Appendix B: Doppler Reactivity Uncertainty Analysis

The Doppler Coefficient temperature dependence is provided in Equation B-1.

$$DC = A\left(T^{-\frac{1}{2}}\right) \tag{B-1}$$

Where DC is the Doppler Coefficient,
A is a constant, and
T is the fuel temperature

The uncertainty in the Doppler Coefficient based on uncertainty in the fuel temperature is provided by differential analysis. The sensitivity of the Doppler Coefficient to a temperature perturbation is provided in Equation B-2.

$$\frac{\partial DC}{\partial T}\left(\frac{1}{DC}\right)\delta T = \frac{A\frac{\partial}{\partial T}\left(T^{-\frac{1}{2}}\right)}{AT^{-\frac{1}{2}}}\delta T = -\frac{1}{2}\frac{T^{-\frac{3}{2}}}{T^{-\frac{1}{2}}}\delta T = -\frac{1}{2}\frac{\delta T}{T} \tag{B-2}$$

Where δT is the temperature perturbation.

Based on the sensitivity provided in Equation (B-2), an uncertainty in the fuel temperature can be translated to an uncertainty in the Doppler Coefficient.

The uncertainty in the fuel temperature was assessed by the NRC staff based on the heat capacity model. The temperature difference used in evaluating the nodal Doppler reactivity is based on Equation (B-3).

$$\begin{aligned} &\int_{T_i}^{T_f} C_p\, dT = \Delta H \\ &\Delta T = T_f - T_i \end{aligned} \tag{B-3}$$

Where C_p is the specific heat,
ΔH is the change in fuel enthalpy (strong function of integral power),
ΔT is the change in temperature,
f denotes final, and
i denotes initial.

The specific heat as a function of temperature is provided in Figure B.1. This figure was taken directly from Reference 4. The figure is for uranium oxide, however, the presence of some gadolinia will have only a minor effect on the nodal temperature response (due to the small number of gadolinia-bearing pins and the impact of the rare-earth addition is small).

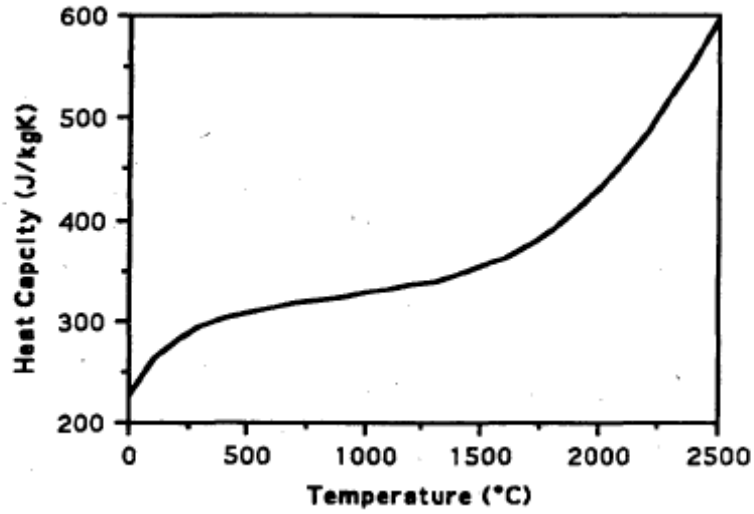

Figure B.1: Heat Capacity of Uranium Oxide as a Function of Temperature

Over the temperature range of interest (~1000 °C) relevant for CRDA analyses, the specific heat is relatively constant in the neighborhood of 300 J/kg-K. The reported standard error is 3 J/kg-K. Therefore, the NRC staff estimates that the heat capacity error is roughly 1 percent, and that the temperature difference uncertainty is essentially proportional (i.e., 1 percent).

Based on the analysis, the NRC staff estimates that the uncertainty in the Doppler reactivity feedback due to uncertainty in the fuel heat capacity is approximately 0.5 percent.