Appendix C: <u>Sample Calculation of Void Reactivity Sensitivity</u>

This appendix performs a calculation of the impact of void-fraction errors on the value of the void reactivity coefficient. The void reactivity is tracked in TRACG04 according to the PANAC11 calculated nodal response surfaces. The relative water density is used in TRACG04 to determine the nodal reactivity. The relative water density is related to the void fraction according to Equation C-1.

$$U = 1 - VFAT + \frac{VFAT}{\rho_{ref}}\left[(1-\alpha)\rho_f + \alpha\rho_g\right]$$

Equation C-1

Where U is the lattice average relative water density
VFAT is the in-channel to total flow area ratio
α is the in-channel void fraction
ρ is the water density
f denotes saturated liquid water density (0.73749 g/cc)
g denotes saturated liquid vapor density (0.03733 g/cc)
ref denotes the reference water density (0.73751 g/cc)

For typical modern fuel designs, the in-channel to total flow ratio is on the order of 2/3. Therefore, the staff assumed a value of 2/3 for this parameter.

The nodal response surfaces are based on quadratic parametric fits of the TGBLA06 calculated lattice parameters. In this case, the staff considered the fit of the reactivity void coefficient. The nodal reactivity as a function of the nodal relative water density is given according to Equation C-2 and, therefore, the void reactivity coefficient can be calculated according to Equation C-3.

$$k_{nodal} = A + BU + \frac{C}{2}U^2$$

Equation C-2

$$\frac{\partial k_{nodal}}{\partial \alpha} = \frac{\partial k_{nodal}}{\partial U}\frac{\partial U}{\partial \alpha} = (B + CU)\left(\frac{\rho_g - \rho_f}{\rho_{ref}}\right)VFAT$$

$$\frac{\partial k_{nodal}}{\partial \alpha} = B\left(\frac{\rho_g - \rho_f}{\rho_{ref}}\right)VFAT + C\left(\frac{\rho_g - \rho_f}{\rho_{ref}}\right)VFAT\left[1 - VFAT + \frac{VFAT}{\rho_{ref}}\left[(1-\alpha)\rho_f + \alpha\rho_g\right]\right]$$

Equation C-3

Where k_{nodal} is the nodal reactivity
A, B, and C are the fitting constants in the nodal response surface
U is the nodal relative water density

The nodal reactivity coefficient is corrected for known biases according to MCNP comparisons. Therefore, the constant term in the expression is known to be accurate based on the void reactivity coefficient correction model. The variation in the void

reactivity coefficient with void fraction is given by the second term in the last expression in Equation C-2. Based on several lattice analyses a typical value of C ranges between 0.1 and 0.2, the staff assumed 0.15 for the current purpose. The change in the nodal void reactivity coefficient for a change in void fraction can be determined based on the second derivative shown in Equation C-3.

$$\frac{\partial^2 k_{nodal}}{\partial^2 \alpha} = C\left[\left(\frac{\rho_g - \rho_f}{\rho_{ref}}\right) VFAT\right]^2 \approx 0.06$$

Equation C-4

Based on the staff's analysis, the sensitivity of the nodal void reactivity coefficient in units of pcm per change in void (% void) per error in void fraction (% void) is approximately 0.6 pcm/%/%. For reference, a typical value of the void reactivity coefficient at limiting cold conditions is approximately –100 pcm/%.