Reduction of burnup reactivity loss in large LMFBR cores by using neptunium 237

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Introduction

Adding neptunium 237 to the fuel of nuclear reactors had been proposed in the wave of the INFCE studies, as a way to make plutonium fuel less proper to nuclear weapons, because of Pu238 heating [1].

Here its insertion is proposed for large fast reactors, with a view to reduce the burnup reactivity loss. Indeed with the very large burnup targets envisaged now for these LMFBRs, currently 150 to 200 MWd/kgHM, this objective is receiving first priority. Several means are being contemplated to improve the internal breeding properties, like the heterogeneous concept (with an axial fertile slice).

The use of Np237 is proposed here as a complementary way, to be checked by R & D work, specially as fabrication, irradiation and reprocessing are concerned.

Physical basis

LWR fuel irradiated at 33,000 MWd/t HM contains at discharge, per tonne of initial uranium, about 0.43 kg Np237 for 9.5 kg Pu.

Very stable, Np237 mainly transmutes under irradiation into Pu238 by neutron capture. Pu238 is fissile, although less good fissile than Pu239. The conversion rate Np237 to Pu238 is quite high, as the Np237 capture rate is high, so that Pu238 forms quicker than Pu239 does from the basic breeding reaction (U238 to U239 to Pu239).

Transmutation from Np237 inserted in the fuel instead of U238 can thus bring a positive reactivity increment.

Two numerical applications have been made to check this, first on a typical fuel composition of SUPER-PHENIX, and secondly on a core composition of SNR2 [2]. The main difference lies in the maximum burnup aimed at, which is, respectively, 80 and 150 MWd/kg HM.

Application to SUPER-PHENIX

A composition typical of the inner core zone of SUPER-PHENIX has been taken to consist of 84.2 w/o uranium and 15.8 w/o plutonium (with americium) with vectors of, respectively,
U235/ U238 = 0.45/ 99.55 %,
Pu238/ Pu239/ Pu240/ Pu241/ Pu242 = 2/ 57/ 24/ 11/ 6 %, plus 1.6 % Am241/Pu.

The KORIGEN depletion code [3] has been used, with cross-sections derived from a modified KfKINR1 cross-section set ; the values of main interest are shown in Table 1. The depletion has been calculated over 2 years operation time, reaching a burnup of 62.7 MWd/kg, a value typical of the fuel average in this inner zone.

Two variants have been compared to this reference case ; Np237 is substituting, respectively, 5 and 10 % of U238, or in other terms, Np represents 4.2 and 8.4 % of the total heavy atoms. The Pu enrichment is kept constant.

The results, illustrated on Figure 1, show the variation of $k_{(infinite)}$ over the irradiation. While in the reference case k_{inf} is steadily decreasing, it increases in both cases with Np ; this is very marked in the last case (8.4 %) : + 0.05 versus - 0.02. But one sees that the irradiation is not long enough to reproduce the same k_{inf} at the end of the 2 years, so that one would have to increase the enrichment of the fuel.

Application to SNR 2

An average fuel composition typical of SNR 2 has been assumed to contain

21 % of plutonium, with a vector of Pu238 / Pu239 / Pu240 / Pu241 / Pu242 = 1/60/25/9/5 % plus 3 % of Am241/Pu, and

79 % of depleted uranium (0.25 % U235)

Burnup calculations have been performed with a small programme using the ORIGEN-2 library ; the one-group cross-sections are very close to those given in Table 1. The irradiation extends over 4 cycles of 1.25 year, thus a total of 5 years at 0.75 load factor.

Many variants have been considered, with Np substituting U or Pu or both, with the aim of reaching the same reactivity at end of life. An approximate reactivity scale has been built from one-group cross-sections.

Some of the main results are given in Table 2, where 2 variants are retained with, respectively, 1 and 5 % Np replacing U and Pu.

Assuming that the reactivity drops in the reference case by 2.5 % dk per year, this reactivity loss is reduced by, respectively 0.33 and 1.1 % dk.

Such results are on line with similar results obtained recently for the CDFR design [4].

Conclusion

The insertion of neptunium 237 into the fuel of LMFBR cores has been checked to be beneficial, as it helps to reduce their burnup reactivity loss. From the application to the case of SNR 2, if one considers 5 % Pu238/Pu to be a practical limit both for fuel fabrication and reprocessing one deduces that an introduction of 3.5 % Np (of the total heavy atoms) would be adequate. A yearly burnup reactivity decrease of 2.5 % dk/k would then be reduced to 1.6 % dk/k. If this is applied as a complement to other means, like the heterogeneous core concept, it helps going in the direction of the ideal zero reactivity decrease, and would greatly decrease the deleterious effects of control rods on the core properties and safety behaviour.

Acknowledgement

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TABLE 1

Cross-sections used
(from modified KfKINR1 set)

Nuclide	σ_c (b)	σ_f (b)	ν
Np237	1.79	0.31	3.01
Pu238	0.70	1.02	2.83
U238	0.31	0.041	2.81
Pu239	0.54	1.86	2.88

TABLE 2

Np insertion in the fuel
Application to SNR 2

Cases fractions of Np-Pu-U	Reactivity loss per year % dk/k	Fraction of residual Np after 5 years %	Pu content in Pu238 after 5 years %
0 - 21 - 79	2.5	-	1.3
1 - 20.7 - 78.3	2.17	55	2.7
5 - 20 - 75	1.4	52	8.1

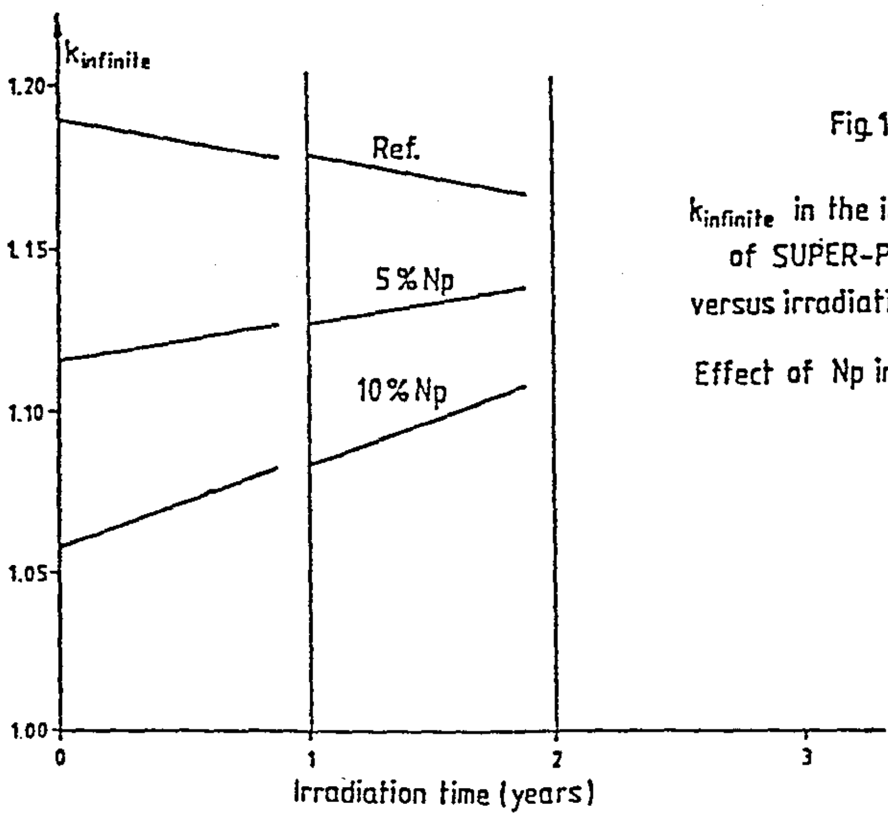

Fig. 1

$k_{infinite}$ in the inner zone of SUPER-PHENIX versus irradiation time

Effect of Np insertion

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