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A SUMMARY OF DENSITY MEASUREMENTS ON MOLTEN FLUORIDE MIXTURES AND A CORRELATION FOR PREDICTING DENSITIES OF FLUORIDE MIXTURES

S. I. Cohen
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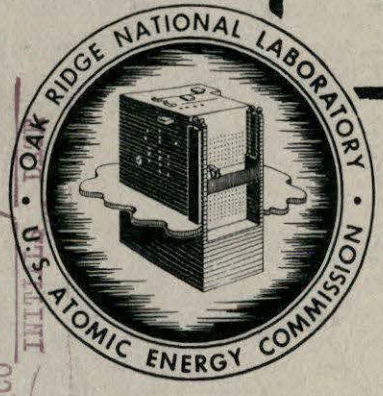

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SUMMARY

This report contains a summary of all the experimental density measurements on molten fluoride mixtures that have been developed for the Aircraft Nuclear Propulsion Project. A correlation of these data is presented which can be used to predict liquid densities of fluoride mixtures of known composition over wide, elevated temperature ranges.

Experimental measurements were made by the buoyancy principle using a plummet suspended in the molten salts from an analytical balance, the entire system being enclosed in a dry-box.

All the information available on compositions, experimental densities, melting points and cubical coefficients of expansion may be found in this report; calculated values of liquid and room temperature densities, molecular weights and molecular volumes of all the mixtures that have been developed for the ANP program are also presented.

INTRODUCTION

Since the outset of the Aircraft Nuclear Propulsion project, interest has been centered on molten fluoride mixtures as the best potential circulating fluids for use in high temperature reactors of the ARE type. During the course of the project, some fifty or more mixtures of fluorides have been suggested and a number of these aroused sufficient interest to merit measurements of their physical properties.

In the early stages of the density research program the experimental accuracy was somewhat lower than in the later stages. During the former period some questions concerning purity of both the molten salts and the blanketing atmosphere arose. Also, the techniques of temperature measurement and control, and weighing facilities were refined during the latter period. As a result, the more recent determinations afford a somewhat higher degree of accuracy than the earlier ones.

The correlation described in this report is based on measurements on all the mixtures that have been studied. In a few instances, notably composition No. 12 (Flinak), it has been possible to make a second set of measurements on a mixture for which the properties had been measured very early in the project, and in these instances the data listed below are the revised values. In past reports on several of the compositions, a correction based

on the volume change of the plummet with temperature was omitted, the error introduced being well within the accuracy claimed for the data. However, this correction has been applied where necessary in this report and it is suggested that in subsequent studies involving the densities of fluorides, the data in this report be used.

DESCRIPTION OF EXPERIMENTAL PROCEDURE

A. Discussion of Method

Density values reported here were determined by the buoyancy principle involving a plummet suspended in a liquid. The density of the liquid, ρ, is defined by

$$\rho = \frac{w_L}{v_L} \tag{1}$$

where,

w_L, weight of liquid displaced by the plummet

v_L, volume of liquid displaced by the plummet

and

$$w_L = W_A - W_L \tag{2}$$

where,

W_A, weight of plummet in air

W_L, weight of plummet in liquid

Upon substituting (2) in (1), there results

$$\rho = \frac{W_A - W_L}{v_L} . \tag{3}$$

The volume of liquid displaced by the plummet, v_L, is also equal to the volume of the plummet and may be determined by weighing the plummet in a liquid of known density (water was used). At room temperature the volume of the plummet is

$$v_{L_o} = \frac{W_A - W_{H_2O}}{\rho_{H_2O}} \tag{4}$$

where,

W_{H_2O}, weight of the plummet in H_2O at room temperature

ρ_{H_2O}, density of water at room temperature

The volume of the plummet at elevated temperatures is

$$v_L = v_{L_o}\left[1 + \beta_p\,(T-T_o)\right] = \frac{W_A - W_{H_2O}}{\rho_{H_2O}}\left[1 + \beta_p\,(T-T_o)\right] \tag{5}$$

where,

T, liquid temperature

T_o, room temperature

β_p, cubical expansion coefficient of the plummet

Upon substituting equation (5) into equation (3), one obtains

$$\rho = \frac{(W_A - W_L)}{(W_A - W_{H_2O})}\;\frac{\rho_{H_2O}}{\left[1 + \beta_p\,(T-T_o)\right]}\;. \tag{6}$$

W_A, W_{H_2O} and the temperature of water were measured before the experiment was started. Values for ρ_{H_2O} and β_p are known; values of W_L at the various temperatures were measured.

Experimental density data are represented in this report by the equation

$$\rho = a - bT \tag{7}$$

Values of the cubical coefficients of expansion were calculated from the defining equation:

$$\beta_L = -\frac{1}{\rho}\left(\frac{d\rho}{dT}\right)_p \tag{8}$$

The experimental data are given in Table 1 and in Figure 3 where the temperature range over which measurements were made on each mixture is shown. The experimental data are also tabulated in Table 4 in the form of equation (7). A simple analysis indicates that these data are probably not in error by more than $\pm$ 5%. Experimental values for the coefficients of cubical expansion of the various liquids may be found in Table 1.

B. Description of the Equipment

The system (see Figure 1) used for taking these measurements consisted principally of a stainless steel plummet suspended in the molten salts by a

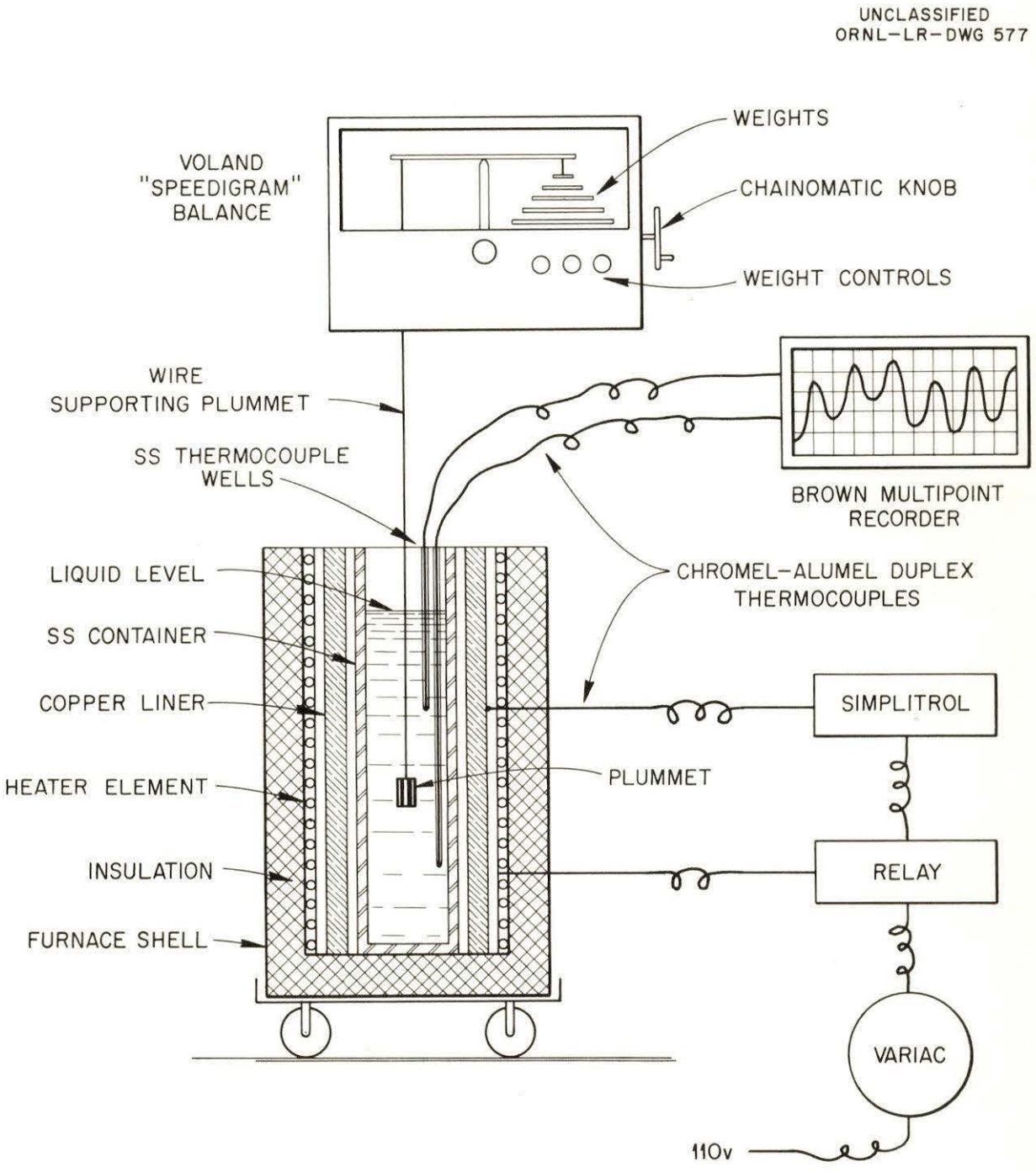

Fig. 1. Schematic Diagram of Density Measurement System.

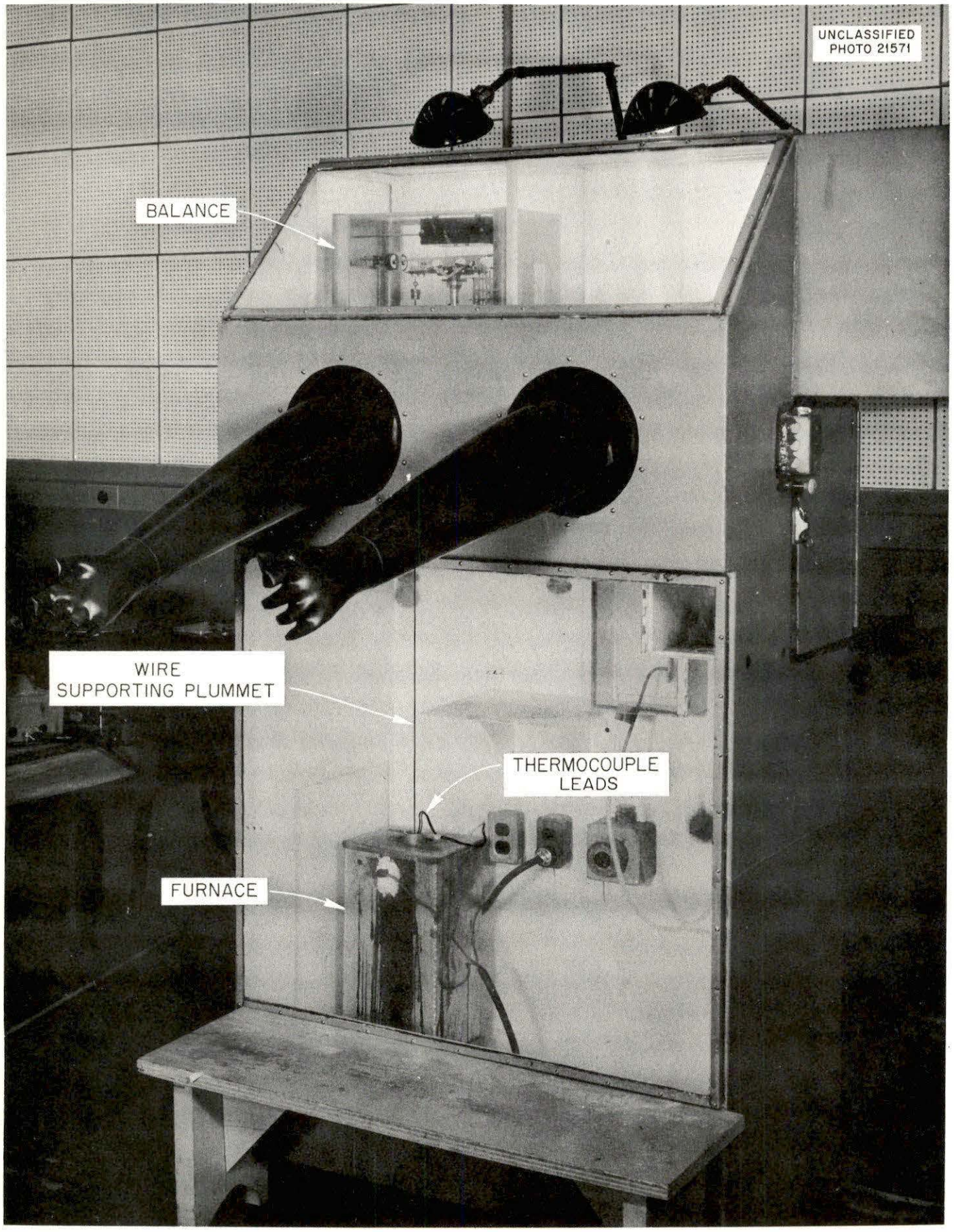

Fig. 2. Photograph of Dry Box Containing Density Measurement System.

fine steel wire from a Voland "Speedigram" balance (a chainomatic balance on which weights larger than 100 mg are controlled mechanically by knobs with no loss in accuracy). The plummets were fabricated from 1/4" No. 316 stainless steel rod. The containers for the molten salts were fabricated from 1 1/2" I.P.S., Schedule 40, No. 316 stainless steel pipe. The tube furnace was mounted on a small rolling platform equipped with ball-bearing casters to facilitate centering of the tube under the balance as well as under the two systems for determining viscosities which were also housed in the dry-box. (Both density and viscosity measurements were made during the same heat-up period. Viscosity studies will be discussed in a separate report).

The temperature of the melt was measured with the aid of two chromel-alumel thermocouples and a Brown multipoint recorder; the couples were inserted in wells made of 1/8" stainless tubing and supported in the liquid salt so that one couple was 2-3 inches below the surface and the other 5-6 inches below the surface. The wire supporting the plummet was of such length that the plummet was suspended at a depth between the two couples. Temperature of the furnace was controlled by a combination of a variac and a Simplitrol with a chromel-alumel thermocouple. The hot junction of this couple was imbedded in the outside surface of a thick-walled copper pipe used as a thermal diffuser between the heating surfaces of the tube furnace and the tube containing the melt. Since this hot junction "sees" the heating element face, a very sensitive temperature control was afforded. As the experiment progressed, the temperature setting was increased by a small

increment and in a short time the temperatures indicated by the two immersed thermocouples rose to a point slightly below that set on the Simplitrol, leveled off and approached each other; at this point the two readings were usually no more than 5 degrees apart. After this practically isothermal condition was reached, a weight reading and the average temperature were recorded.

Since the fluorides in the molten state are very sensitive to the atmosphere, a number of precautions were taken to insure its purity. Argon was circulated through the dry-box and out of a bubbler at a measured rate until the calculated concentration of argon was above 99.9%. These calculations have been checked experimentally by measuring the oxygen concentration of the gas in the dry-box with a Burrell Gas Analyzer. Effort was made to remove the final traces of oxygen and water, these being the chief undesirable impurities, by placing indicating Drierite from a closed container into a flat open dish to get the water and by starting up an oxygen removal device consisting of a tube furnace containing a cartridge of copper filings and equipped with a 15 CFM blower. The filings were brought to red heat and the atmosphere in the dry-box circulated over them. Purity of the atmosphere, which determines the purity of the melt, is indicated by the appearance of the plummet when it is withdrawn from the melt. The plummet, though discolored, will have a clean smooth surface when taken from a clean melt. No difficulty was encountered with condensation on the wire except during measurements on mixtures containing ZrF_4. When working with these salts, the plummet was removed between weighings and the tube containing the melt was covered to retard the zirconium "snow" effect.

EXPLANATION OF THE CORRELATION

Although more than fifty different fluoride mixtures have been developed since the initiation of the ANP program, density measurements have been made on only fifteen of these mixtures. In addition, new mixtures are developed as the program continues. For these reasons it was felt that a method for predicting densities of molten fluorides would be useful and the correlation described below was developed.

The correlation is based on plots of the experimentally determined liquid densities at any one temperature against the calculated densities of the corresponding mixture at room temperature. These room temperature densities are calculated by the formula

$$\rho = \frac{\sum_{i=1}^{N} M_i f_i}{\sum_{i=1}^{N} (M_i/\rho_i) f_i} \qquad (9)$$

where,

ρ, density at room temperature of the mixture (gm/cc)

M_i, molecular weight[1] of a component of the mixture (gm/mol.)

f_i, mol fraction of that component

ρ_i, density at room temperature[1] of that component (gm/cc)

---

[1] The values used for the various components are listed in Table 2 of the appendix.

The numerator is the calculated molecular weight of the mixture and the denominator is the calculated molecular volume of the mixture. Values of the room temperature density calculated from this formula were checked against experimentally determined values for a series of 10 fluoride mixtures and were found to differ by no more than ± 5 percent (Reference 1).

Figure 3 gives the density-temperature data for all of the liquid fluoride mixtures that have been studied to date (References 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12). The figures in parentheses are the calculated room temperature densities. The data given in Table 1 were used in drawing these curves. It is noted that the average liquid densities are proportional to the calculated room temperature densities of the corresponding mixtures.

Figures 4a, 4b, 4c and 4d represent plots of liquid densities against the calculated room temperature densities of corresponding mixtures at 600°C, 700°C, 800°C and 900°C respectively; these isotherms were cross-plotted from Figure 3. Figure 5 is a composite of figures 4a, 4b, 4c and 4d. Knowing only the calculated room temperature density, the liquid density may be predicted for any mixture of fluorides over this temperature range.

Figures 6 and 7 were derived from Figure 5 and give the constants, a and b, for equation 7, as a function of the room temperature density.

The density correlation presented here satisfactorily represents all the experimental measurements on the fluoride mixtures; the mean deviation is about 3% and the maximum deviation is 6%. Table 3 gives the calculated room

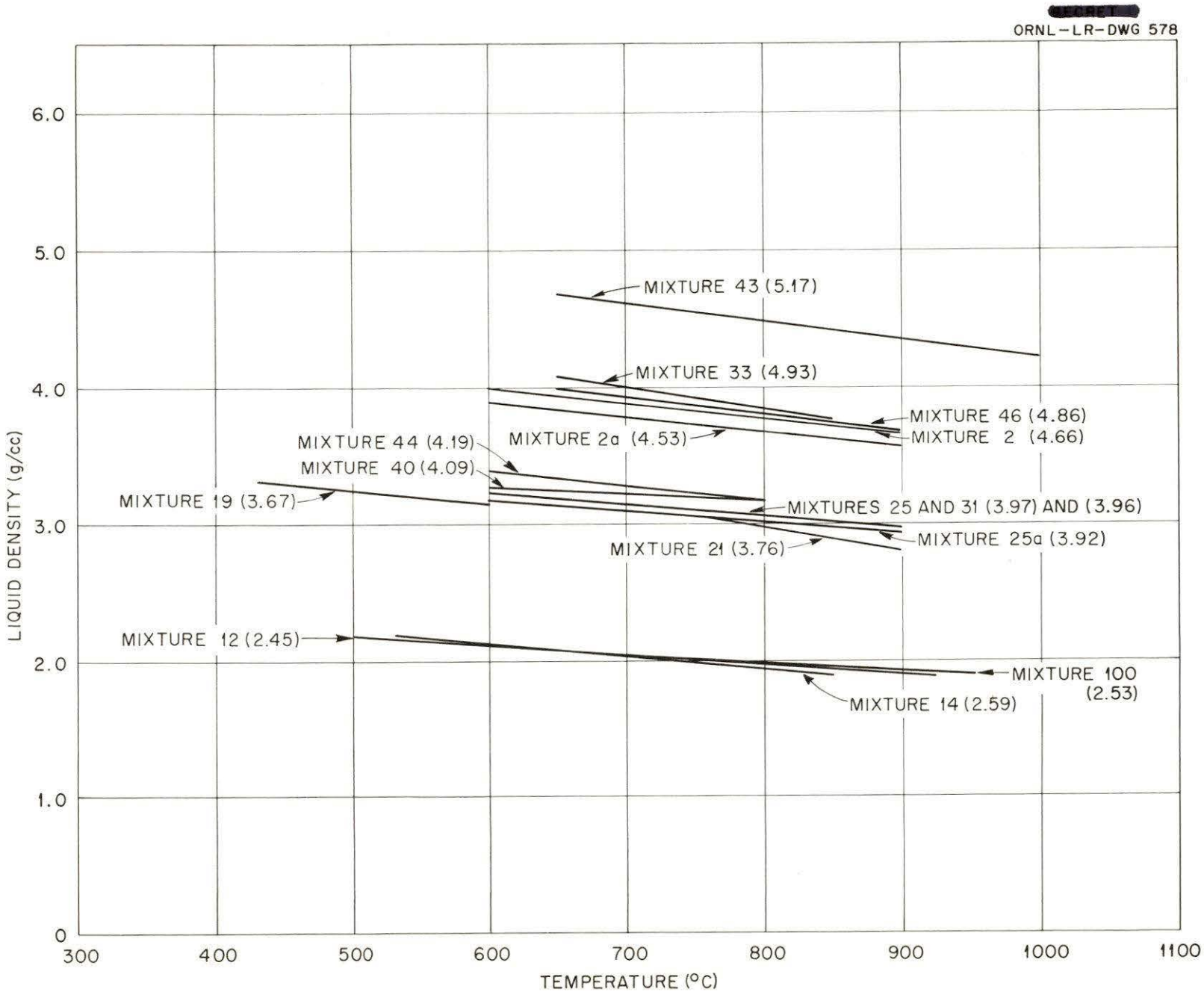

Fig. 3. Densities of Fluoride Mixtures (g/cc) vs. Temperature (°C)(Numbers in Parentheses are Calculated Room Temperature Densities.)

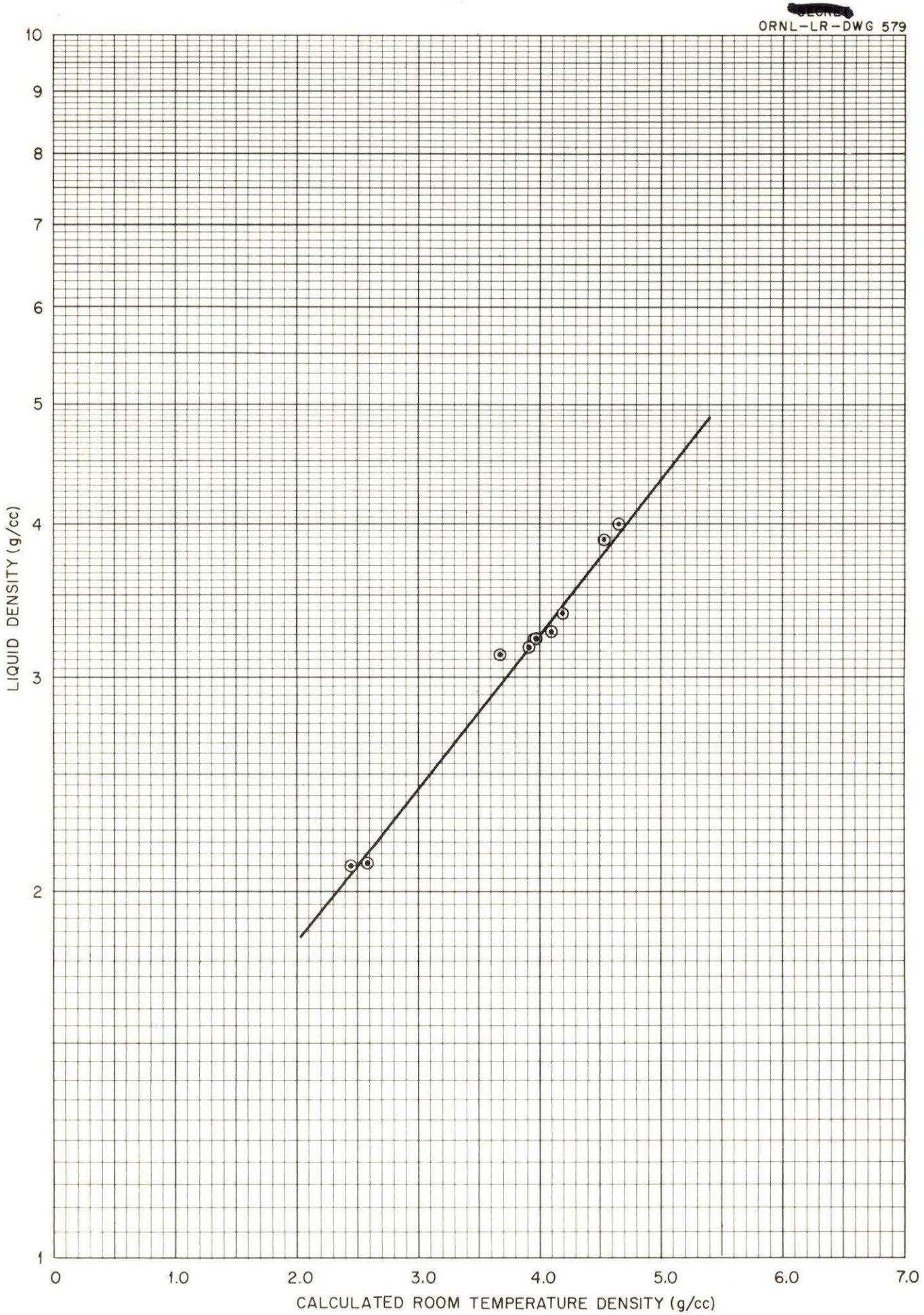

Fig. 4a. Liquid Density at 600° C vs. Calculated Room Temperature Density.

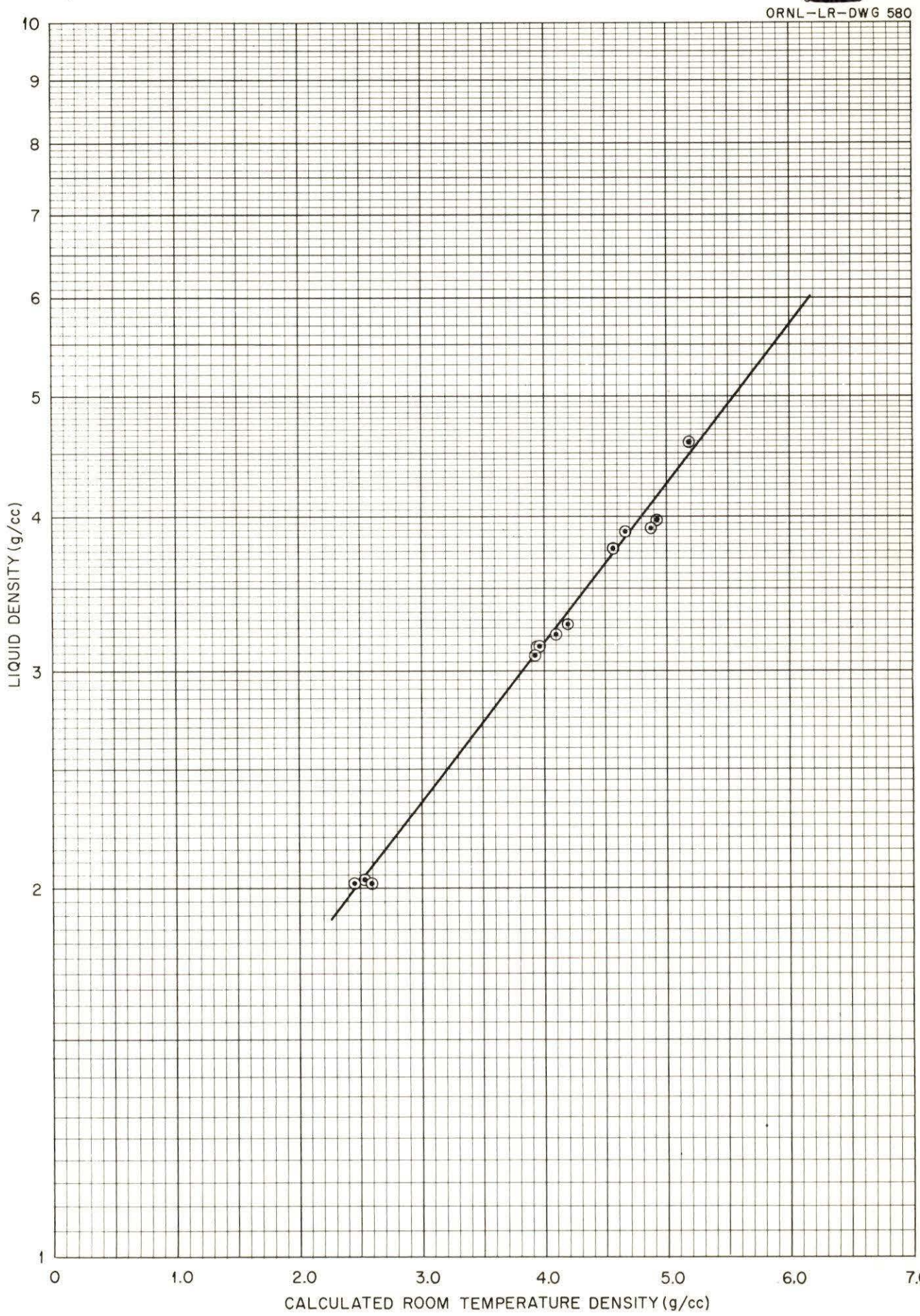

Fig. 4b. Liquid Density at 700° C vs. Calculated Room Temperature Density.

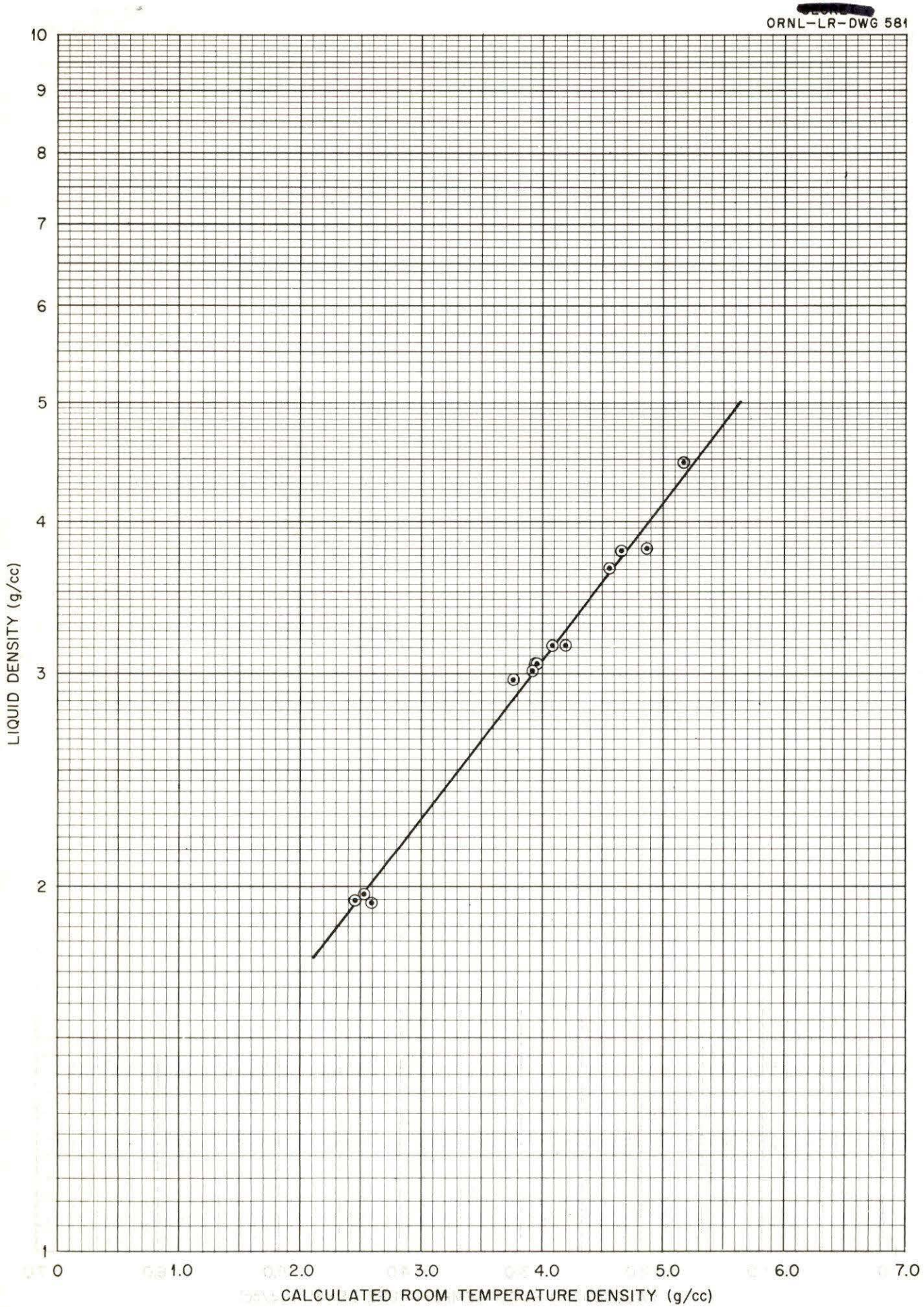

Fig. 4c. Liquid Density at 800° C vs. Calculated Room Temperature Density.

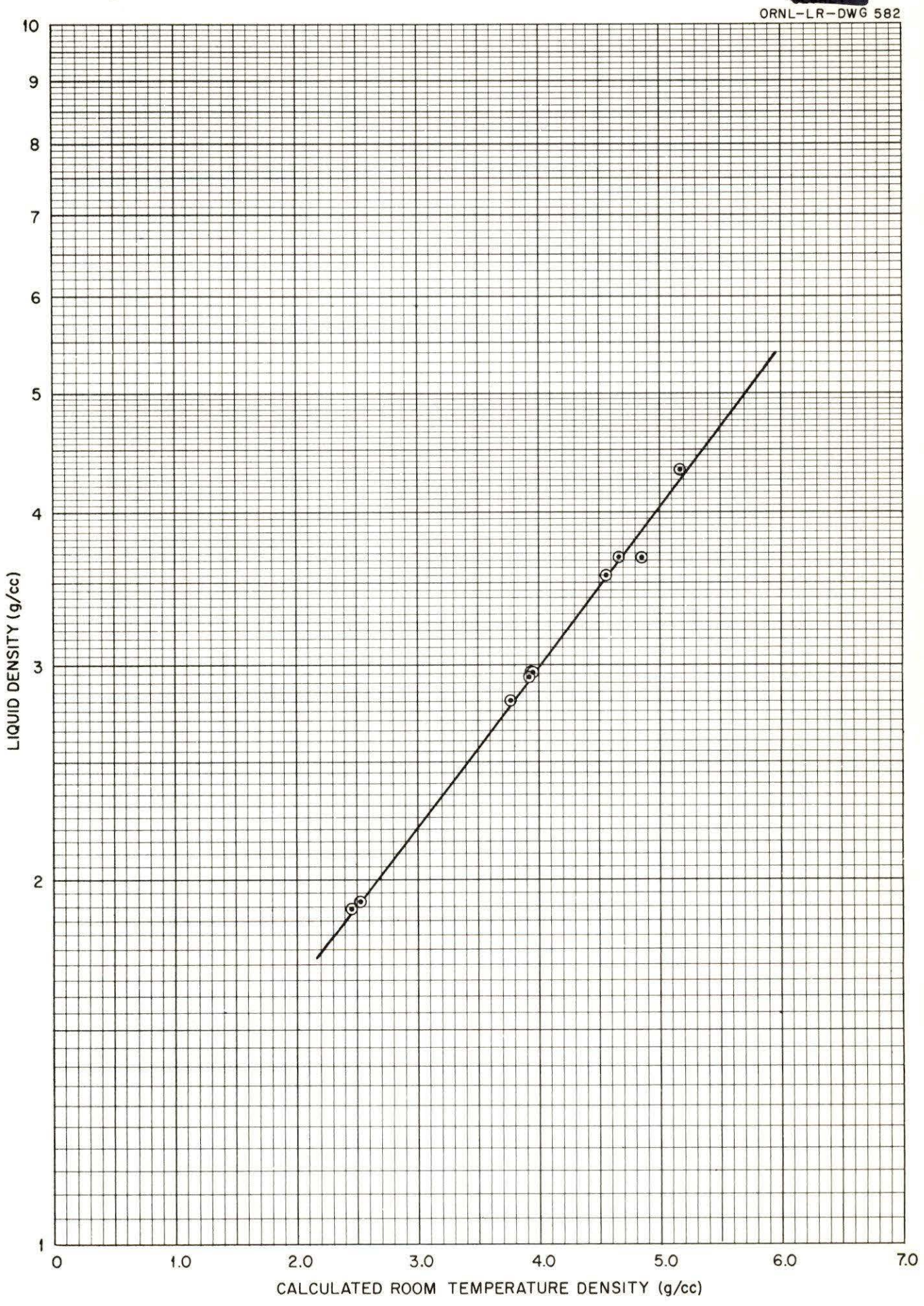

Fig. 4d. Liquid Density at 900° C vs. Calculated Room Temperature Density.

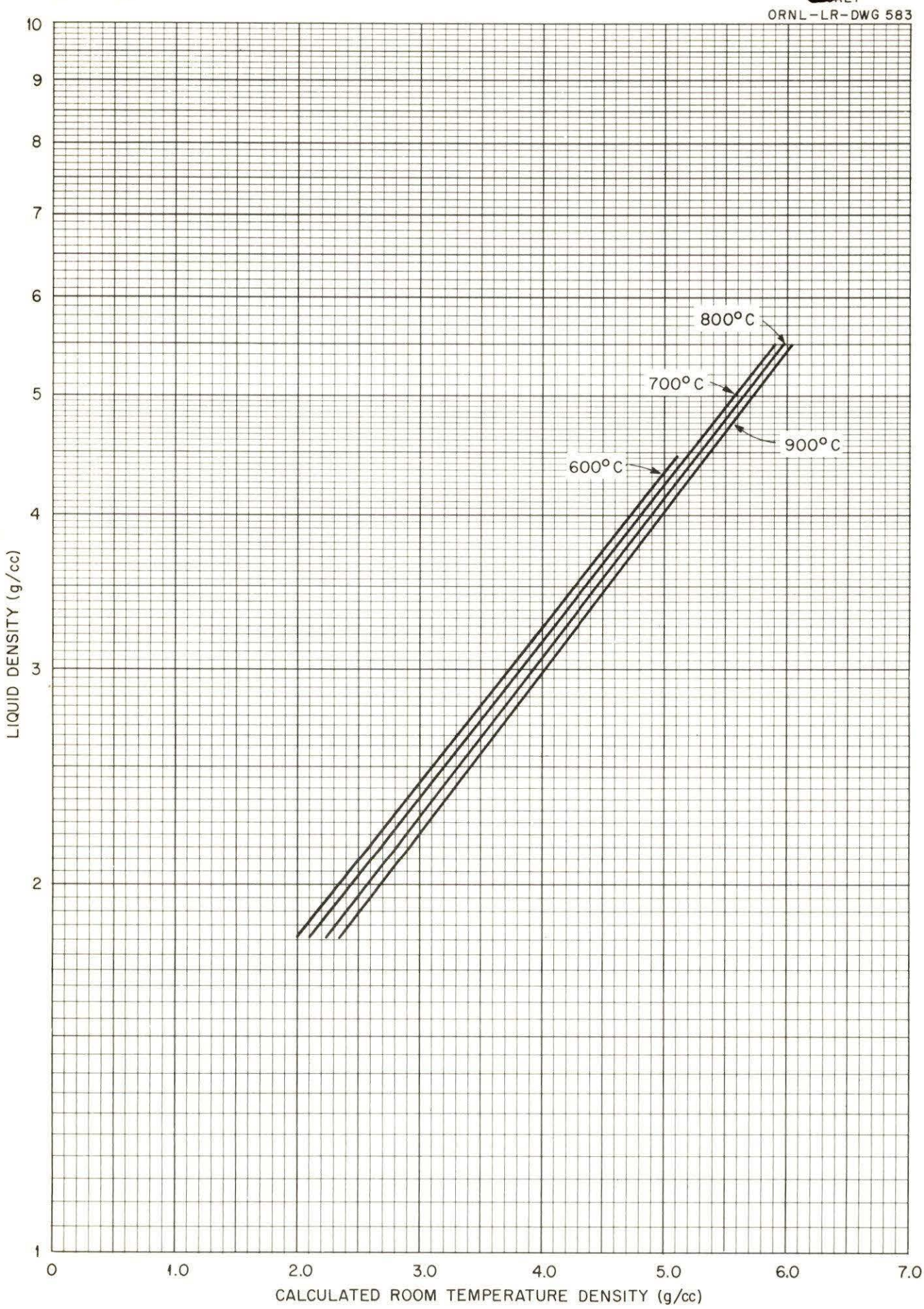

Fig. 5. Liquid Density vs. Calculated Room Temperature Density (Composite of Figures 2a, 2b, 2c, 2d)

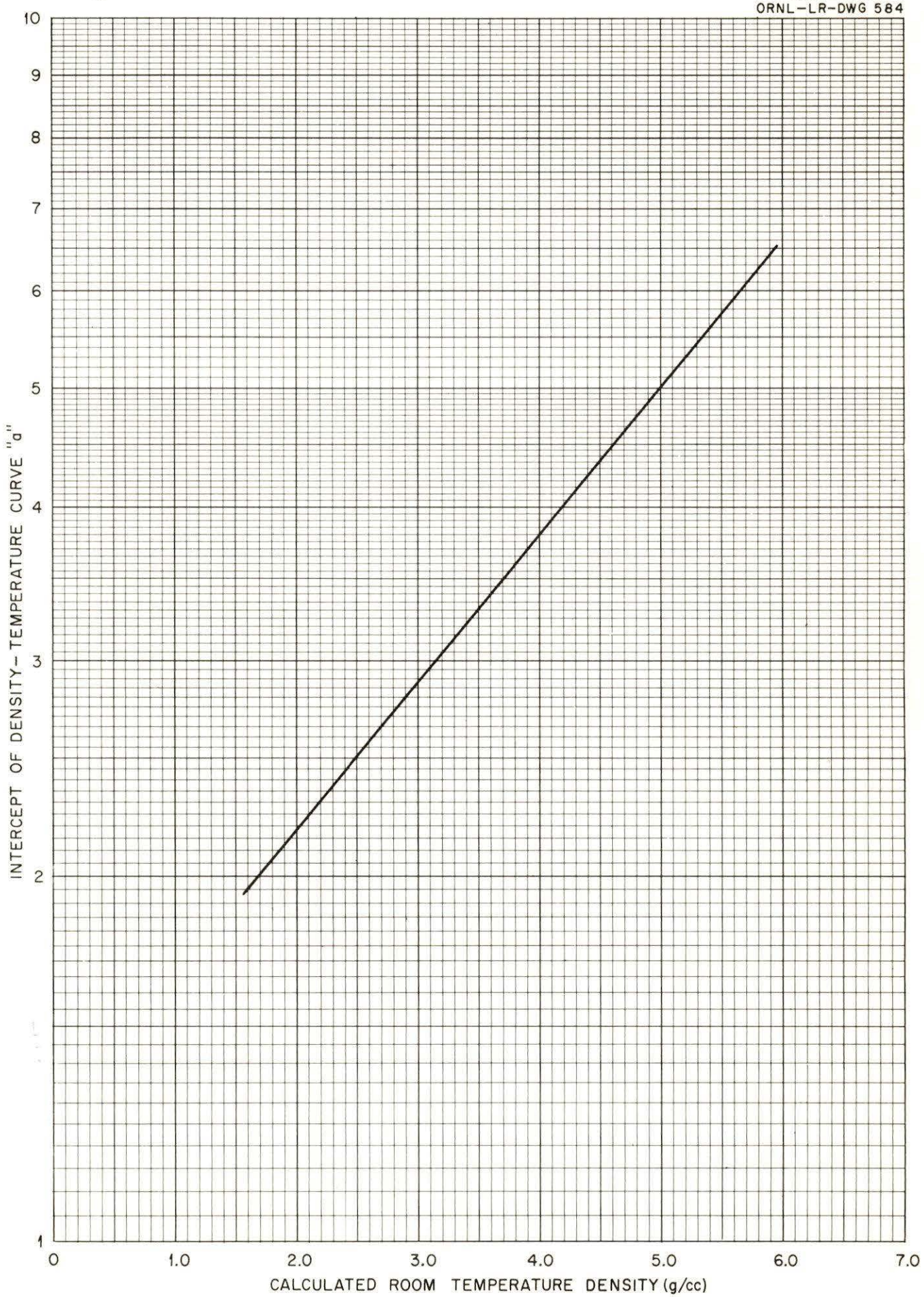

Fig. 6. Intercept of Density-Temperature Curve ("a") vs. Calculated Room Temperature Density.

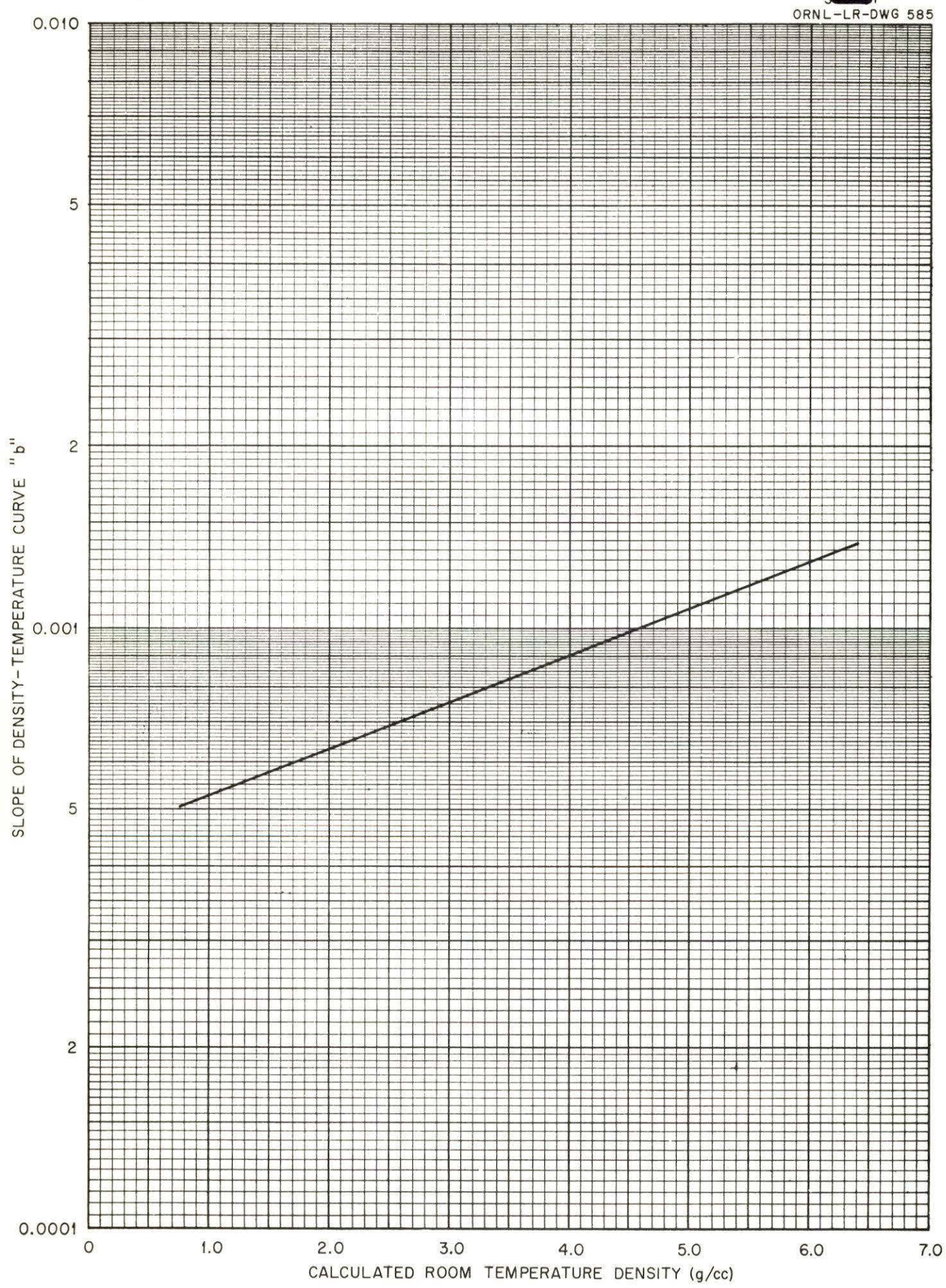

Fig. 7. Slope of Density-Temperature Curve ("b") vs. Calculated Room Temperature Density.

temperature densities, as well as compositions, molecular weights and molecular volumes, for all the fluoride mixtures that have been formulated in the ANP program (References 13 and 14) and Table 4 lists the predicted densities in terms of equation 7 for all of these mixtures as well as the experimentally determined formulae to illustrate the agreement.

Cubical coefficients of expansion at 700°C of the liquids calculated from this correlation are inversely proportional to density and vary from 3.60×10^{-4} (1/°C) for a mixture having a room temperature density of 2.0 (gm/cc) to 2.37×10^{-4} (1/°C) for a mixture having a room temperature density of 5.5 (gm/cc).

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APPENDIX

TABLE 1

EXPERIMENTAL DENSITY-TEMPERATURE DATA

Composition	LIQUID DENSITY (gm/cc) 600°C	700°C	800°C	900°C	Cubical Coefficient of Expansion[2] 1/°C x 10^4	Reference
2	4.00	3.89	3.78	3.67	2.96	2,12
2a	3.88	3.77	3.66	3.55	2.92	3,12
12	2.10	2.02	1.94	1.88	3.61	11
14	2.11	2.02	1.93		4.46	4,12
19	3.13				3.48(600°C)	5,12
21			2.96	2.80	5.51(800°C)	5,12
25	3.23	3.14	3.05	2.96	2.90	5,12
25a	3.17	3.09	3.01	2.93	2.59	5,12
31	3.23	3.14	3.05	2.96	2.96	6,12
33		3.98			3.99	6,12
40	3.27	3.21	3.16		1.71	7
43		4.60	4.47	4.34	2.83	8
44	3.38	3.27	3.16		3.36	9
46		3.91	3.79	3.67	3.07	10
100		2.03	1.97	1.92	2.71	11

[2] Value is for 700°C unless otherwise noted. The calculated range of cubical expansion coefficients is from 3.6×10^{-4} 1/°C to 2.4×10^{-4} 1/°C. The few experimental values which fall outside of this range probably do so because they are based on early or incomplete sets of data.

TABLE 2

CONSTANTS USED IN CALCULATING ROOM TEMPERATURE DENSITIES

Component	Molecular Weight, M_i (gm/mol)	Room Temperature Density, ρ_i (gm/cc)	Molecular Volume, M_i/ρ_i (cc/mol)
LiF	25.9	2.30	11.26
NaF	42	2.79	15.05
BeF_2	47	1.98	23.74
KF	58.1	2.48	23.43
ZrF_4	167.2	4.43	37.74
UF_4	314.1	6.70[3]	46.88
RbF	104.5	3.557[4]	29.38
PbF_2	245.2	8.24	29.75
ThF_4	308.1	6.70[5]	45.99
UF_3	295.1	8.95[6]	32.97

[3]Reference 15

[4]Reference 16

[5]Value for UF_4. Value for ThF_4 not available.

[6]Derived from X-ray data

All other values taken from Lange's Handbook of Chemistry, Eighth Edition

TABLE 3

CALCULATION OF ROOM TEMPERATURE
DENSITIES OF FLUORIDE MIXTURES

$$\rho_{\text{Room Temp.}} = \frac{\text{Mol. Wt. of Mixture}}{\text{Mol. Vol. of Mixture}} = \frac{\sum_{i=1}^{N} M_i f_i}{\sum_{i=1}^{N} (M_i/\rho_i) f_i}$$ where,

M_i, molecular wt. of component

f_i, mol % of that component

ρ_i, density at room temperature of that component

Mixture	Component	f_i	$M_i f_i$	Mol. Wt. of Mixture	$(M_i/\rho_i)f_i$	Mol. Vol. of Mixture	$\rho_{\text{Room Temp.}}$
1	BeF_2	12	5.6	75.2	2.85	19.92	3.77
	NaF	76	31.9		11.44		
	UF_4	12	37.7		5.63		
2	NaF	46.5	19.5	121.0	7.00	25.98	4.66
	KF	26.0	15.1		6.09		
	UF_4	27.5	86.4		12.89		
2a	NaF	48.2	20.2	114.3	7.25	25.25	4.53
	KF	26.8	15.6		6.28		
	UF_4	25.0	78.5		11.72		
3	BeF_2	60.0	28.2	85.8	14.24	25.03	3.43
	NaF	25.0	10.5		3.76		
	UF_4	15.0	47.1		7.03		
4	NaF	35	14.7	167.6	5.27	31.06	5.40
	KF	20	11.6		4.69		
	UF_4	45	141.3		21.10		
5	NaF	60	25.2	135.0	9.03	23.84	5.66
	PbF_2	23	56.4		6.84		
	UF_4	17	53.4		7.97		
6	NaF	30	12.6	46.1	4.52	21.12	2.18
	BeF_2	65	30.6		15.43		
	KF	5	2.9		1.17		

TABLE 3 (Con't.)

CALCULATION OF ROOM TEMPERATURE
DENSITIES OF FLUORIDE MIXTURES

Mixture	Component	f_i	$M_i f_i$	Mol. Wt. of Mixture	$(M_i/\rho_i)f_i$	Mol. Vol. of Mixture	$\rho_{\text{Room Temp.}}$
7	NaF	50	21	126.8	7.53	26.28	4.83
	KF	20	11.6		4.69		
	UF_4	30	94.2		14.06		
8	NaF	100		42			2.79[7]
9	BeF_2	100		47			1.98[7]
10	LiF	100		25.9			2.30[7]
11	KF	100		58.1			2.48[7]
12	NaF	11.5	4.8	41.2	1.73	16.81	2.45
(Flinak)	KF	42.0	24.4		9.84		
	LiF	46.5	12.0		5.24		
13	NaF	53	22.3	128	7.98	25.52	5.02
	RbF	20	20.9		5.88		
	UF_4	27	84.8		12.66		
14	KF	43.5	25.3	44.9	10.19	17.36	2.59
(Flinak)	LiF	44.5	11.5		5.01		
	NaF	10.9	4.6		1.64		
	UF_4	1.1	3.5		.52		
15	NaF	29.5	12.4	50.3	4.44	21.53	2.34
	BeF_2	64.0	30.1		15.19		
	KF	4.9	2.8		1.15		
	UF_4	1.6	5.0		.75		
16	NaF	34.0	14.3	68.0	5.12	22.76	2.99
	BeF_2	57.5	27.0		13.65		
	UF_4	8.5	26.7		3.99		

[7]Taken from Lange's Handbook of Chemistry, Eighth Edition

TABLE 3 (Con't.)

CALCULATION OF ROOM TEMPERATURE
DENSITIES OF FLUORIDE MIXTURES

Mixture	Component	f_i	$M_i f_i$	Mol. Wt. of Mixture	$(M_i/\rho_i)f_i$	Mol. Vol. of Mixture	$\rho_{\text{Room Temp.}}$
17	NaF	47.0	19.7	50.0	7.07	20.12	2.49
	BeF_2	51.0	24.0		12.11		
	UF_4	2.0	6.3		.94		
18	NaF	45.0	18.9	96.5	6.77	20.80	4.64
	LiF	33.0	8.5		3.72		
	UF_4	22.0	69.1		10.31		
19	NaF	5.0	2.1	108.2	.75	29.49	3.67
	KF	51.0	29.6		11.95		
	ZrF_4	42.0	70.2		15.85		
	UF_4	2.0	6.3		.94		
20	NaF	5.0	2.1	104.2	.75	29.16	3.57
	KF	52.0	30.2		12.18		
	ZrF_4	43.0	71.9		16.23		
21	NaF	4.8	2.0	112.1	.72	29.83	3.76
	KF	50.1	29.1		11.74		
	ZrF_4	41.3	69.1		15.59		
	UF_4	3.8	11.9		1.78		
22	KF	46.0	26.7	122.9	10.78	31.53	3.90
	ZrF_4	50.0	83.6		18.87		
	UF_4	4.0	12.6		1.88		
23	KF	41.8	24.3	42.9	9.79	16.99	2.53
	NaF	11.4	4.8		1.72		
	LiF	46.2	12.0		5.20		
	ThF_4	0.6	1.8		.28		
24	KF	18.0	10.5	102.5	4.22	27.00	3.80
	NaF	36.0	15.1		5.42		
	ZrF_4	46.0	76.9		17.36		

TABLE 3 (Con't.)

CALCULATION OF ROOM TEMPERATURE
DENSITIES OF FLUORIDE MIXTURES

Mixture	Component	f_i	$M_i f_i$	Mol. Wt. of Mixture	$(M_i/\rho_i)f_i$	Mol. Vol. of Mixture	$\rho_{\text{Room Temp.}}$
25	KF	17.4	10.1	109.9	4.08	27.70	3.97
	NaF	34.7	14.6		5.22		
	ZrF_4	44.4	74.2		16.76		
	UF_4	3.5	11.0		1.64		
25a	NaF	35.1	14.7	107.7	5.28	27.48	3.92
	KF	17.6	10.2		4.12		
	ZrF_4	44.8	74.9		16.91		
	UF_4	2.5	7.9		1.17		
26	KF	14.0	8.1	111.6	3.28	27.78	4.02
	NaF	36.6	15.4		5.51		
	ZrF_4	45.6	76.2		17.21		
	UF_4	3.8	11.9		1.78		
27	NaF	46.0	19.3	115.5	6.92	27.67	4.17
	ZrF_4	50.0	83.6		18.87		
	UF_4	4.0	12.6		1.88		
28	NaF	48.0	20.2	107.1	7.22	26.84	3.99
	ZrF_4	52.0	86.9		19.62		
29	NaF	42.2	17.7	114.3	6.35	28.16	4.06
	ZrF_4	57.8	96.6		21.81		
30	NaF	50.0	21.0	110.5	7.53	26.77	4.13
	ZrF_4	46.0	76.9		17.36		
	UF_4	4.0	12.6		1.88		
31	NaF	50.0	21.0	104.6	7.53	26.40	3.96
	ZrF_4	50.0	83.6		18.87		
32	NaF	52.0	21.8	102.1	7.83	25.95	3.93
	ZrF_4	48.0	80.3		18.12		

TABLE 3 (Con't.)

CALCULATION OF ROOM TEMPERATURE
DENSITIES OF FLUORIDE MIXTURES

Mixture	Component	f_i	$M_i f_i$	Mol. Wt. of Mixture	$(M_i/\rho_i)f_i$	Mol. Vol. of Mixture	$\rho_{\text{Room Temp.}}$
33	NaF	50.0	21.0	141.4	7.53	28.69	4.93
	ZrF_4	25.0	41.8		9.44		
	UF_4	25.0	78.6		11.72		
34	NaF	57.0	23.9	95.8	8.58	24.81	3.86
	ZrF_4	43.0	71.9		16.23		
35	NaF	57.0	23.9	44.1	8.59	18.80	2.35
	BeF_2	43.0	20.2		10.21		
36	NaF	55.0	23.1	57.6	8.28	20.12	2.86
	BeF_2	40.0	18.8		9.50		
	UF_4	5.0	15.7		2.34		
37	NaF	50.0	21.0	178.05	7.53	30.97	5.75
	UF_4	50.0	157.05		23.44		
38	NaF	50.0	21.0	107.54	7.53	26.59	4.04
	ZrF_4	48.0	80.26		18.12		
	UF_4	2.0	6.28		.94		
39	NaF	65.0	27.3	115.18	9.78	24.82	4.64
	ZrF_4	15.0	25.08		5.66		
	UF_4	20.0	62.80		9.38		
40	NaF	53.0	22.3	106.8	7.98	26.09	4.09
	ZrF_4	43.0	71.9		16.23		
	UF_4	4.0	12.6		1.88		
41	NaF	63.0	26.46	105.95	9.48	24.55	4.32
	ZrF_4	25.0	41.8		9.44		
	UF_4	12.0	37.69		5.63		

TABLE 3 (Con't.)

CALCULATION OF ROOM TEMPERATURE
DENSITIES OF FLUORIDE MIXTURES

Mixture	Component	f_i	$M_i f_i$	Mol. Wt. of Mixture	$(M_i/\rho_i)f_i$	Mol. Vol. of Mixture	$\rho_{\text{Room Temp.}}$
42	NaF	64.5	27.09	129.78	9.71	25.80	5.03
	ZrF_4	6.0	10.03		2.26		
	UF_4	29.5	92.66		13.83		
43	NaF	66.7	28.0	132.6	10.04	25.67	5.17
	UF_4	33.3	104.6		15.63		
44	NaF	53.5	22.5	109.8	8.05	26.20	4.19
	ZrF_4	40.0	66.9		15.10		
	UF_4	6.5	20.4		3.05		
45	NaF	53.0	22.27	100.87	7.98	25.72	3.92
	ZrF_4	47.0	78.6		17.74		
46	NaF	62.5	26.3	125.7	9.41	25.85	4.86
	ZrF_4	12.5	20.9		4.72		
	UF_4	25.0	78.5		11.72		
47	NaF	35	14.7	41.1	5.27	18.20	2.26
	LiF	20	5.2		2.25		
	BeF_2	45	21.2		10.68		
C Test	NaF	66.7	28.0	83.7	10.04	22.61	3.70
	ZrF_4	33.3	55.7		12.57		
50-99	(to be hydroxide mixtures)						
100	LiF	60.0	15.5	32.3	6.76	12.78	2.53
	NaF	40.0	16.8		6.02		
101	LiF	57.6	14.9	43.6	6.49	14.15	3.08
	NaF	38.4	16.1		5.78		
	UF4	4.0	12.6		1.88		

TABLE 3 (Con't.)

CALCULATION OF ROOM TEMPERATURE
DENSITIES OF FLUORIDE MIXTURES

Mixture	Component	f_i	$M_i f_i$	Mol. Wt. of Mixture	$(M_i/\rho_i)f_i$	Mol. Vol. of Mixture	$\rho_{\text{Room Temp.}}$
102	LiF	50.0	13.0	42.1	5.63	17.35	2.43
	KF	50.0	29.1		11.72		
103	LiF	48.0	12.4	52.9	5.41	18.54	2.85
	KF	48.0	27.9		11.25		
	UF_4	4.0	12.6		1.88		
104	RbF	57.0	59.6	70.7	16.75	21.59	3.27
	LiF	43.0	11.1		4.84		
105	RbF	54.7	57.2	80.5	16.07	22.60	3.56
	LiF	41.3	10.7		4.65		
	UF_4	4	12.6		1.88		

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TABLE 4

CALCULATED DENSITY-TEMPERATURE RELATIONSHIPS
FOR ALL FLUORIDE MIXTURES
COMPARISON OF CALCULATED RELATIONSHIPS AND
AVAILABLE EXPERIMENTAL RELATIONSHIPS

Composition	M.P.(°C)	Calculated Density	Experimental Density	Agreement[8]	Reference
1	480	$\rho = 3.60 - 0.00087T$			
2	530	$\rho = 4.55 - 0.00102T$	$\rho = 4.70 - 0.00115T$	> 2%	2,12
2a	558	$\rho = 4.40 - 0.00099T$	$\rho = 4.54 - 0.00110T$	> 2%	3,12
3	465	$\rho = 3.24 - 0.00082T$			
4	708	$\rho = 5.60 - 0.00116T$			
5	465	$\rho = 6.01 - 0.00122T$			
6	435	$\rho = 2.29 - 0.00065T$			
7	575	$\rho = 4.78 - 0.00104T$			
8	992[7]				
9	800[7]				
10	870[7]				
11	880[7]				
12	460	$\rho = 2.47 - 0.00068T$	$\rho = 2.53 - 0.00073T$	> 2%	11
13	490	$\rho = 5.05 - 0.00108T$			
14	452	$\rho = 2.56 - 0.00070T$	$\rho = 2.65 - 0.00090T$	> 3%	4,12
15	433	$\rho = 2.40 - 0.00067T$			
16	500	$\rho = 2.87 - 0.00075T$			
17		$\rho = 2.49 - 0.00069T$			
18	506	$\rho = 4.54 - 0.00101T$			
19	405	$\rho = 3.46 - 0.00085T$	$\rho = 3.78 - 0.00109T$	6% (600°C)	5,12
20	450	$\rho = 3.38 - 0.00084T$			
21	540	$\rho = 3.55 - 0.00087T$	$\rho = 4.27 - 0.00163T$	> 4% (800°C)	5,12
22	605	$\rho = 3.69 - 0.00089T$			
23	450	$\rho = 2.52 - 0.00070T$			
24	450	$\rho = 3.59 - 0.00087T$			
25	545	$\rho = 3.75 - 0.00090T$	$\rho = 3.78 - 0.00091T$	> 1%	5,12
25a	545	$\rho = 3.71 - 0.00089T$	$\rho = 3.65 - 0.00080T$	> 1%	5,12
26	540	$\rho = 3.82 - 0.00091T$			
27	510	$\rho = 4.97 - 0.00093T$			

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TABLE 4 (Con't.)

CALCULATED DENSITY-TEMPERATURE RELATIONSHIPS
FOR ALL FLUORIDE MIXTURES
COMPARISON OF CALCULATED RELATIONSHIPS AND
AVAILABLE EXPERIMENTAL RELATIONSHIPS

Composition	M.P.(°C)	Calculated Density	Experimental Density	Agreement[8]	Reference
28	510	$\rho = 3.79 - 0.00090T$			
29	570	$\rho = 3.86 - 0.00092T$			
30	520	$\rho = 3.93 - 0.00093T$			
31	510	$\rho = 3.75 - 0.00090T$	$\rho = 3.79 - 0.00093T$	>1%	6,12
32	500	$\rho = 3.72 - 0.00089T$			
33	610	$\rho = 4.90 - 0.00107T$	$\rho = 5.09 - 0.00159T$	>5%	6,12
34	490	$\rho = 3.65 - 0.00088T$			
35	360	$\rho = 2.40 - 0.00067T$			
36	>500	$\rho = 2.76 - 0.00073T$			
37	715	$\rho = 6.16 - 0.00123T$			
38	510	$\rho = 3.83 - 0.00091T$			
39	610	$\rho = 4.55 - 0.00102T$			
40	520	$\rho = 3.89 - 0.00092T$	$\rho = 3.60 - 0.00055T$	>2%	7
41	595	$\rho = 4.15 - 0.00096T$			
42	650	$\rho = 5.05 - 0.00107T$			
43	640	$\rho = 5.25 - 0.00111T$	$\rho = 5.51 - 0.00130T$	>3%	8
44	545	$\rho = 4.00 - 0.00093T$	$\rho = 4.04 - 0.00110T$	>3%	9
45	500	$\rho = 3.71 - 0.00089T$			
46	635	$\rho = 4.83 - 0.00105T$	$\rho = 4.75 - 0.00120T$	>5%	10
47	350 ± 20°	$\rho = 2.33 - 0.00066T$			
C Test	625	$\rho = 3.49 - 0.00086T$			
100	652	$\rho = 2.52 - 0.00069T$	$\rho = 2.42 - 0.00055T$	>1%	11
101	645	$\rho = 2.95 - 0.00077T$			
102	492	$\rho = 2.46 - 0.00068T$			
103	>500	$\rho = 2.75 - 0.00073T$			
104	462	$\rho = 3.10 - 0.00079T$			
105	465?	$\rho = 3.36 - 0.00084T$			

[8] Agreement or percent difference = $\frac{\rho_{exp.} - \rho_{calc.}}{1/2\,(\rho_{exp.} + \rho_{calc.})} \times 100$
(Determined at 700°C unless otherwise stated)