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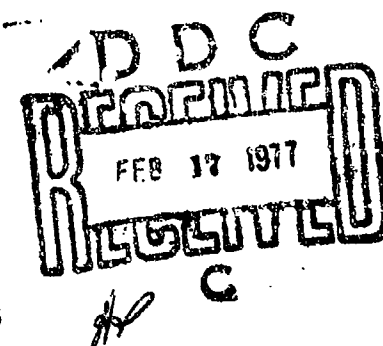
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DIELECTRIC CONSTANT AND LOSS DATA
Part II

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

DECEMBER 1975

TECHNICAL REPORT AFML-TR-74-250, Part II
INTERIM REPORT FOR PERIOD FEBRUARY 1972 - JANUARY 1975



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Chief, Laser Hardened Materials Br.
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The main body of this report lists dielectric constant and loss data on materials measured in this laboratory in the period 1 Feb 72 through Dec 1974. The main sections are inorganic (arranged in order of chemical name), miscellaneous inorganic, and organic (arranged according to manufacturer or supplier). The index following the data section is intended to be a complete reference to Vols. IV, V, and VI of the <u>Tables of Dielectric Materials</u> , the 1972 data report (labelled P.R.) and subsequent data (labelled S).		

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PREFACE

The dielectric constant and loss data presented in this report were measured at the Laboratory for Insulation Research of the Massachusetts Institute of Technology, Cambridge, Massachusetts, by W. B. Westphal. This work was performed between 1 Feb 1972 and 30 Dec 1974 under Contract F33615-71-C-1274, Project No. 7371, Task No. 737101, and Contract F33615-75-C-5020, Project No. 7371, Task No. 73710126, for the Air Force Materials Laboratory.

This report was submitted by the author for publication in September 1975.

The work was administered under direction of the AF Materials Laboratory, with Mr. D. J. Evans (AFML/PLJ) acting as project engineer.

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TABLE OF CONTENTS

	Page
I. Inorganic Compounds	1
Aluminum oxides	1
Coors 96% Al_2O_3 ceramic	1
Duramic HT-960, 96% Al_2O_3 ceramic	1
Foam, supplied by Rockwell Intern. Corp.	2
Mullite, hot-pressed, Air Force Materials Laboratory	2
Alumina cements	3
Green Refractories Co.	3
Castolast G, Harbison-Walker Refractories	3
Kaiser Refractories	3
Beryllium oxide + silicon nitride ceramic	4
Niberlox, National Beryllia Corp.	4
Niberlox 5 " " "	4
Boron nitride, hot-pressed, with BN fibers, Carborundum	5
Yarn and matrix, Philco-Ford	5
Cadmium telluride	6
IRTRAN 6, Eastman Kodak	6
Ferrites, Emerson & Cuming, Inc.	6
Magnesium fluoride, hot-pressed	7
IRTRAN 1, Eastman Kodak	7,8
Magnesium oxide crystals, MIT, Ceramics Laboratory	8
Cr-doped magnesium oxide, Univ. of Colorado	11
IRTRAN 5, Eastman Kodak	11
Spinel, hot-pressed	12
Coors' magnesium aluminate ceramic	12
Silica	12
Dynasil 4000, Dynasil	12
Silica fiber + aluminum phosphate	13
Various experimental samples, Whittaker	13
Silica fiber AS-3DX, Philco-Ford	14-18
Silica fiber, silicone coated, Raytheon Company	18

TABLE OF CONTENTS (cont.)

	Page
I. Inorganic Compounds (cont.)	
Silicates	19
Borosilicate coating, supplied by Rockwell Intern. Corp.	19
Corning 7971 Glass, Corning	19
Pennvernion glass, PPG Industries, Inc.	20
Float Glass, " " "	20
P-18, glass, " " "	21
Silicon nitride ceramic, Raytheon Company	21
Silicon nitride with MgO, hot-pressed, Air Force	
Materials Laboratory	22
With 3 w/o MgO + 5 w/o BN, experimental, Air Force	
Materials Laboratory	22
Zinc selenide, Eastman Kodak	22
Zinc sulfide (95% sphalerite, 5% wurtzite), Eastman Kodak	23
II. Miscellaneous Inorganics	23
Gypsum board (sheet rock), supplied by the Sippican Corp.	23
Shale rock, supplied by Raytheon Company	23-24
Shale rock, oil-rich, supplied by Raytheon Company	25
III. Organics	25
Polyimide laminate Al-300, Atlantic Laminates	25
Plastic ropes, Condex	26
Styrofoam FR, Dow-Corning	26
Sylgard 188, " "	27
Silastics, " "	27
Silicone resin, " "	28
Fiber samples, E.I. Du Pont de Nemours & Company	28
Tedlar, " " " " "	28
"Teflon" TFE 7A, " " " " "	29
" PFA TE 9704, " " " " "	29
" FEP 100 " " " " "	30
"Viton," E. I. Du Pont de Nemours & Company	30

TABLE OF CONTENTS (cont.)

	Page
III. Organics (cont.)	
Esscolam V ₂ T, Electronic Space Systems Corp.	31
Cross-linked polystyrene, General Electric Company	32
Noryl SE-1, SE-1-802, and GFN3, General Electric Company	32,33
Silicone resin laminates, supplied by Lincoln Lab., MIT	33
Polyester + Al + C, MIT Bio-Medical	33
L-600 Polymer, Monsanto	34
Moplen 004 polypropylene, Novamont	35
Dialite 55 P687 laminate, supplied by RCA	35
Fluorosint, supplied by RCA	35
G11 laminate, " " "	36
RTV-511, unloaded, supplied by RCA	36,37
RTV-511, 45 parts zinc oxide, supplied by RCA	37,38
RTV-511, 90 parts zinc oxide, " " "	38,39
Polyurethane sealant P/N 596927, supplied by Raytheon Co.	39
Stycast 2651-40 RQ, supplied by Raytheon Co.	40
Honeycomb laminate, supplied by Rockwell Intern. Corp.	41
Skin, EII	41
Core (nomex), EII	41
Composite, EII	41
Nomex felt, supplied by Rockwell Intern. Corp.	42
Silicone RTV, " " " " "	42
Glastrate (O-C Fiberglass), The Sippican Corp.	42
Infrared windows, Texas Instruments	43
Diallylphalate, glass, Upjohn	43
Epoxy, glass, "	44
Polybutadiene, glass, "	44
Polyurethane foam, "	45
Cyanurate ester resin, Whittaker Corp.	45
Polybutadiene-Astroquartz 3.164-11, Whittaker Corp.	46
Polybutadiene-Kevlar 3.164-10, " "	46
Polyether sulfone (dry sample), " "	47
Polyphenylquinoxaline resin, " "	47
Polyphenylquinoxaline-Astroquartz, " "	47
Polyurethane foam (rigid), Witco Chemical Co.	47

I. INORGANIC COMPOUNDS

Aluminum oxides

Coors 96% Al₂O₃ ceramic

Coors

T°C	1000/T°K	Resistivity ρ (ohm-cm)
500	1.29	6.6 x 10 ⁸
400	1.49	2.0 x 10 ¹⁰
322	1.75	6.0 x 10 ¹¹
226	2.00	3.8 x 10 ¹³
158	2.32	8 x 10 ¹⁴
84	2.80	3 x 10 ¹⁶
66.5	2.95	2 x 10 ¹⁷
25	3.36	1.5 x 10 ¹⁸ *

* Extrapolated value, not measured.

Duramic HT-960, 96% Al₂O₃ ceramic

Duramic Products, Inc.

T°C	Hz	10 ²	10 ³	10 ⁴	10 ⁵	10 ⁶	10 ⁷	10 ⁹	3x10 ⁹
25	κ'	9.33	9.33	9.32	9.32	9.32	9.31	9.29	9.28
	κ''	.00393	.00293	.00182	.00191	.00182	.00233	.00668	.00526
	10 ⁴ tan δ	4.2	3.1	1.95	2.05	1.95	2.5	7.1	5.6
	σ	2.18-13	1.63-12	1.01-11	1.06-10	1.01-9	1.23-8	3.71-6	8.75-6
100	κ'	9.43	9.43	9.42	9.41	9.41	9.40	9.37	
	κ''	.0113	.0065	.0044	.0036	.00272	.00243	.0073	
	10 ⁴ tan δ	11.9	8.9	4.7	3.83	2.9	2.6	7.8	
	σ	6.23-13	3.6-12	2.46-11	2.0-10	1.51-9	1.28-8	4.03-6	
200	κ'	9.59	9.57	9.55	9.55	9.54	9.54	9.50	
	κ''	.0738	.0294	.0102	.0085	.0056	.0040	.0089	
	10 ⁴ tan δ	76.9	30.8	10.7	8.96	5.9	4.2	9.4	
	σ	4.09-12	1.63-11	5.67-11	4.71-10	3.12-9	2.12-8	4.93-6	
300	κ'	10.42	9.95	9.79	9.72	9.69	9.68	9.63	
	κ''	.917	.246	.0759	.0263	.0147	.0103	.0112	
	tan δ	.088	.0247	.00775	.00271	.00152	.00106	.00116	
	σ	5.09-11	1.36-10	4.21-10	1.46-9	8.18-9	5.41-8	6.2-6	
400	κ'	13.26	10.79	10.12	9.96	9.87	9.85	9.79	
	κ''	5.45	1.52	.324	.0972	.0395	.0197	.0137	
	tan δ	.411	.1224	.0321	.00977	.0040	.0020	.00140	
	σ	3.03-10	7.34-10	1.8-9	5.4-9	2.19-8	1.04-7	7.6-6	
500	κ'	21.0	13.96	11.05	10.31	10.11	10.04	9.95	
	κ''	42.4	6.83	1.59	.387	.107	.038	.0172	
	tan δ	2.015	.489	.144	.0375	.0106	.0038	.00173	
	σ	2.33-9	3.72-9	8.83-9	2.14-8	5.95-8	2.-7	9.55-6	

Aluminum oxides

Foam		Supplied by Rockwell International Corp.				
T [°] F		300 MHz	1 GHz	3 GHz	8.52 GHz	14 GHz
-300	κ	1.1171	1.11760	1.11560	1.11370	1.11150
	tan δ	.00015	.00015	.00015	.00007	.000005
-170	κ	1.1165	1.11680	1.11550	1.11320	1.11180
	tan δ	.00012	.00013	.00012	.00011	.00001
74	κ	1.11160	1.11630	1.11550	1.1160	1.11330
	tan δ	.00011	.00008	.00009	.00008	.000038
400	κ	1.1179	1.1180	1.11550	1.11550	1.11410
	tan δ	.00015	.00050	.00035	.00017	.0000015

Mullite, hot-pressed,
at 8.52 GHz

Air Force Materials Laboratory

	T [°] C	κ	tan δ
Dried in vacuum oven at 150°C	25	6.38	.00061
In equilibrium, room humidity	25	6.387	.0021
	98	6.37	.0029
	206	6.39	.0037
	313	6.37	.0052
	451	6.37	.0091
	575	6.41	.0103
	607	6.42	.0101
	746	6.43	.0095
	373	6.38	.0065
	28	6.38	.0020

Alumina cements

Green Refractories Co.

At 300 MHz, 25°C

Sample No.	κ	$\tan \delta$	Density (g/cm ³)	Sample No.	κ	$\tan \delta$	Density (g/cm ³)
1	6.31	.0089	2.707	26	6.24	.0113	2.567
2	6.19	.0109	2.608	27	6.42	.0119	2.629
3	6.14	.0110	2.566	28	6.35	.0108	2.622
25	6.02	.0116	2.453	29	6.58	.0096	2.736

Castolast G at 300 MHz, 25°C

Harbison-Walker Refractories

Sample No.	κ	$\tan \delta$	Density (g/cm ³)		κ	$\tan \delta$	Density (g/cm ³)
R-1	6.87	.0080	2.691	I-2	6.79	.0073	2.689
R-2	6.75	.0103	2.682	I-3	6.75	.0075	2.674
R-3	6.66	.0096	2.665	I-4	6.59	.0073	2.664
I-1	6.83	.0070	2.678	I-5	6.79	.0077	2.663

Alumina cements, at 300 MHz

Kaiser Refractories

Sample No.	Drying T°F	κ	$\tan \delta$	Density (g/cm ³)
3-8	260	7.07	.0073	2.819
4-7	400	6.27	.0063	2.734
5-7	600	6.25	.0062	2.719
8-6	800	5.95	.0050	2.644
20-1	600	5.78	.0096	2.584
11-1	600	6.22	.0072	2.742
19-5	600	5.97	.0072	2.666

Beryllium oxide plus silicon-
nitride ceramic

National Beryllia Corp.

Niberlox, at 8.5 GHz, 25°C

		κ	$\tan \delta$	κ	$\tan \delta$	κ	$\tan \delta$
No. 5	Face 1	7.23	.00124	7.18	.00115		
	2	7.24	.00120	7.18	.00116		
	Average					7.20	.0012
No. 20	Face 1	7.37	.00162	7.32	.00115		
	2	7.36	.00170	7.32	.00114		
	Average					7.34	.0014
No. 100	Face 1	7.94	.00339	7.77	.00355		
	2	7.93	.00170	7.82	.00284		
	Average					7.88	.0030

Niberlox 5, at 8.5 GHz

T°C	κ	$\tan \delta$
25	7.29	.00115
132	7.40	.0011
207	7.46	.0011
314	7.56	.0012
494	7.72	.0014
588	7.80	.0015
704	7.91	.0024
781	8.00	.0035
900	8.08	.0046
1002	8.19	.0060

Boron nitride, hot-pressed,
with BN fibers, at 8.5 GHz

Carborundum

Sample Pc	T°C		
1	25	3.331	.00015 ± .00006
1, reversed	↓	3.314	.00014
2		3.323	.00006
2, reversed		3.330	.00008
1 + 2 stacked		3.330	.000115 ± .00002
1 + 2 reversed		3.321	.000125
1 + 2	100	3.33*	.000111 ± .00005
	201	↓	.000107
	300		.00015
	373		.00018
	421		.00017
	501		.00019
	600		.00021
	711		.00024
	800		.00038
	31	↓	.00009

*Limit of error -.01, + 0.5.

Yarn and matrix,

Philco-Ford

Sample BN-3DX-V, at 8.5 GHz

				Face 2		
		κ	tan δ	T°C	κ	tan δ
25°C, as received,	Face 1	2.862	.00293	25	2.88	.00015
	Face 2	2.897	.00334	200	2.89	.00011
vacuum dried,	Face 1	2.871	.00012	400	2.88	.00020
	Face 2	2.898	.00015	600	2.87	.00006
				800	2.87	.00011
				1000	2.89	.00072
				80	2.88	.00007

Cadmium telluride

IRTRAN 6, at 8.52 GHz, 24°C

Eastman Kodak

κ	$\tan \delta$	ρ [ohm-cm] ⁻¹
$10.45 \pm .03$	$.024 \pm .004$	1.18×10^{-3}

Ferrites

Emerson & Cuming, Inc.

E&C Samples A & B

Sample A

Frequency, MHz	μ'/μ_0	μ''/μ_0	ϵ'/ϵ_0	ϵ''/ϵ_0
1			13.8	.482
18	49.7	44	13.2	.231
55	16.8	30.2	-	-
80	12.8	22.7	-	-
189	12.24	36.6	-	-
300	3.17	26.0	13.01	.195
350	2.93	22.37	-	-
510	1.246	10.17	-	-
580	.905	9.02	-	-
650	.813	8.55	-	-
1000	- .234	7.67	12.34	-

Sample B

1	-	-	13.3	.427
18	51.	78.	13.2	.171
55	12.0	32	-	-
80	-	-	-	-
189	-	-	-	-
300	2.39	23.2	13.36	.116
350	-	-	-	-
510	-	-	-	-
580	-	-	-	-
650	.800	8.16	-	-
1000	- .336	7.64	13.28	<.02

Magnesium fluoride, hot-pressed

Eastman Kodak

IRTRAN 1

$T^{\circ}C$	Hz	10^2	10^3	10^4	10^5	10^6	10^7	4×10^8	8.5×10^8
25	κ'	5.31	5.31	5.31	5.31	5.30	5.30	5.28	5.25
	$10^4 \kappa''$	4.8	4.5	3.2	2.0	2.5	2.6	8.5	12.1
	$10^4 \tan \delta$	.89	.84	.6	.38	.47	.5	1.6	2.3
	δ	2.7E-14	2.5E-13	1.8E-12	1.1E-11	1.4E-10	1.4E-9	2.4E-6	5.4E-6
100	κ'	5.40	5.38	5.36	5.34	5.33	5.33	5.35	
	$10^4 \kappa''$	6.05	8.89	7.66	4.89	4.3	4.8	9.1	
	$10^4 \tan \delta$	1.12	1.65	1.46	.92	.8	.9	1.7	
	δ	3.3E-14	4.9E-13	4.4E-12	2.7E-11	2.4E-10	2.7E-9	2.1E-6	
200	κ'	5.52	5.45	5.45	5.44	5.44	5.43	5.47	
	$10^4 \kappa''$	30.8	17.4	14.3	9.76	6.73	6.0	10.9	
	$10^4 \tan \delta$	5.57	3.19	2.62	1.80	1.22	1.1	2.0	
	δ	1.7E-13	9.6E-13	7.9E-12	5.4E-11	3.7E-10	3.3E-9	2.6E-6	
300	κ'	5.69	5.65	5.65	5.63	5.63	5.61	5.59	
	$10^4 \kappa''$	293	107	46.7	23.3	12.6	9.0	15.7	
	$10^4 \tan \delta$	51.8	18.9	8.26	4.14	2.23	1.6	2.8	
	δ	1.6E-12	6.1E-12	2.6E-11	1.3E-10	7.8E-10	5.8E-9	3.7E-6	
400	κ'	5.85	5.79	5.77	5.76	5.75	5.74	5.72	
	κ''	.149	.034	.0114	.00536	.00276	.00172	22.9	
	$10^4 \tan \delta$	25.4	58.8	19.7	9.31	4.80	3.0	4.0	
	δ	8.3E-12	1.9E-11	6.3E-11	3.1E-10	1.5E-9	9.5E-9	5.4E-6	
500	κ'	7.06	6.21	5.99	5.95	5.93	5.91	5.87	
	κ''	10.86	1.29	.202	.0337	.0105	.0067	.0031	
	$\tan \delta$	1.538	.209	.0339	.00566	.00177	.00113	.00051	
	δ	6.1E-10	7.2E-10	1.1E-9	1.9E-9	5.9E-9	3.7E-8	7.3E-6	
532	κ'							5.91	
	$10^4 \kappa''$							34.3	
	$10^4 \tan \delta$							5.8	
	δ							8.1E-6	
27	κ'	5.325	5.32	5.32	5.32	5.31	5.31		
	$10^4 \kappa''$	17.8	12.9	9.53	7.97	7.31	6.9		
	$10^4 \tan \delta$	3.35	2.42	1.79	1.50	1.38	1.3		
	δ	9.9E-14	7.2E-13	5.3E-12	4.4E-11	4.1E-10	3.8E-9		

Magnesium fluoride, hot-pressed

IRTRAN 1 (cont.)

Comparison of 4 samples at 8.5 GHz, 25°C

		κ'	$10^4 \tan \delta$
Sample 1	Face 1 up	5.276	2.3
	Face 2 up	5.275	2.2
Sample 2	Face 1 up	5.276	2.2
	Face 2 up	5.273	2.0
Sample 3	Face 1 up	5.272	2.4
	Face 2 up	5.274	2.0
Sample 4	Face 1 up	5.283	1.9
	Face 2 up	5.285	2.1

The upward face receives incident energy. Sample was reversed and rotated 90° for second measurement.

Measured density of sample 1 at 25°C: 3.171 g/cm³.

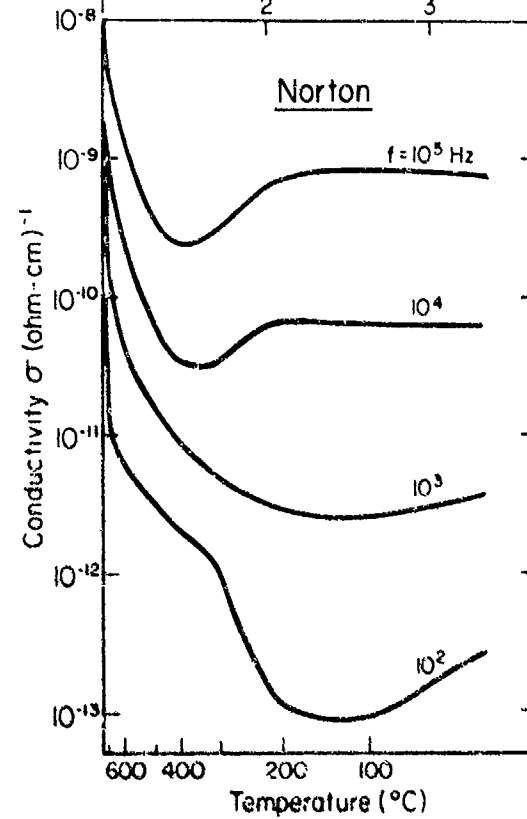
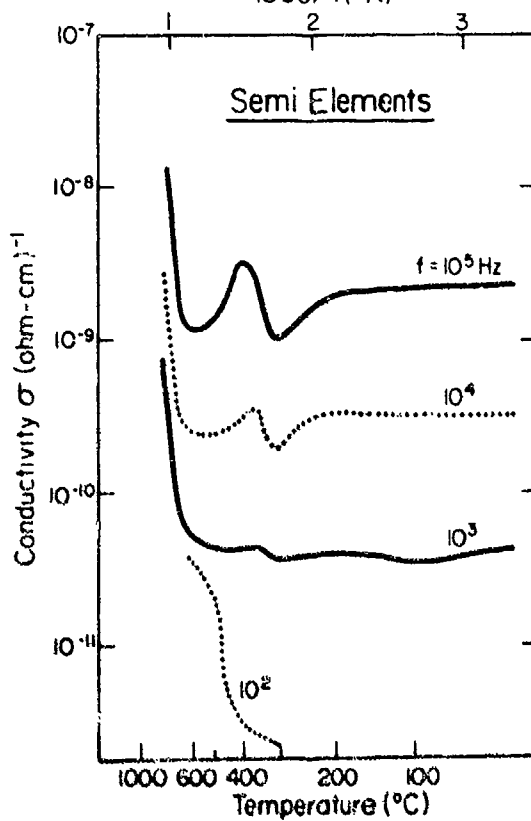
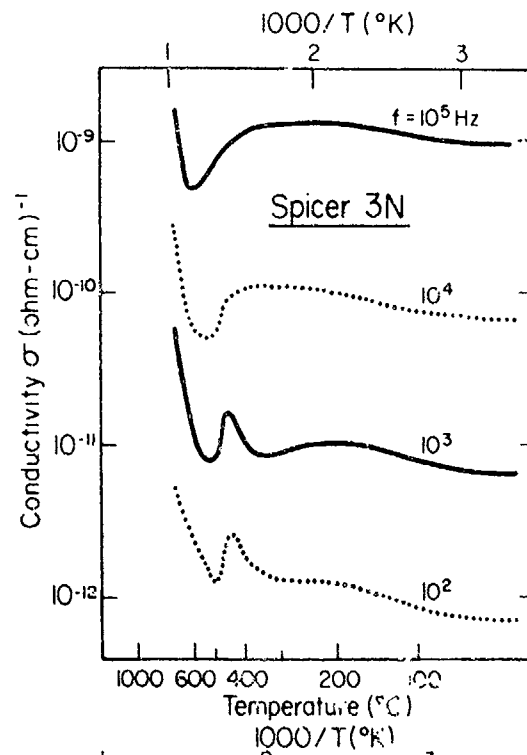
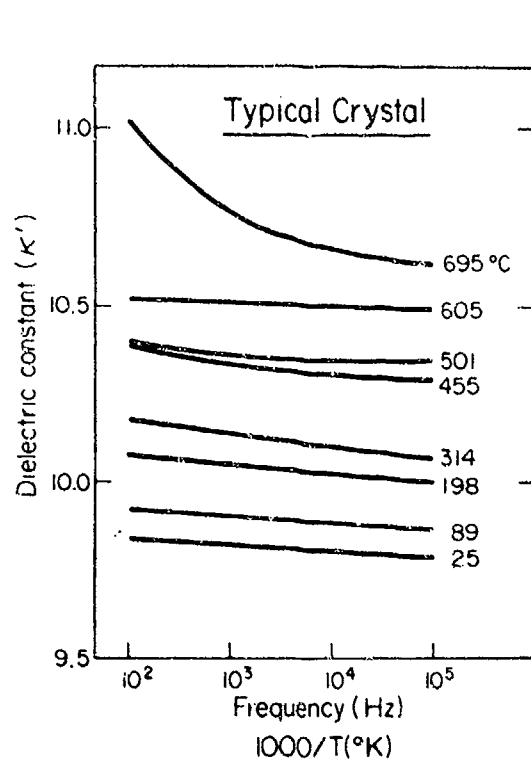
Magnesium oxide crystals

Chemical analysis of single crystals

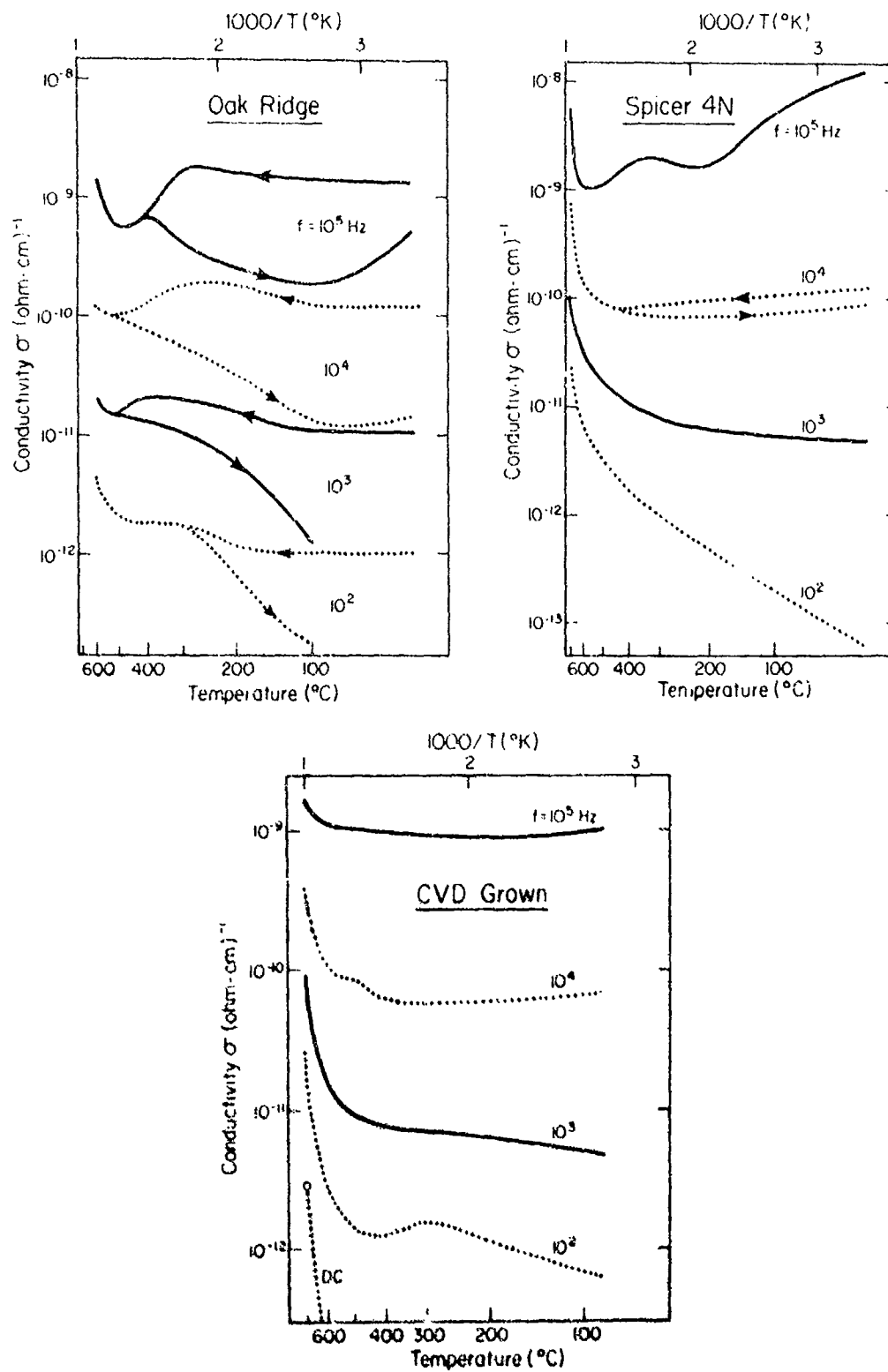
Department of Metallurgy,
Ceramics Laboratory, MIT

	Spicer 3-N	Semi- elements	Norton	Jak Ridge	Spicer 4-N	CVD
Al	70 ppm	10 ppm	10 ppm	10 ppm	10 ppm	100 ppm
Ca	100	50	50	5	5	1
Cr	-	-	10	-	-	10
Cu	5	10	10	5	10	10
Fe	20	50	50	10	50	10
Mn	10	10	5	10	-	-
Si	50	50	10	50	5	10
Zr	-	-	-	-	-	-
<u>Total</u>	305	180	145	90	80	140

Magnesium oxide crystals



Magnesium oxide crystals (cont.)



Cr-doped magnesium oxide

University of Colorado

Comparison of pure and Cr-doped magnesium oxide crystals

Dielectric constant (κ)

Sample	Freq., Hz	100	1 M
Pure		10.13	$10.16 \pm .15$
.068% Cr		-	$9.95 \pm .2$
.3% Cr		10.10	$10.07 \pm .3$

	L	W	T
Pure	1.045	.463	.222-.223
.068% Cr	.8818	.554-.563	.260-.281
.3% Cr	.980	.425-.458	.234

Note: Measurements limited in accuracy by irregular dimensions of samples.

Magnesium oxide

Eastman Kodak

IRTRAN 5, transparent ceramic

Density: 3.57 g/cm^3

At 25°C

Freq., Hz	κ	$\tan \delta$
10^2	9.82	.0014
8.5×10^9	9.72	.00045

Spinel, hot-pressed

Coors' magnesium aluminate ceramic, at 4.3 GHz

Coors

T ^{°F}	κ _{meas}	tan δ
2	8.101	.00012 ± .0005
34	8.119	↓
51.8	8.127	
61	8.135	↓
75.8	8.145 ± .01	
96.2	8.155	↓
115.9	8.167	
133.2	8.179	
149.7	8.191	
184	8.217	
200.2	8.229	.00012 ± .0005

At 76°F Δκ/ΔT = .00060°F.

Silica

Dynasil 4000, at 3 GHz

Dynasil

T ^{°F}	κ _{meas}	tan δ
2	3.8205	.00010
33	3.8212	↓
78	3.8225 ± .005	
104.2	3.8232	↓
124.2	3.8237	
130.8	3.8240	
157.8	3.8245	
169	3.8250	
199.8	3.8261	.00010

At 78°F Δκ/ΔT = .0000268°F.

Note: The values of κ_{meas} included thermal dimension change effect.
The true dielectric constant κ_{corr} can be computed when thermal expansion linear coefficient (α) is known: κ_{corr} = κ_{meas} / (1 + 2αΔT).

Silica fiber + aluminum phosphate
Various experimental samples

Whittaker Corporation

		Sample No. 14			Sample No. 15			Sample No. 16			Sample No. 17		
(Density in g/cm ³)		1.558			1.632			1.753			1.611		
	T ^o C	κ	tan δ	T ^o C	κ	tan δ	T ^o C	κ	tan δ	T ^o C	κ	tan δ	
After cutting	25	2.785	.00152	25	2.875	.00189	25	3.058	.00172	25	2.870	.00121	
		2.767	.00164		2.929	.00218		3.066	.00159		2.845	.00133	
Oven dried	25	2.780	.00146	25	2.869	.00161	25	3.028	.00131	25	2.863	.00129	
		2.767	.00147		2.924	.00175		3.033	.00128		2.839	.00122	
	104	2.77	.00136	50	2.88	.00192	102	3.05	.00140	102	2.87	.00121	
	202	2.76	.00131	103	2.88	.00138	208	3.06	.00143	200	2.88	.00140	
	310	2.79	.00139	204	2.90	.00124	301	3.07	.00186	307	2.90	.00137	
	407	2.80	.00147	302	2.90	.00118	399	3.08	.00201	399	2.91	.00161	
	501	2.81	.00146	400	2.91	.00143	497	3.10	.00228	499	2.93	.00164	
	620	2.82	.00153	495	2.92	.00154	600	3.11	.00216	605	2.94	.00307	
	709	2.82	.00248	595	2.95	.00172	696	3.12	.00339	691	2.95	.00333	
	800	2.84	.00384	699	2.96	.00221	797	3.13	.00439	800	2.97	.00408	
	896	2.85	.00526	796	2.97	.00326	897	3.16	.00760	897	2.99	.00575	
	25	2.77	.00126	896	2.94	.00443	93	3.06	.00197	28	2.87	.00144	
				25	2.88	.00159	25	3.04	.00169				

		Sample No. 18			Sample No. 19			Sample No. 20		
(Density in g/cm ³)		1.729			1.772			1.713		
	T°C	κ	tan δ	T°C	κ	tan δ	T°C	κ	tan δ	
After cutting	25	3.264	.00521	25	3.372	.00605	25	3.075	.00416	
		3.262	.00590		3.394	.00588		3.095	.00405	
Oven dried	25	3.246	.0049	25	3.388	.0057	25	3.089	.00409	
	100	3.27	.0039	104	3.35	.0042	99	3.12	.0048	
	200	3.30	.0036	201	3.37	.0054	198	3.17	.0060	
	299	3.31	.0061	300	3.38	.0095	300	3.18	.0096	
	400	3.30	.0104	404	3.39	.0161	403	3.19	.0166	
	499	3.33	.0166	501	3.43	.0289	490	3.23	.0241	
	597	3.35	.0318	601	3.48	.0498	600	3.28	.0419	
	697	3.38	.0565	699	3.54	.113	699	3.31	.077	
	798	3.40	.0933	799	3.59	.220	800	3.34	.120	
	899	2.42	.141	897	3.22	.797	896	3.40	.228	
	25	3.31	.0047	25	3.37	.0054	25	3.16	.00425	

Silica fiber AS-3DX

Philco-Ford

<u>Sample</u> , as received, 25°C		1 GHz		3 GHz	
		κ	$\tan \delta$	κ	$\tan \delta$
5ZD-1	Face 1	3.130	.00794	3.049	.00826
	Face 2	3.046	.00765	3.051	.00836
2	Face 1	3.001	.00176	2.976	.00183
	Face 2	2.973	.00189	2.964	.00202
3	Face 1	3.159	.00815	3.118	.00850
	Face 2	3.135	.00812	3.106	.00792
4	Face 1	3.031	.00159	3.005	.00212
		3.007	.00151	2.997	.00187

5ZD-1

		T°C	1 GHz		3 GHz	
			κ	$\tan \delta$	κ	$\tan \delta$
After oven drying	Face 1	25	3.025	.00192	3.013	.00235
		25	2.991	.00238	3.010	.00283
Ambient	Face 1	25	3.025	.00424	2.960	.00479
	Face 2	25	2.966	.00434	2.985	.00458
	Face 1	119	3.047	.00236	3.046	.0032
		215	3.022	.00102	3.025	.00110
		305	3.005	.00105	3.012	.00095
		401	3.003	.00123	3.010	.00108
		500	3.001	.00163	3.007	.00126
		55	3.008	.00114	3.014	.00150

Silica fiber AS-3DX (cont.)

Sample 5ZD-2		1 GHz			3 GHz	
		T°C	κ	$\tan \delta$	κ	$\tan \delta$
After oven drying	Face 1	25	2.950	.00068	2.957	.00093
	Face 2	25	2.993	.00095	2.938	.00131
In H.T. holder	Face 1	25	2.949	.00103	2.953	.00119
		101	2.961	.00085	2.958	.00099
		211	2.955	.00078	2.960	.00086
		301	2.954	.00102	2.962	.00085
		403	2.955	.00115	2.960	.00104
		499	2.956	.00136	2.965	.00116
		19	2.950	.00086	2.955	.00097

Sample		8.52 GHz		
		T°C	κ	$\tan \delta$
5ZD-5	Face 1, as received	25	3.131	.00706
	Face 2, " "	25	3.127	.00600
6	Face 1, " "	25	3.068	.00198
	Face 2, " "	25	3.074	.00195
5	Face 1, dried	25	3.071	.00115
		25	3.074	.00332
	Face 1, ambient	38	3.072	.00329
		130	3.061	.00092
		160	3.056	.00078
		212	3.054	.00057
		265	3.049	.00057
		317	3.045	.00065
		373	3.047	.00067
		433	3.053	.00070
		28	3.071	.00086

Silica fiber AS-3DX (cont.)

<u>Sample</u>		8.52 GHz		
	T°C	κ	$\tan \delta$	
5ZD-5				
Ambient	25	3.076	.00353	
	344	3.041	.00054	
	503	3.038	.00060	
	604	3.036	.00090	
	697	3.033	.00101	
	793	3.028	.00124	
	22	3.059	.00052	
5ZD-6	Oven dried, Face 1	25	3.049	.00074
	Face 2	25	3.053	.00077
	In H.T. holder, Face 1	25	3.050	.00112
		139	3.050	.00112
		198	3.041	.00051
		313	3.039	.00056
		400	3.035	.00064
		501	3.037	.00074
		609	3.029	.00090
		694	3.026	.00106
		771	3.025	.00123
		22	3.044	.00035
5ZD-7		14 GHz		
As received, Face 1	25	3.082	.0129	
rotated 90°	25	3.083	.0117	
As received, Face 2	25	3.104	.0069	
rotated 90°	25	3.096	.0071	
Oven dried, Face 1	25	3.038	.0044	
rotated 90°	25	3.040	.0040	

Silica fiber AS-3DX (cont.)

<u>Sample</u>		14 GHz	
5ZD-8	T°C	κ	$\tan \delta$
As received, Face 1	25	2.983	.0058
rotated 90°	25	2.979	.0071
As received, Face 2	25	2.973	.0034
rotated 90°	25	2.950	.0034
Oven dried, Face 1	25	2.950	.00121
rotated 90°	25	2.948	.00148
	25	2.95	.00096
	112	2.95	.00062
	201	2.94	.00058
	296	2.95	.00061
	370	2.94	.00069
	482	2.94	.00105
	511	2.95	.00112
	50	2.95	.00052
5ZD-9		24 GHz	
As received, Face 1	25	3.116	.01127
rotated 90°	25	3.111	.01155
Oven dried, Face 1	25	3.085	.00358
rotated 90°	25	3.081	.00348
Redried, Face 1	25	3.082	.00321
In H.T. holder	25	3.083	.00495
	110	3.08	.00354
	197	3.07	.00178
	309	3.06	.00197
	408	3.06	.00150
	492	3.05	.00117
	584	3.04	.00093
	676	3.04	.00132
	797	3.03	.00131
	18	3.04	.00071

Silica fiber AS-3DX (cont.)

<u>Sample</u>	T ^o C	24 GHz	
		κ	$\tan \delta$
5ZD-10			
As received, Face 1	25	3.013	.00317
rotated 90 ^o	25	3.006	.00305
Oven dried, Face 1	25	2.987	.00099
rotated 90 ^o	25	2.999	.00113
Redried, Face 1			
In H.T. holder	25	3.000	.00154
	99	3.002	.00118
	204	3.00	.00064
	289	3.00	.00061
	380	2.99	.00068
	481	2.99	.00064
	598	2.99	.00079
	680	2.99	.00093
	799	2.98	.00128
	17	2.999	.00079

Silica fiber, silicone coated

Raytheon Co.

<u>As received</u>		Sample F		Sample G	
		κ	$\tan \delta$	κ	$\tan \delta$
Face 1	min	3.173	.00568	2.966	.00268
	max	3.190	.00557	2.979	.00270
Face 2	min	3.185	.00585	2.987	.00279
	max	3.176	.00601	3.000	.00271
<u>After 24 hrs. 110^oC, vac. oven</u>					
Face 1		3.160	.00431	2.985	.00230
Face 2		3.150	.00425	2.990	.00232

Silicates

Borosilicate coating

Supplied by Rockwell International Corp.

T°C		8.52 GHz	14 GHz
-300	κ	2.35	2.30
	$\tan \delta$	.0030	.0030
-170	κ	2.40	2.35
	$\tan \delta$	.0050	.0050
74	κ	2.45	2.40
	$\tan \delta$	.01630	.0160
400	κ	2.50	2.45
	$\tan \delta$	.0180	.0200

Corning 7971 Glass

Corning

At 4 GHz

T°F	κ_{meas}	$\tan \delta$
4	4.01156	.00014 $\pm$.00003
10.6	4.01182	↓
77.7	4.01456 $\pm$.003	.00015 $\pm$.00003
94.2	4.01530	↓
111.2	4.01577	
127.5	4.01693	
143.2	4.01740	
159.4	4.01777	
173.3	4.01882	
182.1	4.01935	
192.3	4.01982	
226.1	4.02051	.00016 $\pm$.00003

Note: The values of κ_{meas} included thermal dimension change effect.
The true dielectric constant κ_{corr} can be computed when thermal expansion linear coefficient (α) is known: $\kappa_{\text{corr}} = \kappa_{\text{meas}} / (1 + 2\alpha\Delta T)$.
The temperature coefficient of dielectric constant $\Delta\kappa_{\text{meas}} / \Delta T (T=78) = .0000377$, which compares favorably with the corresponding values for Corning 7940 fused silica and single-crystal spinel of .0000397 and .000702 respectively.

Silicates

Pennvernon glass

PPG Industries, Inc.

Resistivity in ohm-cm

T°C	60 Hz	1 kHz
21	6.5E10	8.63E9
50	1.7E10	4.03E9
75	6.2E9	1.87E9
100	2.60E9	8.14E8
125	7.8E8	3.65E8
150	2.02E8	1.45E8
175	6.08E7	5.18E7
200	1.88E7	1.78E7
225	6.55E6	6.40E6
250	2.74E6	2.57E6
275	1.20E6	1.12E6
300	5.24E5	5.12E5
325	2.53E5	2.50E5
350	1.43E5	1.37E5

Freq., Hz	60	1 k	1 M
K	8.41	7.74	7.24
P.F.	.059	.0302	.0107

Float Glass

T°C	60 Hz ρ	1 kHz ρ	T°C	60 Hz ρ	1 kHz ρ
25	6.12E10	7.55E9	200	3.85E7	3.8E7
50	3.2E10	4.9E9	225	1.33E7	1.33E7
75	1.2E10	2.65E9	250	5.3E6	5.3E6
100	4.8E9	1.22E9	275	2.15E6	2.15E6
125	1.5E9	5.1E8	300	1.06E6	1.06E6
150	3.8E8	2.17E8	325	4.75E5	4.75E5
175	1.22E8	9.4E7	350	2.55E5	2.55E5

Freq., Hz	60	1 k	1 M
K	8.38	7.87	7.05
P.F.	.0586	.0302	.0110

Silicates

P-18

PPG Industries, Inc.

T ^o C	60 Hz	1 kHz
25	5.30E10	7.44E9
50	1.87E10	3.31E9
75	6.34E9	1.56E9
100	2.02E9	6.55E8
125	4.92E8	2.57E8
150	1.18E8	8.09E7
175	3.28E7	3.10E7
200	1.04E7	1.04E7
225	3.68E6	3.68E6
250	1.47E6	1.47E6
275	6.36E5	6.36E5
300	2.90E5	2.90E5
325	1.42E5	1.42E5
350	7.32E4	7.32E4

Freq., Hz	60	1 k	1 M
κ'	8.62	7.96	7.49
P.F.	.0655	.0168	.0115

Silicon nitride ceramic

Raytheon Company

	T ^o C	κ	$\tan \delta$
As received	25	4.627, 4.637	.0035, .0028
Partially dried	25	4.606 - 4.613	.00187, .00175
In H.T. holder	25	4.61	.0024
	200	4.60	.0013
	419	4.61	.0011
	607	4.60	.0023
	713	4.62	.0043

Silicon nitride with MgO, hot-pressed Air Force Materials Laboratory

Experimental

At 14 GHz

	Thickness (cm)	T°C	Against short		$\lambda/4$ away	
			κ'	$\tan \delta$	κ'	$\tan \delta$
Face 1	.381	25	8.286	.00699	8.26	.00756
Face 2	.381	25	8.289	.00780	8.24	.00793
Face 1	.279	25	8.285	.00645		
Face 2	.279	25	8.286	.00667		
Face 1	.270	108	8.28	.0070		
		197	8.30	.0062		
		308	8.33	.0065		
		403	8.34	.0072		
		494	8.35	.0083		

Silicon nitride, hot-pressed

Air Force Materials Laboratory

with 3 w/o MgO + 5 w/o BN, experimental

At 14 GHz

	T°C	κ	$\tan \delta$
Face 1	25	8.295	.0436
face 2	25	8.250	.0440
	98	8.22	.0413
	210	8.21	.0415
	299	8.22	.0418
	396	8.24	.0425
	500	8.36	.0431
	29	8.18	.0404

Zinc selenide

Eastman Kodak

INTRAN 4, at 8.52 GHz, 24°C

κ	$\tan \delta$	σ [ohm-cm] ⁻¹
10.08	.0063	3.0×10^{-4}

Zinc sulfide (95% sphalerite, 5% wurtzite)
IRTRAN 2, at 8.52 GHz, 24°C

Eastman Kodak

κ	$\tan \delta$	$\sigma \text{ [ohm-cm]}^{-1}$
8.62	.00152	6.18×10^{-4}

II. MISCELLANEOUS INORGANICS

Gypsum board (sheet rock)
($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$)

Supplied by The Sippican Corp.

	Freq., Hz	60	50 k	500 k	3 M	100 M
As received	κ	9.7	2.53	2.45	2.34	2.32
	$\tan \delta$	.92	.0805	.0225	.0125	.0088
Dried	κ	1.875	1.820	1.802	1.788	1.765
	$\tan \delta$	.0172	.00591	.00526	.0050	.0061

Shale rock

Supplied by Raytheon Company

Sample D, EH

50 Hz			1 MHz			10 MHz		
T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
19.5	417.	.810	19.5	10.3	.316	19.5	7.60	.209
57	640.	.564	57	14.9	.486	57	9.38	.293
82	540.	.710	74	17.54	.591	81	10.2	.429
110	475.	1.27	114	20.4	.660	111	11.0	.435
163	390.	1.17	134	20.9	.646	159	9.30	.554
204	350.	1.31	157	19.9	.597	218	8.20	.264
339	742.	4.75	224	11.9	.360	325	7.42	.213
420	117.*	6.63*	259	10.7	.324	426	9.16	.100
			308	10.5	.195			
			312	10.3	.197			
			432	11.2	.242			

*100 Hz.

Shale rock

Raytheon Company

Sample D, 3 GHz, E

T°C	κ	$\tan \delta$
25	5.12	.037
100	5.26	.055
200	5.27	.047
250	5.19	.036
299	4.94	.037
352	5.19	.050
400	5.40	.079
450	7.34	.049

Shale rock

Raytheon Company

Various samples, electric field
oriented with respect to laminar
structure

Sample/Field	Freq., Hz	50	1 M	10 M	30 M	100 M	300 M	1 G	3 G
A, E	κ	-	19.7	14.52	11.5	8.3	5.34	5.24	5.20
	$\tan \delta$	-	.212	.257	.276	.309	.0182	.0174	.025
	ϕ	3.39E5							
A, E $\perp$	κ	9.30	6.37	5.52	5.85	5.80	-	-	-
	$\tan \delta$	.171	.0255	.0217	.0181	.0142	-	-	-
B, E	κ	172	11.58	7.30	6.62	6.05	5.44	5.18	4.97
	$\tan \delta$	.313	.463	.267	.180	.102	.108	.079	.049
B, E $\perp$	κ	102	7.55	5.65	5.50	5.44	-	-	-
	$\tan \delta$	.359	.237	.0937	.061	.040	-	-	-
D, E	κ	264	10.9	7.65	6.72	6.90	5.35	5.15	5.12
	$\tan \delta$	2.60	.322	.219	.176	.130	.0917	.061	.037
D, E $\perp$	κ	55.3	7.62	5.92	5.58	5.30	-	-	-
	$\tan \delta$	.556	.236	.139	.140	.067	-	-	-

Shale rock, oil-rich

Raytheon Company

E //

Freq., Hz	50	1 M	10 M	30 M	100 M	300 M	1 G	3 G
κ	4.68	3.12	2.95	2.88	2.83	2.79	2.76	2.73
$\tan \delta$	.118	.0384	.0339	.0312	.0272	.0264	.0261	.0254

III. ORGANICS

Polyimide laminate AL-300

Atlantic Laminates

At 22°C

	3 GHz		8.5 GHz	
	κ	$\tan \delta$	κ	$\tan \delta$
Best value	4.48	.0132	4.412	.0137

Temperature run on stacked sample, 8.52 GHz

T°C	κ	$\tan \delta$	Sample thickness (cm)	Comments
23.5	4.16	.0097	.635	
98	4.30	.0104	.622	
198	4.41	.0116	.611	
284	4.50	.0116	.599	Smoke detectable
336	4.52	.0125	.597	Noticeably soft
426	4.01	.0142	.633	Smoking profusely
458	2.605	.0097	.824	too much smoke, gelatin-like softness, rapidly expanding
261	2.025	.0048	1.003	

Plastic ropes

Condex

At 25°C, electric field
parallel to sample axis

Frequencies		Condex Tri- Laminar	Condex Urethane	"Glastran" rope
100 kHz	κ	4.77	4.50	4.88
	$\tan \delta$	.043	.047	.0128
1 MHz	κ	4.51	4.22	4.80
	$\tan \delta$	.062	.060	.0167
10 MHz	κ	4.07	3.88	4.73
	$\tan \delta$	.061	.055	.020
100 MHz	κ	3.78	3.66	4.55
	$\tan \delta$	.067	.060	.026
1000 MHz (extra- polated)	κ	3.5	3.4	4.2
	$\tan \delta$	.076	.066	.034

Styrofoam FR

Dow-Corning

At 25°C

	Freq., GHz	At 25°C	
		κ	$\tan \delta$
2 Stacked coax at 1 and 3	1	1.0335	.00005
	3	1.0323	.000077
1 Cylinder	8.5	1.0372	.000109

Sylgard 188

Dow-Corning

Freq., Hz	25°C		-55°C	
	κ	$\tan \delta$	κ	$\tan \delta$
100	2.858	.00292	3.332	.00239
1000	2.854	.00198	3.330	.00271
1500	2.853	.00197	3.329	.00286
8000	2.849	.00191	3.327	.00329
10000	2.849	.00190	3.326	.00332
10 ⁵	2.844	.00178	3.317	.00318
10 ⁶	2.841	.00152	3.308	.00377
10 ⁷	2.839	.00165	3.301	.00665

Silastics

Dow-Corning

Samples E-1600 140 at 8.52 GHz

A			C		
T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
18	3.046	.0193	25	2.740	.0133
-8		.0234*	0	2.775	.0166
-19	3.128	.0204	-24	2.808	.0191
-40	3.118	.0117	-33	2.813	.0183
-77	3.091	.00653	-42	2.815	.0155
-195	3.126	.00598	-63	2.798	.00846
			-80	2.778	.00428
			-100	2.760	.00231
			-130	2.758	.00244
			-151	2.767	.00256
			-195	2.791	.00221
B					
25	2.99	.0118			

* Estimated value, not measured.

Silicone resin

Dow Corning

At 8.52 GHz, 22°C

<u>Material</u>	κ	$\tan \delta$
X-12546	3.381	.00768
XR-43117	2.885	.0176

Fiber samples

E. I. Du Pont de Nemours and Company

At 8.52 GHz

Sample No.	Orientation of electric field to surface fiber direction	T°C	κ	$\tan \delta$
5230-126	arbitrary,	75	3.83	.0530
	" , same	150	4.03	.0775
	" , same	300	4.15	.128
126	0°, E	75	4.21	.0263
	90°, E ⊥	75	3.45	.0263
5230-127	arbitrary,	75	3.64	.0286
	" , same	150	3.71	.035
	" , same	300	3.81	.063
127	0°, E	75	3.96	.0236
	30°	75	3.83	.0238
	45°	75	3.55	.0232
	90°, E ⊥	75	3.32	.0209
127	0°, E	300	4.15	.055

Tedlar

E. I. Du Pont de Nemours and Company

At 25°C, 50% R.H.

Freq.	8.5 GHz	14 GHz	24 GHz
κ	4.38	4.32	4.28
$\tan \delta$	.044	.0040	.035

"TEFLON" TFE 7A

E.I. Du Pont de Nemours & Company

T°C	Hz	10C	1 k	10 k	100 k	1 M	10 M	100 M	300 M	1 G	3 G	8.5 G	14 G	24 G
250	κ	1.91	→						1.91	1.912	1.912	1.912	1.91	1.91
	$10^4 \tan \delta$	10.03	1.62	.60	.09	.14	<.1	-	.6	.5	1.3	2.5	2.4	3.3
150	κ	2.00	→						-	2.00	2.002	2.001	2.001	2.00
	$10^4 \tan \delta$	5.00	.69	.13	.08	.16	.23	-	1.0	1.3	3.2	2.7	3.9	3.5
23	κ	2.03	→						-	2.051	2.050	2.050	2.048	2.047
	$10^4 \tan \delta$	.06	.04	.04	.05	.13	.15	1.4	3.2	3.7	3.4	2.3	2.6	3.0

"TEFLON" PFA TE 9704

E.I. Du Pont de Nemours & Company

T°C	Hz	100	1 k	10 k	100 k	1 M	10 M	100 M	300 M	1 G	3 G	8.5 G	14 G	24 G
23	κ	2.06	→						-	2.060	2.058	2.055	2.052	2.049
	$10^4 \tan \delta$	.27	.20	.23	.33	.80	1.45	4.3	8.4	11.5	14.4	13.6	13.1	12.4
75	κ	-	-	-	-	-	-	-	-	2.043	2.041	2.038	2.035	2.034
	$10^4 \tan \delta$	-	-	-	-	-	-	-	-	11.0	14.0	14.7	14.5	14.1
100	κ	2.03	→						-	2.031	2.029	2.027	-	2.023
	$10^4 \tan \delta$	4.03	.91	.39	-	-	-	-	-	9.4	12.6	14.3	-	15.3
150	κ	2.01	→						-	2.010	2.009	2.007	2.004	2.002
	$10^4 \tan \delta$	28.6	3.96	.77	.40	.43	1.1	-	5.2	8.3	11.1	13.8	14.6	15.3
200	κ	-	-	-	-	-	-	-	1.98	1.979	1.979	1.977	1.974	1.971
	$10^4 \tan \delta$	-	-	-	-	-	-	-	3.1	6.0	9.4	12.2	13.2	14.1
250	κ	1.93	→						-	1.929	1.929	1.928	1.925	1.922
	$10^4 \tan \delta$	33.9	5.34	1.21	.60	.23	.6	-	1.3	4.3	7.2	10.3	11.2	12.5
150°	κ	2.01	-	-	-	-	-	-	-	-	-	-	-	-
	$10^4 \tan \delta$	12.6	1.71	.33	.40	.43	1.1	-	-	-	-	-	-	-
23°	κ	2.06	→						-	-	-	-	-	-
	$10^4 \tan \delta$	.06	.14	.23	.33	.71	1.5	-	-	-	-	-	-	-

*After heating to 250°C.

"TEFLON" FEP 100

E.I. Du Pont de Nemours & Company

	23°C		75°C		100°C		150°C		23°C	
Freq. Hz	κ	$10^4 \tan \delta$	κ	$10^4 \tan \delta$	κ	$10^4 \tan \delta$	κ	$10^4 \tan \delta$	κ	$10^4 \tan \delta$
10^2	2.06	1.21	-	-	2.03	6.01	2.00	32.3	2.06	1.49
10^3		.80	-	-	-	-		4.42		.43
10^4		.89	-	-	-	-		1.14		.13
10^5		2.43	-	-	-	-		1.25		1.72
5×10^5		4.59	-	-	-	-		1.59		3.85
10^6		5.30	-	-	-	-		1.73		4.95
1.5×10^6		5.8	-	-	-	-		-		5.4
2×10^6		5.9	-	-	-	-		-		-
3.5×10^6		5.6	-	-	-	-		-		5.5
10^7	2.05	5.3	-	-	-	-		2.5	2.05	5.1
10^8	2.05	7.0	-	-	-	-		-	-	-
3×10^8	2.05	9.3	-	-	-	-		7.5	-	-
1×10^9	2.047	13.7	2.031	13.2	2.022	12.8	1.999	12.3	-	-
3×10^9	2.045	11.6	2.029	13.3	2.020	13.8	1.997	13.6	-	-
8.5×10^9	2.043	9.0	2.027	10.3	2.018	11.6	1.994	12.8	-	-
1.4×10^{10}	2.040	7.5	2.024	9.4	2.013	11.1	1.986	12.4	-	-
2.4×10^{10}	2.034	6.7	2.014	8.3	2.000	10.0	1.974	11.2	-	-

"VITON", at 24°C

E.I. Du Pont de Nemours & Company

Freq., Hz	κ	$\tan \delta$	γ (ohm-cm) ⁻¹
11.4	10.76	.0347	1.03E-11
150	10.37	.0327	1.97E-11
1000	10.19	.0349	1.08E-10
10^4	9.39	.0310	4.23E-9
10^5	8.00	.148	6.56E-8
5×10^5	6.60	.198	1.63E-7
10^6	5.99	.213	7.08E-7
9.5×10^6	4.27	.194	4.36E-6
1.8×10^7	3.95	.176	6.96E-6
6×10^7	3.64	.160	1.70E-5
3×10^8	3.30	.0951	5.24E-5
1×10^9	3.171	.0725	1.27E-4
3×10^9	3.057	.0542	2.82E-4
8.5×10^9	3.03	.0372	5.25E-4

Standard Conditions

Tedlar both sides	Sample No.	8.5 GHz		14 GHz		24 GHz	
		ϵ	$\tan \delta$	ϵ	$\tan \delta$	ϵ	$\tan \delta$
Single ply	1	2.87	.0181	-	-	2.75	.0179
	2	2.94	.0179	-	-	2.82	.0147
	3	2.93	.0178	-	-	2.76	.0146
	4	2.86	.0174	-	-	2.86	.0155
	5	2.88	.0171	-	-	2.80	.0156
	6	2.76	.0172	2.80	.0180	2.84	.0176
	7	2.76	.0175	2.77	.0168	2.81	.0175
	8	2.73	.0174	2.75	.0165	2.77	.0188
	9	2.73	.0174	2.75	.0165	2.77	.0188
2 Ply same	1	2.86	.0130	2.90	.0127	2.78	.0116
	2	2.85	.0132	2.84	.0122	2.87	.0105
	3	2.88	.0135	2.75	.0121	2.63	.0120
3 Ply same	1	2.88	.0118	2.83	.0121	2.69	.0090
	2	2.88	.0121	2.85	.0126	2.84	.0102
	3	2.88	.0126	2.85	.0129	2.77	.0093
4 Ply same	1	2.88	.0121	2.83	.0116	2.68	.0083
	2	2.89	.0122	2.82	.0112	2.71	.0068
	3	2.89	.0120	2.83	.0115	2.73	.0079
5 Ply uncoated	1	2.88	.0108	2.87	.0107	2.72	.0075
	2	2.93	.0106	2.87	.0098	2.75	.0089
	3	2.86	.0106	2.82	.0096	2.81	.0089

After soaking 24 hrs., distilled water both sides,
then samples punched and measured within two minutes

Tedlar both sides	Sample No.	8.5 GHz		14 GHz		24 GHz	
		ϵ	$\tan \delta$	ϵ	$\tan \delta$	ϵ	$\tan \delta$
Single ply	1	2.89	.0191	-	-	2.77	.0118
	2	2.93	.0192	-	-	2.88	.0144
	3	2.90	.0191	-	-	2.87	.0141
	4	2.87	.0189	-	-	2.83	.0160
	5	2.86	.0190	-	-	2.71	.0117
	6	2.74	.0197	2.85	.0191	2.73	.0195
	7	2.81	.0202	2.81	.0195	2.78	.0153
	8	2.88	.0198	2.84	.0194	2.79	.0164
	9	2.88	.0198	2.84	.0194	2.79	.0164
2 Ply same	1	2.90	.0182	2.88	.0163	2.60	.0123
	2	2.92	.0183	2.88	.0164	2.78	.0119
	3	2.92	.0184	2.87	.0155	2.77	.0123
3 Ply same	1	2.91	.0163	2.93	.0154	2.80	.0107
	2	2.93	.0164	2.84	.0145	2.79	.0114
	3	2.92	.0167	2.93	.0147	2.80	.0117
4 Ply same	1	2.93	.0138	2.89	.0126	2.72	.0084
	2	2.98	.0145	2.80	.0125	2.79	.0087
	3	2.98	.0148	2.84	.0120	2.83	.0089

Cross-linked polystyrene

General Electric Company

Standard conditions

Freq., GHz	.5	1	3	8.5	14	24	90
κ	2.54	2.539	2.535	2.535	2.535	2.531	$2.85 \pm .05$
$\tan \delta$	.00107	.00094	.00063	.00041	.00057	.00084	$.0015 \pm .0005$

After 48 hrs. 30/1 H₂O/NaCl solution

κ	2.54	2.544	2.540	2.538	2.537	2.535	
$\tan \delta$	.00142	.00127	.00107	.00054	.00083	.00108	

Noryl SE-1

General Electric Company

Freq., MHz	κ	$\tan \delta$
100	2.639	.00135
1000	2.635	.00292
3000	2.629	.00545

Noryl SE-1-802

General Electric Company

Standard Conditions

Freq., GHz	.5	1	3	8.5	14	24	90
κ	2.71	2.706	2.699	2.696	2.691	2.69	$2.5 \pm .1$
$\tan \delta$	.0030	.00304	.00319	.00260	.00292	.0034	$.005 \pm .003$

After 48 hrs. 30/1 H₂O/NaCl solution

κ	2.71	2.708	2.705	2.70	2.696	2.69	
$\tan \delta$	.0031	.00281	.00325	.0031	.0039	.00336	

Noryl GFN3

General Electric Company

Standard Conditions

Freq., GHz	.5	1	3	8.5	14	24	90
κ	3.12	3.11	3.10	3.09	3.08	3.06	$2.85 \pm .1$
$\tan \delta$	.0032	.0033	.0037	.00453	.0049	.0053	$.008 \pm .003$

Noryl GFN3 (cont.)

After 48 hrs. 30/1 H₂O/NaCl solution

Freq., GHz	.5	1	3	8.5	14	90
κ	3.13	3.13	3.11	3.10	3.08	3.07
$\tan \delta$	.0034	.0036	.0037	.0046	.0053	.0058

Silicone resin laminates

Supplied by Lincoln Lab., MIT

Sample	Freq., GHz	1	3	8.5
581 Astro Quartz	κ	2.27	2.20	2.28
	$\tan \delta$	.0015	.0011	.0014
E Glass	κ	3.33	3.42	3.38
	$\tan \delta$	.0028	.00403	.0075

Polyester + Al + C

MIT Bio-Medical

Polyester resin (Laminac 4110, American Cyanamid) + 14.5%
(Bakara' purified Al powder) + various amounts of
acetylene black as indicated

Freq., GHz	1	3	8.5
0.24% C			
κ'	5.70	5.18	4.90
$\tan \delta_d$	.167	.122	.088
μ'/μ_0	1.02	.956	.942
$\tan \delta_m$	.037	.036	.032
0.48% C			
κ'	7.10	6.10	5.34
$\tan \delta_d$	.351	.239	.172
μ'/μ_0	1.036	.962	.937
$\tan \delta_m$	.023	.036	.030
0.96% C			
κ'	9.66	7.54	6.02
$\tan \delta_d$	.523	.518	.238
μ'/μ_0	1.04	.993	.921
$\tan \delta_m$	.021	.043	.046
1.92% C			
κ'	18.7	11.15	8.01
$\tan \delta_d$	3.44	.961	.562
μ'/μ_0	1.04	.954	.984
$\tan \delta_m$	.021	.038	.061

L-600 Polymer

Monsanto

Temp.	Hz	1	2	5	10	33.3	10 ²	10 ³	10 ⁴	2x10 ⁴	5x10 ⁴	10 ⁵
25°C 77°F	κ	4.23	4.20	4.17	4.11	4.03	3.91	3.67	3.55	3.49	3.42	3.39
	tan δ	.0227	.0236	.0264	.0281	.0321	.0380	.0315	.0318	.0294	.0274	.0252
	Hz	10 ⁶	10 ⁷	1.8x10 ⁷	10 ⁸	3x10 ⁸	10 ⁹	3x10 ⁹	8.52x10 ⁹	2.4x10 ¹⁰		
25°C	κ	3.29	3.21	3.19	3.15	3.11	3.10	3.07	3.084	3.05		
	tan δ	.0163	.0107	.0099	.0087	.0073	.0072	.00695	.00629	.0083		
	Hz	33	100	333	1000	3333	10 ⁴	10 ⁵	10 ⁶	10 ⁷	10 ⁹	
49.3°C 121°F	κ	4.36	4.26	4.13	4.004	3.86	3.74	3.54	3.39	3.30	3.13	
	tan δ	.0361	.0414	.0462	.0500	.0509	.0487	.0394	.0283	.0185	.0102	
	Hz	3x10 ⁹	8.52x10 ⁹	2.4x10 ¹⁰								
75°C 167°F	κ	3.11	3.10	3.06								
	tan δ	.0099	.0088	.0087								
	Hz	10 ²	10 ³	333	10 ⁴	2x10 ⁴	10 ⁵	10 ⁶	10 ⁷	10 ⁹	3x10 ⁹	8.5x10 ⁹
100°C 212°F	κ	4.65	4.39	4.22	4.06	3.96	3.95	3.50	3.34	3.14	3.12	3.07
	tan δ	.0388	.0534	.0607	.0629	.0622	.0574	.0445	.0287	.0128	.0116	.0094
	Hz	10 ²	10 ³	10 ⁴	10 ⁵	10 ⁶	10 ⁷	10 ⁹	3x10 ⁹	8.5x10 ⁹	2.4x10 ¹⁰	
125°C 257°F	κ	6.08	5.46	4.87	4.29	3.82	3.48	3.21	3.15	3.12	3.10	
	tan δ	.0971	.0260	.0921	.0938	.0773	.050	.0232	.0172	.0141	.012	
	Hz	10 ²	10 ³	10 ⁴	10 ⁵	10 ⁶	10 ⁷	10 ⁹	3x10 ⁹	8.5x10 ⁹	2.4x10 ¹⁰	
150°C 302°F	κ	19.1	13.5	9.19	6.64	4.96	4.03	3.50	3.30	3.22	3.18	
	tan δ	.246	.273	.256	.222	.183	.119	.0617	.034	.027	.022	
	Hz	10 ²	10 ³	10 ⁴	10 ⁵	10 ⁶	10 ⁷	10 ⁹	3x10 ⁹	8.5x10 ⁹	2.4x10 ¹⁰	
175°C 347°F	κ	21.8	20.2	17.15	11.39	7.05	4.58	3.95	3.63	3.42	3.33	
	tan δ	.765	.139	.195	.299	.314	.206	.167	.109	.048	.037	
	κ	31	22	19.6	18.4	13.8	8.20	4.19	3.88	3.55	3.42	
	tan δ	2.9	.55	.087	.094	.252	.368	.231	.59	.070	.051	

Moplen 004 polypropylene

Ncvamont

T°C	Freq., GHz	1	3	Error limits for both freq.
25	κ	2.260	2.254	$\pm .005$
	$\tan \delta$	.00042	.00036	$\pm .00005$
100	κ	2.15	2.14	$\pm .03$
	$\tan \delta$	.00060	.00063	$\pm .00005$

Dialite 55 P687 laminate

Supplied by RCA

At 300 MHz

T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
-143	4.248	.00351	-15.5	4.333	.00594
-128.6	4.257	.00343	-6.8	4.339	.00550
-119	4.262	.00328	0.6	4.351	.00700
-110	4.266	.00338	14.1	4.362	.00743
-101	4.273	.00371	24	4.370	.00783
-89.5	4.289	.00397	25.6	4.373	.00790
-84	4.287	.00449	37.1	4.379	.00857
-47.6	4.309	.00499	47.1	4.383	.00889
-39.9	4.316	.00536	58.1	4.399	.00936
-34.5	4.322	.00507	68.6	4.312	.01015
-29.7	4.323	.00550	75.2	4.319	.0104
-23.2	4.328	.00586			

Fluorosint

Supplied by RCA

At 300 MHz

T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
-149	3.468	.00074 $\pm$.0001	-13.3	3.481	.00074 $\pm$.0001
-133	3.471		-13.6	3.482	
-120.1	3.473		-4.7	3.483	
-116.8	3.472		2.5	3.483	
-104	3.473		11.6	3.486	
-87.8	3.475		22.8	3.485	.00074 $\pm$.00005
-75.6	3.477		26.5	3.486	
-63.6	3.479		33	3.487	.00074 $\pm$.0001
-53.7	3.489		43.7	3.488	
-46	3.479		54.7	3.489	
-40.5	3.480		64.2	3.490	
-33.8	3.481		73.5	3.492	
-25.8	3.481				

G11 laminate

At 300 MHz

Supplied by RCA

T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
76.7	4.849	.0238	- 40.8	4.453	.0094
68.2	4.812	.0228	- 50.2	4.431	.0088
58.8	4.771	.0218	- 60.	4.415	.0081
48.3	4.731	.0197	- 70.5	4.401	.0076
39.2	4.691	.0190	- 80.9	4.384	.0070
28.4	4.649	.0176	- 90.7	4.373	.0064
12.1	4.593	.0156	-100.6	4.363	.0056
6.8	4.572	.01485	-113.6	4.347	.00494
0	4.555	.0141	-121.1	4.338	.0046
-10.	4.524	.0126	-130.	4.332	.0043
-19.2	4.501	.0119	-140.3	4.322	.0041
-31.	4.472	.0107			

RTV-511, unloaded

At 300 MHz

Supplied by RCA

T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
-146.1	3.202	.0109	- 30	3.409	.0118
-133.8	3.228	.0135	- 20.3	3.385	.0097
-122	3.248	.0154	- 8.1	3.364	.0080
-111	3.266	.0170	+ 1.7	3.347	.0071
-100.8	3.280	.0186	10.8	3.332	.0068
- 89.7	3.310	.0218	22.8	3.309	.00625
- 83.6	3.334	.0272	33.3	3.286	.0059
- 68	3.388	.0269	43.6	3.252	.0054
- 60.6	3.413	.0226	52.7	3.222	.0052
- 50.8	3.423	.0186	63.2	3.155	.00505
- 39	3.419	.0140	73	3.123	.0047

RTV-511, unloaded

Supplied by RCA

At 2.2969 GHz

T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
-134.8	3.071	.00190	28.2	3.328	.0270
130	3.073	.00194	19.8	3.335	.0254
119.8	3.090	.0023	- 8.1	3.354	.0215
110	3.109	.0036	+ 2.5	3.324	.0183
98.2	3.142	.0062	12.3	3.309	.0160
89	3.171	.0093	21.8	3.295	.0143
80	3.197	.0130	32.7	3.273	.0124
69.3	3.228	.0178	43.1	3.236	.0112
60	3.254	.0224	52.7	3.194	.0103
50.2	3.281	.0264	64.8	3.145	.0091
41.1	3.307	.0286	72.9	3.133	.0085

RTV-511, 45 parts zinc oxide

Supplied by RCA

At 300 MHz

T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
-128.9	3.546	.0036	20.1	3.832	.0108
117.4	3.580	.0061	+ 9.8	3.816	.0092
112.9	3.599	.0080	- 0	3.800	.0084
103.6	3.635	.0109	10.2	3.780	.0075
90	3.706	.0216	21.6	3.745	.0067
79.9	3.750	.0246	31.3	3.727	.0064
68.2	3.808	.0254	42.4	3.671	.0063
59.6	3.838	.0227	51.5	3.640	.00625
51.3	3.853	.0196	62	3.605	.0062
40.6	3.858	.0153	73.2	3.584	.0065
30.2	3.850	.0131			

RTV-511, 45 parts zinc oxide
At 2.2969 GHz

Supplied by RCA

T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
131.2	3.395	.0072	-10.6	3.675	.0275
120.1	3.404	.0077	+ .6	3.666	.0243
111	3.413	.0082	10	3.654	.0221
99.7	3.445	.0099	21.3	3.636	.0196
90.2	3.479	.0134	26.6	3.623	.0183
81.6	3.514	.0171	32.8	3.608	.0172
69.1	3.557	.0236	35.3	3.600	.0168
60	3.587	.0278	45	3.578	.0160
49.7	3.617	.0314	56.2	3.553	.0152
40.6	3.642	.0324	65.2	3.528	.0146
30.5	3.667	.0318	74.7	3.501	.0142
21.2	3.676	.0299			

RTV-511, 90 parts zinc oxide
At 300 MHz

Supplied by RCA

T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
-129.8	4.047	.0214	-19.3	4.118	.0098
-116.8	4.074	.0228	-10.3	4.102	.0086
-103.8	4.099	.0232	1.0	4.083	.00776
- 90.2	4.122	.0218	6.7	4.073	.00750
- 96.1	4.114	.0223	22.6	4.038	.00675
- 78.9	4.132	.0204	33.8	4.008	.00638
- 69.3	4.136	.0190	43.8	3.976	.00630
- 59.7	4.140	.0169	52.9	3.948	.00645
- 50.2	4.141	.0148	62.9	3.923	.00670
- 39.9	4.138	.0130	72.5	3.907	.00732
- 31.2	4.132	.0115			

RTV-511, 90 parts zinc oxide

Supplied by RCA

At 2.2969 GHz

T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
-129.2	3.662	.0111	20.5	3.923	.0327
120	3.672	.0116	9.8	3.921	.0298
109.7	3.699	.0131	0	3.917	.0269
102.5	3.712	.0139	9.4	3.908	.0246
90.2	3.770	.0181	16.6	3.897	.0229
80.9	3.803	.0229	21.9	3.888	.0215
71.1	3.828	.0272	28.2	3.872	.0202
58.9	3.858	.0326	42.6	3.834	.0182
50.2	3.881	.0346	51	3.810	.0179
40.3	3.900	.0348	61.9	3.775	.0176
30.2	3.916	.0340	72.8	3.742	.0174

Polyurethane sealant P/N 590927

Supplied by Raytheon Company

Average values

Freq., Hz	60	1 k	1 M	10 M	30 M
κ	7.05	6.81	4.71	4.02	3.69
$\tan \delta$	.0150	.0422	.102	.1135	.1106

At 1 kHz

T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
22	6.81	.0422	90	5.72	.0101
30	6.73	.0324	100	5.57	.0140
40	6.62	.0209	110	5.45	.0196
50	6.46	.0145	120	5.34	.0285
60	6.31	.0104	130	5.21	.0391
70	6.12	.0083	140	5.06	.0568
80	5.90	.0086	150	4.84	.0762

Stycast 2651-40 RQ
(Emerson & Cumming)

Supplied by Raytheon Company

Sample No.	Freq., Hz	60	1 k	1 M	10 M	30 M
1	κ	5.09	4.92	4.22	3.96	3.82
	$\tan \delta$	.0305	.0231	.0452	.0435	.0515
2	κ	5.18	4.94	4.28	4.06	3.88
	$\tan \delta$	.0294	.0231	.0449	.0426	.050
3	κ	5.15	4.97	4.28	4.02	3.86
	$\tan \delta$	.0304	.0231	.0451	.0429	.0484
Average	κ	5.14	4.94	4.26	4.01	3.85
	$\tan \delta$	.0301	.0231	.0451	.0430	.050

Temperature runs, 1 kHz

Sample No.	1		2		3		Average	
	κ	$\tan \delta$	κ	$\tan \delta$	κ	$\tan \delta$	κ	$\tan \delta$
T°C								
23	4.98	.0247	5.08	.0245	5.06	.0250	5.04	.0247
30	5.05	.0253	5.15	.0251	5.12	.0265	5.11	.0256
40	5.12	.0280	5.22	.0262	5.25	.0291	5.20	.0276
50	5.29	.0318	5.38	.0307	5.36	.0322	5.34	.0316
60	5.59	.0401	5.86	.0438	5.82	.0456	5.76	.0432
70	6.34	.0776	6.41	.0745	6.37	.0715	6.37	.0745
80	6.96	.0998	7.32	.0976	7.16	.0985	7.15	.0985
90	7.42	.110	7.54	.108	7.50	.109	7.49	.109
100	7.55	.157	7.66	.160	7.70	.162	7.65	.159
110	7.50	.282	7.65	.241	7.76	.255	7.63	.259
120	7.41	.468	7.48	.522	7.58	.450	7.49	.482
130	7.35	.838	7.47	.731	7.50	.685	7.44	.751
140	7.40	1.13	7.52	.948	7.32	.914	7.41	.964
150	7.32	1.18	7.43	.998	6.92	1.17	7.22	1.116
26			4.92	.0185				

Honeycomb laminate

Supplied by Rockwell International Co.

Skin, E||

T ^o F	Freq.	3 GHz	8.52 GHz	14 GHz
74	κ	4.14	4.45	4.40
	$\tan \delta$	.010	.0120	.0160
-300	κ	-	4.35	4.33
	$\tan \delta$	-	.0022	.0025
-170	κ	-	4.40	4.37
	$\tan \delta$	-	.0095	.0080
400	κ	-	4.50	4.45
	$\tan \delta$	-	.018	.0205

Core (Nomex), E||

74	κ	1.1250	1.2305	1.1476
	$\tan \delta$	.00270	.01040	.00735
-300	κ	-	1.184	1.1315
	$\tan \delta$	-	.01500	.00150
-170	κ	-	1.1817	1.1400
	$\tan \delta$	-	.00266	.00470
400	κ	-	1.12986	1.12610
	$\tan \delta$	-	.00195	.00248

Composite, E||

		300 MHz	1 GHz	3 GHz
74	κ	1.4756	1.4484	1.4246
	$\tan \delta$	.00438	.00499	.00543
-300	κ	1.4283	1.4978	1.3893
	$\tan \delta$	.00095	.00087	.00174
-170	κ	1.4550	1.4410	1.4220
	$\tan \delta$	.00220	.00240	.00340
400	κ	1.4339	1.4102	1.3920
	$\tan \delta$	.00159	.000965	.00202

Nomex felt

Supplied by Rockwell International Corp.

T°F	Freq.	3 GHz	8.52 GHz	14 GHz
74	κ	1.21500	1.24400	1.30850
	$\tan \delta$	.00339	.00451	.00560
-300	κ	-	1.22390	1.25780
	$\tan \delta$	-	.00086	.00162
-170	κ	-	1.22460	1.27400
	$\tan \delta$	-	.00159	.00320
400	κ	-	1.23140	1.27280
	$\tan \delta$	-	.00634	.00516

Silicone RTV

Supplied by Rockwell International Corp.

T°F	Freq.	3 GHz	8.52 GHz	14 GHz
74	κ	3.59000	3.55000	3.50500
	$\tan \delta$	.01250	.01850	.021500
-300	κ	-	3.48000	3.63900
	$\tan \delta$	-	.003250	.00363
-170	κ	-	3.57000	3.57000
	$\tan \delta$	-	.01390	.01500
400	κ	-	3.48000	3.46100
	$\tan \delta$	-	.005370	.008970

Glastrate
(O-C Fiberglass)

The Sippican Corp.

Freq., Hz	60	50 k	500 k	3 M	100 M
κ	1.450	1.432	1.417	1.405	1.398
$\tan \delta$	.0228	.0039	.0028	.0022	.0012

Infrared windows

Texas Instruments

TI-1173 and TI-20

8.5 GHz

Sample No.	T ^o C	κ	$\tan \delta$
TI-1173	25	$9.69 \pm .08$	$.0008 \pm .0005$
TI-20	25	$8.037 \pm .04$	$.00046 \pm .00008$
	100	8.041	$.00057 \pm .00012$

Diallylphthalate, glass

Upjohn

At 8.5 GHz

Sample No.	Thickness (cm)	T ^o F	κ	$\tan \delta$
C 1-2	-	77	4.91 4.90	.0087 .0082
C 3-3	-	77	4.91 4.88	.0087 .0073
C 5-6	1.4765	77	4.91 4.91	.0092 .0081
	1.4884	189	4.89	.0117
	1.5347	400	4.85	.0297
	1.554	535	4.83	.0354
	1.4813	77	4.92	.0090

Modified, at 8.5 GHz

B 1-2	-	77	4.47 4.45	.0072 .0071
B 3-4	-	77	4.45 4.39	.0072 .0060
* B 5-6	1.4755	77	4.48	.0073
	1.4846	199	4.49	.0092
	1.5105	400	4.49	.0150
	1.539	539	4.41	.0195
	1.478	77	4.51	.0074

* No appreciable change when sample reversed and rotated 90 degrees.

Epoxy, glass

Upjohn

At 8.5 GHz

Sample No.	Thickness (cm)	T ^o F	κ	$\tan \delta$
R 1-2	-	77	5.03	.0196
			5.07	.0191
R 5-6	-	77	5.05	.0206
			5.07	.0203
* R 3-4	1.221	77	5.04	.0208
	1.240	240	5.03	.0260
	1.259	432	5.09	.0341
	1.299	636	5.17	.0228
	1.223	77	5.01	.0175

* No appreciable change when sample reversed and rotated 90 degrees.

Polybutadiene, glass

Upjohn

At 8.5 GHz

Sample No.	Thickness (cm)	T ^o F	κ	$\tan \delta$
A 1-2	-	77	4.42	.0080
			4.38	.0079
A 5-6	-	77	4.40	.0084
			4.41	.0082
A 3-4	-	77	4.39	.0083
	1.476	77	4.40	.0081
	1.491	200	4.39	.0086
	1.517	401	4.28	.0086
	1.534	561	4.29	.0088
	1.478	77	4.40	.0068

Polyurethane foam
At 300 MHz

Upjohn

2-lb. foam

Sample No.	T ^o C	κ	tan δ
1-3	25	1.038	.00070
2-3	↓	1.038	.00072
3-3		1.036	.00072
4-3		1.036	.00074
1-2		1.036	.00068
1-3 + 2-3		1.040	.00068
	100	1.047	.00151

3-lb. foam

1	25	1.0524	.00109
2	↓	1.0535	.00110

Cyanurate ester resin

Whittaker Corporation

ASR-10500, at 8.5 GHz

	T ^o F	κ	tan δ
As received	73	3.143	.00672
As received, reversed	73	3.142	.00668
In temperature holder	140	3.156	.00798
	201	3.171	.00975
	310	3.181	.0125
	400	3.191	.0137
	502	3.193	.0145
	102	3.121	.00668

Polybutadiene-Astroquartz 3.164-11

Whittaker Corporation

Firestone PM502, at 8.5 GHz

	T ^o C	K	tan δ
As received	73	3.105	.00301
Reversed	73	3.117	.00379
Over quarter wavelength	73	3.072	.00207
Reversed	73	3.079	.00393
After cutting	73	3.102	.00206
Reversed	73	3.129	.00314
In temperature holder	86	3.098	.00178
	159	3.070	.00174
	199	3.063	.00160
	303	3.058	.00141
	391	3.057	.00137
	516	3.039	.00131
	72	3.088	.00164

Polybutadiene-Kevlar 3.164-10

Whittaker Corporation

Firestone PM502, at 8.5 GHz

As received	73	3.257-3.261	.9179-.0190
Reversed	73	3.254-3.258	.0176-.0185
Over quarter wavelength	73	3.231-3.230	.0162-.0170
Reversed	73	3.235-3.235	.0163-.0172
After curing	73	3.220-3.253	.0161-.0179
In temperature holder	74	3.188	.0154
	170	3.226	.0322
	211	3.225	.0262
	310	3.167	.0135
	417	3.062	.0117
	515	3.065	.0156
	116	3.752	.00565
	71	3.061	.00483

Polyether sulfone (dry sample)
SN 300-P, 24 GHz, 24°C

Whittaker Corporation

κ	$\tan \delta$
3.26	.0108

Polyphenylquinoxaline resin
PPQ 401, at 8.5 GHz

Whittaker Corporation

	T°F	κ	$\tan \delta$
As received	73	3.084	.00392
As received, reversed	73	3.047	.00384
in temp. holder	74	3.052	.00384
	154	3.068	.00481
	208	3.074	.00527
	303	3.045	.00604
	402	3.028	.00608
	505	2.994	.00576
	158	3.031	.00467

Polyphenylquinoxaline-Astroquartz
2256-16A, at 24 GHz

Whittaker Corporation

T°C	κ	$\tan \delta$
23.5	3.31	.00128
70	3.31	.00149
120	3.29	.00158
176	3.28	.00158
221	3.27	.00158
260	3.25	.00189
112	3.31	.00158

Polyurethane foam (rigid)

Witco Chemical Co.

D.C. resistivity = 1.7×10^{15} ohm-cm at 25°C

MATERIALS AND COMPANY INDEX*

"Acrawax" C, IV-56
 Acrylate resins, IV-34,35; V-10
 Acrylonitrile-butadiene copolymer, IV-53
 Admiralty Materials Laboratory's silicon nitride, ceramic, P.R.-100
 AFC Alumina, V-21
 AF Materials Laboratory's Zircolite, P.R.-122
 Aircraft-Marine Products, Inc., IV-14; V-74
 Air Reduction Sales Co., V-20
 Air Seal, IV-52
 "Alathou," IV-27,70
 Alberox Corp., P.R.-5
 "Alberox" A-935, A-950, and A-962, P.R.-5
 Alcohols, IV-62
 "Alite" A-389-25 and A-389-P-30, VI-20
 AP-212 and AP-216, V-21
 AP-312, V-21,51
 APO-512-6 and APO-512-7, VI-21
 Alkyd resins, IV-47-49,123,124; V-112,113
 Allied Chemical Corp., P.R.-194
 Allied Chemical fluorocarbon derivative P-1C, P.R.-194
 Allison, William M, and Co, IV-58
 Allyl resins, IV-47,48
 Allymer CR-39, CR-39 + glass, IV-48
 "Alox," National Baryllia, P.R.-31
 "AlSiMag" A-35, IV-3,80
 "AlSiMag" A-196, IV-3,78,79
 "AlSiMag" 211, IV-3
 "AlSiMag" 288, IV-3,81
 "AlSiMag" 243, IV-3,82; VI-34
 "AlSiMag" 393, IV-3
 "AlSiMag" 495, V-5,39-61
 "AlSiMag" 491, IV-6,100
 "AlSiMag" 491 (blue), V-1,32,33
 "AlSiMag" 505, IV-2
 "AlSiMag" 513 (pink), V-1,34,35
 "AlSiMag" 544, V-21,31
 "AlSiMag" 548, V-21,31
 "AlSiMag" 576, V-2,36,37; P.R.-6
 "AlSiMag" 577, V-4,58
 "AlSiMag" 602, V-21,75
 "AlSiMag" 614, VI-10; P.R.-6
 "AlSiMag" 652, V-21; VI-21; VI-8,9
 "AlSiMag" 719; P.R.-6
 "AlSiMag" 754, P.R.-40
 "AlSiMag" 5050, V-234; VI-44
 Alumina (including porcelains), IV-6,96-100; V-1-4,2123,30-52; VI-7-21; P.R.-5-37; 8-1-3
 "AFC," V-21,30
 "Alite," see U.S. Stoneware, V-21,51; VI-20,21
 "Alberox" A-935, A-950, and A-962, P.R.-5
 American Lava
 "AlSiMag" 393, IV-3
 "AlSiMag" 491, IV-6,100; V-1,32,33
 "AlSiMag" 513, V-1,34,35
 "AlSiMag" 544, V-2,21,31
 "AlSiMag" 548, V-21,31
 "AlSiMag" 576, V-2,36,37
 "AlSiMag" 602, V-21
 "AlSiMag" 652, V-21,38,39; VI-8.9
 "AlSiMag" 719, P.R.-6
 Armour Research, Alcoa, P.R.-7,8
 E-11, P.R.-9,10
 E-20, P.R.-11
 A-75, P.R.-15-17
 A-76, P.R.-12-14
 mixtures, P.R.-18
 Centralslab 205 and 206, P.R.-19
 Carborundum 1542, P.R.-19
 Coors
 AB-2, IV-6,98,99
 AD-99, VI-14,15; P.R.-19
 AD-995, P.R.-20
 AL-100, V-2,40
 AL-200, IV-6,96,97; V-2,40; VI-11-13
 96% Al₂O₃, E-1
 EI-95, VI-15,17
 NC-2014, P.R.-20
 RR, P.R.-20
 Coors-NBS 1GP2, P.R.-20
 Corning
 JD-40, V-2,41
 JD-82, V-2,41
 JB-123, V-2
 WD-131, V-2
 JB-183, V-2,41

* In this index Roman numerals refer to Tables of Dielectric Materials, Vols. IV, V, and VI. P.R. refers to Tech. Rep. AFML-TR-72-39. This report is referenced by Arabic number & followed by page numbers.

Alumina (cont.)

Diamonite

B-890, V-2,42
B-890-2, P.R.-21
P3142, V-2,43
P3142-1, P.R.-21
P-2459, V-2,44
F-3530-40, V-3,45
P-3662, P.R.-21

"Duramic" HT-960, 8-1

Frenchtown

4462, IV-6; V-48
6096, V-3,48
7225, P.R.-21
7873, V-3,49

General Ceramic

ADH-211, V-3

General Electric

AT-100, P.R.-22
A-919, P.R.-25
A-923, P.R.-26
A-976, P.R.-27
A-1000, P.R.-28
A-1004, P.R.-29
"Lucalox," P.R.-23,24

International Pipe & Ceramic

TC-301, P.R.-30
TC-320-H, P.R.-30
TC-351, P.R.-30
V-69, P.R.-30

Kearfott

high-purity, V-3,46,47; P.R.-30
hot-pressed in carbon, VI-18,19

Knox pcelain, IV-6, 100

Minneapolis Honeywell

A-127 and A-203, P.R.-31

National Beryllia "Alox", P.R.-31

Norton 99.5%, P.R.-31

7X, V-3,49
172, V-3

Raytheon 1959, P.R.-32

402B, V-3

Rockwell foam, 8-2

"Sintox," V-3

Stearit-Magnesia A.G. A-18,

P.R.-32,33

Stupakoff 15

1510, V-3,51
1540, V-3,50
1542E, V-3
1542P, V-3,50
1550, V-3,50

U.S. Stoneware

A-212, P.R.-34
A-216, P.R.-34

U.S. Stoneware (cont.)

AP-212, V-21

AP-216, V-21

A-312, P.R.-34

AP-312, P.R.-34

"Alite" A-389-25, VI-20

"Alite" A-389-P-30, VI-21

"Alite" APO-512-6, VI-21

"Alite" APO-512-7, VI-21

610, P.R.-34

STD. 30500F, P.R.-35

Western Gold & Platinum

Al-300, V-4,52; P.R.-36

Al-300, modified, P.R.-36

Al-400, P.R.-37

Al-500, P.R.-37

Al-995, P.R.-37

Al-1000, V-4; P.R.-37

Alumina cement, 8-3

Alumina foam, 8-2

Aluminum nitride, Carborundum, hot-pressed, P.R.-1

Aluminum oxide, Linde, single crystal, IV-1,72; V-1,26-28; P.R.-2,3

Aluminum oxide, Union Carbide, single crystal, P.R.-4

Aluminum oxide, multicrystalline, see alumina

Aluminum oxide mixtures, VI-50,51

Aluminum silicates, V-3,6

"Alvar" 11/90, IV-34

Amber, IV-55

Amber Mines, Inc., IV-55

American Concrete Products, P.R.-159

American Cyanamid Co., Plastics

Dev. Labs., IV-21-23,38,46,112,

118-121; V-8,106,107; P.R.-159,160

American Cyanamid Co., Plastics and Resins Div., VI-65

American Cyanamid, cyanoethylnated cotton molding, P.R.-159

American Cyanamid "Cymac" 323, P.R.-160

American Cyanamid, see "Laminac," "Melmac," "Beetle"

American Cyanamid 405 resin, V-8

American Feldmuehle Corp., V-21,30

American Lava, IV-3,4,6,78-82,88-93, 100; V-1,4,5,21,31-37,58-61,75,234; VI-8-10,34,44; P.R.-6,40

American Lava, see "AlSiMag"

American Optical Co., IV-9; P.R.-77,82

American Optical, Amersil, P.R.-82

American Optical, phosphate glass, IV-9; P.R.-77

American Phenolic Corp., see Amphenol
 American Smelting and Refining Co., IV-13
 Amersil, clear, translucent, P.R.-82
 Amicon Corp., P.R.-160
 Amicon Corp., conformal coating 1517-36-3, P.R.-160
 Ammonium dihydrogen phosphate, IV-1
 Amphenol Corp., IV-28; P.R.-161
 Amphenol Corp., polyethylene, irradiated, P.R.-161
 "Amplifilm," IV-14; V-74
 Aniline-formaldehyde resins, IV-21
 Apatite, P.R.-126,127
 "Aplazon" Wax "W," IV-56
 "Araldite" Adhesive, Type I, (natural and silver), IV-50
 "Araldite" casting resin, Type B, IV-49,125
 "Araldite" casting resin G, IV-49
 "Araldite" E-134, IV-49
 Argus Chemical Corp., U.S. Peroxygen Div., P.R.-197
 Armour Research, P.R.-7-18,198
 "Aroclor" 1221, 1232, 1242, 1248, IV-63
 1254, IV-63; VI-78-83
 1260, 1262, 5442, IV-64
 1268, 4465, 5460, IV-15
 Armour Research, aluminum oxide, P.R.-7-18
 Asbestos, IV-13
 Asbestos filled plastics, IV-16; V-8,9,84,85,96,97
 Asphalt pavement and asphalts, P.R.-156
 Asphalts and cements, IV-56
 Astrophyllite, P.R.-127
 "Astroquartz," 8-46,47
 "Atlac" 382, V-11,12
 Atlantic Laminates, 8-25
 Atlas Powder Co., V-11,12
 Attenuator materials, IV-43-45; V-13,15,17,18,22,234-244, VI-44,45; P.R.-79,80,81, 148,175
 AVCO Research, P.R.-161
 AVCO Research, polyvinylidene fluoride, P.R.-161
 Avisun Corp., P.R.-162,163
 Avisun polypropylene, natural & plateable, P.R.-162,163
 Bakelite Corp., IV-15,16,20,27-29, 36,48,57,58,64; V-12; P.R.-180
 "Bakelite" BM-120, IV-15,16,69
 "Bakelite" BM-250, BT-48-306, BM-16981, and BM-16981 powder, IV-16
 "Bakelite" BRS-16631 + glass, IV-48
 BV-17-85 + glass, IV-16
 PLLA-5005, V-12
 "Bakelite" polystyrenes, IV-36
 "Bakelite" polyvinyl chloride-acetate, see "Vinylites"
 Balata, precipitated, IV-51
 Balsa wood, The Sippican Corp., P.R.-192
 Barium fluoride, single crystal, P.R.-38,39
 Barium-strontium titanate, IV-5,6
 Barium titanate, IV-5; V-1
 Barium titanate and plastic mixtures, IV-43
 Basalt, Hawaiian, high-density, P.R.-136
 low-density, P.R.-137
 deep ocean basalt, P.R.-137
 Basalt, synthetic, P.R.-139
 Battelle Memorial Institute, P.R.-45
 Battelle boron nitride, hot-pressed, P.R.-45
 "Bayol," "Bayol"-D, -F, -16, IV-65,66
 Beef steak, lean, frozen and vacuum dried, P.R.-199
 Beeswax, white, yellow, IV-57
 "Beetle" resin, IV-23
 Bell Telephone Laboratories, IV-3,83; V-56,57; VI-28,29; P.R.-72
 Bell Labs. F-66, IV-3,83; V-56,57; P.R.-72
 Benotoite, P.R.-127
 Bentonite, IV-14; V-74
 Benzenes and diphenyls, chlorinated, IV-63
 Benzenes, chloro-, IV-64
 Benzoguanamine-formaldehyde resin, IV-23
 "Berlox," BeO, P.R.-41
 Beryl, P.R.-128,129
 Beryllia, IV-6; V-21,24,52,53; VI-22-27; P.R.-39-43
 American Lava "AlSiMag" 754, P.R.-40
 Beryllium Corp., hot-pressed, V-21,53
 crucible grade, V-21,52

Beryllia (cont.)

Brush
 B-6, P.R.-40
 B-7-6, P.R.-40
 B-7-37, P.R.-40
 cold-pressed, VI-24,25
 F-1, P.R.-41
 hot-pressed, VI-22,23
 sintered, VI-26,27
 Coors BD-98, P.R.-41
 National Beryllia "Berlox", P.R.-41
 cold-pressed, P.R.-41
 North American translucent,
 P.R.-42,43
 Norton, Iv-6
 Beryllium Corp., The, V-21,52,53
 Beryllium oxide, multicrystalline,
 see Beryllia
 Beryllium oxide + silicon-nitride,
 8-4
 Beryllium oxide, single crystal,
 Electronic Space Products, P.R.-39
 Beryllium orthosilicate, single
 crystal KSC 7013, Elec. Space
 Products, P.R.-44
 Biphenyl, diisopropyl and monoiso-
 propyl, V-19
 Biphenyls, chlorinated, IV-15,63,64
 Birch plywood, P.R.-193
 Bismuth silicate ceramic, P.R.-44
 Bitumen, natural, IV-56
 "Boltaron" 6200-10, V-10
 "Bozalloy," P.R.-50,51
 Boron nitride, V-6,76,77; VI-48,49;
 P.R.-45-57
 Boron nitride, density effect, P.R.-45
 Boron nitride, Battelle, hot-pressed,
 P.R.-45
 Carborundum, hot-pressed, 1956,
 V-6,76
 Carborundum, hot-pressed,
 Grade A, P.R.-47
 Grade HP (1962), P.R.-46,48
 Grade M, P.R.-49
 Carborundum, hot-pressed with
 BN fibers, 8-5
 High-Temperature Materials,
 pyrolytic, P.R.-50,51
 National Carbon, see Union Carbide
 and Carbon
 Raytheon, pyrolytic, P.R.-52,53
 Union Carbide & Carbon, pyro-
 lytic (see High-Temperature
 Materials)
 pyrolytic laminate, P.R.-54

Boron nitride (cont.)

Union Carbide & Carbon (cont.)
 cold-pressed, P.R.-57
 hot-pressed HBR, P.R.-56
 HBN, P.R.-57
 HD-0025, VI-48,49
 HD-0056, P.R.-54
 HD-0086, P.R.-54
 HD-0092, P.R.-55
 HD-0093, P.R.-55
 HD-0094, P.R.-55
 Boron nitride alloys, V-6,79; VI-50,51
 Boron nitride, yarn, 8-5
 Borosilicate coating, 8-19
 Brand-Rex Co., IV-40; VI-11,105;
 P.R.-181-183
 Bread and bread dough, P.R.-202
 Bromund, E. A., and Co., IV-57
 Brown Univ. silicon, single crystal,
 P.R.-78
 Brunswick Corp., Defense Products
 Division, P.R.-95
 Brunswick slip-cast, SiO₂, P.R.-95
 Brush BeO
 B-6, P.R.-40
 B-7-6, P.R.-40
 B-7-37, P.R.-40
 cold-pressed, VI-24,25
 F-1, P.R.-41
 hot-pressed, VI-22,23
 sintered, VI-26,27
 Brush Electronics Co., IV-1,73;
 VI-22,27; P.R.-40,41
 Budd Company, The, P.R.-164,165
 Budd copper-clad laminate, PE1153,
 P.R.-164,165
 Budd DiClad-522, polytetrafluoro-
 ethylene, fiberglass laminate,
 P.R.-164
 Buna S (GR-S) and compounds, IV-52
 Bureau of Standards casting resin,
 IV-40
 Butadiene-acrylonitrile copolymer,
 IV-53
 Butadiene, chloro-, IV-53,62
 Butadiene-styrene copolymer, IV-38,52
 "Butvar," low OH and 55/98, IV-34
 n-Butyl alcohol, IV-62
 Butyl rubbers, IV-52
 Butyraldehyde, IV-62
 Cable oil 5314 and PL101270, IV-65
 Cadmium telluride, IRTRAN 6, 8-6
 Calcite, P.R.-58
 Calcium carbonate, single crystal
 mineral, P.R.-58

Calcium fluoride, single crystal,
 V-1; P.R.-59-61
 MIT, LIR, V-1
 MIT, Crystal Physics Lab., P.R.-59
 MIT, Ceramics Lab., P.R.-60
 mixture with "Reflon," V-10
 Calcium sulfate, 8-23
 Calcium titanate, IV-5
 California Research Corp., IV-65
 Candy and Co., Inc., IV-57
 Cantol Wax Co., IV-59
 "Carberlox," National Beryllia,
 P.R.-80
 Carbon, diamond, V-1
 Carbon and plastic mixtures,
 IV-32,41; V-239,240
 Carbon tetrachloride, IV-62
 Carbonyl iron and plastic
 mixtures, V-15
 Carborundum Co., The, V-6,76;
 VI-46,47; P.R.-1,19,46-49,
 79,166; 8-5
 Carborundum boron nitride,
 Grade A, Grade BP, and
 Grade M, P.R.-46-49
 hot-pressed, V-6,76,77; 8-5
 silicon nitride alloy, V-6,79
 Carborundum EKONOL (polyester
 resin), P.R.-166
 Carborundum silicon carbide,
 P.R.-79
 Carborundum 1542, P.R.-19
 Carborundum "Castolast," 8-3
 Catalin Corp. of America, IV-16-18,
 36,39,119
 "Catalin" 200, 500, and 700 base,
 IV-16,17
 "Catalin" 8012, IV-39, 119
 "Catalin" EK 2784, IV-39
 Celanese Corp. of America, IV-24,
 25,114,115; V-9,10,12,90
 Celanese MR-31C, MR-33C, MX-186,
 and MX-218, V-12
 Cellular Rubber Products, Inc.,
 IV-51
 Cellulose acetate LL-1, IV-23
 Cellulose acetate + plasticizer, IV-24
 Cellulose acetates, IV-23,24; V-9
 Cellulose derivatives, IV-23-25;
 V-9,90,91,92; P.R.-159
 Cellulose nitrate and camphor, IV-25
 Cellulose propionate, IV-25,114;
 V-9,90
 Cellulose triacetate ("CTA"), V-9,92
 Cements and asphalts, IV-56
 Cements, alumina, 8-3
 Genco "Sealstix," IV-56
 Centralab.:
 aluminas 205, 206, P.R.-19
 steatites 302, 400, 410, 452,
 IV-3,84-77
 Centralab. Div., Globe-Union, Inc.,
 IV-3,84-87; P.R.-19
 Central Scientific Co., IV-56
 "Ceram" 61-1, V-5,65
 "Ceram" 61-2, V-5,66
 "Ceram" 61-3, V-5,67
 "Ceram" 61-4, V-6,68
 "Ceram" 61-5, V-6,69
 Ceramics for Industry, P.R.-148
 Ceramics for Industry
 CFI 1003, CFI 1006 attenuator
 materials, P.R.-148
 Ceresse Wax AA and brown, IV-57
 Ceresin, white and yellow, IV-57
 Cerium fluoride, ceramic, MIT,
 LIR, P.R.-61
 Cesium bromide, V-1
 Cesium iodide, V-1
 Cetylacetamide, IV-56
 "Chemelac" M1405, M1406, M1407,
 M1411, and M1412, IV-32
 "Chemelac" M1414, IV-32; V-241
 "Chemelac" M1418-2, M1418-5,
 M1422, and M1423, IV-33
 "Chemelac" B-3, IV-56
 Chemplast, Inc., P.R.-166
 Chemplast "Zitex," low density
 polytetrafluoroethylene film,
 P.R.-166
 Chlorinated benzenes and biphenyls,
 IV-15,63,64; VI-78-83
 β -chloroethyl-2,5-dichlorobenzene,
 IV-64
 Chlorostyrenes, ortho and para,
 copolymer, IV-42
 Chlorotrifluoroethylene dimer,
 trimer, V-18
 Chlorotrifluoroethylene tetramer,
 pentamer, hexamer, V-19
 Chromium oxide, Linde, single
 crystal, P.R.-62
 Ciba Co., Inc., IV-21,49,50,125;
 P.R.-108; P.R.-180
 Ciba epoxy resins, IV-49,50,125;
 P.R.-180
 "Cibanite," IV-21
 Ciba tantalum oxide, optical grade
 powder, P.R.-108
 Climax Molybdenum Co., VI-45

Clinoenstatite, see magnesium metasilicate
 Coal, powdered, P.R.-191
 single lump, P.R.-192
 Coating, borosilicate, 8-19
 Cobalt ferrite, MIT samples, V-136, 177, 206
 Cobalt oxide, P.R.-63
 cobalt-nickel oxide, mixed crystal, MIT, Crystal Physics Lab., P.R.-63
 Coffee, P.R.-202
 Columbia Univ., P.R.-75
 Columbia University manganese fluoride, tetragonal crystal, P.R.-75
 Components and Systems Lab., see U.S. Components and Systems Lab.
 Concrete pavement, P.R.-157
 Concrete, artificial, P.R.-159
 Condex Co., 8-26
 Conformal coating, Amicon Corp., P.R.-160
 "Conolon" 506, V-8
 Continental Diamond Fibre Co., IV-18,19,21,26,27,31,32; V-8,12,14,80-83,88,93,104,108,114
 (now a division of The Budd Co., see also Budd)
 Cooking oil, Kremax, Armour, P.R.-198
 Coors alumina
 AB-2, IV-6,98,99
 AD-99, VI-14,15; P.R.-19
 AD-995, P.R.-20
 AL-100, V-2,40
 AI-200, IV-6,96,97; V-21;VI-11-13
 96% Al_2O_3 , 8-1
 EI-95, VI-16,17
 MC-2014, P.R.-20
 RR, P.R.-20
 NBS 10F2, P.R.-20
 Coors BeO BD-98, P.R.-41
 Coors Porcelain Co., IV-6,94-99; V-2,21; VI-11-17; P.R.-19-20,41
 Coors Spinel, 8-12
 "Copolene" B, IV-28
 Copper halides, pressed powder, MIT, LIR
 copper bromide, P.R.-63
 copper chloride, P.R.-63
 copper iodide, P.R.-63
 Cordierite, P.R.-67
 "Corfoam" 114, IV-19
 Cornell Aeronautical Labs., IV-48,124
 Corning aluminas
 JD-40, JD-82, JB-183, V-2,41
 JB-123 and W.D0131, V-2
 Corning Fotoceram, VI-40,41
 Corning Fotoform, VI-36-39
 Corning Glass Code Nos.0010, 0014, 0080, 0090, 0100, 0120, 0330, 1723, 1770, 1990, 1991, 3320, 7040, 7050, IV-9,102; P.R.-89,149
 7052, 7055, 7060, 7070, IV-10, 102; V-62.63
 7230, 7570, 7720, 7740, 7750, IV-10
 7900, 7911, IV-10; V-5,64; VI-35
 7911, IV-10,103
 7940, P.R.-83
 7941, P.R.-96
 7971, 8-19
 Corning 7945 multiform glass, P.R.-96
 Corning Glass Nos. 8460, 8830,IV-10
 8603, V-5
 8871, 9010, Lab. No. 189CS, IV-11
 Corning Glass code 9606, VI-42,43; P.R.-149
 Corning Glass No. 119BUC, P.R.-89
 Corning Glass Works, IV-9-11,26,41, 42,102,103; V-2,5,6,41,62-71; VI-35-43; P.R.-83,89,96; 8-19
 Cotton molding, Amer. Cyanamid, P.R.-159
 Crepe, pale and compounds, IV-51
 Cresylic-acid formaldehyde resins, IV-18,19,68,70
 "Crolite" No. 29, IV-4
 "Cronar," V-13,109
 Crowley Co., polyiron attenuator, P.R.-167
 Crowley, Henry I. and Co., Inc.
 IV-4,7; V-217-219; P.R.-167
 "Crowloy" 20, IV-7; V-217
 "Crowloy" 70, IV-7
 "Crowloy" BX114, IV-7; V-219
 Crystals, inorganic, IV-1,2,72-77; V-1,26-30,133-135; VI-2-6; P.R.-2,4,38,39,44,58,59,60,62, 63,65,66,68,77,78,80,81,103-105,106,107,109,115,117,123-134
 Crystals, organic, IV-15
 Custom Materials, Inc., P.R.-167
 Custom Materials, Load 4101, 707-4, 707-(3.75), P.R.-167
 Cyanurate ester resin, 8-45
 "Cymac," 325, VI-65; P.R.-160
 "Dacron"-filled plastics, V-8,10,12, 14,110
 "Darex" No. 3, 43E, X-34, X-43, IV-38
 "DeKhotinsky" cement, IV-56
 Delaware Research and Development Corp., V-9
 Dennison Mfg. Co., IV-58

Desert sand, P.R.-143
Dewey and Almy Chemical Co.,
Organic Chemicals Div., IV-38
"Diala" Oil, IV-66
"Dialite" 55 P687 laminate, 8-35
Diallyl phenyl phosphonate
resin, IV-48
Diamond, V-1
Diamonite Products Division,
U.S. Ceramic Tile Co.,
V-2, 3, 42-45; PR-21
"Diamonite" B-890, V-2, 42
B-890-2, P.R.-21
"Diamonite" P-3142, V-2, 43
P-3142-1, P.R.-21
P-3459, V-2, 44
P-3530-40, V-3, 45
P-3662, P.R.-21
Diatomaceous-earth ceramic,
IV-6, 101
Dibutyl sebacate, IV-62
Dichloronaphthalenes, mixture
of the 1,2-, 1,4-, and
1,5-isomers, IV-58
Dichloropentanes Nos. 14 and
40, IV-63
2,5-Dichlorostyrene, IV-64
DI-CUP, P.R.-196
Diisopropyl biphenyl, V-19
"Dielectrene" 100, IV-21
"Dilecto" (hot punching) XXX-P-26,
IV-19; V-80-81
"Dilecto" ("Mecoboard"), IV-18;
V-82, 83
"Dilecto" GB-112S, IV-27
"Dilecto" GB-112T, IV-31, 32; V-104
"Dilecto" GB-116E and GB-126E, V-14
"Dilecto" GB-181E, V-14, 114
"Dilecto" GB-261S, IV-26; V-93
"Dilecto" GM-1, V-8, 88
"Dilecto" GM-PE, V-12, 108
Dinitrobenzene, VI-77
Dioctyl sebacate, IV-62
Diphenyl, see biphenyl
Dodge Industries, Inc., P.R.-167
Dodge Industries FLUORGLAS E 650/2-1200,
P.R.-167
Dow Chemical Co., IV-36-42, 46, 64, 117;
V-91; P.R.-194
Dow Chemical "Dowtherm" A, P.R.-194
Dow Corning Corp., IV-26, 27, 41, 42, 54,
55, 66, 67, 126; V-9, 20, 94, 95; VI-52-
57; P.R.-168; 8-26-28
Dow Corning fluids
200 and 500, IV-66
550 and 710, IV-67
Dow Corning molding compound 306,
P.R.-168
Dow Corning resins
996 and 2101, IV-26
2103, IV-26, 27
2105, V-9, 94
2106, V-9, 95-101; VI-57
XR-7141; VI-56
R-7501, VI-52, 53
R-7521, VI-54, 55
X-12546, XR-43117, 8-28
Dow Corning Silastics
120, 125, 150, 152, 160, 167,
180, IV-54
181 and 250, IV-54, 126
6167, IV-55, 126
6181, X4342, IV-55
E-1600 140; 8-27
XF6620, IV-55; V-20
X6734 and 7181, IV-55
RTV 501, 521, 1602, 5350,
S-6538, P.R.-168
Dow Corning "Styrofoam" FR, 8-26
Dow Corning "Sylgard" 182, 184,
and DC-92.007, P.R.-168
"Sylgard" 188, 8-27
Dow C-244, IV-36
Dow experimental plastic Q-166,
Q-166 + fiberglass, Q-200.5, IV-39
Dow experimental plastic Q-247.1,
IV-36
Q-344, IV-40
Q-406, IV-37, 117
Q-409, IV-42
Q-475.5, IV-40
Q-764.6 and Q-767.2, IV-37
Q-817.1, IV-37, 117
"Dowtherm" A, P.R.-194
Dupont, E. I. de Nemours & Co.
Electrochemicals Dept., IV-33, 64
Film Dept., V-9, 13, 92; 8-28
Organic Chemicals Dept. (Elasto-
mers Div.), IV-53; P.R.-194
Photo Products Dept., V-13, 109
Pigments Dept., IV-4
Plastics Dept., P.R.-169-171,
173, 174; 8-28-30
Polychemicals Dept., IV-23, 25,
27, 32, 34, 35, 58, 113; V-10, 89;
VI-58
Textile Fibers Dept., V-8, 10,
12, 14, 110; P.R.-172; 8-28
fluorinated ethers, Organic
Chemicals Dept., P.R.-194
"VITON," Organic Chemicals Dept.,
8-30

Dupont (cont.)

"H" film, Plastics Dept.,
P.R.-169-171

"Kapton," 500 H film, Plastics
Dept., P.R.-171

Nomex honeycombs, Textile Fibers
Dept., P.R.-172; 8-28,41,42

"Teflon" FEP, TFE, T-100, 100X, 9033,
TEF-7, TFE-6c, Tedlar, TFE-7A,
Teflon R PFA TE 9704, FEP 100,
Plastics Dept., Chestnut Run Lab.,
IV-32; V-24; VI-58; P.R.-173,174;
8-28-30

"Duramic" HT-960, 8-1

"Durez" 1601, natural, IV-17

"Durez" 11863, IV-20

Durez Plastics, Div., Hooker Electro-
chemical Co., IV-17,20

"Durite" No. 500, IV-17

"Durite" No. 221X, IV-19

Durite Plastics, Inc., now the Borden
Co., IV-17,19

"Duroid" (1" thick sheet), P.R.-184

"Duroid" 5650, VI-59-61

"Duroid" 5850, VI-62-64

Dynasil Corp. of America, P.R.-84,96;
8-12

Dynasil 4000 glass, P.R.-84; 8-12

Dynasil slip-cast, P.R.-96

East Coast Aeronautics, Inc., V-11

Eastman Kodak Co., IV-15,62;

P.R.-67; 8-7,8,11,22,23

"Ecco" L65, V-11

"Eccofoam" FH, Emerson & Cuming,
P.R.-176

"Eccofoam" GL, V-8

"Eccofoam" H1K (1000°F), V-7

"Eccofoam" H1K (500°F), V-14,115

"Eccofoam" PS, V-10

"Eccogel" 1265, Emerson & Cuming,
P.R.-176

"Eccosorb" HFX122, V-13,237

"Eccosorb" HFX123, V-13,238

"Eccosorb" HF155, HF680, HF853,
HF1000, HF2050, V-13

"Eccosorb" MF110, MF112, MF114,
and MF116, V-15

"Eccosorb" MF117, V-15,242

Eggwhite, P.R.-202

ELKONOL (polyester resin), P.R.-166

Electronic Mechanics, Inc., IV-13,108

Electronized Chemicals Corp., P.R.-175

Electronized Chemical "Polyguide,"
P.R.-175

Emerson & Cuming, V-7,8,10,11,13-15,
115,237,238,242; P.R.-175-176

Emerson & Cuming A-19 attenuator
material, P.R.-175

Emerson & Cuming

"Eccofoam" FH, P.R.-176

"Eccofoam" GL, V-8

"Eccofoam" H1K (1000°F), V-7

"Eccofoam" H1K (500°F), V-14,115

"Eccofoam" PS, V-10

Emerson & Cuming "Eccogel" 1265,
P.R.-176

Emerson & Cuming ferrites; 8-6

Emerson & Cuming Stycast 2651-40 RQ,
8-40

Elastomers, IV-51-55; V-127-129

Electronic Space Systems Corp., 8-31

"Elvacet" 42A-900, IV-33

"Elvanol" 51A-05, 50A-42, 70A-05,
72A-05, 72A-51, IV-33

Engineering Research and Dev. Lab.,
see U.S. Army Eng. Res. and
Dev. Lab.

Enjay Co., Inc., IV-28,39,50

"Ensolute" M22240, M22239, 5036,
IV-31

"Epon" Resin RN-48, IV-50

"Epon" 828, V-16,116-125; VI-68-75;
P.R.-186,187

"Epon" X-131, V-16; VI-74-76

Epoxy resins, IV-49,50,125; V-14-
16,114,126; VI-67-76; P.R.-180

Epoxy laminates with

"Dacron," V-14

"Fiberglass," IV-50; V-14,16,22,
114,124,125; VI-67,72-76;
8-46

"Nylon," V-14

"Orlon," V-14

E Resin, IV-50

Esso Laboratories, see Enjay Co.,
P.R.-195

"Esscolam" V2T, 8-31

Esso "Teresso" oil, V-78; P.R.-195

"Estawax," IV-57

Ethers, fluorinated, P.R.-194

"Ethocel" LT5, IV-25,115; V-91

Ethyl alcohol, IV-62

Ethyl cellulose, IV-25,115; V-91

Ethylene Chemical Corp., V-10

Ethylene Glycol, IV-62

Ethylpolychlorobenzene, IV-64

"Ferramic" A, V-159,191,220

"Ferramic" B, V-160,192,221

"Ferramic" C, V-161,193,222

"Ferramic" D, V-162,194,223
 "Ferramic" E, V-163,195,224
 "Ferramic" G, V-164,196,225
 "Ferramic" H-1, V-4,166,198
 "Ferramic" H, V-165,197,226
 "Ferramic" I, V-167,227
 "Ferramic" J, V-168,199,228
 "Ferramic" K, V-169,229
 "Ferramic" N, V-200
 "Ferramic" Q (rec'd Dec. 1953),
 V-170,230
 "Ferramic" Q (rec'd Aug. 1954),
 V-171,201,231
 "Ferramic" Q₂, VI-32,33
 "Ferramic" Q-3, P.R.-150
 "Ferramic" R-1, R-4, R-5, R-6,
 P.R.-150
 "Ferramic" MF874, V-172,202
 "Ferramic" 1118, V-173,232
 "Ferramic" 1326B, V-174,203
 "Ferramic" 1331, V-175,204,233
 "Ferramic" 3308, P.R.-150
 "Ferramic" 3310 (experimental),
 V-176; P.R.-150
 "Ferramic" 3321, P.R.-150
 "Ferramic" 3330, P.R.-150
 Ferrites and garnets, IV-7;
 V-4,54,133-204,206-233;
 VI-28-33; P.R.-150; 8-6
 "Ferrottron" 119, V-17,205,244
 "Ferrottron" 308, 309, V-18
 Ferroxcube Corp. of America, V-4
 "Ferroxcube" 105, V-4
 "Fiberfrax" board, V-6,78; VI-46,47
 "Fiberglass" laminates, IV-16,18,
 22,25-27,31,32,47-50,68;
 V-8-11,13,14,16,22,86-88,93-95,
 98-101,104; VI-56,57; P.R.-189-190
 "Fiberglass" see E glass, Owens-
 Corning X994 laminates or resin
 Fiber samples, 8-13-18,28
 "Fibestos" 2050IVA C-1686, IV-24
 Films, see trade names as Croner,
 Mylar, Kapton, Quantum tape,
 etc., or chemical name
 Filtered Resin Products, Inc., IV-56
 Fir plywood, P.R.-193
 Float glass, PPG, 8-20
 Fluorinated ethers, P.R.-194
 Fluorocarbon derivative P-1C,
 P.R.-194
 FLUOROGLAS E 650/2-1200, P.R.-167
 "Fluorosint" (1960), P.R.-179;
 (1973), 8-35
 Foam, alkyd diisocyanate, chlorinated,
 IV-24
 Foam, alkyd diisocyanate (cont.)
 epoxy, V-14
 polyimide, P.R.-178
 polystyrene, IV-37; P.R.-188
 polymethane, P.R.-179,188
 "Foamglas," IV-11
 Formaldehyde resins
 aniline, IV-21
 benzguanamine, IV-23
 cresol, IV-18,19,68,70
 melamine, IV-21,22,112
 phenol, IV-15-19,109-111; V-8J-87
 phenolaniline, IV-20
 urea, IV-23
 Formica Co., The, IV-17,20,21,25,
 46,47
 "Formica" FF-41 (sheet, rod stock),
 IV-21,68
 "Formica" FF-55, IV-21,69
 "Formica" G7, G6, IV-25
 "Formica" Grade MF-66, IV-20,68
 "Formica" XX, LE, IV-17,68
 "Formica" YN-25, IV-17
 "Formica" Z65, IV-46
 "Formica" Z80, IV-47
 "Formvar," Type E, IV-34
 "Forticel" No. 28102, IV-25; V-90
 "Forticel" JLB-(H), V-9
 "Forticel" JMB-(M), V-9
 "Fortiflex" A, V-10
 "Fotoceram" (843 GU) and (843 GZ),
 V-5; VI-40,41
 "Fotoform" B(843 GU), V-5; VI-36,37
 "Fotoform" C(843 GU), V-5; VI-38,39
 "Fractol" A, IV-66
 Frenchtown Porcelain Co., IV-6;
 V-3,48,49; P.R.-21
 Frenchtown alumina
 4462, IV-6; V-3,48
 6096, V-3,48
 7225, P.R.-21
 7873, V-3,49
 Fullers earth, Foxboro, P.R.-141
 Furfuraldehyde resin, phenol, IV-19
 Fused quartz, IV-11,104; V-72,73;
 P.R.-85-97
 "Gafite" cast polymer, IV-34
 Gasoline, aviation, 100 and 91
 octane, IV-85
 General Aniline and Film Corp.,
 IV-34,46
 General Cable Corp., IV-52
 General Ceramics Co., IV-4,8,83;
 V-3,4,54,55,159-176,191-204,220-233;
 VI-32,33; P.R.-150,152,176,177

General Ceramics ADH-211, V-3
 BM3054, V-4,55
 7292, IV-4, V-55
 General Ceramics "Ferramics," see
 "Ferramics"
 General Electric Co., IV-63-65
 Chemical Materials Dept., IV-48
 Electronic Components Div.,
 IV-13,106,107; P.R.-22-29,73,
 153,154
 Lamp Div., IV-11,104; V-72,73
 Plastics Dept., IV-50; 8-32,33
 Silicone Products Dept., IV-55;
 P.R.-85-87,176,177
 General Electric fused quartz,
 Type 101, IV-11,104; V-72,73
 General Electric Isomica 4950,
 P.R.-153
 General Electric "Lexan," P.R.-177
 General Electric F-118, F-202 mag-
 nesium orthosilicate, P.R.-73
 General Electric Mycalex,"
 P.R.-153,154
 General Electric silicone rubber
 RTV-11, P.R.-176
 SE900, P.R.-177
 General Mills, Inc., IV-23
 Geon 2046, 80365, 80384, IV-29
 Gilsonite, IV-56
 Glass, alkaline lead silicate, IV-11
 Glass, alkali-silica, IV-12,105;
 P.R.-93, see also mixed silicate
 glass and various glass mfgs.
 Glass, aluminum borosilicate, IV-10
 aluminum zinc-phosphate, IV-9
 barium borosilicate, IV-10
 borosilicate, IV-9,101
 Glass, Dynasil 4000, P.R.-84; 8-12
 "E", IV-11
 General Electric 101, clear
 P.R.-85-87
 iron-sealing, IV-9,102
 Glass, lead-barium, IV-9
 lime-alumina-silicate, IV-9
 low alkali, potash-lithia-boro-
 silicate, IV-10,102; V-62,63
 mixed silicate, P.R.-89-94
 phosphate 2043x, 2279x, IV-9
 potash-lead silicate, IV-9
 potash-soda-barium silicate, IV-9
 silica, IV-10,103; V-64; P.R.-82-88
 soda-borosilicate, IV-9,10
 soda-lead-borosilicate, IV-10
 soda-lime-silicate, IV-9,11
 soda-potash-borosilicate, IV-9

Glass (cont.)
 soda-potash-lead-silicate, IV-9
 soda-potash-lithia-borosilicate,
 IV-10
 soda-silica, IV-11
 soda-silicate, P.R.-93
 Glass, "Spectrosil" A, P.R.-88
 "Spectrosil" B, P.R.-88
 "Vitreosil," optical Grade,
 P.R.-88
 "Vitreosil," commercial grade,
 P.R.-88
 Glass ceramic 9606, VI-42,43
 Glass Lamicoid No. 6038, IV-21,70
 Glass and mica, IV-13,69,106-108;
 P.R.-153-155
 Glass powder and plastic mixtures,
 IV-41,42
 Glasses, IV-9-12,101-105; V-5,6,62-73;
 VI-35-43; P.R.-82-94; 8-20,21
 Glastic Corp., IV-47,49
 "Glastic" GF, MM, MP and A-2, IV-49
 "Glastic" S and MF, IV-47
 "Glastron" rope, 8-26
 "Glastrate" (O-C Fiberglass), 8-42
 Glyco Products Co., IV-56,59
 "Glyptol" No. 1201 (red), IV-48
 Goodrich, B.F., Chemical Co.,
 IV-29,30
 Goodyear Aircraft Corp., IV-48; V-8,9,
 84-87,96-101
 Goodyear Tire and Rubber Co., Plastics
 Dept., IV-40,51,52
 Granite, Quincy, P.R.-138
 Virginia, P.R.-138
 Grease, Dow Corning, No. 4, IV-67
 high vacuum, V-20
 Grease, "KEL-F" No. 40, IV-63
 Green Refractories, cements, 8-3
 Greenstone, Virginia, P.R.-139
 GR-I (butyl rubber) and compound,
 IV-52
 GS-S (Buna S) and compounds, IV-51
 Gulf Oil Corp., IV-58; VI-84,85
 Gulf 303 oil, VI-84,85
 Gutta-percha, IV-51
 Gypsum board, 8-23
 Hafnium oxide, multicrystalline,
 Zircoa, P.R.-54
 Halite, P.R.-135
 "Halowax" No. 1001, IV-57
 No. 11-314, IV-58
 Oil 10C0, IV-64
 Harbison-Walker cements, 8-3

Hardman, H. V., Co., Inc., IV-49,51
 Harshaw Chemical Co., The,
 IV-1,2; V-1,30
 Hartwell, N. H. and Sons, Inc.,
 V-10
 Haveg Industries, Inc.,
 Taunton Div., P.R.-153
 "Havelex" glass-bonded micas:
 Types 1080, 1090, 1101, 2101,
 2103, 2801, 2803, P.R.-154
 Hawaiian soil, P.R.-141,142
 Haynes Stellite, Div. of Union
 Carbide and Carbon, P.R.-101
 Heptacosafuorotributyl, IV-63
 Heptane, IV-62
 Hercules Powder Co., Inc., IV-23;
 V-16; P.R.-196
 Hercules DI-CUP, dicumyl peroxide,
 P.R.-196
 VUL-CUP, a,a'-bis(t-butyl per-
 oxy) diisopropylbenzene,
 P.R.-196
 Hexachlorobutadiene, IV-62
 Hexamethylene-adipamide polymer,
 IV-23,113
 Hexane, V-19
 "H"-film, P.R.-169-171
 Honeycomb laminates, P.R.-172; 8-41
 Hood Rubber Co., IV-22
 Hooker Electrochemical Co.,
 IV-62; V-13
 Hooker 32A, V-13
 Houghton Labs., Inc., IV-50,
 V-15,16,126
 Munson, C. W., V-7
 "Hycar" OR "Cell-tite," IV-52
 Hydrocarbon polymer, cross-linked,
 IV-50
 Hydrocarbons, petroleum, IV-65-66;
 VI-84,85
 12-hydroxystearin, IV-58
 "Hysol" 6000 and 6020, IV-50
 6000 HD, V-15,126
 6030-B, V-15
 XL-6060, V-15
 XL-6080, V-16
 "Hy-tuf" laminate Grade GF181, IV-50

 Ice, IV-1; P.R.-145-147
 Ignition sealing compound No. 4, IV-67
 Instant coffee, powder, P.R.-202
 Instant tea, powder, P.R.-202
 International Pipe & Ceramic, P.R.-30,72
 International Pipe & Ceramic alumina,
 P.R.-30

 International Pipe & Ceramic
 steatite, P.R.-72
 Iron and plastic mixtures,
 IV-43,44; V-243
 Iron-manganese oxide and plastic
 mixtures, IV-45
 ITRAN 1, Kodak magnesium fluoride,
 8-7,8
 ITRAN 2, Kodak zinc sulfide,
 8-23
 ITRAN 4, Kodak zinc selenide,
 8-22
 ITRAN 5, Kodak MgO multicroystal,
 P.R.-67; 8-11
 ITRAN 6, Kodak cadmium telluride,
 8-6
 Irvington tape, V-17
 Irvington varnish and Insulator Co.,
 V-17
 Isobutylene-isoprene copolymer, IV-52
 Isomica 4950, General Electric,
 P.R.-153

 Jet fuels JP-1, JP-3, IV-65; JP-4,
 V-19
 Johns-Manville, IV-13; P.R.-158

 Kaiser Refractories, cement, 8-3
 "Kapton," P.R.-171
 Kearfoot alumina, V-3,46,47; VI-18,19
 Kearfoot Co., Inc., V-3,46,47;
 VI-18,19
 Kearney, James R., Corp., IV-52
 "Kel-F," IV-31
 "Kel-F" Alkanes 464, 695, V-18
 8126, 10157, 12188, V-19
 Grade 300 and 300-P25, IV-31,116
 X200, V-10,102,103
 Grease No. 40, IV-63
 oil, Grade No. 1 and No. 3, IV-63
 oil, Grade No. 10, IV-63,
 V-130,131
 wax No. 150, IV-58
 Kellogg, M. W., Co., The, IV-31,58,
 63,116; V-10,18,19,102,103,130,131
 Kennecott Copper, P.R.-191
 Kerosene, IV-65
 "Kevlar," 8-46
 Knox Porcelain Corp., IV-6,100
 Kodak Co., see Eastman Kodak Co.
 Kodak ITRAN 1, 8-7,8
 ITRAN 2, 8-23
 ITRAN 4, 8-22
 ITRAN 5, 8-11
 ITRAN 6, 8-6

"Koroseal" 5CS-243, IV-30
 "Kralastic" BE, BM, D, EBMU, F,
 IV-53
 KRS-5, IV-2,76
 KRS-6, IV-2,75
 Kuhne-Libby Co., IV-57

 "Laminac" 4115, IV-46,120
 4-205, IV-46,121
 "Laminac" 4232, V-106,107
 PDL7-627 and PDL7-650, IV-46,120
 Laminare BD-44 and BK 174, IV-42,48
 Laminated Plastics, Inc.,
 see Glastic Corp.
 Laminate Grade G11, 8-36
 Laminates and impregnated batts,
 see filler or resin:
 Asbestos-filled plastics
 "Dacron"-filled plastics
 Epoxy laminates
 "Fiberglas" laminates
 Melamine GMC
 "Nylon"-filled plastics
 "Orlon"-filled plastics
 Paper laminates
 Phenolic resin plus fillers
 Polyester resin plus fillers
 Polystyrene plus fillers
 Silicone resin plus fillers
 Lancaster Glass Co., P.R.-89-92
 Lancaster mixed silicate glasses,
 7352, 7357, L1957, L9100,
 P.R.-89-92
 Lanthanum aluminate, single crystal,
 National Lead, P.R.-65
 Lava, V-21,75
 Lead bromide, single crystal, MIT,
 Crystal Phys. Lab., P.R.-66
 Lead chloride, P.R.-66
 Lead chloride/lead bromide,
 P.R.-66
 Leather, sole, IV-60
 "Lexan," General Electric, P.R.-177
 Limestone, P.R.-139
 Limonite, P.R.-135
 Linde Air Products Co., The,
 IV-1,2,72,77; V-1,26-28;
 VI-2,6; P.R.-2,3,62
 Liquids, aliphatic, IV-62,63:
 V-18,19,130,131
 aromatic, IV-63,64; V-19; VI-78-81;
 see Table of Contents of the P.R.
 inorganic, IV-61; V-18
 organic, IV-62-67; V-18,19,20;
 VI-78-87; see Table of Contents of
 the P.R.
 Liquids, petroleum, IV-65,66; VI-84,45;
 P.R.-195
 silicone, IV-66,67; V-20; VI-86,87
 lithium fluoride, IV-1
 lithium-nickel ferrite, V-137,178
 Litton Industries, P.R.-117
 "Loalín," IV-36
 Lovell Chemical Co., IV-57,58; V-16
 "Lucalox," General Electric,
 P.R.-73,24
 Lucent Products Ltd., VI-66
 "Lucidol," P.R.-196
 "Lucite" HC 202, V-10
 "Lucite" HM-119 and HM-140, IV-34,70
 "Lucite," sintered, IV-34
 "Lucoflex," IV-30
 Lucoflex Plastic Fabricating, Inc.,
 IV-30
 "Lumarith," XFA-H4 and 22361, IV-20,
 25,70
 Lunar rocks, Apollo 11 and 12,
 P.R.-139
 "Lupersol" 101, P.R.-197
 "Lupersol" 130, P.R.-196
 "Lustrex" loaded glass mat, IV-41

 3-M Company, IV-63; V-16,17,22; VI-67;
 P.R.-178
 "3-M" board, P.R.-178
 3-M "Scotchcast" 221, P.R.-178
 Magnesia
 Kodak ITRAN 5, P.R.-67; 8-11
 MIT, IIR, P.R.-68,69
 Minneapolis Honeywell, P.R.-70,71
 Magnesite, P.R.-135
 Magnesium aluminate (spinel), single
 crystal, Union Carbide, P.R.-66
 hot-pressed, Coors, 8-12
 Magnesium-aluminum silicate
 (cordierite), multicrystalline,
 Raytheon, P.R.-67
 Magnesium carbonate, pressed powder,
 P.R.-67
 Magnesium ferrite (MIT samples), V-178,
 179,207
 Magnesium fluoride, ITRAN 1, 8-7,8
 Magnesium-manganese ferrite (MIT
 samples), V-139,140,180,181,208
 Magnesium-manganese-zinc ferrite
 (MIT samples), V-141,182
 Magnesium manganite, V-4,34
 Magnesium metasilicate, steatite
 fired to clinopteatite, multi-
 crystalline; Bell Telephone Labs.
 F-16 P.R.-72

Magnesium metasilicate (cont.)
 Intern. Pipe & Ceramic TC503,
 P.R.-72
 Magnesium orthosilicate, multicryst.,
 General Electric F-118, P.R.-73
 F-200, P.R.-73
 Magnesium orthosilicate, Steatit-
 Magnezia A.G. Frequentia M., P.R.-74
 Magnesium oxide, IV-1; V-29; P.R.-67-71;
 8-11
 Norton, single crystal, IV-1; V-29;
 P.R.-68
 Single crystals, Univ. of Colorado
 and MIT, 8-8,9,10
 Magnesium silicate, IV-3, 78-82; VI-34
 Magnesium titanate, IV-4; P.R.-75
 Magnesium titanate and plastic
 mixture, IV-43
 Magnetite and plastic mixtures,
 IV-44,45
 Mallinckrodt Chemical Works,
 IV-44,45,61,62
 Manganese fluoride, single crystal,
 Columbia Univ., P.R.-75
 Manganese-magnesium ferrite,
 (MIT samples), V-139,140,180,
 181,208
 Manganese-magnesium-zinc ferrite
 (MIT samples), V-141,182
 Marble S-303, IV-13
 Marbon, Chemical Div. of Borg-
 Warner Corp., IV-38
 "Marbon" S Buna S hardboard, IV-52
 "Marbon" S (Code 7206), S-1
 (Code 7253), 8000 and 9200, IV-38
 Marco Chemicals, Inc., now Celanese
 Corp. of America, IV-47
 Marco Resin, "MR"-21C, "MR"-23C,
 and "MR"-25C, IV-47
 "Marcol," IV-65
 Marinite, P.R.-193
 Markite Co., V-22,235,236
 "Markite" 3985, V-22,235
 "Markite" 12812, V-22,236
 "Marlex" 50, V-10
 Martin Co., The, VI-57
 Mason. loams, P.R.-143
 Massachusetts Institute of Technology
 Bio-Medical Dept., 8-33
 Cryogenic Engineering Lab., V-18
 Crystal Physics Lab., P.R.-38,39,
 49,63,66,77,78,103-105,106,107,
 109

Massachusetts Institute of Tech-
 nology (cont.)
 Laboratory for Insulation Res.
 IV-1,2,5,11,12,26,37,41-46,
 62,64,105; V-1,133-136,138,
 139,142-158,177,179,180,183-
 190,206-216,239,240,243;
 P.R.-44,61,63,69,69,93,102,
 110-114,115,116
 Lincoln Laboratory, V-140,141,
 176,178,181,182; VI-30,31
 Metallurgy Department, P.R.-60;
 8-8,9,10
 National Magnet Laboratory (now
 Francis Bitter Natl. Magnet
 Lab.), P.R.-192
 Mathieson Chemical Corp., see Olin
 Mathieson
 Mathieson Plastic CY-8 and CQ-10DM,
 IV-41
 Meat, IV-60; P.R.-199
 "Mecoboard," IV-18; V-82-83
 Melamine-formaldehyde resins,
 IV-21,22,112; V-8,88
 Melamine GMG, IV-21,70
 "Melmac" 7278 + "E" glass, IV-22
 "Melmac" molding compound 1500,
 1502, IV-22,112
 "Melmac" resin 592, IV-21
 "Melmac" Type 1077 (Ivory WB 43),
 IV-21
 Mercury compounds, hot-pressed
 mercurous chloride, P.R.-76
 mercuric iodide, P.R.-76
 mercuric sulfide, P.R.-76
 Meta-dinitrobenzene, VI-77
 Methacrylate resins, IV-34,35
 "Methocel," IV-25
 Methyl alcohol, IV-62
 Methyl cellulose, IV-25
 Methylstyrene polymer, VI-65
 Methylstyrene-styrene copolymer,
 IV-39
 Mica, Canadian, IV-13
 Mica, glass-bonded, IV-13,69,106-108;
 P.R.-153-155
 Mica, ruby, IV-13
 Mica and glass, IV-13,69,106-108;
 V-7,79
 Mica-filled plastics, IV-16,17,18,
 20; V-7
 "Micaramic," V-7
 "Micarta" No. 254, IV-18

"Micarta" No. 259, IV-22,68
 "Micarta" No. 299, IV-19,68
 "Micarta" No. 495, IV-18,68,70
 Mica Insulator Co., IV-21
 "Millimar," IV-56
 Minneapolis-Honeywell Regulator Co.,
 P.R.-31,70,71
 Minneapolis-Honeywell magnesium oxide,
 ceramic, P.R.-70-71
 Minnesota Mining and Mfg. Co., now
 3-M Co., IV-63; V-16,17,22;
 VI-67; P.R.-178
 Minnesota Mining and Mfg. EC-612, V-17
 "Missileon," V-17
 Mitchell-Rand Insulation Co., Inc.,
 IV-57-59
 Molding compounds, XM-3, IV-20
 201, V-9,94; P.R.-158
 "Moly-Sulfide," VI-45
 Monoisopropyl biphenyl, V-19
 Monsanto Chemical Co., Plastics
 Div., IV-15,18,20,22,24,30,36,
 37,41-45,63,64; VI-78-83;
 P.R.-178; 8-34
 Monsanto L-600 polymer, 8-34
 Monsanto OS-45, OS-59, and OS-82,
 V-19
 Monsanto polyimide foam, P.R.-178
 "Moplen" Q04 polypropylene, 8-35
 Morse, Herbert B., and Co.,
 V-16,17
 Morse 200, V-16
 280, 300, 400, 6060-C, and
 6062, V-17
 Mullet oil, P.R.-197
 Mullite, V-3; hot-pressed, 8-2
 Multiform glass, Corning, P.R.-96
 Muscovite, IV-13
 Mycalex Corp. of America, IV-13;
 V-7,79; P.R.-153-155
 "Mycalex" K10, IV-13
 "Mycalex" 400, IV-17,69
 "Mycalex" 410, 500, 555, 560,
 620, P.R.-153-155
 "Mycalex" 2821, IV-13,106,107
 "Mykroy" Grade 8 and 38, IV-13,108
 "Mylar" A, V-13

 Naphthalene, IV-15
 Naphthalene, chloro-, IV-64
 Narco Resins and Coatings Co., V-8
 National Beryllia "Carberlox,"
 P.R.-80
 National Beryllia Corp., P.R.-31,
 41,80; 8-4
 National Beryllia high-purity BeP,
 P.R.-41
 National Carbon Co., Inc., V-18;
 VI-48-51; P.R.-4,50,51,54-57,66,
 101,189; now div. of Union
 Carbide & Carbon
 National Lead, P.R.-65
 National Lead LaAlO₃ single crystal,
 P.R.-65
 National Research Corp., V-3
 Naugatuck Chemical, Div. of U.S.
 Rubber Co., IV-47,53
 Naugatuck Laminating Resin MP and
 MT, IV-47
 Neoprene GN and compound, IV-53
 Neptunite, P.R.-129
 "Niberlox"-5, -20, -100, 8-4
 Nickel ferrite (MIT samples), V-133-
 135, 142,143,183,209
 Nickel-lithium ferrite (MIT samples),
 V-137,178
 Nickel oxide, single crystal, P.R.-49
 Nickel-zinc ferrite (MIT samples),
 V-144-157,184-190,210-216
 Nitrobenzene, IV-64
 Nitrobenzene, meta-di, VI-77
 Nitrogen, gas, V-20
 Nitrogen, liquid, V-18
 Nitrous oxide gas, V-20
 "Nomex" honeycombs, P.R.-172; 8-41
 "Nomex" felt, 8-42
 Nopco Chemical Corp., P.R.-170
 Nopco Chemical polyurethane foam,
 P.R.-179
 North American Aviation Co., P.R.-42,
 43,100
 North American Aviation silicon
 nitride, pyrolytic, P.R.-100
 North American Aviation trans-
 lucent BeO, P.R.-42,43
 Norton Co., IV-1,6; V-3,29,49;
 P.R.-31,68
 Norton 99.5% Al₂O₃, P.R.-31
 Norton 7X, V-3,49
 Norton 17Z, V-3
 Norton MgO single crystal, P.R.-68
 "Noryl" GFN3, SE-1, SE-1-802,
 8-32,33
 Novamont Corp.
 "Nylon" 66 and 610, IV-23
 "Nylon" FM 10, 001, IV-23,113; V-89
 "Nylon"-filled plastics, IV-17;
 V-8,12,14,82,83

oil, No. 10, IV-63
 Oils, petroleum, IV-65,66; V-19;
 VI-84,85
 Olin Mathieson Chemical Corp., IV-61;
 V-20
 "Opalwax," IV-58
 "Orlon"-filled plastics, V-8,10,12,14
 Owens Corning CR-262, 57M, EA63, EA73,
 X600, V-6
 Owens-Corning Fiberglas Corp., IV-11,16,
 22,47,48; V-6,8,13; P.R.-93
 Owens-Illinois Glass Co., P.R.-93
 Owens-Illinois EE9, EE 10, mixed
 silicate glass, P.R.-93
 "Ozokerite," IV-58

 Panelyte, Grade 140 and 776, IV-17,22
 Paper, Kraft, V-18
 Royalgrey, IV-60
 Paper laminates, IV-17,19,21-23,45; V-80
 Paraffin, natural, IV-58
 Paraffin wax 132° ASTM and 135° AMP,
 IV-58
 "Paraplex" P13, IV-48,122
 "Paraplex" P43, IV-48; V-12,111
 "Parowax," IV-58
 Particle boards, U.S. Plywood & Evans
 Products, P.R.-193
 Pavement, see concrete or asphalt
 "Pelron" 9420, 9422, 9423, and
 9424, V-11
 Pennsylvania Industrial
 Chemical Corp., IV-39,50
 "Penovermen" glass, 8-20
 Pennwalt Corp., P.R.-196
 Pennwalt "Lucidol," t-butyl per-
 benzoate, P.R.-196
 Pennwalt "Lupersol" 130,
 2,5-diethyl-2,5-di(t-butyl-
 peroxy) hexyne-3, P.R.-196
 "Penton," V-16
 "Perfluorodihexyl ether, IV-63
 "Permafil," 3256, IV-50
 "Permo" pottling compound, No. 49
 and No. 51, IV-49,51
 Petroleum oils, IV-65,66;
 VI-84,85; P.R.-195
 Phenol-aniline-formaldehyde
 resins, IV-20
 Phenol-formaldehyde resins,
 IV-15-19,109-111
 Phenol-furfuraldehyde resin, IV-19
 Phenolic, expanded, IV-19
 Phenolic paper laminate JH-141C,
 IV-18
 Phenolic resin with asbestos,
 V-8,84,85
 with "Dacron," V-8
 with "Fiberglas," V-8, 86,87
 with "Nylon," V-8
 with "Orlon," V-8
 Phenolic spheres, V-12
 Phenolics, IV-15-20,109-111;
 V-8,80-87
 Philco-Ford Co., P.R.-97,98; 8-5,
 14-18
 Philco-Ford boron nitride yarn and
 matrix, 8-5
 Philco-Ford silica fiber composites,
 1-X8-Q-M, P.R.-98
 AS-3BX-176-17, P.R.-98
 AS-3BX, 8-14-18
 Philips Chemical Co., V-10
 Philips Petroleum Co., V-19
 "Phoresin," IV-48
 Phosphate glasses, IV-9; P.R.-77
 Picatinny Arsenal, see U.S. War
 Department
 "Piccolastic" D-125, IV-39
 "Piccopale," Resin, IV-50
 Pine board, F.R.-193
 Pipestone, V-7
 Pittsburgh Corning Corp., P.-11;
 V-13,19
 Pittsburgh Plate Glass Co., P.R.-94;
 8-20,21
 Plaskon Div., IV-22,23,47,49,123;
 V-112,113
 "Plaskon" 911, IV-47
 "Plaskon" Alkyd 411, 420, 422, 440,
 440A and 442, IV-49
 "Plaskon" Alkyd Special, Electrical
 Granular, IV-49,123; V-112,113
 "Plaskon" melamine, IV-22
 "Plaskon" urea, natural and brown,
 IV-23
 "Plasticell," IV-31
 Plastic Metals, Div. of National
 U.S. Radiator Corp., IV-47,44
 Plastics, Raytheon, P.R.-180
 "Plast-iron" and plastic mixtures,
 IV-43,44
 Plate glass, P.R.-94
 Plax Corp., IV-35
 "Flexiglass," IV-34
 "Plicene" Cement, IV-56
 "Pliobond" H-190-C, IV-52
 "Pliolite" and "Pliolite" GR, IV-51
 "Pliolite" S5, S3, S6B and S6,
 IV-40

Plywood, Birch, P.R.-193
 11, P.R.-193
 Polaroid Corp., IV-35,37,40; V-11
 Polaroid Resin C, IV-40
 "Polactron" No. 24, IV-46
 "Policap," V-16
 "Polinel," IV-58
 Polyamide resins, IV-23,113; V-8,12,14,
 82,83,89
 Polybutadiene, 8-44,46
 Polybutene, IV-59
 Polybutyl methacrylate, IV-35
 Poly-2-chlorobutadiene-1,3, IV-53
 Polychlorostyrenes, IV-41,42
 Polychlorotrifluoroethylene, IV-31,
 58,63,116; V-10,102,103
 Polycyclohexyl methacrylate, IV-35
 Polycyclostyrene, V-11
 Polydiallyl phthalate, IV-48; 8-43
 Poly-2,5-dichlorostyrene, IV-40-
 42,70
 Poly-2,5-dichlorostyrene + fillers,
 IV-42-45; V-243
 Poly-3,4-dichlorostyrene, IV-42
 Polyesters, IV-46-48,120-123; V-11,
 12,13,106-111; 8-33,45
 Polyester resin with "Dacron,"
 V-12,110
 Polyester resin with "Fiberglass,"
 IV-47,48; V-12,13,22,106,107,108
 Polyester resin with aluminum and
 carbon, 8-35
 Polyester resin with "Nylon," V-12
 Polyester resin with "Orlon," V-12
 Polyester resin with phenolic
 spheres, V-12
 Polyether, chlorinated, V-16
 Polyether sulfonate, 8-47
 Polyethylene, irradiated, P.R.-161
 Polyethylene, IV-27,28,70; V-10;
 P.R.-183
 Polyethylene DE-3401, IV-27
 Polyethylene (effect of milling),
 IV-28
 Polyethyl methacrylate, IV-35
 "Polyglas" D⁺, IV-42
 "Polyglas" M, IV-22
 "Polyglas" P⁺, IV-41
 "Polyglas" S, IV-26
 "Polyguide," P.R.-175
 Polyimide foam, P.R.-178
 Polyimide laminate, 8-25
 Polyiron attenuator, P.R.-167
 Polyisobutylene, Run 5047-2, IV-28
 Polyisobutylene B-100 + Marbon B,
 IV-28
 Polyisobutylmethacrylate, IV-35
 Polymer Corp. of Pennsylvania,
 V-17,18205,244; VI-66; P.R.-179
 Polymethyl methacrylate, IV-34,70;
 V-10
 "Polypenco" 0-200, 5; VI-66
 Polyphenylquinoxaline, 8-47
 Polypropylene, Avison Corp.,
 P.R.-162,163
 Polypropylene, Novamont Corp., 8-35
 Polysiloxane resin, IV-26,27; V-9;
 VI-52-57
 Polystyrene, IV-25-37,117
 Polystyrene, cast in vacuo and cast
 in air, IV-37
 cross-linked, IV-39,40,119; V-11,
 105; VI-66; P.R.-181-182; 8-32
 hydrogenated, IV-46
 α -methylstyrene, IV-37,117
 Polystyrene + chlorinated diphenyl,
 IV-37
 Polystyrene Fibers Q-107, IV-37
 Polystyrene + fillers, IV-41;
 V-10,239,240
 Polystyrene foam, P.R.-198
 Polystyrene Foam Q-103, IV-37
 Polysulfone, P.R.-189
 Polytetrafluoroethylene, IV-31-33,
 70; V-10,104; VI-58-64;
 P.R.-166,173,174
 Polytetrafluoroethylene tape,
 P.R.-186
 "Polythene" A-3305, IV-27,70
 Polytrifluorostyrene, V-11
 Polyurethane foams, Napco, P.R.-179
 Sippican, P.R.-188
 Upjohn, 8-45
 Polyurethane rope, 8-23
 Polyurethane sealant F/N 596927,
 8-39
 Polyvinyl acetal, IV-34
 Polyvinyl acetate, IV-33
 Polyvinyl alcohol-acetates, IV-33
 Polyvinyl butyral, IV-34
 Poly-N-vinylcarbazole, IV-46
 Polyvinyl chloride 1006, 1018,
 1216, 1406, W-174, W-175, and
 W-176, IV-30
 Polyvinyl chloride-acetate, IV-28-31
 Polyvinyl chloride-acetate +
 plasticizer, IV-28,29
 Polyvinyl chlorides, IV-28-31; V-10
 Polyvinylcyclohexane, IV-46
 Polyvinyl formal, IV-34
 Polyvinylidene and vinyl chlorides,
 IV-31

Polyvinylidene fluoride, AVCO, P.R.-161
 Poly- -vinylnaphthalene, IV-46
 Poly-2-viny;pyridine, IV-46
 Polyvinyl resins, IV-27-46
 Polyvinyltoluene, IV-37,117
 Poly-p-xylylene, IV-37
 Porcelain No. 4462, IV-6
 Porcelains, IV-6,94-100; V-2,3,5,21,
 40,59-61
 Porous Ceramic AF-497, IV-6,101
 Porous ceramics, see low-density
 alumina, silica, silicates
 Potassium bromide, IV-1
 chloride, V-1
 dihydrogen phosphate, IV-1,73
 Potato chips, P.R.-199
 Potatoes, raw, P.R.-199
 Potato starch, granular and
 gelatinized, P.R.-200,201
 "Primol"-D, IV-66
 Proctor and Gamble Co., IV-60
 n-Propyl alcohol, IV-62
 "Prystal," IV-17
 "pyralin," IV-25
 "Pyranol" 1467, 1476, and 1476,
 IV-63,64
 "Pyrex," IV-10
 "Pyroceram" 9606, VI-42; P.R.-149
 "Pyrotex," V-8

 Quantum, Inc., P.R.-180
 Quantum Radar tape, P.R.-180
 Quartz, fused, IV-11,104; V-6,72,73;
 P.R.-85-88
 Quartz crystal, natural, P.R.-80,81
 Quartz fiber, AS-3DX-1R, Philco-
 Ford, P.R.-97
 Quartz sand, powder, P.R.-135
 "Quinorgo" No. 3000, IV-13
 "Quinterra," IV-13

 Radar tape, Quantum, Inc., P.R.-180
 Raybestos-Manhattan, Inc., V-8,9
 Raytheon Mfg. Co., V-3; P.R.-32, 52,
 53,67,100,139,158,180; 8-18,21,23-25
 Raytheon Al₂O₃, multicrystal, P.R.-32
 boron nitride, pyrolytic, P.R.-52,53
 magnesium-aluminum silicate
 (Cordierite ceramic), P.R.-67
 silicon nitride, ceramic, P.R.-100;
 8-21
 Raytheon 402B, V-3
 "Resimene" 803-A, IV-22
 Resin (polyester), EKDOL, P.R.-166

 Resinous Products Div., see Rohm
 and Haas Co.
 "Resinox" 7934, IV-20
 "Resinox 10231, IV-18,109
 "Resinox" 10900, IV-18,110
 Resins, natural, IV-55,56
 Rex, Corp., IV-40; V-11,105
 Rex, William Brand, Div. of
 American Enka (now Brand-Rex Co.),
 P.R.-181-183
 "Rexolene" P, P.R.-183
 "Rexolite" 1422, IV-40; V-105;
 P.R.-181
 "Rexolite" 2101, V-11
 "Rexolite" 2200, P.R.-182
 Rezolin, Inc., IV-19
 "Rhyolite," P.R.-140
 Robertson, H. H., Co., IV-48,123;
 V-12,19
 "Rocketon," V-17
 Rocks, see Table of Contents of the
 P.R.; 8-23-25
 Rogers Corp., VI-59-64; P.R.-184,185
 Rogers Corp. "Duroid" (1" thick
 sheet), P.R.-184
 "Duroid" 5870 (1966), P.R.-185
 Rogers Paper Mfg. Co., IV-60
 Rohm and Haas Co., IV-30,34,48,
 62,122; V-12,111
 Ropes, plastic, 8-26
 "Royalite" 149-11, M21982-1 and
 M22190, IV-53
 RTV-11, P.R.-176; RTV-501, P.R.-168;
 8-36-39; RTV-521, -1602, -5350,
 S-6538, P.R.-178; RTV, 8-42
 Rubber, butyl (GR-I), IV-52
 Rubber, cellular, IV-51
 Rubber, cyclized, IV-51,52
 Rubber, GR-S (Euna S) and com-
 pounds, IV-52
 Rubber, Heves and compounds, IV-51
 Rubber, natural, IV-51
 Rubber, nitrile, IV-53
 Rubber, silicone, IV-54,55,126;
 V-127-129, P.R.-177
 Rubber Reserve Corp., IV-51,52
 Rubidium manganese fluoride,
 single crystal, MIT, Crystal
 Physics Lab., P.R.-49
 Rutgers University, School of
 Ceramics, V-4
 Rutgers' wallastonite E16, V-4
 Rutile, IV-2,4,77

S-40 and S-60 resins, IV-39
 St. Regis Paper Co., Panelyte
 Division, IV-17,22
 Salcs, granulated and fine flakes,
 Raytheon, P.R.-158
 Sand and resin mixtures, see epoxy,
 silicone, etc.
 Sands
 Desert, P.R.-143
 Holliston, P.R.-144
 Quartz, P.R.-135
 Slattersville, P.R.-144
 Soil, IV-14
 Sandstone, almond, P.R.-140
 "Santicizer" 9, IV-15
 Sapphire, IV-72; V-1,26-28;
 VI-2-6; P.R.-2-4
 "Saran" B-115, IV-31
 Sauereisen Cements Co., V-7
 Sauereisen Cement No. 1, V-7
 "Scotchcast" 221, P.R.-178
 "Scotchply" Type 1001, V-16
 "Scotchply" Type 1002, V-22;
 VI-67
 "Scotchply" XPM-107, V-22
 "Scotch" tape No. 39, V-17
 Sealing Wax, Red Express, IV-58
 Sealing compound, V-17; 8-39
 "Selectron" 5003 + glass, IV-47
 "Selectron" 5084 monomer, V-19
 "Selectron" 5084 resin, V-13
 Selenium, amorphous, IV-13
 Selenium, multicrystalline, IV-1
 Service boards, John Manville's,
 P.R.-158
 Shale, 8-23,24,25
 Sharples Chemicals Div., Penn.
 Salt Mfg. Co., IV-63
 Shawinigan Products Corp., IV-34
 Sheet glass, P.R.-94
 Shellac, natural Zinfo, pure C
 garnet & garnet dewaxed, IV-56
 Shell Chemical Corp., IV-50;
 V-16,116-125; VI-68-76;
 P.R.-186,187
 Shell Chemical "Epon" 828 +
 PMDA epoxies, P.R.-186,187
 Shell Development Co., IV-46-48
 Shell Oil Co., IV-56,66
 Silastics 120, 125, 150, 152,
 160, 167, 180, IV-54
 181, IV-54,126
 250, IV-54,126
 6167, IV-55,126
 6181, X4342, IV-55

Silastics (cont.)
 XF6734, IV-55
 7181, IV-55
 RTV-501, -521, -1602, -5350,
 S-6538, P.R.-168
 Silica, IV-11,103; V-70,71;
 P.R.-83,84; 8-12
 Silica, slip-cast, Brunswick,
 P.R.-95
 Dynasil, P.R.-96
 Silica fiber composites, P.R.-98,99;
 8-13-18
 Silicate glasses, IV-9-11,101,102;
 V-5,62-69; VI-35-43; P.R.-89-94;
 8-19-21
 Silicon, single crystal, intrinsic,
 cubic, MIT, Crystal Physics Lab.,
 P.R.-78
 Silicon, single crystal, undoped,
 Brown University, P.R.-78
 Silicon carbide, multicrystalline,
 Carborundum, P.R.-79
 Silicon carbide with BeO, National
 Beryllia Corp. "Carberlox,"
 P.R.-80
 Silicon dioxide, fused, IV-11,103;
 V-70,71; P.R.-82-88
 Silicon dioxide, natural quartz
 mineral, Fort Monmouth, P.R.-80,81
 Silicon dioxide, sintered, Brunswick
 slip-cast, P.R.-95
 Brunswick slip-cast with 2.5%
 Cr₂O₃, P.R.-95
 Corning Code 7941, P.R.-96
 Corning multifilm glass, P.R.-96
 Silica slip-cast, Dynasil, P.R.-96
 Silicon dioxide fibers
 Quartz fiber sample, Philco-Ford,
 AS-3DX-1R, P.R.-97
 Silica fiber composites, Philco-
 Ford 1-XB-O-M, P.R.-98
 AS-3DX 176-17, P.R.-98
 AS-3DX, 8-14-18
 Silica fiber composites in
 aluminum phosphate matrix,
 Whittaker Corp., P.R.-99; 8-13
 Silica fiber, silicone coated,
 Raytheon Co., 8-18
 Silicon dioxide glasses
 "Amersil" (clear, translucent),
 P.R.-82
 Corning 7940, P.R.-83
 Dynasil 4000, P.R.-84
 G.E. 101, clear, P.R.-35-87
 "Spectrosil" A, P.R.-88

Silicon dioxide glasses (cont.)
 "Spectrosil" B, P.R.-88
 "Vitreosil," optical grade, P.R.-88
 "Vitreosil," commercial grade,
 P.R.-88
 Silicon dioxide, mixed silicate glasses,
 see also Glass
 Corning Lab. No. 119BUC, P.R.-89
 Corning Lab. Code 1723, P.R.-89
 Lancaster 7352, 7357, L1957,
 L9100, P.R.-89-92
 Owens-Corning X994, P.R.-93
 Owens-Illinois EE9 and EE10, P.R.-93
 Pittsburgh Plate Glass Co.,
 Plate glass, P.R.-94
 Silicon nitride, ceramic
 Admiralty Labs., P.R.-100
 AFML, 8-22
 Raytheon, P.R.-100; 8-21
 Union Carbide & Carbon, P.R.-101
 Silicon nitride + beryllium oxide, 8-4
 Silicon nitride, pyrolytic, P.R.-100
 Silicon nitrite alloy, V-6,79
 Silicone alloys C-1147 and C-1328, V-9
 Silicone fluids
 DC XF-6620, V-20
 SF96-40, IV-67; VI-86,87
 SF96-100 and SF96-1000, IV-67
 DC200 and DC500, IV-66
 DC550 and DC710, IV-67
 Silicone glass laminates, IV-26,27;
 V-9,93-95,100,101; VI-56,57
 Silicone grease, V-20
 Silicone laminate DC2105, V-9,94
 Silicone laminate DC2106, V-9,95
 Silicone laminates, 8-33
 Silicone molding compound XM-3, IV-26
 Silicone resin DC301, V-9,94
 Silicone resin DC996 and DC2101, IV-26
 Silicone resins, IV-25-27; V-9;
 VI-52-57; 8-28
 Silicone resins with asbestos, V-9,
 96,97
 Silicone resins with "Fiberglas,"
 V-9,93-95,98-101; VI-56,57
 Silicone rubber SE-450, IV-55; V-127
 SE-555, IV-55
 SE900, P.R.-177
 SE-977, IV-55; V-129
 RTV-11, P.R.-176
 Silicone rubbers, IV-54,55,126;
 V-127-129; P.R.-176-177
 Silicone varnish, IV-26; V-18
 Silver iodide, pressed powder,
 MIT, Lab. Ins. Res., P.R.-102
 Sintered silicon dioxide, P.R.-95,96
 "Sintox," V-3
 Sippican Corp., The, P.R.-158,188,
 192; 8-42
 Sippican polystyrene foam, P.R.-188
 Sippican polyurethane foam, P.R.-188
 Sippican service boards, P.R.-158
 Snow, IV-1
 Soap, IV-60
 Socony Mobil Oil Co., Inc., IV-57,58
 Formerly Socony-Vacuum Oil Co.,
 Inc.
 Soda silicate glass, MIT, Lab. Ins.
 Res., P.R.-93
 Sodium chloride, IV-2; P.R.-103
 Sodium chloride, aqueous solu-
 tions, IV-61
 Southern Alkali Corp., IV-48
 "Spectrosil" A, P.R.-88
 "Spectrosil" B, P.R.-88
 Sperry Gyroscope Co., V-18
 Spinel, P.R.-66; 8-12
 Spodumene, P.R.-130-132
 Sponge Rubber Products Co., IV-19,
 31,52
 Sprague Electric Co., IV-39
 Spruce Pine Mica Co., V-7
 Stanco Distributors, Inc., IV-65,66
 Standard Oil Co. of N.J., IV-58
 Standard Oil Development Co.,
 see Enjay Co., Inc.
 Steak, beef, IV-60; P.R.-199
 Steatite bodies, IV-3,4,78-87;
 V-4,55-57; VI-34; P.R.-72-74
 Steatite Body 7292, IV-4,83
 Steatite Type 303, 400, 410 and
 452, IV-3,84-87
 Steatit-Magnesia A.G., P.R.-32,74
 Steatit-Magnesia A-18, P.R.-32-33
 Steatit-Magnesia Frequentia M,
 P.R.-74
 Sterling Varnish Co., The, V-18
 Sterling M50 varnish on paper, V-18
 Strontium fluoride, single crys-
 tal, MIT, Crystal Physics Lab.,
 P.R.-106,107
 Strontium titanate, IV-5
 Strontium titanate and plastic
 mixtures, IV-43
 Stupakoff Ceramic and Mfg. Co.,
 IV-6,101; V-3,4,50,51
 Div. of the Carborundum Co.
 Stupakoff 1510, V-3,51
 1540, V-3,50
 1542E, V-3

Stupakoff (cont.)
 1542P, V-3,50
 1550, V-4,50
 "Stycast" HiK, LoK and
 TPM-3, V-11
 "Stycast" 2651-40RQ, 8-40
 "Stypol" 16B resin, IV-46,
 123; V-110
 "Stypol" 16C resin, IV-48
 "Stypol" 16D resin, IV-48; V-12
 "Styraloy" 22, IV-38
 "Styramic" No. 18, IV-37
 "Styramic" HT, IV-42,43
 Styrene copolymers, cross-
 linked, IV-39,40,119;
 V-11,105
 Styrene copolymers, linear,
 IV-38,39,118,119
 Styrene dimer, IV-64
 Styrene N-100, dry and
 saturated with water, IV-64
 Styrene-acrylonitrile copoly-
 mer, IV-38,53,118
 "Styrofoam" 103.7, IV-37
 "Styron" C-176,411-A, 475,
 666 and 671, IV-36
 Suet, IV-60
 Sulfur, crystalline, IV-2
 sublimed, IV-2
 "Supramica" 500, V-7,79
 "Sylgard" 182, 184, D92.007,
 P.R.-168
 188, 8-27
 Syncor Products Co., V-6
 Synthetic basalt, P.R.-139

 "Tam Ticon" B, BS, C, MC, and S,
 IV-4,5,43
 "Tam Ticon" T-S, T-L and T-M,
 IV-4
 Tantalum oxide, ceramic, Ciba
 powder, fired at L.I.R.,
 MIT, P.R.-108
 Taylor Fibre Co., IV-18,27,111
 Taylor Grade GGG, IV-18,111
 Grade GSC and GSS, IV-27
 Tea, powder, P.R.-202
 "Tedlar," 8-28
 "Teflon," IV-31-33,70; V-24,104;
 VI-58-64; P.R.-173-174
 "Teflon" 9033, P.R.-174
 "Teflon" FEF (1963), P.R.-173
 "Teflon" TFE (1964), P.R.-173
 "Teflon" TEF-7 (1964), P.R.-173
 "Teflon" TFE-6C (1964), P.T.-173
 "Teflon" T-100, P.R.-174

 "Teflon" 100X, P.R.-174
 "Teflon" TFE 7A, 8-29
 PFA TE9704, 8-29
 TFE FEP100, 8-30
 "Teflon" + calcium fluoride,
 IV-32; V-10
 "Teflon" fiberglass laminates,
 GB-112T; IV-31,32; V-104; P.R.-164
 FLUORGLAS E, P.R.-167
 Duroids, VI-62-64; P.R.-184,185
 Tellite Corporation, P.R.-188
 Tellite 3A, P.R.-188
 "Tenite" I 008A H₂, H₄, M, MH, S
 and S₄, IV-24
 "Tenite" II 2054A H₂, H₄, MH, MS, S₂,
 S₄, IV-24
 Tennessee Eastman Corp., IV-24
 Tennessee Marble, Inc., IV-13
 Teresso V-78, P.R.-195
 Terphenyl, meta-, nona, ortho-, and
 para-, IV-15
 Terphenyls, chlorinated, IV-64
 Tetrachloroethylene, IV-62
 Tetra alkyd silicate ester, V-19
 Texas Instruments, infrared
 windows TI-20, TI-1173, 8-43
 Thallium bromide, IV-2,75
 Thallium bromide-chloride, IV-2,75;
 P.R.-109
 Thallium-bromide-iodide, IV-2,76;
 P.R.-109
 Thallium chloride, V-1; P.R.-109
 Thallium fluoride pressed powder,
 P.R.-109
 Thallium iodide, IV-2,74; P.R.-109
 Thermal American Fused Quartz Co.,
 P.R.-88
 Thermoplastic Composition 1766 EX
 and 3738, IV-58
 3767A, IV-59
 Thiokol Chemical Corp., IV-54
 "Thiokol" Type FA, PRI and ST, IV-54
 Thorium oxide, ceramic, Zircoa,
 P.R.-110,112,
 MIT, Lab. Ins. Res., P.R.-113,114
 TI Pure R-200, IV-4
 Titanate ceramics, IV-5,6
 Titania and titanate bodies, IV-4-6,
 88-93
 Titanium Alloy Mfg. Div., National
 Lead Co., IV-4,5,42,43
 Titanium dioxide, rutile, IV-2,4,77
 Titanium dioxide ceramics, IV-4,5
 Titanium dioxide + plastic mixtures,
 IV-33,42
 Tobe Deutschmann, VI-78-83

Toluene sulfonamides, mixtures of ortho- and para isomers, IV-15
 Topaz, P.R.-133,134
 Tourmaline, P.R.-134
 "Transil" Oil 10C, IV-65
 Trichlorobenzenes, mixture of isomeric, IV-64
 Trichloronaphthalenes, mixture of isomeric, IV-64
 α -Trinitrotoluene, IV-15

 UDP 333 Liquid, P.R.-197
 "Ultron" Wire Compound UL300, UL1004 and UL24001, IV-30
 Union Carbide & Carbon Corp., V-18; P.R.-4,50,51,54-57,66,101,180,181
 Union Carbide boron nitride, hot-pressed, Grade HD0056, HD0086, HD0092, HD0093, HD0094, HBN, HBR, P.R.-54-57
 cold-pressed, P.R.-57
 pyrolytically deposited, "Boralloy," P.R.-50,51
 pyrolytic laminate, P.R.-54
 Union Carbide magnesium aluminate (spinel), P.R.-66
 Union Carbide "Polysulfone," P.R.-189
 Union Carbide silicon nitride, ceramic, P.R.-101
 Union Carbide R-63 Varnish, V-18
 Upjohn, 8-43-45
 Urea-formaldehyde resins, IV-23
 U.S. Army Engineering Research and Dev. Lab., Fort Belvoir, Va., IV-2,74-76; VI-77
 U.S. Army Res. and Dev. Labs., Fort Monmouth, N.J., P.R.-80,81
 U.S. Bureau of Fisheries, mullet oil, P.R.-197
 U.S. Ceramic Tile Co., see Diamonite Products Div.
 U.S. Gasket Co., IV-32,33
 U.S. Industrial Chemical Co., IV-62
 U.S. National Bureau of Standards, IV-40; P.R.-20
 U.S. Peroxygen Division, Argus Chemical Corp., P.R.-197
 U.S. Peroxygen USP 333 Liquid, P.R.-197
 U.S. Polymeric Chemicals, Inc., V-9
 U.S. Rubber Co., IV-31,40,52,53,56
 U.S. Sonics, P.R.-75
 U.S. Sonics magnesium titanate, multicrystal, P.R.-75

 U.S. Stoneware Co., The, V-21,51; VI-20,21; P.R.-34,35
 U.S. Stoneware Al_2O_3 , A-212, A-216 A-312, 610, Std. 3050°F, P.R.-34,35
 U.S. War Department, Picatinny Arsenal, IV-15
 Urethane, see polyurethane

 Vanadium oxide, pressed powder, P.R.-114
 Varnished glass cloth, V-18
 Varnished linen tape, V-17
 Varnished paper, V-18
 "Vaseline," IV-65
 "Vibron" 140 and 141, IV-40
 Victor Chemical Works, IV-48
 "Vinylite" QYNA, VG-5544 and VG-5901, IV-28
 "Vinylite" VG-5904, VYHH, VYNS, and VYNW, IV-29
 "Vinylite" VU-1900, IV-29,70
 2-Vinylpyridine-styrene copolymer, IV-46
 "Vistawax," IV-59
 "Viton," 8-30
 "Vitresil," commercial grade, P.R.-88
 "Vitresil," optical grade, P.R.-88
 VUL-CUP, P.R.-196

 Wallace & Tiernan, Inc., P.R.-197
 Wallace & Tiernan "Lupersol" 101, 2,5-dimethyl-2,5-di(t-butylperoxy) hexane, P.R.-197
 War Dept., Picatinny Arsenal, see U.S. War Department
 Water, conductivity, IV-61
 Wax 3760, IV-59
 Wax Compound F-590 and No. 1340, IV-59
 Wax S-1167 and S-1184, IV-59
 Waxes, IV-56-59; V-16,17
 Weber, Hermann, and Co., IV-51
 "Wesgo" AL-300, V-4,52
 "Wesgo" AL-1009, V-4
 Western Gold & Platinum Works, V-4,52; P.R.-36,37
 Western Gold & Platinum aluminum oxide AL-300, AL-300 (modified), AL-400, AL-500 (multicryst.), AL-995, AL-1003, P.R.-36,37
 Westinghouse Electric Corp., Research Labs., IV-18,19,22
 Whittaker Corp., P.R.-99; 8-13,45-47
 Whittaker silica fiber composites, P.R.-99
 Witco Chemical Co., 8-47

Wollastonite, V-4,58
 Wood, IV-59; P.R.-193
 Wood, birch plywood, Sippican,
 P.R.-193
 fir plywood, Sippican, P.R.-193
 Marinite board, Sippican,
 P.R.-193

 Ytterbium ferrite, VI-28-31
 Yttrium oxide, ceramic, Zircoa,
 P.R.-116
 Yttrium oxide, single crystal,
 MIT, Lab. Ins. Res., P.R.-115

 Zinc ferrite (MIT samples), V-158
 Zinc-magnesium-manganese ferrite
 (MIT samples), V-141,182
 Zinc-nickel ferrite (MIT samples),
 V-144-157
 Zinc oxide, single crystal,
 Airtron Div., Litton
 Industries, P.R.-117
 Zinc selenide, 8-22
 Zinc sulfide, 8-23
 Zinsser, Wm, and Co., IV-55,56
 Zircoa ceramics:
 "C", P.R.-118
 Thorium oxide, P.R.-110-112
 Y-790, P.R.-64
 Y-904, P.R.-119
 Y-1362, P.R.-120,121
 "Zircolite," ceramic, P.R.-122
 Zircon, P.R.-123-125
 Zirconia,
 Zircoa "C", Y-904, Y-1362,
 P.R.-118-121
 "Zircolite," P.R.-122
 Zirconium oxide ceramics,
 see Zirconia
 Zirconium silicate (zircon),
 ceramic, IV-6,94,95; V-5,59-61
 single crystal, P.R.-123-125
 "Zitex," P.R.-106
 Zophar Mills, Inc., IV-59