X-17410

UNCLASSIFIED

BNL-1149

Subject Category: PHYSICS

UNITED STATES ATOMIC ENERGY COMMISSION

SERIAL REPORTS ON START-UP EXPERIMENTS. NO. 1. THE HOT ROD EXPERIMENT

By
J. Chernick
J. W. Kunstadter

November 29, 1950

Brookhaven National Laboratory
Upton, New York

Technical Information Service, Oak Ridge, Tennessee

UNCLASSIFIED

Work performed under Contract No. AT-30-2-Gen-16.

Date Declassified: November 14, 1955.

Printed in USA, Price 20 cents. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

GPO 822907 - 1

SERIAL REPORTS ON START-UP EXPERIMENTS

#1. The Hot Rod Experiment

By J. Chernick and J. W. Kunstadter

November 29, 1950

Introduction

The purpose of this new series of reports is to present in roughly finished form the results of the various start-up experiments on the BNL reactor as soon as the analysis of the experimental data is completed.

Details of the Hot Rod Experiment

The hot rod experiment arose from a suggestion of Dr. C. Williams. The purpose of the experiment was to determine the metal temperature coefficient of the reactor. Computations by the theoretical group indicated that if several cartridges were heated to a few hundred degrees Centigrade and placed in channels near the reactor center, a change of a few inhours of reactivity would result during the cooling period. The experimental technique used, at the suggestion of Dr. L. B. Borst, was the following: with the hot cartridges in place, the control rods were adjusted to produce a slightly falling reactor period at a negligible power level. As the cartridge temperatures decayed, the reactivity of the reactor increased until a positive period was observed. The #9 control rod was then adjusted to bring the reactor slightly below critical. This procedure was repeated several times during the experiment, which ran from 11 A.M. to 3 P.M. on August 30, 1950. Parts of the experimental run are shown in Fig. 1.

The metallurgy group provided six insulated cartridges for the experiment. A description of the cartridges and their cooling characteristics in still air is given in Metallurgy Memorandum No. 200. The cooling curves are shown in Fig. 2. Three iron-constantan thermocouples were brazed to the surface of the fuel rods at the center and 16" from each end of the rods. Readings taken with these thermocouples during the hot rod experiment have been averaged and the results are shown in Fig. 3. Although the temperatures recorded by the 18 individual thermocouples differed somewhat, the precision of the hot rod experiment did not warrant any refinement of the unweighted average temperatures shown in Fig. 3.

The heated cartridges were placed in three centrally located channels, viz., at $x = 0, \pm 1, y = 0$ in our usual reactor coordinate system. The loading pattern was then a normal one with 419 channels loaded in an approximately cylindrical array (Fig. 4). There was no air flow through the reactor during the experiment.

Meteorological conditions during the experimental run were excellent. The microbarograph record for the 30th of August (Fig. 5) shows a level stretch only from 10 A.M. to 4 P.M. which fortunately covers the entire period of the experimentdl run. Barometric fluctuations during the experiment were less than 0.005 inches of Hg which is about as close as the recorders in use at that time could be read. The following accurate pressure readings were taken at the meteorology station on August 30:

Time	Atmospheric Pressure (Inches of Hg)
1030 EST	29.900
1330	29.900
1630	29.910

One difficulty with the experiment that should be noted was the time lost in loading the cartridges and in equilibrating the reactor. The cartridges came out of the oven at 10:47 A.M. at an average temperature of 450°C. Loading was completed at 11:04 and the reactor was brought to its first "slightly falling" period at 11:33 -- a total dead time of about 45 minutes during which the average metal temperature was reduced to 250°C (Fig. 3). The dead time could undoubtedly have been considerably reduced if it had been possible to repeat the experiment.

Results of the Experiment

The data required to interpret the hot rod experiment are the following:

1. The exact times at which the reactor was critical. These times can be estimated from the minima of the power output (neutron flux) curves as shown in Fig. 1. The counting rate readings were taken from three registers which were read consecutively every 20 seconds.

2. The average metal temperature at critical. The required data can be read from Fig. 3.

3. The sensitivity of the #9 control rod at the 419 channel loading pattern (Fig. 4). Experimental data of $\frac{\Delta(ih)}{\Delta(cm)}$ vs. centimeters of rod movement are plotted in Fig. 6.

The results of the experiment are summarized in the following table:

Table I

Time at Critical	Elapsed Time (min.)	#9 Rod Position (cm.)	$\frac{\Delta ih}{\Delta cm}$	Δih	Average Metal Temperature T (°C)	ΔT
11:42	55	336.03			223	
12:39	112	340.02	.200	.798	120	-103.
13:02	135	341.02	.203	.203	97.8	- 22.2
13:32	165	342.02	.204	.204	76.2	- 21.6
14:22	215	343.03	.205	.207	53.8	- 22.4

Correction for Increase in Graphite Temperature

A small correction must be introduced to account for the increase in graphite temperature during the experiment. If we assume that all the heat lost by the metal goes into increasing the graphite temperature in the reactor core, we find that close to 5% of the reactivity change during any interval of time is due to the graphite temperature coefficient. In the present experiment the graphite effect is opposite to that of the metal. This results in the following correction to Table I:

Table II

Interval of Time	Δk (ih) (Observed)	Δk(ih) (Corrected)	ΔT (°C)	$\Delta k/\Delta T$ (ih/°C)
11:42 - 12:39	.798	.838	-103	-.0081
12:39 - 13:02	.203	.213	- 22.2	-.0096
13:02 - 13:32	.204	.214	- 21.6	-.0099
13:32 - 14:22	.207	.217	- 22.4	-.0097

From Table II we obtain a coefficient of $-0.0093 \pm .0004$ inh per °C rise in cartridge temperature. The accuracy of the experiment is probably about 10% in view of possible errors in the control rod calibration, critical time and temperature estimates, etc. However, our results may be compared with the independent analysis of Dr. C. Williams shown in Table III.

Table III

Time at Critical	#9 Rod Position	$\frac{\Delta ih}{\Delta cm}$	Δih	Av. Temp. (°C)	$\frac{\Delta ih}{\Delta T}$
11:45	336.03	.19		210.4	
12:39	340.02	.20	.778	117.5	-.0084
13:02	341.02	.201	.2005	95.5	-.0091
13.33	342.02	.203	.202	74.0	-.0094
14:17	343.03	..205	.206	51.9	-.0094

Weight Factors

The experimental temperature coefficient of -.0093 inh/°C is based on a total of only three channels of the 419 channels loaded. We wish to obtain the uniform temperature, normal flux metal temperature coefficient at this loading. This coefficient will, however, vary somewhat with the loading pattern. It will therefore be useful eventually to define a standard uniform temperature, uniform flux temperature coefficient in order to compare results obtained at different loadings and under different temperature distributions.

According to the usual statistical weight theory, weighting factors are found, for uniform temperature conditions, from the average value of $(nv)^2$ over the reactor core. Thus for a cylindrical loading the radial weight factor is

$$J_o^2\,(j_1\ r/R) + J_1^2\,(j_1\ r/R)$$

where r is the loading radius and R the extrapolated radius of the reactor. For a square loading the corresponding factor is

$$\left[\frac{1}{2} + \frac{L}{2\pi \ell} \sin \frac{\pi \ell}{L} \right]^2$$

with ℓ the loading width and L the extrapolated width of the reactor.

At the 419 channel loading, r = 11.55, R = 14.55 lattice units, and the appropriate weight factor is 0.414. If the loading were considered square the weight factor would be 0.402 which shows that the weight factor is not particularly sensitive to geometry. We thus obtain

$$-.414 \times \frac{419}{3} \times .0093 = -.54 \text{ inh}/^{\circ}\text{C}$$

for the uniform temperature, normal flux, metal temperature coefficient of the BNL reactor at a cylindrical loading of 419 channels.

Control Rod Calibration

The data obtained during the calibration of the #9 and #15 rods at the 419 channel loading are summarized in Table IV.

Table IV

Control Rod Calibration for 419 Channel Loading

Position #15 Rod (cm in)	Position #9 Rod (cm in)	Reactor Period (min)	Inhours
0	475.02	-28.7 ± .3	-2.16
	462.00	116 ± 15	.52
	450.05	15.8 ± .02	3.69
260.00	460.00	-19.6 ± .2	-3.18
	450.04	-89.8 ± 4.2	- .68
	440.04	34.2 ± .2	1.74
	430.04	14.7 ± .01	3.97
300.00	440.01	-38.4 ± .1	-1.60
	430.04	59.3 ± 1.0	1.01
330.03	430.04	-21.0 ± .1	-2.98
	420.03	-360 ± 13	- .17
	410.06	24.9 ± .2	2.38
360.00	410.00	-26.6 ± .4	-2.34
	400.02	211.2 ± 18.6	.29
	390.03	21.4 ± 0.1	2.76
394.93	410.14	- 8.89 ± .07	-7.34
	384.96	-43.9 ± .7	-1.40
	350.07	8.10 ± .02	6.98
400.00	400.06	-9.51 ± .10	-6.82
414.09	360.05	99.5 ± .4	.61
440.06	350.04	-21.1 ± .3	-2.96
	340.03	-127 ± 6	- .48
	330.05	45.3 ± .5	1.32
	320.05	19.7 ± .2	2.98
	310.05	12.5 ± .1	4.62
450.00 (?)	280.05	-48.4 ± 1.0	-1.27
	270.05	-410 ± 49	- .15
	260.00	73.9 ± 0.7	.81

The reactor periods were determined by least squares from the register readings. Since three registers were employed, the precision of the determinations could be estimated and is generally within 2%, although a few of the standard errors are considerably larger. The reactor periods were converted to inhours by the use of the Hughes formula. The plot of the sensitivity of the #9 rod (Fig. 6) was obtained by differencing Table IV for fixed values of the #15 control rod position. The calibration curve for the #9 rod (Fig. 7) was then found by graphical integration. Subracting the effect of the #9 rod, we get the calibration curve for the #15 rod shown in Fig. 8.

POWER OUTPUT OF REACTOR (NEUTRON COUNTING RATE)

vs

TIME

"HOT ROD EXPERIMENT", 8/30/50

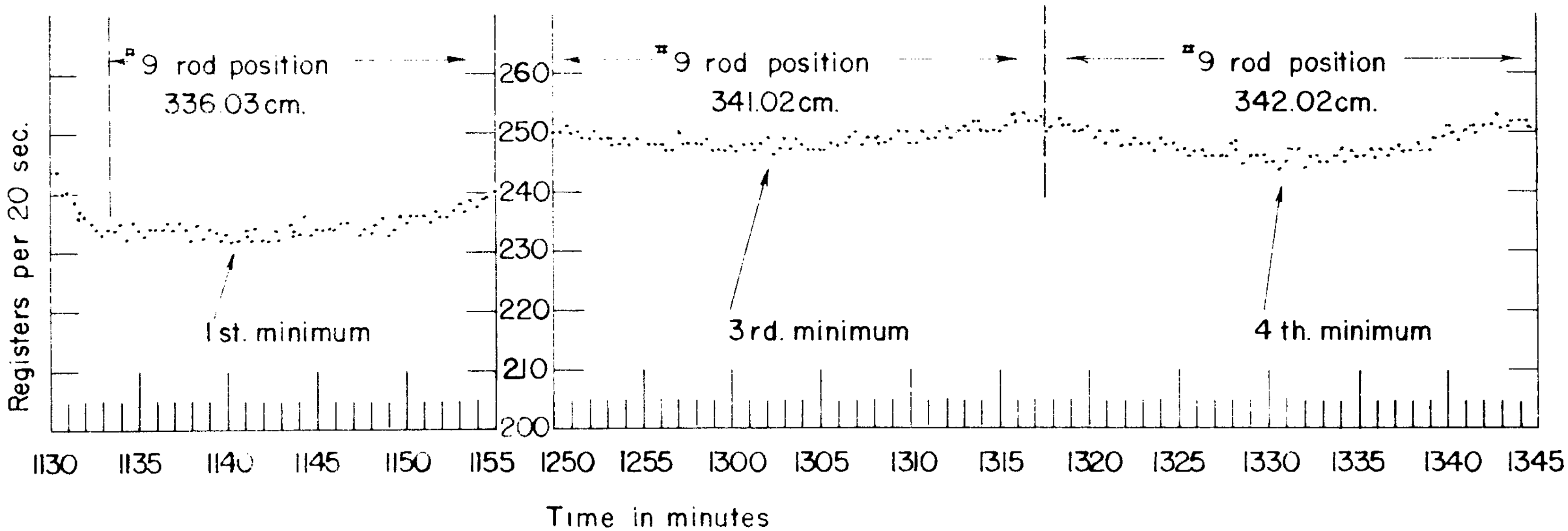

FIG. 1

BNL LOG # D-1616

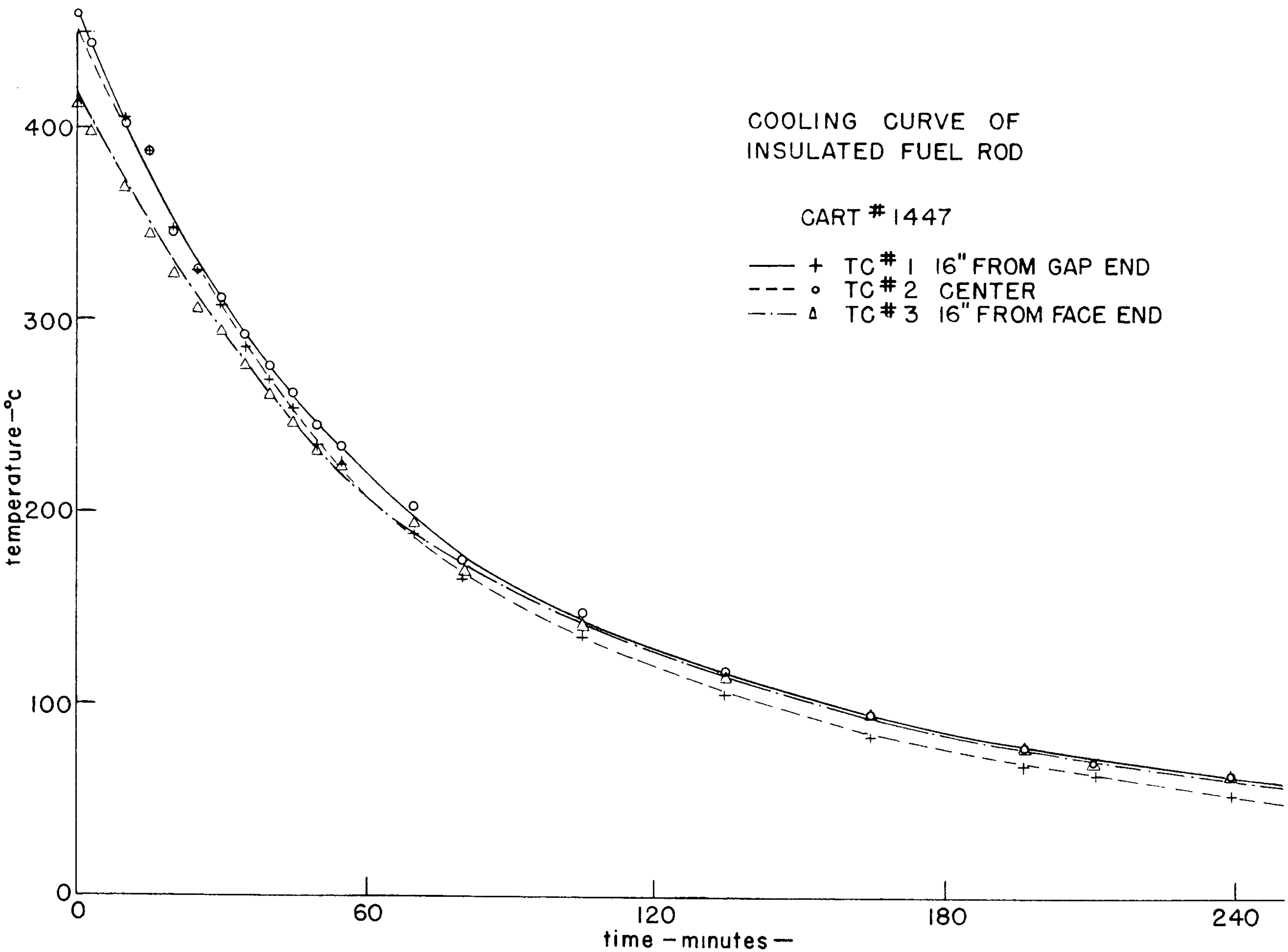
COOLING CURVE OF
INSULATED FUEL ROD
CART # 1447
+ TC # 1 16" FROM GAP END
o TC # 2 CENTER
Δ TC # 3 16" FROM FACE END
temperature – °C
time – minutes –
0
100
200
300
400
0
60
120
180
240

FIG. 2

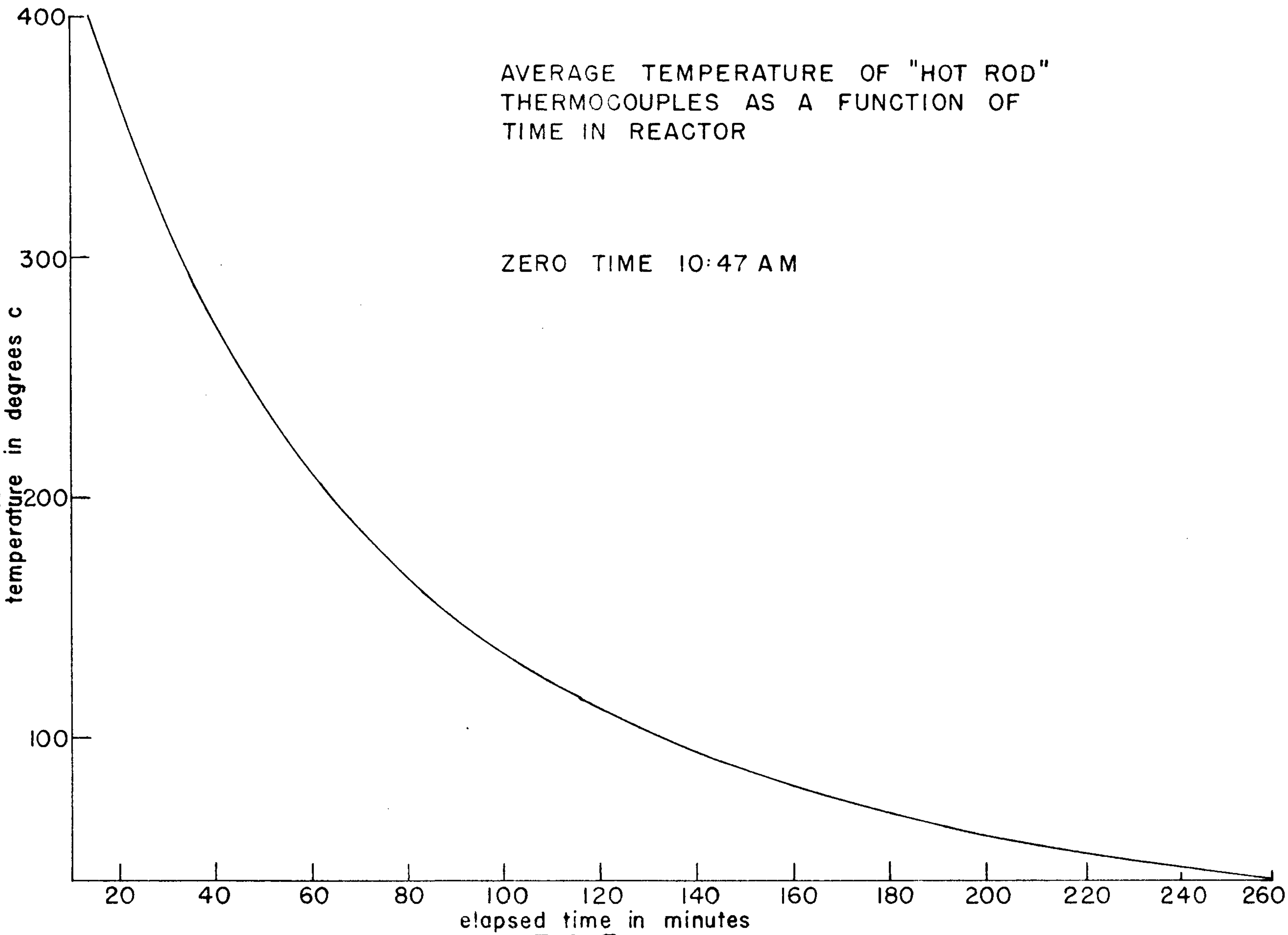

FIG. 3

BNL LOG# D-1617

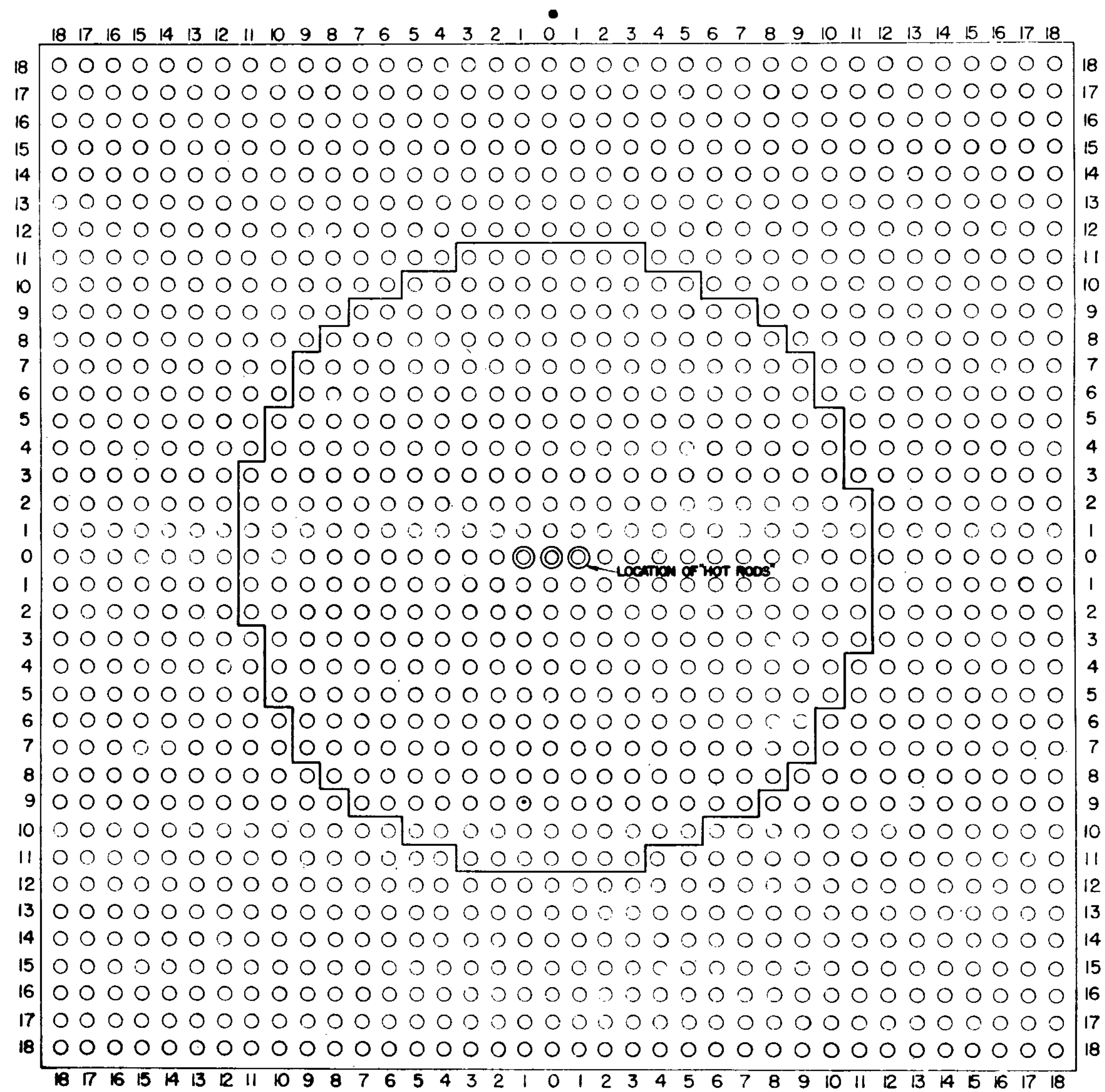

FIG. 4
LOADING PATTERN FOR "HOT ROD" EXPERIMENT
(419 LOADED CHANNELS OUTLINED)

BNL LOG # D-1621

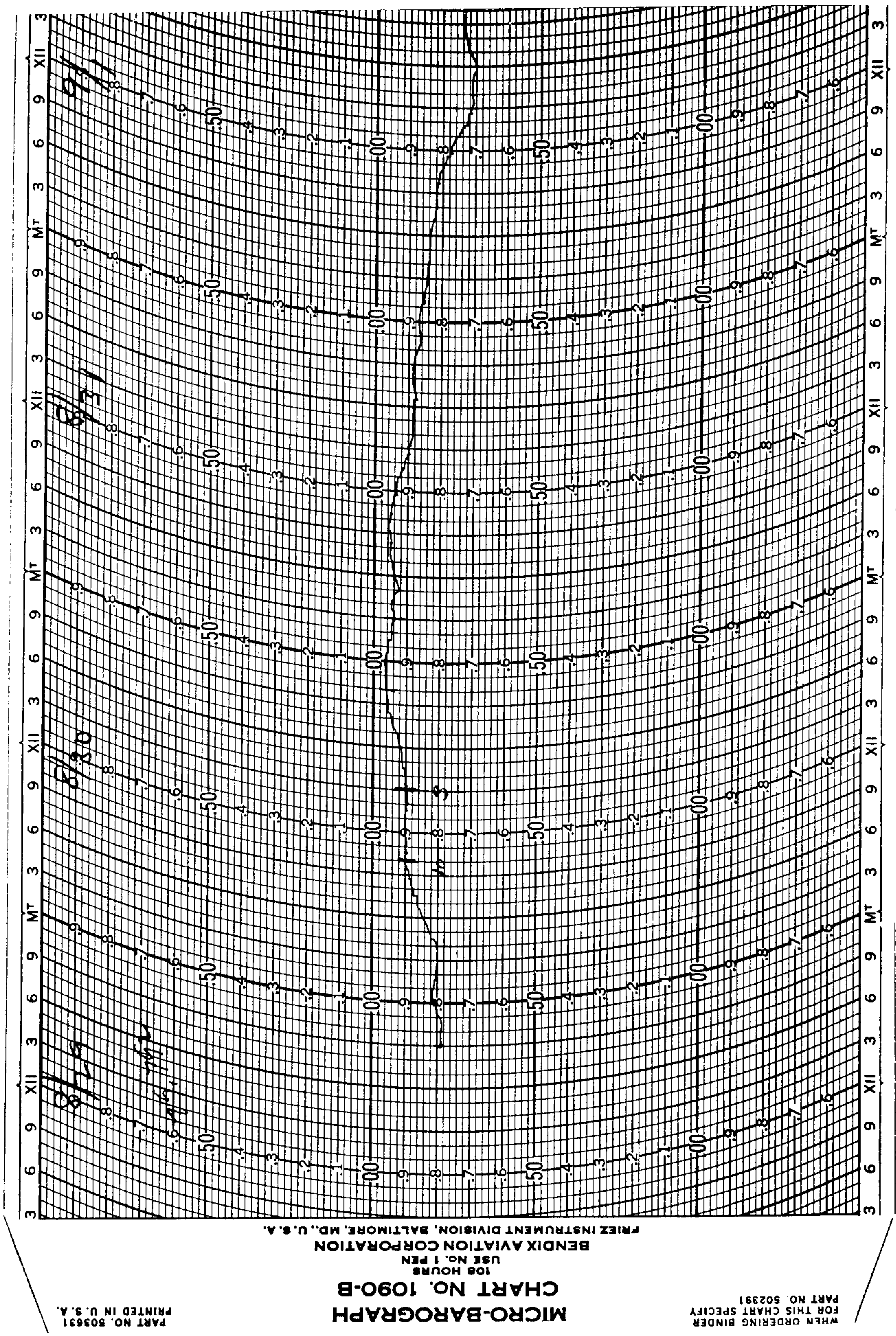

Figure 5. Barograph Record for the 30th of August, 1950.

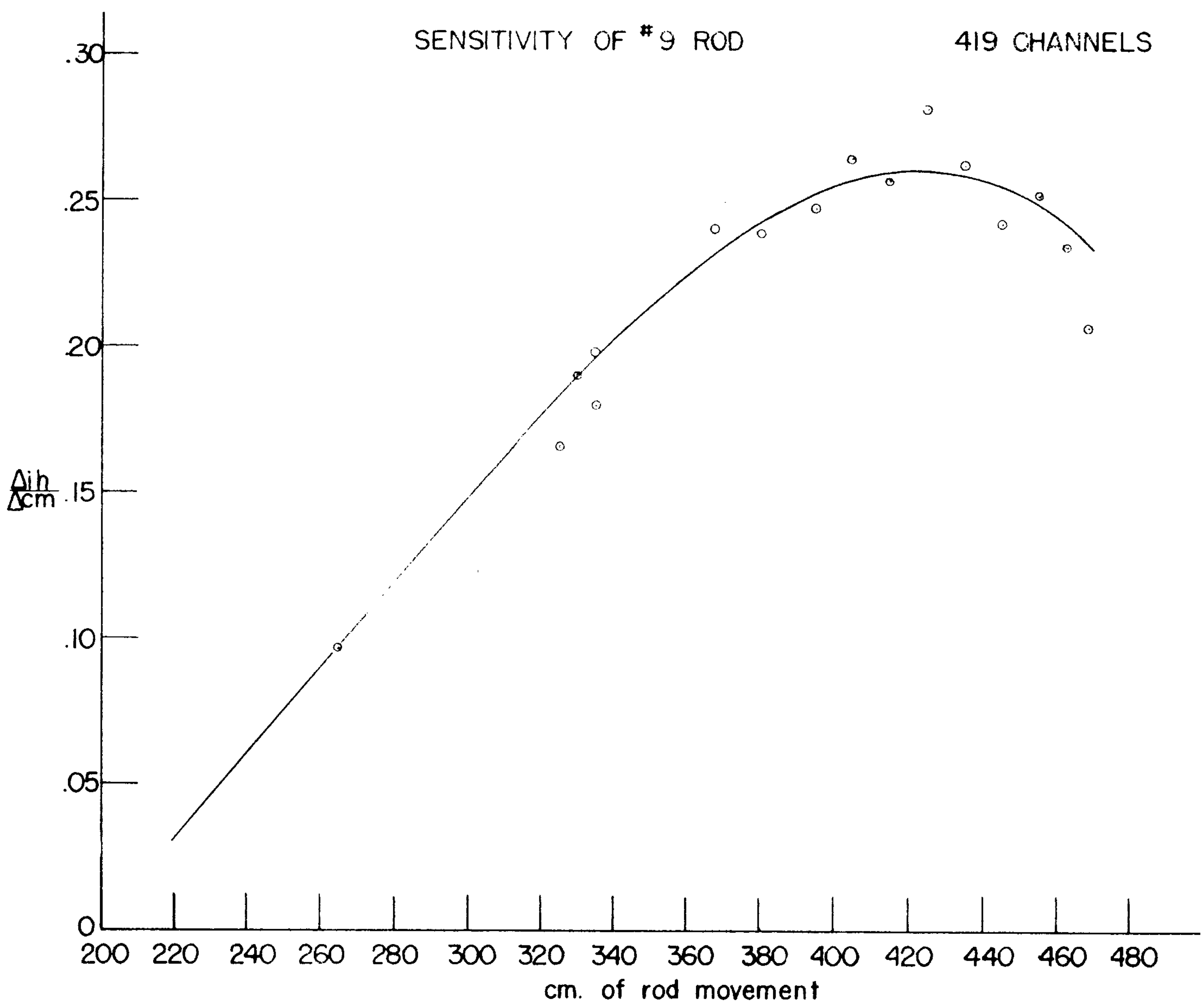

FIG. 6

BNL LOG # D-1618

CALIBRATION CURVE FOR #9 ROD 419 CHANNELS

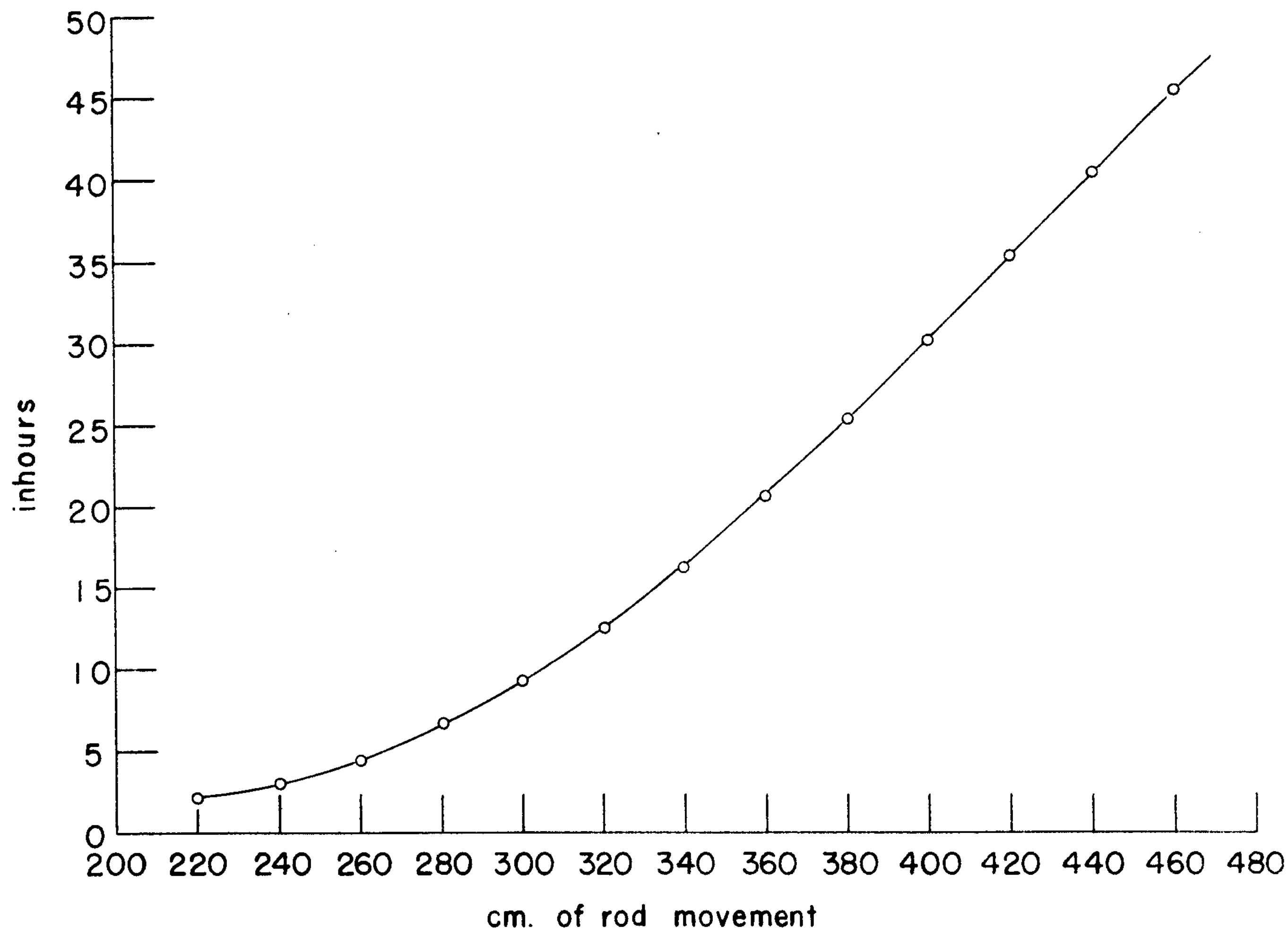

FIG. 7

BNL LOG # D-1619

CALIBRATION CURVE FOR #15 ROD 419 CHANNELS

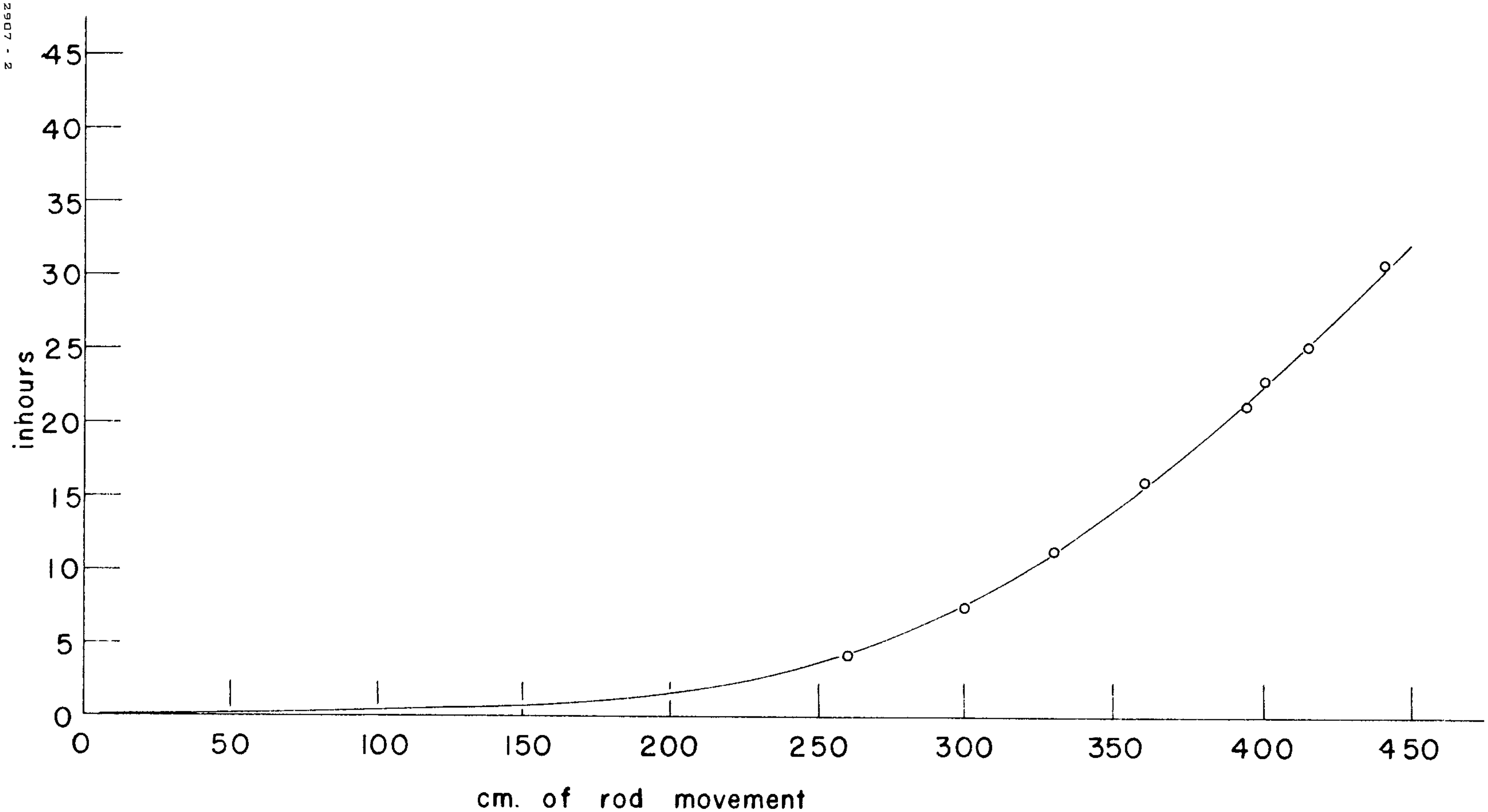

FIG. 8

BNL LOG # D-1620

GPO 822907 - 2