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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
T. N. Jones



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

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# TABLE OF CONTENTS



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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

[redacted]

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

[redacted]

## 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, $\rho$, 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

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

[redacted]

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

$\rho_{H_2O}$, 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

$\beta_p$, cubical expansion coefficient of the plummet

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

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

[redacted]

$W_A$, $W_{H_2O}$ and the temperature of water were measured before the experiment was started Values for $\rho_{H_2O}$ and $\beta_p$ are known, values of $W_L$ at the various temperatures were measured

Experimental density data are represented in this report by the equation

$$\rho = a - bT \qquad (7)$$

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

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

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

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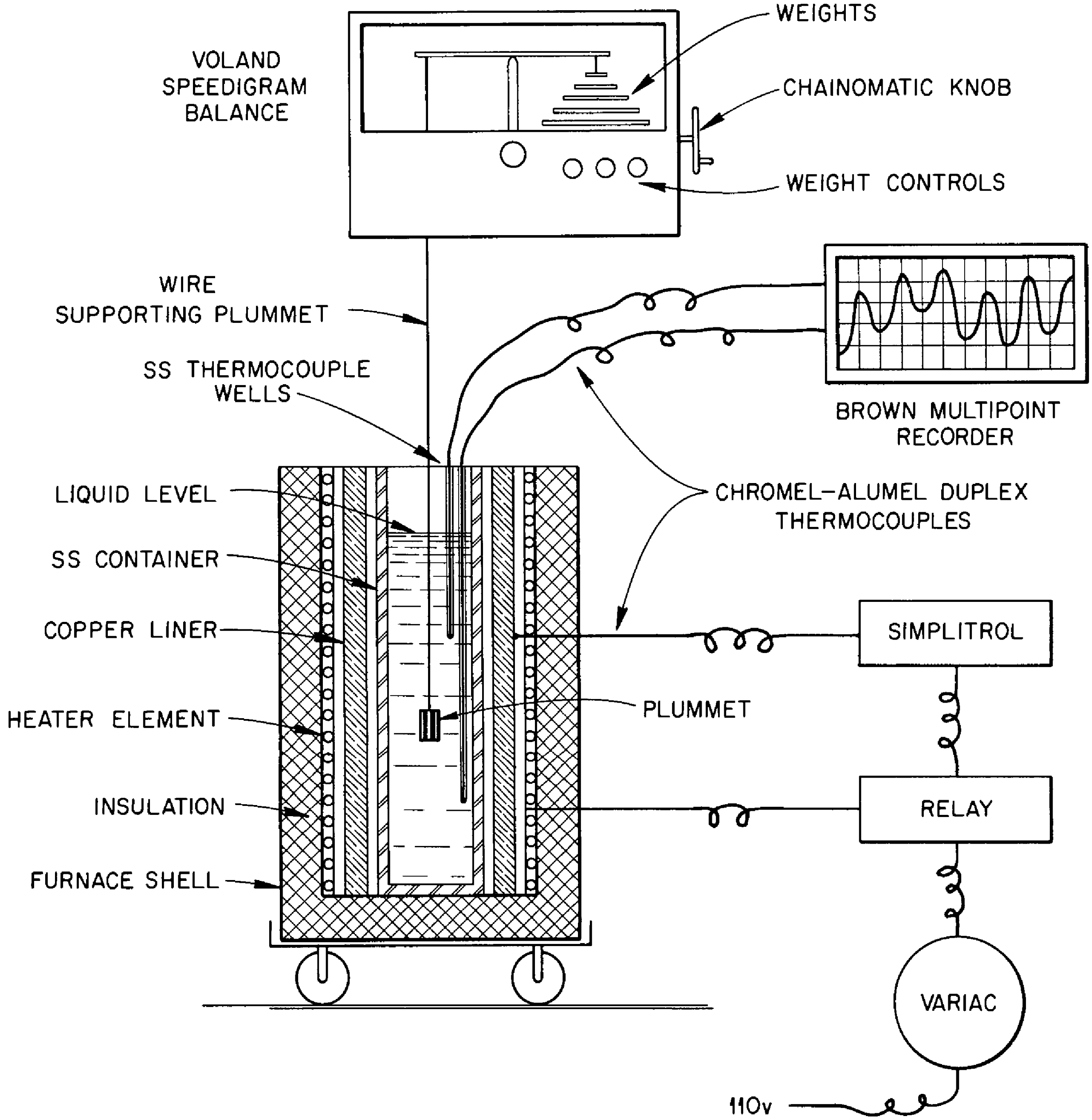


Fig 1 Schematic Diagram of Density Measurement System

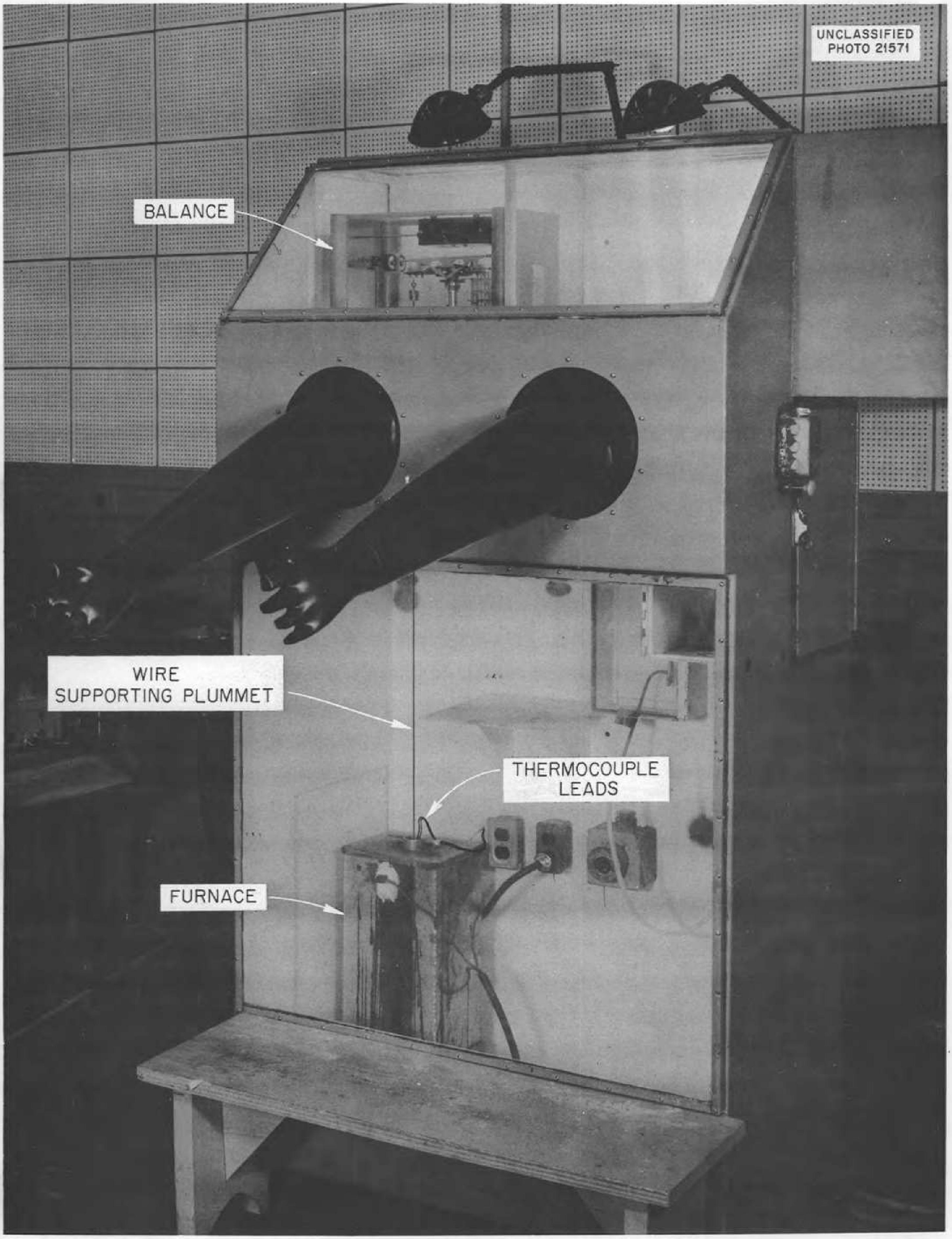


Fig. 2. Photograph of Dry Box Containing Density Measurement System.

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

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## 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,

$\rho$, 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

$\rho_i$, 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

[redacted]

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

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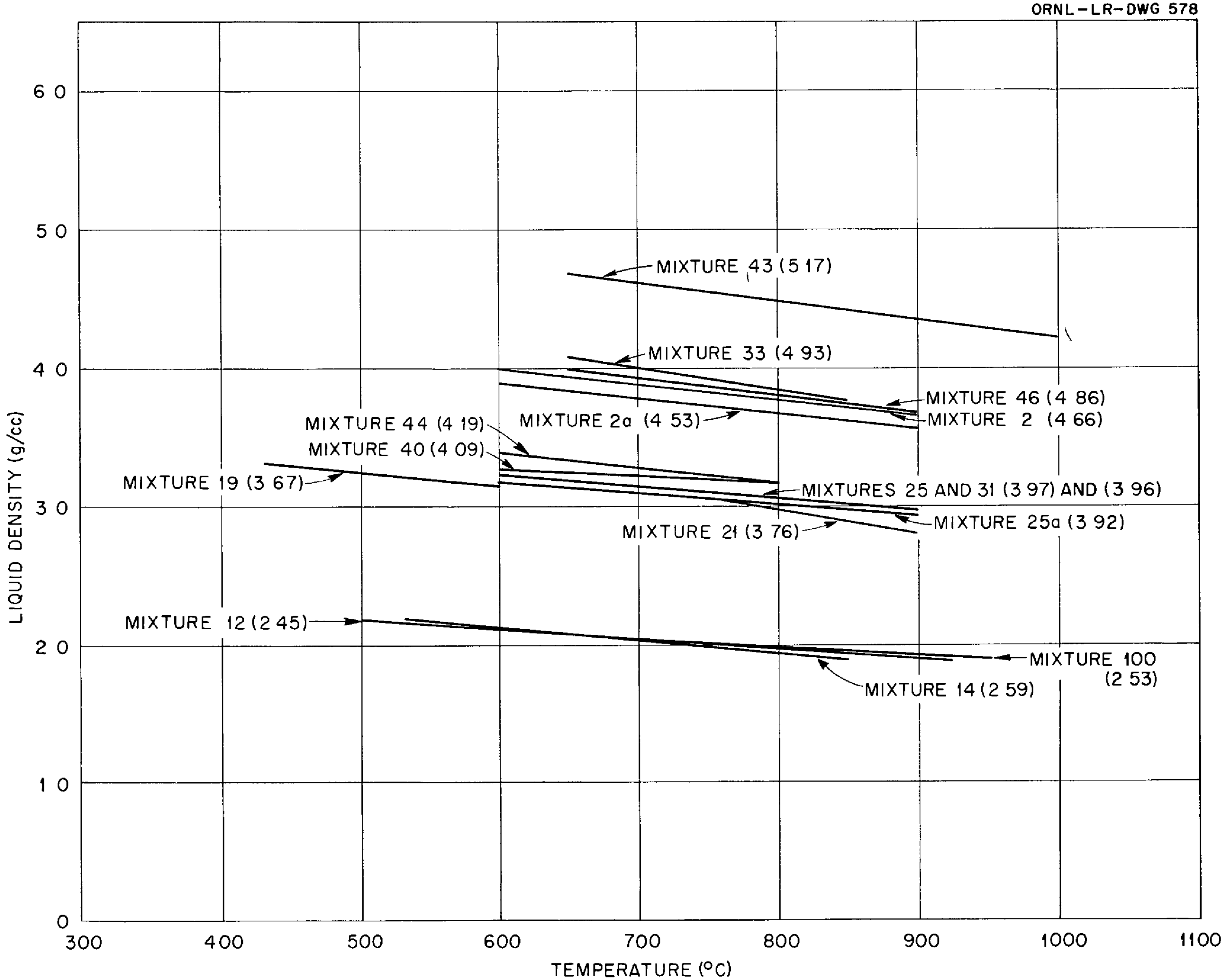


Fig 3 Densities of Fluoride Mixtures (g/cc) vs Temperature (°C)(Numbers in Parentheses are Calculated Room Temperature Densities)

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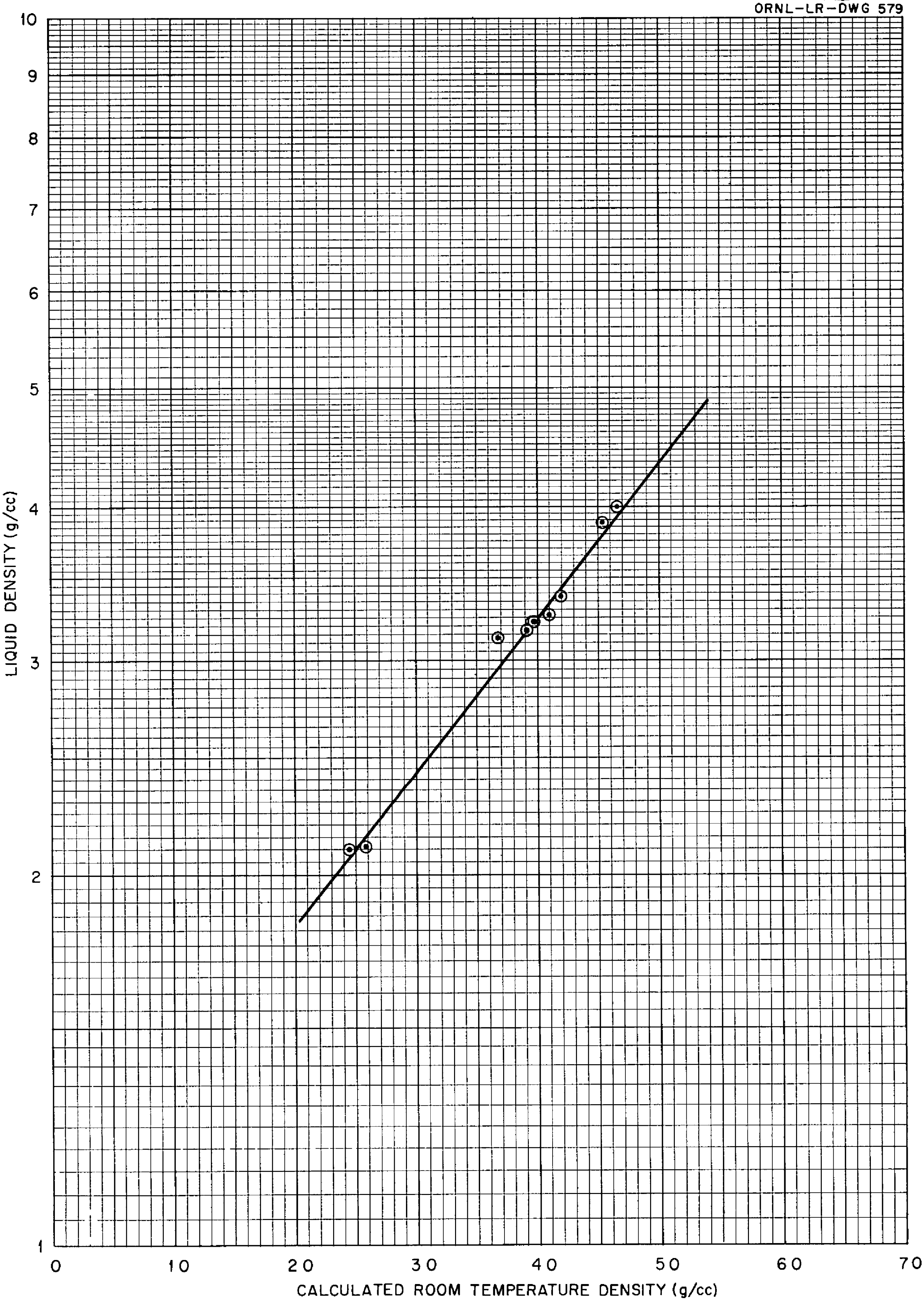


Fig 4a Liquid Density at 600° C vs Calculated Room Temperature Density

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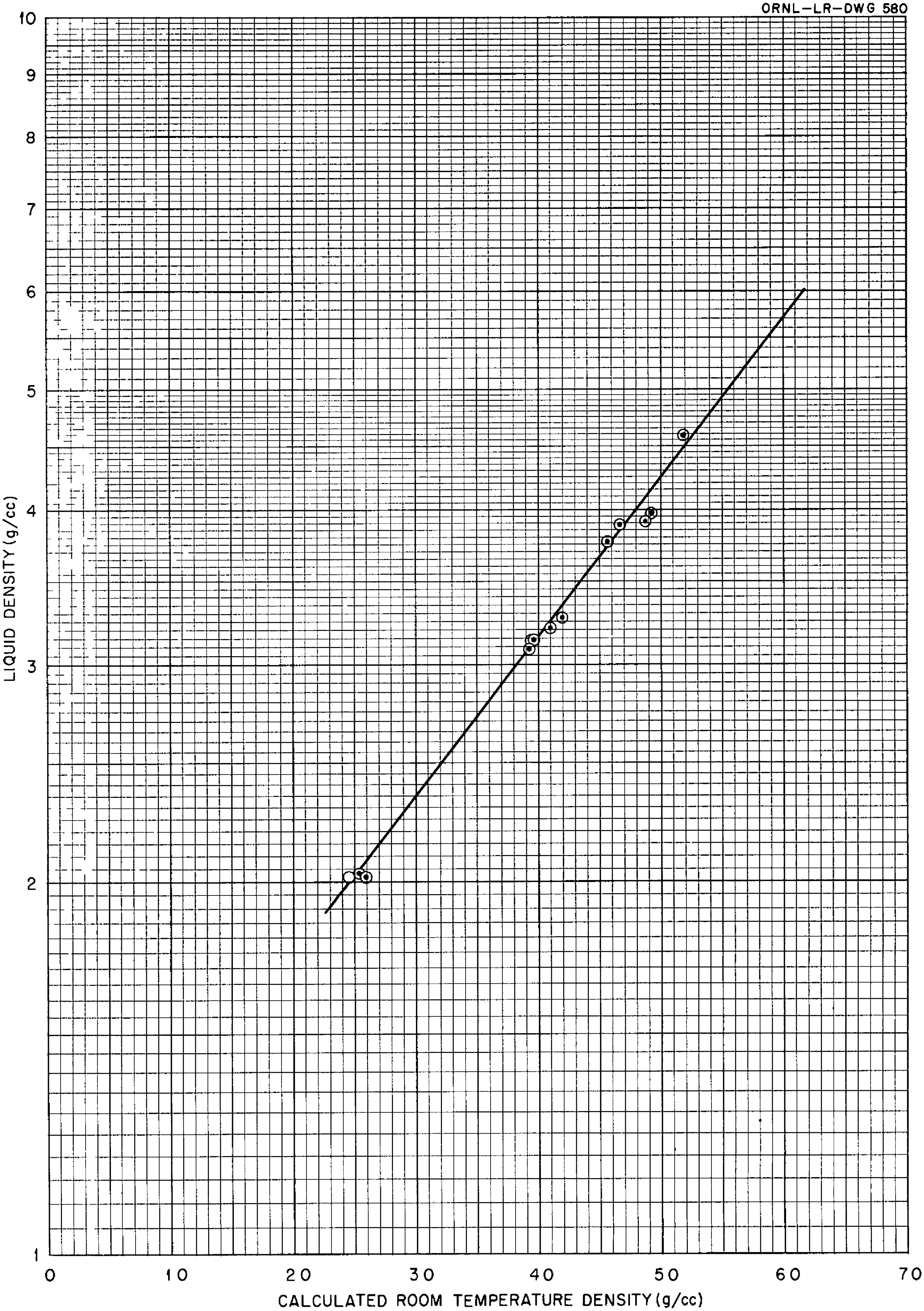


Fig 4b Liquid Density at 700° C vs Calculated Room Temperature Density

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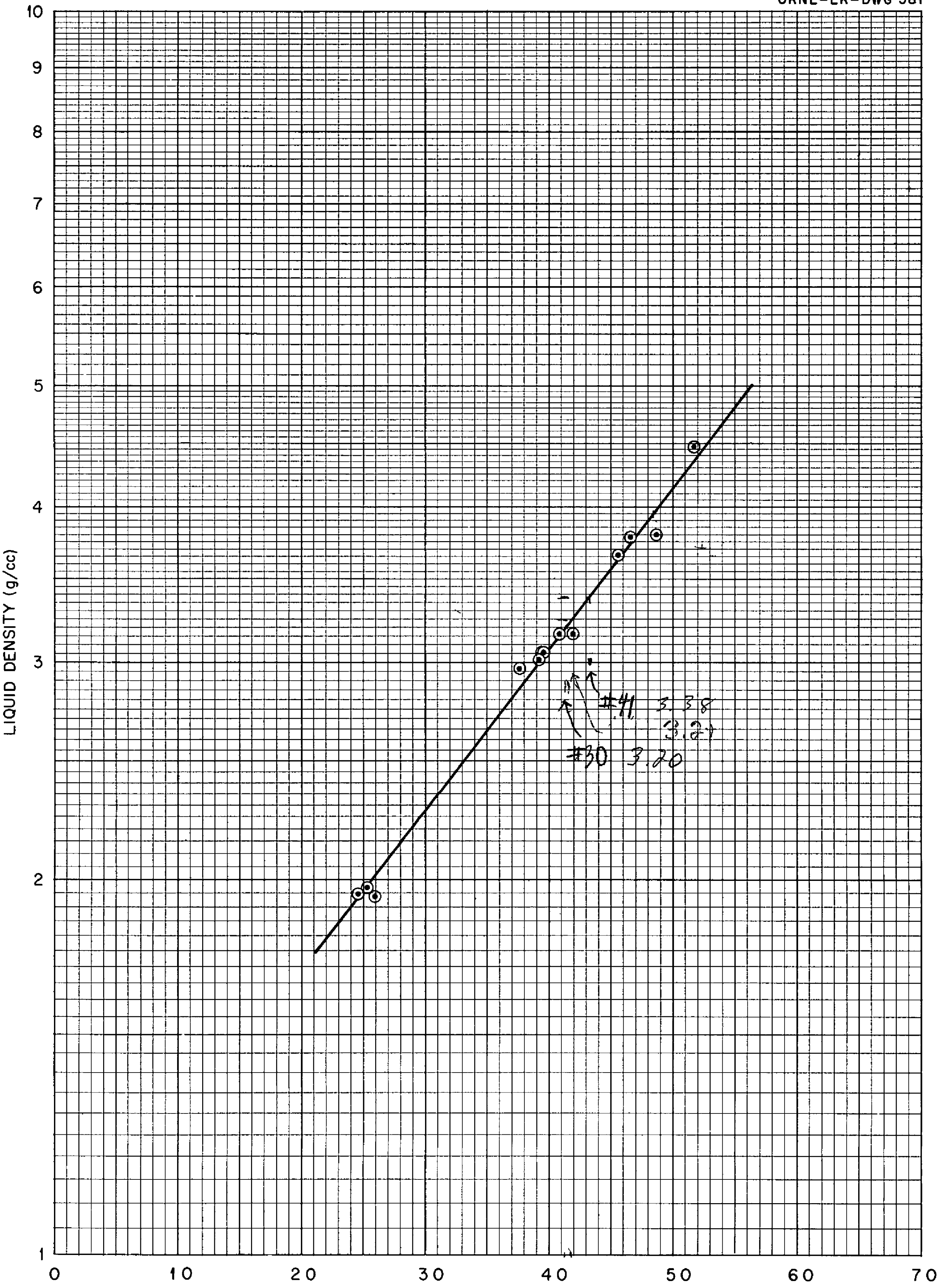


Fig 4c Liquid Density at 800° C vs Calculated Room Temperature Density

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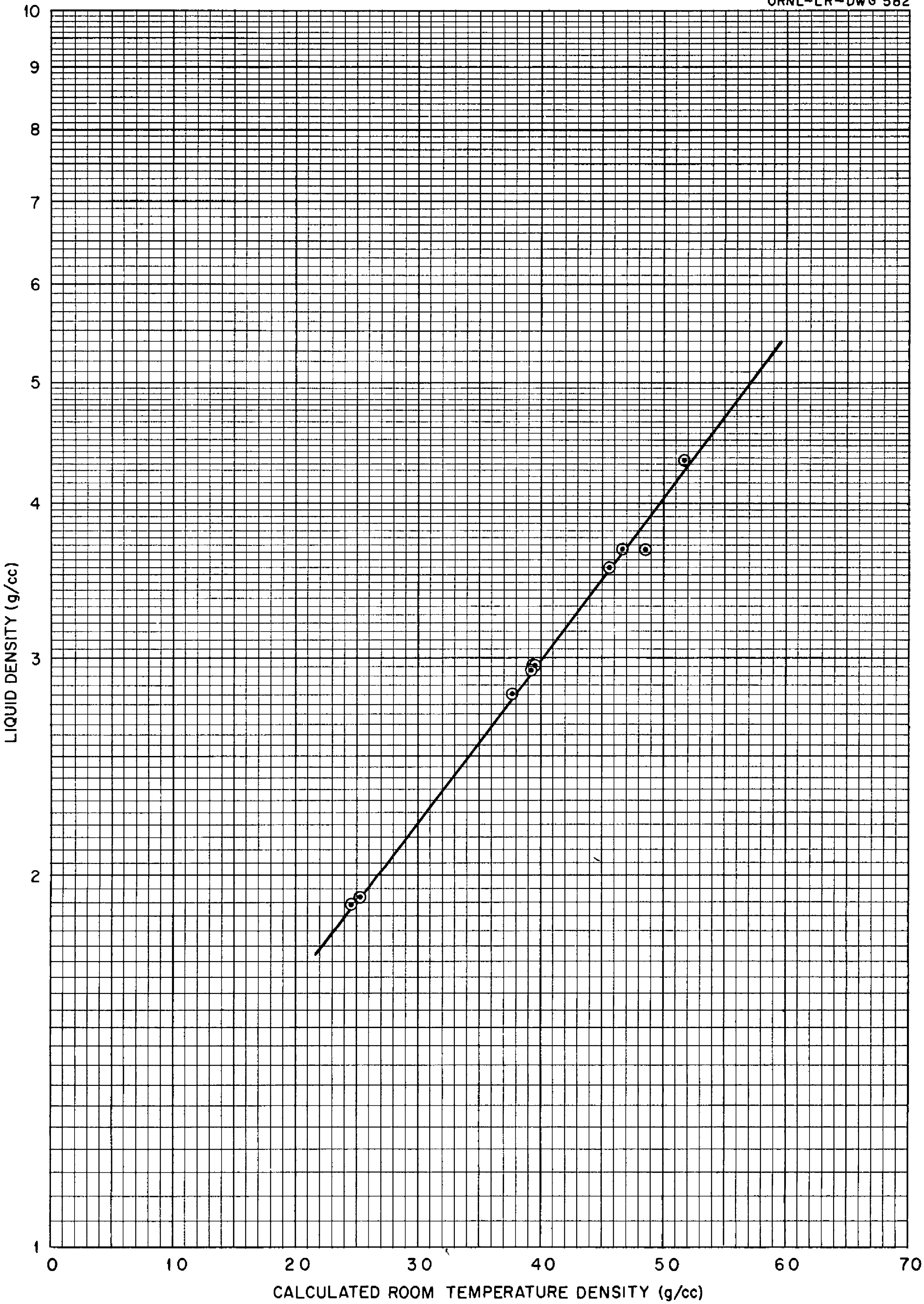


Fig 4d Liquid Density at 900° C vs Calculated Room Temperature Density

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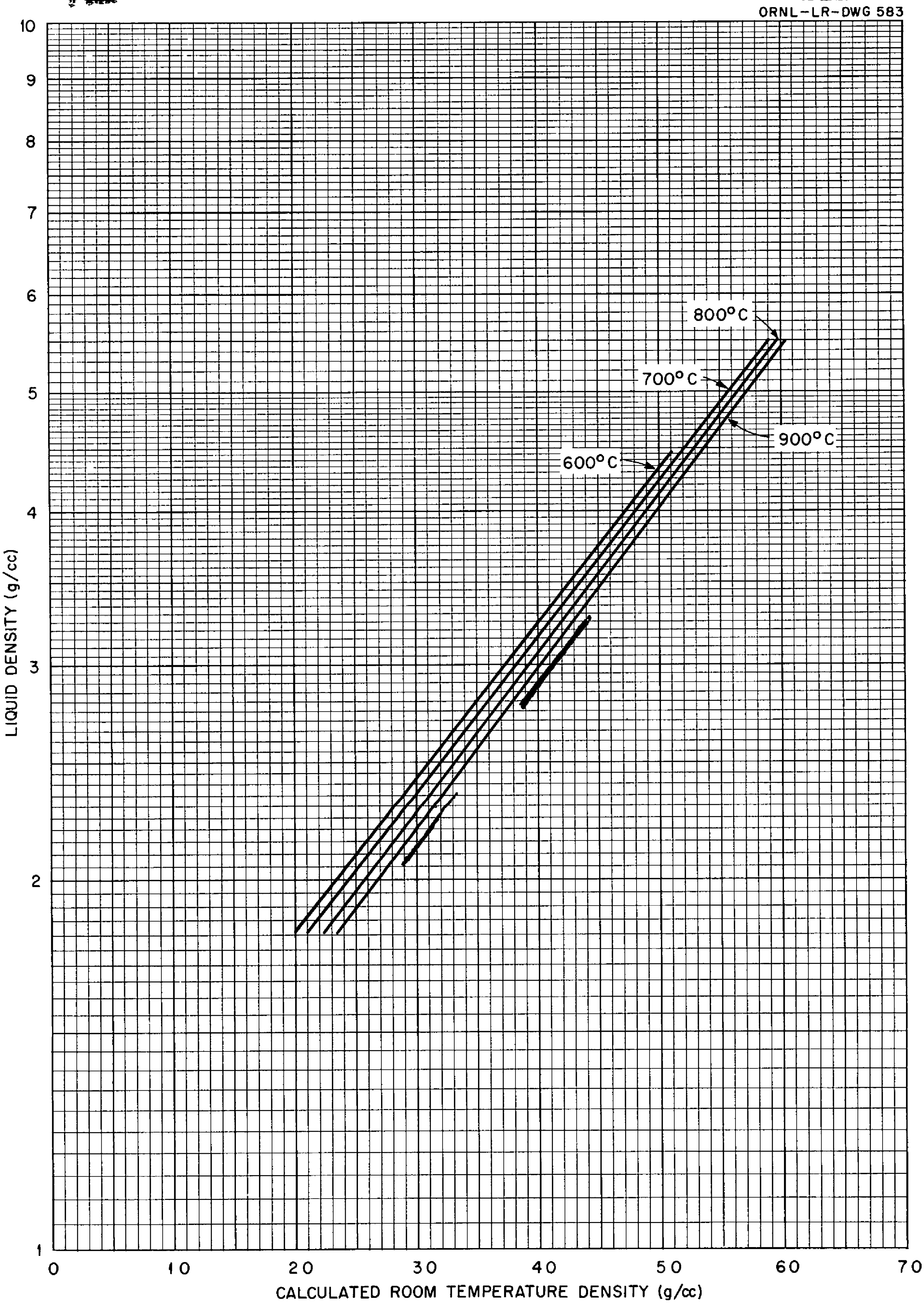


Fig 5 Liquid Density vs Calculated Room Temperature Density (Composite of Figures 2a 2b 2c 2d)

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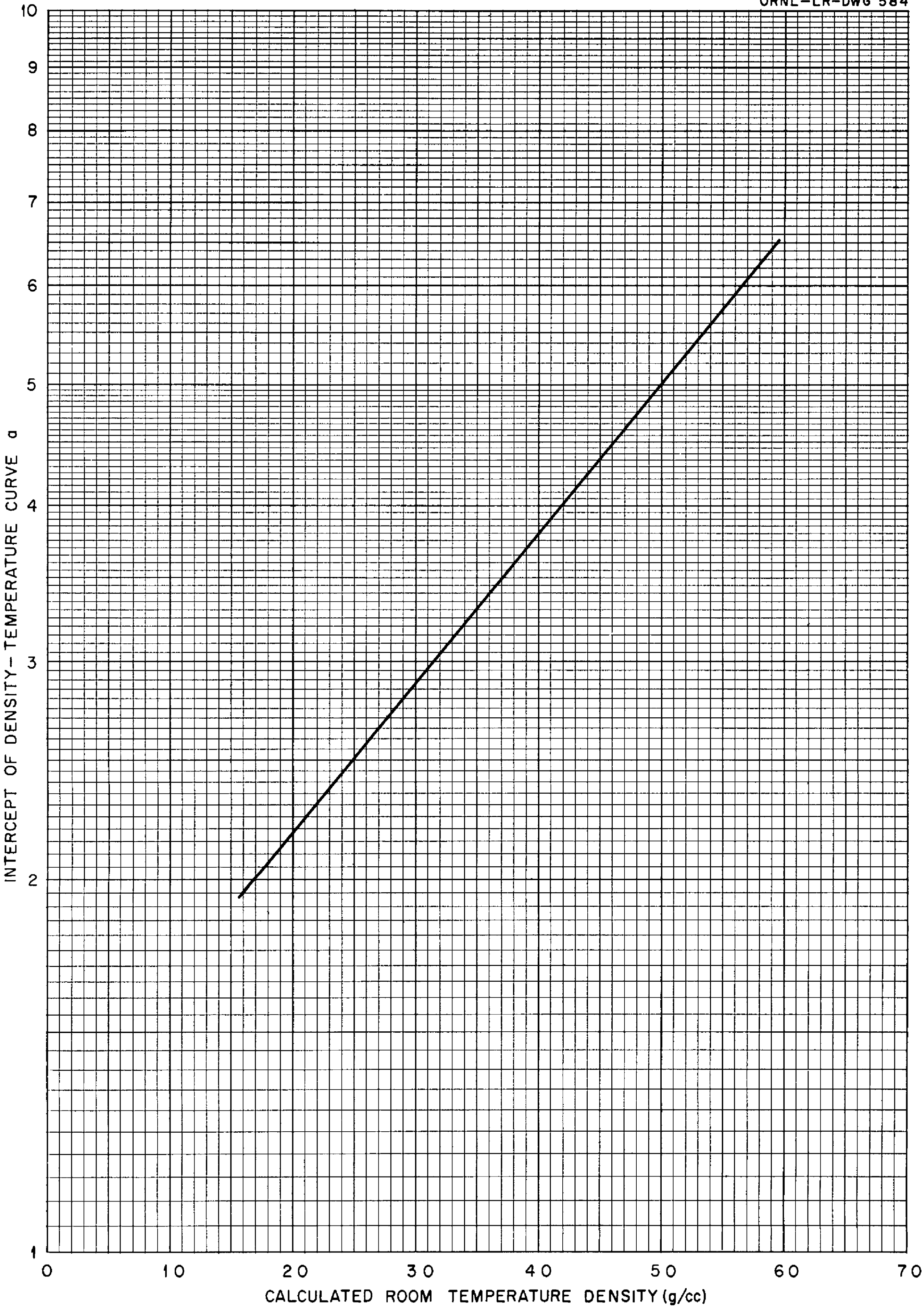


Fig 6 Intercept of Density-Temperature Curve ( a ) vs Calculated Room Temperature Density

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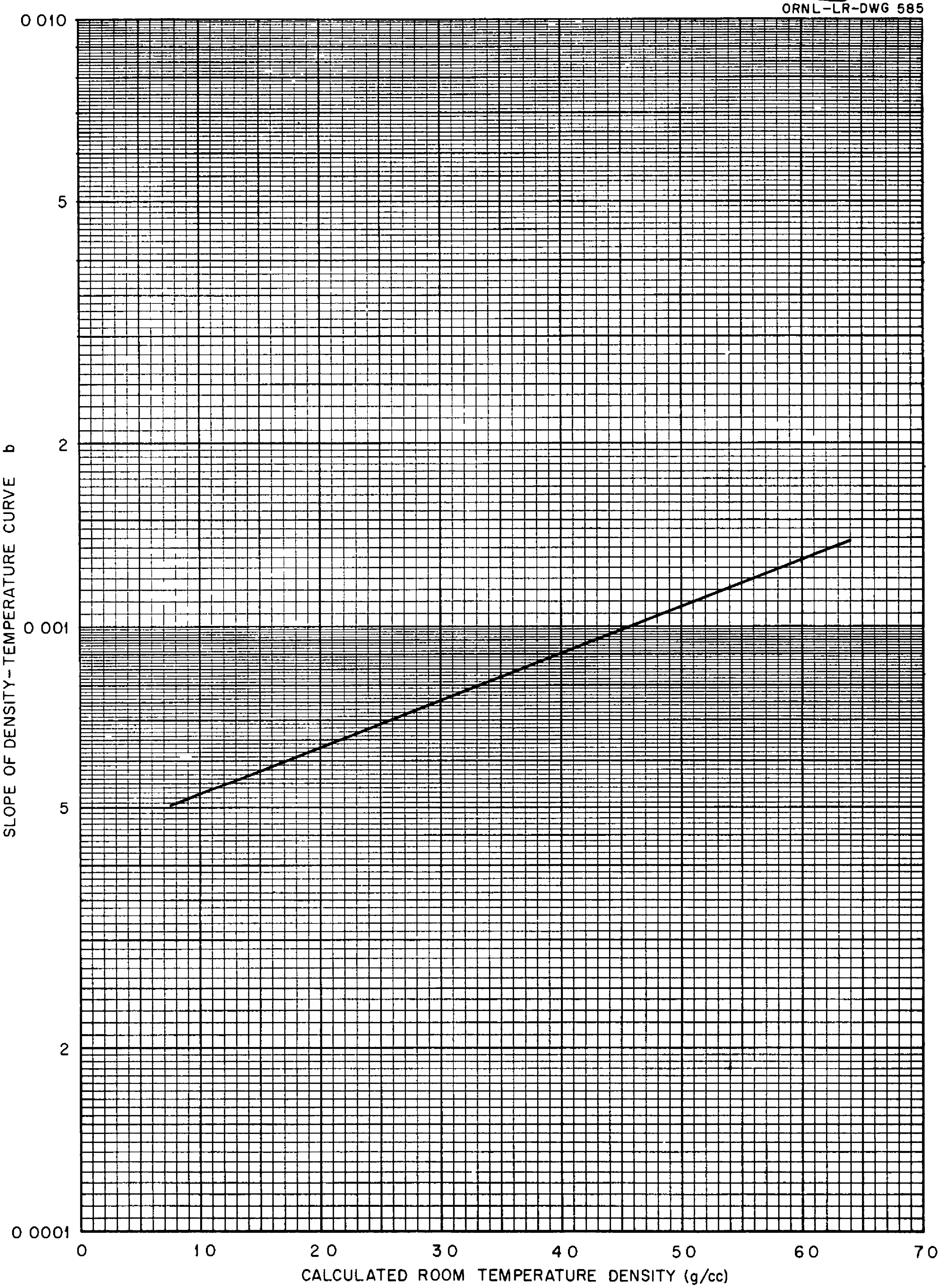


Fig 7 Slope of Density-Temperature Curve ( b ) vs Calculated Room Temperature Density

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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 $3\ 60 \times 10^{-4}$ ($1/^{o}C$) for a mixture having a room temperature density of 2 0 (gm/cc) to $2\ 37 \times 10^{-4}$ ($1/^{o}C$) for a mixture having a room temperature density of 5 5 (gm/cc)

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# APPENDIX



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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 x $10^{-4}$ 1/°C to 2 4 x $10^{-4}$ 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

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TABLE 2

CONSTANTS USED IN CALCULATING ROOM TEMPERATURE DENSITIES

| Component | Molecular Weight, $M_1$ (gm/mol) | Room Temperature Density, $\rho_1$ (gm/cc) | Molecular Volume, $M_1/\rho_1$ (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

[redacted]

[redacted]



## 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

$\rho_i$, 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 | | |

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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 | $\rho_{Room\ Temp}$ |
|---|---|---|---|---|---|---|---|
| 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 (Flinak) | NaF | 11 5 | 4 8 | 41 2 | 1 73 | 16 81 | 2 45 |
| | 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 (Flinak) | KF | 43 5 | 25 3 | 44 9 | 10 19 | 17 36 | 2 59 |
| | 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

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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 | $\rho_{Room\ Temp}$ |
|---|---|---|---|---|---|---|---|
| 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 | | |

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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 | $\rho_{Room\ Temp}$ |
|---|---|---|---|---|---|---|---|
| 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 | | |

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TABLE 3 (Con't )

CALCULATION OF ROOM TEMPERATURE
DENSITIES OF FLUORIDE MIXTURES

| Mixture | Component | $f_1$ | $M_1f_1$ | Mol Wt of Mixture | $(M_1/\rho_1)f_1$ | Mol Vol of Mixture | $\rho_{Room\ Temp}$ |
|---|---|---|---|---|---|---|---|
| 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 | | |

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TABLE 3 (Con't )

CALCULATION OF ROOM TEMPERATURE
DENSITIES OF FLUORIDE MIXTURES

| Mixture | Component | $f_1$ | $M_1 f_1$ | Mol Wt of Mixture | $(M_1/\rho_1)f_1$ | Mol Vol of Mixture | $\rho_{Room\ Temp}$ |
|---|---|---|---|---|---|---|---|
| 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 | | |
| | $UF_4$ | 4 0 | 12 6 | | 1 88 | | |

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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 | $\rho_{Room\ Temp}$ |
|---|---|---|---|---|---|---|---|
| 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 | | |

107 ——— → 2.09 @ 800°C.

for $C_p$ see ORNL-1956

Th Cond. of 107 — .035 W/cm °C

2 BTU

For Inf.
Cohen,
Powers

[redacted]

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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 | ρ = 3 60 - 0 00087T | | | |
| 2 | 530 | ρ = 4 55 - 0 00102T | ρ = 4 70 - 0 00115T | > 2% | 2,12 |
| 2a | 558 | ρ = 4 40 - 0 00099T | ρ = 4 54 - 0 00110T | > 2% | 3,12 |
| 3 | 465 | ρ = 3 24 - 0 00082T | | | |
| 4 | 708 | ρ = 5 60 - 0 00116T | | | |
| 5 | 465 | ρ = 6 01 - 0 00122T | | | |
| 6 | 435 | ρ = 2 29 - 0 00065T | | | |
| 7 | 575 | ρ = 4 78 - 0 00104T | | | |
| 8 | 992[7] | | | | |
| 9 | 800[7] | | | | |
| 10 | 870[7] | | | | |
| 11 | 880[7] | | | | |
| 12 | 460 | ρ = 2 47 - 0 00068T | ρ = 2 53 - 0 00073T | > 2% | 11 |
| 13 | 490 | ρ = 5 05 - 0 00108T | | | |
| 14 | 452 | ρ = 2 56 - 0 00070T | ρ = 2 65 - 0 00090T | > 3% | 4,12 |
| 15 | 433 | ρ = 2 40 - 0 00067T | | | |
| 16 | 500 | ρ = 2 87 - 0 00075T | | | |
| 17 | | ρ = 2 49 - 0 00069T | | | |
| 18 | 506 | ρ = 4 54 - 0 00101T | | | |
| 19 | 405 | ρ = 3 46 - 0 00085T | ρ = 3 78 - 0 00109T | 6% (600°C) | 5,12 |
| 20 | 450 | ρ = 3 38 - 0 00084T | | | |
| 21 | 540 | ρ = 3 55 - 0 00087T | ρ = 4 27 - 0 00163T | > 4% (800°C) | 5,12 |
| 22 | 605 | ρ = 3 69 - 0 00089T | | | |
| 23 | 450 | ρ = 2 52 - 0 00070T | | | |
| 24 | 450 | ρ = 3 59 - 0 00087T | | | |
| 25 | 545 | ρ = 3 75 - 0 00090T | ρ = 3 78 - 0 00091T | > 1% | 5,12 |
| 25a | 545 | ρ = 3 71 - 0 00089T | ρ = 3 65 - 0 00080T | > 1% | 5,12 |
| 26 | 540 | ρ = 3 82 - 0 00091T | | | |
| 27 | 510 | ρ = 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 | ρ = 3 79 - 0 00090T | | | |
| 29 | 570 | ρ = 3 86 - 0 00092T | | | |
| 30 | 520 | ρ = 3 93 - 0 00093T | | | |
| 31 | 510 | ρ = 3 75 - 0 00090T | ρ = 3 79 - 0 00093T | >1% | 6,12 |
| 32 | 500 | ρ = 3 72 - 0 00089T | | | |
| 33 | 610 | ρ = 4 90 - 0 00107T | ρ = 5 09 - 0 00159T | >5% | 6,12 |
| 34 | 490 | ρ = 3 65 - 0 00088T | | | |
| 35 | 360 | ρ = 2 40 - 0 00067T | | | |
| 36 | >500 | ρ = 2 76 - 0 00073T | | | |
| 37 | 715 | ρ = 6 16 - 0 00123T | | | |
| 38 | 510 | ρ = 3 83 - 0 00091T | | | |
| 39 | 610 | ρ = 4 55 - 0 00102T | | | |
| 40 | 520 | ρ = 3 89 - 0 00092T | ρ = 3 60 - 0 00055T | >2% | 7 |
| 41 | 595 | ρ = 4 15 - 0 00096T | | | |
| 42 | 650 | ρ = 5 05 - 0 00107T | | | |
| 43 | 640 | ρ = 5 25 - 0 00111T | ρ = 5 51 - 0 00130T | >3% | 8 |
| 44 | 545 | ρ = 4 00 - 0 00093T | ρ = 4 04 - 0 00110T | >3% | 9 |
| 45 | 500 | ρ = 3 71 - 0 00089T | | | |
| 46 | 635 | ρ = 4 83 - 0 00105T | ρ = 4 75 - 0 00120T | >5% | 10 |
| 47 | 350 ± 20° | ρ = 2 33 - 0 00066T | | | |
| C Test | 625 | ρ = 3 49 - 0 00086T | | | |
| 100 | 652 | ρ = 2 52 - 0 00069T | ρ = 2 42 - 0 00055T | >1% | 11 |
| 101 | 645 | ρ = 2 95 - 0 00077T | | | |
| 102 | 492 | ρ = 2 46 - 0.00068T | | | |
| 103 | >500 | ρ = 2 75 - 0 00073T | | | |
| 104 | 462 | ρ = 3 10 - 0 00079T | | | |
| 105 | 465? | ρ = 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)

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