H_2 Solubility Data from B&W

50-320

Mr. L. B. Marsh
U.S. Nuclear Regulatory Commission
Bethesda, Maryland

Subject: TMI-II Gas Bubble Volume Calculat

Enclosed is some summary information regarding our calculations of the TMI-II gas bubble volume. This information has been transmitted (telecopy) to Dick Wilson of Met. Ed. Operations and the NRC representative in the TMI-II control room. We believe further communcations are necessary to confirm that everyone concurs on the validity of the equations and the test procedure being run or to plan further testing and analysis.

D W Berger

D. W. Berger

Babcock & Wilcox

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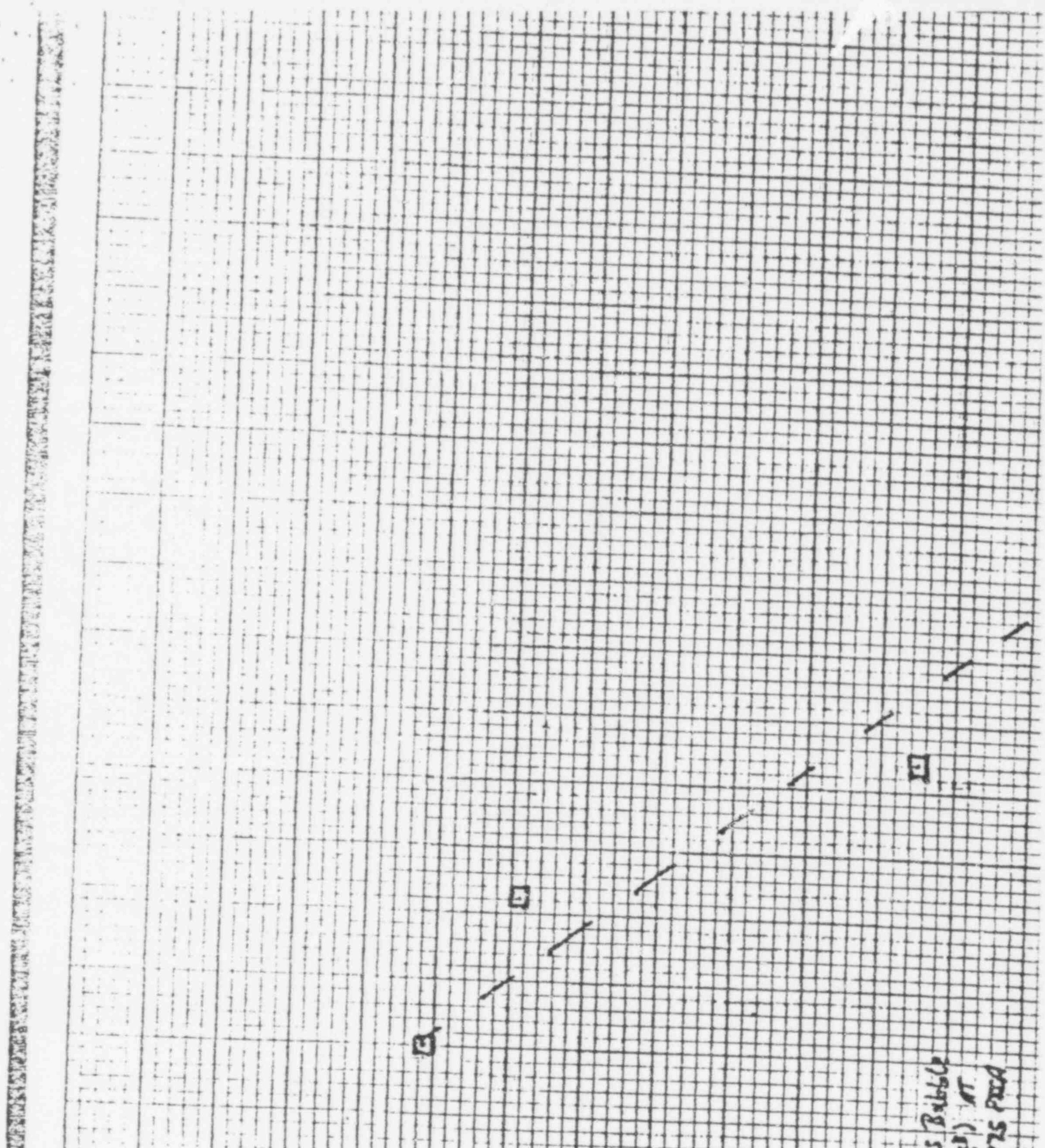

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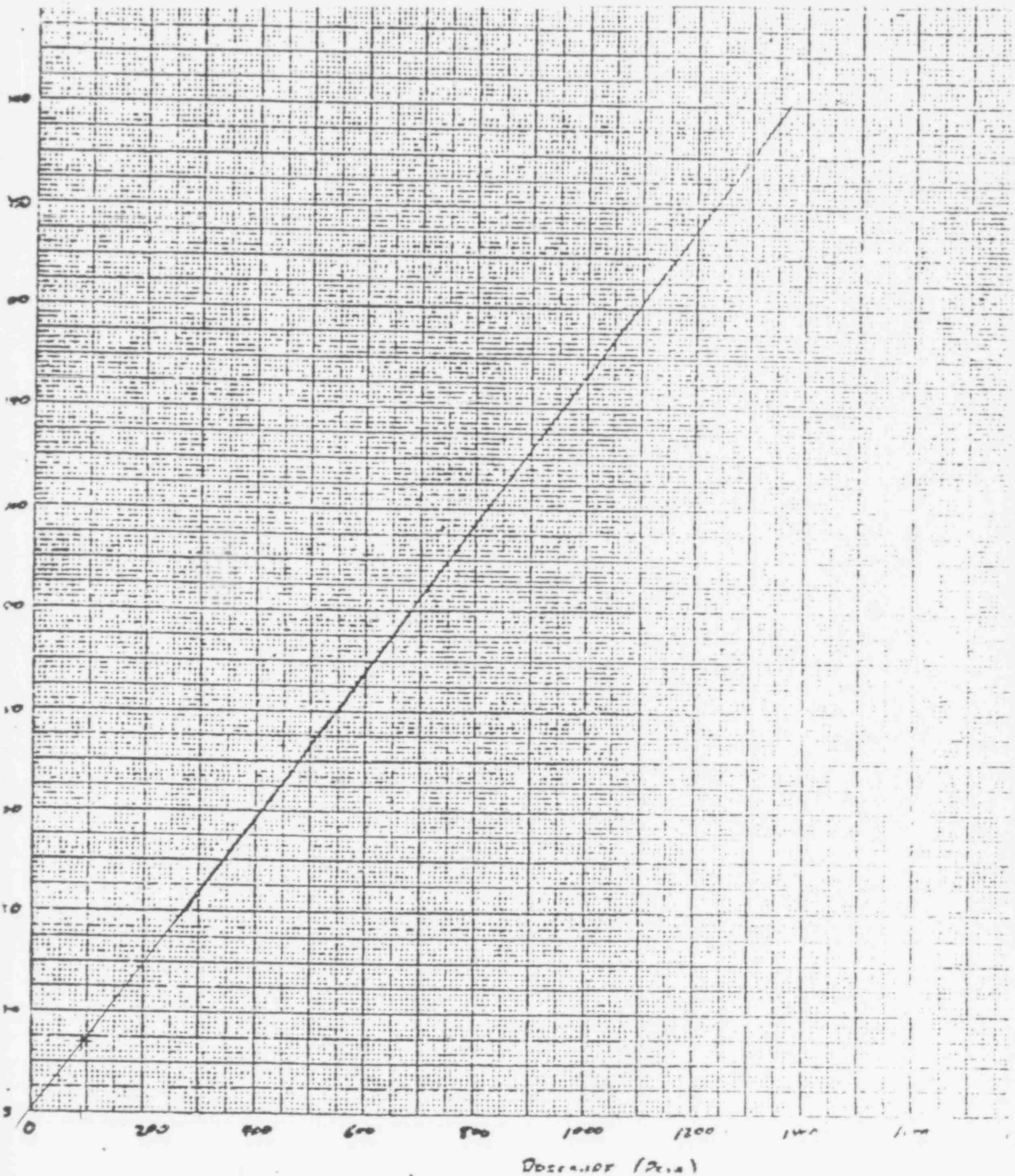
	RCS		PZR		MAT		V_{gas} (ft³)
	Press	Temp	Level	Temp	Level	Temp	
T_1	955	278.2	196	545.6	49.5	81	
T_2	1046	277.7	192.2	556.6	33	81	
Δ	+91	-.5	-3.8		-16.5		393
T_1	957	280	195.1	545.7	53.3	72	
T_2	1055	279.4	192.7	557.9	39.6	70	
Δ	+98	-.6	-2.4		-13.7		328.1
T_1	945	280.5	201.2	544.6	50.7	78	
T_2	1050	280.5	192.6	557.1	45.3	75	
~~Δ~~	~~+105~~	-0-	-8.6		-5.4		103.23
T_1	955	280.9	216.8	545.9	53.3	75	
T_2	1065	281.3	208.3	558.2	50.6	74	
Δ	+110	+.4	-8.5		-2.7		-10.66



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Volume of Bubble Calculation

$$V_{Bubble} = \frac{P_2}{P_1 - P_2}\left[C_{PZR}\left(\frac{\nu_{s_2}^{RCS}}{\nu_{s_2}^{PZR}} L_2^{PZR} - \frac{\nu_{f_1}^{RCS}}{\nu_{f_1}^{PZR}} L_1^{PZR}\right)\right.$$

$$+ C_{MUT}\left(\frac{\nu_f^{RCS}}{\nu_f^{MUT}}\right)\left(L_2^{MUT} - L_1^{MUT}\right) - M_{RCS}\left(\frac{\partial \nu^{RCS}}{\partial T^{RCS}}\right)\left(T_2^{RCS} - T\right.$$

$$- M_{RCS}\left(\frac{\partial \nu^{RCS}}{\partial P^{RCS}}\right)\left(P_2 - P_1\right) + M_{RCS}\left(\frac{\partial S}{\partial P}\right)\left(P_2 - P_1\right)$$

P_2 = RC Sys Press After Change
P_1 = RC Sys Press Before Change
C_{PZR} = Level to Volume Conversion for Pzr. = 3.178 ft³/in
C_{MUT} = " " " " " MUT = 4.128 ft³/in
ν_f^{RCS} = Specific Volume of water at RCS temp, superheated steam table
$\nu_{f_2}^{PZR}$ = " " " " " Pzr. " after change, saturated s
$\nu_{f_1}^{PZR}$ = " " " " " " " before " , "
ν_f^{MUT} = " " " " " MUT " , saturated steam tables
L_2^{PZR} = Level in pressurizer after change, inches
L_1^{PZR} = " " " before " , "
L_2^{MUT} = " " makeup tank after change, inches
L_1^{MUT} = " " " " before " , "
$\frac{\partial \nu^{RCS}}{\partial T^{RCS}}$ = change in RCS specific vol. per °F = 9×10^{-6} ft³/Lbm-F

$\frac{\partial \nu^{RCS}}{\partial P^{RCS}}$ = Change in RCS specific volume per pound pressure = -10^{-7} ft³/

$\frac{\partial S}{\partial P}$ = Change in solubility of H_2 per pound pressure = 5.837×10 ft³/Lb

M_{RCS} = Mass of RCS = $6.166 \times 10^{+5}$ lbs

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RATE OF CHANGE OF SOLUBILITY AS A FUNCTION OF [illegible]

$T = 280°F = 137.8°C$

Conc (cc/Kg)		Conc (SCF/LB)		Conc (CF/LB)	Press Atm	Press PSI
400		6.41×10^{-3}		1.59×10^{-4}	18.6	273
600	500	9.61×10^{-3}	9.61×10^{-3}	2.39×10^{-4}	27.7	410
800		—		3.18×10^{-4}	37.2	547
1000		—		3.98×10^{-4}	46.5	683
1200		—		4.78×10^{-4}	55.8	820
1400	1500	0.02243		5.57×10^{-4}	65.1	957
1600		—		6.37×10^{-4}	74.4	1094
1800		—		7.16×10^{-4}	83.7	1230
2000		0.032		7.96×10^{-4}	93.0	1367

$$\text{Conc}\left(\frac{SCF}{LB}\right) = \text{Conc}\left(\frac{cc}{Kg}\right) \times \frac{0.4536\ Kg/LB}{28,317\ cc/SCF}$$

$$\text{Conc}\left(\frac{CF}{LB}\right) = \text{Conc}\left(\frac{cc}{Kg}\right) \times \frac{0.4536\ Kg/LB}{28317\ cc/FT^3} \times \frac{14.7\ Psia}{890\ Psia} \times \frac{740°R}{492°R}$$

$$\frac{dc}{dP} \cong -\left(\frac{C_2 - C_1}{P_2 - P_1}\right) = -\left(\frac{5.57 \times 10^{-4} - 4.78 \times 10^{-4}}{957 - 820}\right) = -5.766 \times 10^{-7} \left(\frac{CF/LB}{PSI}\right)$$

Density:

$0.0056\ lb/ft^3 \times \frac{890 \times 492}{14.7 \times 740}$

$0.225\ lb/ft^3$ at 890 psia 280 °F

REFERENCE CONDITIONS 875 PSIG & 280°F

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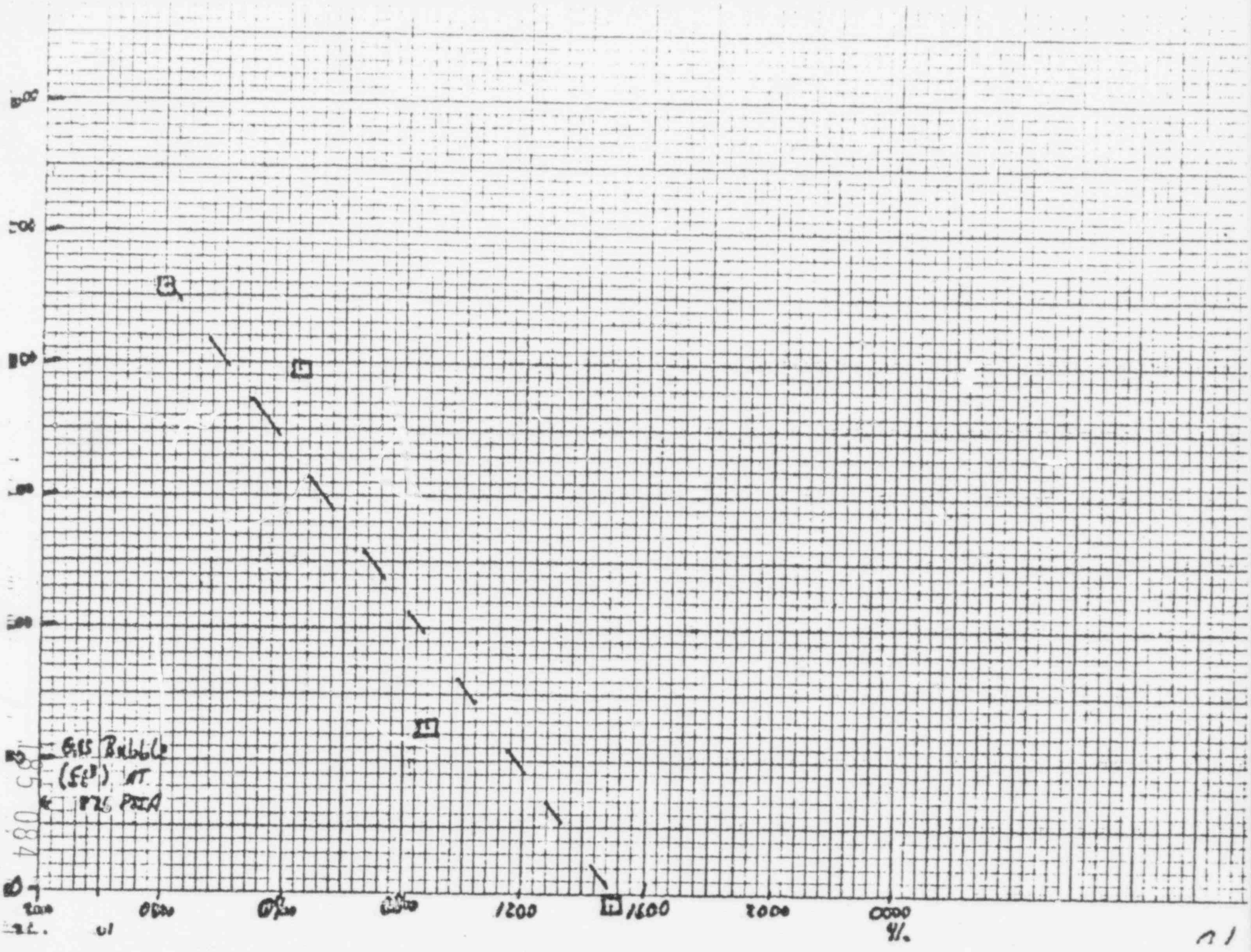
Gas Bubble
(ft³) AT.
1200
1600
2000
0000

Br.—(*Continued*)

t, °C	$10^{-4} \times K$	t, °C	$10^{-4} \times K$
28	6.37	60	19.1
30	6.88	70	24.4
40	10.1	80	30.7
50	14.5	Lit.	(102, 103)

Cl, Chlorine (Cl_2); *cf. also* (2, 46, 66)

t, °C	β	t, °C	β	t, °C	β	t, °C	β
10	3.148	18	2.440	26	1.970	50	1.216
11	3.047	19	2.368	27	1.923	60	1.025
12	2.950	20	2.299	28	1.880	70	0.862
13	2.856	21	2.238	29	1.839	80	0.683
14	2.767	22	2.180	30	1.799	90	0.39
15	2.680	23	2.123	35	1.608	100	0.00
16	2.597	24	2.070	40	1.450	Lit.	(106)
17	2.517	25	2.019	45	1.320		

t, °C	0	3	6	9	12	Lit.
β	4.61	3.93	3.42	3.03	2.77	(3)

H, Hydrogen, (H_2); *cf. also* (48)

p_{H_2}, mm	560	600	650	700	727	Lit.
$10^4\alpha$, 25°C	1814	1807	1798	1790	1786	(20)

t, °C	20	25	Lit.
K	5.07×10^7	5.18×10^7	(39)

t, °C	$10^{-7} \times K$	t, °C	$10^{-7} \times K$
0	4.391	14	4.928
1	4.430	15	4.964
2	4.470	16	4.998
3	4.509	17	5.034
4	4.548	18	5.070
5	4.587	19	5.107
6	4.625	20	5.138
7	4.664	21	5.170
8	4.703	22	5.203
9	4.742	23	5.234
10	4.778	24	5.265
11	4.818	25	5.296
12	4.854	26	5.325
13	4.891	Lit.	(91)

t, °C (97, 99, 100)	$10^{-7} \times K$	t, °C	$10^{-7} \times K$
0	4.401	20	5.192
1	4.447	21	5.228
2	4.491	22	5.264
3	4.537	23	5.302
4	4.580	24	5.340
5	4.623	25	5.374
6	4.669	26	5.408
7	4.710	27	5.443
8	4.758	28	5.477
9	4.797	29	5.510
10	4.834	30	5.540
11	4.871	35	5.638
12	4.909	40	5.709
13	4.947	45	5.765
14	4.982	50	5.809
15	5.017	60	5.810
16	5.052	70	5.78
17	5.087	80	5.74
18	5.120	90	5.71
19	5.155	100	5.66

t = 19.5°C (15)				t = 23°C (15)		
p_{H_2}, mm	$10^3\alpha$	p_{H_2}, mm	$10^3\alpha$	p_{H_2}, mm	$10^3\alpha$	p_{H_2}, mm
900	16.78	5000	16.41	1100	16.01	5000
1000	16.76	5500	16.28	1500	16.00	5500
1500	16.78	6000	16.14	2000	16.00	6000
2000	16.75	6500	15.97	2500	15.99	6500
2500	16.73	7000	15.80	3000	15.98	7000
3000	16.71	7500	15.59	3500	15.96	7500
3500	16.67	8000	15.36	4000	15.92	8000
4000	16.61	8250	15.23	4500	15.85	8200
4500	16.52					

He, Helium; *cf. also* (46, 111)

$$\log_{10} K = \frac{0.05223}{T} \times (-3053) + 8.584\text{; range, 2 to 30°C}$$

t, °C (1)	0	10	20	30	40
$10^{-7} \times K$	9.78	9.54	9.50	9.39	9.19

Kr, Krypton; *cf. also* (46, 111)

t, °C	0	10	20	30	40	50	60
$10^{-7} \times K$	0.945	1.170	1.510	1.850	2.182	2.471	2.6[illegible]

N, Nitrogen (N_2); *cf. also* (16, 46)

t, °C	20	25
K	5.939×10^7	6.297×10^7

p_{N_2} mm	$10^3\alpha$, 25°C	p_{N_2} mm	$10^3\alpha$, 25°C	p_{N_2} mm	$10^3\alpha$
270	14.38	500	14.26	800	1[illegible]
300	14.37	601.6	14.20	830	1[illegible]
400	14.31	700	14.28	Lit.	([illegible]

Atmospheric N_2, = 98.815 vol. % N_2 + 1.185 vol. % A

t, °C	$10^{-7} \times K$	t, °C	$10^{-7} \times K$	t, °C	$10^{-7} \times K$	t, °C	$10^{-7} \times K$
0	4.007	9	4.893	18	5.731	27	6[illegible]
1	4.103	10	4.988	19	5.818	28	6[illegible]
2	4.200	11	5.084	20	5.906	29	6[illegible]
3	4.299	12	5.178	21	5.991	30	6[illegible]
4	4.395	13	5.273	22	6.076	35	7[illegible]
5	4.496	14	5.365	23	6.160	40	7[illegible]
6	4.593	15	5.457	24	6.244	45	7[illegible]
7	4.694	16	5.548	25	6.331	50	8[illegible]
8	4.794	17	5.638	26	6.411		

Argon-free N_2, computed from the above values

t, °C	$10^{-7} \times K$	t, °C	$10^{-7} \times K$	t, °C	$10^{-7} \times K$	t, °C	$10^{-7} \times K$
0	4.077	15	5.550	30	6.846	45	7[illegible]
5	4.572	20	6.004	35	7.235	50	8[illegible]
10	5.074	25	6.435	40	7.608		

Atmospheric N_2 (98, 99, 100)

t, °C	$10^{-7} \times K$	t, °C	$10^{-7} \times K$	t, °C	$10^{-7} \times K$	t, °C	$10^{-7} \times K$
0	4.016	10	5.079	20	6.109	30	7[illegible]
1	4.116	11	5.184	21	6.208	35	7[illegible]
2	4.219	12	5.291	22	6.298	40	7[illegible]
3	4.323	13	5.399	23	6.394	45	8[illegible]
4	4.428	14	5.497	24	6.485	50	8[illegible]
5	4.535	15	5.606	25	6.574	60	9[illegible]
6	4.641	16	5.710	26	6.670	70	9[illegible]
7	4.753	17	5.811	27	6.759	80	9[illegible]
8	4.861	18	5.912	28	6.845	90	9[illegible]
9	4.970	19	6.013	29	6.932	100	9[illegible]

Argon-free N_2, computed from the above values

t, °C	$10^{-7} \times K$	t, °C	$10^{-7} \times K$	t, °C	$10^{-7} \times K$	t, °C	$10^{-7} \times K$
0	4.089	15	5.704	30	7.149	45	[illegible]
5	4.609	20	[illegible]	35	7.614	50	[illegible]
10	5.168	25	6.686	40	8.051		

Henry Constant. 20 - 374°C

$P = 1500$ psi

$H = A + B \cdot \frac{1}{T}$ H in atm/mole fraction.

$A \times 10^{-4} = 9.01$ ~~$\times 10^{0}$~~ atm $= 5.8\%$

$B = 5.83 \quad = 5.2\%$

Reference: Journal Chem. Eng. Data.
Vol. 5 pp. 10-15 (1960)
D. M. Himmelblau
"Solubility of Inert gases".

$P = H\,X \qquad x = \frac{M_H}{(M_w + M_H)}$ ~~$x = \frac{\frac{M_S}{M_H}}{M}$~~

$C = \frac{w_H}{w_{H_2O}} = \frac{x}{1-x}\frac{M_A}{M_S}$

$\frac{dC}{dP} = \frac{dx(1-x) + dx\,x}{(1-x)^2}\frac{M_A}{M_S} = \frac{dx}{(1-x)^2}\frac{M_A}{M_S} = \frac{dx}{dp}\frac{1}{(1-x)^2}\frac{M_A}{M_S}$

$dP = H\,dx \qquad \frac{dx}{dP} = \frac{1}{H}$

$\frac{dC}{dP} = \frac{1}{H}\frac{1}{\left(1-\frac{P}{H}\right)^2}\frac{M_A}{M_S} = \frac{1}{\left(H^{1/2} - \frac{P}{H^{1/2}}\right)^2}\frac{M_A}{M_S} = \frac{\cancel{9.813 \times 10^{-3}}}{1.2406 \times 10^{-6}}$

$\frac{dC'}{dp'} = \frac{\nu_H}{14.7}\frac{dC}{dp} = \frac{3.95}{14.7} \times 1.2406 \times 10^{-6} = 3.334 \times 10^{-7}$

$C' = \frac{C}{}\,\nu_H =$ at 1200 + 280°F

$P'_{psi} = 14.7 \times P$

$H = \left\{9.01 + \frac{5.83}{138}\right\} \times 10^4 = 8.97 \times 10^4$

$P = 68$ atm.

$\nu_1 = \frac{1}{0.0056}\,\frac{181 \times 740}{68 \times 492} = 3.95$

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