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DENSITY OF FUSED MIXTURES OF SODIUM FLUORIDE, BERYLLIUM FLUORIDE, AND URANIUM FLUORIDE

B. C. Blanke, E. N. Bousquet, L. V. Jones,
E. L. Murphy, and R. E. Vallee

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Mound Laboratory
Miamisburg, Ohio **Operated By**
Monsanto Chemical Company
Research and Engineering Division

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Category

CHEMISTRY - GENERAL

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I. ABSTRACT

The density of mixtures in the ternary system, sodium fluoride-beryllium fluoride-uranium fluoride, was investigated by means of the determination of the loss in weight of a solid of known volume immersed in the fused mixture from the liquidus temperature to 900°C. The results have been assembled in tabular and graphical form.

II. SUMMARY

Mound Laboratory has been assigned the problem of determining phase relationships and physical properties of some fused salt mixtures. The densities of fused mixtures of sodium fluoride, beryllium fluoride, and uranium tetrafluoride were determined as a function of composition and temperature from the liquidus point up to 900°C. The method used was the determination of the loss in weight of a solid of known volume immersed in the fused mixture. Because of the toxic nature of the samples and because of the high temperatures involved, special handling methods and apparatus were used. The apparatus for determining densities was operated under an inert gas atmosphere to minimize corrosion problems, and was designed in such a way that the errors resulting from remote, high-temperature operation were minimized.

The results have been assembled graphically to show the variation with temperature of the density of mixtures having a constant mole fraction of uranium tetrafluoride. Graphs and tables have also been made to show how density varies with composition at several temperatures.

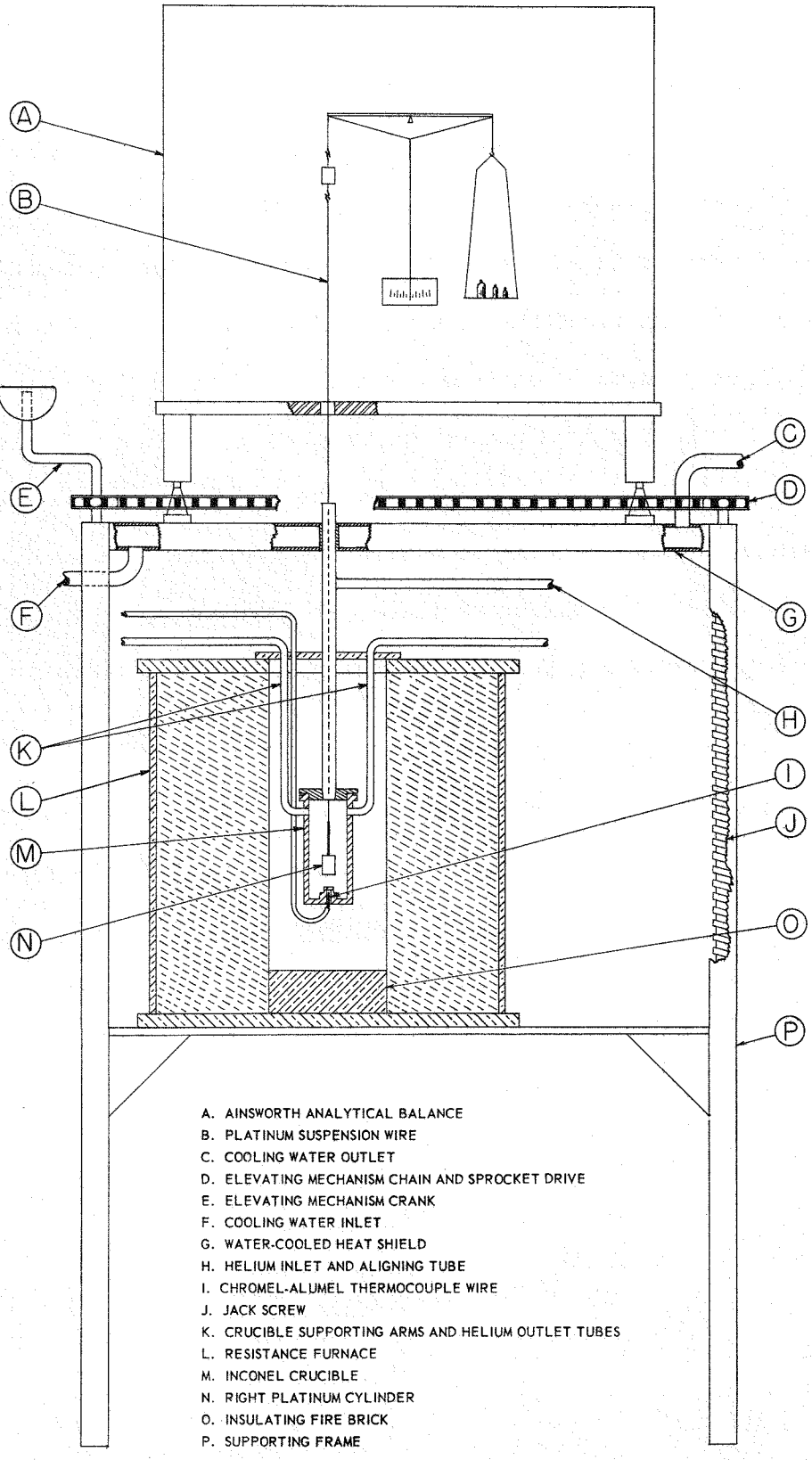

Figure 1. Schematic Diagram of Density Apparatus

III. EXPERIMENTAL METHOD

The methods considered for determining the density of the fused salt mixtures were measurement with the pycnometer, determination of the weight of fused salt which overflowed as a result of the immersion of a solid of known volume, the use of the volumenometer, the measurement of the pressure of gas needed to displace a fixed head of liquid, and the determination of the loss in weight of an object of known volume immersed in the sample. The overflow method was rejected because its use necessitated excessive handling of the toxic samples, and because of the unknown and variable surface tension of the samples. A pycnometer was made but proved unsatisfactory because of bubble formation and holdup of sample in the instrument. Modification of the pycnometer to a volumenometer proved unsatisfactory for the same reasons. Sample handling and measurements at high temperatures were also a problem with this method. The method which proved to be most satisfactory, especially with regard to the handling of toxic samples, was the determination of the loss in weight of a solid of known volume immersed in the molten sample. It was by this method that all the data reported here were determined. Other investigators who have made use of the loss-in-weight method for density determinations were Brunner[2], Arndt and Gessler[1], Lorenz[9,10,11], Jaeger[6,7,8], and Mashoretz and Lundina[12].

APPARATUS

The density apparatus is shown schematically in Figure 1. Figures 2 through 5 show details of the density apparatus and related equipment. A right cylinder of platinum (N) was supported by approximately 4 centimeters of 0.052-inch diameter platinum wire which was in turn supported by approximately 75 centimeters of 0.020-inch diameter platinum wire (B). The heavier

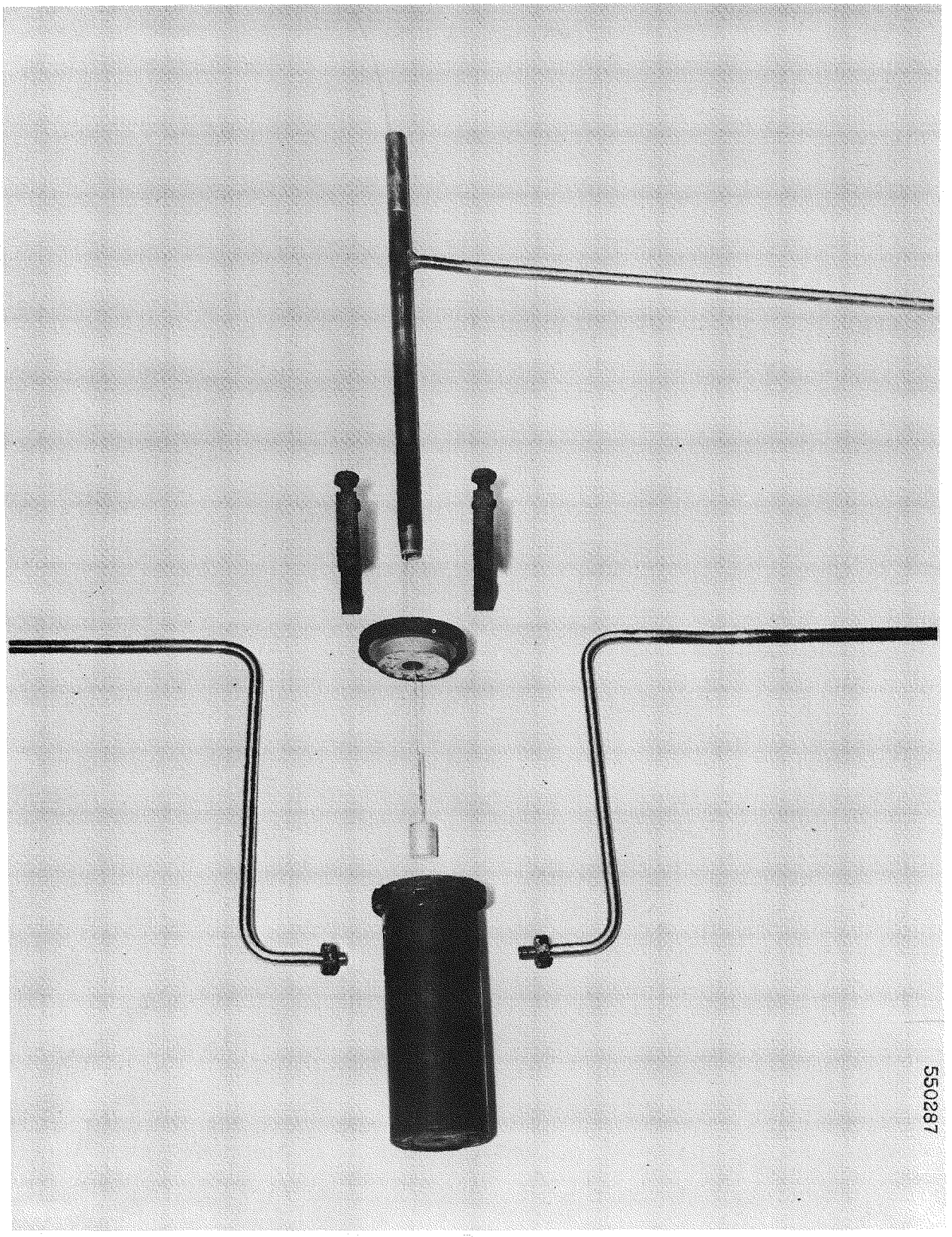

Figure 2. Inconel Crucible Assembly and Platinum Sinker

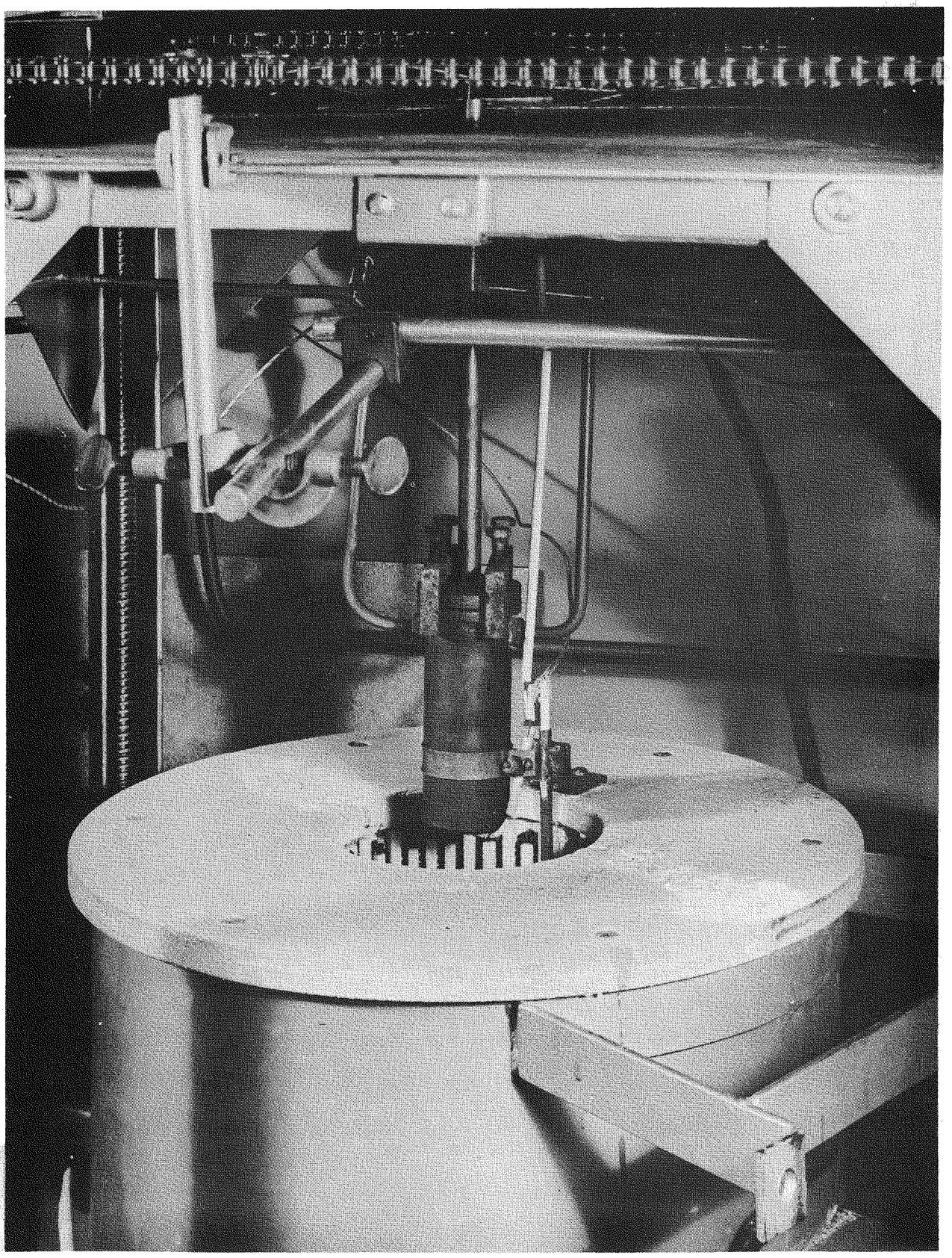

Figure 3. Crucible and Furnace Assembly

intermediate wire was found necessary to withstand the corrosive action of the samples. The 0.020-inch platinum wire passed through the vertical portion of the helium-inlet and aligning tube (H), through an opening in the water-cooled heat shield (G), and finally through a hole in the bottom of the balance case as shown in Figure 1. Inside the balance case the wire was connected to a counterweight attached to the arm of a standard Ainsworth analytical balance (A). The counterweight was used to take the place of the weight of the left-hand pan, which was removed. The volumes of the platinum cylinders were calculated after measuring their dimensions to the nearest 0.0001 inch with a micrometer. From the known coefficient of expansion of platinum, it was possible to calculate the volumes of the cylinders at the temperature of each density measurement. Typical physical dimensions of the three cylindrical assemblies that were used are shown in Table 1. The varying cylinder size resulted from remachining for the removal of surface imperfections caused by corrosion. The weight and volume of the cylinder was arbitrary, but in order to decrease the relative error due to the surface tension effect on the platinum wire, a large cylinder was preferred.

TABLE 1

TYPICAL PHYSICAL DIMENSIONS OF
PLATINUM SINKER ASSEMBLIES

Sinker Assembly	Support Wire Dia. in.	Length of Cylinder in.	Diameter of Cylinder in.	Total Mass g
1	0.052	0.6139	0.5904	58.8137
2	0.052	0.5829	0.4999	42.8339
3	0.043	0.6258	0.5366	52.2835

Since the mechanism for elevating the furnace (consisting or four jack screws, the chain and sprocket drive, and hand crank), the crucible supporting arms, the crucible aligning rods (Figure 3), and the helium flow system over the crucible are shown in Figure 1 and in Figures 3 and 4, they will not be described here in detail. The furnace was raised or lowered by the four jack screws (J) which were turned simultaneously by the chain and sprocket arrangement (D) and the hand crank (E).

The inert atmosphere, necessary because of the corrosive action of air on the apparatus at the higher temperature in the presence of fluoride, was provided by allowing approximately 10 cubic feet per hour of helium, which had been dried by passing through a liquid nitrogen trap, to flow into the helium inlet tube (H). Four cubic feet per hour of this helium passed through the Inconel crucible and was removed through one of the side arms supporting the crucible by an exhaust pump which was vented outside the building. This flow of helium removed any toxic and corrosive fumes produced by the heated sample and inhibited the collection of beryllium fluoride on the wire supporting the platinum sinker. The remaining six cubic feet per hour of helium was allowed to flow out through the top of the helium inlet and aligning tube (H), which prevented diffusion of air into the hot crucible. Vertical alignment of the crucible was obtained by adjustment of the crucible-aligning rods, shown in Figure 3, which were attached to the vertical portion of the helium-inlet and aligning tube (H).

The furnace (L) was a 2300 watt, 110/220 volt unit with a center opening

five inches in diameter and thirteen inches long, designed to operate at temperatures up to 1000°C. The temperature of the furnace was controlled with a Foxboro controller connected to a chromel-alumel thermocouple located inside the furnace. The temperature of the sample was measured using a chromel-alumel thermocouple (I) located in the thin-walled well in the bottom of the Inconel crucible (M). This temperature was recorded on a 6-point Leeds and Northrup recorder and was determined by switching the thermocouple leads to a Rubicon portable potentiometer. The water-cooled heat shield (G) effectively shielded the balance from thermal radiation.

The crucible (M), with dimensions of 1-3/8-inch I.D. by 4-inch internal depth, and the crucible lid were fabricated from Inconel, which was found to be the material most satisfactory in withstanding the corrosive nature of the melted samples and the repeated cleaning operations. Nickel tubing was used for the side-arm supports (K) and the helium inlet tube (H). The tubing used for the side arms was 1/4-inch O.D. by 1/8-inch I.D. and the tubing for the helium inlet tube was 1/4-inch O.D. by 3/16-inch I.D. for the horizontal portion, and 7/16-inch O.D. by 3/8-inch I.D. for the vertical portion. Stainless steel was used for the remaining components of the crucible assembly.

PROCEDURE

In obtaining a density measurement, the Inconel crucible, containing the previously prepared sample of approximately 50 milliliters and the weighed platinum cylinder of known dimensions, was assembled and fastened into position above the furnace. The thermocouple, and the helium and vacuum lines were then attached. The crucible assembly was brought into vertical alignment with the

aid of a "bubble" level using the two aligning rods. The assembled and aligned apparatus is shown in Figure 3. After alignment, the furnace was raised into position. The opening in the top of the furnace around the arms and thermocouple wire was closed with precut transite plates and asbestos paper to minimize heat loss and to maintain a more constant temperature inside the furnace during the experiment. A flow of dried helium was started over the sample and the furnace was turned on. The Foxboro controller was adjusted to the desired initial temperature setting (usually 900°C). Temperature equilibrium of the sample was attained in 1-1/2 to 2 hours and the final temperature, as measured on the Rubicon potentiometer, varied less than 0.5°C.

It was necessary to know the depth of immersion of the cylinder and wire to calculate the volume of platinum immersed. The position of the cylinder was located by carefully lowering the cylinder into the melted sample until it touched the top of the thermocouple well. The cylinder was then raised 0.25 inch and fastened to the counterweight on the balance arm in this position. With this information and the coefficient of expansion of platinum and of Inconel, the depth of immersion could be calculated at the temperature of any measurement.

The apparent mass of the cylinder and supporting wire was next determined by standard weighing procedure. It was found necessary to mix the sample and remove any entrapped gas bubbles from the surface of the cylinder by rapidly raising and lowering the cylinder in the melt. This gas-bubble formation was a consistent occurrence especially at the beginning

of a run at the higher temperatures. The cylinder was alternately agitated and weighed until the balance readings agreed to within ± 0.0015 gram . The temperature of the sample was determined using the Rubicon potentiometer immediately after taking the final balance reading.

The length of the 0.052-inch platinum wire below the sample surface was determined by assuming, as a first approximation to the density, that the volume of the platinum cylinder alone was the total volume of platinum immersed. From this volume, the known dimensions of the Inconel crucible and the platinum cylinder and wire, and this "trial density", the depth of the melt was calculated. Since the position of the cylinder with respect to the crucible bottom was known, the volume of platinum wire immersed could be calculated, and a final density determined.

The temperature of the melt was reduced a desired amount (usually 50°C) and the above procedure repeated. After the final measurement was made, the platinum cylinder was lifted from the sample to the top portion of the crucible, the furnace was lowered to speed up the cooling, and the crucible and its contents were allowed to cool to room temperature before being removed.

As can be seen in Figure 4, the entire density apparatus was housed in a large hood to minimize exposure of personnel to any toxic fumes.

The salts used to prepare the samples were beryllium fluoride, sodium fluoride, and uranium tetrafluoride. The beryllium fluoride used was analytical-grade, supplied by the Brush Beryllium Corporation, and contained a minimum of 99.0 per cent beryllium fluoride. It was used "as received" for sample preparation.

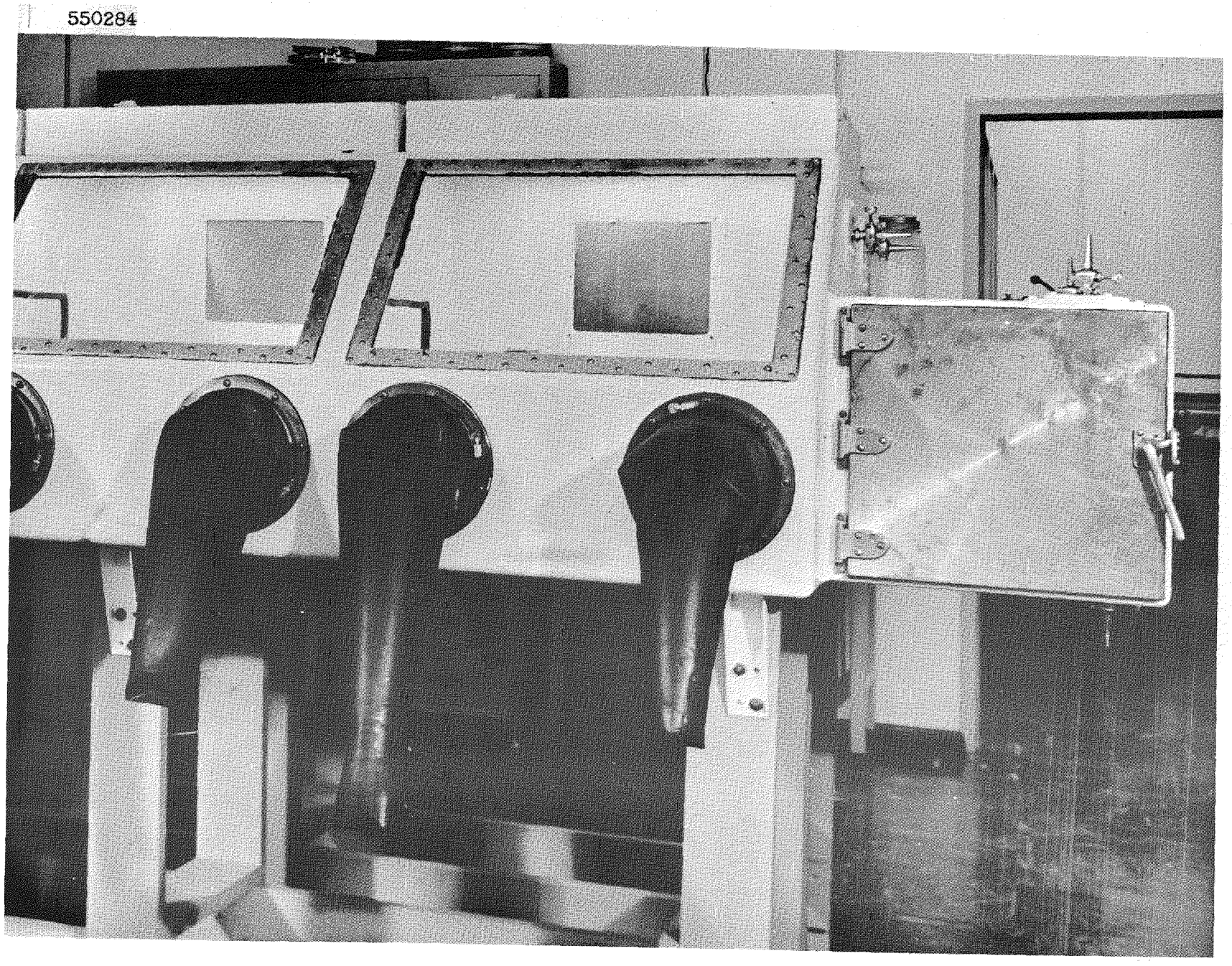

Figure 6. Stainless Steel Sample Preparation and Storage Hood

The sodium fluoride used was analytical reagent-grade and was dried at 200°C to 220°C for at least 24 hours before use. The uranium fluoride was treated to reduce oxide content as follows. The salt was placed in nickel crucibles (65-milliliter capacity) which were placed in a vacuum reactor. The system was evacuated while being heated to 750°C. When this temperature was attained, hydrogen fluoride gas was admitted and allowed to flow over the salt for approximately one hour while the temperature was maintained. After one hour the heater was turned off and the hydrogen fluoride was removed by a flow of hydrogen gas. The hydrogen was allowed to flow over the salt until the temperature of 150°C was reached. The salt was then allowed to cool overnight under a blanket of hydrogen gas. All the salts used were stored in a stainless steel drybox, shown in Figure 6. The salts were pulverized when necessary, weighed, and mixed in the drybox. The samples were melted in nickel crucibles using induction heating and transferred by pouring into the Inconel sample crucible. This melting procedure was necessary to decrease the volume of the sample so that it could be contained by the Inconel crucibles. The melting procedure also helped insure homogeneity of the sample.

After each run, it was necessary to clean the crucible assembly and the platinum cylinder and wire before reuse. Since the platinum cylinder was removed from the melt before the sample solidified, the amount of sample adhering to the cylinder was usually small and was readily removed by immersion in a molten potassium bisulfate bath. The platinum

cylinder and wire assembly was then washed in a 50:50 hydrochloric acid-water solution and in distilled water. Finally, it was flame-dried and allowed to cool before being weighed and measured. The major portion of the sample was removed from the Inconel crucible by melting and pouring. The remaining portion was removed by water leaching or by a sodium hydroxide fusion and water-washing process.

ERRORS

The calculated errors in measurement are listed below:

1.	Dimension of platinum cylinder and wire	± 0.0005 in.
2.	Weight of platinum cylinder and wire in air	± 0.0001 g
3.	Weight of platinum cylinder and wire in sample	± 0.001 g
4.	Temperature of melt	± 0.5°C
5.	Depth of immersion of platinum cylinder and wire	± 0.050 in.
6.	Coefficient of expansion of platinum	± 0.00001°C^{-1}
7.	Weight of melt in crucible	± 0.000 g - 4.000 g
8.	Sample composition	± 0.02 g for each component

The error introduced by measurements 2, 3, 4, 6, and 8 are small in comparison with the error in measurements 1, 5, and 7. Their effect on the overall error will not be considered.

The error introduced in the measurement of the dimensions of the platinum cylinder and wire is by far the largest as shown by the following example:

Measurement	Minimum	Maximum
Radius of sinker	0.26588 in.(0.68212 cm)	0.26905 in.(0.68339 cm)
Length of sinker	0.6292 in.(1.59817 cm)	0.6302 in.(1.60070 cm)
Mass of sinker	53.9624 g	53.9624 g
Fiber radius	0.026 in.(0.06604 cm)	0.026 in.(0.06604 cm)
Sample weight	136.23 g	136.23 g
Pan weight	20.1817 g	20.1817 g
Balance reading	27.9131 g	27.9131 g
K(Platinum)	1.00870	1.00870
Radius = (r)K	0.68805 cm	0.68934 cm
Vol. of Pt cyl.	2.39759 cm^3	2.41029 cm^3
Total mass	48.0948 g	48.0948 g
Loss in mass	5.8676	5.8676 g
Trial density	2.4473 g/cm^3	2.4344 g/cm^3
Sample volume	55.665 cm^3	55.960 cm^3
Effective volume	59.17 cm^3	59.47 cm^3
Melt depth	5.99 cm	6.02 cm
Top of cylinder	3.54 cm	3.54 cm
Fiber length	2.45 cm	2.48 cm
Fiber volume	0.03415 cm^3	0.03457 cm^3
Final volume	2.43174 cm^3	2.44486 cm^3
Final density	2.4129 g/cm^3	2.4000 g/cm^3

$$\Delta\rho = 0.0129 \text{ g/cm}^3 \quad \text{or}$$

$$\frac{0.0129}{2.4000} \times 100 = 0.54\% = \pm\ 0.27\% \text{ error}$$

Measurements 5 and 7 both affect the final density by producing an error in the volume of platinum wire immersed in the melt. An error of 0.050 inch (0.127 cm) in the immersion depth for the largest platinum wire (0.052 in.) would be equal to $[\rho_{Pt} \pi r^2 h]$ grams or $(21.45) \times (3.14) \times (0.066)^2 \times (0.127) = 0.037$ grams of platinum as weighed in air. The weight of this length of wire as weighed in a typical sample of density 2.0 would be $(19.45) \times (3.14) \times (0.066) \times (0.127)$, $= 0.0335$ grams of platinum as weighed in the sample. The difference in these two weights, 0.0035 grams, would account for a percentage error of $\frac{0.0035}{3.35} \times 100$ or approximately 0.10% for the smallest platinum cylinder, where the weight loss in the sample is 3.35 grams, and less for the larger cylinders. An error of 4.0 grams, due to loss of sample in transfer operations, in a typical sample of density 2.0 would be equivalent to a volume of 2.0 milliliters, or a change in melt depth in the crucible of about 0.16 centimeter. When computed on the same basis as error 5, this would be equal to a percentage error of $\frac{0.16}{0.127} \times 0.10\% = 0.13\%$. The total error of measurement is $\pm [(0.27)^2 \times (0.10)^2 \times (0.13)^2]$ or $\pm$ 0.32%.

The other errors involved, which would probably account for a larger percentage change in density than the calculated errors shown above, are: (1) loss of volatile material, expecially beryllium fluoride, from the sample during melting and transferring to the Inconel crucible and during the density measurements, (2) the surface tension effect of the melt on the platinum wire and on the crucible, and (3) the thermal effect of the helium flow over the melt.

THEORY AND CALCULATIONS

The absolute density of a substance at temperature, t, is defined by

$$\rho_t = \frac{M}{V} \qquad (1)$$

where ρ = density
M = mass
V = volume

In the cgs system M is expressed in grams and V in cm^3. Density is usually expressed as relative density, i.e., the density compared to that of water at its temperature of maximum density, 3.98°C.

The sinker assembly is first weighed in air and then weighed in the sample, with the sinker and a definite length of wire immersed.

The relationship of this apparent loss in weight of the sinker to density, neglecting the buoyancy effect of air on the weights and sinker and the surface tension effects of the molten sample on the platinum wire, can be expressed as:

$$\rho = \frac{W_A - W_L}{V_i}$$

where, ρ = density
W_A = Wt. of sinker assembly in air
W_L = Wt. of sinker assembly in liquid
V_i = volume of liquid displaced

The volume, V_i, can be calculated from the dimensions if the amount of platinum wire immersed in the melt is known. As a first approximation, the volume of the platinum immersed is assumed to be equal to that of the platinum cylinder, and a "trial" density is calculated. From this trial density and the Inconel crucible dimensions, a corrected depth of immersed platinum wire is calculated. Using this corrected depth of immersion, a final density is calculated.

Thermal expansion values for platinum were obtained from the work of Halborn and Day[5], and from Esser and Eusterbrock[3]. The thermal expansion of nickel alloys was taken from Mellor[13], the work of Harrison[4], and of Wise and Schaefer[15].

Sample Calculation The following data were known, or were obtained, prior to the density determination:

Sample Composition:	46 mole % NaF 48 mole % BeF_2 6 mole % UF_4	
Sinker Data:	Radius	0.26855 in. = 0.68212 cm
	Length	0.6292 in. = 1.59817 cm
	Mass	53.9624
Platinum wire radius		0.026 in. = 0.06604 cm
	Sample weight*	= 136.23 g
	Pan weight	= 20.1817 g

* Calculated from previous experimental knowledge that 2.25 moles of sample is equal to approximately 50 ml.

The following data were recorded for each temperature during the determination:

Thermocouple millivolts = 37.71 at 908.8°C

Balance reading = 27.9131 g

Coefficient of expansion of platinum (K) at 908°C = 1.00870

From the above data the calculation of a final density was made as follows:

Radius of platinum cylinder at 908°C:

$$r_t = r_o k_t = (0.68212)\ (1.00870) = 0.68805 \text{ cm}$$

Volume of platinum cylinder:

$$V_t = \pi r_t^2 h = (3.1416)\ (0.68805)^2\ (1.59817 \times 1.00870) = 2.39759 \text{ cm}^3$$

Total mass:

Balance reading plus pan weight = 27.9131 + 20.1817 = 48.0948 g

Loss in mass: (of platinum cylinder + wire on immersion)

(Platinum assembly weight in air) − (total mass) =
53.9624 − 48.0948 = 5.8676 g

Trial density:

$$\text{Loss in mass} = \frac{5.8676}{2.39759} = 2.4473 \text{ g/cm}^3$$

Sample volume:

$$\frac{\text{Total sample weight}}{\text{Trial density}} = \frac{136.23}{2.4473} = 55.665 \text{ cm}^3$$

Effective volume:

Sample volume + volume of platinum cylinder + thermocouple well volume:

$55.67 + 2.40 + 1.10 = 59.17 \text{ cm}^3$

Melt depth: taken from graph prepared to show volume/centimeter of crucible

$$\frac{\text{Effective Volume}}{\text{volume/centimeter of depth}} = \frac{59.17}{9.88} = 5.99 \text{ cm}$$

Top of cylinder (distance from crucible bottom to top of cylinder) =

platinum cylinder length + distance between cylinder and thermocouple well + length of thermocouple well.

= 1.61 + 0.63 + 0.93 cm

= 3.54 cm

Fiber length:

Melt depth to top of cylinder 5.99 - 3.54 = 2.45 cm

Fiber volume:

$$\pi r_t^2 h = (3.1416)\ (0.06604 \times 1.00870)^2\ (2.45) = 0.03415 \text{ cm}^3$$

Final volume:

= platinum cylinder volume + fiber volume

= 2.39759 + 0.03415

= 2.43179 cm^3

Final density:

$$\rho = \frac{\text{Loss in mass}}{\text{Final volume}} = \frac{5.8676}{2.43174} = 2.4129 \text{ g/cm}^3$$

IV. RESULTS

If a series function for linear expansion is assumed, then an expression for the effect of temperature on density may be derived as follows:

$$L = L_o (1 + \alpha t + \beta t^2 + \ldots\ldots\ldots\ldots\ldots)$$

$$V = L^3 = L_o^3 (1 + \alpha t + \beta t^2 + \ldots\ldots\ldots)^3$$

$$= V_o (1 + 3\alpha t + 3(\alpha^2 + \beta) t^2 + \ldots\ldots)$$

$$= V_o (1 + \alpha' t + \beta' t^2 + \ldots\ldots\ldots\ldots\ldots)$$

where L = length at temperature, t

t = temperature, ^oC

L_o = original length

V = volume at temperature, t

V_o = original volume

α, β = coefficients

Then:
$$\rho = \frac{m}{v} = \frac{m}{V_o [1 + \alpha' t + \beta' t^2 + \ldots\ldots\ldots]}$$

ρ = density

m = mass

Most of the curves are essentially linear over the region studied indicating that the β' and higher coefficients are small; therefore:

$$\rho \simeq \frac{m}{V_o [1 + \alpha' t]}$$

or

$$\rho \simeq \frac{m}{V_o} [1 - \alpha' t]$$

Compositions of mixtures were planned so as to have fixed concentrations of one component since the density would then be a function only of the temper-

ature and the concentration of one of the other components.

Figure 7a through 7t shows the density as a function of temperature for mixtures containing constant mole fractions of uranium tetrafluoride. The temperature axes have been displaced on each graph to prevent confusion of the curves. The relative slope of these curves indicated the reliability of the data. When a uniform integral of composition change exists in such a family of curves, the interval between curves may be used to determine whether data are reasonable in value, and to aid in deciding which of the data obtained from several runs using mixtures of identical composition are acceptable. This method was also useful in tracking down instrumental errors.

Figure 8 shows the density of several mixtures containing 66.67 mole per cent sodium fluoride. These mixtures were studied to obtain data on the compositions falling on the phase diagram "join" between the compounds Na_2BeF_4 and Na_2UF_6.

Figure 9 shows data obtained on three mixtures containing only sodium fluoride and uranium tetrafluoride.

Densities at several temperatures (usually 600°, 700°, and 800°C) were obtained by interpolation from the foregoing curves in order to further evaluate density as a function of composition. On Figure 10a, b, and c density versus mole per cent sodium fluoride has been plotted at 600°C and 800°C for mixtures having fixed mole per cents uranium tetrafluoride. Figure 11 shows how density varies with mole per cent uranium tetrafluoride in mixtures containing a constant 50:50 ratio of sodium fluoride to beryllium fluoride. These data are listed in Table 5.

Isometric sketches have been drawn to show more clearly the relationship existing between the slopes of the curves derived from density data taken at various uranium tetrafluoride concentrations when the concentrations of the other two constituents are varied (at constant temperature). On Figure 12 density is shown as a function of both sodium fluoride and uranium tetrafluoride concentrations at 800°C; Figure 13 shows the variation with beryllium fluoride and uranium tetrafluoride concentrations. The compositions studied are plotted on triangular coordinates in Figure 14. Measurements were limited to the area shown because of experimental difficulties encountered with mixtures having a liquidus temperature higher than 850°C, or with the high vapor pressure and viscosity of beryllium fluoride-rich mixtures.

Table 2 lists interpolated densities of mixtures having constant uranium tetrafluoride concentrations at 600°, 700°, and 800°C. Table 3 lists interpolated densities for mixtures having constant sodium fluoride concentrations, and Table 4 shows interpolated densities of mixtures with constant beryllium fluoride concentrations.

V. ACKNOWLEDGEMENT

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TABLE 2

Density of Mixtures Having a Constant Mole Per Cent

UF_4 at 600°C, 700°C and 800°C

Composition, Mole Percent			Density (ρ) at		
UF_4	NaF	BeF_2	600°C	700°C	800°C
60	40	0		5.569	5.465
60	30	10		-	5.469
60	20	20		-	5.451
47	46	7		5.079	4.933
47	37	16		5.089	4.961
47	26.5	26.5		5.087	4.959
35	58	7		4.539	4.418
35	46	19		4.491	4.380
35	32.5	32.5		4.499	4.381
35	20	45		4.493	4.419
35	10	55		4.476	4.431
35	0	65		-	4.502
24	76	0	4.063	3.980	3.895
24	70	6	4.022	3.940	3.845
24	58	18	4.006	3.918	3.828
24	46	30	3.850	3.787	3.725
24	30	46	-	3.794	3.711
24	20	56	-	-	3.796
15	76	9	3.416	3.354	3.291
15	70	15	3.379	3.297	3.215
15	42.5	42.5	3.311	3.244	3.154
12	76	12	3.171		3.017
12	70	18	3.162		3.013
12	64	24	3.122		2.983
12	58	30	3.117		2.986
12	52	36	3.104		2.973
12	46	42	3.094		2.978

TABLE 2 (cont'd)

Density of Mixtures Having a Constant Mole Per Cent

UF_4 at 600°C, 700°C and 800°C

Composition, Mole Percent			Density (ρ) at		
UF_4	NaF	BeF_2	600°C	700°C	800°C
10	76	14	3.031		2.879
10	70	20	3.024		2.874
10	64	26	3.002		2.852
10	58	32	2.954		2.804
10	52	38	2.926		2.794
10	46	44	2.927		2.797
8	76	16	-		2.687
8	70	22	2.834		2.695
8.1	65.9	26	2.786		2.677
8	64	28	2.819		2.683
8	58	34	2.779		2.650
8	52	40	2.767		2.639
8	46	46	2.749		2.632
6	76	18	-		2.543
6	70	24	2.633		2.505
6	64	30	2.604		2.481
6	58	36	2.601		2.477
6	52	42	2.573		2.445
6	46	48	2.579		2.441
6	40	54	2.553		2.447
6	30	64	2.489		2.412
4	76	20	-		2.328
4	70	26	2.476		2.350
4	64	32	2.467		2.345
4	58	38	2.443		2.313
4	52	44	2.397		2.279
4	46	50	2.381		2.275

TABLE 2 (cont'd)

Density of Mixtures Having a Constant Mole Per Cent

UF_4 at 600°C, 700°C and 800°C

Composition, Mole Percent			Density (ρ) at		
UF_4	NaF	BeF_2	600°C	700°C	800°C
2	76	22	-		2.152
2	70	28	2.249		2.144
2	64	34	2.254		2.144
2	58	40	2.227		2.118
2	52	46	2.211		2.104
2	46	52	2.181		2.082
0	80	20	-		2.024
0	66.7	33.3	2.111		2.034
0	60	40	2.113		2.007
0	52.9	47.1	2.099		2.034
0	50	50	2.070		1.969
0	40	60	2.086		1.982
0	20	80	-		1.971

TABLE 3

Density of Mixtures Having a Constant Mole Per Cent NaF at 600°C, 700°C and 800°C

Composition, Mole Percent			Density (ρ) at		
NaF	BeF_2	UF_4	600°C	700°C	800°C
66.6	33.3	0	2.11		2.01
66.6	30.74	2.54	2.31		2.22
66.6	28.61	4.72	2.49		2.36
66.6	25.07	8.26	2.81		2.66
66.6	22.31	11.02	3.03		2.88
66.6	20.10	13.22	3.13		2.98
64	24	12	3.122		2.983
64	26	10	3.002		2.852
64	28	8	2.819		2.683
64	30	6	2.604		2.481
64	32	4	2.467		2.345
64	34	2	2.254		2.144
64	36	0	2.108		2.008
58	0	42	-	4.946	4.830
58	7	35	-	4.539	4.418
58	18	24	4.006	3.918	3.828
58	30	12	3.117	-	2.986
58	32	10	2.954	-	2.804
58	34	8	2.779	-	2.650
58	36	6	2.601	-	2.477
58	38	4	2.443	-	2.313
58	39	3	2.399	-	2.277
58	40	2	2.227	-	2.118
58	41	1	2.121	-	2.025
58	42	0	2.103	-	2.005

TABLE 3 (cont'd)

Density of Mixtures Having a Constant Mole Per Cent

NaF at 600°C, 700°C and 800°C

Composition, Mole Percent			Density (ρ) at		
NaF	BeF_2	UF_4	600°C	700°C	800°C
76	24	0		-	2.018
76	22	2		2.198	2.152
76	20	4		2.377	2.328
76	18	6		2.605	2.543
76	16	8		2.751	2.687
76	14	10		2.958	2.879
76	12	12		3.076	3.017
76	9	15		3.354	3.291
76	6	18		3.548	3.494
76	0	24		3.980	3.898
70	6	24	3.975		3.856
70	15	15	3.377		3.215
70	18	12	3.162		3.013
70	20	10	3.024		2.874
70	22	8	2.834		2.695
70	24	6	2.633		2.505
70	26	4	2.476		2.350
70	28	2	2.249		2.144
70	30	0	2.113		2.012
52	36	12	3.104		2.973
52	38	10	2.926		2.794
52	40	8	2.767		2.639
52	42	6	2.573		2.440
52	44	4	2.397		2.279
52	45	3	2.295		2.182
52	46	2	2.211		2.104
52	47	1	2.137		2.033
52	48	0	2.098		1.992

TABLE 3 (cont'd)

Density of Mixtures Having a Constant Mole Per Cent

NaF at 600°C, 700°C and 800°C

Composition, Mole Percent			Density (ρ) at		
NaF	BeF_2	UF_4	600°C	700°C	800°C
46	0	54	-	5.379	5.231
46	7	47	-	5.075	4.929
46	19	35	-	4.491	4.380
46	30	24	3.850	3.787	3.725
46	42	12	3.094	-	2.978
46	44	10	2.927	-	2.797
46	46	8	2.749	-	2.632
46	48	6	2.579	-	2.441
46	50	4	2.381	-	2.275
46	52	2	2.181	-	2.082
46	53	1	2.115	-	2.020
46	54	0	2.088	-	1.985

TABLE 4

Density of Mixtures Having a Constant Mole Per Cent

BeF_2 at 600°C, 700°C and 800°C

Composition, Mole Percent			Density (ρ) at		
BeF_2	NaF	UF_4	600°C	700°C	800°C
0	76	24	4.063	3.980	3.898
0	58	42	-	4.946	4.830
0	46	54	-	5.379	5.231
0	40	60	-	5.569	5.465
0	30	70	-	-	5.873
10	76	14	-	3.263	3.202
10	70	20	3.713	3.641	3.571
10	66	24	3.985	3.898	3.846
10	58	32	-	4.363	4.253
10	55	35	-	4.498	4.380
10	46	44	-	4.922	4.810
10	43	47	-	5.082	4.942
10	30	60	-	-	5.469
20	76	4	-	-	2.328
20	74	6	-	-	2.530
20	72	8	-	-	2.693
20	70	10	3.024	2.949	2.874
20	68	12	3.143	3.069	2.996
20	58	22	3.700	3.620	3.541
20	56	24	3.980	3.896	3.811
20	46	34	-	4.422	4.309
20	45	35	-	4.491	4.380
20	33	47	-	5.088	4.960
20	20	60	-	-	5.401

TABLE 4 (cont'd)

Density of Mixtures Having a Constant Mole Per Cent

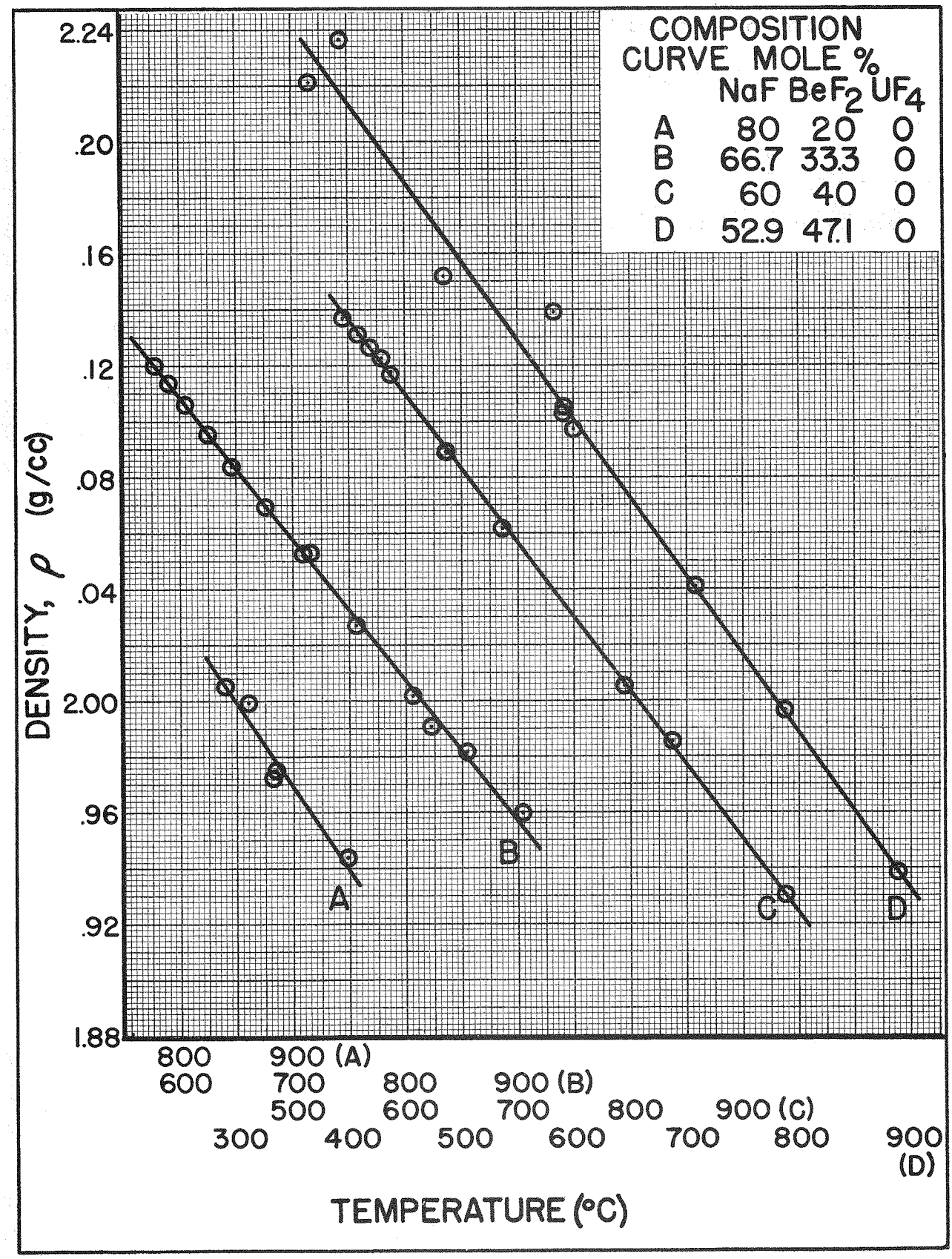
BeF_2 at 600°C, 700°C and 800°C

Composition, Mole Percent			Density (ρ) at		
BeF_2	NaF	UF_4	600°C	700°C	800°C
30	70	0	2.113	-	2.012
30	68	2	2.249	-	2.144
30	66	4	2.470	-	2.348
30	64	6	2.604	-	2.481
30	62	8	2.803	-	2.670
30	60	10	2.969	-	2.821
30	58	12	3.117	-	2.986
30	46	24	3.850	3.787	3.725
30	35	35	-	4.498	4.381
30	30	40	-	4.743	4.610
40	60	0	2.113	-	2.007
40	58	2	2.227	-	2.118
40	56	4	2.427	-	2.294
40	54	6	2.583	-	2.456
40	52	8	2.767	-	2.639
40	50	10	2.926	-	2.796
40	48	12	3.096	-	2.977
40	46	14	3.208	-	3.099
40	40	20	2.512	3.558	3.598

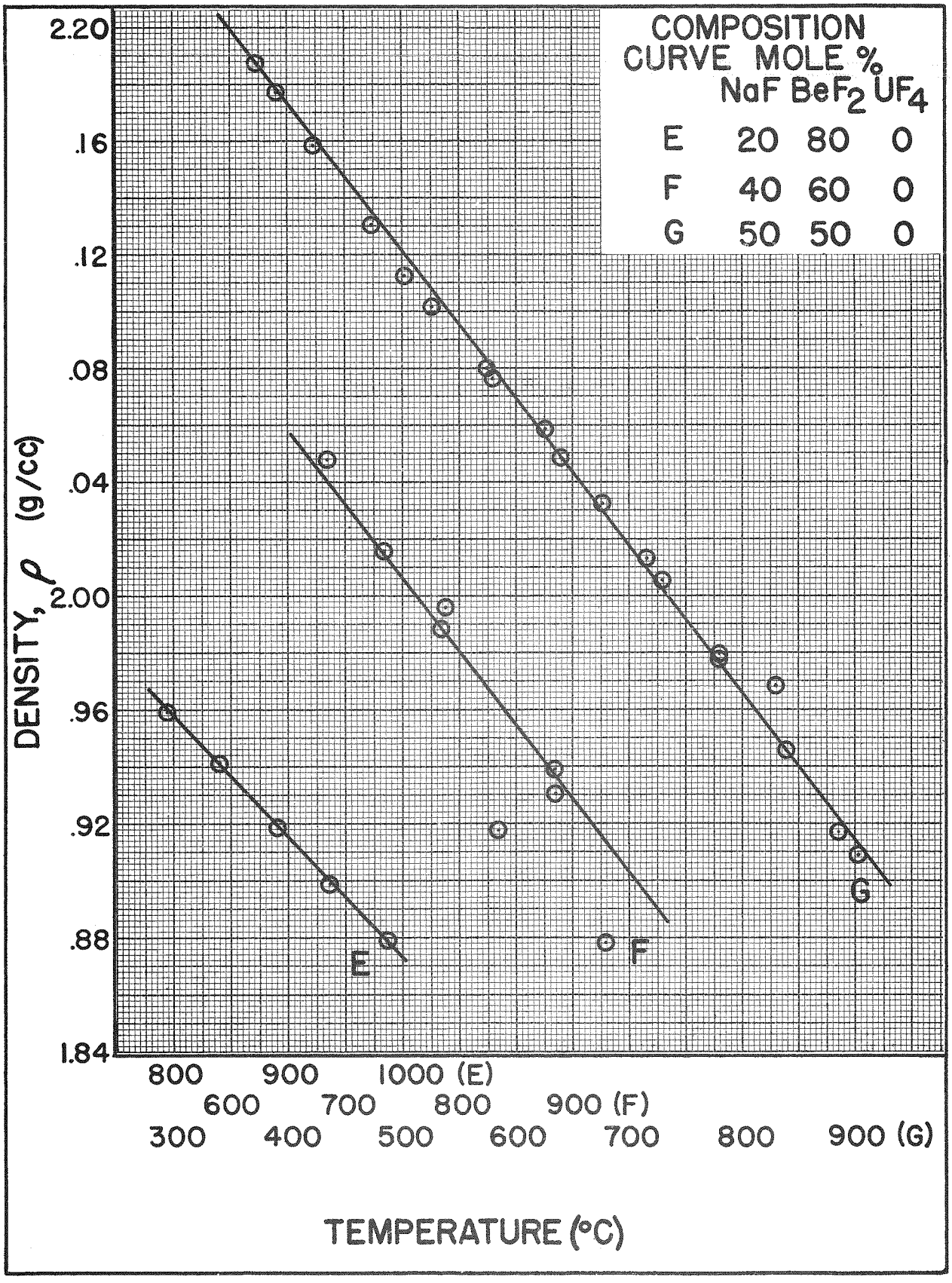
TABLE 5

Density of Mixtures Having a Constant Ratio of NaF to BeF_2 at 600°C, 700°C and 800°C

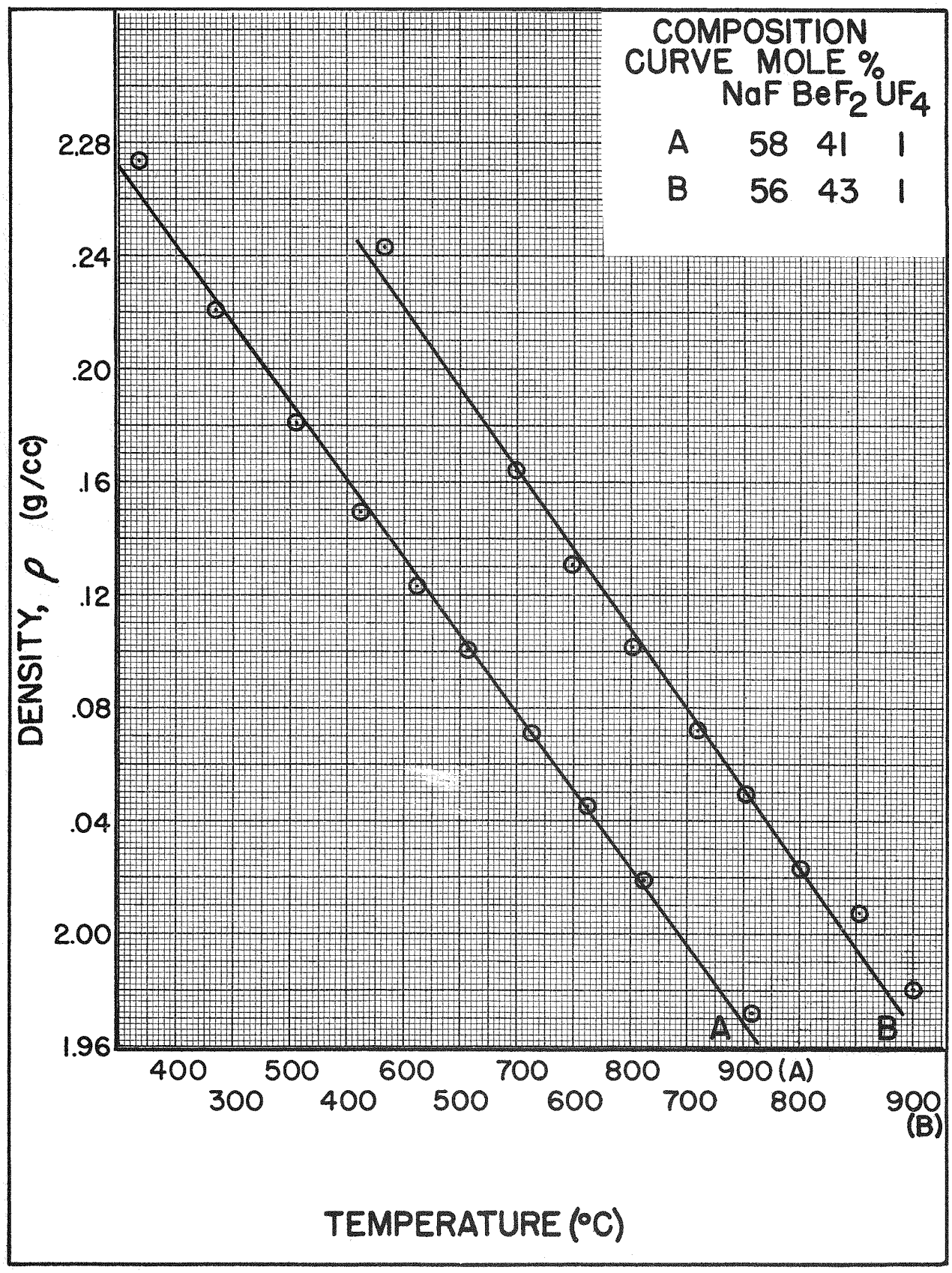
Composition, Mole Percent			Density (ρ) at		
NaF	BeF_2	UF_4	600°C	700°C	800°C
50	50	0	2.070	-	1.969
49	49	2	2.196	-	2.092
48	48	4	2.384	-	2.277
47	47	6	2.578	-	2.442
46	46	8	2.749	-	2.632
38	38	24	-	3.791	3.718
42.5	42.5	15	3.311	3.245	3.184
40	40	20	3.631	3.561	3.490
32.5	32.5	35	-	4.499	4.381
26.5	26.5	47	-	5.087	4.959
20	20	60	-	-	5.401



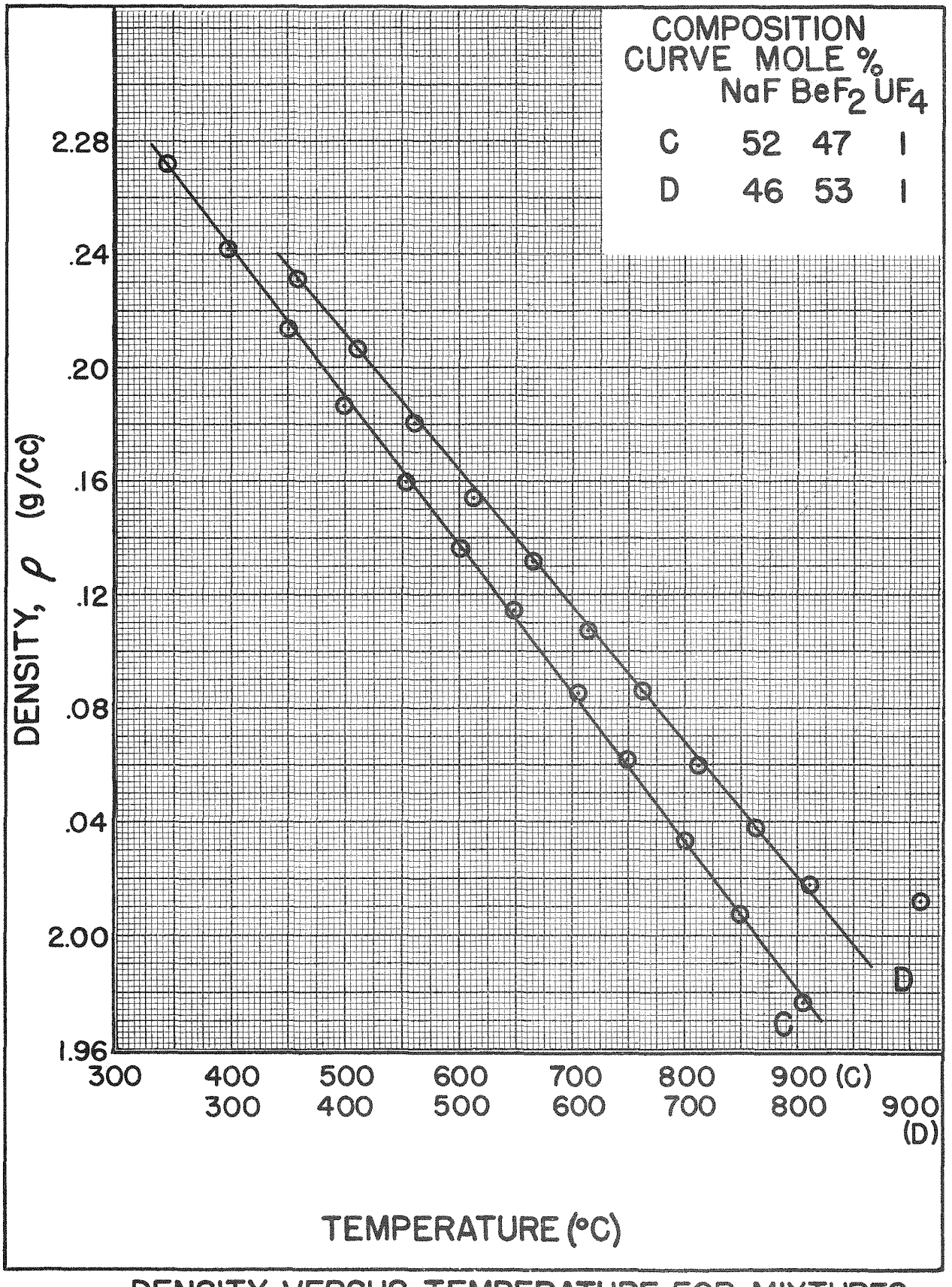
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7a1



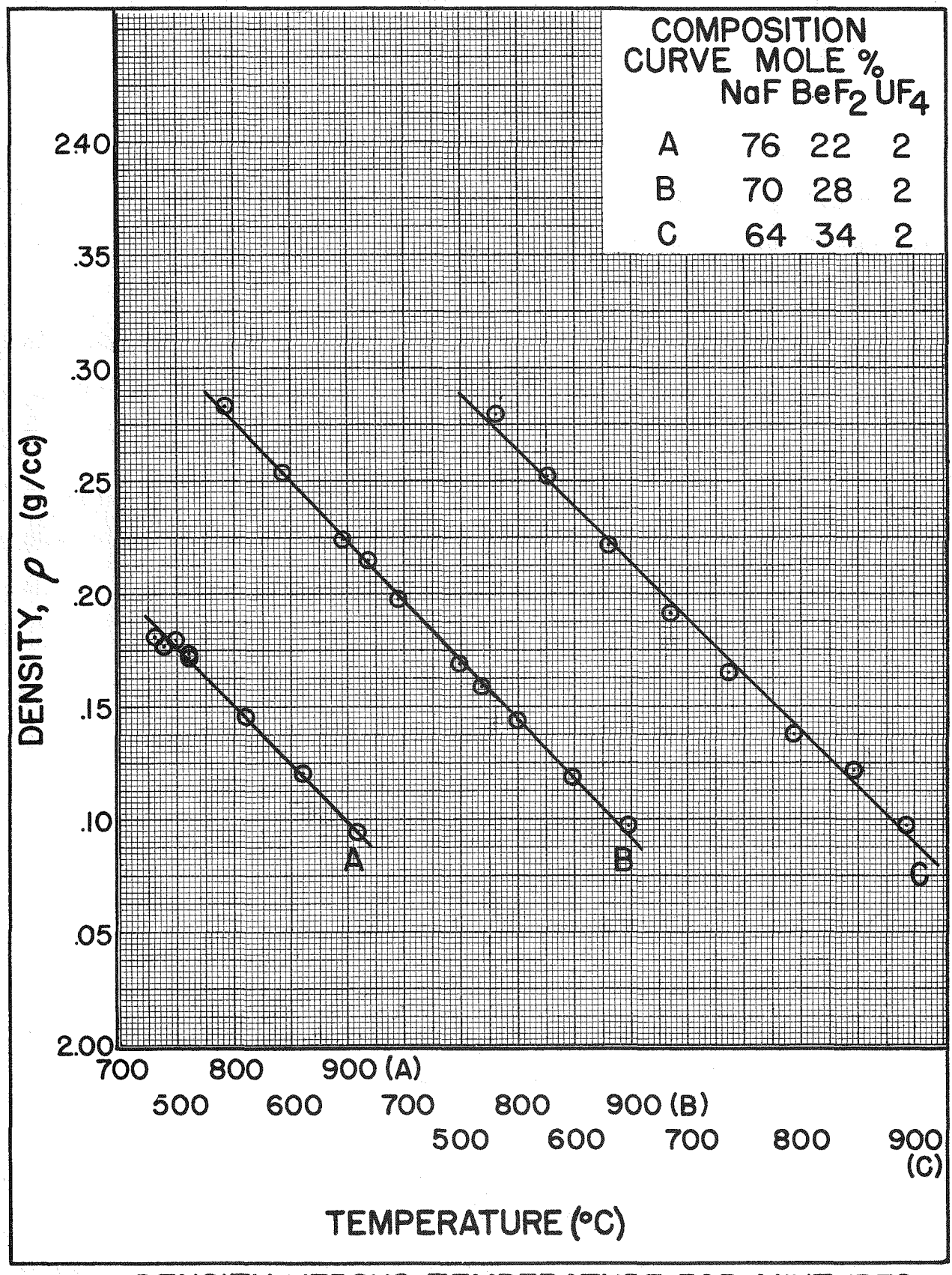
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7a2



DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7b1

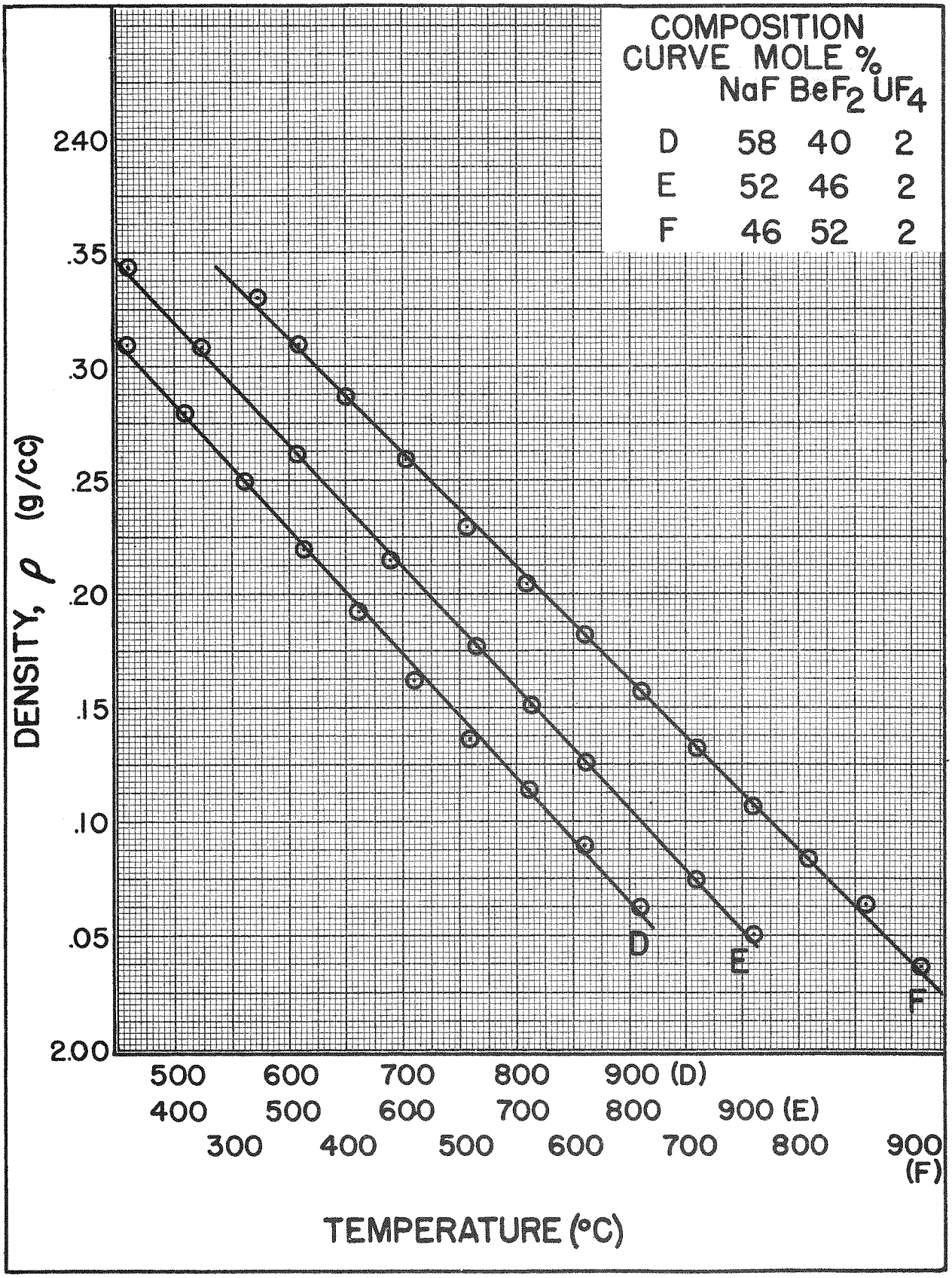


DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7b2

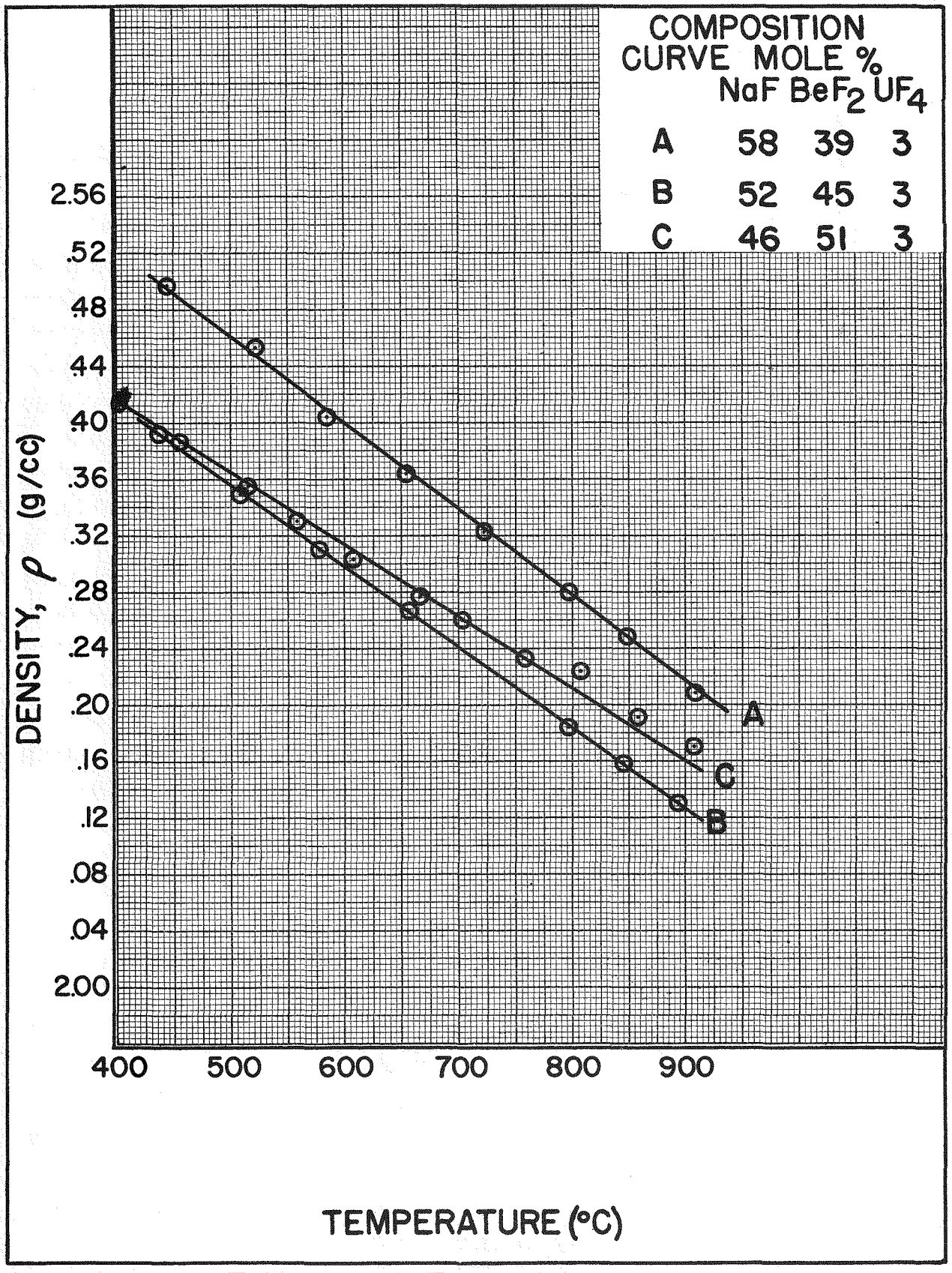


DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4

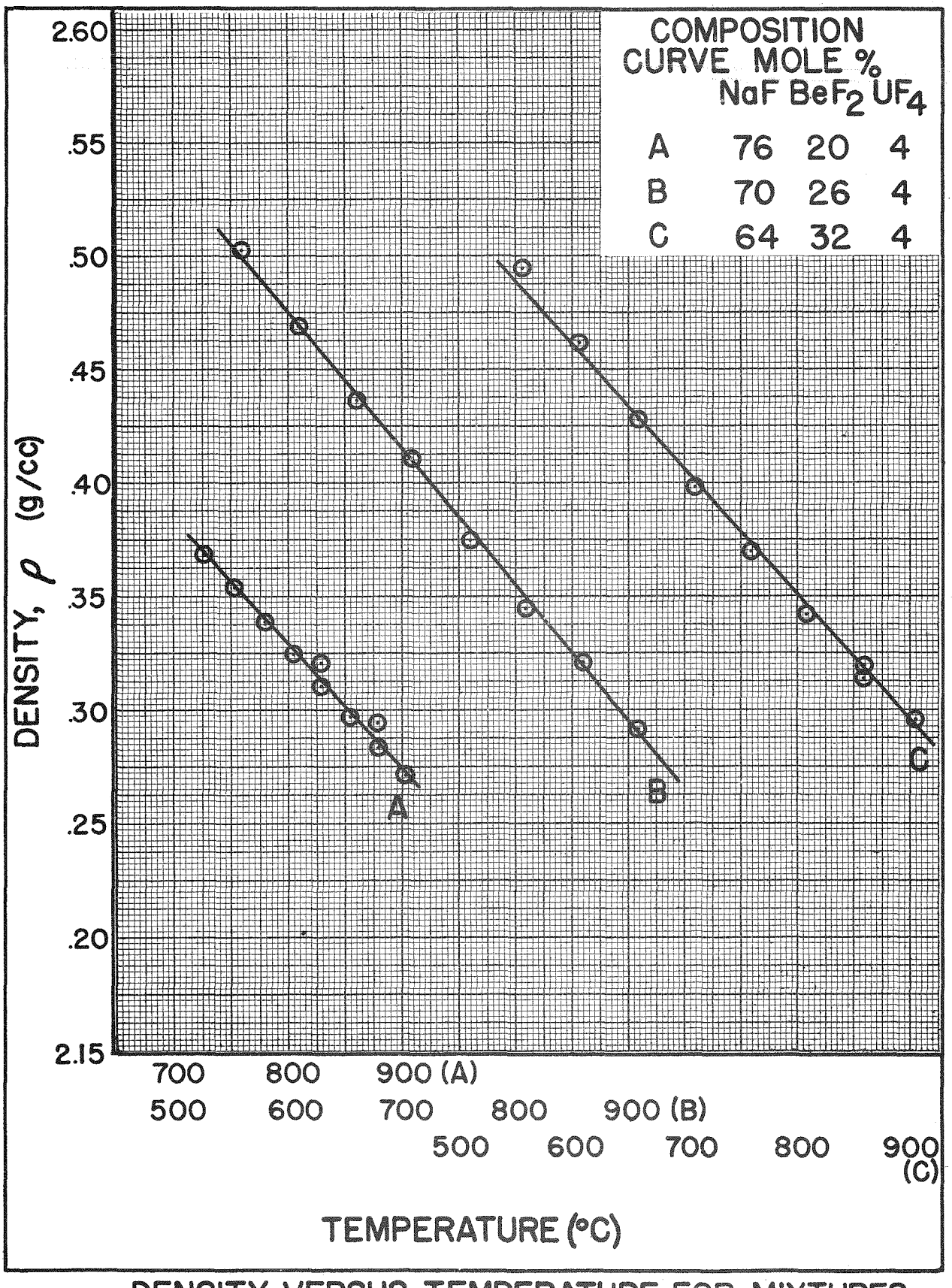
FIGURE 7c1



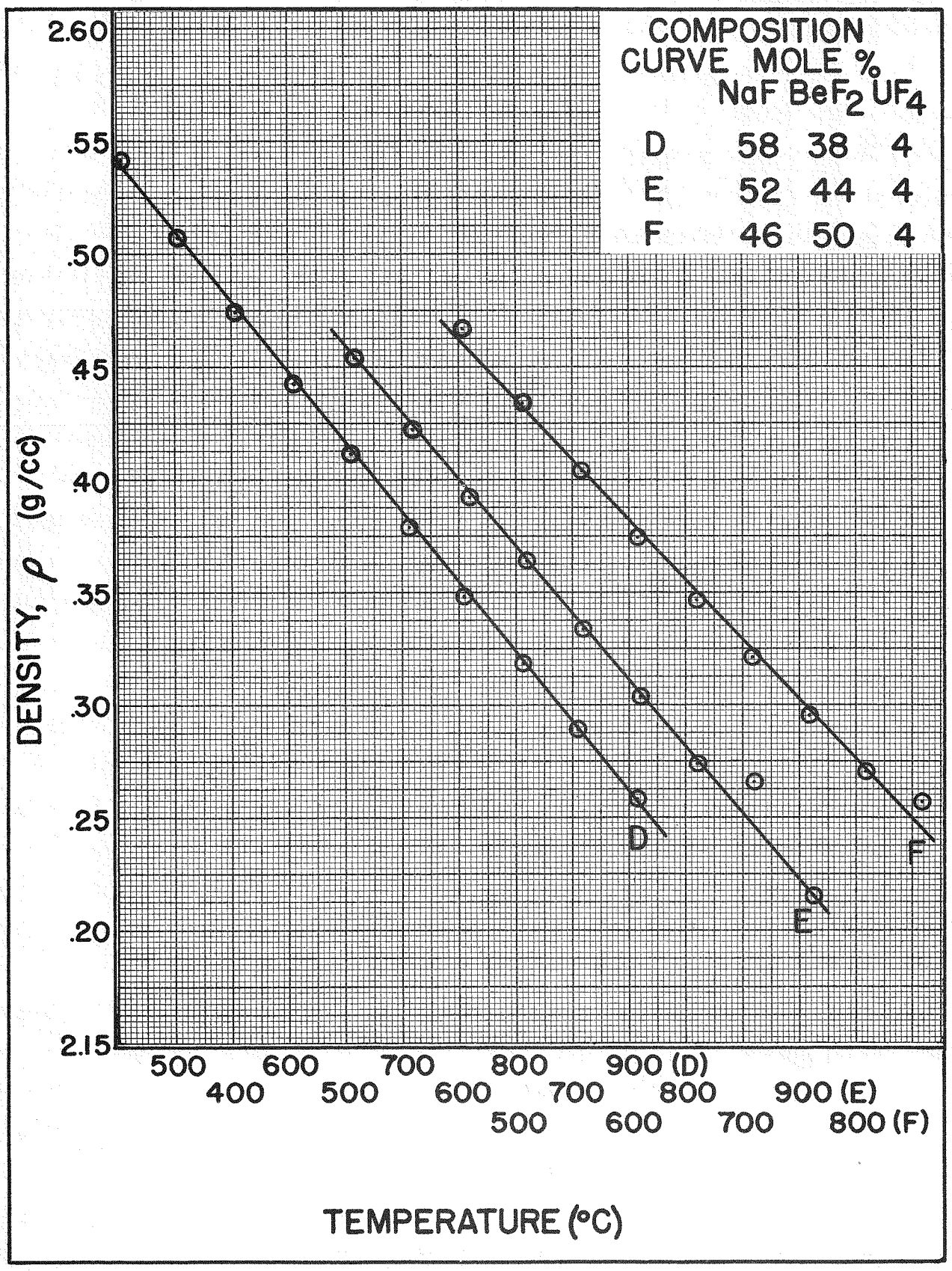
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7c2



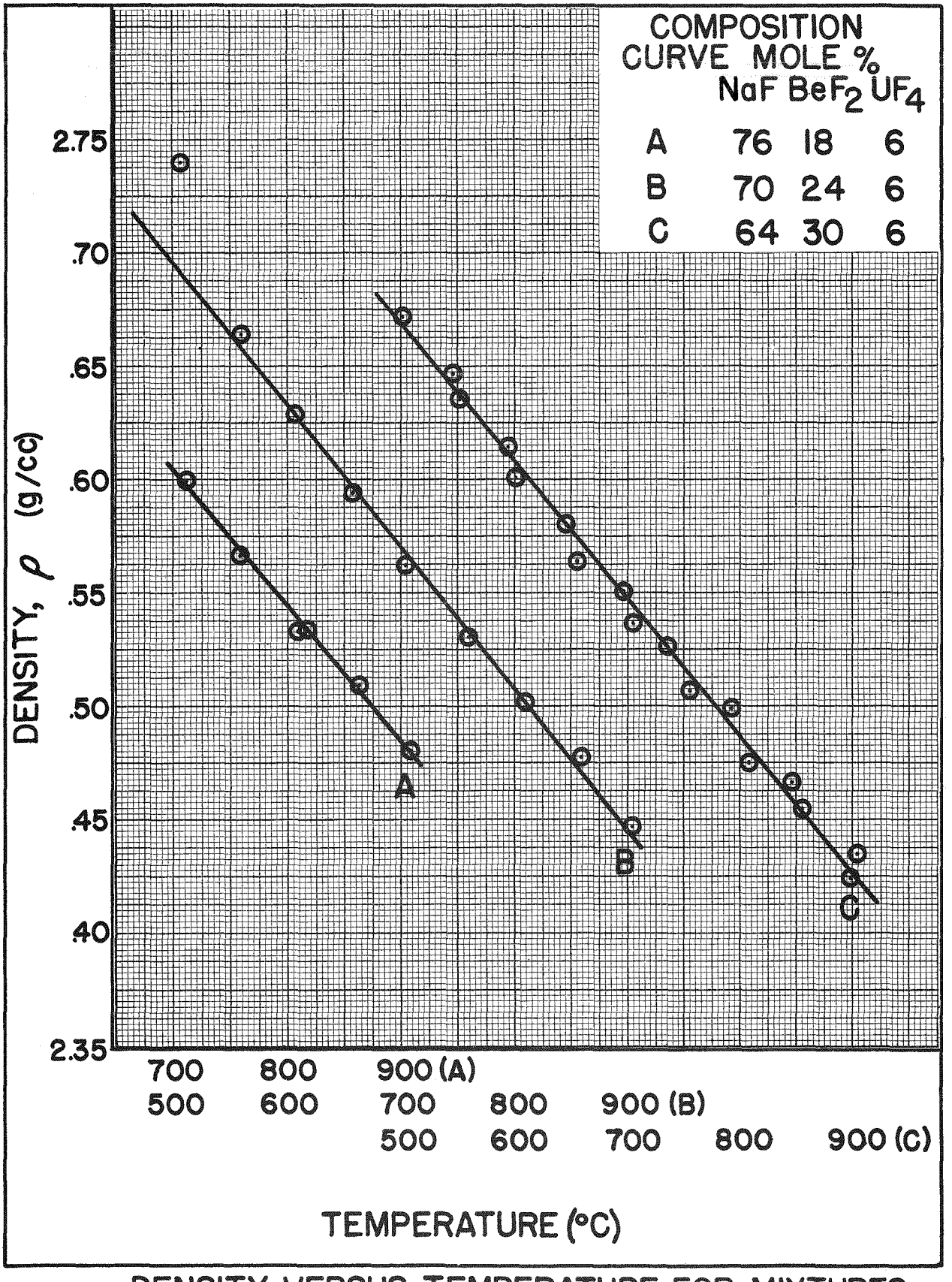
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7d



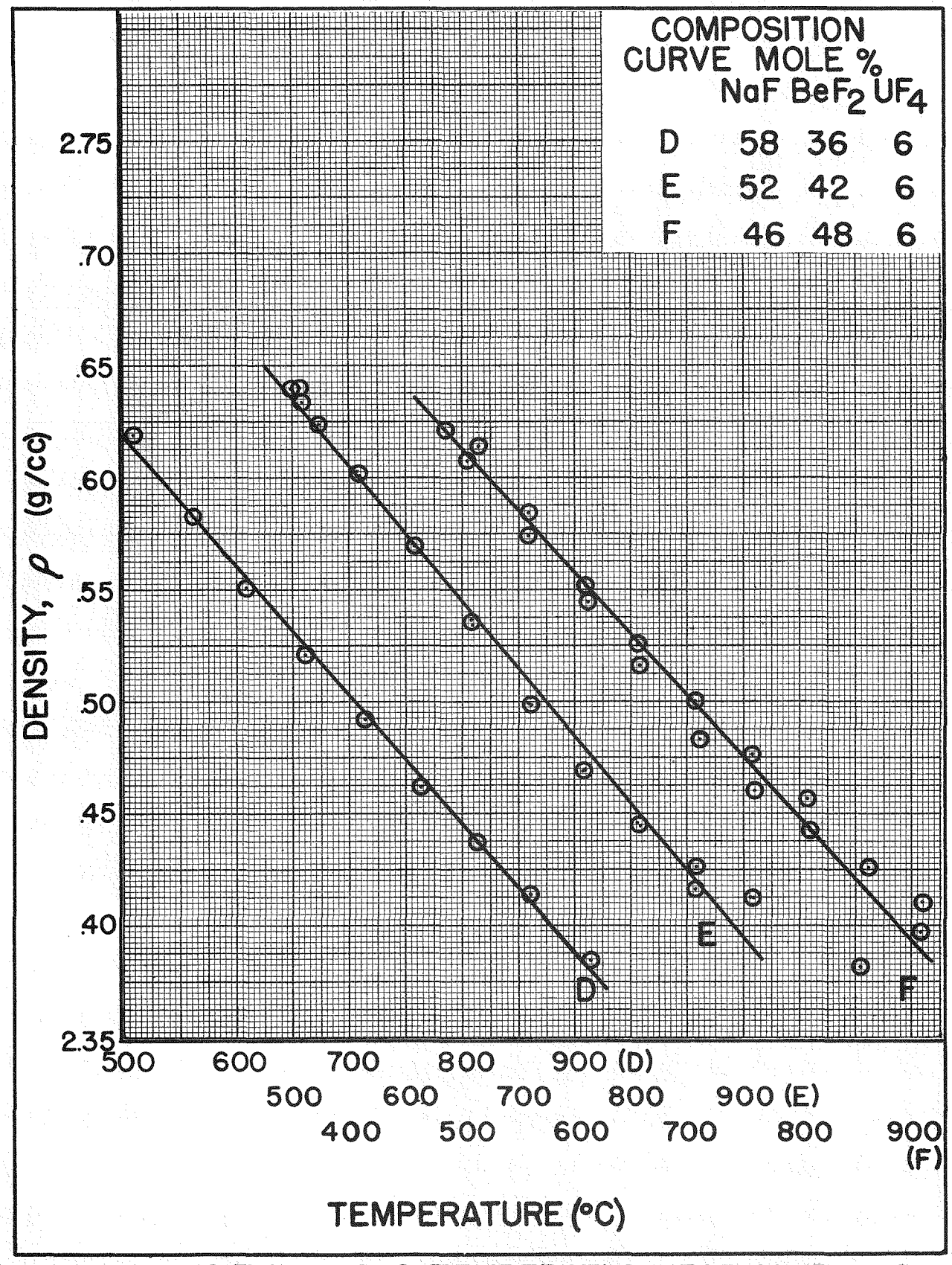
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7e 1



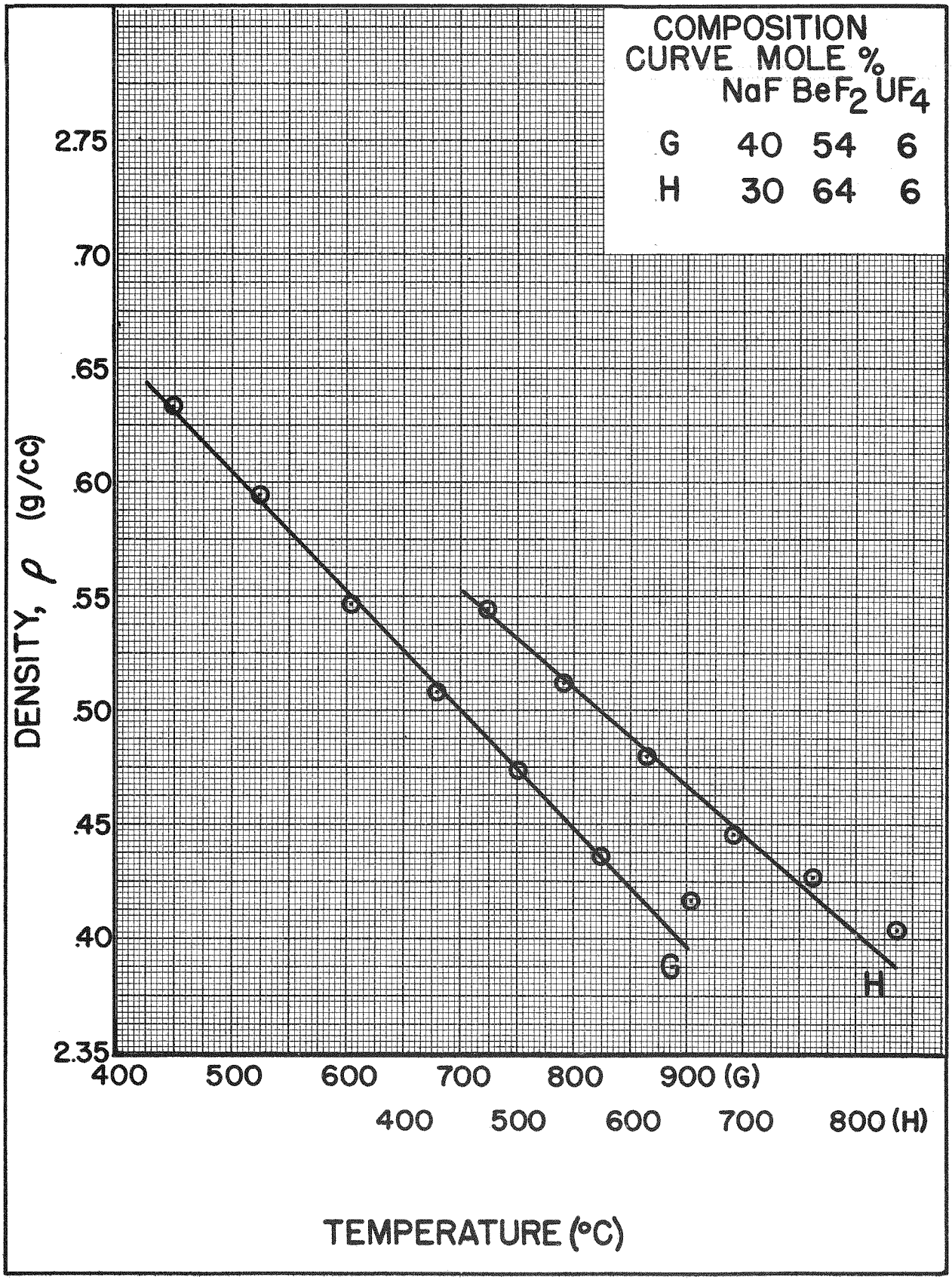
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7 e 2



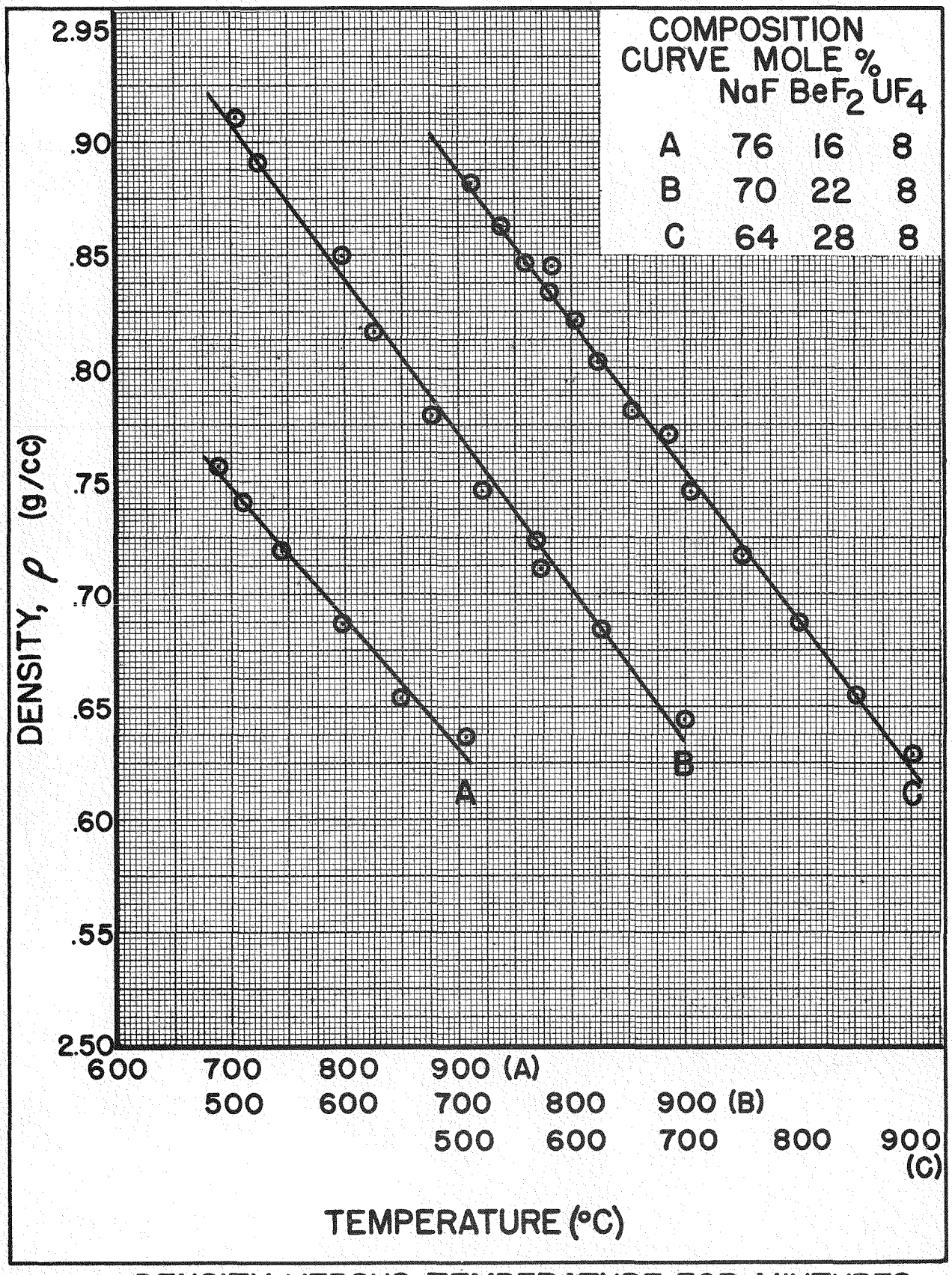
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7f 1



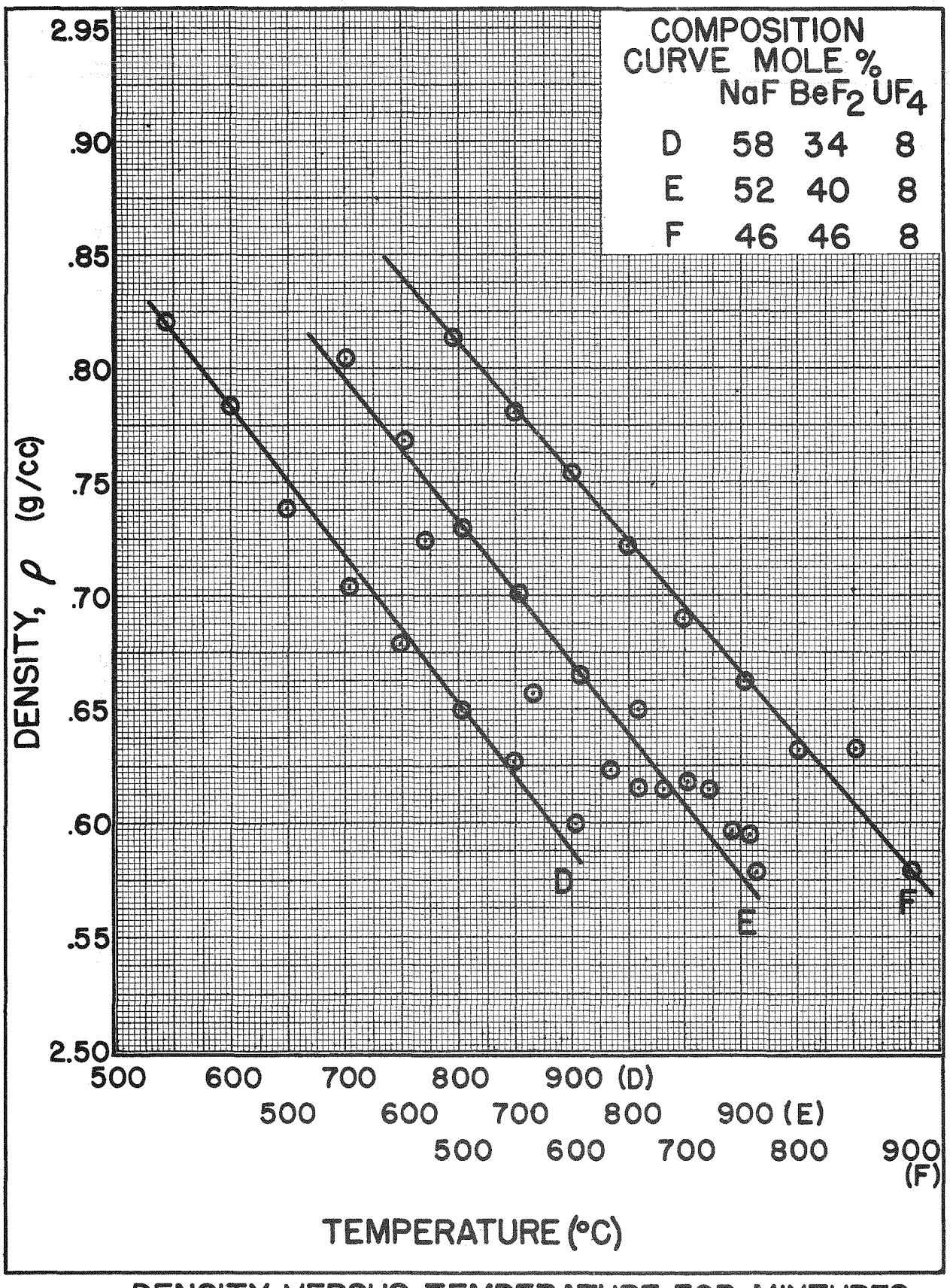
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7f 2



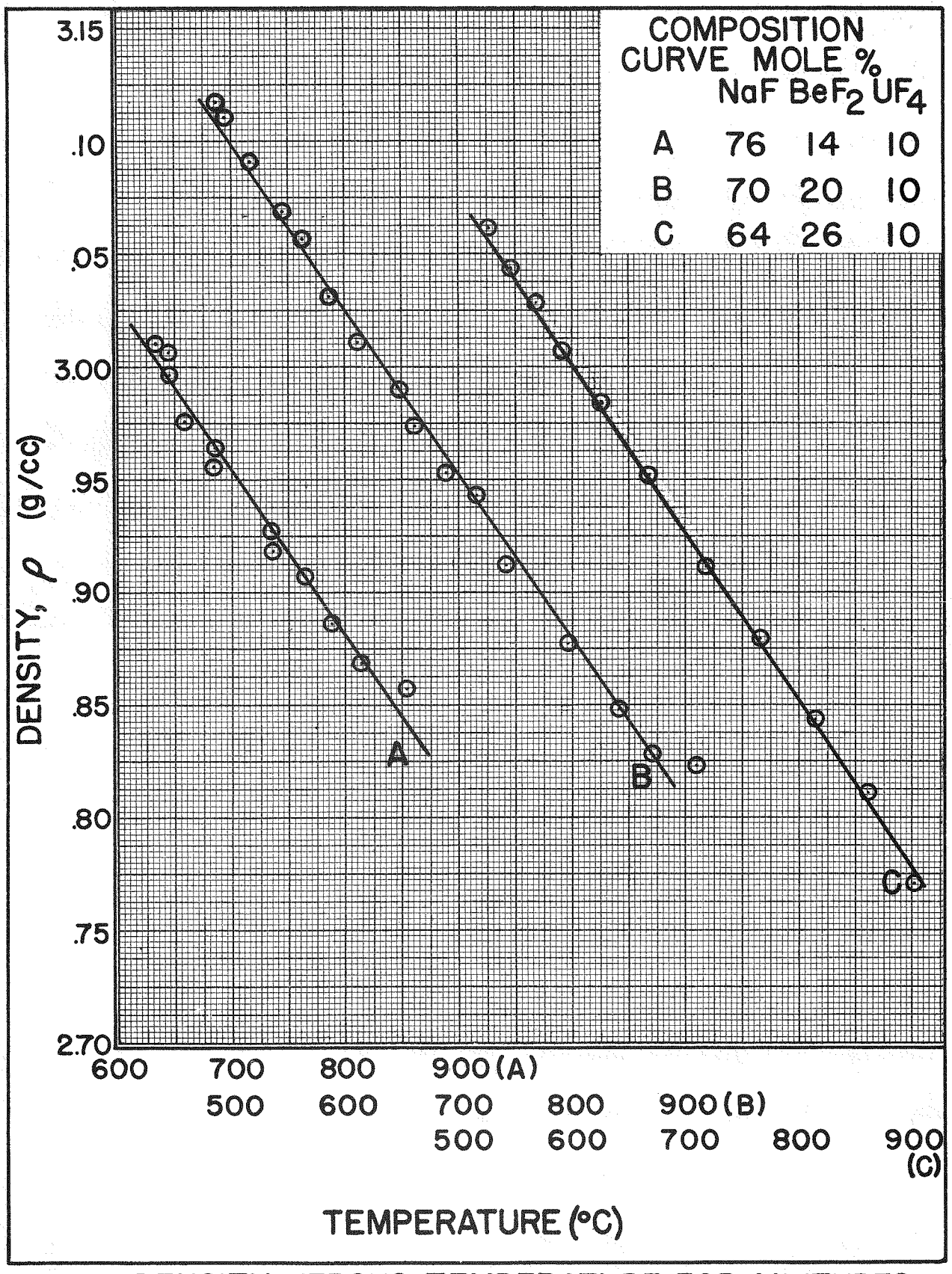
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7 f 3



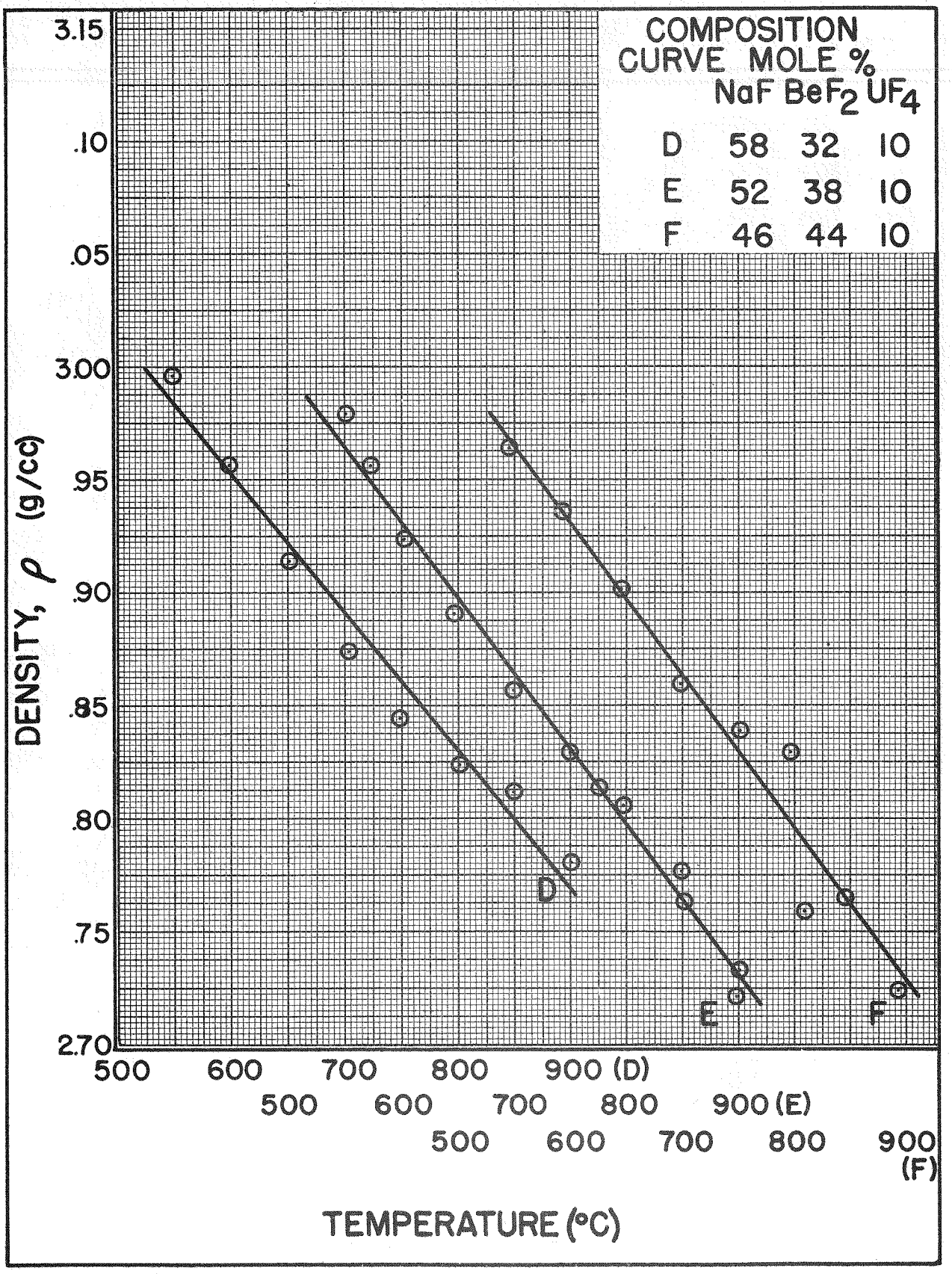
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7g1



DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7g2

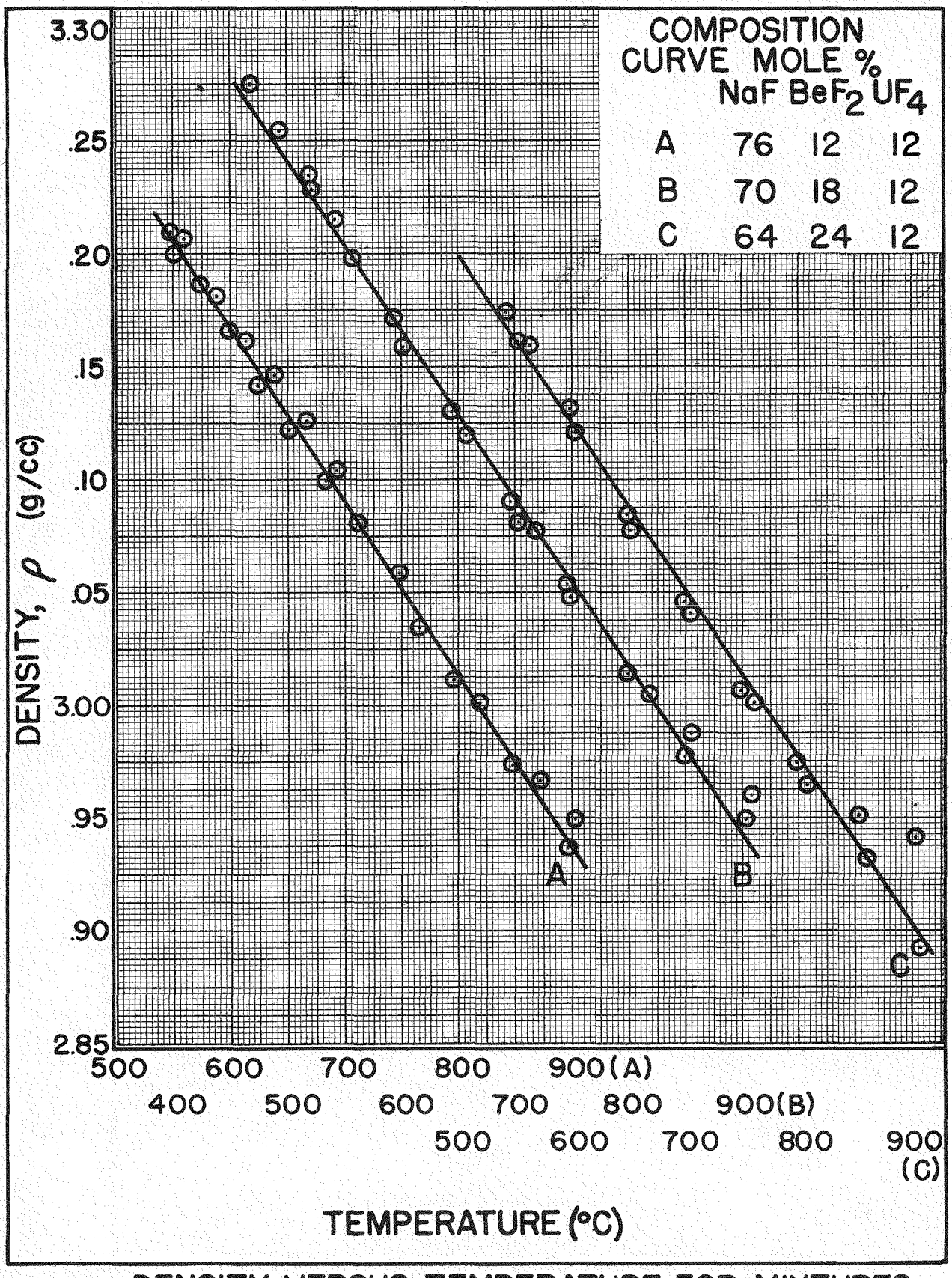


DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7h1



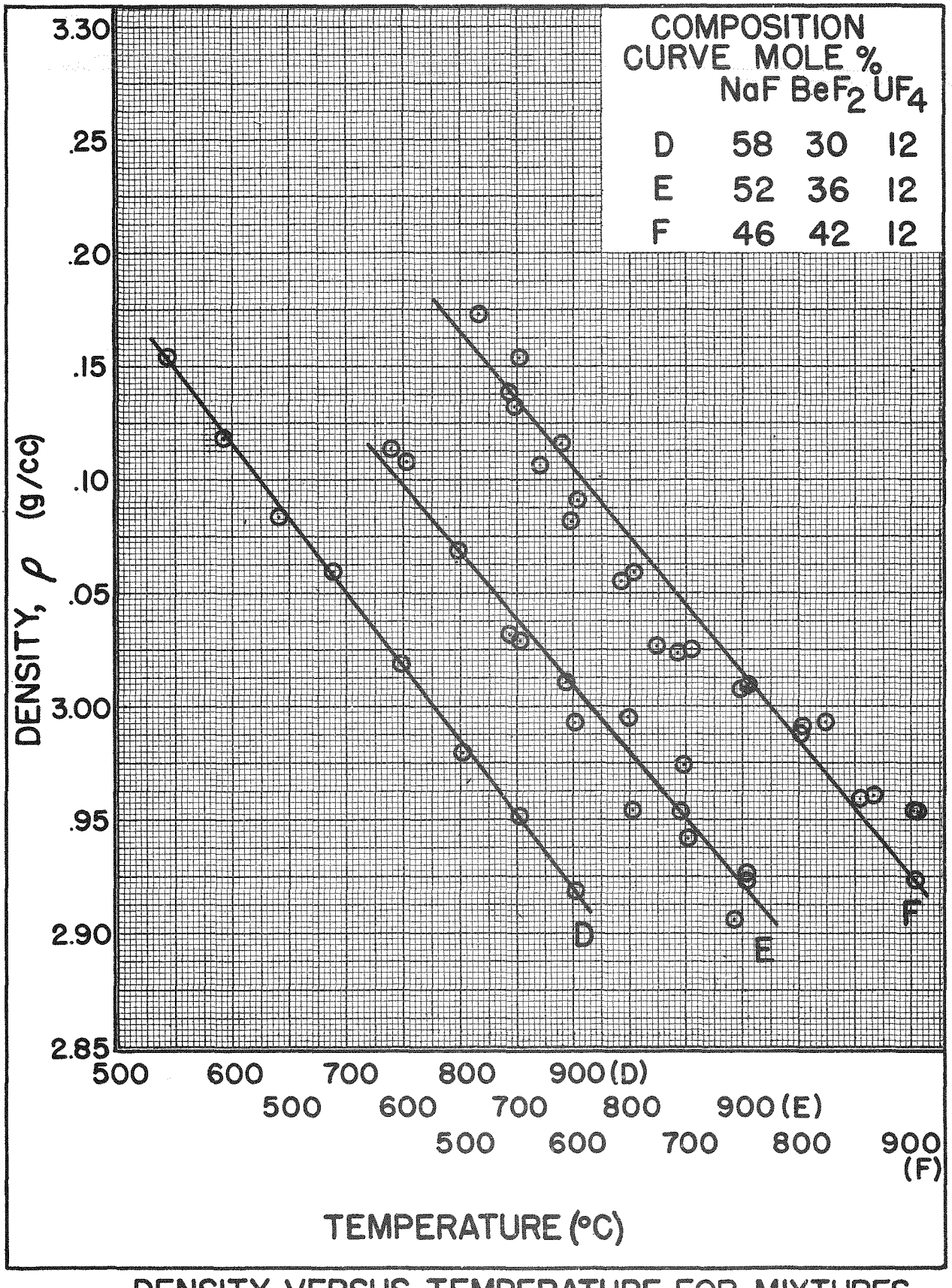
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4

FIGURE 7h 2

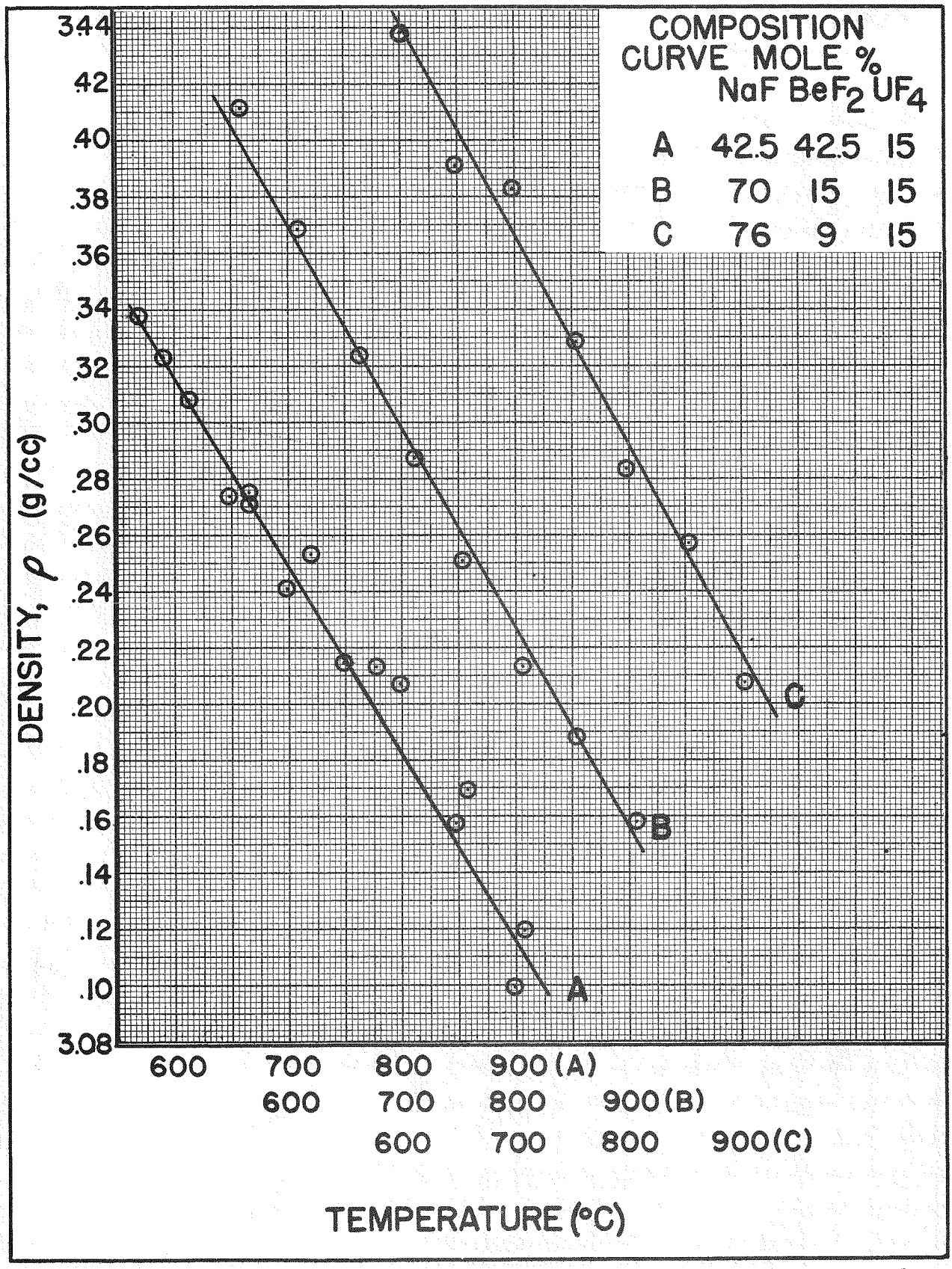


DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4

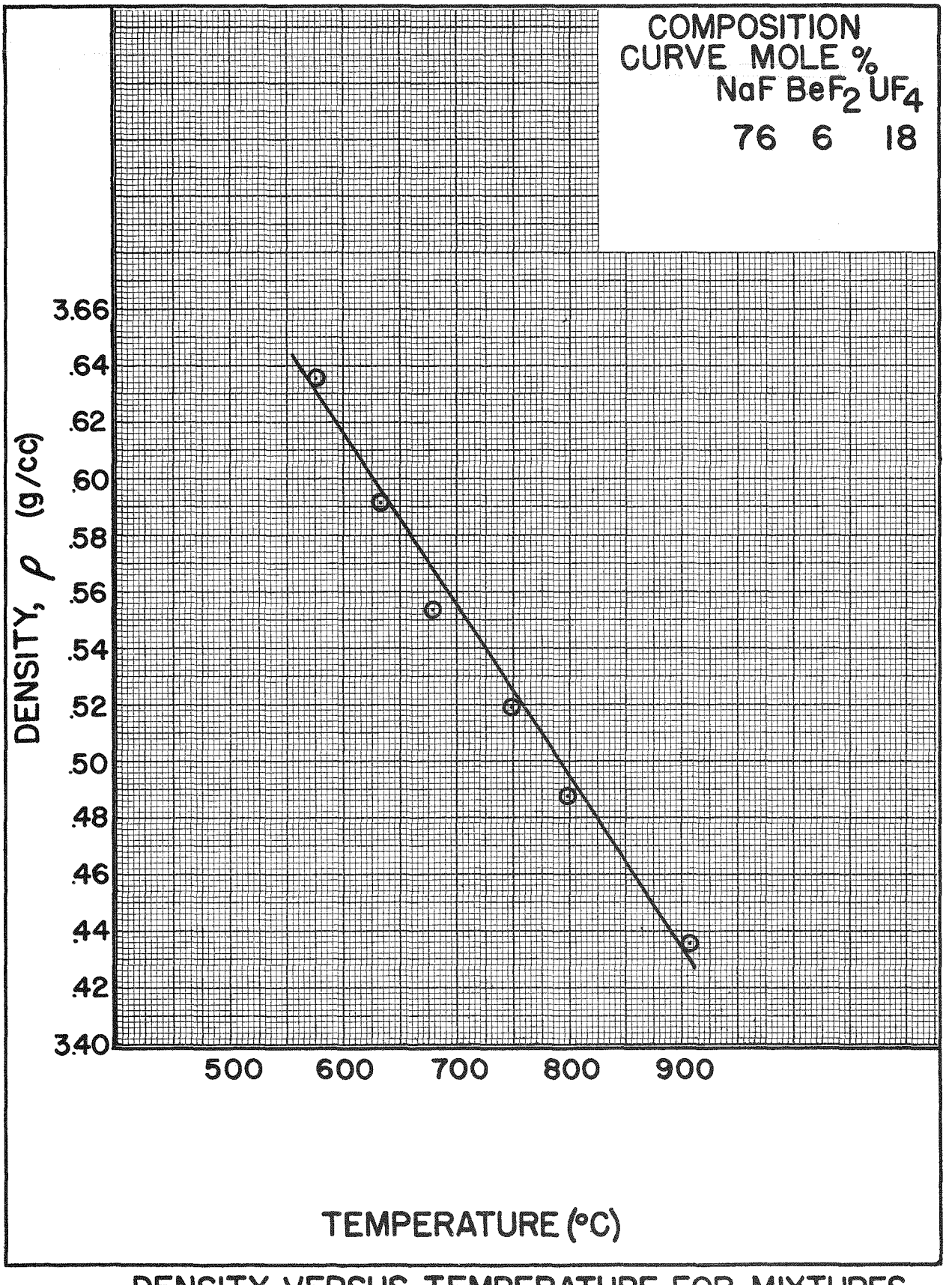
FIGURE 7 j 1



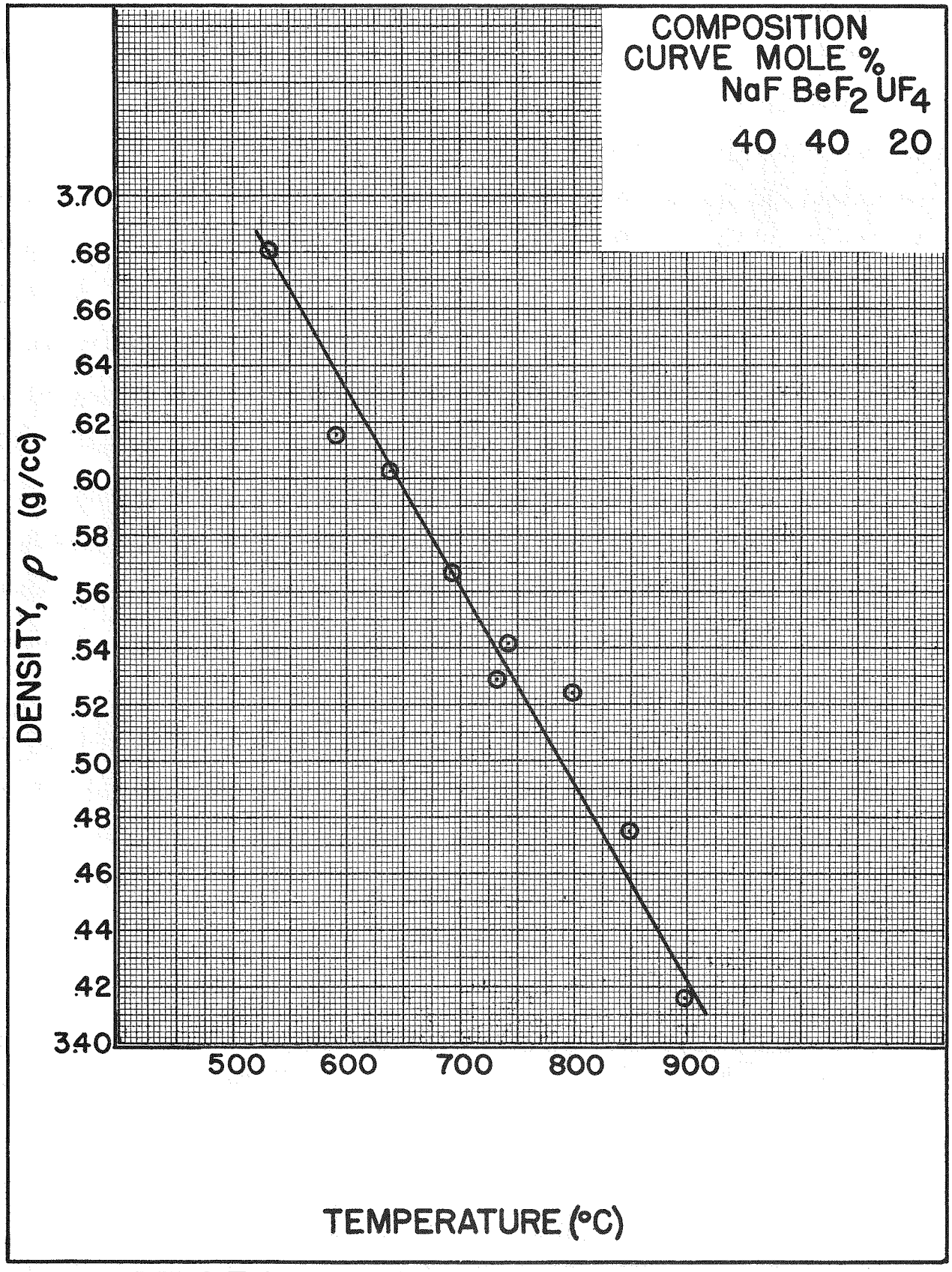
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7j2



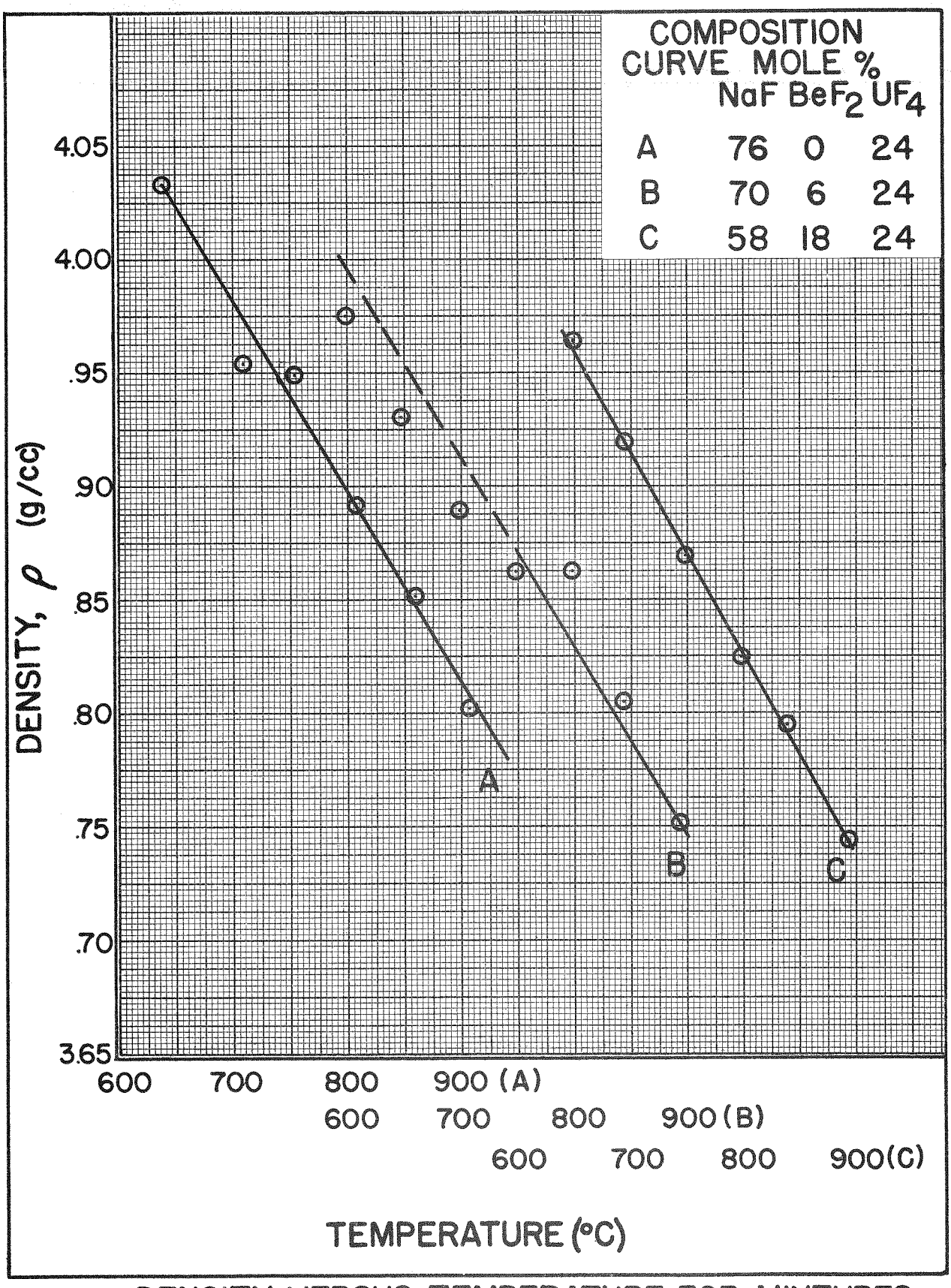
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7k



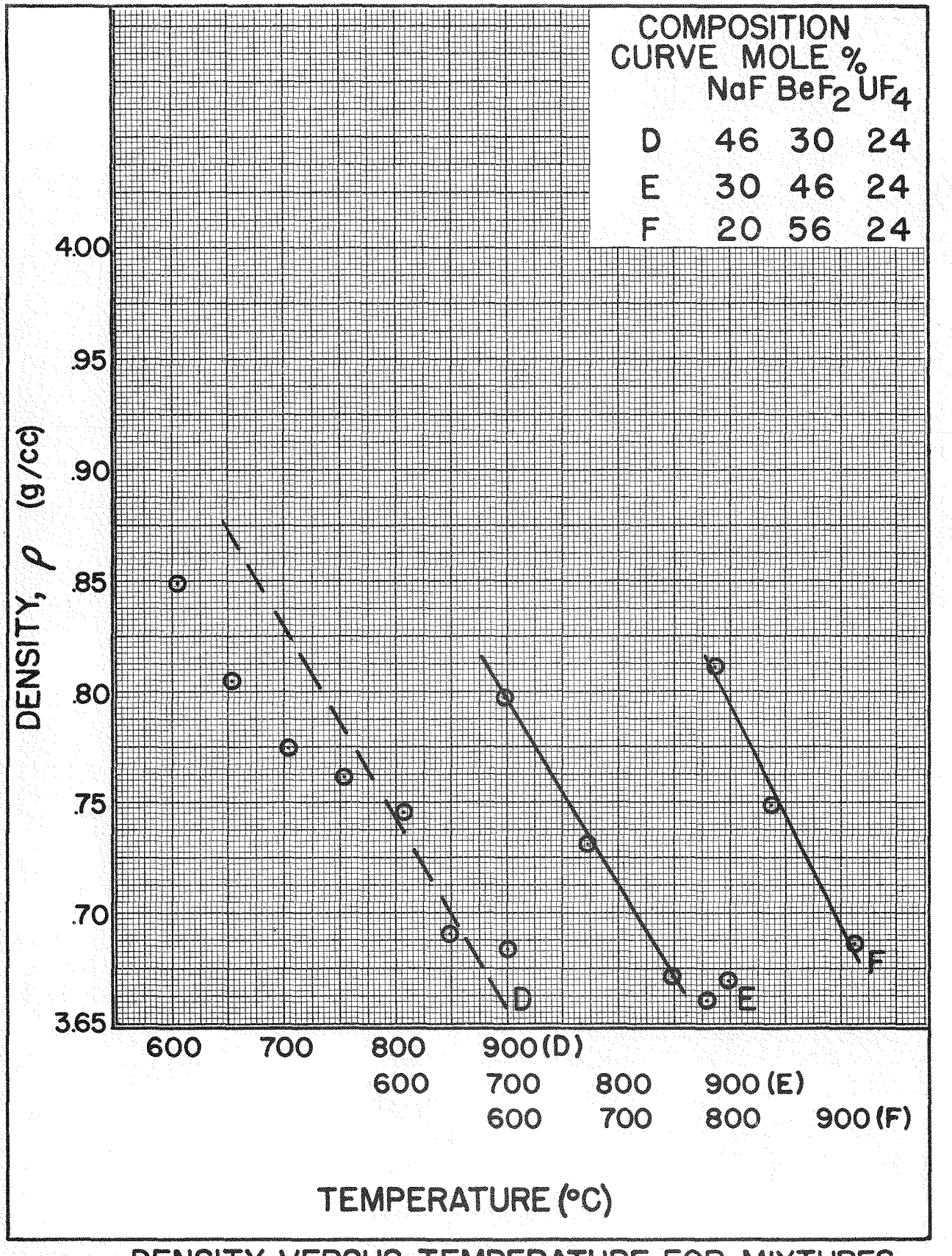
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7 m



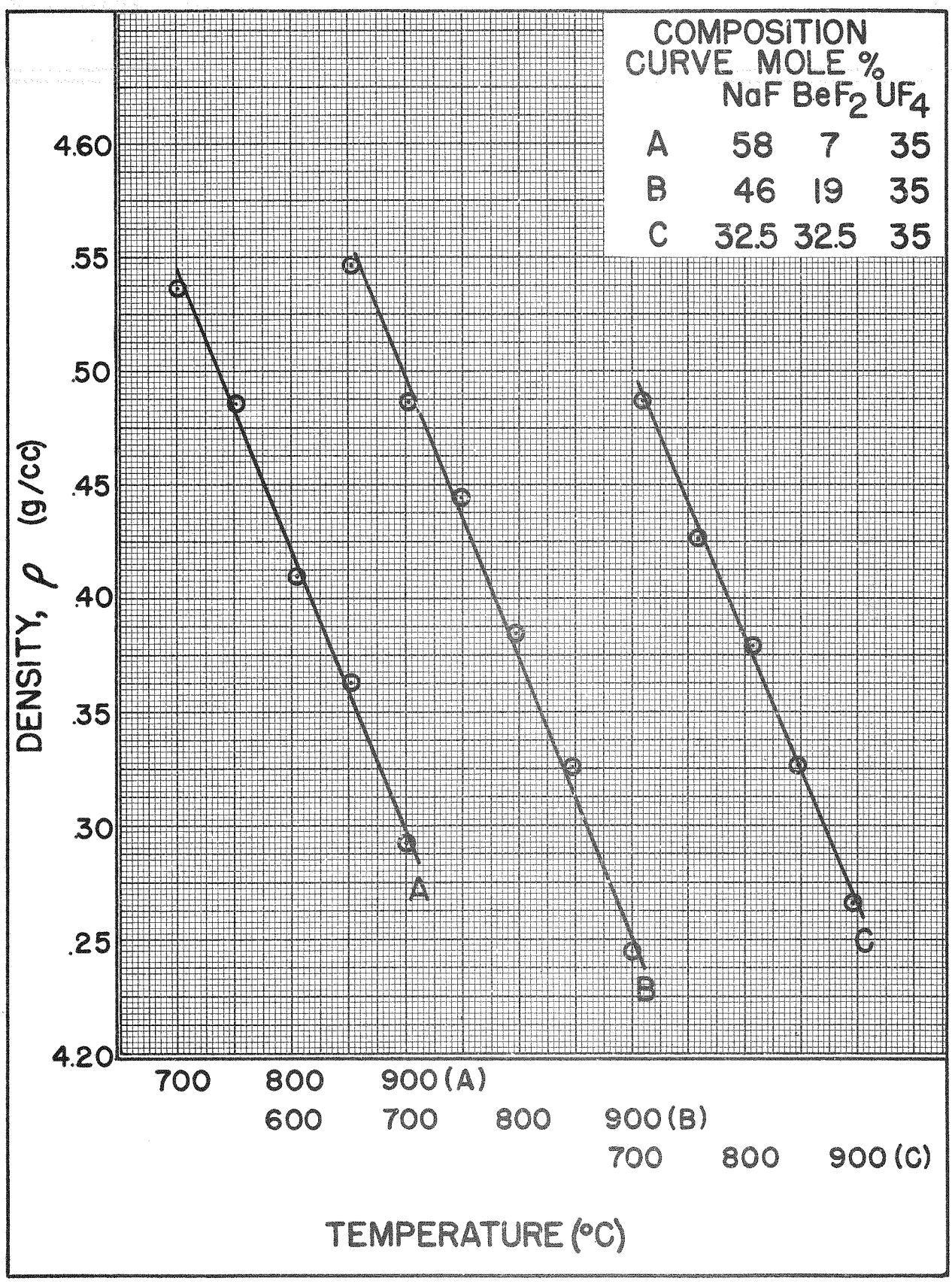
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7n



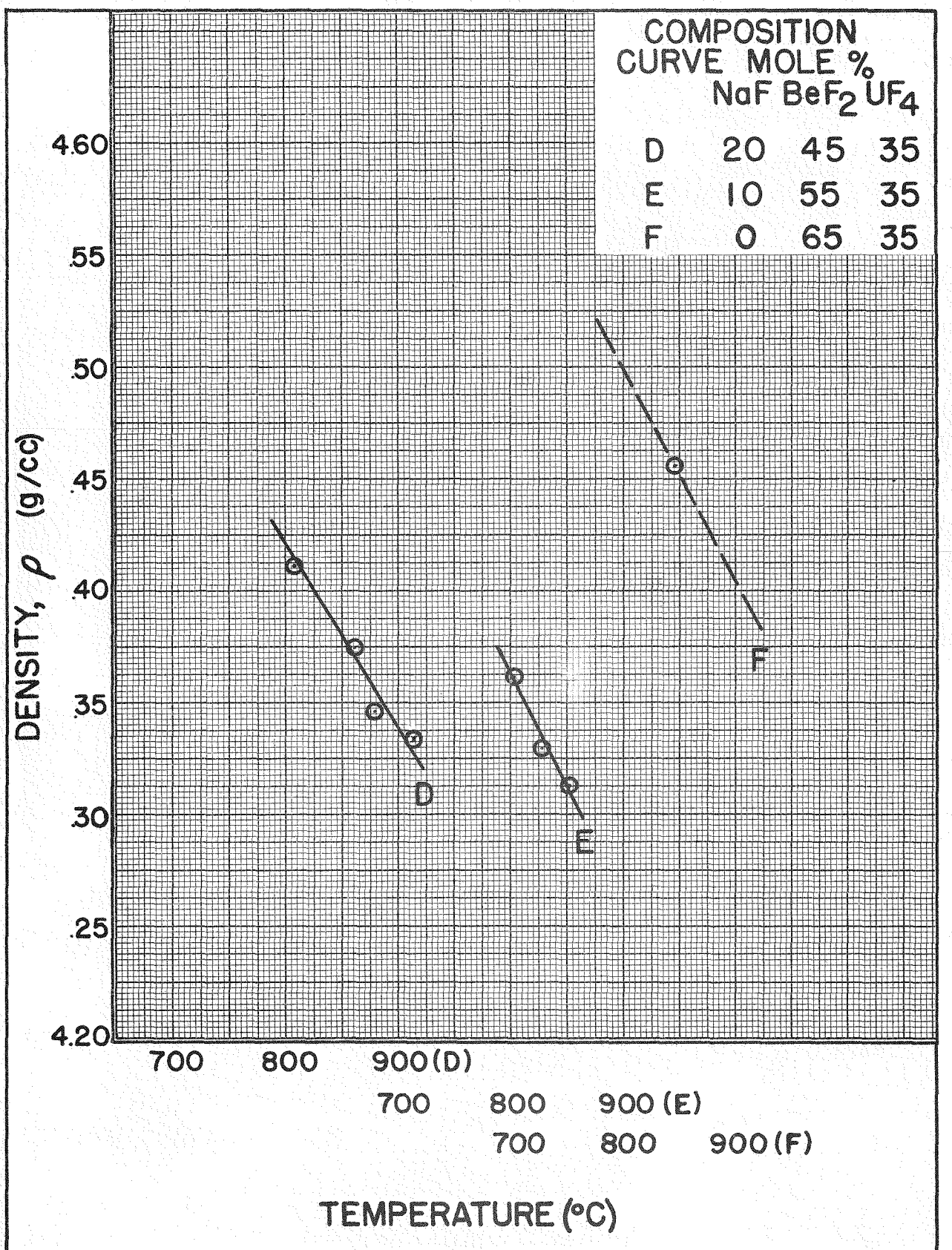
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7p1



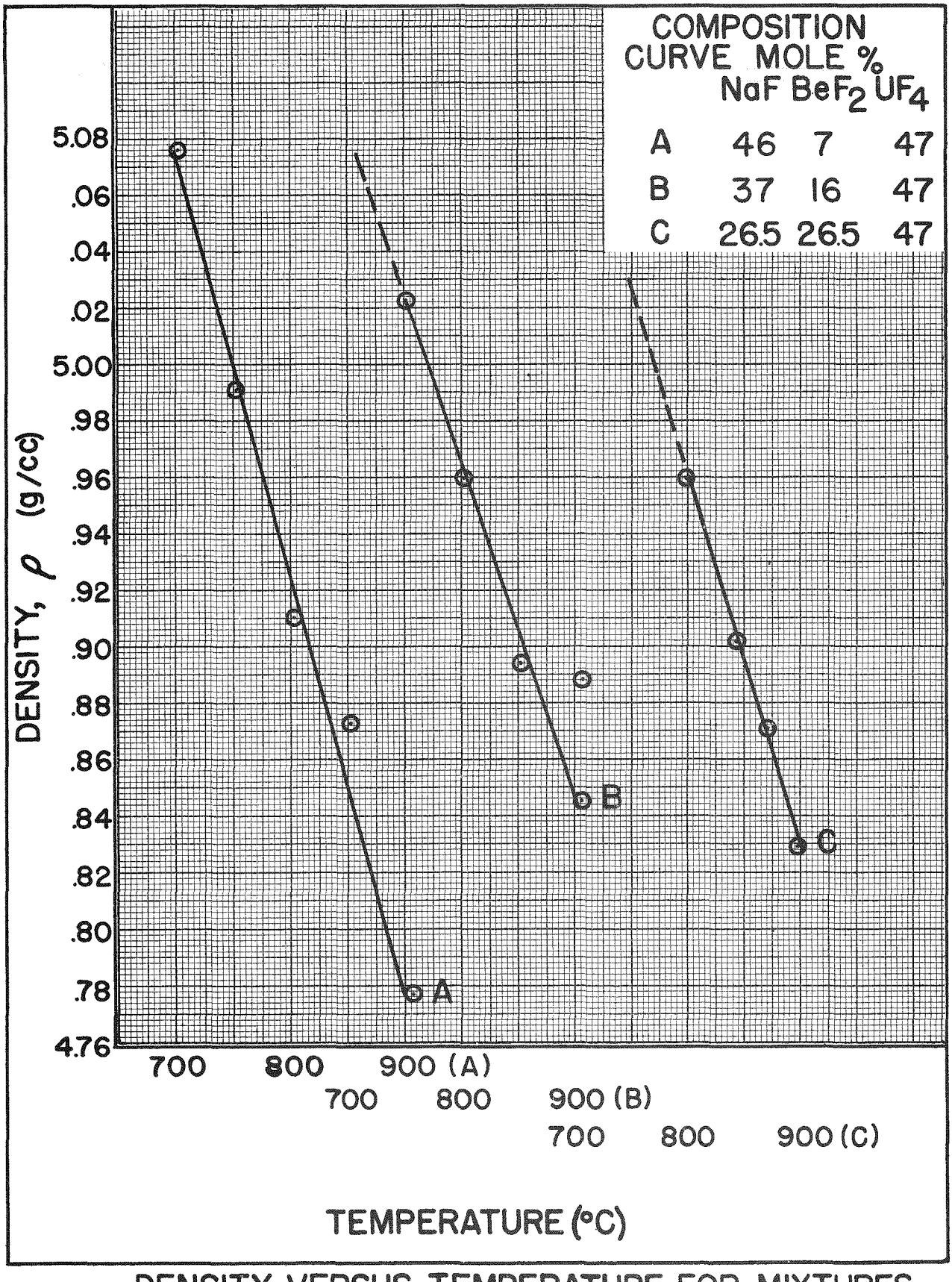
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7p 2



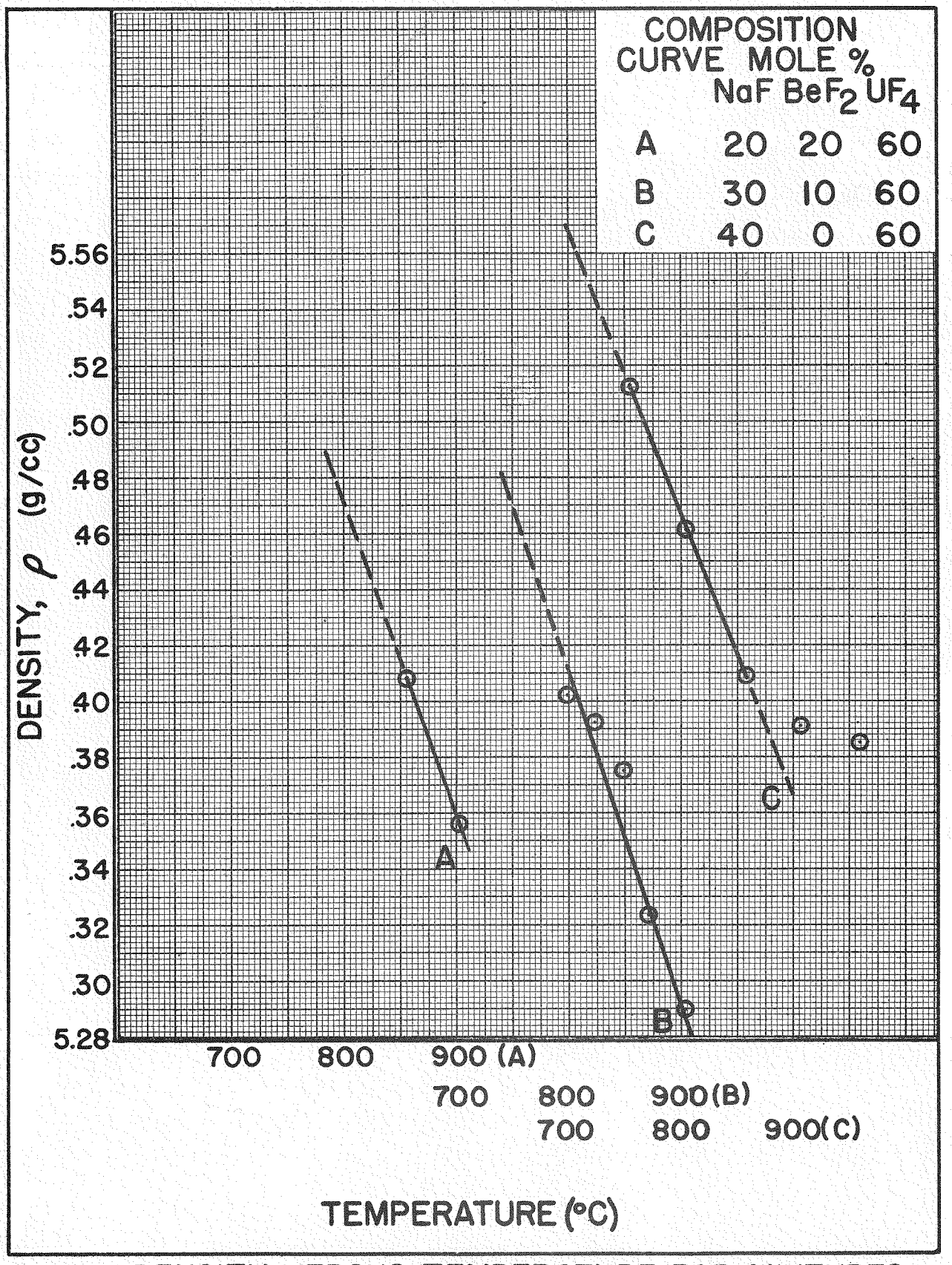
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7r1



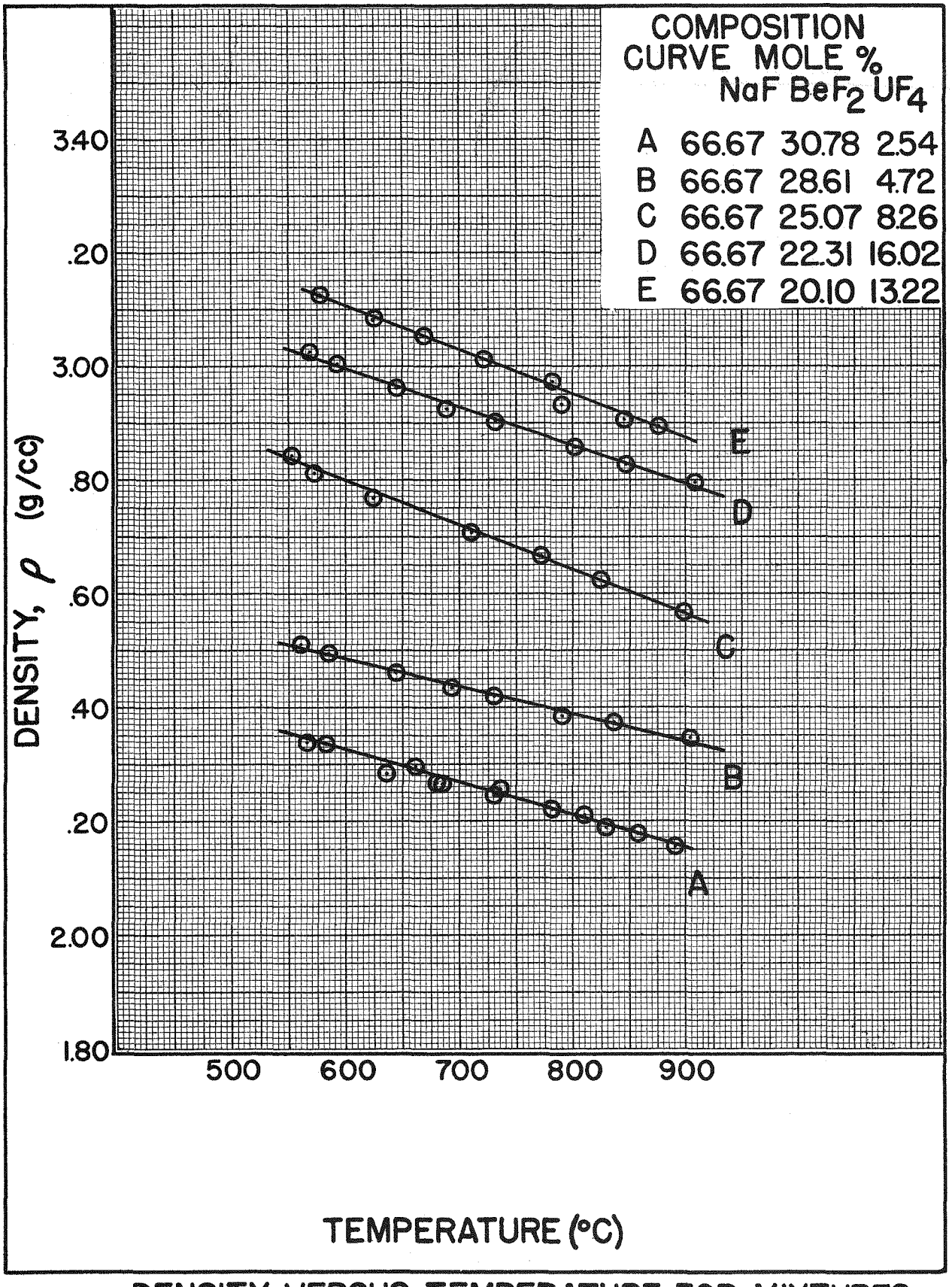
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7r2



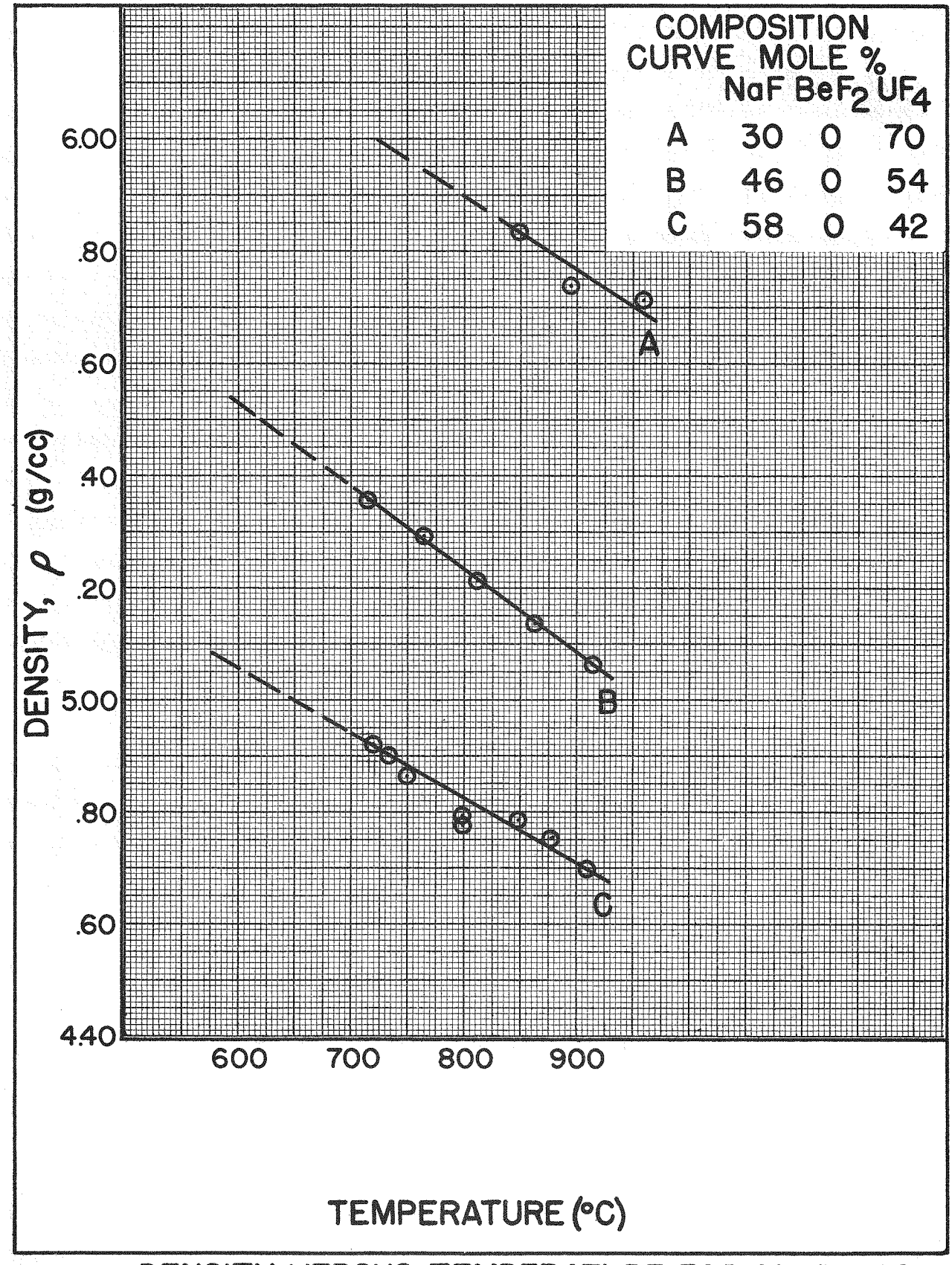
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7 s



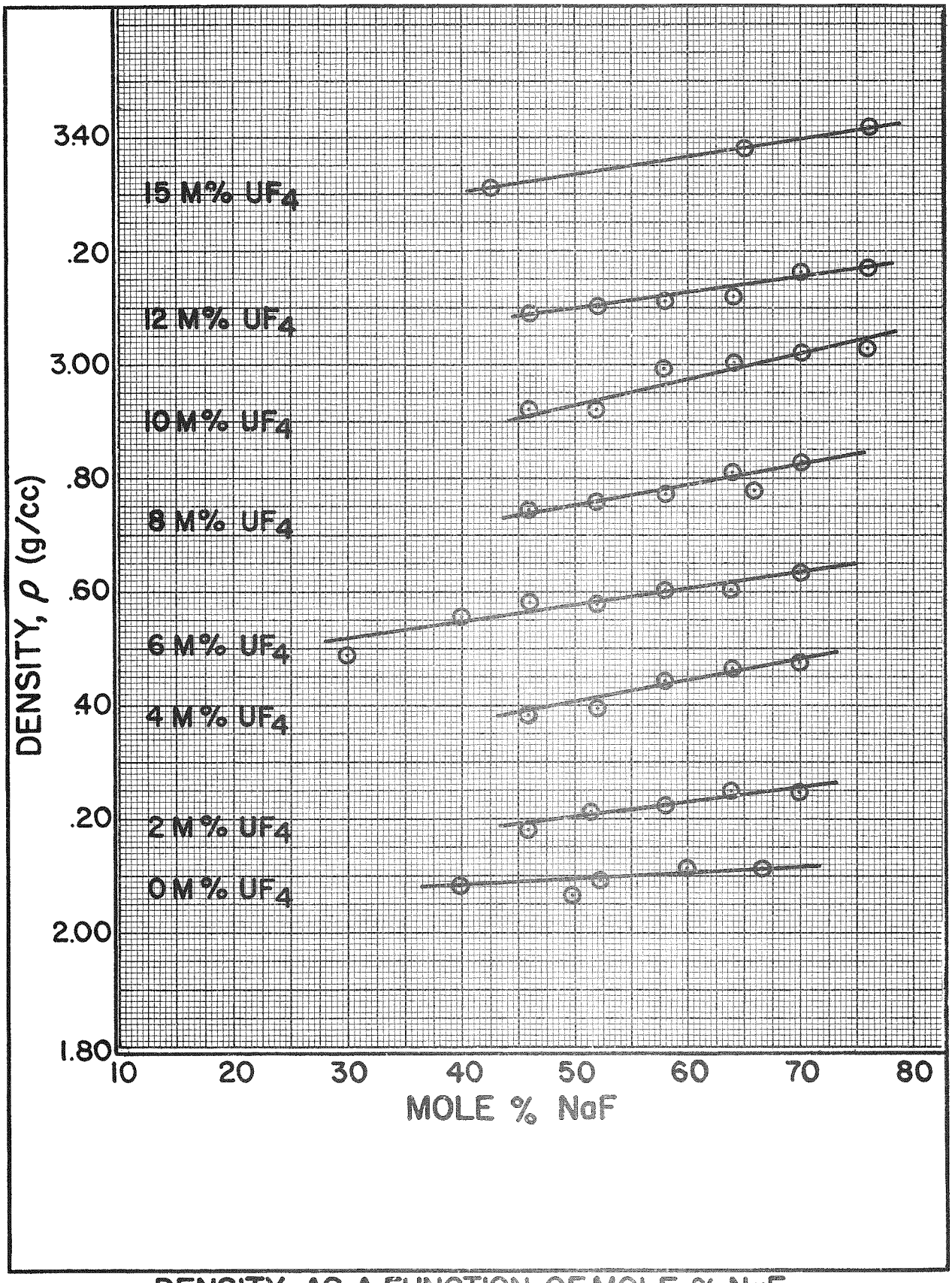
DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 7 t



DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 8

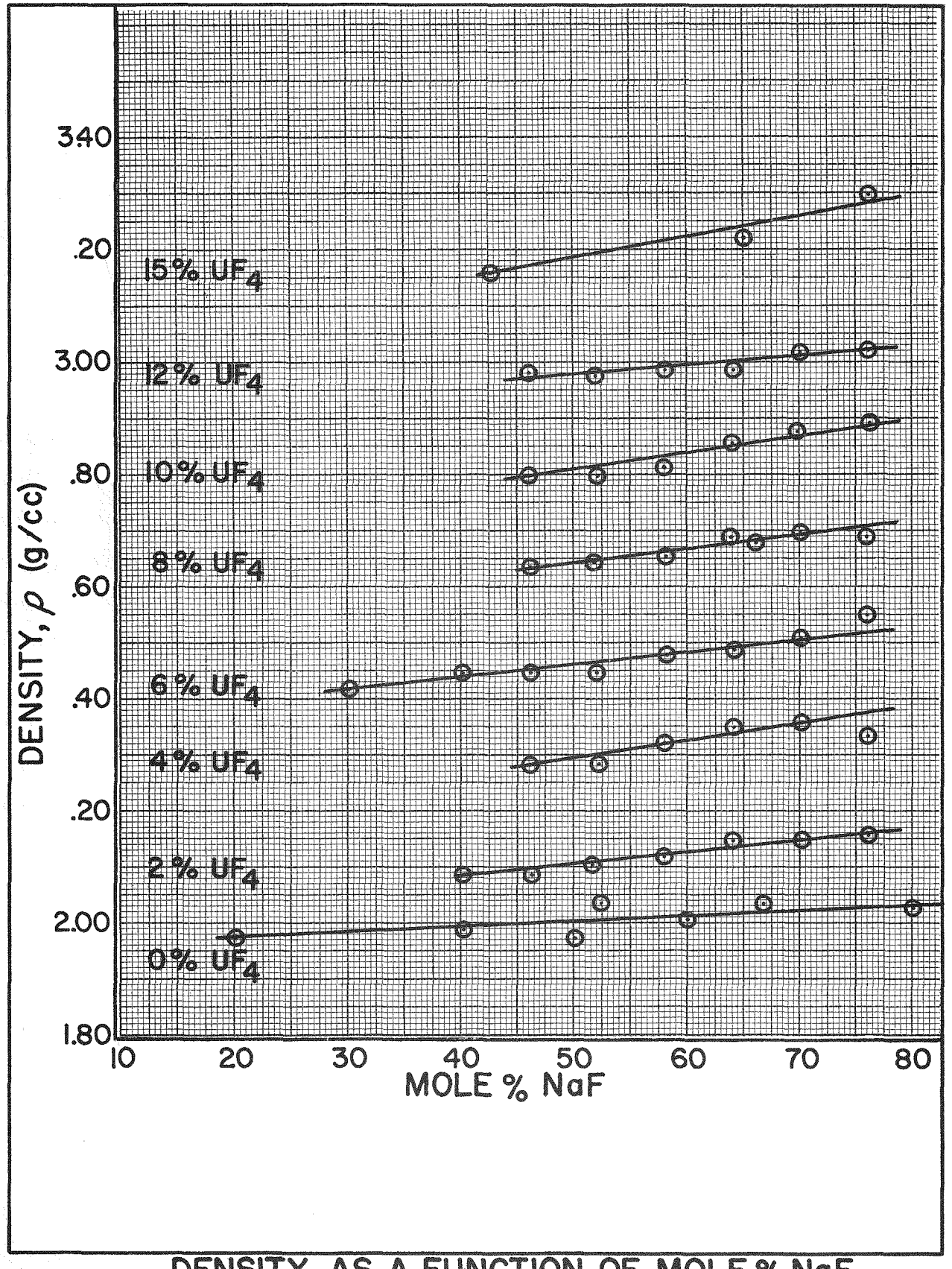


DENSITY VERSUS TEMPERATURE FOR MIXTURES OF NaF, BeF_2 AND UF_4
FIGURE 9



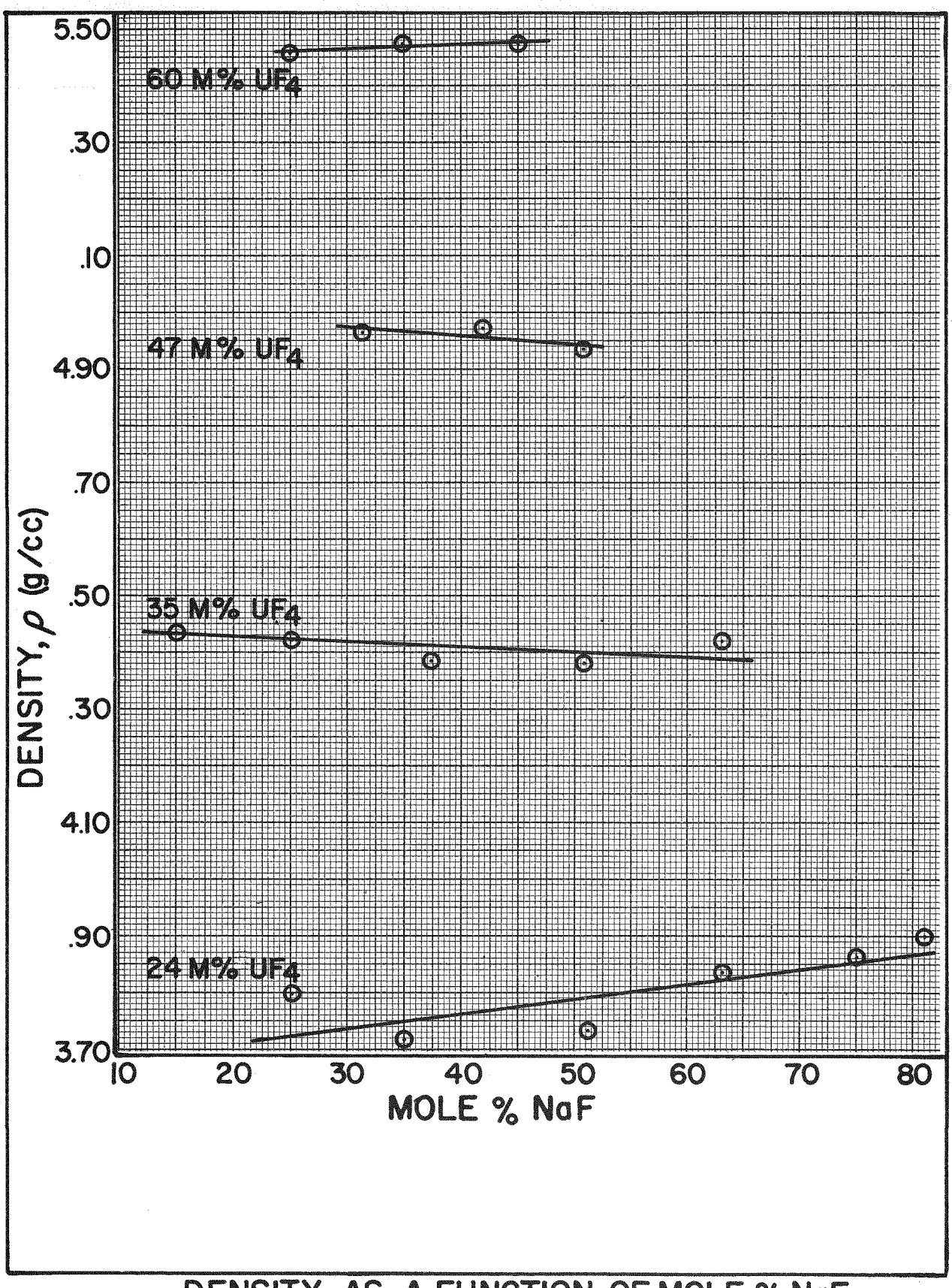
DENSITY AS A FUNCTION OF MOLE % NaF AND UF_4 AT 600° C

FIGURE 10a



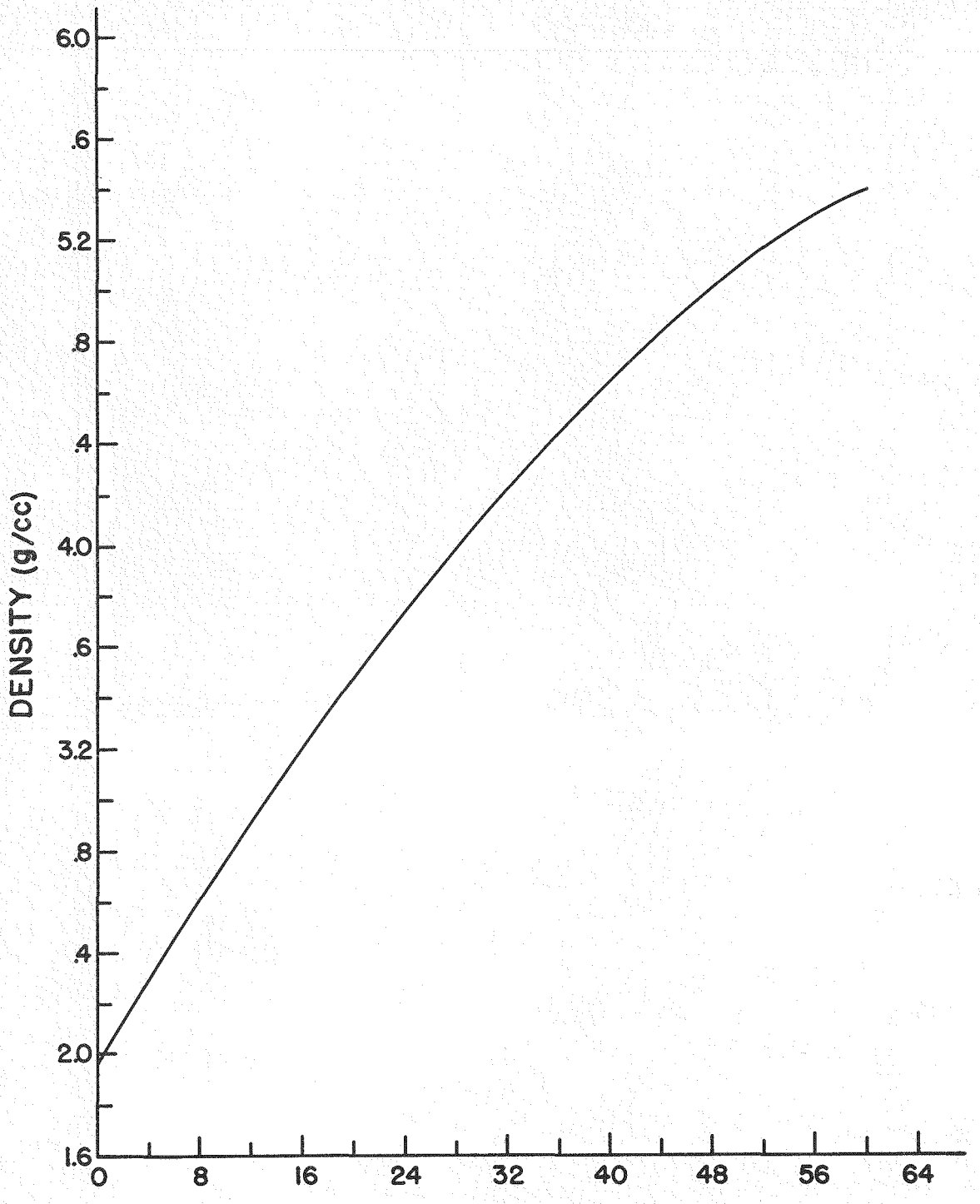
DENSITY AS A FUNCTION OF MOLE % NaF AND UF_4 AT 800°C

FIGURE 10b1

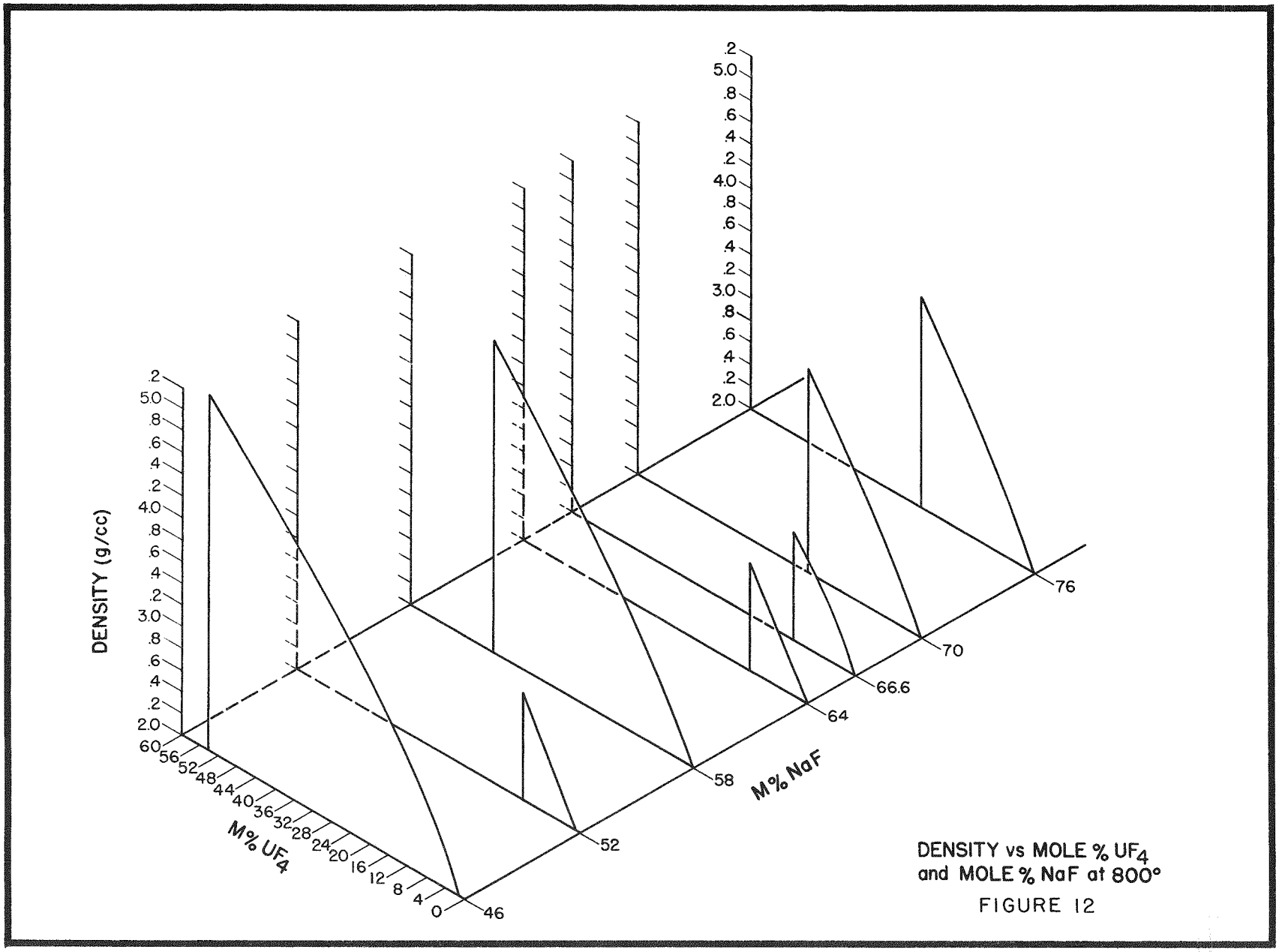


DENSITY AS A FUNCTION OF MOLE % NaF AND UF_4 AT 800°C

FIGURE 10b2

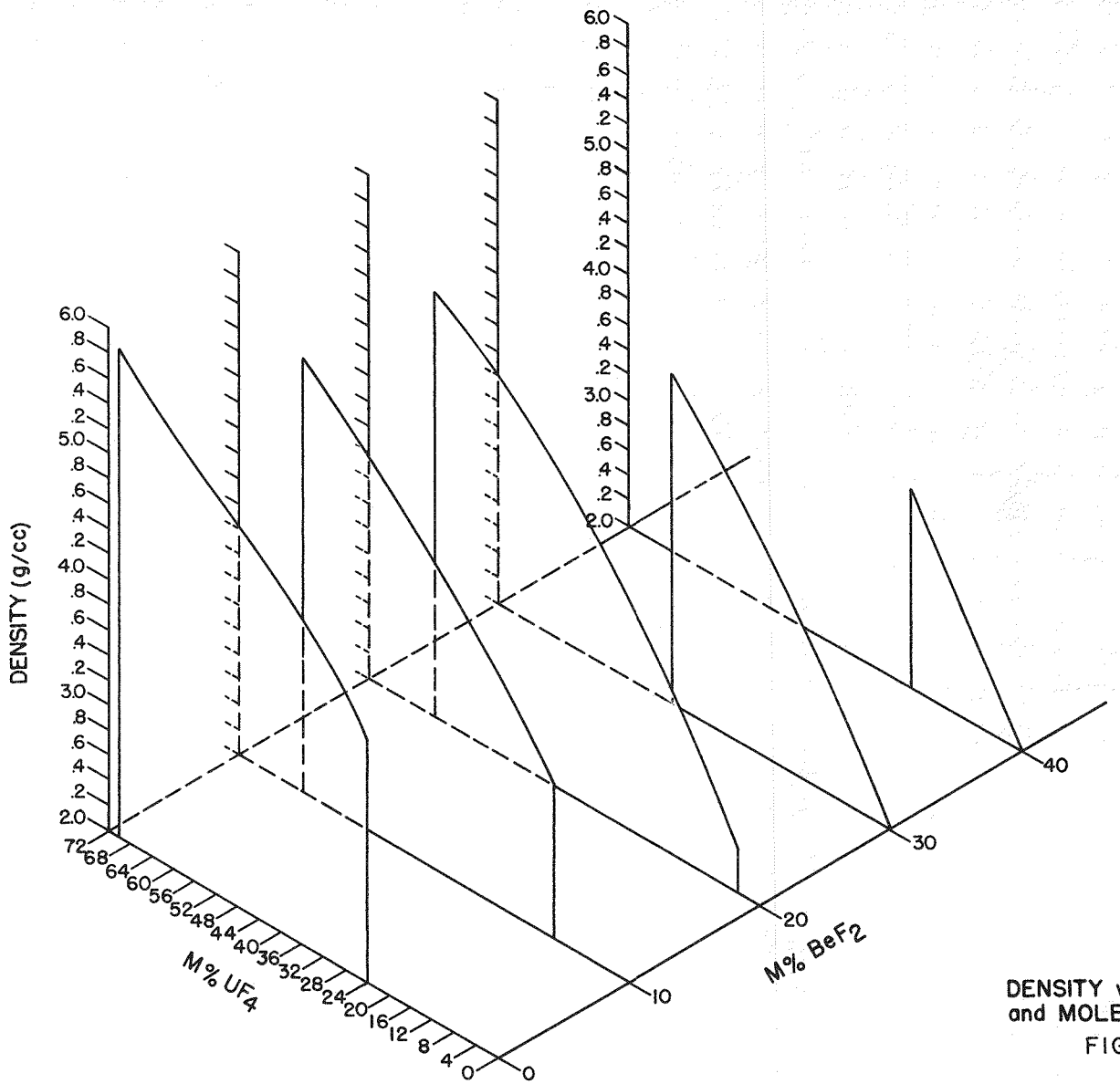


DENSITY VERSUS MOLE % UF_4 WITH
MOLE % NaF = MOLE % BeF_2 at 800°
FIGURE 11



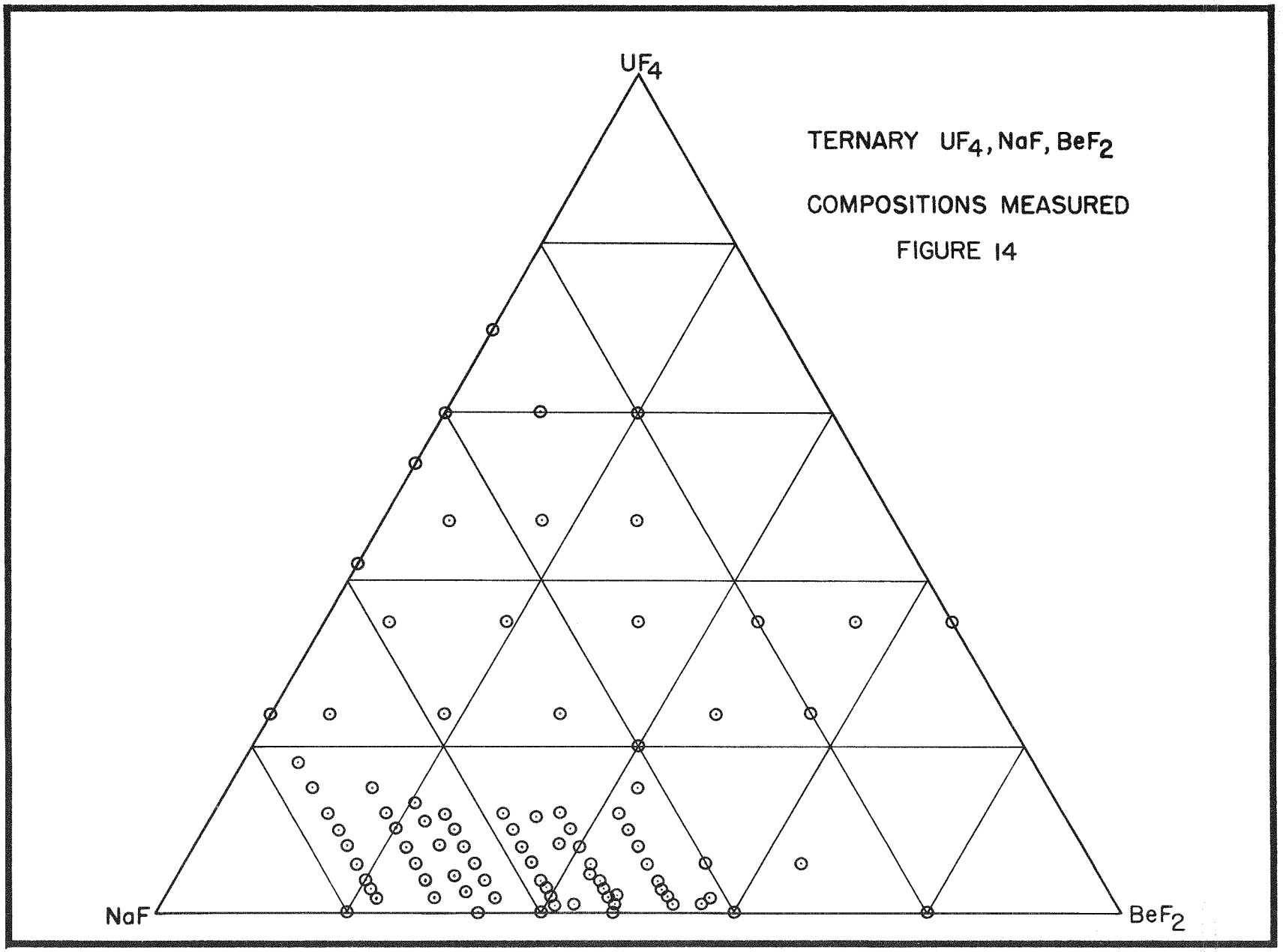
DENSITY vs MOLE % UF_4 and MOLE % NaF at 800°

FIGURE 12



DENSITY vs MOLE % UF_4 and MOLE % BeF_2 at 800°

FIGURE 13



TERNARY UF_4, NaF, BeF_2

COMPOSITIONS MEASURED

FIGURE 14