Preliminary Control Blade Study Results

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There is a project underway to physically replace the control blades in the UMLRR because of some blistering that has been observed with one the existing four large control blades -- Blade 3 is the real culprit here and it has been under increased observation for several years now. In planning for the blade replacement, some GE drawings of the original blades were discovered that differ in physical design from the diagram and description given in the original UMLRR FSAR. In particular, the GE drawings suggest that the Boral poison material already has an inherent Al clad, and that this composite material is then inserted in an aluminum clad to make up the control blade for the UMLRR -- essentially giving the 50 w/o B_4C Boral poison a double layer of Al clad (the poison layer in this model is only 0.125 inches thick). In contrast, the FSAR drawing suggests that the Boral poison layer is 0.255 inches thick and only contains a single clad layer of about 0.06 inches. In addition, since the FASR did not explicitly describe the B_4C-Al mix in the Boral, a 35 w/o B_4C composition was assumed, which is the stated composition of the regulating blade (or RegBlade, for short). This contradictory information about the control blades has created somewhat of a dilemma, since the current VENTURE and MCNP models of the UMLRR give reasonable blade worth comparisons to measured data, yet these models are based on the original FSAR diagram (as have all our calculations for the last 25 years). At this point, it is not clear exactly what is installed in the facility -- although evidence from early documents associated with the reactor points towards the GE drawings as the "as built design".

In addition to these two blade options, we also need to plan for the new blades which will be a single metal matrix composite (MMC) material with no explicit clad. The poison BORALCAN material (also sometimes referred to as BORTEC) is a homogeneous MMC mix of B_4C and Al, with a total thickness of 0.375 inches. For the UMLRR control blades, a 23 w/o B_4C composition was used.

Table 1 summarizes some key parameters for the three control options: the FSAR model, the new GE DWG model, and the new MMC model. Three different MCNP models were constructed to simulate these configurations and each model was run with Blade 3 at three different heights so that we could evaluate the excess reactivity and total worth of Blade 3 -- Blade 3 was selected since it will be the first blade that is replaced and tested as part of a systematic blade replacement program. With three blade models and three blade positions, a total of nine MCNP runs were completed. All the MCNP simulations were run with 400M histories which gives a 1σ uncertainty in the k value of about ± 0.00004 which, in turn, leads to a 3σ uncertainty in the $\Delta k/k$ estimates less than ± 0.0002 or ± 0.02 %$\Delta k/k$ -- thus, the MCNP predictions for the change in reactivity should be quite reasonable.

Table 1 Key parameters for three different blade configurations.

Model	Poison Thickness (inches)	B_4C Component (w/o)	B10 Areal Density (g B10/cm^2)
FSAR	0.255	35	0.0815
GE DWG	0.125	50	0.0564
MMC	0.375	23	0.0815

The reference MCNP core model is the M-2-7 core configuration with BOL fuel densities (recall that the M-2-7 layout has a graphite reflector element in grid location D5). On May 13, 2015, the measured banked critical blade height with a Xe-free M-2-7 configuration was 16.2 inches withdrawn with the RegBlade at 8 inches out. Blade worth curves were generated at this time and, from the measured data, the total worth of Blade 3 is about 3.39 %Δk/k and the excess reactivity associated with Blade 3 is about 0.79 %Δk/k, where the phrase "excess reactivity" is the reactivity change accompanying the movement of a blade from its critical height to its fully withdrawn height (16.2 inches to 25 inches for the case of Blade 3 in the UMLRR for this specific configuration).

The results from the MCNP analysis with comparison to the measured data for Blade 3 are summarized in Table 2. Here we can observe two important results/conclusions:

1. The uncertainty in the construction and modeling of the existing blades (FSAR vs. GE DWG models) does not have a significant effect on the predicted blade worth -- there is only a 5-6% difference in the FSAR and GE DWG worth estimates and this is in the range of uncertainty in the experimental measurement. The total worth for the GE DWG model, for this case, is closer to the measured result.
2. The new MMC blades should have essentially the same worths as predicted by the FSAR model that has been in use for 25+ years (this was expected since the B10 areal density is essentially the same). Thus, the measured worth of the new blades should be comparable to or greater than the measured worths of the existing blades.

Important Note: The calculated total blade worth estimates here are determined from fully-in vs. fully-out computations in MCNP. In practice, the measured integral worth curves are determined using a dynamic inverse kinetics method where the remaining blades are re-banked to keep the system near critical during the measurement procedure. The re-banking procedure affects the axial flux shape which, in turn, affects the axial shape of the worth curve. Without re-banking, the computed worth curves tend to be somewhat more bottom-peaked relative to the measured results that keep the UMLRR near critical during the blade worth measurements. This affect is apparent, for example, with the slightly under-predicted excess reactivity with both the FSAR and GW DWG models for Blade 3. This re-banking procedure can be simulated in the computer model, but this approach usually requires a minimum of 7-8 k_{eff} values to obtain enough data to do a reasonable curve fit to obtain the integral worth curve -- and, in MCNP, this can involve up to 150 hours or more of computing time to develop a single blade worth curve and total worth estimate. Thus, the fully-in vs. fully-out method used here is only an approximate method

-- but it can be obtained with significantly less computational effort and overall time, and it gives a reasonable estimate of the expected worth observed in the physical system.

Table 2 MCNP raw k_{eff} data and summary results for various Blade 3 worths with three different control models.

		Calculated k_{eff} Value			
Case #	**Blade 3 Position (inches out)**	**FSAR Model**	**GE DWG Model**	**MMC Model**	**Measured Result**
1	16.2	1.01312	1.01499	1.01259	1.00
2	25	1.02073	1.02237	1.02027	--
3	0	0.98406	0.98772	0.98364	--
Blade 3 excess ρ (%Δk/k)		0.74	0.71	0.74	0.79
total Blade 3 worth (%Δk/k)		3.65	3.43	3.65	3.39

Notes:

1. Blades 1, 2, and 4 are at 16.2 inches withdrawn and the RegBlade is at 8 inches out for all the MCNP models.
2. The computed 'critical' k_{eff} >> 1.0 because BOL fuel densities are used in the MCNP model (i.e. the current model does not account for fuel depletion and fission product buildup).
3. The Blade 3 excess reactivity is computed as $\Delta\rho = (k_2 - k_1)/k_1k_2$.
4. The total worth of Blade 3 is computed as $\Delta\rho = (k_2 - k_3)/k_2k_3$.
5. The measured results were determined from the Blade 3 worth curves generated on May 13, 2015 with the M-2-7 configuration and all four original control blades in place.

As a second test to check the above results, a similar set of MCNP calculations were performed for Blade 4 -- this blade was chosen since it has the maximum worth in the current M-2-7 configuration. Six new runs were made to simulate the fully withdrawn and fully inserted states for the three different blade models and, along with the reference calculations for the blades at 16.2 inches out, these calculations give a complete set of blade worth data for Blade 4 similar to that discussed above for Blade 3.

The Blade 4 results are summarized in Table 3 and, quite simply, they tell the same story as discussed previously for Blade 3 -- that is, they show the same trends, thus supporting the two conclusions noted above.

Thus, it is expected that the measured worth of the new blades should be equal to or slightly greater than the measured worths of the existing blades -- but we will have to wait for actual experimental data to confirm these expectations…

Table 3 MCNP raw k_{eff} data and summary results for various Blade 4 worths with three different control models.

		Calculated k_{eff} Value			
Case #	**Blade 4 Position (inches out)**	**FSAR Model**	**GE DWG Model**	**MMC Model**	**Measured Result**
1	16.2	1.01312	1.01499	1.01259	1.00
2	26	1.02193	1.02349	1.02149	--
3	0	0.97952	0.98349	0.97889	--
Blade 4 excess ρ (%Δk/k)		0.85	0.81	0.86	0.92
total Blade 4 worth (%Δk/k)		4.24	3.97	4.26	3.59

Notes:

1. Blades 1, 2, and 3 are at 16.2 inches withdrawn and the RegBlade is at 8 inches out for all the MCNP models.
2. The computed ‘critical’ k_{eff} >> 1.0 because BOL fuel densities are used in the MCNP model (i.e. the current model does not account for fuel depletion and fission product buildup).
3. The Blade 4 excess reactivity is computed as $\Delta\rho = (k_2 - k_1)/k_1k_2$.
4. The total worth of Blade 4 is computed as $\Delta\rho = (k_2 - k_3)/k_2k_3$.
5. The measured results were determined from the Blade 4 worth curves generated on May 14, 2015 with the M-2-7 configuration and all four original control blades in place.