ORNL
MASTER COPY

UNCLASSIFIED

X-821

[redacted]

OAK RIDGE NATIONAL LABORATORY
Operated By
UNION CARBIDE NUCLEAR COMPANY

UCC

POST OFFICE BOX P
OAK RIDGE, TENNESSEE

EXTERNAL DISTRIBUTION AUTHORIZED

ORNL
CENTRAL FILES NUMBER
56-3-72

DATE: March 7, 1956

COPY NO. 30

SUBJECT: GAMMA HEATING MEASUREMENTS IN THE BULK SHIELDING REACTOR

TO: Distribution

FROM: F. T. Binford, E. S. Bettis and J. T. Howe

OAK RIDGE NATIONAL LABORATORY LIBRARIES
3 4456 0604315 3

DISTRIBUTION

1. L. G. Alexander
2. E. S. Bettis
3. D. S. Billington
4. F. T. Binford
5. R. B. Briggs
6. C. D. Cagle
7. W. R. Casto
8. H. C. Claiborne
9. T. E. Cole
10. J. A. Cox
11. J. P. Gill
12. K. M. Henry
13. J. T. Howe
14. E. B. Johnson
15. P. R. Kasten
16. G. W. Keilholtz
17. J. A. Lane
18. F. C. Maienschein
19. A. F. Rupp
20. W. H. Tabor
21. H. L. Watts
22. A. M. Weinberg
23. C. E. Winters
24. W. L. Wright
25-28. Lab. Records
29. Central Research Library
30. ORNL-RC

UNCLASSIFIED

GAMMA HEATING MEASUREMENTS IN THE BULK SHIELDING REACTOR

By

F. T. Binford, E. S. Bettis and J. T. Howe

ABSTRACT

A series of experiments to determine the rate of gamma heating in construction materials in the vicinity of a reactor core of the M.T.R. type were carried out in the Bulk Shielding Reactor at The Oak Ridge National Laboratory. The method used employed measurement of the transient temperature of the samples during heating in the gamma field and cooling after removal from the gamma field. Results suitable for use in connection with the engineering design of reactor structures were obtained using aluminum, lead, iron, and copper samples.

GAMMA HEATING MEASUREMENTS IN THE BULK SHIELDING REACTOR

E. S. Bettis, F. T. Binford and J. T. Howe

I INTRODUCTION

One of the problems frequently encountered in the design of a nuclear reactor is that of determining the temperature distribution in structural members in the reactor.

These structural members, if they are near enough to the core to be subject to appreciable internal heating due to the deposition of energy from gamma radiation, must be properly cooled to prevent the development of excessive temperatures. Methods of calculating such temperature distributions, given the heat generation rate, the physical constants of the material under consideration, and a description of the method of heat removal, are well known[1]. Estimation of the heat generation rate itself, however is often difficult.

In order to determine the heat generation rates in structural members in connection with the design of the Oak Ridge Research Reactor a series of experiments, which will be described below, were performed at Oak Ridge National Laboratory using the Bulk Shielding Reactor[2] which is the prototype swimming pool reactor and is similar in many respects to the O.R.R.

II THEORETICAL CONSIDERATIONS

Consider a small solid body which has thermal conductivity k, and in which starting at some time $t = 0$, heat is generated uniformly at a constant rate Q (energy/unit time.unit volume). Now if L is a characteristic dimension of the body, and if the quantity $QL^2/2K$ is small, then the temperature of the body can be considered to be virtually independent of position in the body.

Assume that heat is lost from the body only by conduction at the surface and that the rate of loss of heat is proportional to the temperature difference between the body and its surroundings. Then the net change in heat content can be expressed in the form

$$(1) \qquad V\rho C \, d\theta(t)/dt = \varphi V - hS\theta(t)$$

where here the temperature of the surroundings has been arbitrarily chosen to be zero, and

V = volume of the body
C = specific heat
ρ = density
$\theta(t)$ = temperature of the body at time t
h = heat transfer coefficient
S = surface effective in heat removal

Upon letting the initial temperature of the body be zero we have for the temperature at time t

$$(2) \qquad \theta(t) = \frac{\varphi}{\mu}\left(1 - e^{-\lambda t}\right)$$

where for convenience we have set

$$\mu \equiv hS/V$$
$$\lambda \equiv hS/C\rho V$$

and

$$(3) \qquad \mu = \rho C \lambda$$

Consider now the same body at initial temperature θ_0. With no heat generation the net change in heat content becomes

$$(4) \qquad V\rho C \, d\theta(t)/dt = -hS\theta(t)$$

whence the temperature at time t is given by

$$(5) \qquad \theta(t) = \theta_0 e^{-\lambda t}$$

where the value of λ in (5) is the same as the value of λ in (2)

Thus if the body is heated to a temperature θ_0 and then the internal heat source is removed and the body allowed to cool, the value of λ can be found from a semi-log plot of the cooling curve. Using the value of λ and

the known values of ρ and C the constant μ can be computed. Once these constants are known substitution of some known pair of values of t and $\theta(t)$ into (2), the heating equation, permits calculation of Q.

Provided that the assumptions set forth above are valid, this method of determining the heat generation rate has two main advantages: (1) The only physical constants that it is necessary to know are the sample density and the specific heat of the material from which it is made. (2) By altering either the heat transfer surface, S, or the heat transfer coefficient, h, it is possible to adjust the rate of temperature rise to a convenient level without the necessity of knowing the absolute value of either parameter.

The obvious disadvantages include the fact that both k, the conductivity, and C, the specific heat vary with temperature. In general these variations can be neglected if the proper temperature range is used. For example for Aluminum the value of C increases approximately 8% between 0° and 100° centigrade, while the value of k remains virtually constant over the same range. In the experiments described both C and k have been assumed constant.

The variation of h with temperature depends on the conditions at the surface and if, for example, the surface of the body is kept in contact with water and the body is permitted to become quite hot, thermal convection currents will be set up which will materially effect the value of h. As will be shown later this problem can easily be taken care of.

III EXPERIMENTAL PROCEDURE

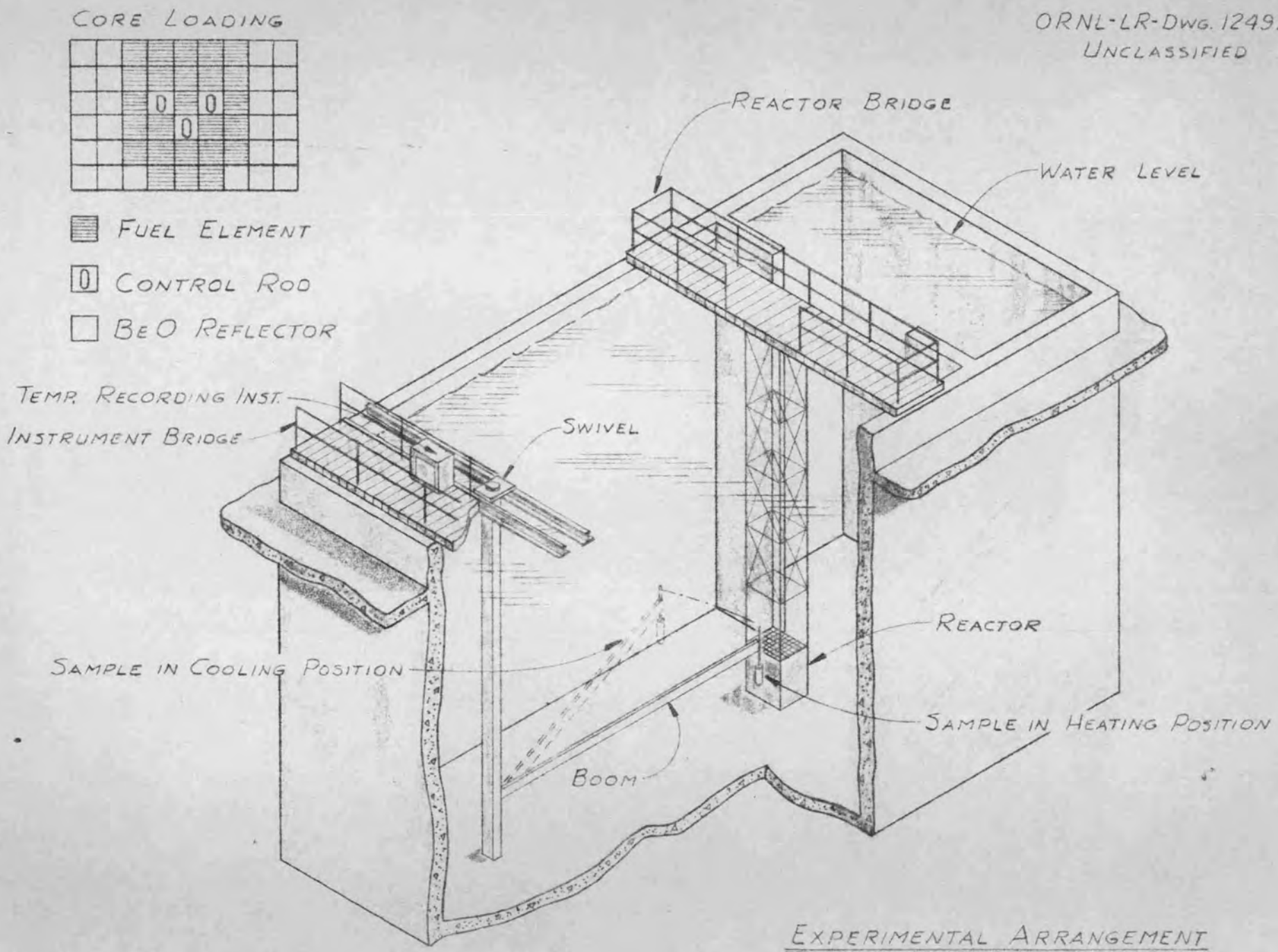
In general procedure was to place a sample of the material to be examined in the gamma field from the Bulk Shielding Reactor which was operating at a constant power level. The temperature change of the sample with

time was then recorded by means of a thermocouple imbedded in the sample and connected to a recording millivoltmeter. When a suitable temperature was reached the sample was removed from the gamma ray field and the rate of cooling observed on the same instrument. The entire process was accomplished with the sample immersed in the 20' x 20' x 40' reactor pool which contains water at a temperature of approximately 90°F. This large volume of water, the temperature of which changes very slowly with time, served as an effective thermostat thus fulfilling the requirement that the surrounding temperature remain constant during the course of the experiment. A diagram of the experimental arrangement together with the core loading in use is shown in Fig. 1.

Preliminary tests indicated that the heat loss from the surface of the metal samples when immersed directly in the water was so high that it was impossible to obtain satisfactory temperature rises. Therefore the sample, which consisted of a small cylinder of the material under consideration was suspended from the thermocouple wires inside a small capsule of aluminum or brass. The cylinder was positioned by means of three phonograph needles so that it could not touch the side of the capsule. The thermocouple leads were taken to the surface of the water through plastic tubing with a water tight seal where the tubing joined the capsule. In view of the preliminary tests mentioned above it is clear that the surface temperature of the capsule remains virtually the same as the surrounding water thus obviating the possibility of changes in h due to convection currents. The arrangements used are illustrated in Figs. 2a & 2b.

The experimental procedure consisted of positioning the capsule containing the sample on the center line of the B.S.F. core at a predetermined

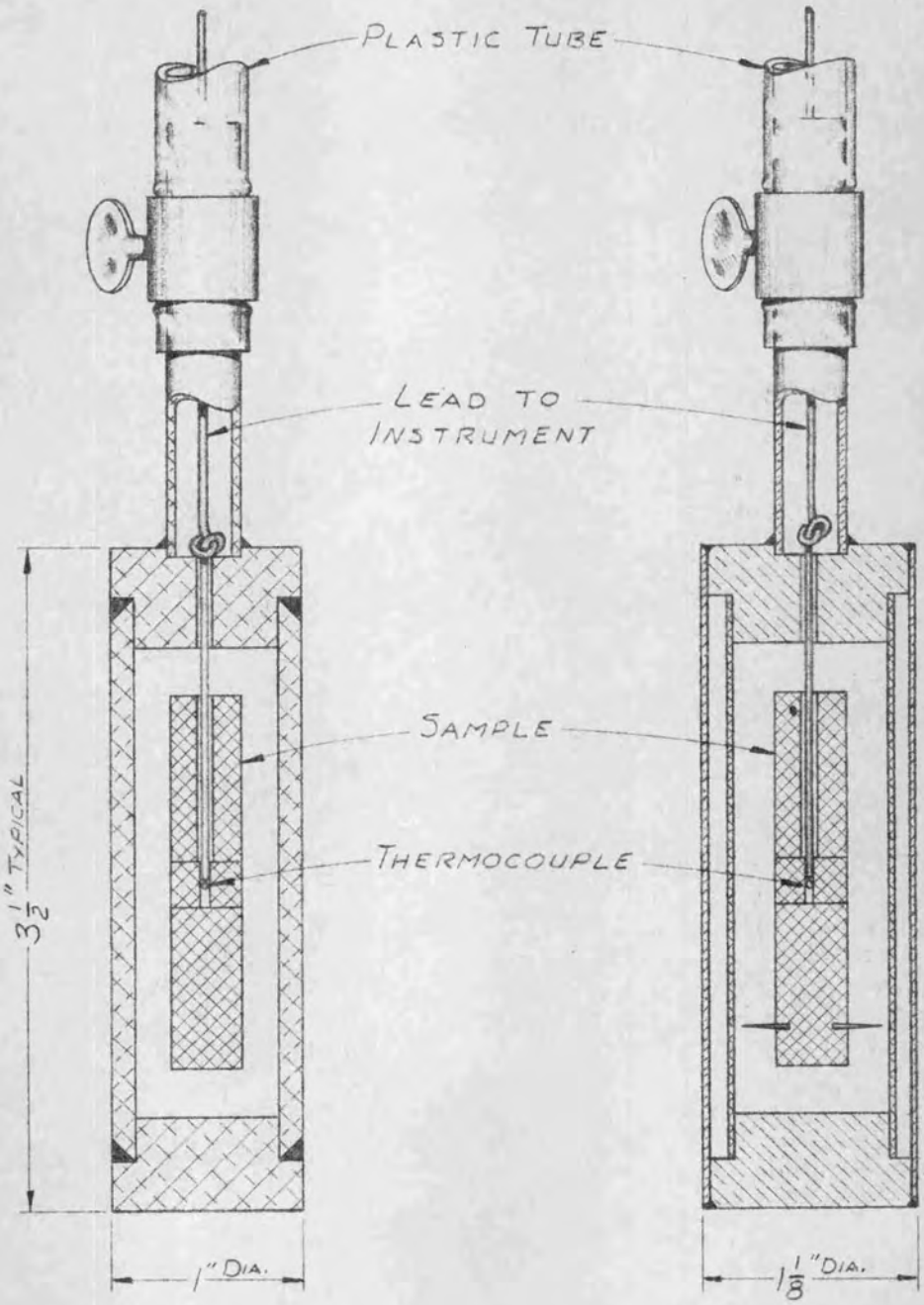
ORNL-LR-DWG. 12493
UNCLASSIFIED



EXPERIMENTAL ARRANGEMENT
FIG.-1

ORNL-LR-DWG. 12494
UNCLASSIFIED

FIG.-2
SAMPLE CAPSULES



(a) ALUMINUM CAPSULE
(NO RADIATION SHIELD)

(b) BRASS CAPSULE
(RADIATION SHIELD)

horizontal distance from the reactor by hanging it from a boom approximately ten feet long. The boom was then rotated through an angle of 90° to remove the capsule from the vicinity of the core. The reactor was started up and when the proper steady-state power level was achieved the capsule was swung back into position and the temperature recorded as a function of time.

After a suitable temperature rise occurred the capsule was again swung away from the reactor and the cooling curve was recorded.

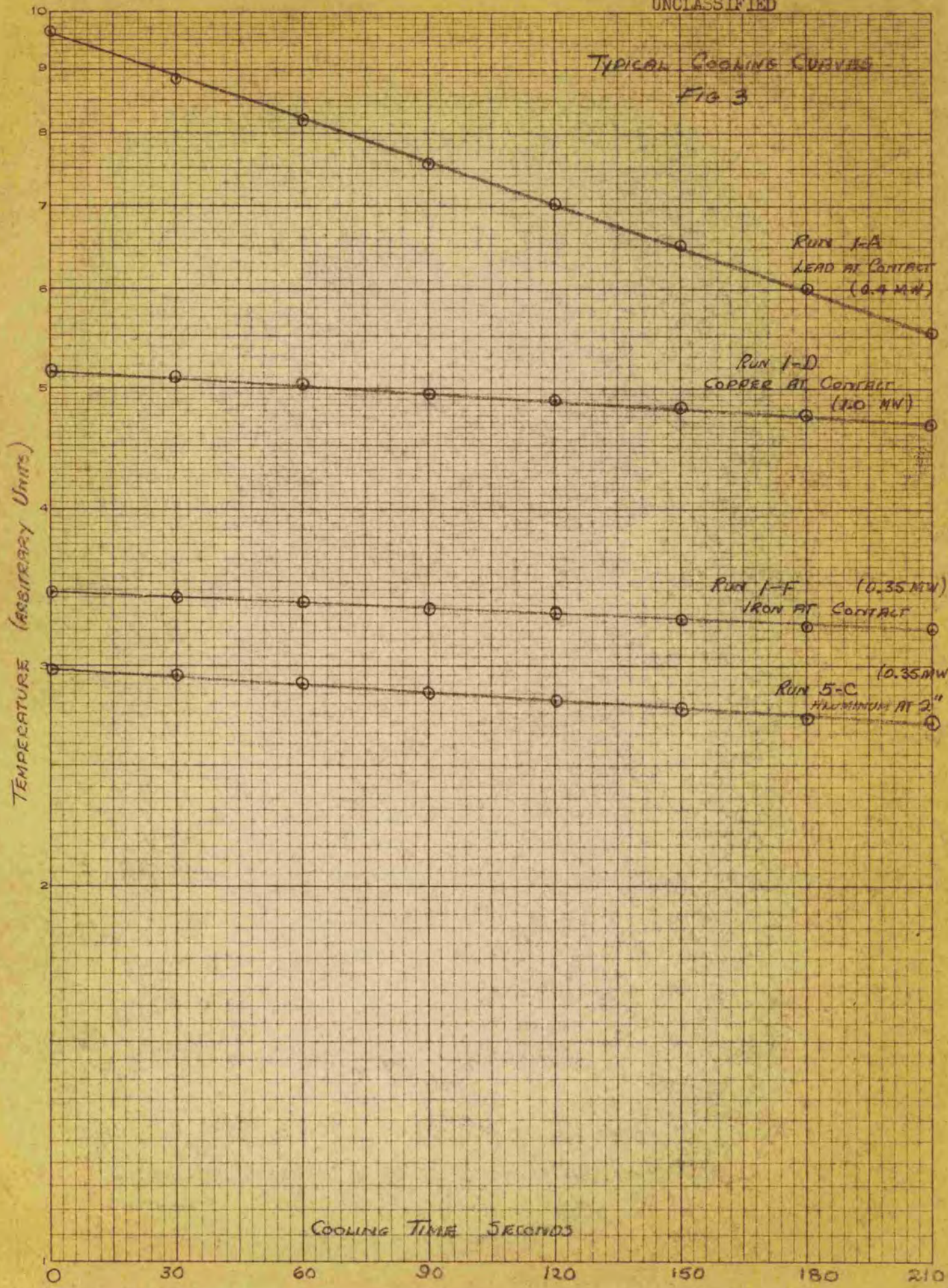
In some cases a vacuum was maintained on the capsule during the heating and cooling processes and in other natural circulation of air was permitted through the thermocouple tube. No significant difference was noted. Determinations were made using lead, aluminum, iron, and in one case copper samples. The first experiments on lead were run using an aluminum capsule (Fig. 2a). In the later experiments a brass capsule which incorporated a bright aluminum radiation shield between the sample and the capsule wall was used (Fig. 2b). No significant difference was noted in the results.

The measurements with the lead sample were made at the surface of the reactor and at distances from the core of 3", 6", and 9". For aluminum and iron the heat generated in the samples was lower and it was not possible at the power level available to obtain reliable results at distances greater than 4" from the core. Measurements using these materials were made at the reactor surface and at distances of 2" and 4" from the core. One determination was made at the surface using a copper sample.

IV RESULTS

Semi-log plots of typical cooling curves obtained are reproduced in Fig. 3. The values of λ were determined from these plots and the corresponding values of ρ were calculated, using the relation (3). The constants employed were

ORNL-LR-Dwg.-12580
UNCLASSIFIED



EUGENE DIETZGEN CO.
NO. 340-L110 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
1 CYCLE X 10 DIVISIONS PER INCH

Material	C (cal/gm °C)	g/cc
Pb	0.032	11.3
Al	0.23	2.7
Fe	0.115	7.87
Cu	0.094	8.94

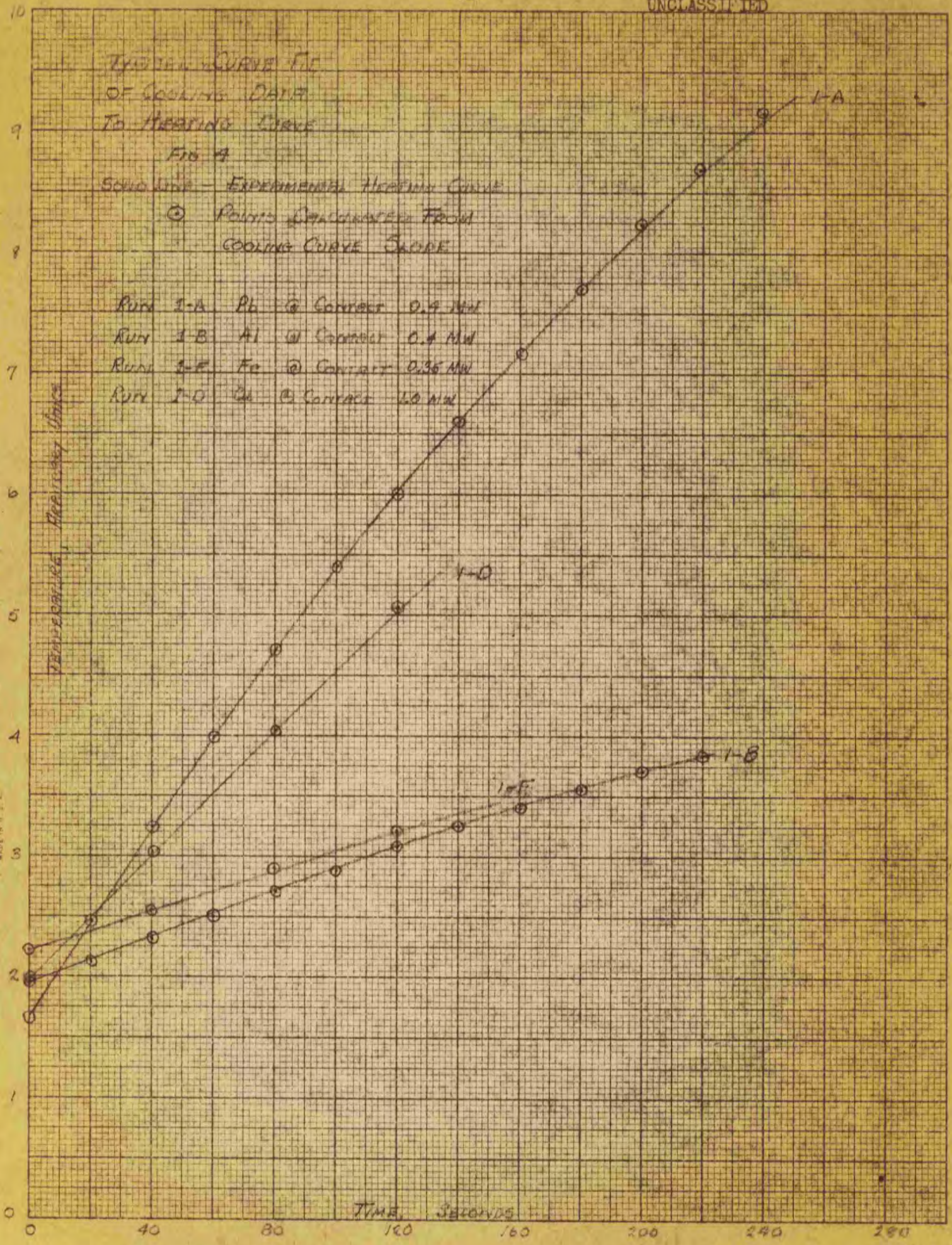
Several temperatures were chosen from each heating curve and, using the corresponding values of λ taken from the cooling curves, the magnitude of Q was calculated. In order to check the accuracy of these values and to determine whether or not the heat loss term was indeed proportional to the difference in temperature between the sample and its surroundings each of the heating curves was reconstructed using the calculated value of Q and the corresponding value of λ found from the cooling curve. In every case the calculated heating curve was an accurate fit to the experimental curve. Several typical fits are shown in Fig. 4. The solid lines are the experimental curves while the points are values of $\theta(t)$ from equation (2) using the calculated values of Q and ρ . and the experimental value of λ.

The numerical results obtained are shown in tables I, II, III, and IV. The average values obtained for the heat generation rates have been plotted against distance in water from the reactor face in Fig. 5. It can be seen that reasonably straight lines are obtained. The relaxation lengths are 4.5" for the case of lead, 4.3" for the case of iron, and 3.8" for the case of aluminum.

V DISCUSSION

Powell and Snyder[3] have demonstrated the strong energy dependence of the absorbtion coefficient for the materials examined (Fig. 6). It is obvious that changes in the gamma energy spectrum will result in corresponding changes in the heat generation rates. In general a given energy flux is more effective in producting heat in a thin slab of absorber if it is

ORNL-LR-Dwg.-12581
UNCLASSIFIED



359-12 KEUFFEL & ESSER CO.
10 X 10 to the ½ inch, 5th lines accented.
MADE IN U.S.A.

TABLE I

SUMMARY OF HEAT GENERATION DATA FOR LEAD

RUN #	DATE	POSITION	POWER		WATTS/GM MEGAWATT	REMARKS
1A	1/31/56	C	0.4 MW	215.3	0.264	Al capsule - no shield - vacuum
2A	2/1/56	C	0.1 MW	137.3	0.295	" " " "
3A	2/1/56	C	0.4 MW	172.3	0.292	" " " "
4A	2/1/56	C	0.4 MW	169.8	0.283	" " " "
5A	2/1/56	C	0.2 MW	138.1	0.339	" " " "
6A	2/1/56	C	0.2 MW	142.2	0.262	" " " "
9A	2/2/56	C	0.4 MW	160.9	0.291	" " " "
15A	2/2/56	C	0.4 MW	167.4	0.262	" " " - no vacuum
16A	2/2/56	C	0.4 MW	146.3	0.280	" " " - vacuum
				AVG	0.285	
7A	2/1/56	3"	0.75 MW	154.4	0.133	Al capsule - no shield - vacuum
10A	2/2/56	3"	0.4 MW	134.1	0.162	" " " "
11A	2/2/56	3"	0.4 MW	125.9	0.156	" " " "
				AVG	0.150	
8A	2/1/56	6"	1 MW	136.5	0.072	Al capsule - no shield - vacuum
12A	2/2/56	6"	0.4 MW	105.6	0.079	" " " "
13A	2/2/56	6"	0.4 MW	112.1	0.079	" " " "
				AVG	0.077	
14A	2/2/56	9"	0.4 MW	120.2	0.037	Al capsule - no shield - vacuum
1E	2/13/56	9"	1 MW	88.6	0.034	Brass capsule - shield - no vacuum
2E	2/14/56	9"	0.75 MW	112.9	0.041	" " " " "
				AVG	0.037	

TABLE II

SUMMARY OF HEAT GENERATION DATA FOR ALUMINUM

RUN #	DATE	POSITION	POWER		WATTS/GM MEGAWATT	REMARKS
1B	2/2/56	C	1 MW	118.1	0.175	Al capsule - no shield - vacuum
2B	2/2/56	C	0.4 MW	95.5	0.198	" " " " "
1C	2/9/56	C	1 MW	91.0	0.177	Brass capsule - shield - no vacuum
2C	2/9/56	C	1 MW	102.4	0.184	" " " " "
3C	2/15/56	C	0.35 MW	78.3	0.208	" " " " "
				AVG	0.188	
4C	2/15/56	2"	1 MW	86.0	0.103	Brass capsule - shield - no vacuum
5C	2/15/56	2"	0.35 MW	64.6	0.122	" " " " "
6C	2/15/56	2"	1 MW	68.0	0.114	" " " " "
				AVG	0.113	
7C	2/15/56	4"	1 MW	68.8	0.064	Brass capsule - shield - no vacuum
8C	2/16/56	4"	1 MW	70.1	0.064	" " " " "
				AVG	0.064	

TABLE III

SUMMARY OF HEAT GENERATION DATA FOR IRON

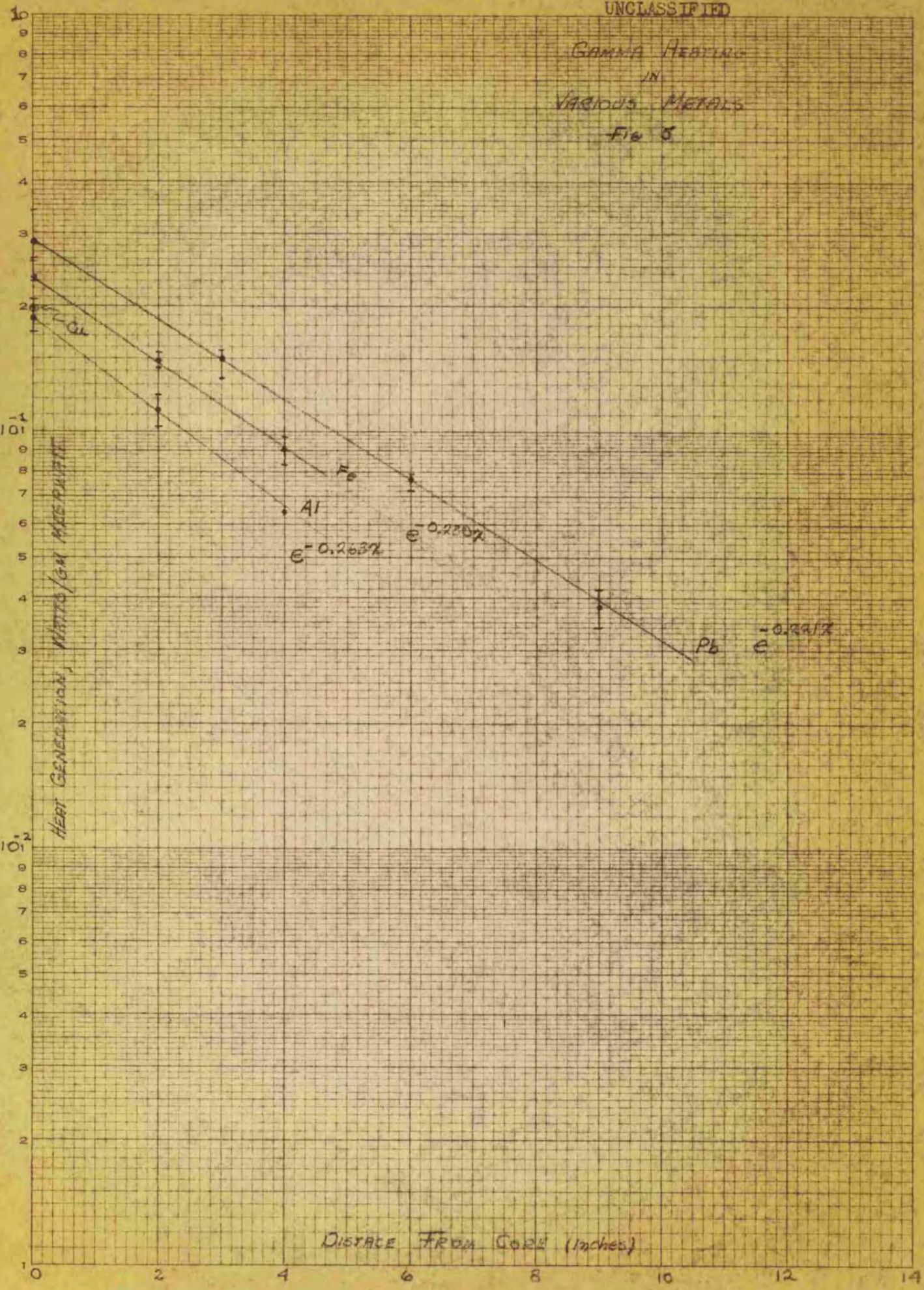
RUN #	DATE	POSITION	POWER		WATTS/GM MEGAWATT	REMARKS
1F	2/16/56	C	0.35 MW	71.9	0.234	Brass - shielded - no vacuum
4F	2/17/56	C	0.35 MW	86.7	0.230	" " " "
5F	2/17/56	C	0.35 MW	92.7	0.236	" " " "
				AVG	0.233	
2F	2/16/50	2"	0.35 MW	60.2	0.144	Brass - shielded - no vacuum
6F	2/17/50	2"	0.35 MW	89.7	0.150	" " " "
7F	2/17/50	2"	0.35 MW	89.7	0.154	" " " "
				AVG	0.149	
3F	2/16/50	4"	0.35 MW	51.5	0.083	Brass - shielded - no vacuum
8F	2/17/50	4"	0.35 MW	70.0	0.097	" " " "
9F	2/17/50	4"	0.35 MW	56.2	0.091	" " " "
				AVG	0.090	

TABLE IV

SUMMARY OF COPPER DATA

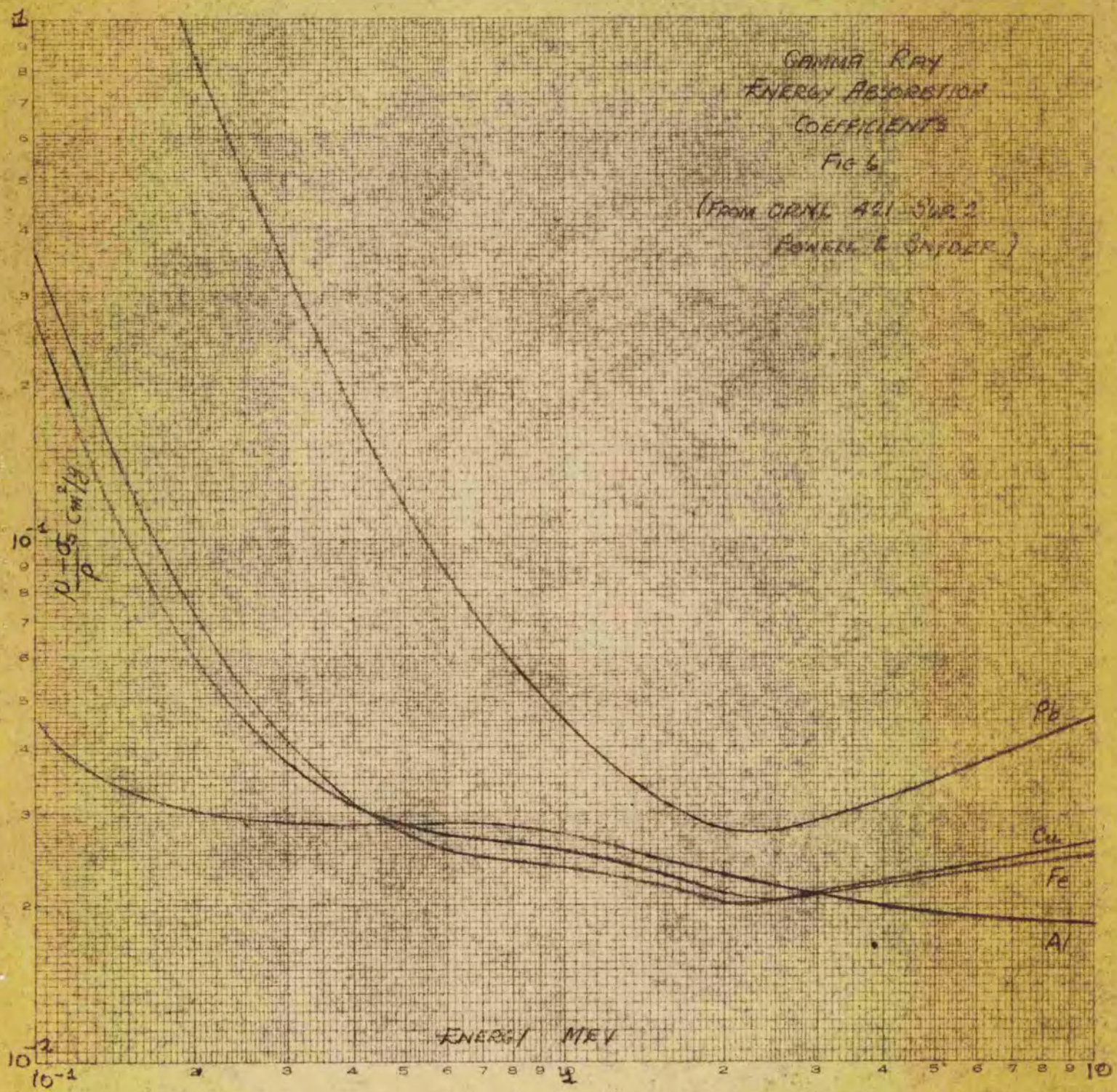
	RUN #	DATE	POSITION	POWER		WATTS/GM MEGAWATT	REMARKS
Cu	1D	2-15-56	C	1 MW	90.70	0.197	Brass - shield - no vacuum

ORNL-LR-Dwg.-12582
UNCLASSIFIED



EUGENE DIETZGEN CO.
MADE IN U.S.A.
NO. 340-L312 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
3 CYCLES X 12 DIVISIONS PER INCH

ORNL-LR-Dwg.-12583
UNCLASSIFIED



NO. 340-L22 DIETZGEN GRAPH PAPER
LOGARITHMIC-2 CYCLES X 2 CYCLES
EUGENE DIETZGEN CO.

carried by many low energy photons rather than by fewer high energy photons. For this reason it must be emphasized that these results are valid only in cases where the gamma spectrum is approximately that of the B.S.F. The B.S.F. Spectrum has been measured by Maienschein and Love[4] and the energy flux distribution found is plotted in Fig. 7. As is easily seen this distribution is displaced toward the higher energies as the distance (in water) from the reactor is increased. Very little change in spectrum is to be expected over the range in which the present series of experiments were conducted.

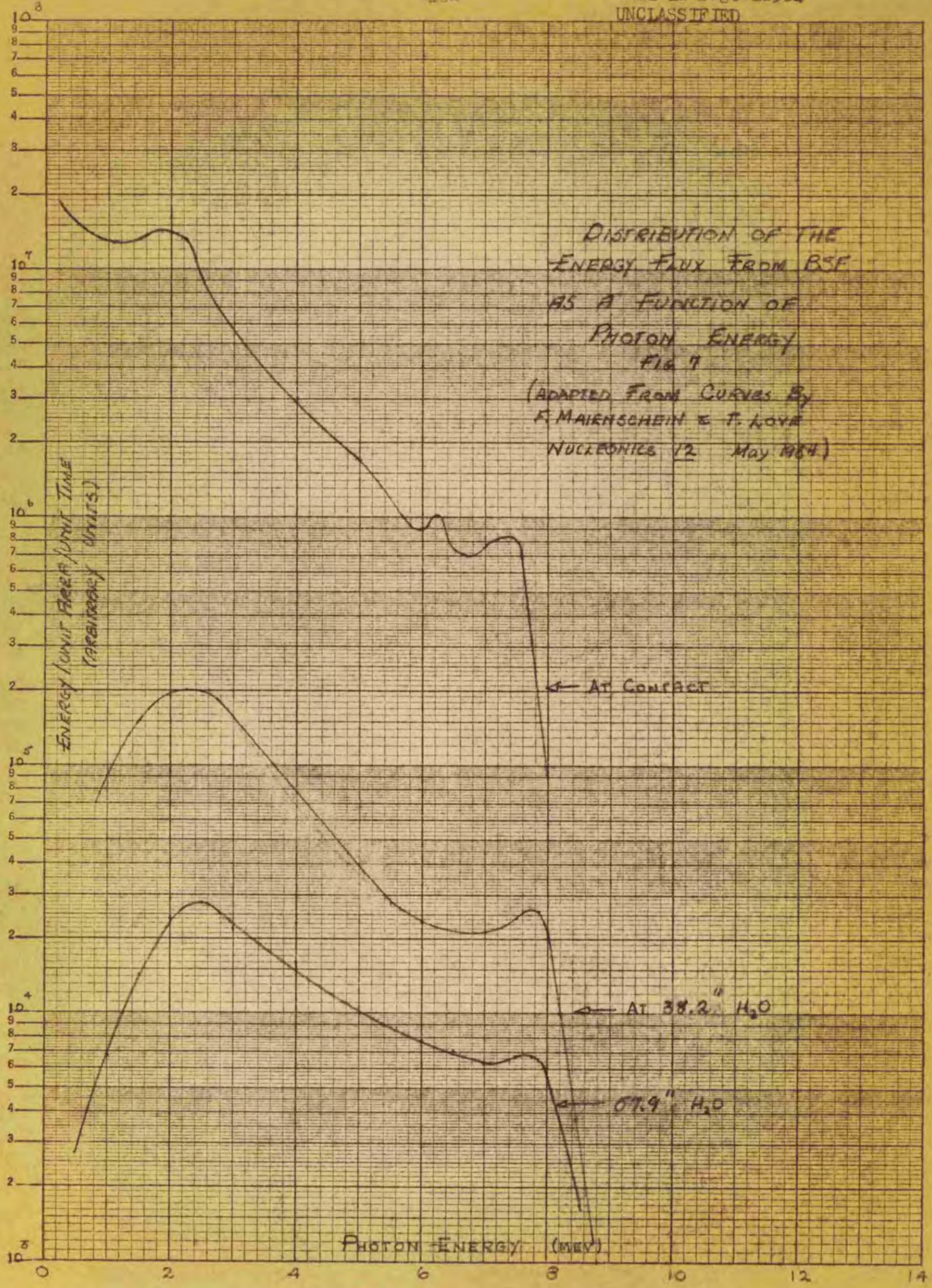
As was pointed out previously the character of the procedure is such that it is not necessary to have a knowledge of the actual heat transfer mechanism beyond the fact that for each determination it depends only on the first power of the temperature of the sample. That this is so is established by the shape of the curves obtained. Losses by radiation which vary as the difference of the fourth power of the surface temperature difference are kept small by restricting the temperature to which the sample is permitted to rise. That these losses are actually negligible is further substantiated by the fact that the introduction of the radiation shield in some of the experiments gave no observable change in the results.

The rate of heat transfer varied from run to run as evidenced by the variation in the values of λ. It is thought that most of the heat loss occurred due to conduction by the thermocouple wires and through the phonograph needles to the wall of the capsule and thence to the pool water.

Several authors[5,6] have reported results obtained by the measurement of static temperatures in various locations in the M.T.R. and in the L.I.T.R.*

Note: Several classified reports on this subject exist but have been purposely omitted.

ORNL-LR-DWG.-12584
UNCLASSIFIED



K+E SEMI-LOGARITHMIC 359-91G
KEUFFEL & ESSER CO. MADE IN U.S.A.
5 CYCLES X 70 DIVISIONS

In view of the probable differences in the energy spectrum because of the presence of beryllium and graphite surrounding the positions in which these measurements were made, it is not possible to make a direct comparison of the results.

It should also be pointed out that in the present measurements the heat generation obtained is an average over the volume of the sample and will be materially effected by the thickness of the sample. Lower results would be obtained for thicker samples.

The measurements described above were undertaken in order to obtain engineering data for the design of the O.R.R. and are of a preliminary nature. It is expected that further experiments utilizing the advantages of the transient behavior of the temperature will be made in the near future. It is believed however that the results already obtained are quite valid for use in the engineering design of reactors having gamma ray spectra similar to that of the Bulk Shielding Reactor.

VI ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of the operating staff of the Bulk Shielding Facility which made possible the prosecution of these investigations.

VII REFERENCES

1. Carslaw, H. S., Jaeger, J. C., Conduction of Heat in Solids, Oxford Press.
2. Breazeale, W. M., NUCLEONICS, 10 No. 11, 56 (1952).
3. Snyder, W. S., Powell, J. L., Supplement 2 to ORNL 421.
4. Maienschein, F. C. & Love, T. A., NUCLEONICS, 12 No. 5, 6 (1954).
5. Hogg, C. H., Gamma Heating Measurements in the MTR, IDO-16093-PPCo (declassified).
6. Witzig, W. F., Experiments in the Materials Testing Reactor Gamma Heating, WAPD-79 (declassified).