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730-V-33 (REV 6/59)

234 001

WRITTEN BY W. W. Davis W. D. Leggett	**ATOMICS INTERNATIONAL** *A Division of North American Aviation, Inc.* **TECHNICAL DATA RECORD**	TDR NO. 2073
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OTHER	PROJECT OMR	DATE August 20, 1957
		PAGE 1 OF 27

TO:

C. M. Wheelock

COPIES TO:

OMR Distribution
W. O. Allen
W. D. Leggett

SUBJECT:

OMR Nuclear Parameter Survey

CONTENTS:

I STATEMENT OF PROBLEM

ABSTRACT

A parameter survey was conducted on the Organic Moderated Reactor (OMR) to determine the nuclear effect of temperature, enrichment, fuel to moderator volume ratio, fuel element size, and fuel element container variation. Temperatures ranged from 300 to 700°F; enrichments from 1.5 to 1.9%; and fuel to moderator volume ratios from .1333 to .545. Fuel element sizes of 3.75, 4.5, and 5.5" were considered. The stainless steel fuel element container thickness was varied from 20 to 80 mils, and also 200 mil aluminum was substituted for the steel. Results were obtained as values of k_{eff} which ranged from .927 to 1.152 through 150 problems. It was concluded that fuel element size should be at least 4.5 inches, fuel to moderator volume ratio in the neighborhood of 0.30, and enrichment 1.7% assuming 8% excess k for poisoning, burn-up, and control.

DISCUSSION

In the design of any reactor a compromise must be made between nuclear considerations and engineering principles. This survey was conducted to provide a guide as to how structural changes and operating temperatures will affect the OMR from a nuclear viewpoint.

234 002

To give a rough picture of the reactor under consideration some approximate characteristics are listed below[1]:

Fuel Element: Ten 1.8% enriched uranium, aluminum clad plates to an element — held in place by aluminum side plates — each element contained in a stainless steel box roughly 5" x 5" x 6'.

Core: 69 elements (6 of which are control) on 6" centers forming a right circular cylinder about 60" across and 6' tall.

Reflector-Shield: 4" of Terphenyl on sides and bottom — 25" of Terphenyl on top — 8" of iron around the sides.

Power: 45,000 kw thermal — 11,400 kw electrical.

Flux: average thermal flux about 10^{15} neutrons/cm^2-sec.

Nomenclature:

- E enrichment, $N_{25}/\left[N_{25} + N_{28}\right]$
- S square side of fuel element container
- t_{cn} thickness of fuel element container
- T moderator temperature, °F
- V_f/V_m ratio of volume of fuel to volume of moderator.

The calculations were based on a three-region, six inch square, unit cell (Figure 1) consisting of:

1. fuel element, region 0
2. fuel element container, region cn
3. surrounding moderator, region 1

Basic parameters (k_∞, B_m^2, $\emptyset$, etc.) of this cell were calculated using the OMR cell code[2] on the IBM-704. These results were used to calculate[3] the constants necessary for a three-group, three-region solution from the Wanda II code[4]. Constants for Terphenyl and fast and epithermal transport and scattering cross sections were gathered from references (5) and (6). Calculations not run on the IBM-704 were done to slide rule accuracy.

For three different fuel element sizes k_{eff} was obtained as a function of enrichment, temperature, and fuel to moderator volume ratio. For each size (S = 3.75, 4.5, 5.5") k_{eff} was determined for T = 3, 4, 5, 6, and 700°F with V_f/V_m ratios of 0.1333, 0.215, 0.307, 0.417, 0.545 at a constant enrichment of 1.8%. With T constant at 600°F, k_{eff} was determined for E = 1.5, 1.6, 1.7, 1.8, and 1.9% for each value of V_f/V_m. For these runs the stainless steel fuel element container thickness was 40 mils.

An additional study of the effect of fuel element container thickness and material was made for the 4.5" element. Using stainless steel thicknesses of approximately 20, 40, and 80 mils (corresponding to steel volume fractions of 1, 2, and 4% respectively) k_{eff} was determined for each value of V_f/V_m at a constant temperature of 600°F. With V_f/V_m constant at .307 the range of temperatures was covered for the same steel thicknesses. This procedure was repeated for an aluminum container 200 mils thick. For all of these runs the enrichment was constant at 1.8%.

The following exceptions are to be noted throughout the survey:

1. The small size of the 3.75" fuel element would not allow V_f/V_m values of .417 and .545.

2. An error made early in the survey caused the 500° results to appear unreasonable. Since the trend of the data was sufficiently established without these points, they were not re-run and are excluded from the results.

RESULTS

The results are presented in a series of graphs showing k_{eff} as a function of the various parameters (Appendix I). A pictorial summary of the graphs appears on page 8 . The results are tabulated on page 25.

For the most part increasing temperature produced a negative effect on reactivity. For the 3.75" fuel element, however, both positive and negative effects occurred. This was due to the larger organic gap between fuel elements which caused a greater flux peaking. Thus when the temperature was initially increased and all 1/V cross-sections decreased proportionally, there was a greater incremental decrease in the flux peaking than when the peaking was not as large to begin with. This increased the positive effect of the thermal utilization. The increase was enough in some cases to override other negative effects, thus producing increasing reactivity. As the temperature was further increased, however, the incremental decrease in peaking became smaller due to previous flattening, and the negative effects began to override the positive.

If the temperature effects for the three fuel element sizes are observed together, the effect of the organic gap is further illustrated. Thus, with the 3.75 inch element size (largest gap), the positive effect due to the greater flux peaking (as discussed above) is shown. With the 4.5 inch size (medium gap) the smaller positive effect was overridden by the negative effect. Finally with the 5.5 inch size (smallest gap) the predominant negative effect had become approximately linear.

In every case the effect of increasing enrichment was an increasing k_{eff}. The trend was close to being linear.

With increasing V_f/V_m, k_{eff} increased initially, then reached a peak and started downward. This is the usual case of f increasing and p decreasing. Initially the addition of fuel caused f to increase more than p decreased; as more fuel replaced moderator, however, p decreased more than f increased causing the curve to drop.

Increasing the steel fuel element container thickness caused an expected loss of reactivity. Using 200 mil aluminum in place of the steel produced about the same effect as 20-40 mil steel.

RECOMMENDATIONS

1. Fuel element size should be at least 4.5 inches due to likelihood of positive temperature coefficient below this size. The 4.5 inch size also gives maximum reactivity.

2. Fuel to moderator volume ratio should be kept in the neighborhood of 0.30.

3. Under the above conditions and assuming about 8% excess k for poisoning, burnup, and control, the enrichment required would be about 1.7%.

REFERENCES

1. An Organic-Moderated Nuclear Steam Plant, Atomics International, AI-1717, August 30, 1956.

2. Davis, W. W., OMR Cell Code for IBM-704, NAA-SR-MEMO-2067, August 20, 1957.

3. Deutch, R. W., Computing 3-Group Constants for Neutron Diffusion, Nucleonics, Vol. 15, No. 1, January, 1957.

4. Marlowe, O. J., Saalbach, C. P., Culpepper, L. M., McCarty, D. S., Wanda - A One-Dimensional Few Group Diffusion Equation Code for IBM-704, WAPD-TM-28, November, 1956.

5. Conerty, M. C., Storm, M. L., Petrie, C. D., Zweifel, P. F., Calculations of Fast and Thermal Group Constants with Application to Diphenyl, KAPL-1643, October 29, 1956.

6. Cobb, J. E., Review of OMR Criticality, NAA-SR-MEMO-1775, November 14, 1956.

APPENDIX I

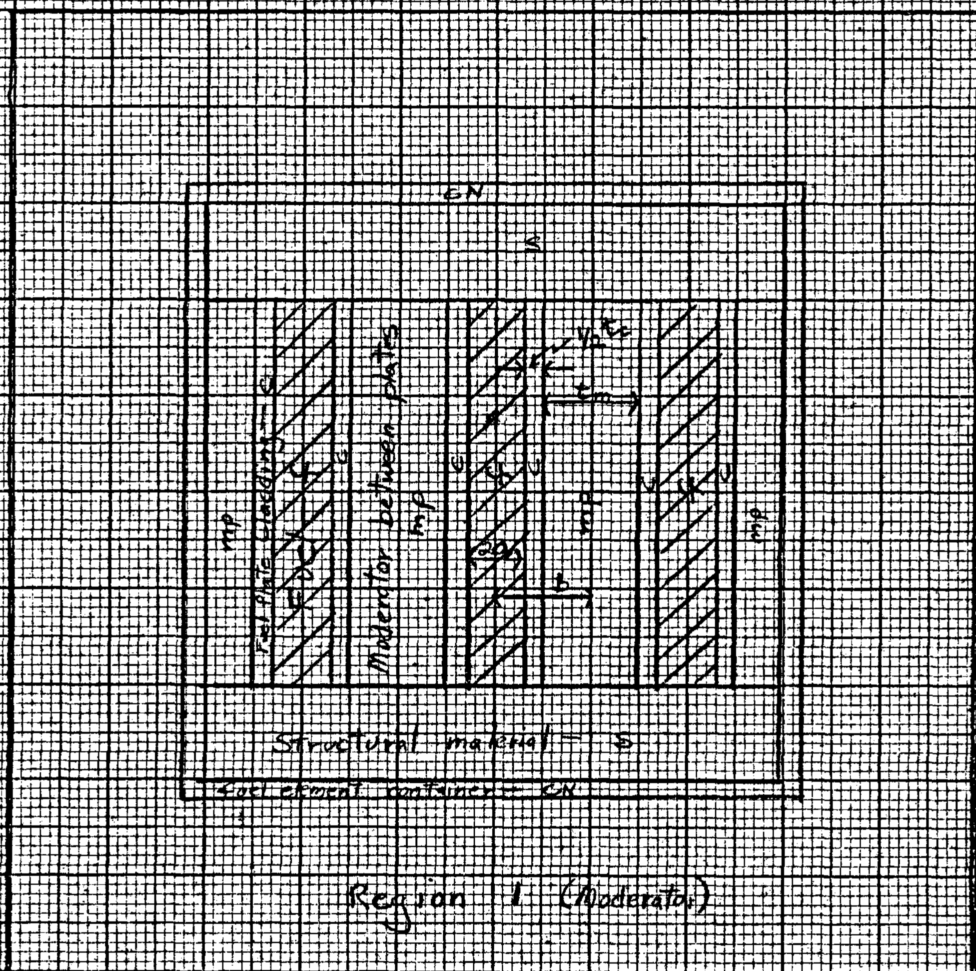

Figure 1. Schematic of OMR unit cell.
(Only 3 plates shown for cleaner presentation)

SUMMARY OF GRAPHS

FIGURE 2

S = 5.5"

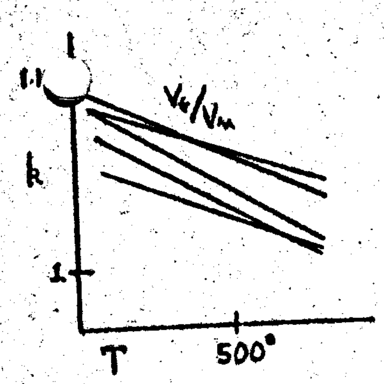

Fig. 3

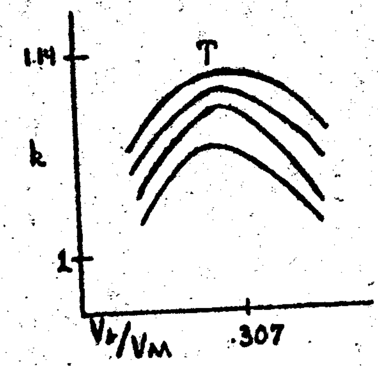

Fig. 4

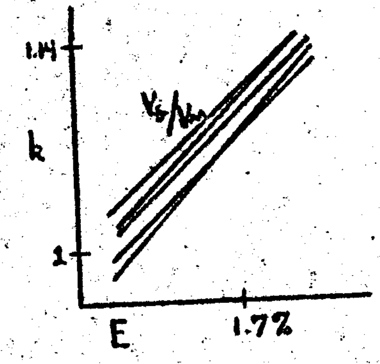

Fig. 5

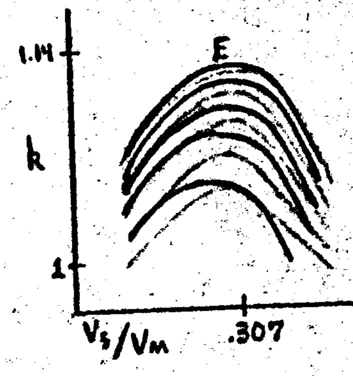

Fig. 6

S = 4.5"

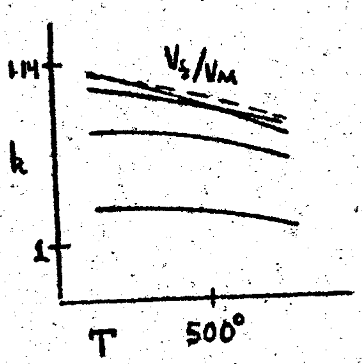

Fig. 7

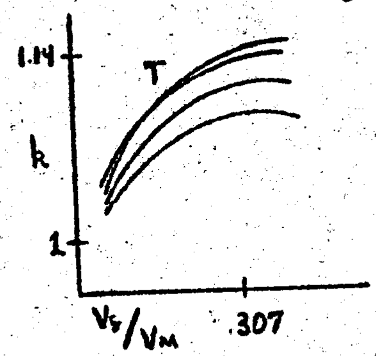

Fig. 8

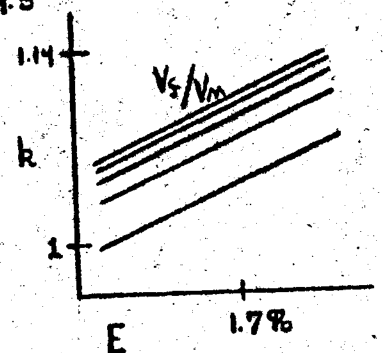

Fig. 9

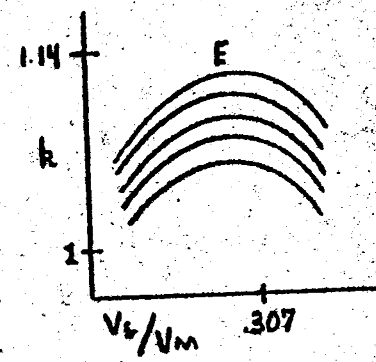

Fig. 10

S = 4.5"

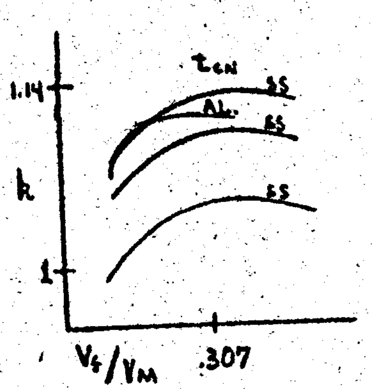

Fig. 11

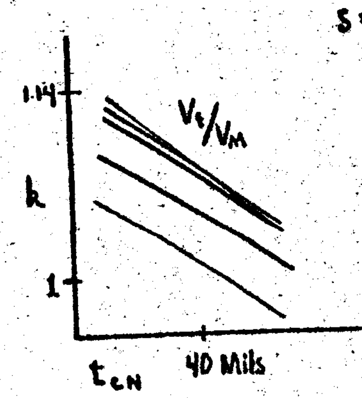

Fig. 12

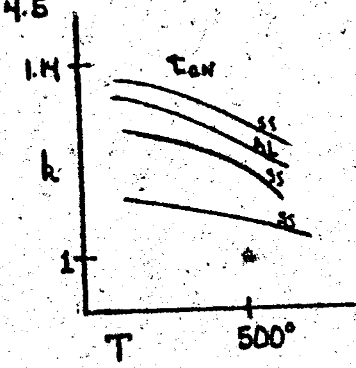

Fig. 13

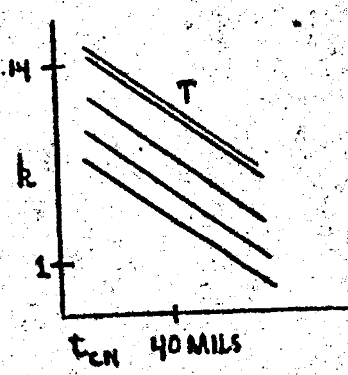

Fig. 14

S = 3.75"

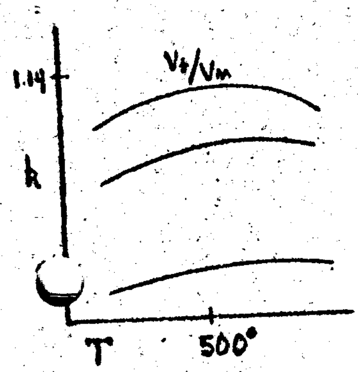

Fig. 15

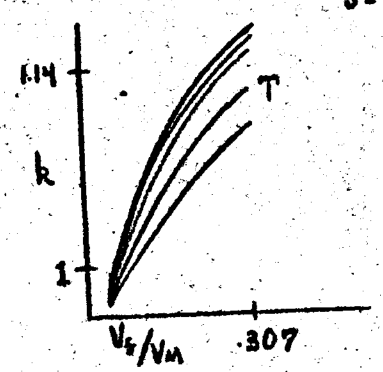

Fig. 16

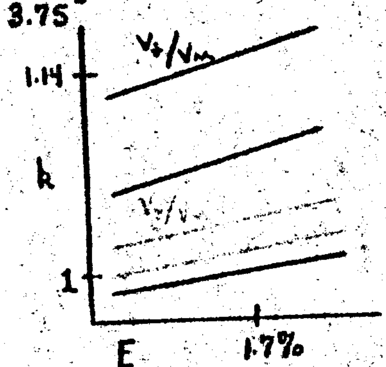

Fig. 17

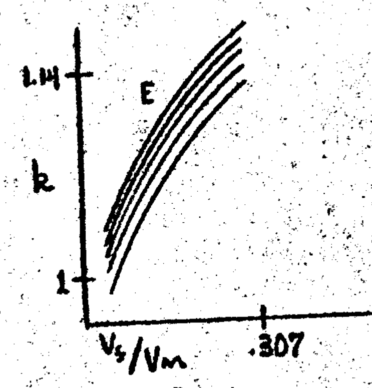

Fig. 18

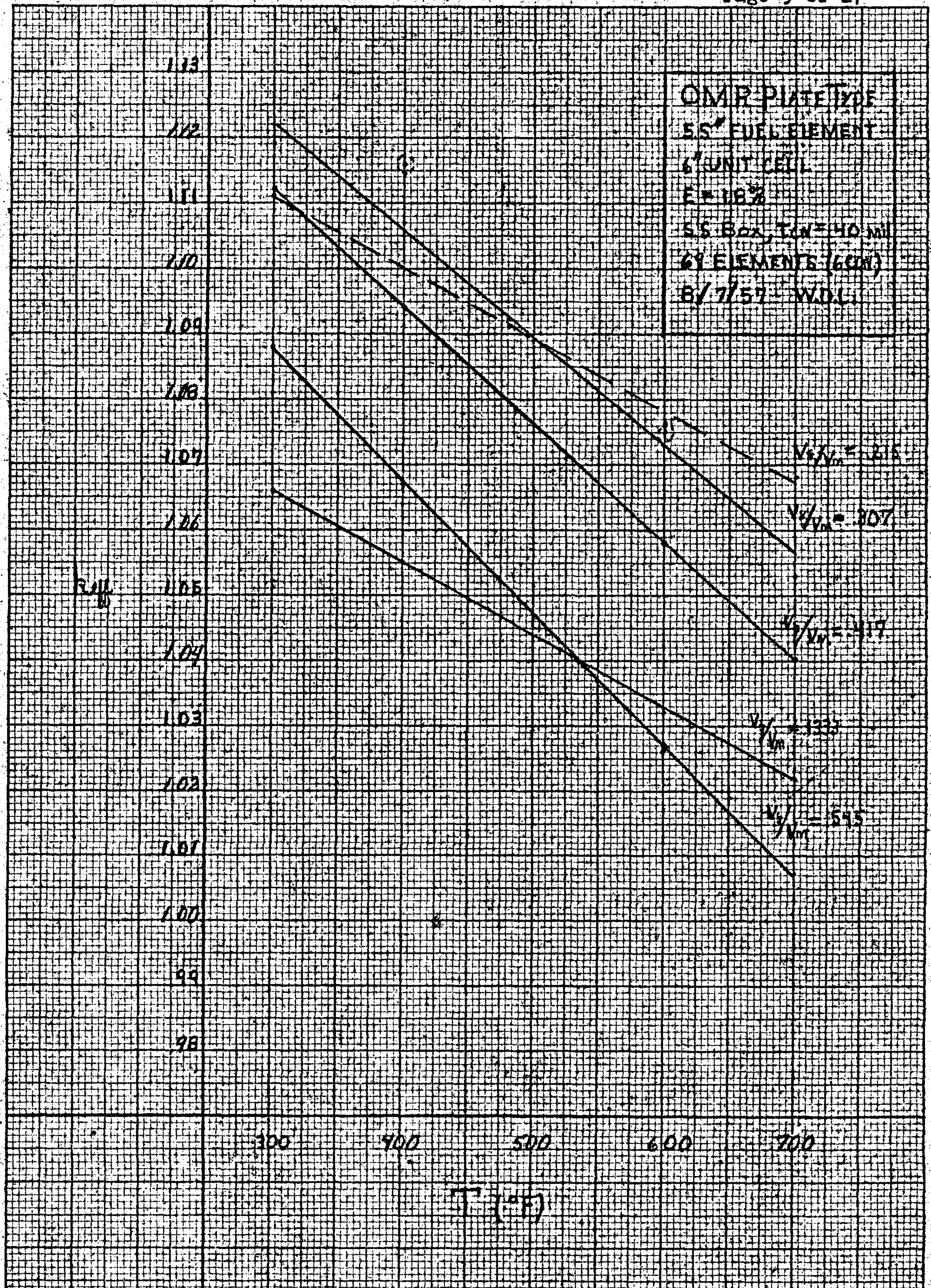
OMR PLATE TYPE
5.5" FUEL ELEMENT
6" UNIT CELL
E = 18%
S.S. Box, T_W = 40 mil
69 ELEMENTS (6CON)
8/7/57 - W.D.L.
Vf/Vm = .215
Vf/Vm = .307
Vf/Vm = .417
Vf/Vm = .1333
Vf/Vm = .545
k_eff
1.13
1.12
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1.00
.99
.98
300
400
500
600
700
T (°F)

FIGURE 8

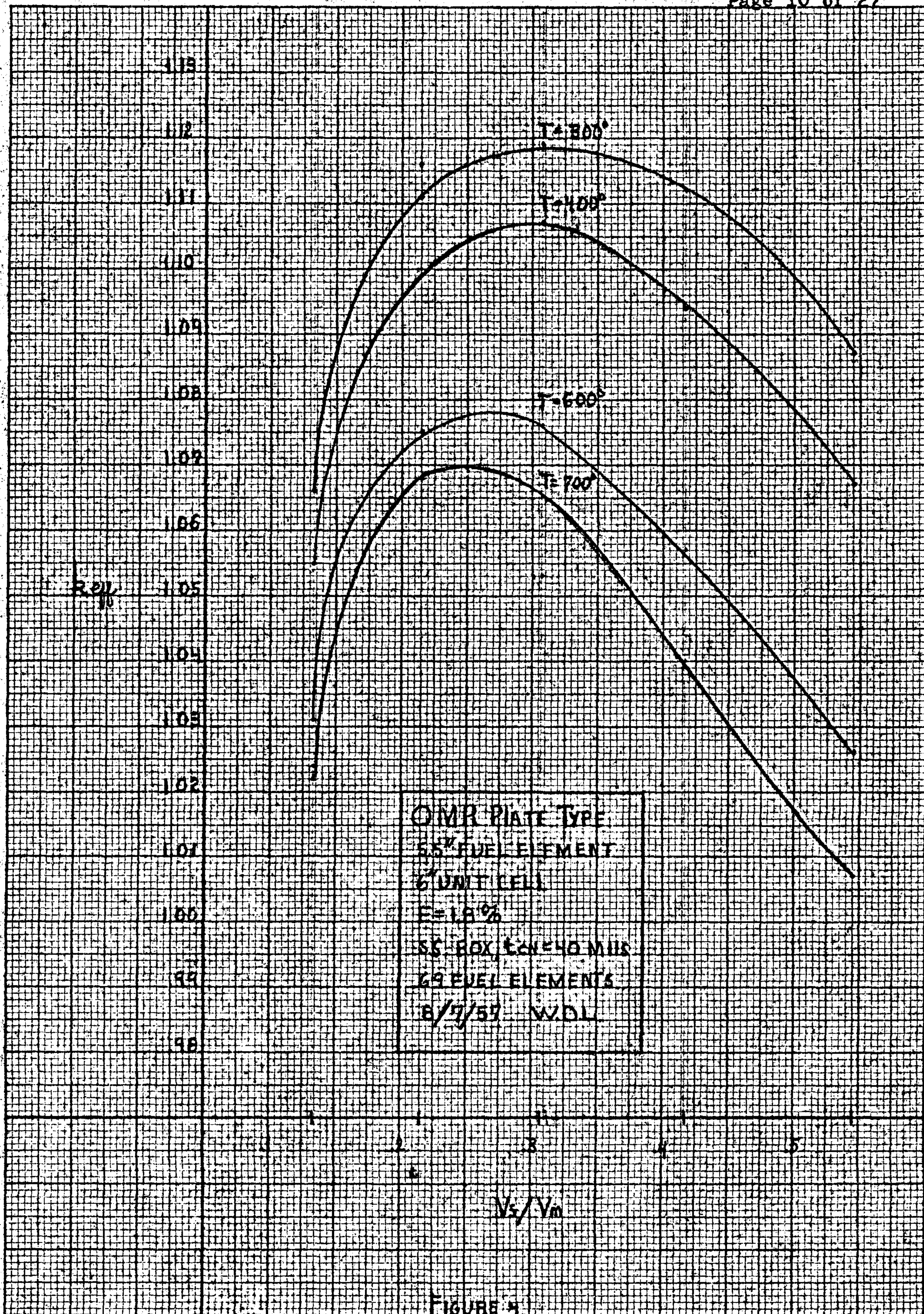
T=300°
T=400°
T=600°
T=700°
Keff
1.13
1.12
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1.00
.99
.98
.1
.2
.3
.4
.5
OMR PLATE TYPE
5.5" FUEL ELEMENT
6" UNIT CELL
E=1.8%
SS BOX, tcn=40 MILS
69 FUEL ELEMENTS
8/7/57 WDL
Vf/Vm

FIGURE 4

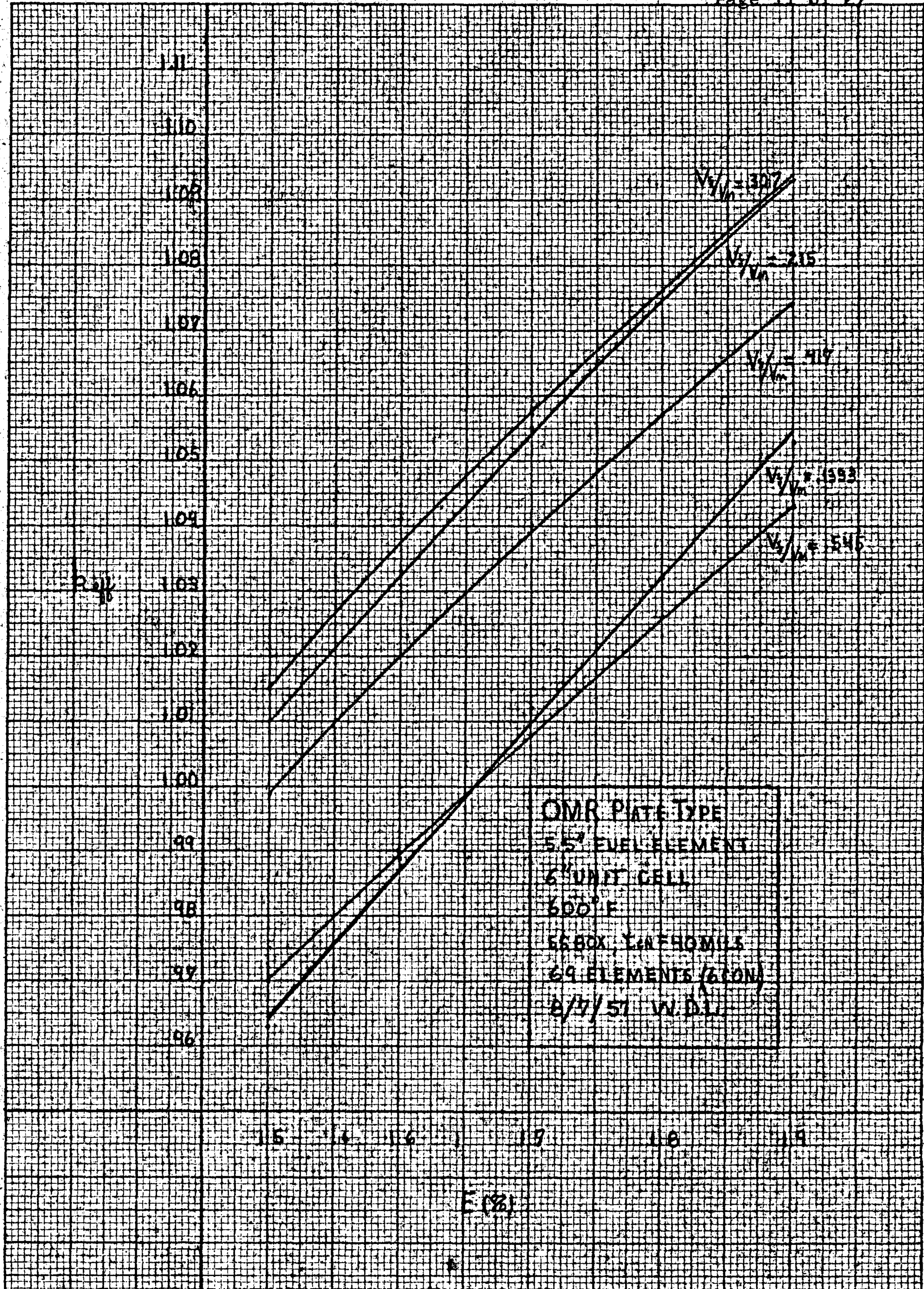
OMR Plate Type
5.5" Fuel Element
6" Unit Cell
600° F
66 BOX, tclad = 40 MILS
69 ELEMENTS (6 CON)
8/7/51 W.D.L.
E (%)

Figure 5

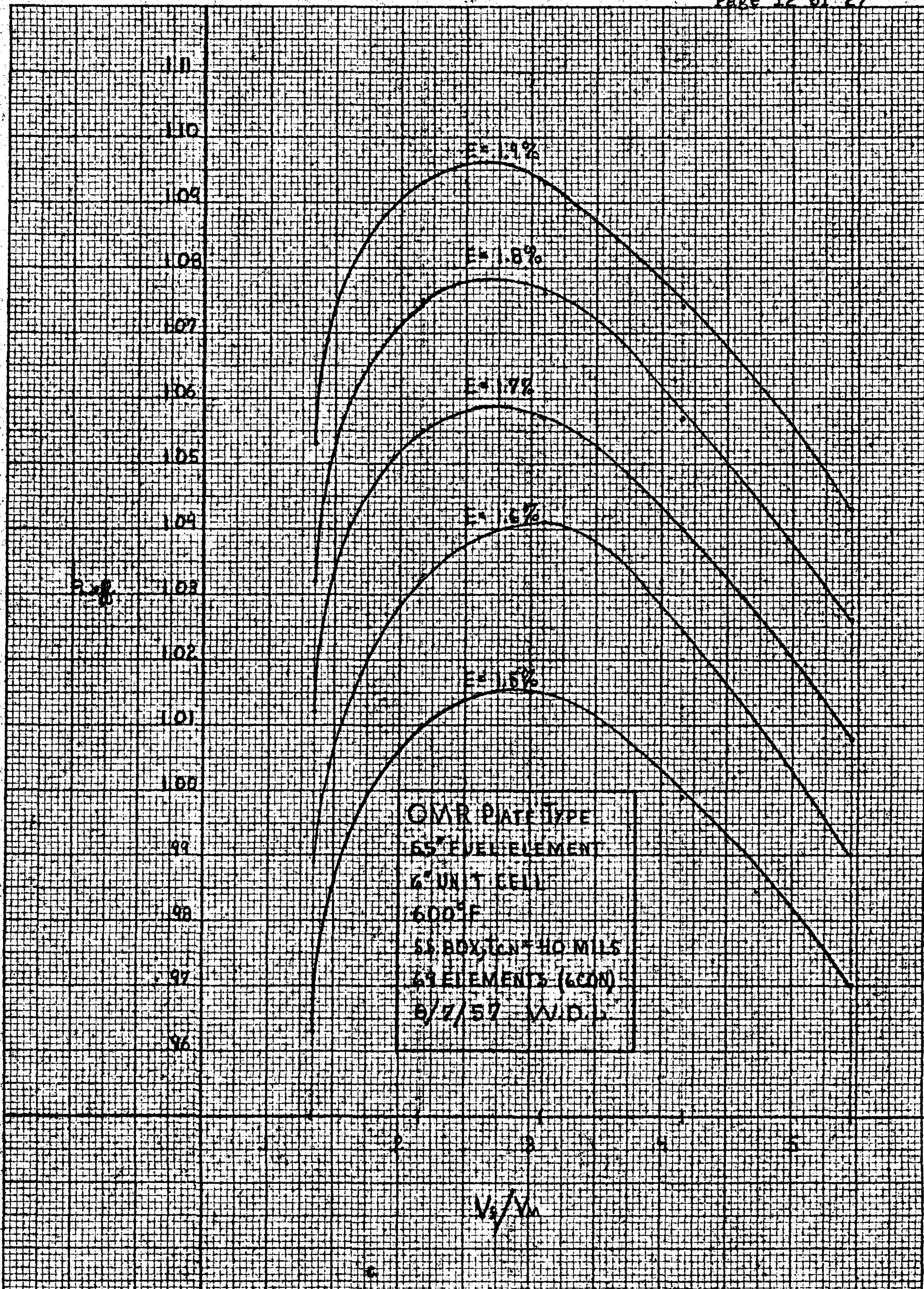
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1.00
.99
.98
.97
.96
Keff
E=1.9%
E=1.8%
E=1.7%
E=1.6%
E=1.5%
2
3
4
5
Vs/Vm
OMR PLATE TYPE
6.5" FUEL ELEMENT
6" UNIT CELL
600°F
SS BOX, tcn = 40 MILS
69 ELEMENTS (6CON)
8/7/57 W.D.L.

FIGURE 6

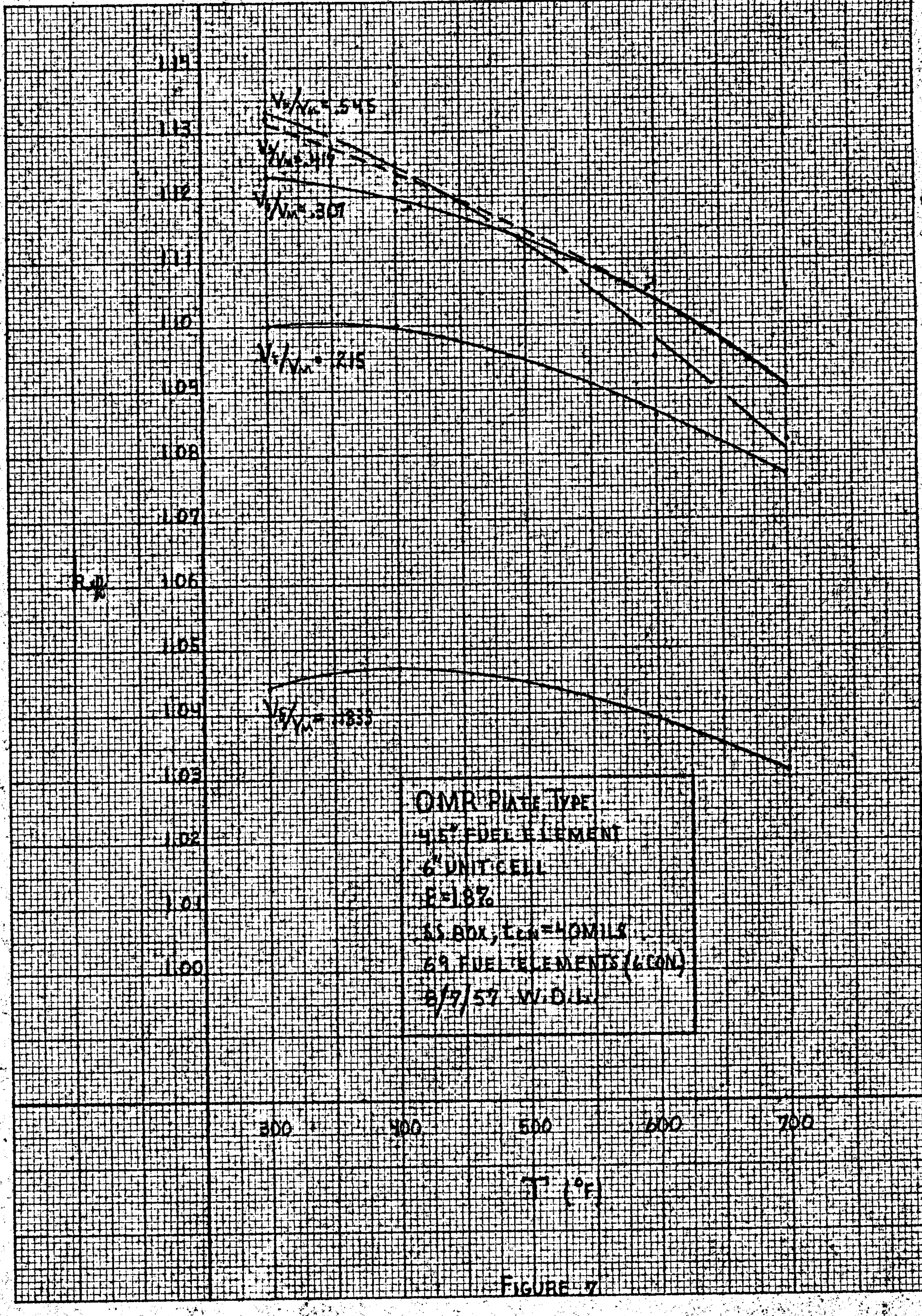
V_f/V_M = .545
V_f/V_M = .419
V_f/V_M = .307
V_f/V_M = .215
V_f/V_M = .0833
1.13
1.12
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1.00
300
400
500
600
700
T (°F)
OMR PLATE TYPE
4.5" FUEL ELEMENT
6" UNIT CELL
E = 18%
SS BOX, t_{can} = 40 MILS
69 FUEL ELEMENTS (6 CON)
8/7/57 W.D.L.

FIGURE 7

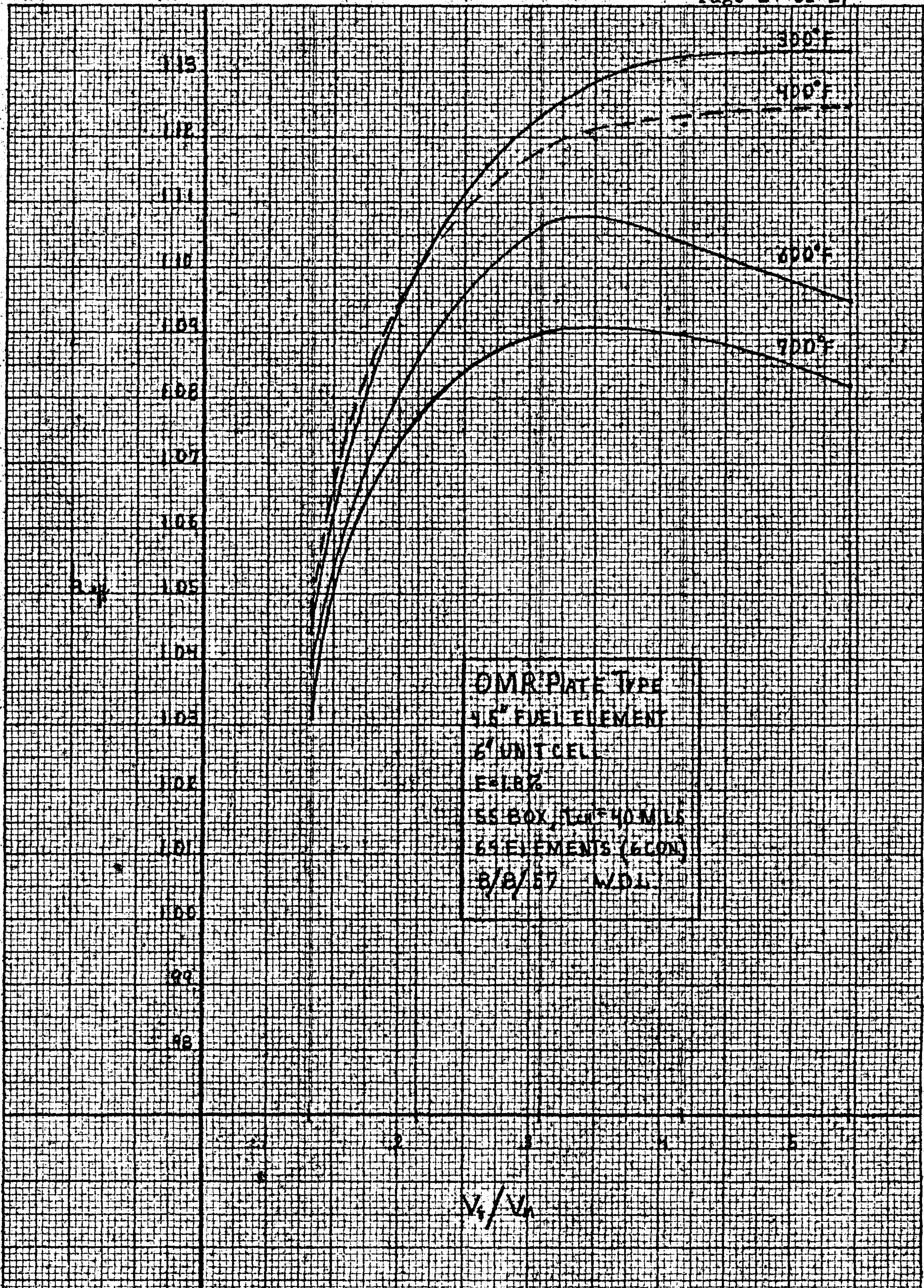
300°F
400°F
600°F
700°F
1.13
1.12
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1.00
.99
.98
.1
.2
.3
.4
.5
V_f/V_h
OMR PLATE TYPE
4.5" FUEL ELEMENT
6" UNIT CELL
65 ELEMENTS (6 CON)
8/8/57 W.D.L.

FIGURE 8

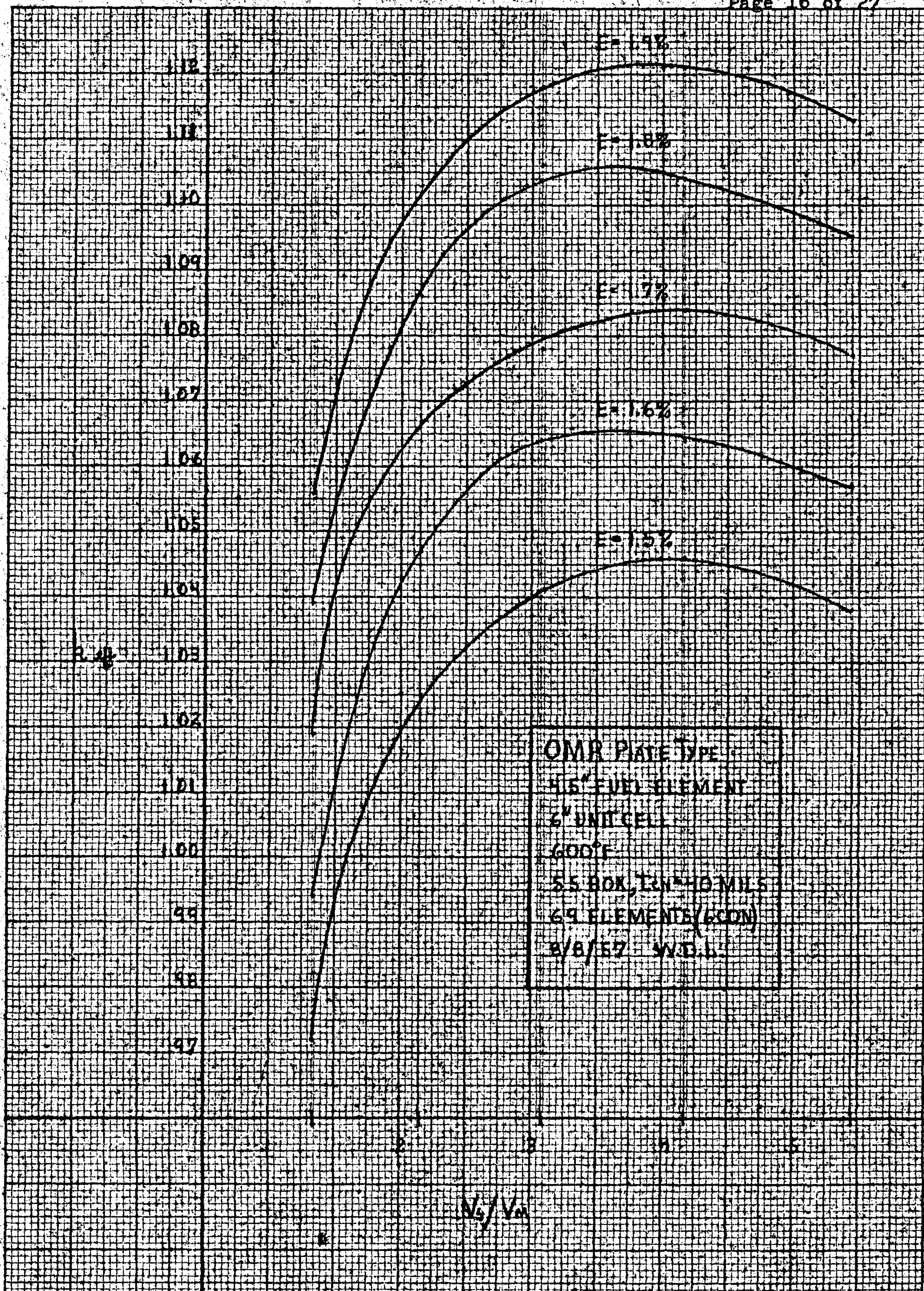
E=1.9%
E=1.8%
E=1.7%
E=1.6%
E=1.5%
1.12
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1.00
.99
.98
.97
1
2
3
4
5
OMR PLATE TYPE
4.5" FUEL ELEMENT
6" UNIT CELL
600°F
8/8/57 W.D.L.
V_s/V_m

FIGURE 10

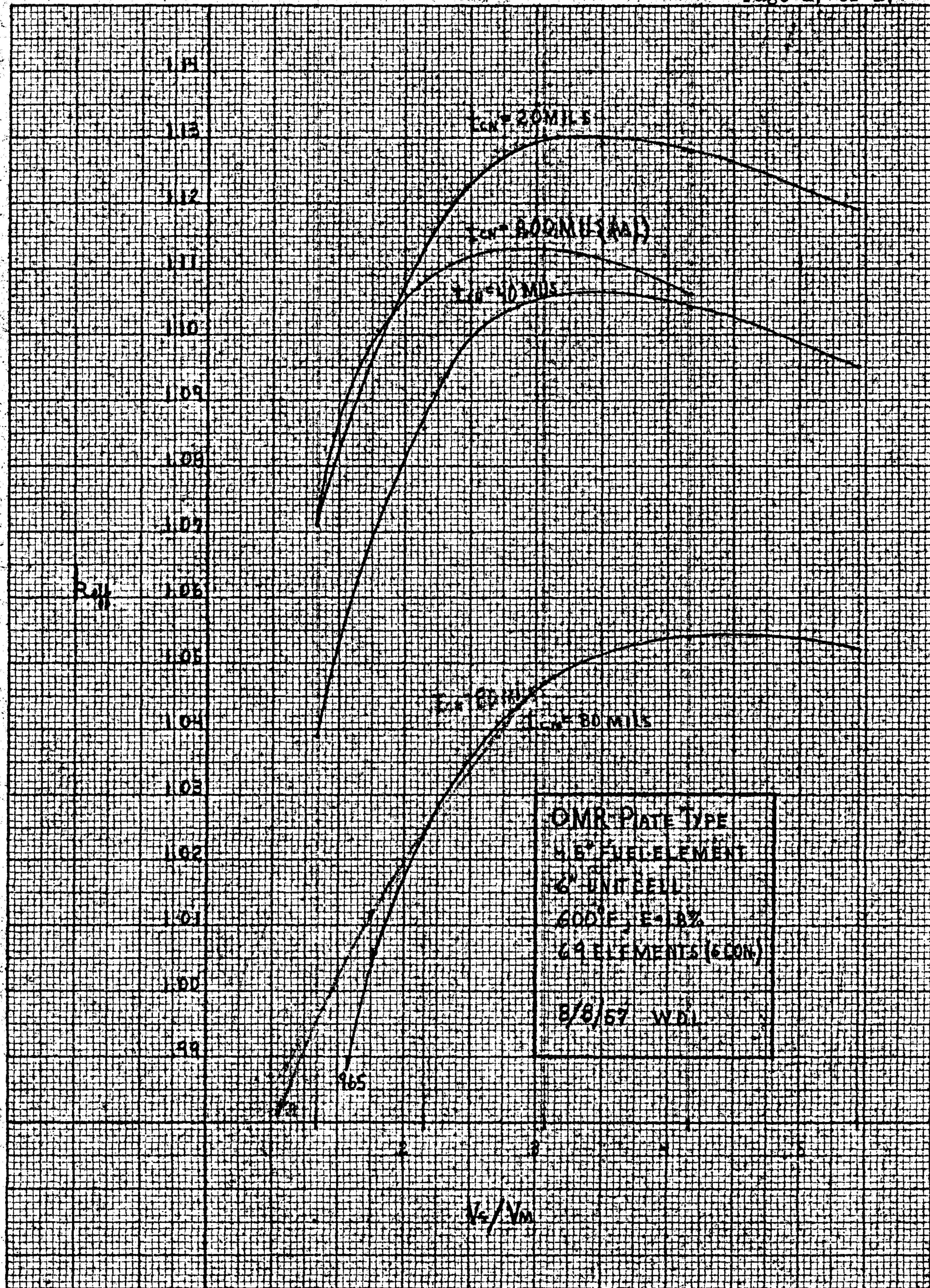
1.14
1.13
1.12
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1.00
.99
K_{eff}
t_{cn} = 20 MILS
t_{cn} = 80 MILS (Al)
t_{cn} = 40 MILS
t_{cn} = 80 MILS
.965
2
3
4
5
V_c/V_m
OMR PLATE TYPE
4.5" FUEL ELEMENT
6" UNIT CELL
600°F, E = 1.8%
69 ELEMENTS (6 CON)
8/8/57 W.D.L.

FIGURE 11

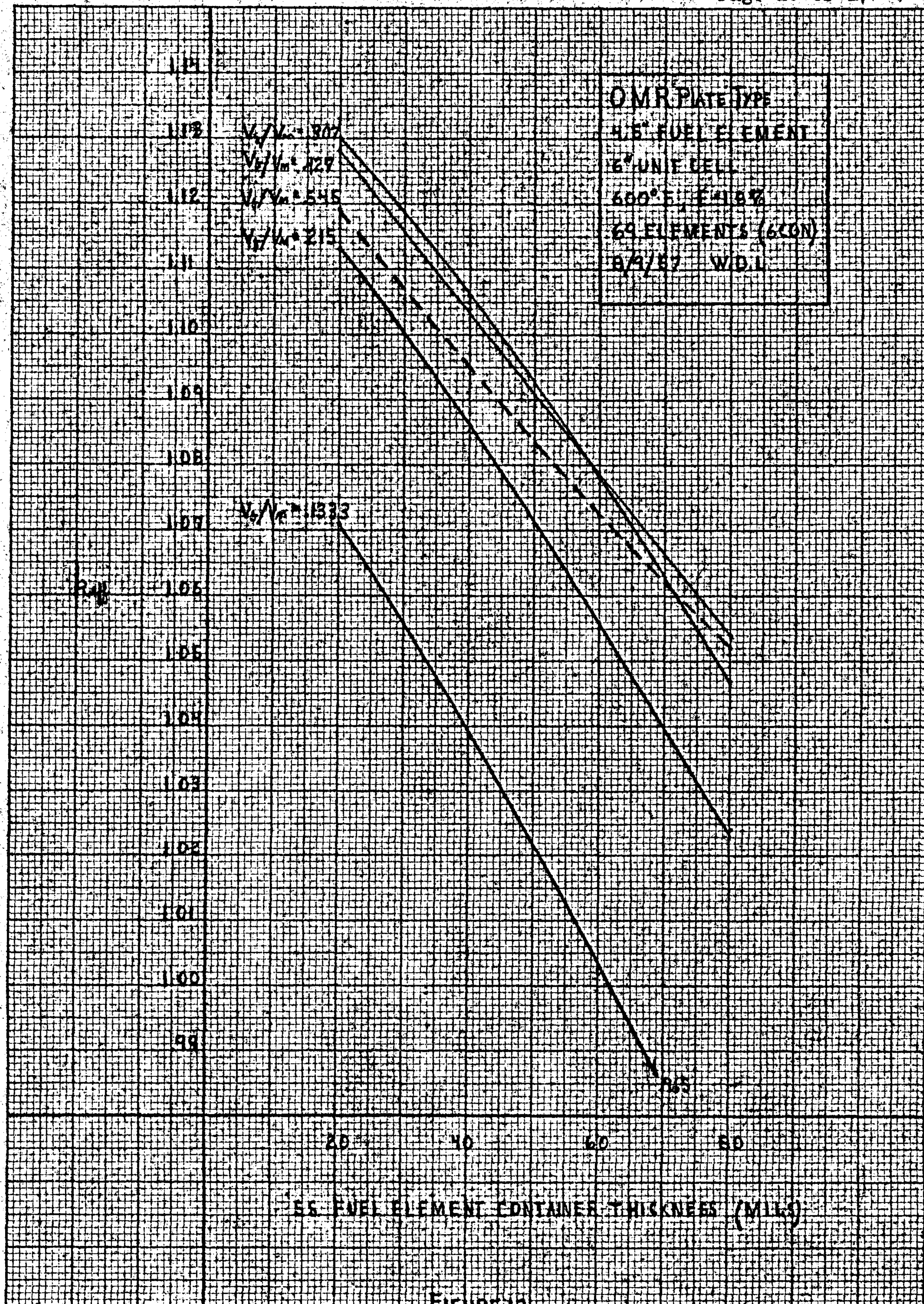
OMR PLATE TYPE
4.5" FUEL ELEMENT
6" UNIT CELL
600°F, E=18%
69 ELEMENTS (6CON)
8/9/57 W.D.L.
1.14
1.13
1.12
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1.00
.99
Rw
Vf/Vm = .807
Vf/Vm = .429
Vf/Vm = .545
Vf/Vm = .215
Vf/Vm = .1333
.65
20
40
60
80
SS FUEL ELEMENT CONTAINER THICKNESS (MILS)

FIGURE 12

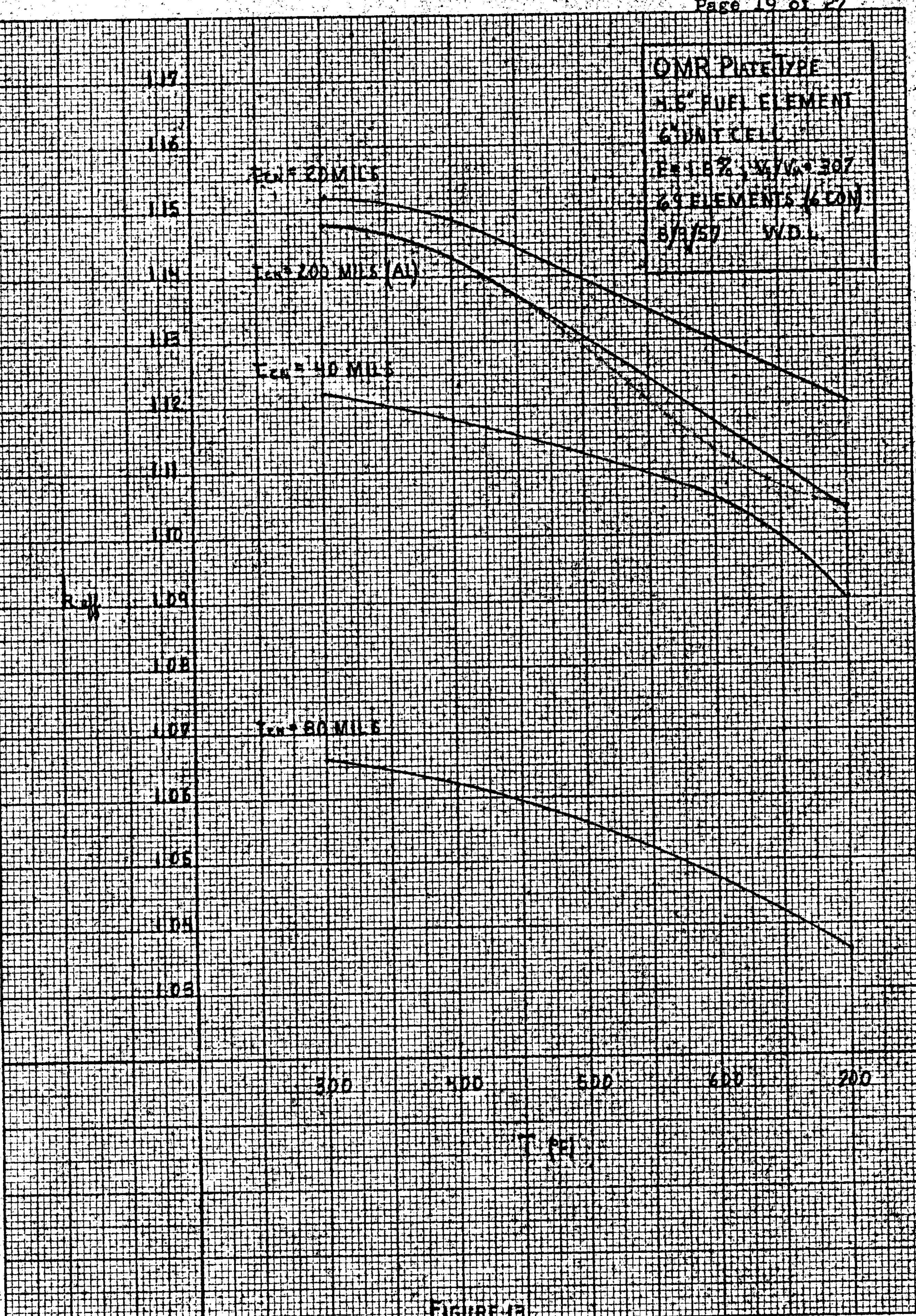
OMR PLATE TYPE
4.5" FUEL ELEMENT
6" UNIT CELL
E=1.8%; V1/V0=.307
69 ELEMENTS (6 CON)
8/9/57 W.D.L.
Tcw=20 MILS
Tcw=200 MILS (Al)
Tcw=40 MILS
Tcw=80 MILS
1.17
1.16
1.15
1.14
1.13
1.12
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
keff
300
400
500
600
700
T (°F)

FIGURE 13

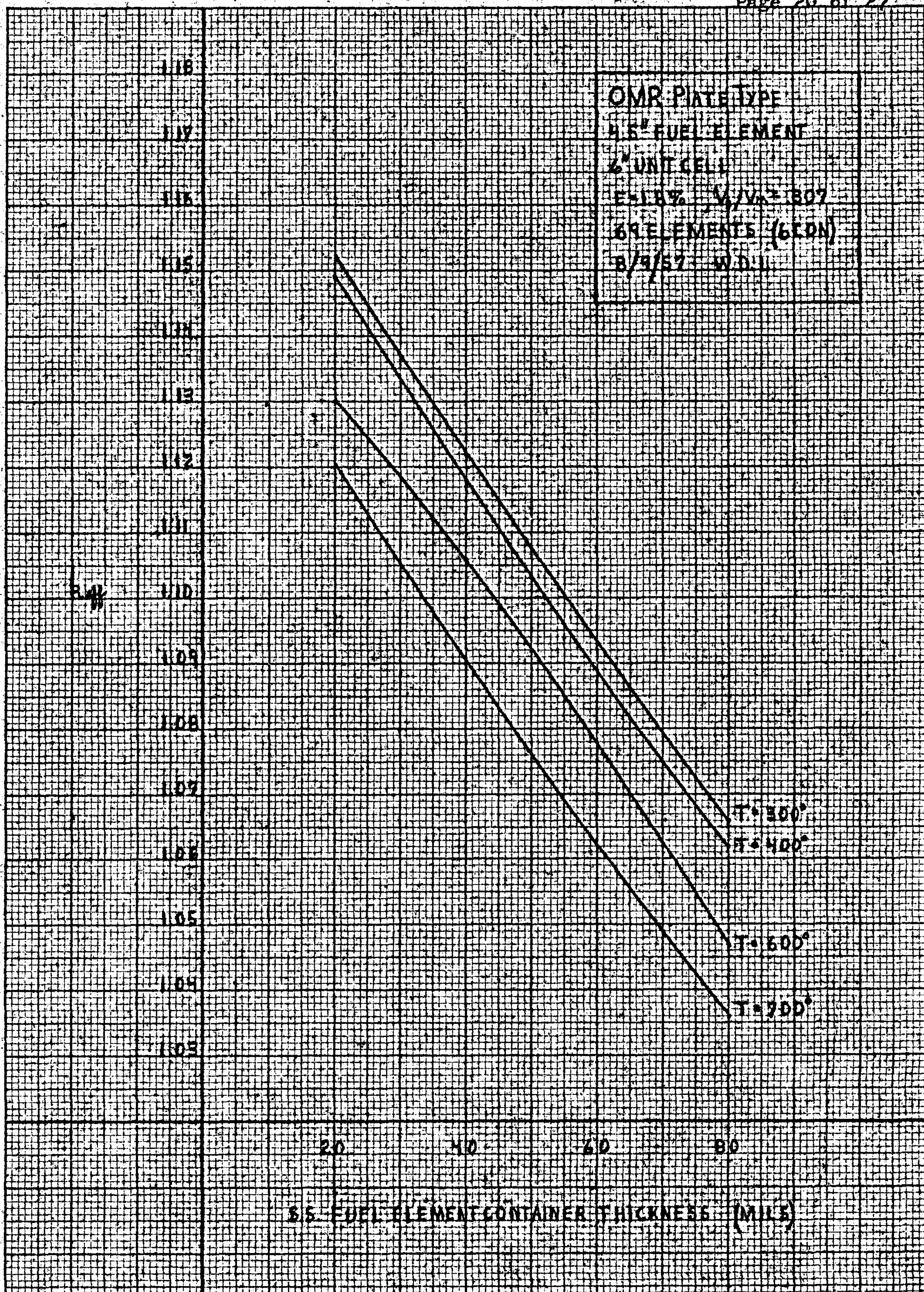
OMR PLATE TYPE
4.5" FUEL ELEMENT
6" UNIT CELL
69 ELEMENTS (6CON)
1.18
1.17
1.16
1.15
1.14
1.13
1.12
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
T = 300°
T = 400°
T = 600°
T = 700°
20
40
60
80
S.S. FUEL ELEMENT CONTAINER THICKNESS (MILS)

FIGURE 14

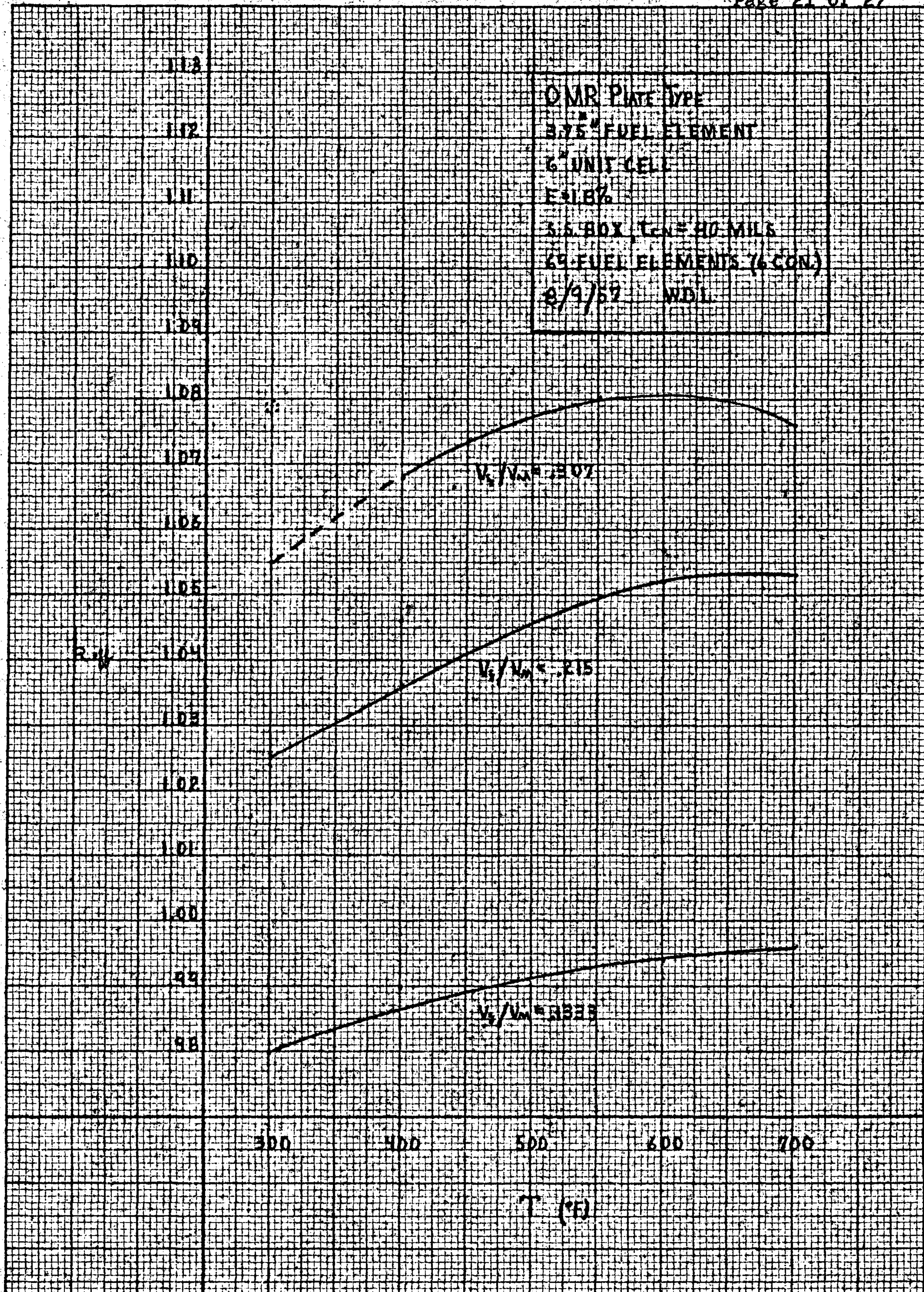
OMR PLATE TYPE
3.75" FUEL ELEMENT
6" UNIT CELL
E=1.8%
S.S. BOX, tCN = 40 MILS
69 FUEL ELEMENTS (6 CON.)
8/9/57 WDL
1.13
1.12
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1.00
.99
.98
K∞
Vs/VM = .307
Vs/VM = .215
Vs/VM = .0323
300
400
500
600
700
T (°F)

FIGURE 15

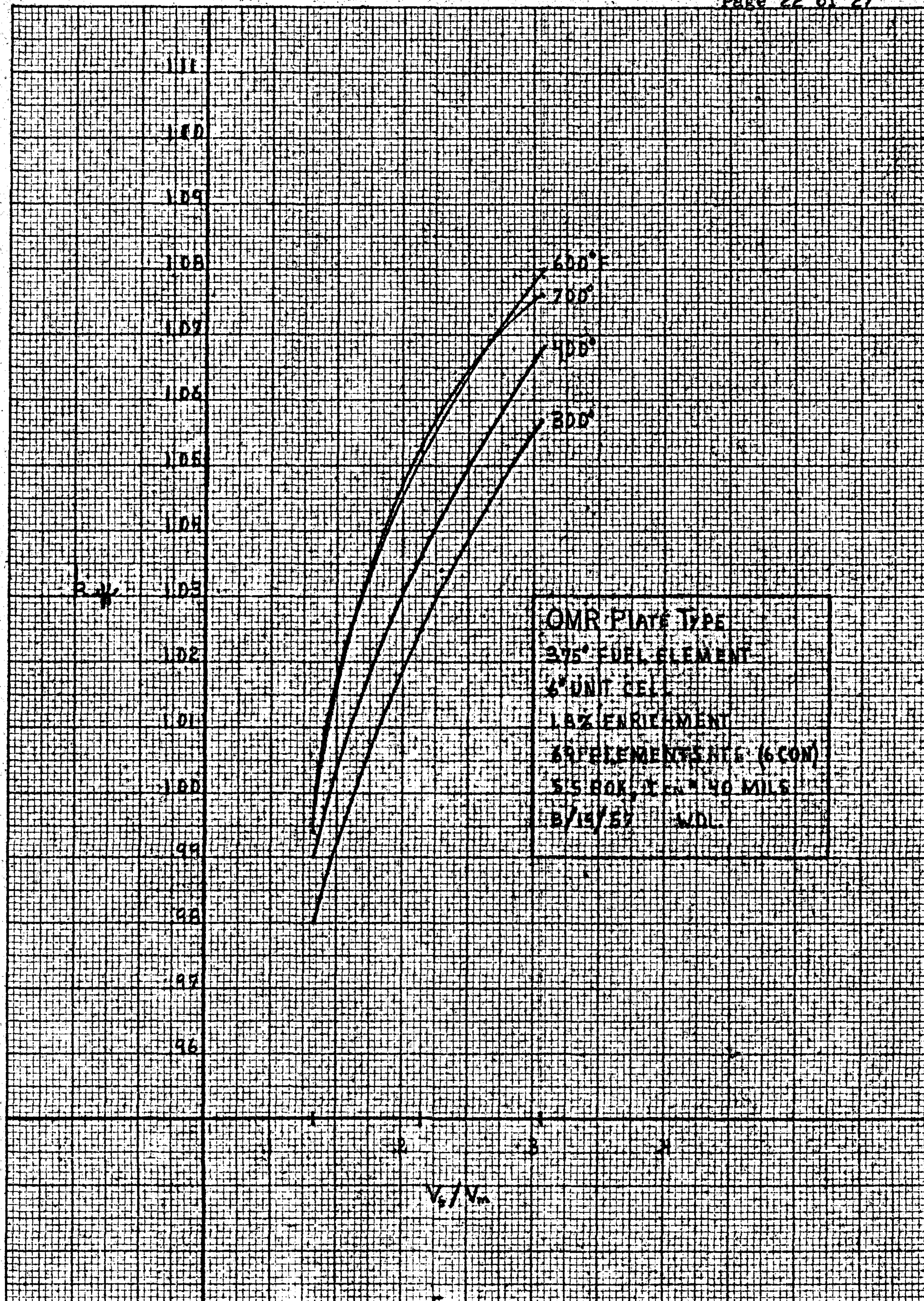
600°F
700°
400°
300°
OMR Plate Type
375" FUEL ELEMENT
6" UNIT CELL
1.8% ENRICHMENT
8/19/57 W.D.L.
.1
.2
.3
.4
V_s/V_m

FIGURE 16

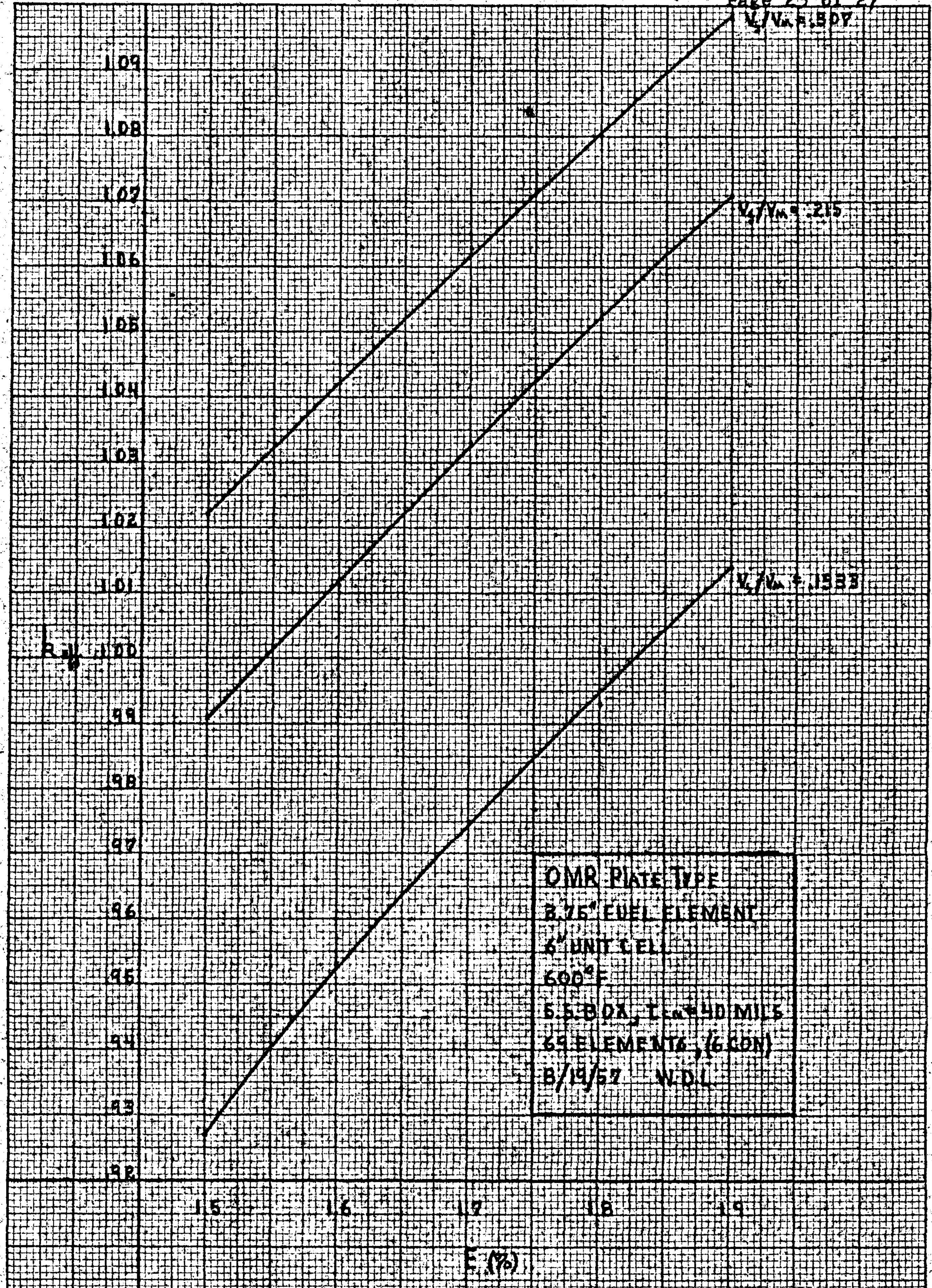
V_s/V_m = .307
V_s/V_m = .215
V_s/V_m = .1533
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
R
1.00
.99
.98
.97
.96
.95
.94
.93
.92
1.5
1.6
1.7
1.8
1.9
E (%)
OMR PLATE TYPE
3.75" FUEL ELEMENT
6" UNIT CELL
600°F
5.5 BOX, t = 40 MILS
69 ELEMENTS, (6 CON)
8/19/57 W.D.L.

FIGURE 17

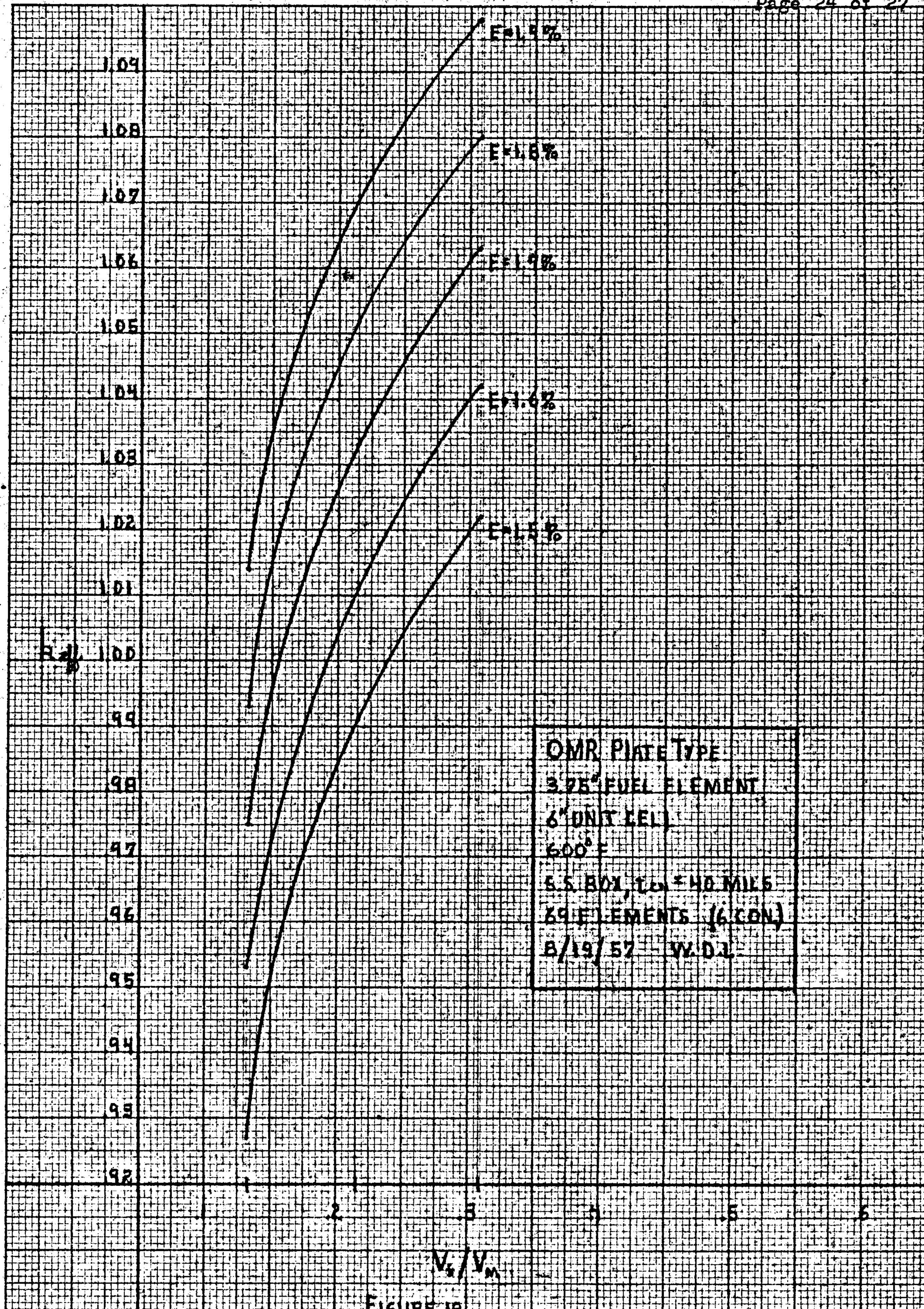
E=1.9%
E=1.8%
E=1.9%
E=1.6%
E=1.5%
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1.00
.99
.98
.97
.96
.95
.94
.93
.92
.1
.2
.3
.4
.5
.6
V_s/V_m
OMR PLATE TYPE
3.25" FUEL ELEMENT
6" UNIT CELL
600° F
S.S. BOX, t_{ss} = 40 MILS
69 ELEMENTS (6 CON.)
8/19/57 W.D.L.

FIGURE 18

RESULTS

S = 5.5"   E = 1.8%

V_f/V_m	.1333	.215	.307	.417	.545
T, °F	k_{eff}				
300	1.066	1.111	1.119	1.112	1.087
400	1.055	1.116	1.107	1.094	1.067
600	1.032	1.075	1.076	1.057	1.026
700	1.022	1.068	1.053	1.040	1.007

S = 5.5   T = 600°F

V_f/V_m	.1333	.215	.307	.417	.545
E, %	k_{eff}				
1.5	.963	1.010	1.015	.999	.970
1.6	.989	1.033	1.041	1.020	.990
1.7	1.012	1.055	1.057	1.040	1.008
1.8	1.032	1.075	1.076	1.057	1.026
1.9	1.053	1.093	1.093	1.074	1.043

S = 4.5   E = 1.8%

V_f/V_m	.1333	.215	.307	.417	.545
T, °F	k_{eff}				
300	1.044	1.100	1.123	1.132	1.133
400	1.047	1.100	1.118	1.122	1.125
600	1.039	1.086	1.106	1.104	1.095
700	1.031	1.077	1.090	1.090	1.082

S = 4.5 T = 600°

V_f/V_m	.1333	.215	.307	.417	.545
E,%	k_{eff}				
1.5	.972	1.025	1.040	1.046	1.038
1.6	.994	1.047	1.064	1.064	1.057
1.7	1.019	1.067	1.078	1.084	1.077
1.8	1.039	1.086	1.106	1.104	1.095
1.9	1.056	1.103	1.118	1.121	1.113

S = 3.75 E = 1.8%

V_f/V_m	.1333	.215	.307
T,°F	k_{eff}		
300	.980	1.025	1.079
400	.990	1.036	1.068
600	.994	1.052	1.080
700	.996	1.053	1.076

S = 3.75 T = 600°F

V_f/V_m	.1333	.215	.307
E,%	k_{eff}		
1.5	.927	.991	1.022
1.6	.953	1.011	1.042
1.7	.975	1.033	1.063
1.8	.993	1.052	1.080
1.9	1.014	1.071	1.098

S = 4.5, E = 1.8%, T = 600°

V_f/V_m	.1333	.215	.307	.417	.545
t_{cn}, mils	k_{eff}				
20	1.071	1.113	1.130	1.128	1.119
40	1.039	1.086	1.106	1.104	1.095
80	.965	1.024 *	1.047	1.054	1.052
200, AL	1.073	1.106	1.113	1.106	---

S = 4.5 E = 1.8% V_f/V_m = .307

T	300°	400°	600°	700°
t_{cn}, mils	k_{eff}			
20	1.152	1.149	1.130	1.120
40	1.122	1.118	1.106	1.090
80	1.066	1.062	1.047	1.036
200, AL	1.148	1.143	1.113	1.104