I-1.3 Spectral Emissivity, $\epsilon(\lambda)$ — Aluminum Oxide

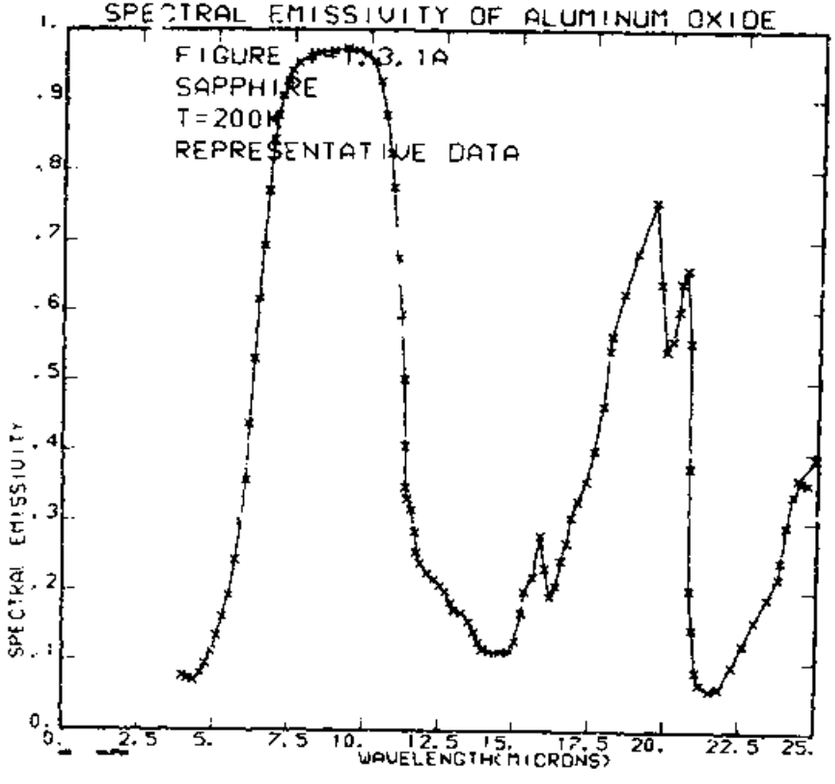
Representative curves for the spectral emissivity of bulk alumina, bulk sapphire, and powdered sapphire are presented in this section. Supplementary to this in Section III-1.3 are data for liquid alumina droplet emissivity and surface roughness effects on alumina emissivity. Additional data on emissivity are contained in Section I-1.4, where the reflectance data are summarized. Since Kirchhoff's law $\epsilon = 1-R$ applies only to the proper angular complements, a conversion of all reflectance to emissivity has not been made.

I-1.3.1 Bulk Al_2O_3

The bulk forms of Al_2O_3, sapphire (α-Al_2O_3) and alumina have different emissive properties, as shown in Figures I-1.3a, b, and c. All bulk Al_2O_3 shows a distinct emissivity maximum from approximately 4μ to 11μ, the onset of this peak shifting to shorter wavelengths as the sample temperature is increased. Representative data for sapphire are from Stierwalt (Ref. ISE-16) over a temperature range 4.2°K to 200°K and a spectral range 1μ to 125μ; the data of Blau (Ref. ISE-5) for 99 percent pure alumina over a temperature range of 800°K to 1300°K is taken to be representative of the pressed and sintered forms of Al_2O_3. A precision of 4 ± percent as claimed by Blau (Ref. ISE-5) is taken to be representative of all data shown in Figures I-1.3.1 and I-1.3.2, although no explicit statement of precision is given by the other references shown. The effect of differences in sample surface preparation on Al_2O_3 emissivity has been studied by Richmond (Ref. ISE-13) and has been found to be negligible below 14μ. The relatively minor effect of temperature can be seen in the data of Section III-1.3. Data from other researchers on many bulk forms of Al_2O_3 are included in Section III-1.3 in graphical and tabular form, where are also more detailed descriptions of the representative data.

Table I-1.3.1a Spectral Emissivity of Aluminum Oxide, T = 200°K — Representative Data

λ	ε	λ	ε	λ	ε
4.025	7.775E-02	4.202	7.350E-02	4.377	7.125E-02
4.[illegible]	8.150E-02	4.778	9.475E-02	4.973	1.115E-01
5.163	1.345E-01	5.342	1.605E-01	5.523	1.[illegible]E-01
5.7[illegible]	2.425E-01	5.914	2.959E-01	6.068	3.[illegible]E-01
6.156	4.385E-01	6.311	5.312E-01	6.446	6.175E-01
6.581	6.938E-01	6.732	7.710E-01	6.896	8.[illegible]E-01
7.010	8.770E-01	7.145	9.066E-01	7.300	9.271E-01
7.4[illegible]	9.414E-01	7.655	9.529E-01	8.025	9.621E-01
8.339	9.685E-01	8.780	9.719E-01	9.225	9.745E-01
9.511	9.711E-01	9.889	9.662E-01	10.135	9.545E-01
10.36[illegible]	9.269E-01	10.556	8.788E-01	10.[illegible]23	8.[illegible]E-01
10.930	7.761E-01	11.015	6.758E-01	11.[illegible]25	5.947E-01
11.254	5.023E-01	11.331	4.060E-01	11.[illegible]45	3.[illegible]78E-01
11.[illegible]15	3.312E-01	11.523	3.161E-01	11.[illegible]74	3.[illegible]43E-01
11.[illegible]47	2.547E-01	11.868	2.396E-01	12.[illegible]95	2.[illegible]23E-01
12.342	2.[illegible]06E-01	12.533	2.077E-01	12.[illegible]09	1.[illegible]95E-01
12.877	1.825E-01	13.036	1.710E-01	13.297	1.[illegible]73E-01
13.52[illegible]	1.552E-01	13.710	1.410E-01	13.[illegible]43	1.[illegible]26E-01
13.977	1.168E-01	14.199	1.125E-01	14.[illegible]30	1.[illegible]35E-01
14.896	1.138E-01	15.036	1.280E-01	15.[illegible]58	1.[illegible]75E-01
15.3[illegible]3	1.99[illegible]E-01	15.614	2.202E-01	15.867	2.[illegible]95E-01
16.007	2.322E-01	16.181	1.920E-01	16.[illegible]86	2.[illegible]72E-01
16.5[illegible]5	2.430E-01	16.728	2.683E-01	16.[illegible]66	3.[illegible]66E-01
17.393	3.294E-01	17.350	3.575E-01	17.[illegible]11	4.[illegible]10E-01
17.897	4.6[illegible]8E-01	18.089	5.443E-01	18.144	5.650E-01
18.[illegible]90	6.2[illegible]8E-01	18.951	6.835E-01	19.[illegible]69	7.[illegible]65E-01
19.752	6.408E-01	19.970	5.433E-01	20.[illegible]97	5.[illegible]96E-01
20.358	6.[illegible]10E-01	20.437	6.415E-01	20.[illegible]16	6.[illegible]03E-01
20.753	5.504E-01	20.790	3.780E-01	20.[illegible]03	2.[illegible]03E-01
20.9[illegible]7	1.[illegible]73E-01	21.048	8.[illegible]0[illegible]E-02	21.[illegible]74	6.[illegible]8[illegible]E-02
21.[illegible]90	5.923E-02	21.840	6.325E-02	22.[illegible]78	9.[illegible]25E-02
22.921	1.[illegible]56E-01	22.997	1.580E-01	23.[illegible]16	1.[illegible]91E-01
23.7[illegible]9	2.[illegible]42E-01	23.827	2.460E-01	24.[illegible]07	2.[illegible]94E-01
24.217	3.389E-01	24.473	3.591E-01	24.[illegible]01	3.[illegible]55E-01
24.385	3.627E-01	24.955	3.923E-01	25.[illegible]95	4.[illegible]24E-01
25.6[illegible]3	5.267E-01	26.2776	5.738E-01	27.[illegible]16	5.[illegible]35E-01
28.447	6.388E-01	30.426	6.630E-01	32.[illegible]68	6.[illegible]67E-01
34.[illegible]69	6.812E-01	37.484	6.835E-01	40.496	6.835E-01
44.669	6.835E-01				


SPECTRAL EMISSIVITY OF ALUMINUM OXIDE
FIGURE I-1.3.1A
SAPPHIRE
T=200K
REPRESENTATIVE DATA
SPECTRAL EMISSIVITY
WAVELENGTH(MICRONS)
0.
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.
2.5
5.
7.5
10.
12.5
15.
17.5
20.
22.5
25.

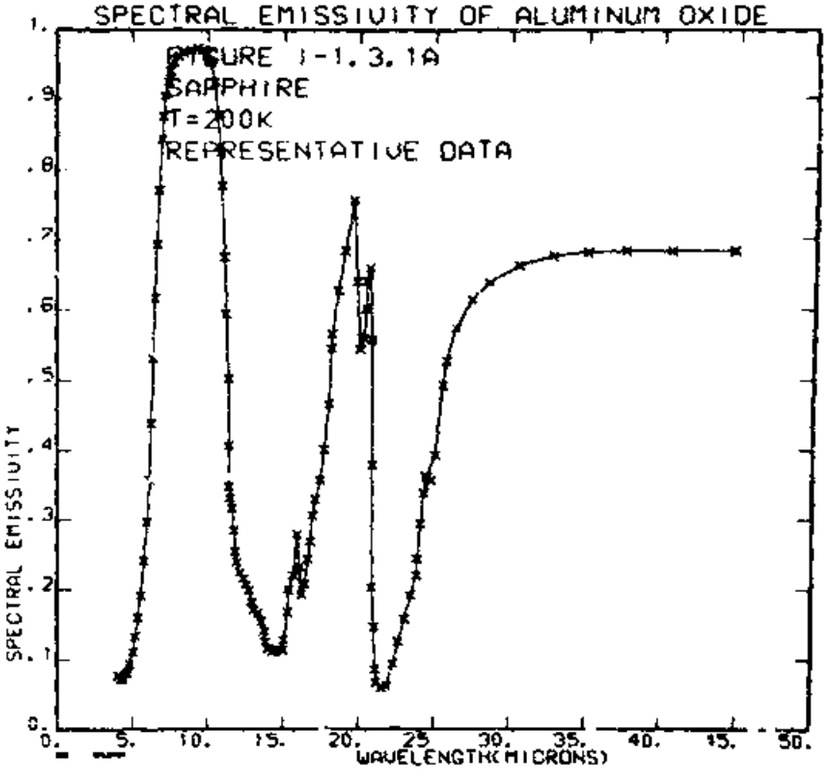
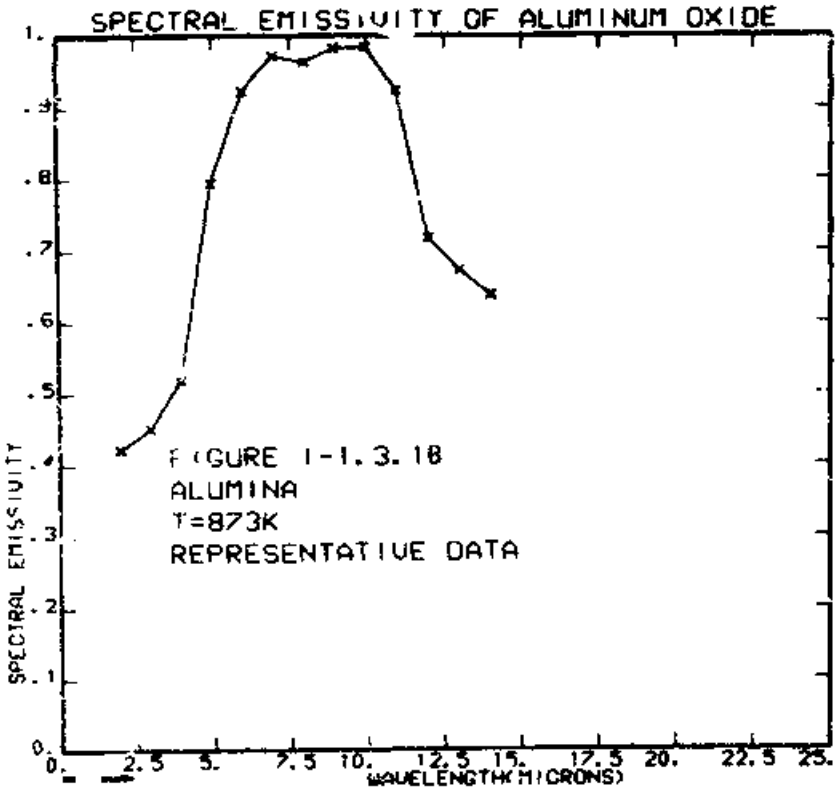

SPECTRAL EMISSIVITY OF ALUMINUM OXIDE
FIGURE I-1.3.1A
SAPPHIRE
T=200K
REPRESENTATIVE DATA
SPECTRAL EMISSIVITY
WAVELENGTH(MICRONS)
0.
.1
.2
.3
.4
.5
.6
.8
1.
5.
10.
15.
20.
25.
30.
35.
40.
45.
50.

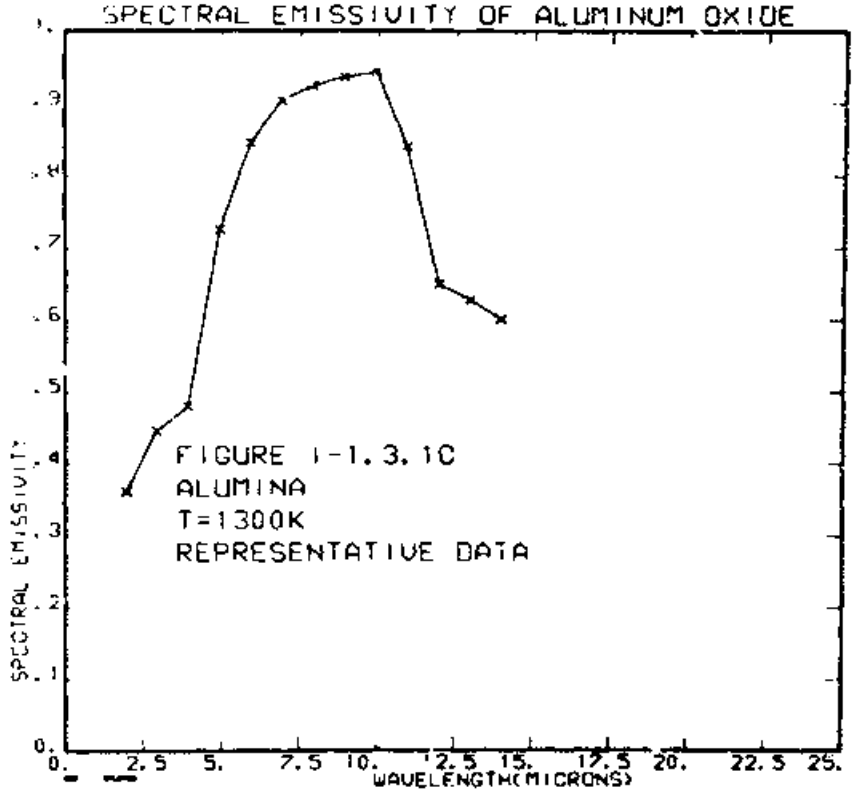
Table I-1.3.1b Spectral Emissivity of Alumina, T=873°K — Representative Data

λ	ε	λ	ε	λ	ε	λ	ε
1.974	.726	2.967	.953	3.967	.920	4.970	.735
2.370	.923	3.957	.972	7.975	.964	8.942	.983
2.961	.954	10.971	.924	11.984	.717	12.985	.673
14.011	.639						

Table I-1.3.1c Spectral Emissivity of Alumina, T = 1373°K — Representative Data

λ	ε	λ	ε	λ	ε	λ	ε
1.965	.963	2.937	.975	3.926	.982	4.941	.726
2.342	.946	3.932	.968	7.909	.925	8.331	.937
2.943	.944	10.935	.842	11.972	.650	12.974	.630
13.955	.651						


SPECTRAL EMISSIVITY OF ALUMINUM OXIDE
SPECTRAL EMISSIVITY
WAVELENGTH(MICRONS)
0.
2.5
5.
7.5
10.
12.5
15.
17.5
20.
22.5
25.
FIGURE I-1.3.1B
ALUMINA
T=873K
REPRESENTATIVE DATA


SPECTRAL EMISSIVITY OF ALUMINUM OXIDE
SPECTRAL EMISSIVITY
WAVELENGTH(MICRONS)
0.
2.5
5.
7.5
10.
12.5
15.
17.5
20.
22.5
25.
FIGURE I-1.3.1C
ALUMINA
T=1300K
REPRESENTATIVE DATA

I-1.3.2 Powdered Aluminum Oxide

The representative spectral emissivity of powdered Al_2O_3 over a particle size range of 0.06 - 30 μ and a temperature of 300°K is shown in Figure I-1.3.2. The values of $\epsilon(\lambda)$ reported by Aronson (Ref. ISE-2) and Shreed (Ref. ISE-17) are much higher for $\lambda > 12\mu$ than the bulk materials, but do show the decrease at 11μ from a plateau starting at approximately 4μ. The sharp peak occuring at 3μ is due to water contamination of the sample and is not present in the high temperature data. The complete set of particle emissivity data is contained in Section III-1.3. The representative curve is for 9 WCA alumina particles at 300°K as measured by Aronson (Ref. ISE-2).

Table I-1.3.2 Representative Data, Alumina Particles, T = 300°K

λ	ε	λ	ε	λ	ε
7.330	7.441E-01	7.371	7.676E-01	7.398	7.451E-01
7.433	7.314E-01	7.482	7.587E-01	7.549	7.856E-01
7.633	7.817E-01	7.672	7.841E-01	7.705	7.913E-01
7.727	7.891E-01	7.756	7.876E-01	7.778	7.911E-01
7.805	7.899E-01	7.831	7.896E-01	7.856	7.983E-01
7.831	8.106E-01	7.914	8.081E-01	7.981	8.042E-01
8.014	8.153E-01	8.042	8.239E-01	8.068	8.326E-01
8.097	8.329E-01	8.118	8.291E-01	8.172	8.291E-01
8.201	8.399E-01	8.233	8.425E-01	8.261	8.387E-01
8.289	8.437E-01	8.315	8.640E-01	8.341	8.793E-01
8.369	8.839E-01	8.394	8.887E-01	8.437	8.869E-01
8.408	8.855E-01	8.518	8.941E-01	8.577	8.956E-01
8.634	8.968E-01	8.634	9.081E-01	8.672	9.142E-01
8.756	9.345E-01	8.775	9.357E-01	8.834	9.503E-01
8.938	9.641E-01	8.979	9.620E-01	9.043	9.715E-01
9.117	9.664E-01	9.241	9.796E-01	9.265	9.912E-01
9.401	9.906E-01	9.638	9.960E-01	9.319	9.959E-01
10.050	9.952E-01	10.263	9.867E-01	10.354	9.604E-01
10.439	9.432E-01	10.502	9.368E-01	10.590	9.321E-01
10.665	9.123E-01	10.709	9.115E-01	10.728	9.007E-01
10.787	8.971E-01	10.819	8.891E-01	10.877	8.891E-01
10.926	8.745E-01	10.969	8.696E-01	11.039	8.610E-01
11.114	8.551E-01	11.179	8.550E-01	11.226	8.576E-01
11.274	8.501E-01	11.359	8.487E-01	11.456	8.418E-01
11.479	8.339E-01	11.546	8.353E-01	11.625	8.353E-01
11.683	8.442E-01	11.737	8.408E-01	11.777	8.503E-01
11.882	8.573E-01	11.954	8.625E-01	12.012	8.739E-01
12.123	8.745E-01	12.169	8.822E-01	12.235	8.855E-01
12.308	8.901E-01	12.433	8.908E-01	12.497	8.847E-01
12.566	8.832E-01	12.664	8.879E-01	12.710	8.852E-01
12.739	8.898E-01	12.874	8.820E-01	12.979	8.817E-01
13.031	8.811E-01	13.184	8.849E-01	13.302	8.839E-01
13.323	8.729E-01	13.657	8.758E-01	13.725	8.771E-01
13.788	8.722E-01	13.944	8.547E-01	14.084	8.652E-01
14.199	8.617E-01	14.374	8.531E-01	14.501	8.575E-01
14.599	8.590E-01	14.683	8.634E-01	14.842	8.615E-01
14.934	8.624E-01	15.122	8.884E-01	15.235	8.971E-01
15.373	8.759E-01	15.452	8.531E-01	15.558	8.336E-01
15.633	8.314E-01	15.737	8.415E-01	15.774	8.580E-01
15.892	8.715E-01	15.964	8.822E-01	16.070	8.783E-01
16.139	8.639E-01	16.394	8.497E-01	16.584	8.059E-01
16.669	7.681E-01	16.801	7.374E-01	16.950	7.336E-01

Table I-1.3.2 Representative Data, Alumina Particles, T = 300°K (continued)

λ	ε	λ	ε	λ	ε
17.018	7.597E-01	17.223	8.359E-01
17.432	8.218E-01	17.584	8.202E-01
17.733	8.425E-01	17.852	8.524E-01
18.020	8.783E-01	18.123	8.899E-01
18.226	8.936E-01	18.599	8.886E-01
19.952	8.564E-01	19.108	8.630E-01
19.824	8.713E-01	19.896	8.681E-01
20.322	8.382E-01	20.474	8.365E-01
20.492	8.751E-01	20.709	8.896E-01
21.255	8.955E-01	21.443	8.758E-01
22.266	9.247E-01	22.525	8.076E-01
23.059	9.308E-01	23.272	8.163E-01
23.759	8.556E-01	24.018	8.756E-01
24.756	8.481E-01	24.963	8.469E-01
25.651	8.422E-01		

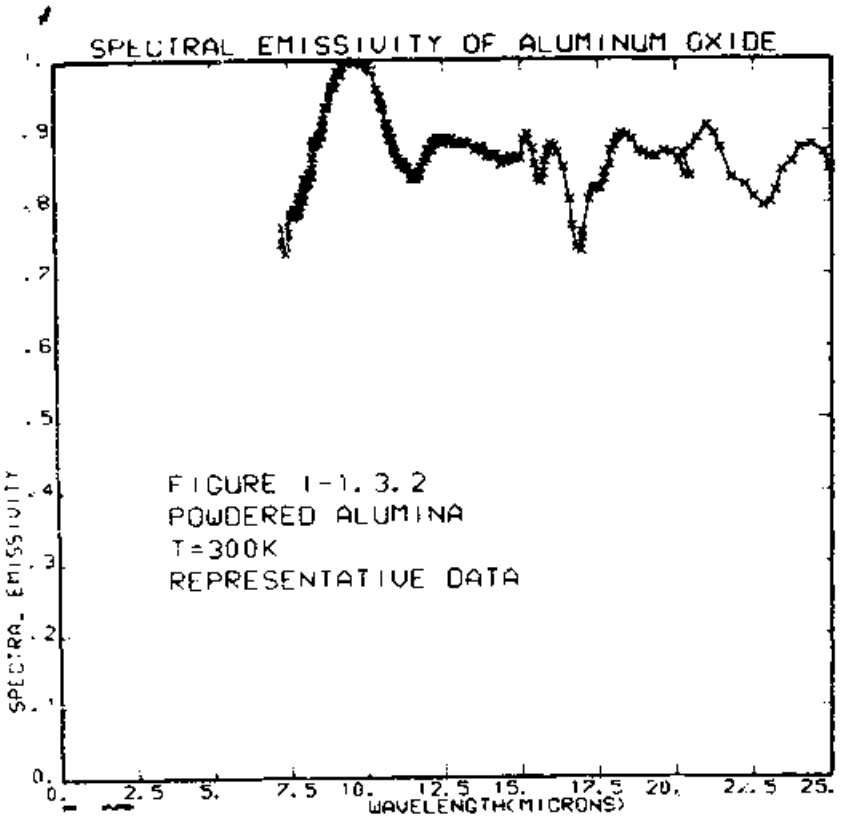


FIGURE I-1.3.2
POWDERED ALUMINA
T=300K
REPRESENTATIVE DATA

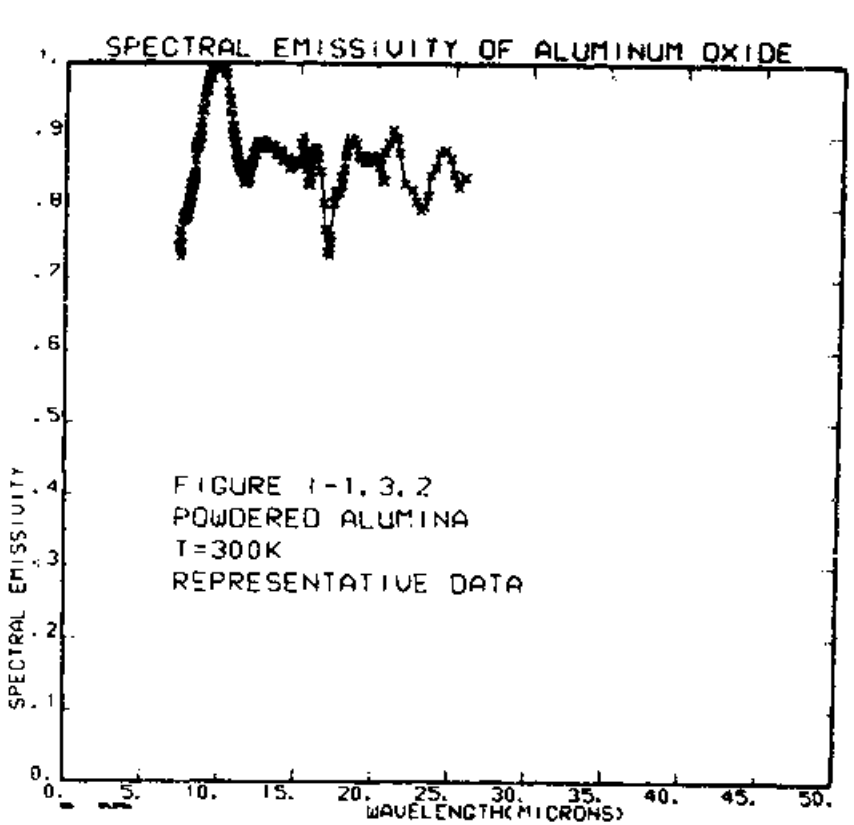


FIGURE I-1.3.2
POWDERED ALUMINA
T=300K
REPRESENTATIVE DATA

I-1.4 Total Normal Emissivity, $\epsilon(T)$ — Aluminum Oxide

The total emissivities of bulk alumina and sapphire have been measured in the literature for temperatures ranging from 63°K to 1800°K. The representative curve for alumina data, constructed by fitting a third order polynomial to data from References 1TE-4 and 1TE-5 is shown in Table I-1.4 and Figure I-1.4. $\epsilon(T) = 0.77$ at low temperatures, then goes through an apparent minimum of about 0.37 at 1660°K. No experimental error is quoted for these data.

$\epsilon(T)$ for sapphire is given in Section III-1.4 in tabulated form in Ref. 1TE-2 and 1TE-6, and appears to be less than the alumina emissivity over the range of temperatues covered, 200°K to 1273°K.

One reference (1TE-3) gives $\epsilon(T)$ for rocket exhaust particles from T = 1389°K to 2222°K. This is presented in Section III-1.4.

Table I-1.4 Bulk Alumina Total Emittance — Representative Data

$T(^{o}K)$	$\epsilon(T)$	$T(^{o}K)$	$\epsilon(T)$	$T(^{o}K)$	$\epsilon(T)$
0.000	.7722	900.000	.5359	1780.000	.3766
20.000	.7713	920.000	.5291	1800.000	.3791
40.000	.7692	940.000	.5224	1820.000	.3816
60.000	.7673	960.000	.5157	1840.000	.3834
80.000	.7651	980.000	.5090	1860.000	.3866
100.000	.7626	1000.000	.5024	1880.000	.3902
120.000	.7600	1020.000	.4959	1900.000	.3942
140.000	.7570	1040.000	.4895	1920.000	.3986
160.000	.7539	1060.000	.4831	1940.000	.4034
180.000	.7505	1080.000	.4769	1960.000	.4087
200.000	.7468	1100.000	.4709	1980.000	.4143
220.000	.7430	1120.000	.4647	2000.000	.4204
240.000	.7389	1140.000	.4588	2020.000	.4269
260.000	.7347	1160.000	.4530	2040.000	.4339
280.000	.7303	1180.000	.4474	2060.000	.4413
300.000	.7256	1200.000	.4419	2080.000	.4492
320.000	.7208	1220.000	.4365	2100.000	.4575
340.000	.7158	1240.000	.4313		
360.000	.7107	1260.000	.4263		
380.000	.7054	1280.000	.4214		
400.000	.6999	1300.000	.4167		
420.000	.6943	1320.000	.4122		
440.000	.6886	1340.000	.4079		
460.000	.6827	1360.000	.4038		
480.000	.6767	1380.000	.3999		
500.000	.6707	1400.000	.3962		
520.000	.6644	1420.000	.3927		
540.000	.6581	1440.000	.3894		
560.000	.6517	1460.000	.3864		
580.000	.6453	1480.000	.3836		
600.000	.6387	1500.000	.3811		
620.000	.6321	1520.000	.3788		
640.000	.6254	1540.000	.3768		
660.000	.6186	1560.000	.3751		
680.000	.6118	1580.000	.3736		
700.000	.6050	1600.000	.3725		
720.000	.5981	1620.000	.3716		
740.000	.5912	1640.000	.3710		
760.000	.5843	1660.000	.3708		
780.000	.5774	1680.000	.3708		
800.000	.5704	1700.000	.3712		
820.000	.5635	1720.000	.3719		
840.000	.5566	1740.000	.3729		
860.000	.5497	1760.000	.3743		
880.000	.5428				

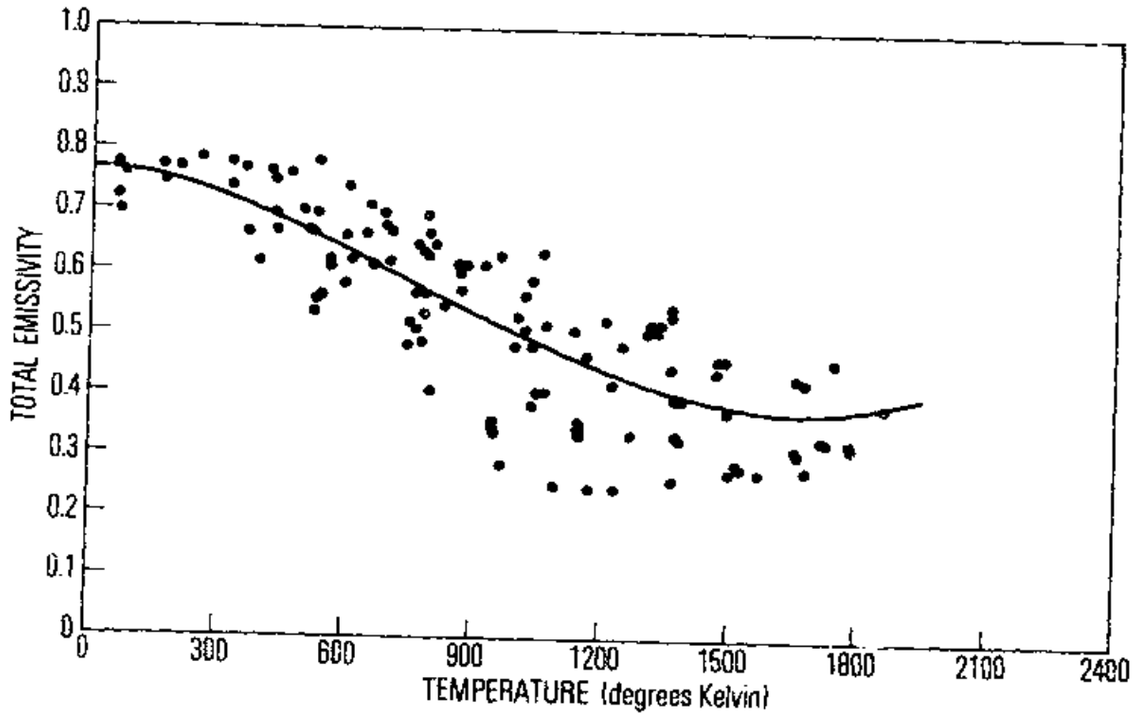


Figure I-1.4 The Total Normal Emissivity of Aluminum Oxide as a Function of Temperature