THE EFFECT OF INCREASING TEMPERATURE ON k_{eff} FOR FISSILE MATERIAL OUTSIDE REACTORS

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LIST OF ACRONYMS & SYMBOLS

ACRYNOM	DEFINITION
k_{eff}	*effective neutron multiplication factor*
SRNS	*Savannah River Nuclear Solutions, LLC*
SRS	*Savannah River Site*
DOE	*Department of Energy*
α	*alpha phase of Pu metal*
β	*beta phase of Pu metal*
γ	*gamma phase of Pu metal*
δ	*delta phase of Pu metal*
δ'	*delta prime phase of Pu metal*
ε	*epsilon phase of Pu metal*
WTP	*Waste Treatment Project*
DWPF	*Defense Waste Processing Facility*

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PURPOSE

Nuclear Criticality Safety Evaluations typically employ room temperature cross sections, material densities, and dimensions. Processes that have been and are in development for conversion of legacy wastes in tanks, e.g., Waste Treatment Project (WTP) at the Hanford Remediation Site and Defense Waste Processing Facility (DWPF) at the Savannah River Site, utilize melters that operate at elevated temperatures, 1500 to 1900 $^{\circ}$C. The applicability of room temperature data to processes such as these has been questioned. Also questioned was the applicability of room temperature data for the analyses across the Savannah River Site (SRS) where the temperature may be elevated, such as in a postulated fire. This analysis was performed to examine the effect of temperature over the relatively small range encountered in normal and abnormal operations at SRS that does not include DWPF melters.

SCOPE

This analysis documented herein is limited to fast systems of fissile metal and oxide cylinders on concrete at temperatures no greater than 640 $^{\circ}$C, the melting point of plutonium. Because thermal expansion data for various types of structural materials was not readily available, structural materials were not included in the analysis.

METHODOLOGY

Both MCNP and SCALE were used for this analysis. The models consisted of fissile metal and oxide cylinders, with an H/D=1, on concrete. Masses used in the models were 4.4 Kg of plutonium metal, 5 Kg of plutonium oxide, 8 Kg of uranium metal, and 10 Kg of uranium oxide. Cross section libraries available with the MCNP code include a limited number of cross sections that have been corrected for elevated temperatures. Furthermore, these MCNP supplied cross sections are limited to a selected number of fissile isotopes.[1] Unlike MCNP, SCALE corrects the cross sections based on the temperature of the medium as input by the user. In developing the calculational models utilized herein, the following was employed:

- ✓ *Non fissile elements were modeled at room temperature (293 K). This includes all nuclides employed to define the air and concrete regions, as well as the oxygen in the oxide systems.*
- ✓ *Only the cross sections of ^{235}U and ^{239}Pu were employed at higher temperatures. The examined cross sections (MCNP cross sections) and their corresponding temperatures are listed in Table 1 for ^{235}U and ^{239}Pu. Note further that the temperatures of Table 1 were also investigated with SCALE for consistency.*
- ✓ *The fissile material was assumed to be pure, i.e. pure ^{235}U and ^{239}Pu. Inclusion of fissionable materials or other contaminants will reduce k_{eff} with temperature so modeling the fissile material as pure is conservative.*
- ✓ *The cylinder is modeled with H/D=1 in order to minimize leakage, and hence enhance the system's calculated k_{eff}. Furthermore, by allowing H/D=1, any potential reactivity changes would be enhanced as well.*

[1] *Temperature dependent cross sections can be generated with NJOY.*

- ✓ *Volumetric expansion of the fissile system (metal and oxide) as a consequence of higher temperatures was modeled. The mass was conserved by appropriately varying the density. The density, was modeled as follows:*
  - *The theoretical density of the oxide systems was utilized herein in order to maximize any reactivity changes that may occur due to temperature variations.*
  - *Allotropic phases of Pu were included in these studies.*
- ✓ *Thermal expansion data for plutonium metal and oxide were obtained from the Plutonium Handbook, A Guide to the Technology, Volumes I and II, edited by O. J. Wick.*
- ✓ *Thermal expansion data for uranium metal were obtained from A/CONF.15/P/49, High Temperature Properties of Uranium and Its Alloys, and thermal expansion data for uranium oxide were obtained from ORNL/TM-2000/351, Thermophysical Properties of MOX and UO2 Fuels Including the Effects of Irradiation.*

Results of these parametric studies are presented in Tables 2 and 3 and 4. Table 2 lists the calculated k_{eff} from both MCNP and SCALE for uranium metal and oxide, and Table 3 for plutonium oxide. Table 4 shows the calculated k_{eff} from both MCNP and SCALE for plutonium metal including the effect of the phase changes.

CONCLUSION

For these simple fast systems containing pure ^{235}U and ^{239}Pu, there appear to be slight increases in k_{eff} at various temperature steps, primarily for plutonium metal and oxide these changes are within the analysis uncertainty. The effect of temperature on other fissile and fissionable materials was not examined in this study. With the exception of plutonium oxide, the largest calculated k_{eff} is obtained using room temperature cross sections, densities, and dimensions. Although both MCNP and SCALE calculate slightly higher k_{eff} values at intermediate temperatures, the overall effect is a slight decrease over the entire temperature range.

Table 1: MCNP Cross Sections

Temperature (°C)	Cross Section	
	Uranium	Plutonium
25	92235.60c	94239.60c
117	92235.12c	94239.12c
200	92235.13c	94239.13c
300	92235.14c	94239.14c
475	92235.15c	94239.15c
637	92235.16c	94239.16c

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Table 2: Calculated k_{eff} for Uranium

Temperature (°C)	Uranium Metal			Uranium Oxide		
	Density (g/cm^3)	MCNP ±σ	SCALE ±σ	Density (g/cm^3)	MCNP ±σ	SCALE ±σ
25	18.900	0.593 ±0.001	0.593 ±0.001	10.960	0.456 ±0.001	0.457 ±0.001
117	18.799	0.592 ±0.001	0.591 ±0.001	10.922	0.455 ±0.001	0.454 ±0.001
200	18.725	0.589 ±0.001	0.592 ±0.001	10.896	0.454 ±0.001	0.456 ±0.001
300	18.632	0.588 ±0.001	0.589 ±0.001	10.864	0.452 ±0.001	0.456 ±0.001
475	18.461	0.584 ±0.001	0.587 ±0.001	10.807	0.451 ±0.001	0.451 ±0.001
637	18.294	0.581 ±0.001	0.583 ±0.001	10.753	0.450 ±0.001	0.451 ±0.001

Table 3: Calculated k_{eff} for Plutonium Oxide

Temperature (°C)	Density (g/cm^3)	MCNP ±σ	SCALE ±σ
25	11.460	0.578 ±0.001	0.577 ±0.001
117	11.454	0.574 ±0.001	0.580 ±0.002
200	11.449	0.578 ±0.001	0.577 ±0.001
300	11.443	0.579 ±0.001	0.577 ±0.001
475	11.432	0.577 ±0.001	0.571 ±0.001
637	11.422	0.577 ±0.001	0.576 ±0.001

Table 4: Calculated k_{eff} for Plutonium Metal

Temperature (°C)	Density (g/cm^3)	Phase	MCNP ±σ	SCALE ±σ
25	19.810	α	0.789 ±0.001	0.786 ±0.002
117	19.735		0.788 ±0.001	0.784 ±0.002
	17.740	β	0.741 ±0.001	0.736 ±0.002
200	17.695		0.739 ±0.001	0.736 ±0.002
	17.155	γ	0.726 ±0.001	0.720 ±0.003
300	17.112		0.724 ±0.001	0.719 ±0.002
	15.918	δ	0.694 ±0.001	0.693 ±0.002
452	15.933		0.695 ±0.001	0.689 ±0.002
	15.990	δ'	0.697 ±0.001	0.696 ±0.002
475	16.007		0.698 ±0.001	0.696 ±0.002
	16.406	ε	0.706 ±0.001	0.700 ±0.002
637	16.337		0.706 ±0.001	0.702 ±0.002