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A PHWR WITH SLIGHTLY ENRICHED URANIUM ABOUT THE FIRST CORE

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Abstract

Many different studies have been performed in Argentina regarding the use of slightly enriched uranium in the PHWR nuclear plants. These referred mainly to operating plants so that a transition had to be considered from the present natural uranium fuel cycle to the slightly enriched one. In this analysis, technical and economical arguments are presented which favor the use of a natural uranium initial core. The levelized fuel costs are shown to be practically insensitive to the first core and a fast transition is more influential than an initially enriched core.

1. INTRODUCTION

The use of slightly enriched uranium (SEU) in a PHWR has been the subject of a number of analysis, showing the advantages in generating cost and fissile material savings.

The use of this fuel cycle in presently operating reactors is made through a transition from the equilibrium natural uranium (NU) core to an homogeneous SEU core.

Some studies report also different optimizations of the plant in order to adapt the design to the benefits of this new cycle from the start-up. Nevertheless a series of considerations of technical and economical nature favor the solution of starting the PHWR plant with natural uranium and switching afterwards to a SEU cycle by means of an adequate transition.

2. THE START-UP CORE

For a PHWR reactor which operates under on-power refuelling, the initial core is a great singularity from the point of view of the excess reactivity. In fact, the multiplication is of a magnitude never repeated along the plant's life. This means that during the start-up and a long initial period the design must assure the control of this reactivity in all possible situations.

In this sense, the batch refuelling of a LWR makes the first core a less singular situation.

The PHWR plant operates during the initial phase with a high concentration of neutron poison either in the form of boron, depleted uranium, etc. Of course this implies a loss of burnup associated to the first core or even further. Thus, it is conceptually contradictory to enrich the initial core and at the same time increase the poison content to control a higher reactivity.

Moreover, this poisoning in the SEU case will last a longer period because the fuel must reach a higher burnup untill the equilibrium reactivity excess is reached. This excess is similar to the natural uranium case because the tipical operational transients, like xenon recovering require similar reactivity reserves both in the NU and SEU cases.

For the argentine NPPs, the use of 0.85% enrichment in the fuel adds approximately 6000 pcm to the initial core reactivity. To give an idea of what this value means, in the case of Atucha 1 NPP (350Mwe), all the safety rods control a reactivity of around 8400 pcm in the cold core.

From a licencing perspective, the NU initial core solution is preferred, because it is the normal and well established procedure for a PHWR, and the core is much less reactive in the long transition from start-up to the equilibrium situation.

In other words, what is here suggested is that a NU initial core is a solution conciliating technical and economical aspects.

3. GENERATING COSTS

In the following, an economic evaluation is presented for different alternatives of NPP start-up.

The methodology used to calculate generating costs is that of levelized lifetime costs at constant money which is considered adequate for this comparison.

3.1 CANDU reactor

In this case levelized generating costs were calculated for two identical plants, 881 Mwe each, hipotetically started-up with a NU core and a SEU core respectively. The enrichment used was 0.9% U235.

The data for cost evaluation were taken from reference [1]. The prices adopted for uranium and conversion were 40 U$S/kg and 8 U$S/kg as the latest information about fuel cycle costs was not available.

The commissioning date was fixed in year 2000, with a plant lifetime of 30 years. The discount rate adopted was 5% and the effect of adopting 10% was included in the analysis. All costs were discounted at the commissioning date.

As both plants are considered identical, without design changes related to the SEU cycle, capital costs are the same and amount to 23.6 mills/kwh. The corresponding value in [1] is 22.8 mills/kwh, but the load factors used in the calculation are referred ambiguously.

The initial and final cores are included in the fuelling costs, so the comparison is made on this component only.

Tables I and II show the results of levelized fuelling costs for 5% and 10% discount rate respectively.

The different cases correspond to the following description:

(0) : Reference case. The first core and the following are NU with the indicated exit burnups,

-1st. core: 6375 Mwd/tonU
-2nd. core: 7500 Mwd/tonU (equilibrium)

(1) : The first core and the following are SEU with 0.9% enrichment. The exit burnups are,

-1st. core: 10000 Mwd/tonU
-2nd. core 14000 Mwd/tonU (equilibrium)

(1-a) : Same as (1) but with a different burnup sequence ,

-1st. core: 9000 Mwd/tonU
-2nd. core: 12000 Mwd/tonU
-3rd. core: 14000 Mwd/tonU (equilibrium)

(2) : The first core is NU and the following are SEU with 0.9% enrichment and the indicated exit burnups,

-1st. core: 6375 Mwd/tonU
-2nd. core: 12000 Mwd/tonU
-3rd. core: 14000 Mwd/tonU (equilibrium)

(2-a) : Same as (2) but with a different burnup sequence,

-1st. core: 6375 Mwd/tonU
-2nd. core: 9000 Mwd/tonU
-3rd. core: 11000 Mwd/tonU
-4th. core : 14000 Mwd/tonU (equilibrium)

Cases (1) and (2) represent a fast transition to the equilibrium SEU core and cases (1-a) and (2-a) a slower transition.

The burnup values are reasonable for the present calculations but of course they are only indicative and depend on the particular fuel management adopted in each case.

TABLE I : LEVELIZED FUELLING COSTS. 5% DISCOUNT RATE

CASE	FUELLING COST (mills/kwh)	SAVING (%)
(0) NU	2.13	
(1) SEU	1.69	20
(1-a) SEU	1.74	18
(2) NU-SEU	1.71	20
(2-a) NU-SEU	1.80	15

The results show that fuelling costs are reduced in the range 18%-20% when the SEU fuel cycle replaces the NU cycle. When the transition to equilibrium is delayed in time costs increase.

Levelized costs practically do not change if the start-up core is NU or SEU: cases (1), (2), provided that the transition to equilibrium is fast. When the transition is slow the difference increases: cases (1-a), (2-a).

Results are also sensitive to the discount rate. The benefits of the SEU cycle decrease with increasing discount rate.

The SEU cycle is more sensitive to discount rate than NU. This is mainly due to the fact that for NU the back-end costs are relatively more important and so there is a compensation between the penalization of front-end costs and the reduction of back-end cost contribution when a higher rate is considered. The relative weight of the back-end component is 27% for 5% discount rate and it drops to 15% for 10% discount rate.

In the SEU cases the figures corresponding to the back-end component are 18% and 10% respectively. This reduced importance of the back-end inhibites the above mentioned compensation.

Of course the difference in cost between a NU and a SEU initial core (14 million U$S and 20 million U$S respectively), has a decisive influence in the results.

TABLE I I : LEVELIZED FUELLING COSTS. 10% DISCOUNT RATE

CASE	FUELLING COST (mills/kwh)	SAVING (%)
(0) NU	2.10	
(1) SEU	1.78	15
(1-a) SEU	1.84	12
(2) NU-SEU	1.80	14
(2-a) NU-SEU	1.91	9

3.2 Atucha 2 reactor

Table 3 shows results for the argentine Atucha 2 NPP. This is a 750 Mwe PHWR, currently under construction. The enrichment in this case was 0.85% and local fuel cycle costs were considered except for the back-end data which were interpolated among those reported in reference [2] for once-through cycles.

The description of the cases studied is as follows:

(0) : Reference case. The first core and the following are NU with the indicated exit burnups,

-1st. core: 6375 Mwd/tonU
-2nd. core: 7500 Mwd/tonU (equilibrium)

(1) : The first core and the following are SEU with 0.85% enrichment. The exit burnups are,

-1st. core: 9000 Mwd/tonU
-2nd. core 12000 Mwd/tonU (equilibrium)

(1-a) : Same as (1) but with a different burnup sequence ,

-1st. core: 8000 Mwd/tonU
-2nd. core: 10000 Mwd/tonU
-3rd. core: 12000 Mwd/tonU (equilibrium)

(2) : The first core is NU and the following are SEU with 0.85% enrichment and the indicated exit burnups,

-1st. core: 6375 Mwd/tonU
-2nd. core: 10000 Mwd/tonU
-3rd. core: 12000 Mwd/tonU (equilibrium)

(2-a) : Same as (2) but with a different burnup sequence,

-1st. core: 6375 Mwd/tonU
-2nd. core: 8000 Mwd/tonU
-3rd. core: 10000 Mwd/tonU
-4th. core: 12000 Mwd/tonU (equilibrium)

Again, cases (1) and (2) represent a fast transition to the equilibrium SEU core and cases (1-a) and (2-a) a slower transition. The burnup values are, as before, only indicative.

Table III resumes the principal results.

TABLE I I I: LEVELIZED FUELLING COSTS. 5% DISCOUNT RATE

CASE	FUELLING COST (mills/kwh)	SAVING (%)
(0) NU	6.73	
(1) SEU	4.91	27
(1-a) SEU	5.03	25
(2) NU-SEU	5.04	25
(2-a) NU-SEU	5.18	23

The general behaviour of costs is similar to the preceeding case but here the results show less sensitivity to the transition.

It is very clear that in a case with higher fuelling costs, the benefits of the SEU cycle are bigger, specially reminding that in this case the results correspond to a lower enrichment: 0.85% U235.

4. CONCLUSIONS

Many different studies have been performed in Argentina regarding the use of slightly enriched uranium in the PHWR nuclear plants. These referred mainly to operating plants so that a transition had to be considered from the present natural uranium fuel cycle to the slightly enriched one. Little has been said about the start-up core of a new plant.

In this analysis, technical and economical arguments are presented which favor the use of a natural uranium initial core.

From a technical point of view, we can say that for a PHWR, with on power refuelling, the initial core is a singularity in the plant's life. During the long start-up period a very high excess reactivity has to be controlled and this situation is never repeated.

The plant is thus operated during a long period with a high poison content which of course produces a reduced mean burnup of the first core. In the SEU case the poisoned start-up core lasts a longer period because the fuel must achieve aproximately twice the burnup of the NU case (for 0.85% U235 enrichment), before the reactivity excess reaches the standard equilibrium value.

From a licencing point of view, the NU initial core solution is preferred because the reactor is much less reactive during the long transition from the start-up to the equilibrium situation.

Moreover, the economical side of the problem does not favor an initial SEU core.

The levelized fuel costs are shown to be practically insensitive to the first core and a fast transition is more influential than an initially enriched core.

In our case where the sources of investment are scarce, the different cost between a NU and SEU initial core is relevant.

A more flexible fuel design plays an important role in speeding-up this transition and also in reaching high load factors which are of mayor importance in the economics of the plant.

REFERENCES

[1] Projected Costs of Generating Electricity. Update 1992. OECD, Paris.

[2] The Economics of the Nuclear Fuel Cycle. OECD, Paris,1985.

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