycle in our nuclear plants have been performed and recently a series of SEU fuel elements began its irradiation in Atucha 1 NPP. The enrichment adopted is 0.85% U235. This value is high enough to enable doubling the burnup in the equilibrium core, (roughly from 6000 Mwd/tonU to 11400 Mwd/tonU), and sufficiently low to admit its use with only minor alterations in the fuel management scheme, using the same fuel element and avoiding hardware modifications in the plant.

It can be added that even if the enrichment adopted is well below the theoretical optimum of 1.2% U235, there is little incentive to go further, due mainly to the fact that econonomical savings decrease exponentially with enrichment and for this particular case almost 70% of the maximum attainable saving is reached with 0.85% U235. Furthemore, higher fissile content would imply costly structural changes in the installation.

2. THE FUEL ROLE IN SEU

Extensive studies have been performed in Canada, related with the use of SEU in Candu reactors even if irradiations in power plants have not yet been initiated.

Also KWU identified this fuel cycle as an interesting alternative for PHWRs in the first phases of the Atucha 1 project. Moreover, Germany established a precedent with the conversion of the 57 Mwe MZFR reactor from NU to SEU [1]. This PHWR reactor operated around 10 full power years with enriched fuel: 0.85% U235 first and 1% U235 later. In this period, the fuel exit burnup increased gradually from approximately 7000 Mwd/tonU to 12000 Mwd/tonU in the first step and finally to 16000 Mwd/tonU.

In Argentina, the interest in this fuel cycle began as said, early at the time of the first NPP project. In 1985 twelve SEU fuel assemblies were fabricated for Atucha 1 and recently (January 1995) their introduction in the core was initiated. The fuel design considered up to now is almost identical to the original NU fuel assembly.

It is clear that the fuel plays a principal role in the implementation of the SEU cycle. Once the equilibrium core is reached the fuel exit burnup and the burnups at which shuffling operations are performed are notably higher. Even in the long transition from the natural to the enriched core, the burnup increases steadily, not only for the SEU but also for the NU fuel.

A more flexible fuel, resistant to PCI defects in this extended burnup range is of great significance.

2.1 Use of annular pellets

In [2] a revision was made of the proposed improvements in order to solve the problems related with burnup extension, going from simple solutions as increased gaps, shorter pellets, to more complex ones as graded enrichment or the CANFLEX design.

Here we analyze a modification consisting in the use of annular pellets in the outer ring of the cluster. This design produces several performance benefits. The improvement achieved depends on the void volume in the pellets which at the same time represents a certain burnup decrese. These parameters (power ratios and burnup loss) are quantified for the Atucha I and Embalse NPPs even if our attention is focused mainly on the Atucha case, because of its more inmediate importance.

The particular fuel management scheme used in this plant is broadly as follows:

If the core is imaginarily divided in tree concentric "zones": central, middle and outer, we can say that the fresh fuel is introduced in the middle zone, it is shuffled radially to the center when it has reached a mean burnup of approximately 2500-3000 Mwd/tonU and in the last step it is moved towards the outer zone at burnups in the order of 5000 Mwd/tonU. In this location it reaches the exit burnup and from here it is removed from the reactor.

The general outline is the same for the SEU case, except that the "zones" are different and the shuffling operations are performed at higher (almost doubled) burnups.

The movement from the middle to the central zone, with its abrupt increase in power density is the most delicate related to fuel performance. Also other non-stationary maneuvres like starts-up and power cycles affect the fuel behaviour and favours PCI defects.

In the SEU cycle, these power ramps occur at higher burnups, increasing fuel defects risks.

The use of annular pellets in the outer ring of the fuel assembly, reduces the temperature in the highly rated fuel, reducing the fission gas release, the internal pressure and providing additional space for pellet expansion. The resulting power redistribution in the cluster improves the maximum to average bundle power ratio (peaking factor), meaning that the fuel assembly can be operated at higher power without decreasing the margin to design limits.

3. RESULTS

In Fig. 1, a cross section of the fuel elements used in the two argentine NPPs is shown: (a) the well known Candu 37 rods fuel element in Embalse NPP, and (b) the Atucha 1 cluster with 36 fuel rods and a structural rod in the outer ring.

FIGURE 1

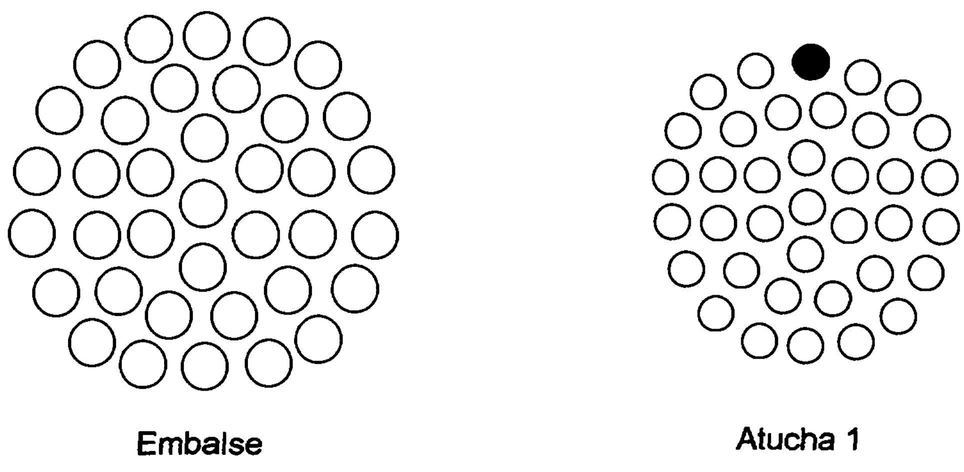

Fig. 2 resumes the relative power in the outer ring of rods in the Embalse cell, when natural uranium and 0.85% U235 are used as fuel in the current bundle. The two additional curves correspond to the use of annular pellets in the outer ring with a central void region corresponding to 6% and 11% of the pellet volume. The calculations were performed with WIMS code [3].

The improvement in the overpower of the outer rods is evident. The maximum value of the curves or peaking factor is reduced when annular pellets are used. This implies that for the same bundle power, the linear power density in the most exposed rod diminishes.

In Table I the behaviour of the peaking factor is given for both NPPs. Increasing the void volume inside the pellet, the peaking factor improves, but the UO2 loss produces a burnup reduction which imposes a compromise between the two parameters.

Using voids in a range from 6% to 11% of pellet volume, reductions in peaking factors of 1.8% to 4.4% for Embalse and 2.7% to 5.5% for Atucha 1 can be achieved. This comparison is made with respect to the actual design with natural uranium fuel. If it is made with respect to slightly enriched fuel the figures improve.

FIGURE 2

Relative Power in Outer Ring

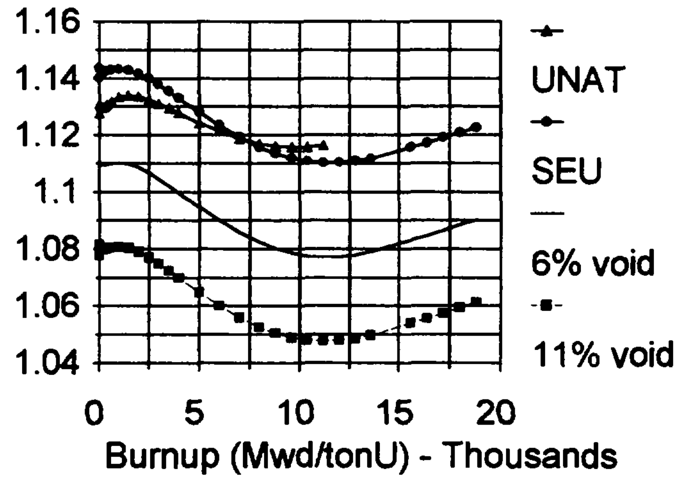

TABLE I: PEAKING FACTORS FOR EMBALSE AND ATUCHA 1

Natural uranium	0.85% U235	0.85% U235 11% void	0.85% U235 6% void
EMBALSE			
1.13	1.14	1.08	1.11
ATUCHA1			
1.10	1.11	1.04	1.07

From this point of view, enriched fuel with the new design performs better than the actual fuel with natural uranium.

The burnup losses have been estimated between 140 and 250 Mwd/tonU for annular pellets with 6% and 11% void volumes in the Embalse case. This is very reasonable keeping in mind that this low enrichment would allow a burnup increase from 7500 to 12500 Mwd/tonU.

For Atucha 1 the estimations are respectively 80 and 160 Mwd/tonU. Again these values are small compared to the burnup increase produced by SEU. In this case reactor calculations confirmed the preliminary estimations on burnup losses [4]. The overall reactor calculations were performed with the PUMA code [5] and some results are given in Table II.

TABLE II : RESULTS FOR ATUCHA 1

	Natural uranium	0.85% U235	0.85% U235 11% void	0.85% U235 6% void
Exit burnup (Mwd/tonU)	6000	11140	10980	11060
Maximum channel power (Mw)	7.34	6.79	6.80	6.79
Maximum linear power (w/cm)	509	451	424	436

The fuel management schemes used for the equilibrium core are different for the natural uranium and enriched fuel. In the enriched case the fuel enters the core more peripherically and of course is shuffled towards the center at higher burnups.

The maximum channel power and maximum linear power which in the natural uranium case are found in the central core zone are shifted considerably towards the periphery due to the flattening of the power distribution produced by SEU.

The results confirm a decrease of 3.3% in the maximum linear power density for 6% volume void and 6% decrease for 11% volume void.

4. CONCLUSIONS

We have analyzed a simple modification of the PHWR fuel element in order to improve its performance in the case of SEU fuel and its related burnup extension. The new design replaces the outer ring pellets by annular ones.

This modification allows to operate the fuel a higher power rate than the actual natural uranium bundle. The allowed increase ranges between 1.8% and 4.4% for pellet holes equivalent to 6% and 11% of pellet volume in the Embalse NPP case. This figures change to 2.7% to 5.5% for the same relative void volumes in the case of the Atucha 1 NPP.

The corresponding burnup losses are small in the context of the SEU cycle values.

There are other solutions which improve even more drastically the peaking factor in the fuel as for example the CANFLEX design or the graded enrichment. Nevertheless, the proposed solution has the advantage of being easy to implement in our case, being good enough for the burnups involved in the SEU cycle.

This design improves the fuel behaviour with respect to the burnup extension derived from the slight enrichment and it is also interesting in case an overall power upgrade is considered.

REFERENCES

[1] FRISCHENGRUBER,K.,DUSCH,F.,"Developement Potential and Advanced Fuel Cycles in KWU Type PHWRs",IAEA TC on Advanced and Heavy Water Reactor Technology, Vienna, Austria,1984.

[2] NOTARI,C., MARAJOFSKY,A., "Analisis del combustible levemente enriquecido para un PHWR", GACC-P.ULE-inf. no.5/94. CNEA,1994.

[3] HALSALL,M.J, "A summary of WIMSD4 input options", AEEW-M1327,1980.

[4] SERRA,O., Report in preparation.

[5] GRANT,C., " PUMA, sistema para la simulación del funcionamiento de reactores nucleares. Fundamentos teóricos y su utilización". CNEA-Re-163,1980.