BWR CONTROL BLADE DEPLETION MODELING IN MICROBURN-B2

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ABSTRACT

Control blade depletion is rigorously treated through microscopic depletion of B-10 atoms in the B_4C compound of neutron absorber. The depletion method is implemented in the MICROBURN-B2 core simulator and tested for actual BWR fuel cycles which have seen many control blade replacements. The effect on the hot operating condition is relatively small but not negligible if there is a large number of CR blades replaced during a fuel shuffle. The effect on cold critical cores, especially local critical state points, is favorable for eliminating some abnormal cold critical k-effective results. Combined with multiple control blade type simulation capability, the new model improves the accuracy of cold critical prediction.

I. Introduction

In the current analysis of BWRs core physics at Framatome ANP, the control blade is assumed to be fresh. The main absorber material of a BWR control blade is B_4C of which B-10 atoms are depleted as the blade stays inserted during reactor operation. An old control blade which reached its lifetime may have lost as much as 10 % of its negative reactivity. The effect of B-10 depletion on the core k-effective and power distribution has been considered to be insignificant and, thus ignored in typical analyses. Recently a control blade B-10 depletion model was installed in the MICROBURN-B2 BWR core simulator.(1) This model and its effect on the improvement in predicted results are described in this paper.

II. Methodology

The control blade B-10 microscopic absorption cross section is strongly dependent on the B-10 atom density itself through the self-shielding effect. Thus its dependency on B-10 density is quantified during lattice homogenization. In addition, various homogenized lattice parameters are included in the tabulation of B-10 microscopic absorption cross sections (σ_{B10}) for use in MICROBURN-B2 as follows:

$$\sigma_{B10,g} = f(N_{B10}, E, IV, CR, L) \quad (1)$$

where

N_{B10} = B-10 atom density
E = lattice average exposure
IV = instantaneous void fraction (or moderator density)
CR = control blade type
L = lattice type

g = group index

The change in the nodal macroscopic absorption cross sections at any state point of a reactor operation is modeled as follows:

$$\Sigma_{a,g} = \Sigma_{a,g,0} + N_{B10}\sigma_{B10,g} - N_{B10,0}\sigma_{B10,g,0} \quad (2)$$

where

$\Sigma_{a,g}$ = nodal macroscopic absorption cross section at depleted B-10 state

$\Sigma_{a,g,0}$ = nodal macroscopic absorption cross section at initial B-10 state

$N_{B10,0}$ = initial B-10 atom density for fresh control blade

$\sigma_{B10,g,0}$ = B-10 microscopic absorption cross section for fresh control blade

The depletion of B-10 is based on the homogeneous nodal surface flux at the wide water gap side instead of nodal average flux. This is to account for the physical location of control blade. Thus, the depletion equation is formulated as follows:

$$N_{B10}(t_i) = N_{B10}(t_{l-1}) \exp(-\Delta t_l(\sigma_{B10,1}\,\varphi_1 + \sigma_{B10,2}\,\varphi_2)) \quad (3)$$

where $\sigma_{B10,g}\,\varphi_g$ (g=1,2) is the average B-10 reaction rate of the four blade wings and φ_g is homogeneous nodal surface flux. This model is implemented in MICROBURN-B2 in conjunction with control blade shuffling capability.

III. Results

III.A Verification of B-10 Depletion Rate

Control blade B-10 depletion rate determines the life expectancy of a control blade. The MICROBURN-B2 model is verified against the multi-group, heterogeneous transport calculation by CASMO-4[(2)]. Controlled realistic colorset cores are selected for this purpose. One such a core is presented in Figure 1. The colorset core is burned for 30,000 MWd/MTU and the control blade B-10 is depleted during this period. The comparison of B-10 depletion rate (remaining B-10 fraction) for this model core is presented in Figure 2.

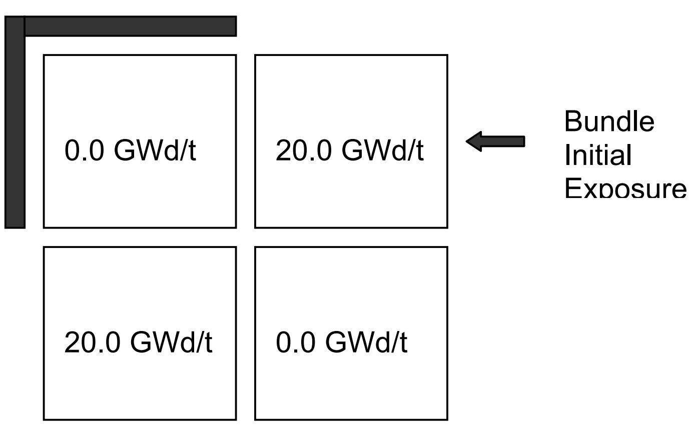

Figure 1 Sample Colorset Core Geometry for Control Blade Depletion

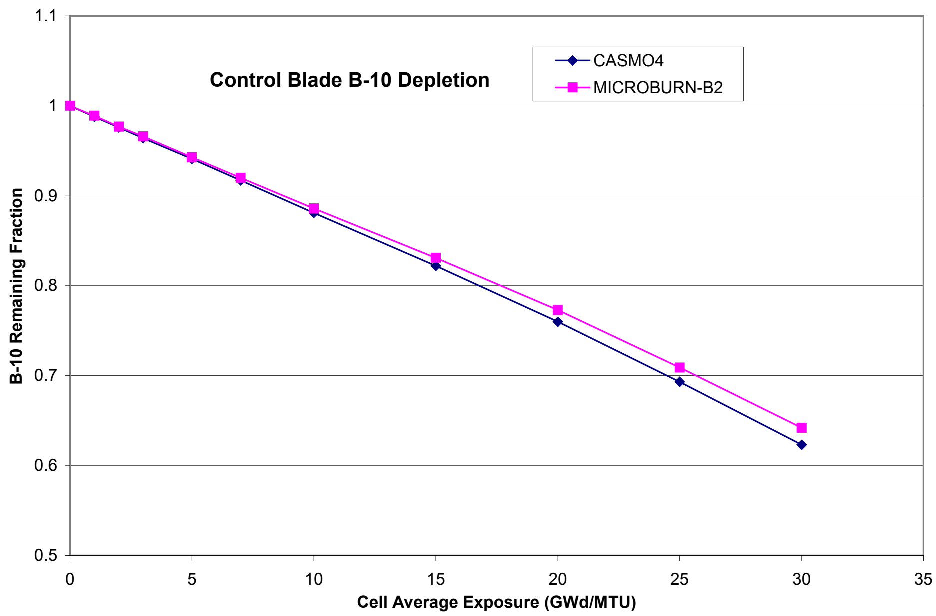

Figure 2 Control Blade B-10 Depletion Rate Comparison

III.B Validation of Control Blade Depletion Effect

An operating BWR is selected to validate the predicted effect of control blade depletion. This BWR, named as BWR-A, has replaced its control blades over the last few cycles. During this period, some fuel bundles were controlled by new control blades which have larger B-10 density than older control blades. Also, a new generation of control blades has been introduced which is different in design from the original equipment installed by the reactor vendor. The current analysis treats all of the control blades as the same type. This may not impact much the hot operating condition due to the strong void reactivity effect.   The largest impact should be seen in the cold critical prediction.

Figure 3 shows the trend of cold critical k-effective for BWR-A Cycle 1 through 9. With the control blade B-10 depletion (CR B-10 Burn), the cold critical k-effective trend becomes more stable.   Especially the cold critical k-effective change over cycle exposure within a cycle is significantly decreased.   The largest impact is seen at Cycle 6 EOC cold criticals and Cycle 7 BOC cold criticals, which coincides with the replacement of an old control blade batch with a batch of new blades at the Cycle 6 to Cycle 7 fuel shuffle (see Table 1 below). This agreement indicates that the MICROBURN-B2 model is capable of accurately predicting the B-10 depletion effect on the control rod worth.

Table 1. Control Blade Replacement History in BWR-A

Beginning of Cycle	1	2	3	4	5	6	7	8	9
Number of control blades replaced	0	0	0	0	0	0	24	11	9

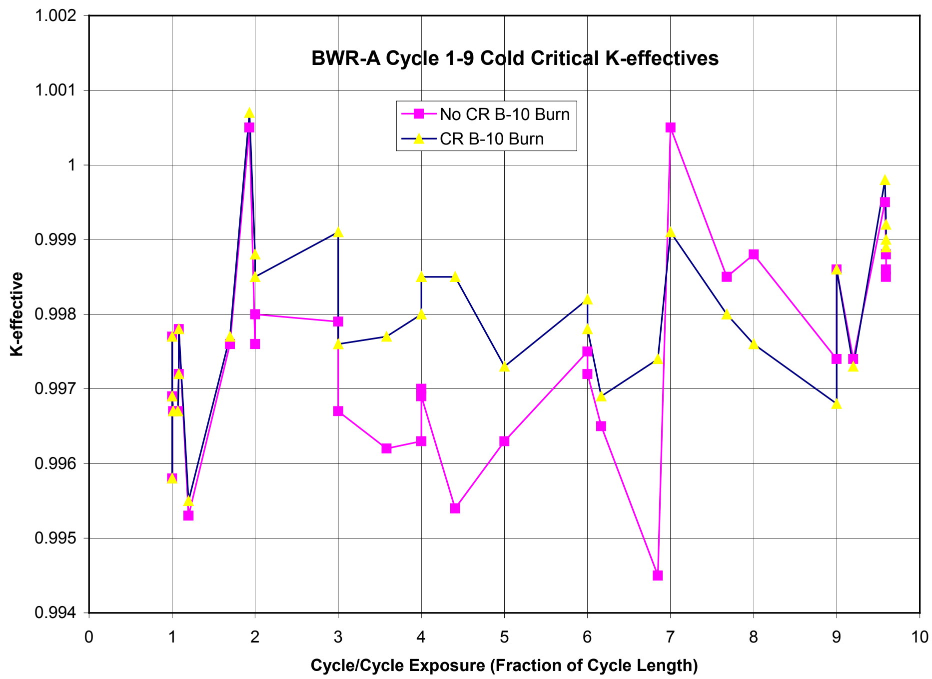

Figure 3 Effect of Control Blade B-10 Depletion on Cold Critical K-effectives

IV. References

1. St. Misu, H. Moon, "The SIEMENS 3D Steady State BWR Core Simulator MICROBURN-B2", Proc. Int. Conf. Nucl. Sci. and Tech., Vol. 2, P 1097, Long Island NY, Oct.1998

2. M. Edenius, B. H. Forssen and C. Gragg, "The Physics Model of CASMO-4," Proc. Adv. In Math. Comp. & Reactor Physics, Vol 10-1, Pittsburg, Pennsylvania (April 1991).