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# Improvements of Nuclear Fuel Management in Pressurized Water Reactors (PWR)

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SUBGROUP A

# IMPROVEMENT OF NUCLEAR FUEL MANAGEMENT IN PRESSURIZED WATER REACTORS (PWR)

J. P. Schwartz

The severe variations to which the different elements contributing to the determination of the fuel cycle cost are subjected have led to a reopening of the problem of "optimization" of nuclear fuel management. The increase in costs of uranium ore, isotope separation work units (swu), reprocessing, the political implications of proliferation associated with the employment of reprocessing operations have been at the origin of a reassessment of present-day management.

It therefore appeared to be appropriate to study variants with respect to a reference mode represented by the management of the PWR 900 MWe systems, without burnable poison in the cycle at equilibrium (Case 3 of Table 1). In order to obtain a complete view of impacts of such modifications, computations were carried out as far as the appraisal of the cycle cost and with reprocessing.

There has likewise been added to this the estimate of the gain anticipated from certain improvements in the neutron balance contributed at the level of the lattice.

## COMMENT

The complete determination of a core management constitutes a voluminous study involving many components, positioning of assemblies, control of reactivity, method of fine control, ... in order to achieve in each case the operating characteristics (peak power ...) corresponding to all conceivable situations up to accidental configurations (ejection of rods ...). It is not a matter of undertaking this work within the present scope but to set forth promising methods at the same time emphasizing possible difficulties. /2

Likewise, the complete study of the fuel cycle in the reactor and outside of the reactor under all hypotheses envisaged has not been done here. For example, the characteristics obtained in the different cases, more particularly with respect to enrichment, are not necessarily compatible with the capabilities of French reprocessing plants either operating or planned.

*Numbers in the right margin indicate pagination in the original text.

## 1. FRACTIONATION OF REFUELINGS

Refueling presently takes place by thirds each year. An examination has been made of the impact of refueling by halves and by quarters. The variation of the period of the cycle in the reactor should be taken into account owing to its impacts on the availability of the power plant. It has been assumed here that the period of refueling was constant, one month, during which the lack of energy to be supplied was compensated for by an energy of substitution estimated at 10 c/kWhr. The load factor outside of refueling is assumed to be constant.

| Case Number | 1 | 2 | $3_{ref}$ | 4 | 5 |
|---|---|---|---|---|---|
| Refueling | 1/2 | 1/2 | 1/3 | 1/3 | 1/4 |
| Enrichment (percent) | 3.1 | 3.35 | 3.1 | 3.8 | 3.8 |
| Rate of specific burnup ($GW_d/t_U$) | | | | | |
| with waste | 28.5 | 31.5 | 31.8 | 41 | 43.5 |
| per cycle | 14.25 | 15.75 | 10.6 | 13.7 | 10.9 |
| Energy supplied per t Unat (GWhr/$tU_{nat}$) | | | | | |
| without recycling U | 35.7 | 36.3 | 40 | 41.4 | 44 |
| with recycling U | 49.1 | 48.9 | 51.3 | 50.6 | 52.4 |
| Cost of cycle at equilibrium (c/kWhr) with reprocessing | 2.83 | 2.77 | 2.62 | 2.56 | 2.45 |
| Gain over ref. 3 (c/kWhr) | -0.21 | -0.15 | | 0.06 | 0.17 |
| Refueling period (month) | 15.8 | 17.3 | 12 | 15.2 | 12.3 |
| Impact on availability (c/kWhr) | 0.68 | 0.61 | 0.91 | 0.70 | 0.88 |
| Gain over ref. 3 (c/kWhr) | 0.23 | 0.30 | | 0.21 | 0.03 |
| Total gain over ref. 3 (c/kWhr) | 0.02 | 0.15 | | 0.27 | 0.20 |

With regard to energy produced by one ton of natural uranium as well as the cycle cost in its true sense, only the increase in fractionation (Case 5) contributes an improvement amounting to 2% for the former and 6.5% for the latter. Since the availability was practically unchanged, this gain is preserved. The appreciable effect of the availability should be noted which, with the hypotheses taken, encourages long cycles, hence increase in enrichment (Case 4). A shutdown proportional to the duration of the cycle would reduce this effect to zero. /3

Depending on the case being considered and in order to arrive at a viable solution, difficulties differing in nature should be solved:

For long cycles (Cases 1, 2 and 4), the control of reactivity (burnable poison, effectiveness of control rods), management of peak power.

In the case of high fuel irradiation rates (Cases 4 and 5), the rating of the fuel.

COMMENT

The open cycle has a greater susceptibility of the energy which can be extracted from natural uranium with the management mode. The variations of neutron conditions are reflected in reality more strongly with the neutron balance without being damped by taking more complete account of the fertile-fissile conversion. This is why in Case 5 there is found a 10% increase in potential energy of natural uranium.

## 2. MODIFICATION OF THE LATTICE

The effect of an increase in the moderation ratio has been studied, at the same time assuming maintenance of a negative temperature coefficient of the moderator.

The increase in the moderation ratio can be obtained furthermore by different methods:

By keeping the dimensions 17 x 17

Keeping the external diameter of the cladding and reduction of the diameter of the fuel pellet and thickening of the cladding or creation of a central hole in the fuel pellet.

Reduction of the external diameter of the cladding anf fuel.

Going to a dimension of 19 x 19 in which the hydaulic diameter could be maintained.

An increase in the moderation ratio by 10% leads to a gain of 3% /4
over the fuel cycle cost with the same duration of operating cycle and as a first approximation notwithstanding the method by which it is performed. Over the energy supply by natural uranium, the gain is at the level of 2% (5% with open cycle).

To the extent that the same core size is maintained and the same power, it will be necessary to cope with problems of fuel service life under an increased fuel irradiation level and with a fuel rating which can be found increased by 10% depending on the geometry of the lattice used.

## 3. MODIFICATION OF STRUCTURES

The replacement of the grids of the assemblies made of inconel

by grids made of zircoloy contributes to an increase of 2% by the energy supplied and of the cycle cost.

## CONCLUSION

The considerations which have just been presented show that modifications of reactor management of fuel can constitute a positive contribution in search for an energy balance and a more favorable cycle cost. Nevertheless, this contribution, in order to turn out to be reasonable, should always be accompanied by taking into account more severe operating conditions at the level of the cycle in the reactor (extension of the period whence problems of core control) or of the fuel (increase in fuel irradiation load and fuel rating).

Finally, these considerations do not modify the relative positions of the open cycle and the cycle with reprocessing. Capable of improving both cycles, they keep for the reprocessing cycle an advantage of 20 to 40% over the energy balance of the uranium cycle alone.