Feasibility of Partial LWR Core Loadings with Inert Matrix Fuel

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Summary

The world plutonium inventory is steadily growing due to the unavoidable production of plutonium in current-day light water reactors (LWRs) and the de-allocation of weapon-grade plutonium from dismantled nuclear arms [1]. Accordingly, efforts are being made to increase the Pu-consumption in LWRs by using new Pu-containing inert matrix fuels (IMFs).

Nowadays, MOX fuel is widely used in LWRs in the form of partial core loadings [2]. The maximum amount of MOX fuel is typically limited to about 40% of the core inventory. As a result, the plutonium consumption does not exceed the amount of plutonium which is produced from the uranium present in the core. In addition, there are some disadvantages of using MOX fuel. Usually the MOX assemblies are more expensive than UO_2 assemblies, the time the MOX assemblies have to spend in the wet storage pool is longer, and the use of soluble boron which is enriched in ^{10}B is sometimes demanded by nuclear safety inspectorates to achieve the specified shutdown margins.

Usually, the amount of spent fuel to be reprocessed and hence the amount of plutonium to be brought back into the core are fixed. Doing this in the form of a once-through uranium-free IMF could represent a useful complementary strategy to the currently practised single recycling of plutonium as MOX. The current paper reports on a comparatory investigation of partial IMF and MOX loadings in an actual 1000 MWe PWR power plant.

For this study, several real-life cycles of the plant, including cycles with partial MOX loadings, were first modelled using the CMS system [3, 4, 5]. Comparisons of the calculated results with measured data in terms of the boron let-down curves and detector signal distributions showed good agreement for both UO_2 as well as MOX loadings.

Two different strategies were then investigated in order to study the behaviour of partial IMF core loadings and to get a direct comparison with MOX fuel. In a first step, every MOX assembly was substituted by an IMF (Pu-Er-Zr oxide) assembly for all cycles with partial MOX loadings. This study brought out certain basic differences between IMF and MOX fuel. Thus, for example, because burnable poison is used within IMF, the boron let-down curves of the cores with partial IMF loadings are flatter than those of the cores with partial MOX loadings. Figure 1 shows the comparison between a cycle with 16% IMF and 16% MOX loadings. Increasing the amount of IMF in the same way as MOX for the succeeding cycles

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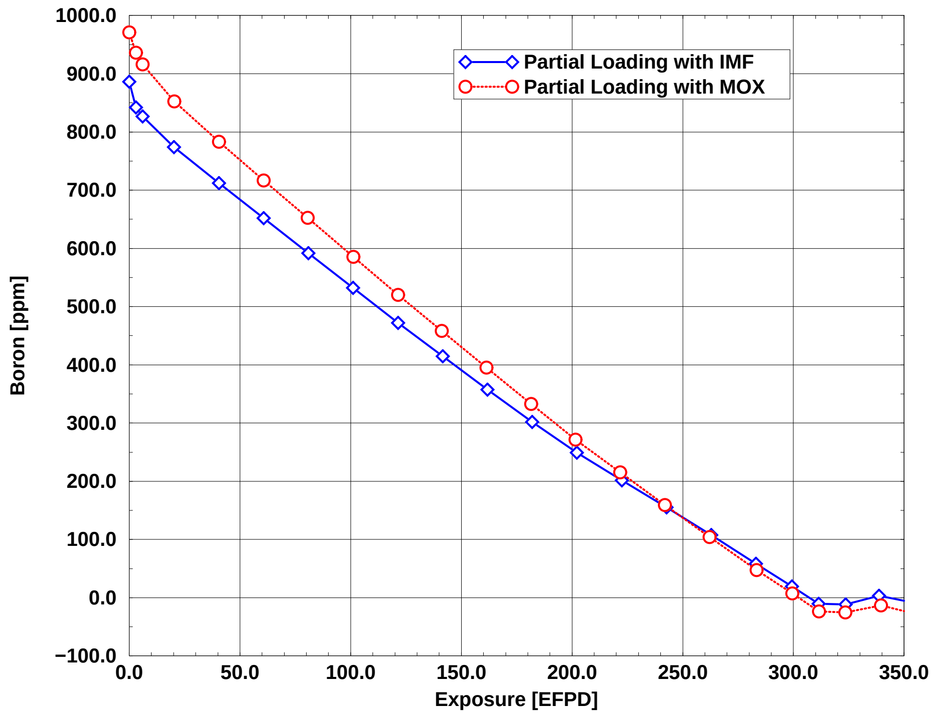
results in an even greater difference between the boron let-down curves. This indicates, that the use of enriched boron may not be necessary.

Fig. 1: Comparison between Boron Let-down Curves of the PWR Core with IMF and MOX Partial Loadings (16% in each case)



The calculated radial power distributions have shown that the average power in the IMF assemblies is more than 10% lower than in the MOX assemblies at beginning of cycle, while the power of the UO_2 assemblies is greater. During burnup, the power in the IMF assemblies remains approximately constant and that in the UO_2 assemblies decreases.

Following this first set of comparisons, core loadings with IMF have been designed which contain, on the average, the same amount of plutonium as the cores with the partial MOX loadings considered. Because IMF contains about 50% more plutonium than MOX fuel, these cores were loaded with about 30% less IMF assemblies than MOX assemblies and the free positions were filled with UO_2 assemblies. Still, the plutonium consumption for such an IMF core is around twice as large as in the original core with the corresponding MOX loading. Thus, a real plutonium reduction would be possible with less IMF assemblies containing the same amount of plutonium as a 40% MOX loading (self-generated mode).

The full paper will also provide a partial validation of the calculational results reported for the IMF core loadings. This will be done on the basis of an analysis of some of the recently initiated experimental efforts to validate the neutronics and irradiation behaviour of a Pu-Er-Zr oxide IMF [6, 7, 8, 9]. Use has been made, in this context, of results from the Halden irradiation test IFA-651.1 and their modelling with a PSI version of the TRANSURANUS code [10, 11, 12] for deducing the fuel temperature used in the SIMULATE-3 [5] calculations. Furthermore, neutronics measurements in the PROTEUS facility and have been analysed with CASMO-4 [13], to provide partial validation of the assembly calculations.

References

[1] J.-S. Choi, IAEA in N. Numark, A. Michel (eds): Conference Report of the International Conference on the Future of Plutonium; October 2000, Brussels, Belgium.

[2] P. Ledermann, D. Grenèche; Proc. of the International Conference in Future Nuclear Systems GLOBAL'99, Aug./Sep. 1999, Jackson Hole, Wyoming, USA.

[3] M. Edenius, K. Ekberg, B.H. Forssen, D. Knott: CASMO-4, a Fuel Assembly Burnup Program; User's Manual, StudsvikSOA-951, Studsvik of America, Newton MA, Sep. 1995.

[4] T. Bahadir: CMS-Link User's Manual; StudsvikSOA-9704, Studsvik of America, Newton MA, 1997.

[5] A.S. DiGiovine, J.D. Rhodes: SIMULATE-3 User's Manual; StudsvikSOA-9515, Studsvik of America, Newton MA, 1995.

[6] R.P.C. Schram, K. Bakker, H. Hein, J.G. Boshoven, R.R van der Laan, T. Yamashita, G. Ledergerber, F. Ingold: Design and Fabrication Aspects of a Plutonium-Incineration Experiment using Inert Matrices in a Once-Through-then-Out Mode; Prog. Nucl. Energy 383-4 (2001) 259-262.

[7] U. Kasemeyer, Ch. Hellwig, Y.-W. Lee, G. Ledergerber, D.S. Sohn, G.A. Gates, W. Wiesenack: The Irradiation Test of Inert-Matrix Fuel in Comparison to Uranium Plutonium Oxide Fuel in the Halden Reactor; Prog. Nucl. Energy 383-4 (2001) 309-312.

[8] Ch. Hellwig, U. Kasemeyer: Modelling the Behaviour of Inert Matrix Fuel with TRANSURANUS-PSI; Enlarged Halden Group Meeting, March 2001, Lillehammer, Norway.

[9] R. Chawla, P. Grimm, P. Heimgartner, F. Jatuff, G. Ledergerber, A. Lüthi, M. Murphy, R. Seiler, R. van Geemert: Integral Measurements with a Plutonium Inert Matrix Fuel Rod in a Heterogeneous Light Water Reactor Lattice; Prog. Nucl. Energy 38/3-4 (2001) 359-362.

[10] K. Lassmann, L. van de Laar: TRANSURANUS Handbook, Version 1 Modification 2, Year 1998; European Commisiion, JRC-ITU, Karlsruhe, Germany, 1998.

[11] K. Lassmann, A. Schubert, J. van de Laar, C.W.H.M. Vennix: Resent Developments of the TRANSURANUS Code with Emphasis on High Burnup Phenomena; IAEA Technical Committee Meeting on Nuclear Fuel Behaviour Modelling at High Burnup, Lake Windermere, UK, June 2000.

[12] R. Chawla, C. Hellwig, F. Jatuff, U. Kasemeyer, G. Ledergerber, B.H. Lee, G. Rossiter: First Experimental Results from Neutronics and In-Pile Testing of a Pu-Er-Zr Oxide Inert Matrix Fuel; ENS TOPFUEL 2001, Stockholm, Sweden, 27-30 May 2001.

[13] M. Mori, M. Kawamura, K. Yamate: CASMO-4SIMULATE-3 Benchmarking Against High Plutonium Content Pressurized Water Reactor Mixed-Oxide Critical Experiment; Nuclear Science and Engineering, 121, 41-51, 1995.