MASTER

TEMPERATURE COEFFICIENTS OF THE
REACTIVITY MEASUREMENT FACILITY

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PHILLIPS
PETROLEUM
COMPANY

ATOMIC ENERGY DIVISION

NATIONAL REACTOR TESTING STATION
US ATOMIC ENERGY COMMISSION

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SUMMARY

The temperature coefficient of the Reactivity Measurement Facility was found to be $49 \pm 1 \mu\text{k}/^\circ\text{C}$ ($1 \mu\text{k} = 10^{-6} \Delta k/k$) in the range 15.4 to 17.8 $^\circ\text{C}$. The change in the net reactivity of a standard sample was -0.48 ± 0.02 , -0.66 ± 0.03 , and $-0.78 \pm 0.02 \mu\text{k}/^\circ\text{C}$ in three measuring positions. These low values generally make temperature corrections insignificant. The above results are compared with previous determined values.

This information developed in the RMF should be generally applicable to flux-trap-type reactors such as the Advanced Reactivity Measurement Facility (ARMF) and ARMF-II, now under construction. RMF was dismantled in April 1962.

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I. INTRODUCTION

The effect of temperature changes in a nuclear reactor is generally of importance to precision measurements of the reactor response. The densities of moderator, fuel, and absorber materials, and hence the available excess reactivity, are related to temperatures. The importance in large power reactors where temperature changes are large is obvious. Perhaps less obvious is its importance in low power critical facilities such as the Reactivity Measurement Facility (RMF). The temperature rise due to the power generated by the RMF, is but a small fraction of a degree ($\approx 0.03^{\circ}\text{C}$ for 10 watts). The greater change is the result of environment, independent of reactor power level and not readily controlled by the operator. The MTR canal in which the RMF is located is subjected to the needs of MTR operation; hence, relatively large fluctuations are observed.

The interest in temperature effects in connection with the RMF is two-fold. The most obvious effect is on the critical point of the reactor which appears as a drift in the empty reactor reading (no sample in reactor). Of greater interest, however, is the effect of a temperature change on sample measurements. The reactivity value of a sample is the net change in reactivity of the RMF due to the sample. The temperature coefficient of reactivity for a sample measurement is defined as the net change in this reactivity measurement per degree centigrade change in temperature. It is a function, among other factors, of the sample geometry and composition, and of the measurement position in the reactor. A coefficient in terms of change in reactivity per unit reactivity does not appear to be meaningful because of this dependence.

The observed overall temperature response is the sum of two effects which result from the change in water density. For a temperature rise, the decrease in moderator in the lattice results in a negative reactivity effect, whereas the decrease of absorber, which effect predominates in the center water hole, causes a positive reactivity. The two effects nearly cancel each other giving only a small overall positive coefficient. The sample coefficient depends on various factors but perhaps predominately on the relative change in the displaced water resulting from the difference in volume expansion of the capsule and the water it displaces. A slight shift in the neutron spectrum also results, the effect of which would

depend on the neutron absorption characteristics of the sample material.

The purpose of this report is to present temperature coefficient values obtained from actual sample measurements made during the week of May 11-15, 1959. An unusually large change in canal temperature occurred with periods of relatively constant temperature before and after the change. The RMF was operated continuously during this period so that uncertainties introduced by shutdown and restarting the reactor were avoided. The shim position also was not changed. A large number of measurements were made both on the empty reactor (no sample in place) and on a standard capsule. Thus, the temperature coefficients, both for the RMF itself and for a sample measurement, were obtained.

Previous measurements on the temperature coefficients of the RMF have been reported in the 1958 Geneva Conference.⁽¹⁾ These results are also included for comparison along with some unpublished values. Calculations were made by McMurtry, et al.,⁽²⁾ during the design of the RMF to show how the temperature coefficient of reactivity of the reactor would vary with the size of the center water hole. Results reported herein are in fair agreement with his conclusions.

The Reactivity Measurement Facility is a critical assembly of MTR type fuel elements in the MTR canal. A cross section of the core is shown in Fig. 1. The reactor has a center water hole and a special fuel element in which samples may be placed for measurement. A servo control system continually adjusts the regulating rod to keep the reactor just critical. The change in position of the regulating rod is related to the reactivity change by a calibration curve based on period measurements. A detailed description is given in reference (1).

II. EXPERIMENTAL PROCEDURE

The experimental arrangement and procedure are briefly outlined here. Solutions sealed in plastic capsules which in turn were contained in watertight aluminum capsules were lowered by attached nylon fishing line into the desired RMF experimental locations shown in the core diagram of Fig. 1. In the center water hole positions 1 and 3 were defined by three spaced lucite plates with matched holes in the center and near the northwest corner. The lattice location (position 4) needed only a lower spacer for vertical positioning since the 1.25 inch square hole was just large enough to accommodate the aluminum capsule.

The usual procedure was to place the active samples individually and sequentially into the various positions for measurement. Interspersed were measurements, at frequent intervals, of a "standard" sample and of the empty reactor (no sample in place) which are used in this report to determine temperature coefficients. The standard was identical to the other samples except that the active material (uranium or boron) was missing. It is used to correct sample values for extraneous reactivity effects.

The temperature was measured by means of a calibrated thermistor positioned in the lattice center plane, the position of which is indicated in the core diagram of Fig. 1. The temperature here is considered to be

RMF Core Diagram

Figure 1

a reasonably good average for the whole reactor except when the temperature is changing rapidly.

III. RESULTS

The temperature history during this period (May 11-15, 1959) is reproduced in Fig. 2. It began with a period of fairly constant temperature followed by a sharp rise to a maximum. Then another period of almost constant temperature followed by a slow drop.

Fig. 3 gives a plot of the critical point of the reactor as a function of temperature. The reactivity recorded for each point is the value of the regulating rod calibration curve which has an arbitrary zero reference point. Hence, the absolute value of reactivity is not significant, but rather the change indicated. The sequence of the changes corresponding to the temperature history is shown by arrows in Fig. 2. It will be noted that in general the reactivity values when compared to the average straight line through all data are slightly higher during periods of rising temperature and lower when the temperature is dropping. This is due to a time lag in the temperature equilibrium at the temperature measurement point in the lattice. Data recorded here were taken only during relatively stable temperature conditions, i.e., the temperature was constant or changing at a constant rate.

The reactor temperature coefficient was calculated from data near the temperature extremes of Fig. 2 during which times the temperature was nearly constant. This value along with prior determinations is listed in Table I and plotted in Fig. 4. Table II records the empty reactor readings actually used. The data were subjected to a least squares fit to a straight line. The precision index given is a maximum change in the slope due to the scatter of the points. Since the scatter is due to the systematic effect involving a small rise and fall of temperature the actual value should be significantly better than the $\pm 1 \mu\text{k}/^\circ\text{C}$ would indicate ($1 \mu\text{k} = 10^{-6} \Delta\text{k}/\text{k}$).

The net values of the standard sample (capsule number 60) used during these measurements are given in Table III. Since measurements in positions 1, 3, and 4 were usually made consecutively the average temperature and empty reactor reading is also given for each point.

The temperature coefficient for the sample measurements was determined from the slope of the straight line relating the net reactivity to temperature. The data for each position were subjected to a least squares fit to a straight line. The slope, dp/dT , is the temperature coefficient of reactivity for the sample in units of $\mu\text{k}/^\circ\text{C}$. Results are summarized in Table IV. Also given for comparison are similar results obtained by S. B. Gunst (1) from RMF measurements of zircaloy-2 encapsulated natural UO_2 pellets.

IV. DISCUSSION

The reactor temperature coefficients listed in Table I represent values obtained at different times and under conditions that are not necessarily comparable. In the measurements made during September, 1955

Temperature History, RMF Water Moderator, May 12-15, 1959

Figure 2

Effect of Water Temperature on Reactivity of RMF

Figure 3

TABLE I

SUMMARY OF RMF TEMPERATURE COEFFICIENT MEASUREMENTS

Temperature Coefficient $\mu\text{k}/^{\circ}\text{C}$	Temp. Range $^{\circ}\text{C}$		Date	Remarks
	Initial	Final		
49.0 ± 1	15.4	17.8	May 1959	Value obtained in this report. Sample holder in place.
39 ± 4	26.0	22.8	June 1957	Obtained from WAPD-28 transient run with sample holder in place. See reference (1).
30.6	30.0	24.8	July 1956	Empty reactor, see reference (1).
33	23.7	29.5	July 1956	Sample holder and air tube in center water hole.
24	30.7	25.3	July 1956	Sample holder and air tube in center water hole.
36.6	25.9	22.2	Sept. 1955	Empty reactor.
36.0	26.1	21.8	Sept. 1955	Empty reactor.

Summary RMF Reactivity Coefficient Measurements

Figure 4

TABLE II

DATA USED IN CALCULATION OF TEMPERATURE COEFFICIENT OF RMF

<u>$\rho, \mu\text{k}$</u>	<u>$T, ^\circ\text{C}$</u>	<u>$\rho, \mu\text{k}$</u>	<u>$T, ^\circ\text{C}$</u>
427.0	15.635	534.6	17.833
427.5	15.644	534.6	17.828
427.9	15.656	534.6	17.827
428.1	15.644	534.4	17.825
429.0	15.672	534.4	17.822
429.7	15.678	534.1	17.820
430.6	15.691	534.4	17.818
430.3	15.696	534.0	17.818
430.1	15.698	533.5	17.820
429.0	15.693	533.2	17.821
427.7	15.684	533.1	17.823
426.4	15.670	533.3	17.818

Least squares fit of data to a straight line

$$\rho = - 340.05 + 49.04T$$

TABLE III

REACTIVITY DATA ON STANDARD CAPSULES

1959 Date	Time	Temperature °C	Reactivity μk Empty Reactor	Net reactivity in μk of standard capsule		
				Position 1	Position 3	Position 4
May 12	0600	15.672	429.0	132.3	205.0	-189.8
	0800	15.691	430.6	132.2	204.7	-190.0
	1135	15.684	427.7	131.8	204.2	-190.4
	1545	15.529	416.5	131.5	205.5	-190.3
	1910	15.427	412.1	131.8	204.7	-190.4
May 13	1905	17.689	531.2	130.9	203.8	-191.8
May 14	0200	17.827	534.6	130.7	203.3	-192.0
	0340	17.822	534.4	130.4	203.2	-192.5
	0810	17.821	533.2	131.0	203.2	-192.0
	1000	17.818	533.3	130.8	202.5	-192.3
	1400	17.783	529.7	131.0	203.9	-191.9
	1705	17.710	524.9	131.1	203.5	-191.3
	2100	17.608	519.3	131.2	203.5	-191.7
May 15	0000	17.543	515.7	131.3	204.1	-191.3
	0155	17.495	513.2	130.9	203.8	-191.3
	0400	17.451	511.1	130.9	203.7	-191.5
	0600	17.398	508.3	131.0	203.2	-191.8
	0700	17.376	506.6	130.7	203.5	-191.4
	1006	17.314	502.0	131.2	204.0	-191.6
	1351	17.236	497.9	131.3	203.8	-191.2
	1600	17.170	497.2	131.2	203.5	-191.5
	2001	17.135	494.8	131.6	203.7	-191.4
			Average	131.22	203.83	191.34

TABLE IV

TEMPERATURE COEFFICIENT OF NET SAMPLE REACTIVITY IN THE RMF

Sample	RMF Position*	Temperature Range °C	Ave. Net Reactivity μk	Temperature Coefficient $\mu\text{k}/^\circ\text{C}$
No. 60 Eta Standard	1	15.4--17.8	131.2	- 0.48 $\pm$ 0.02
No. 60 Eta Standard	3	15.4--17.8	203.8	- 0.66 $\pm$ 0.03
No. 60 Eta Standard	4	15.4--17.8	-191.3	- 0.78 $\pm$ 0.02
WAPD-28 No. D Standard	1	22.8--26.0	500	+ 0.1 $\pm$ 0.2
WAPD-28 No. D Standard	3	22.8--26.0	560	- 1.8 $\pm$ 0.3

* See Fig. 1

and July 1956, the temperature changes were obtained by steam heating the water in the RMF area. Reactivity measurements made at the temperature extremes were used to calculate the average value of the temperature coefficient for this range. Although it was assumed equilibrium had been attained later experience indicates an appreciable inherent uncertainty in this assumption. With a reasonable estimate of $\pm 4 \mu\text{k}/^\circ\text{C}$ given to this uncertainty it is apparent that a significant temperature dependence of the temperature coefficient exists. However, to assume more than a linear dependence is not warranted with the available data. A weighted linear fit results in

$$\frac{dp}{dT} = 78 - 1.8T .$$

If this relationship is applicable to sufficiently high temperatures, a reversal in the sign of dp/dT occurs at about 44°C .

The temperature coefficient of the standard eta capsule is seen to be small but statistically significant. The data include readings taken at times when the rate of temperature change was appreciable but uniform. No obvious separation was observed, however, between net reactivities taken during periods of rising or falling temperatures. The calculated uncertainty in the slope, i.e., the coefficient, is less than five percent. The larger errors in the WAPD-28 data are assumed to be due to less stable temperature conditions at the time of measurement. The difference between the two sets of values emphasizes the dependence of the temperature reactivity effect on sample material. The value for WAPD-28 appears to be lower in magnitude in the center but is appreciably more negative in the corner position than for the eta capsule. For a complete understanding of these temperature effects measurements are needed for various materials, including absorbers, fissionable materials, and combinations of both.

Since the rate of temperature change in the RMF area is rarely as high as 0.04°C per hour during measurement, it is reasonable to conclude that normally for any series of sample measurements corrections in the net reactivity because of temperature changes is not warranted. The error in reactivity would be less than the statistical fluctuations usually observed at constant temperature. During periods of temperature instability the uncertainty increases greatly and, therefore, in general it is inadvisable to make measurements. Changes in temperatures over a long period of time along with other changes may be adequately accounted for by comparison with a similar measurement on a standard.

V. ACKNOWLEDGMENTS

The entire RMF staff aided in obtaining the measurements reported here. Miss Ruth Peereboom was largely responsible for tabulating the data and handling the IBM calculations.

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