ABSTRACT

Burnup calculations have been performed to calculate reactor physics parameters like reactivity coefficients and kinetic parameters as a function of burnup for MOX fuel with different moderator-to-fuel ratios. From the reactor physics point of view, MOX fuel in a PWR with a moderator-to-fuel ratio of 4 is very similar to UO$_2$ fuel with a ratio of 2, except for the delayed neutron fraction which is reduced by 50%.

I. INTRODUCTION

The slow down of fast reactor development urges for another solution to get rid of the plutonium generated in light water reactors. One possibility is to recycle this plutonium in Mixed-OXide (MOX) fuel assemblies in PWRs before disposition or further use. When the fissile $^{235}$U in standard UO$_2$ fuel is replaced by a mixture of plutonium isotopes, the reactor physics parameters of the fuel change considerably with associated impact on the controllability of the reactor.

This paper describes the reactor physics impact of MOX fuel in PWRs. The fuel temperature coefficient (FTC), the moderator temperature coefficient (MTC), the boron reactivity worth (BRW), the critical boron concentration (CBC), the moderator void coefficient (MVC), the neutron generation time ($\Lambda$), and the effective delayed neutron fraction ($\beta_{\text{eff}}$) have been calculated as a function of burnup for standard UO$_2$ fuel and for MOX fuel. The reference reactor used in the calculations is a French N4 PWR operated with five batches of UO$_2$ fuel with an initial enrichment of 4% and an exit burnup of 47.5 GWd/tHM. The calculations on the MOX fuel have been done for several moderator-to-fuel volume (MF) ratios ranging from 2 to 4. The plutonium in the spent fuel has been recycled four times.

II CALCULATIONAL PROCEDURES

The calculations have been performed with the OCTOPUS burnup and criticality code system, applying the BONAMI-NITAWL-XSDRNPM codes for the resonance shielding and 1-D neutron spectrum calculations, and the ORIGEN-S code for the burnup calculations. Nuclear data used are based on the JEF2.2 and EAF4.1 libraries.

The reactivity coefficients and kinetic parameters have been calculated at a number of branchings during the burnup. The FTC has been calculated by increasing the fuel temperature with 100 K, the MTC by increasing the moderator temperature with 10 K, the BRW by increasing the boron density with 100 ppm and the MVC by decreasing the moderator density to 1% of its nominal value. All reactivity coefficients have been calculated by $\frac{\delta k}{k}$. At each branching, an adjoint calculation has been performed to calculate the contributions of the individual nuclides to the FTC by means of first-order perturbation theory and to calculate $\Lambda$ and $\beta_{\text{eff}}$.

The plutonium density in the MOX fuel and the CBC in the moderator have been determined by assuming that the fuel reactivity decreases linearly as a function of burnup, and that the core contains the same number of assemblies of each of the five fuel batches. Then the reactivity curve of the third fuel batch resembles that of the equilibrium core, and the plutonium density should be such that $k_\infty$ during the third fuel batch equals that of standard UO$_2$ fuel (1.057), while the CBC should be such that the reactivity loss during the third fuel batch is zero. Then the boron concentration, which is assumed to decrease linearly as a function of burnup, compensates for the reactivity loss due to depletion of fissile material and buildup of fission products. The result is a constant $k_\infty$ with value of 1.057 during the third fuel batch. Because the plutonium density and the boron concentration depend on each other, these two parameters had to be determined iteratively.

The scheme for the plutonium recycling calculations is shown in figure 1. For the first recycling, the isotopic composition of the plutonium in the spent UO$_2$ fuel is used for the manufacturing of the MOX fuel. For the second, third and fourth recycling, the spent MOX fuel is assumed to be blended with a three times larger amount of spent UO$_2$ fuel before reprocessing. The sensitivity of the results to this blending ratio has not been investigated. All recycling calculations have been done for MF ratios varied.