Maximum Reactivity Insertion

Raising the temperature of TRIGA® fuel has a strong, prompt negative reactivity effect, which can overcome a rapid reactivity insertion such as that produced by the firing of the transient rod or the accidental ejection of a high negative reactivity worth experiment. The quantity that captures this effect is the prompt negative temperature coefficient discussed in Section 4.5.4.2. There is a limit to the protection provided by this feedback, since the peak fuel temperature attained before the feedback terminates the transient increases with the magnitude of the inserted reactivity. The Nordheim-Fuchs model was used to compute the maximum reactivity pulse that can occur without exceeding the safety limit of 1100 C established in Section 4.5.4.1.3.

In the Nordheim-Fuchs model it is assumed the transient is so rapid that 1) the temperature rise is adiabatic and 2) delayed neutrons can be neglected. Thus, the model is given by the following set of equations from General Atomics document GA-7882 "Kinetic Behavior of TRIGA Reactors":

$$\Delta T\ average = \frac{2\Delta kp}{\alpha}$$

Where *ΔT average* is the average temperature increase in the fuel, *Δkp* is the portion of the step reactivity insertion which is above prompt critical, and α is the prompt negative temperature coefficient.

This average temperature increase is not the final value of interest as the fuel must remain below 1100 C safety limit in all location where fuel temperature exceeds the average temperature. The peak temperature is given below where PF is the worst case peaking factor derived in chapter 4 and T_o is the initial temperature.

$$T_{peak} = T_o + PF \times \Delta T\ ;$$

β = 0.0075;
T_o = 20 C and 200 C;
PF = 3.69.

Although some quantities, such as the peak reactor power, can also be calculated from the GA methodology they are of little important in this accident analysis as the only value of concern is peak fuel temperature. Note while the maximum power is a function of fuel heat capacity, average temperature and peak fuel temperature are not.

In order to simplify the calculations, the prompt negative temperature coefficient is assumed to be fixed at the initial temperature of 20 C and 200 C. This assumption is conservative as the prompt negative temperature coefficient grows in absolute value (a larger feedback) as fuel temperature increases for 20/20 and 30/20 fuel for all expected burnups (figure 13.1). In other words, after the accidental prompt excursion fuel temperature will increase, thus increasing the prompt negative temperature coefficient, though credit is not taken for this effect.

Two cases were examined for 20/20 and 30/20 of various burnup. The first assumes the reactor is at ambient temperature (20 C) when the excursion takes place. The second case assumes the reactor is at approximately 1 MW with an average core temperature of 200 C.

TABLE 13-4 MAXIMUM REACTIVITY INSERTION AND RELATED QUANTITIES FOR VARIOUS FUELS AND BURNUPS

Fuel Type	Burnup (%)	Heat Capacity Cp (watt-sec/°C)	Minimum Heat Capacity Cp (watt-sec/°C)	Prompt Negative Temperature Coefficient α (Δk/k°C)	Minimum Prompt Negative Temperature Coefficient α (Δk/k°C)	Reactivity ρ_o ($)
20/20	0	$7.12x10^4+143T$	74060	$4.91x10^{-5}+1.93x10^{-7}T-9.73x10^{-11}T^2$	5.30E-05	2.03
20/20	13	$7.12x10^4+143T$	74060	$4.90x10^{-5}+1.32x10^{-7}T-7.82\ x10^{-11}T^2$	5.16E-05	2.01
20/20	33	$7.12x10^4+143T$	74060	$5.24x10^{-5}+7.45x10^{-8}T-6.13\ x10^{-11}T^2$	5.39E-05	2.05
30/20	0	$7.39x10^4+145T$	76800	$4.84x10^{-5}+1.59x10^{-7}T-7.3\ x10^{-11}T^2$	5.16E-05	2.01
30/20	15	$7.39x10^4+145T$	76800	$4.71x10^{-5}+9.13x10^{-8}T-4.63\ x10^{-11}T^2$	4.89E-05	1.95
30/20	39	$7.39x10^4+145T$	76800	$5.02x10^{-5}+3.10x10^{-8}T-2.24\ x10^{-11}T^2$	5.08E-05	1.99

Fuel Type	Burnup (%)	Heat Capacity Cp (watt-sec/°C)	Heat Capacity @200 C Cp (watt-sec/°C)	Prompt Negative Temperature Coefficient α (Δk/k°C)	Prompt Negative Temperature Coefficient at 200 C α (Δk/k°C)	Reactivity ρ_o ($)
20/20	0	$7.12x10^4+143T$	99800	$4.91x10^{-5}+1.93x10^{-7}T-9.73x10^{-11}T^2$	8.38E-05	2.36
20/20	13	$7.12x10^4+143T$	99800	$4.90x10^{-5}+1.32x10^{-7}T-7.82\ x10^{-11}T^2$	7.23E-05	2.17
20/20	33	$7.12x10^4+143T$	99800	$5.24x10^{-5}+7.45x10^{-8}T-6.13\ x10^{-11}T^2$	6.48E-05	2.05
30/20	0	$7.39x10^4+145T$	100200	$4.84x10^{-5}+1.59x10^{-7}T-7.3\ x10^{-11}T^2$	7.73E-05	2.25
30/20	15	$7.39x10^4+145T$	100200	$4.71x10^{-5}+9.13x10^{-8}T-4.63\ x10^{-11}T^2$	6.35E-05	2.03
30/20	39	$7.39x10^4+145T$	100200	$5.02x10^{-5}+3.10x10^{-8}T-2.24\ x10^{-11}T^2$	5.55E-05	1.90

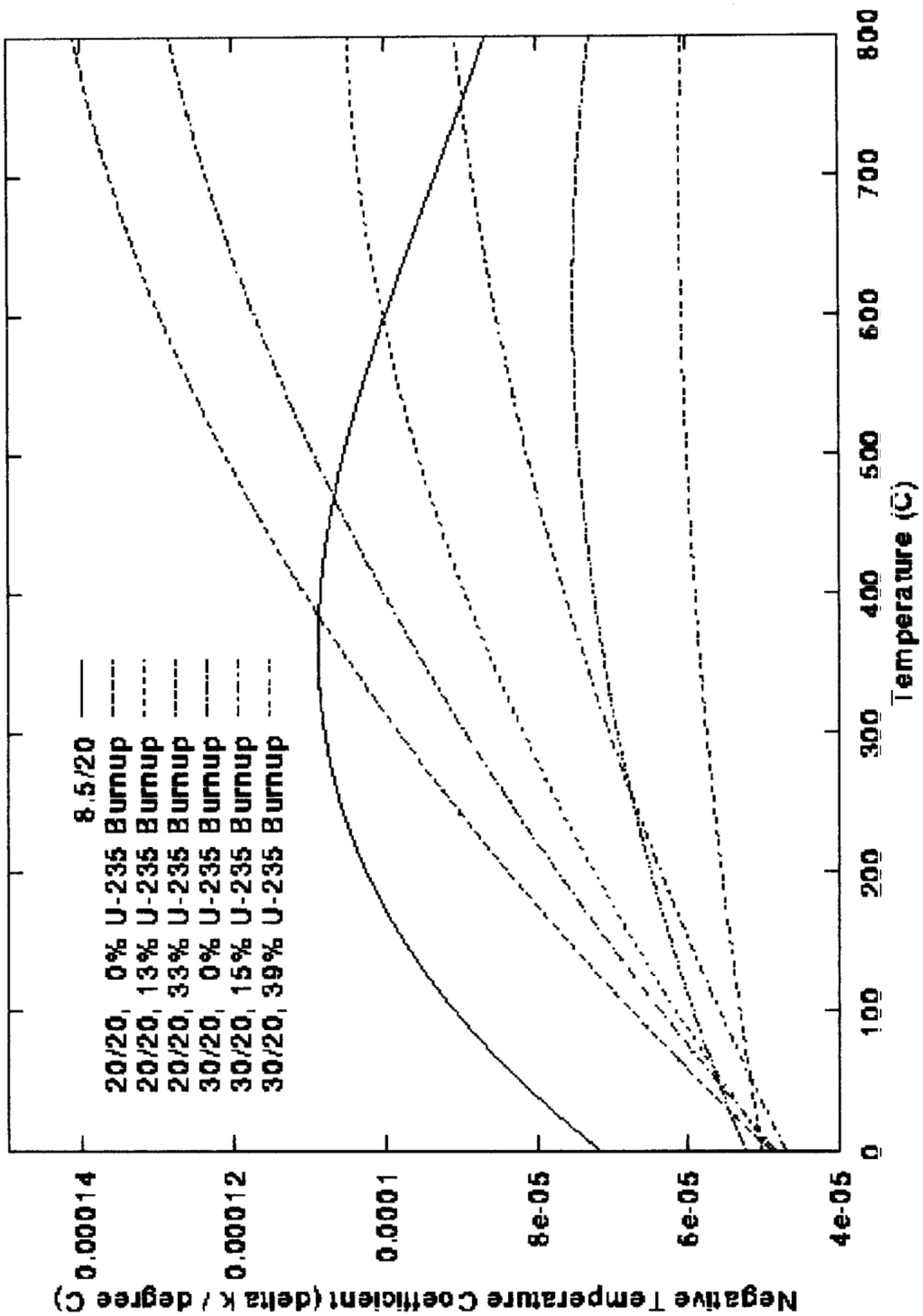

FIGURE 13.1 PROMPT NEGATIVE TEMPERATURE COEFFICIENT FOR TRIGA® FUELS

The worst-case result in Table 13-4, $1.90, is considered as the maximum accidental reactivity insertion that could occur with no risk of fuel damage. This scenario occurs with a very high burnup core and while the reactor is operating at approximately 1 MW. Given the conservative nature of this analysis, the actual burnup of the core, and the large number of 20/20 element in the LCC, the actual accidental reactivity insertion that would not result in fuel temperatures beyond 1100 C is likely well in excess of $1.90.