SOME NUCLEAR EXPERIMENTS ON THE SRE

by

C. Guderjahn

The experiments which were performed were (1) dry subcritical assembly, (2) subcritical multiplication measurements to determine the worth of various types of elements, (3) flux mapping of the subcritical reactor, and (4) wet critical assembly.

The experimental work was performed by the following members of the Experimental Neutron Physics Group.

R. W. Campbell
C. Guderjahn
J. Johnson
R. Laubenstein
H. Royden
G. Zwetzig

In addition, members of the Sodium Graphite Reactors Group assisted in the work. Work was done under Project 4125.

I CRITICAL ASSEMBLY

A total of 21 fuel elements were loaded in the dry room temperature SRE in order to determine the critical mass. The configuration of the core at this time is shown by Fig. 1. During the loading, the counting rate of 5 fission counters placed in channels 2, 4, 65, 71, and 80 was observed. A plot of normalized* inverse count rate vs number of fuel elements loaded was made during the assembly in order to predict criticality. The average of the data from the 3 symmetrically placed counters (4, 65, 71) is given in Table 1. The data are plotted in Fig. 3. The dry critical mass as determined from this plot is 22.2 fuel elements. The critical mass as predicted by each counter is listed in Table II.

The reactor was heated to 400°C with 19 fuel elements in the core and filled with sodium. Fuel loading was continued until criticality was reached. The configuration of the core at criticality is shown in Fig. II. During the loading, the counting rate of fission counters placed in channels 2, 4, 65, and 71 was observed. The average of the normalized inverse counting rate of the 3 symmetrically placed counters is given in Table I and plotted in Fig. 3. The normalization factor is the same as for the dry subcritical experiment. The critical mass as determined by a control rod calibration is 32.64 ± .10 fuel elements at 400°F.

* The inverse counting rate was normalized by multiplying it by the counting rate at the beginning of the experiment with no fuel present.

TABLE I

Average of the normalized inverse counting rates of fission counters placed in channels 4, 65 and 71. The data are so normalized that the inverse counting rate with no fuel present is one.

No. of Fuel Elements in Core	Last Channel Loaded	Normalized Inverse Counting Rate
0		1
1	44	
2	33	
3	43	
4	55	
5	56	0.447
6	34	0.372
7	45	
8	57	0.293
9	54	
10	22	0.214
11	35	
12	32	0.163
13	21	
14	23	0.116
15	42	
16	67	0.0815
17	46	0.0663
18	68	0.0488
19	69	0.0362
20	31	0.0246
21	36	0.0131
	Reactor heated & sodium added	
21		.0588
22	53	
23	66	
24	58	
25	70	.0302
26	10	
27	11	
28	20	
29	24	.0139
30	74	
31	75	.00525
32	41	
33	47	Reactor Critical

TABLE II

Extrapolated Critical Mass of Dry SRE as Given by Each Counter

Counter in Channel	Extrapolated Critical Mass
2	22.40
4	22.20
65	22.35
71	22.00
80	22.10
Average of all counters	22.2
Average of symmetrically placed counters (4, 65, 71)	22.2

II SUBCRITICAL MULTIPLICATION MEASUREMENTS

The reactivity of the subcritical SRE was estimated from subcritical multiplication measurements in the following manner. The multiplication, M, was taken as:

$$M = \frac{C}{A}$$

where A = counting rate with all rods out and no fuel present.

C = counting rate at condition for which multiplication is desired.

The reactivity, ρ, was then calculated with the use of the following relation

$$\rho = \frac{1}{1 - M}$$

It must be emphasized that the multiplication and thus the reactivity may be in considerable error by a constant percentage. However, no better values could be obtained without going critical and making period measurements. The results are useful since it makes possible the comparison of the worth of fuel elements and poison elements. Table III gives the results of the multiplication measurements as calculated from the data of the three symmetrically placed counters, (channels 4, 65, 71).

TABLE III

WORTH OF VARIOUS ELEMENTS IN SRE

AS CALCULATED FROM MULTIPLICATION MEASUREMENTS

	*
20th fuel element (channel 31)	+ 1.2%
21st fuel element (channel 36)	+ 1.2%
Fuel element in channel 35 (20 fuel elements in place)	+ 1.7%
Dummy element #50 (19 fuel elements in place)	+ 0.4%
Control rod #1 (19 fuel elements in place)	- 4.0%
Safety rod thimble without rod	- 0.6%
Th-5% U^{235} fuel element in place of a uranium element in channel 44	- 0.3%
Th-5% U^{235} fuel element in place of a uranium element in channel 35	- 0.24%
Th-5% U^{235} fuel element in place of a uranium element in channel 36	- 0.20%

From the measurements of the worth of the Th-U^{235} element, it is possible to estimate the amount of enrichment needed to make a Th-U element equal in value to a uranium element.

We may obtain the total reactivity change due to replacing each uranium element with a Th-5% U element by summing up the change due to each replacement.

* Change in reactivity caused by the insertion of the element.

# of Elements in Ring	Decrease in Reactivity Due to Replacing Each Element in Dry SRE	Total Decrease Due to Replacing Each Element in Ring
1	0.3	0.3
6	0.27 (interpolated)	1.62
12	0.24	2.88
3	0.2	0.6
	Total Change	5.4%
	Average change/element	0.25%

Increasing the U-235 content in each element will cause the following reactivity change.

$$\Delta\rho = \Delta\eta\,\epsilon\,p\,f\,\frac{e^{-B^2\tau}}{1+L^2B^2} \cong \frac{\Delta\eta}{\eta}\,k_{eff}$$

It is assumed that $\epsilon\,pf\,\dfrac{e^{-B^2\tau}}{1+L^2B^2}$ does not change much if the enrichment is increased. The change $\Delta\rho$ should be 5.4% to make the Th-U elements equal in value to the uranium elements. The following formula gives η for 93% enriched uranium in thorium.

$$\eta = 0.93\,\nu\,\sigma_f\,\frac{A}{(0.93\,\sigma_f + 0.93\,\sigma_c + .07\,\sigma_u) + (1-A)\,\sigma_{Th}}$$

where ν = no. of neutrons/fission = 2.5

σ_f = thermal fission cross section of U-235.

σ_c = radiative capture cross section of U-235 for thermal neutrons.

σ_u = capture cross section of U-238 for thermal neutrons.

σ_{Th} = capture cross section of thorium for thermal neutrons.

A = Atomic percent of uranium

η is plotted as a function of A in Fig. 4.

The Th-U fuel element tested in the reactor contained 5.4% uranium. This corresponds to an η of 1.76. The required $\eta + \Delta\eta$ is then

$$\eta + \Delta\eta = 1.755 + 0.054 \times 1.76 = 1.85$$

This corresponds to a fuel concentration of 7.6% uranium or 7.1% U-235.

The results of the foregoing calculation must be used with caution since a small error in the measured reactivity change would lead to a large error in required fuel concentration. This experiment will be repeated with the reactor wet critical and much more reliable numbers will be obtained at that time.

The temperature coefficient of reactivity of the dry subcritical SRE was also estimated from subcritical multiplication measurements. Gold foils were placed in channels 2, 4, 65 and 71 before and after heating the reactor electrically preparatory to the introduction of sodium. The foils were exposed for about 1 hour with all control and safety rods withdrawn and 21 fuel elements in place. The foils were counted on a 2 pi proportional flow counter. Correction was made for source decay. The temperature coefficient was positive and equal to 0.0025%/F° over the temperature range 70°F - 305°F.

III FLUX MAPPING OF THE DRY SUBCRITICAL REACTOR

Cadmium covered and bare gold foils were exposed in various channels in the core and reflector of the dry subcritical SRE. The reactor was loaded with 21 fuel elements and had a negative reactivity of about 1.3% as estimated from subcritical multiplication measurements. The foils were placed in graphite foil holders which were in turn placed in stainless steel thimbles which extended into the core. The thimbles were movable and could be placed in either fuel channels or corner channels. Some foils were attached with adhesive tape to the surface of fuel elements also. The results of the flux measurements are given in the following graphs.

Fig. 5 - Axial thermal flux in channels 2, 6, 4, 61, 12, 50 and on the fuel element in channel 44. The flux is peaked up in channels 50 and 44 by the source which is in channel 39 at the midplane.

Fig. 6 - Axial epithermal flux in channels 2, 6, 4, 61, 12, 50 and on the fuel element in channel 44.

Fig. 7 - Radial thermal flux 2 feet from reactor center plane. This plot is the average of measurements made 2 feet above and below the midplane. This position was selected in order to minimize the effect of flux peaking near the source in channels 50 and 44. The data are insufficient to make a good buckling measurement.

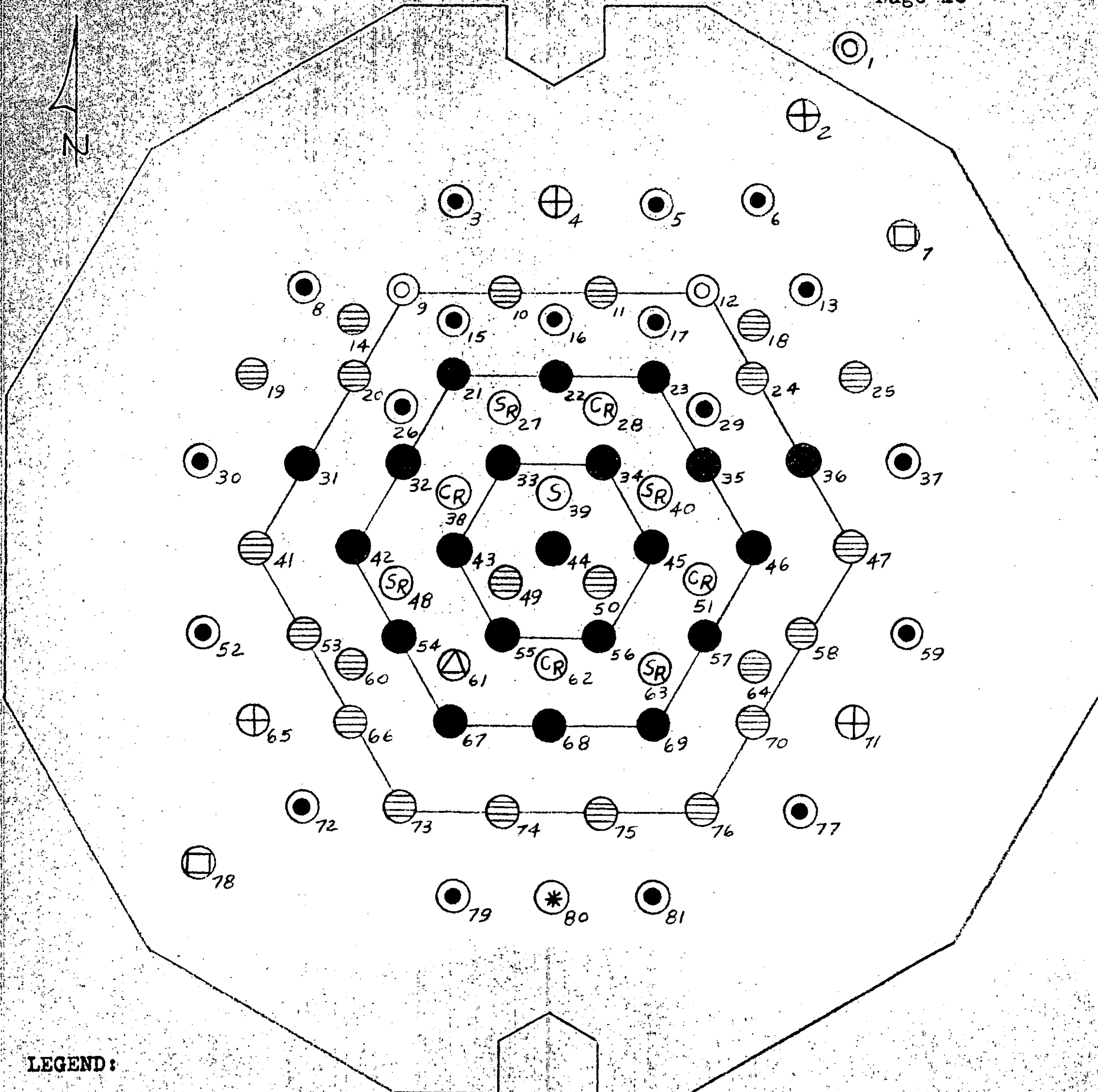
Fig. 8 - Average axial thermal flux in channels 61, 12, and 4, compared with theoretical prediction. The average was made by normalizing the flux to 1 at the midplane and then averaging. The flux in channel 50 was not included in this average since the flux in the channel was peaked up by the source. The theoretical flux was calculated from two group theory by F. L. Fillmore.*

* Personal communication

It is seen that the experimental data agrees fairly well with the flux calculated from a buckling of 180.01 X 10^{-6} cm^{-2}.

The axial buckling for the dry SRE as predicted by F. L. Fillmore is 164.76 microbucks.* The flux as calculated from this buckling is also plotted in Fig. 8. The difference (15 microbucks) between measurement and theory corresponds to about -0.8% reactivity. This is quite good agreement since at the time of measurement, the reactor was about 1.3% subcritical.

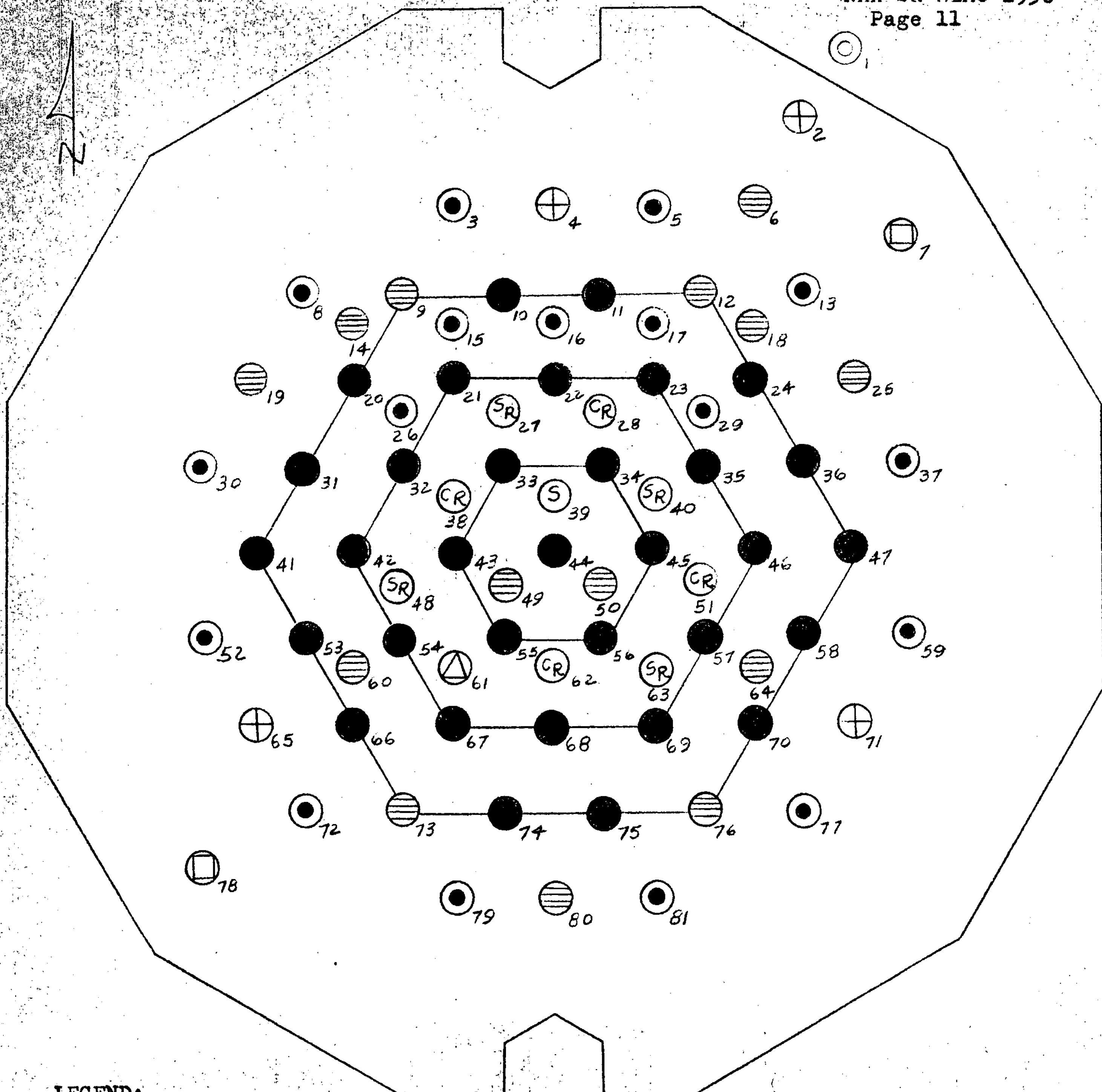
*Personal communication



LEGEND:

- Fuel
- Dummy element
- Plugs shielded (over empty through tubes)
- Plugs shielded (not over through tubes)
- Instrument thimble (containing fission counter)
- Fission Chamber (without thimble)
- Temperature Measuring Element
- Sodium Level Indicator
- S Source
- SR Safety rod
- CR Control rod

FIG. 1 SRE CORE CONFIGURATION AT END OF DRY SUBCRITICAL TEST



LEGEND:

- Fuel
- Dummy element
- Plugs shielded (over empty through tubes)
- Plugs shielded (not over through tubes)
- Instrument thimble (containing fission counter)
- Temperature Measuring Element
- Sodium Level Indicator
- S Source
- SR Safety rod
- CR Control rod

FIG. 2 SRE CORE CONFIGURATION AT END OF WET CRITICAL TEST

FIG. # APPROACH TO CRITICALITY OF DRY & WET SRE

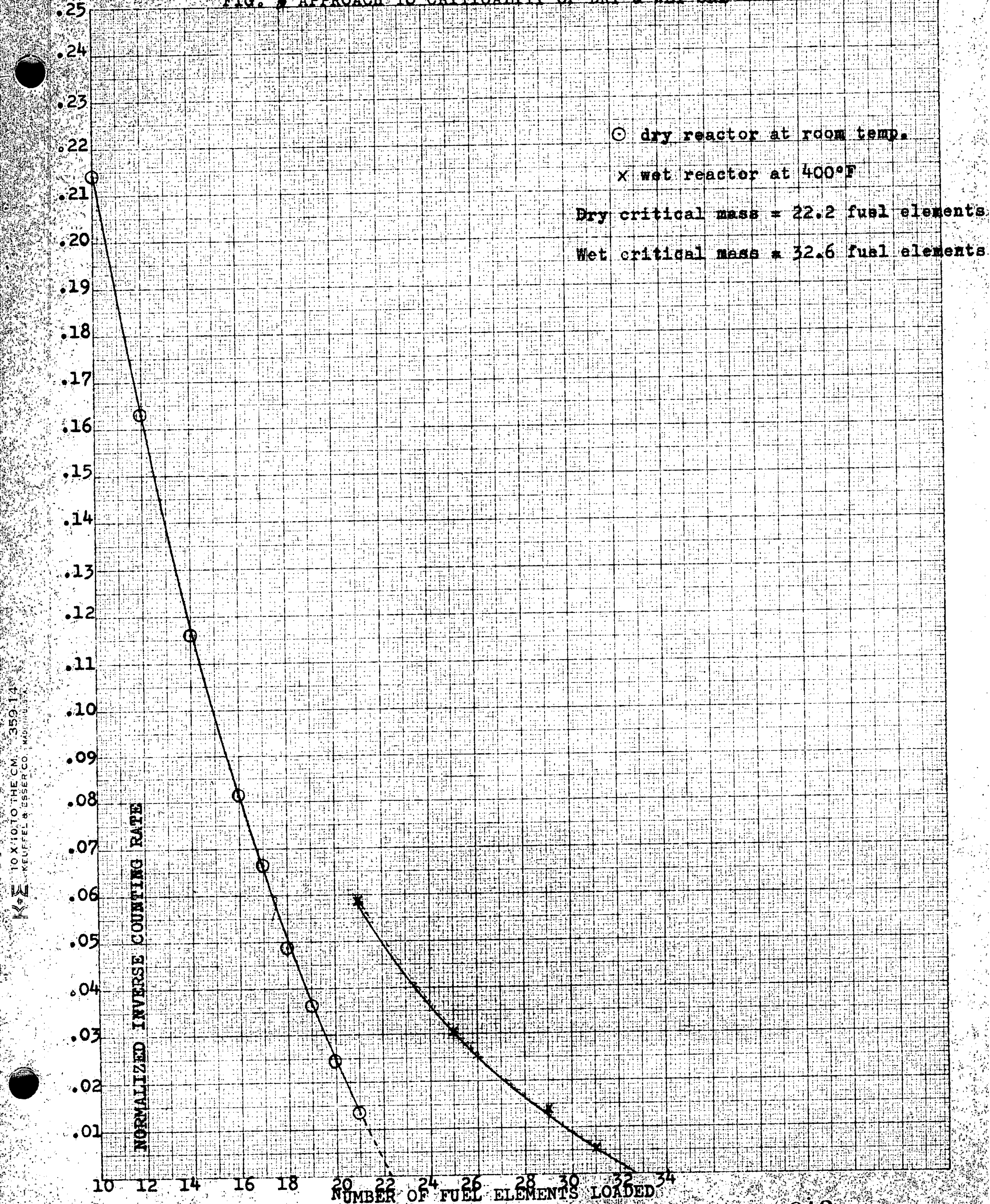


FIG. 4

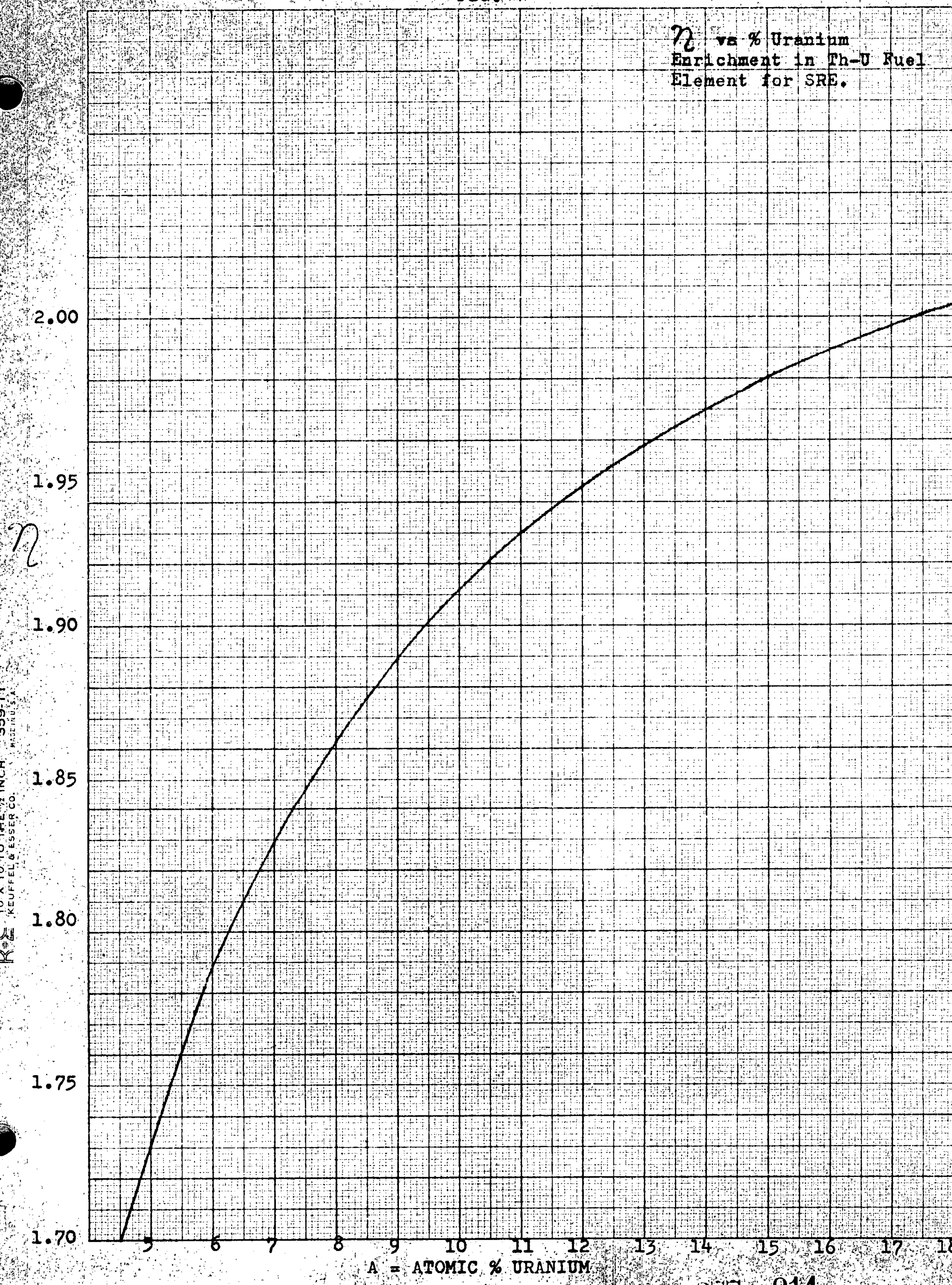

η vs % Uranium
Enrichment in Th-U Fuel
Element for SRE.
η
2.00
1.95
1.90
1.85
1.80
1.75
1.70
5
6
7
8
9
10
11
12
13
14
15
16
17
18
A = ATOMIC % URANIUM
K+E 10 X 10 TO THE 1/2 INCH 359-11
KEUFFEL & ESSER CO.

FIG. 5, AXIAL THERMAL FLUX OF DRY SRE
IN CHANNELS 2, 6, 4, 61, 12, 50 AND ON FUEL ELEMENT IN CHANNEL 44

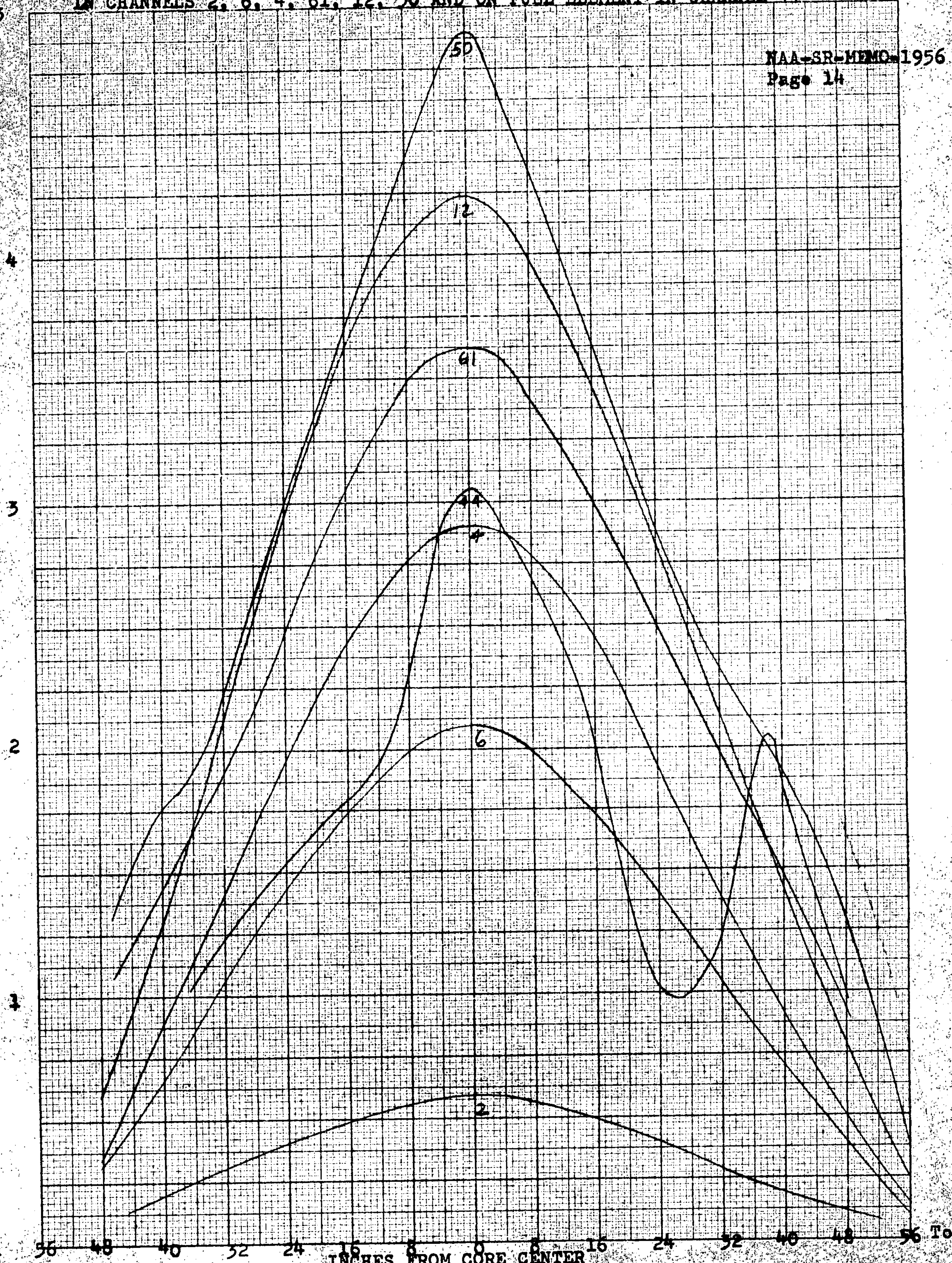


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FIG. 6, AXIAL EPITHERMAL FLUX OF DRY SRE IN CHANNELS 2, 6, 4, 61, 12, 50 AND ON FUEL ELEMENT IN CHANNEL 44

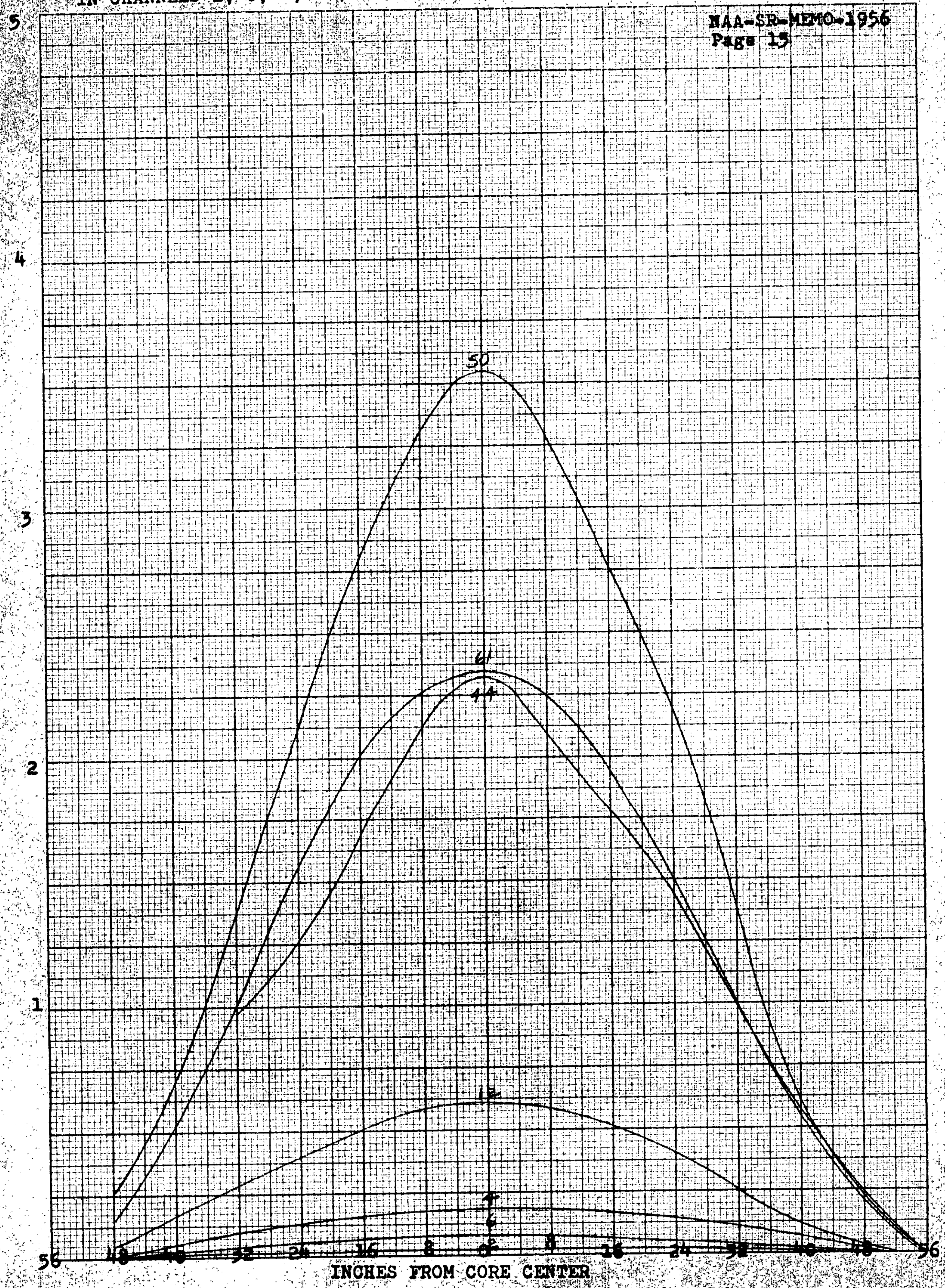
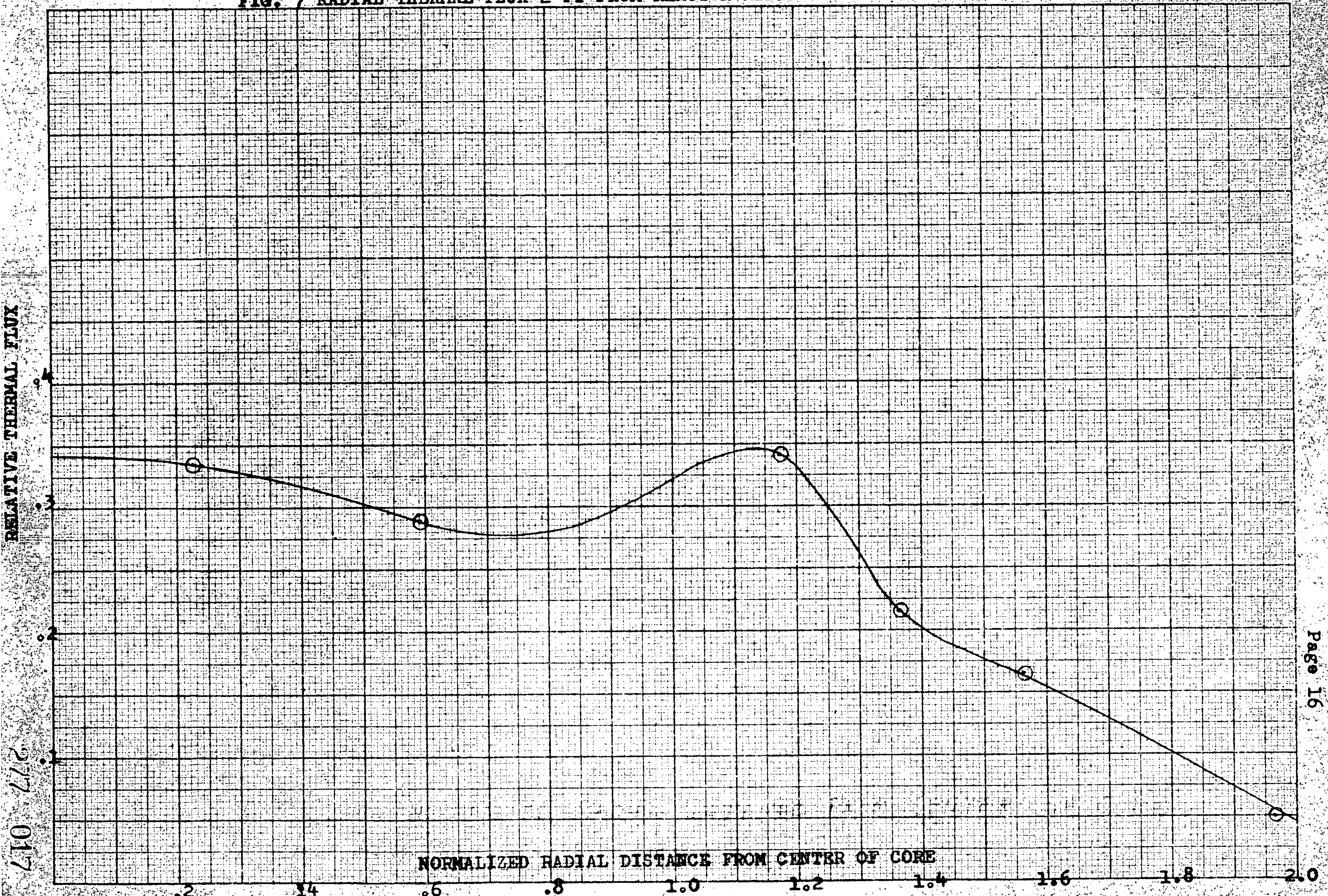


FIG. 7 RADIAL THERMAL FLUX 2 FT FROM REACTOR MIDPLANE



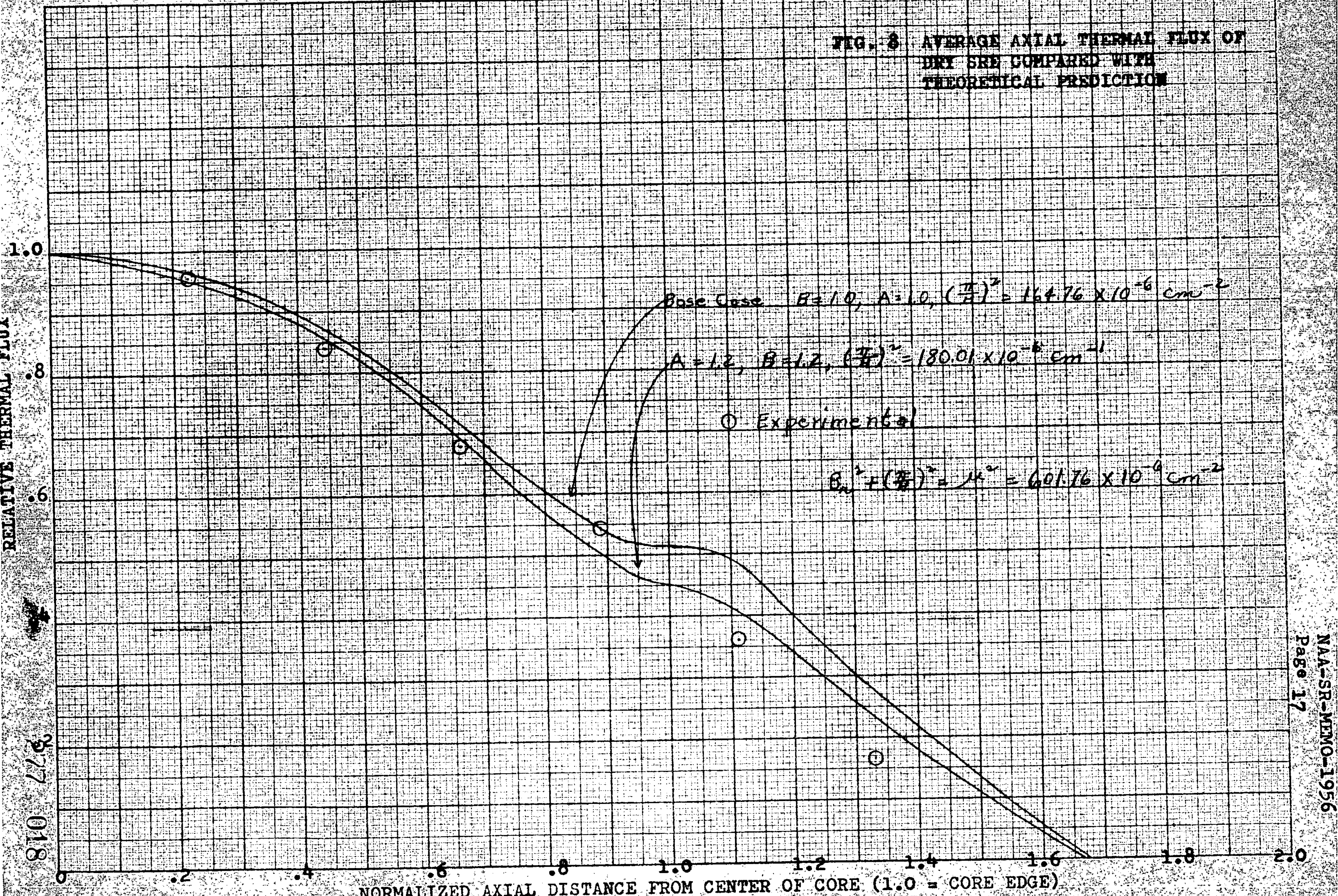


FIG. 8 AVERAGE AXIAL THERMAL FLUX OF DRY SRE COMPARED WITH THEORETICAL PREDICTION
RELATIVE THERMAL FLUX
1.0
.8
.6
.4
.2
Base Case B=1.0, A=1.0, $(\frac{\pi}{H})^2 = 164.76 \times 10^{-6}\ cm^{-2}$
A=1.2, B=1.2, $(\frac{\pi}{H})^2 = 180.01 \times 10^{-6}\ cm^{-1}$
⊙ Experimental
$B_r^2 + (\frac{\pi}{H})^2 = \mu^2 = 601.76 \times 10^{-6}\ cm^{-2}$
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
NORMALIZED AXIAL DISTANCE FROM CENTER OF CORE (1.0 = CORE EDGE)

810 277

Distribution: SRE Experiment List

E. Ash
R. Balent
W. Brown
R. Burch
R. Campbell
R. Carter
E. Cohen
R. Dickinson
F. Faris
F. Fillmore
K. Foster
L. Glasgow
C. Guderjahn
J. Howe
D. Johnson
J. Johnson
B. Kramer
R. Laubenstein
R. McLain
J. Owens
W. Rodeback
H. Royden
S. Siegel
M. Walske
R. Williams
G. Zwetzig