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Partial Temperature Coefficients for the 5 Kwe Reactor

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ABSTRACT

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Temperature coefficients for the 5 Kwe reactor are calculated and compared to previous experiments and reactors. The recommended isothermal temperature coefficient is $-0.18 \text{ } ^\circ\text{F}^{-1}$.

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I. Introduction

An evaluation of temperature coefficients for the 5 Kwe reactor is described in this report, and a recommended set is given. These temperature coefficients of reactivity are required to predict the kinetic behavior of the reactor during operation.

For convenience, the coefficients are divided into prompt and delayed. The prompt temperature coefficient includes the fuel coefficient and the outlet grid coefficient. The delayed coefficient consists of the inlet grid coefficient (which includes the reflector motion caused by the expansion of the inlet grid plate on the reflector) and the reflector heating coefficient. The fuel coefficient is made up of the spectral, Doppler, and the axial fuel expansion coefficients. The total isothermal temperature coefficient consists of the net sum of the prompt and delayed coefficients.

II. Method of Analysis

The k-difference method was used to evaluate the coefficients; this consisted of comparing the k-effective eigenvalue of the base BOL reactor model (5 Kwe, 1.018" pitch, 85 elements) with the eigenvalues of other reactor models that isolate the various effects which cause the reactivity to change with temperature.

The nuclear model used for the cold case is described in the Appendix. All calculations were made using the APC code in the leakage iteration mode with the standard 28-group cross-section library, S_4 constants and P_1 corrected P_0 transport theory approximation. The

cross-sections were weighted over a ZrH spectrum and are based on ENDF/B data. The accuracy of this technique in predicting reactivity is described in Reference 3.

First the cold (room temperature) case was calculated. Then, raising this temperature to a higher level, the several changes that occur due to heating were evaluated one at a time. This was repeated for several temperatures up to 1340°F. $\beta_{\text{eff}} = 0.0076$ was used to convert k_{eff} differences into dollars. The results are presented in Section IV. Table I shows all the coefficients that were calculated with this method assuming a rise of 1200°F in temperature. Another series of calculations was made in order to compare the k-difference method with perturbation theory calculations. This involved using the worth distributions as calculated by the perturbation code COMPOZ ⁽⁷⁾. The differences in reactivities were obtained from the worth distributions for each change in the reactor that occurs as the temperature increases. The temperature coefficients were found to be somewhat higher than in the k-difference method in most cases, but in general showed a similar trend. This is especially true in the spectral and Doppler effects where the calculations consist of finding the total displacement of the worth curves when the cross-sections involved go from cold to hot temperatures, i.e., when the effect is purely a spectral shift. (These coefficients are tabulated in Section IV). However, there still exists some uncertainty in the COMPOZ distributions due to discrepancies between transverse leakages, and part of the error in the computations is due to that, especially in cases involving geometrical changes in the model.

Table I
Summary of Calculated Partial Temperature
Coefficients (k-difference method)

	<u>With</u> <u>Poison</u>	<u>Without</u> <u>Poison</u>
Spectral	+ 0.007	-0.066 ($^{\circ}$ F)
Doppler	-0.0212	-0.022
Fuel Axial Expansion	<u>-0.048</u>	<u>-0.048</u>
Fuel Coefficient	-0.063	-0.136
Inlet	-0.058	
Outlet	- .036	
Reflector	<u>- .034</u>	
	-0.191	

Note: The poison loading is \$3.00 of natural gadolinium, deposited uniformly on the surface of all fuel slugs.

III. Comparison of Methods with Experiment

There has been no experimental work on the 5 Kwe reactor, and to establish a reference for the analytical results, an investigation of the analytical method applied to experimentally proven previous reactors was conducted.

To compare and normalize the fuel coefficient for the 5 Kwe reactor the k-difference approach was used to calculate the fuel temperature coefficient of the S8DR reactor. The model used has been described in References 1, 2, and 3. This computation gave a fuel coefficient of $-0.099 \text{ } \text{ } / ^\circ\text{F}$.

Some experiments with automatic startup and mercury injection tests on the S8DR were conducted in 1969. Analysis of these experiments (4) yielded a prompt fuel temperature coefficient of $-0.105 \text{ } \text{ } / ^\circ\text{F}$, about 6% greater than the calculated value.

This comparison indicates that the analytic method used here is valid and can be used to predict the prompt fuel temperature coefficient of ZrH reactors.

Rhoades and Swenson (5) analyzed and compared the k-difference method with experiments using the SNAPTRAN machine results on the transient fuel coefficients. They found the analytical fuel temperature coefficient to be within $\pm .02 \text{ } \text{ } / ^\circ\text{F}$ of the experimental results for gadolinium poison-loaded SNAP systems. Figures I and II show the comparison for Gd-155 loadings of \$2.31 and \$4.12 (hot).

To calculate the inlet grid coefficient it is necessary to find the effect of the reflector moving away from the reactor core due to expansion of the inlet grid when it gets hot. The gap between the reflector and reactor vessel increases which increases the axial leakage of neutrons due to streaming through the gap. To estimate and compare the gap effect, the S8DR model was calculated analytically with the k-difference method and yielded 0.4 ϵ /mil of gap worth.

The experimental data, obtained from the SCA-4A critical assembly gives a value of about 1.5 ϵ /mil of gap. (Reference 6). Other analytical attempts to estimate the difference between experiment and theory due to neutron streaming were not successful, and a normalization to experiment has been used for the 5 Kwe reactor to calculate the inlet and outlet grid temperature coefficients.

IV. Results of Analysis and Normalization to Experiment

Table I is a summary of the analytical temperature coefficients obtained with the k-difference method. Figure III shows the dependence of the fuel coefficient components on temperature. It may be observed that, within the accuracy limits, the slopes of the curves are constant which implies that the temperature coefficients are constant throughout the operating temperature range.

Table II presents the COMPOZ calculations for this reactor.

Table III shows the recommended temperature coefficients for the 5 Kwe reactor. These numbers are a result of combining analytic values (when the theory appeared to be reliable) with experimental normalization (based on previous reactors and experiments as discussed in Section III.)

Table II

COMPOZ Temperature Coefficients for the 5 Kwe Reactor

Spectral	+ 0.009 $\text{d}/^{\circ}\text{F}$
Doppler	-0.022
Axial Fuel Expansion	<u>- .050</u>
Fuel Coefficient	-0.063 $\text{d}/^{\circ}\text{F}$
Inlet Grid	-0.095
Outlet Grid	-0.069
Reflector Heating	<u>-0.050</u>
Isothermal Coefficient	- .277 $\text{d}/^{\circ}\text{F}$

Table III

Recommended Temperature Coefficients for the 5 Kwe Reactor

Spectral	+ .007
Doppler	- .022
Fuel Axial Expansion	<u>- .051</u>
Fuel Coefficient	- .066
Inlet Grid	- .060
Outlet Grid	- .020
Reflector Heating	<u>- .034</u>
Isothermal	- .18¢. °F

FIG I

FIG II

V. References

1. Swenson, L. D., "SNAP 8 Development Reactor Nuclear Analysis", AI-AEC-12864 (October 31, 1969).
2. Goetz, C. A., "As-Built S8DR Nuclear Calculation Model, " TI-568-13-011 (May 9, 1968).
3. Bost, D. S., "Comparison of Calculated and Experimental Reactivities of SNAP Reactors", TI-653-260-001 (Aug. 4, 1971).
4. Audette, R. F., "SNAP 8 Automatic Startup and PCS Mercury Injection Simulation Tests", AI-AEC-12850 (Oct. 31, 1969).
5. Rhoades, W. A. and Swenson, L. D., "Theoretical vs Experimental Effects of Burnable Poisons on the SNAPTRAN-1 Reactor", TI-658-240-025. (Sept. 13, 1972).
6. Clifford, D. W., "Interim Report on the SNAP Critical Assembly 4A (SCA-4A) Experimental Results", NAA-SR-10245 (CRD) (March 20, 1965).
7. Lekach, V. S., "COMPOZ, A Transport Theory Perturbation Code", Technical Document to be published.

VI. Appendix

The nuclear model below is for the cold 5 Kwe reactor (16" core height, 1.018" pitch, 85 elements)

DENSITY TABLES (atoms $\times 10^{24}$ /cc)

RADIAL

	<u>CORE</u>	<u>INTERFACE</u>	<u>VESSEL +GAP</u>	<u>REFLECTOR</u>
NaK	0.1237	.1195		.0338
Glass	.00992			
SS		.3338	.388	.0108
Hx	.0898			
Be				.9293
BeO		.5467		
H	.04348			
U28	8.231E-5			
Zr	.02669			
Gd155	2.55E-7			
Gd157	2.653E-7			
W				
U25	.001135			

DENSITY TABLES (atoms x 10²⁴/cc) (continued)

	Shield	Void	Vessel	AXIAL Plenum	Lower Grid	Core	Collar Button	Upper Grid
NaK				1.0	.7996	.1237	.1237	.7293
Glass						.00992		
SS			1.0		.1142		.1613	.2168
Hx					.0862	.0898	.2063	.0539
Be								
BeO								
H						.04348		
U28						8.231E-5		
Zr						.02669		
Gd 155						2.55E-7		
Gd 157						2.653E-7		
W	.0619							
U25						.001135		

FIG. III - Reactivity Components vs. Temperature

The cross sections were selected for the current SNAP library which is on the TXS Z63 disk.

<u>ID</u>	<u>Title</u>
20	NaK, 20°C, Macro, Core Wtg., Bost 11/6/70
25	Glass, 20°C, Macro, Core Wtg., Rooney 3/25/71
31	316 SS, 20°C, Macro, Core Wtg, Ottewitte
33	Hast X280, 20°C, Macro, Core Wtg, Bost 3/5/71
52	Be, 296K, Macro, B1 Core Wtg, Bost 4/23/71
53	BeO, 296K, Macro, B1 Core Wtg., Bost 4/23/71
1021	H (Zr), 296K, Inf AI Core (Flange) 3/2/71
92821	U238, 296K, 16640B Ai Core Wtg. 12/28/70
340021	Zr (H), 296K, 43.8B B1 Core (Flange) 3/2/71
364501	Gd 155, 20°C, Inf B2 ABS. Only, Bost 2/7/72
364701	Gd 157, 20°C, Inf A2 Bas. only, Bost 2/7/72
374001	W, 20°C, Inf B1 Core Wtg 11/6/70
392521	U235, 296K, 1051 B B2 Core Wtg 2/22/71