

Dielectric Properties of Lunar Simulant Materials II

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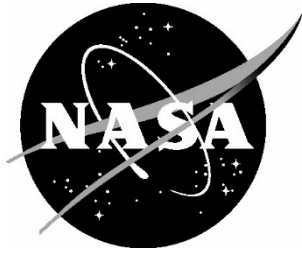
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By

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Abstract

This is an addition to the NASA/TP- 20250009115 (Rickman et al., 2025), containing dielectric measurements made by Microwave Properties North (MPN) on six additional materials of interest to lunar applications. The materials are NU-LHT-2M-AGGL, JSC-1A-AGGL, Stillwater Anorthosite, two olivine samples, and an ilmenite. The measured values at 2466 MHz for these 6 additional materials, as well as the “Looyenga scaled” values for a density of 1.75 g/cc, are reported herein. Measurement protocols, data processing, presentation, and this document structure follow the pattern set in the above referenced paper. The result is a collection, including both papers, of 29 uniformly measured and processed data sets covering lunar regolith simulants and some related materials. Of special note, the leakage of a small amount of oxygen into the MPN system, in spite of the use of flowing Ultra High Purity argon, has resulted in visual confirmation of oxidation of some samples at high temperatures during the runs. The influence of this on the dielectric constant values has not yet been measured, but experience suggests only a small effect.

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1 Introduction

This report is a continuation of NASA/TP– 20250009115 (Rickman et al., 2025). We explicitly note that the data reported herein, like the data in Rickman et al. (2025), contain many features which we do not attempt to explain. As a practical matter, even the simplest simulant, and to a lesser extent any of the natural feedstocks used in a simulant, are extremely complex mixtures. The purpose of this document is to add 6 additional data sets, covering 5 samples, to the existing knowledge base. Methods of data acquisition, equations, data manipulation, document format, and logic are the same in both papers. Therefore, this document should be used in conjunction with the previous report. If the reader is not familiar with high temperature dielectric measurements on materials similar to the lunar regolith, it is strongly recommended to read sections 1 – 5 of the cited document. It is important to note the measurements behind the data and plots presented here have been scaled to a single sample density of 1.75 g/cc (Looyenga, 1965; Rickman et al., 2024), thus allowing direct comparison between materials.

The materials measured and some details of the measurements are given in tabular form in Table 1.1. Table 1.1 also provides the reference designation used within MPN, the name of the MPN report, and an index identifier, such as “A27”, which is used in this report. In this document when it is necessary to refer to a specific measurement, we use the index or the MPN reference designation.

There are two appendices in this report. Appendix A gives the as measured values of ϵ' , ϵ'' , both at 2466 MHz, as well ϵ' , ϵ'' after scaling to a pellet density of 1.75 g/cc. This appendix also gives the Half Power Depth (HPD) computed from the ϵ' and ϵ'' values, the time in hours since the beginning of the run, and the actual temperature, in °C, recorded for a measurement. All of these values are reported against a temperature used as an index into the data. Note, as was done in the previous report, the index temperature is used in all subsequent parts of this report unless explicitly noted. The second appendix, Appendix B, gives the full reports provided by Microwave Properties North (MPN) for each of the 6 runs reported herein. These reports detail the experimental conditions, observations, graphs of the data, tabulated measurements for all frequencies measured, and in some cases photographs. Sample order for the data tables in Appendix A and B are in the order of the measurements given in Table 1.1.

For clarity, this paper is concerned at all points with the Relative Complex Permittivity, ϵ^* , defined as

$$\epsilon^* = \epsilon_r' - (j^* \times \epsilon_r'')$$

Where j^* is the square root of negative 1, $\sqrt{-1}$. The principal values reported in this document are ϵ_r' and ϵ_r'' . These two values are referred to as the real and imaginary part of the permittivity, or relative permittivity and dielectric loss. For more information on complex permittivity see Von Hippel (1954).

Table 1.1. Material, Run Conditions, Index, MPN Identifier, and Report File Name

Material	Temp °C	Gas	Density		Index	Microwave Properties North Designations	
			Start	End		MPN ID	Report Name
Anorthosite Stillwater	1400	H2	2.06	2.26	A23	NASA2589	MPN-337_NASA_Rickman_Stillwater Anorthosite.docx
JSC-1A-AGGL	1100	Ar	2.09	2.12	A24	NASA2583	MPN-337_NASA_Rickman_JSC-1A-AGGL_Argon.docx
	1100	H2	2.03	2.09	A25	NASA2591	MPN-337_NASA_Rickman_JSC-1A-AGGL_4%Hydrogen.docx
NU-LHT-2M-AGGL	1225	H2	2.06	2.08	A26	NASA2587	MPN-337_NASA_Rickman_2nd Run NU-LHT-2M-AGGL.docx
Olivine	1150	Ar	2.21	2.2	A27	ECERF1437	ECERF_6_mod (2).doc
	1000	N2	2.25	2.23	A28	QUEENS2433	MPN-308_Ravash_QUEENS_Olivine.docx
Ilmenite	1000	N2	2.92	2.85	A29	QUEENS2435	MPN-308_Ravash_QUEENS_Ilmenite.docx

None of the samples were pre-treated.

Key

Temp: The approximate peak temperature

Gas: The environment around the sample during measurement. It was either “Ar” - Ultra-High Purity (UHP) Argon, “H2” - UHP argon with 4% H₂, or “N2” - UHP Nitrogen.

Density: In g/cc, the starting and end pellet densities

Index: Reference identity for this report

MPN: Microwave Properties North internal tracking ID and customer report name

2 Results

All of the following graphs use the measurements at 2466 MHz scaled to a sample density of 1.75 g/cc. This density is an arbitrary value chosen to be within the range of *in situ* lunar material.

2.1 Stillwater Anorthosite

This material is the anorthosite used in the production of all of the NU-LHT-series simulants, including NUW-LHT-5M. For source location information and other information refer to Rickman et al. (2024 b) and Stoeser and Wilson (2007).

The material is not pure plagioclase; it contains approximately 5 - 10 volume % other minerals, which include orthopyroxene, clinopyroxene, sericitic alteration, and other alteration suites, see images Figures 2.1.4 and 2.1.5.

Figure 2.1.1 gives the data for this material. It is hypothesized that either, or both, the high values centered near 800 °C in the ϵ'' or the low centered at 1000 °C in ϵ'' were caused by the secondary minerals. The displacement between the heating and cooling leg in ϵ' shows the material went through an irreversible phase change, (melting?).

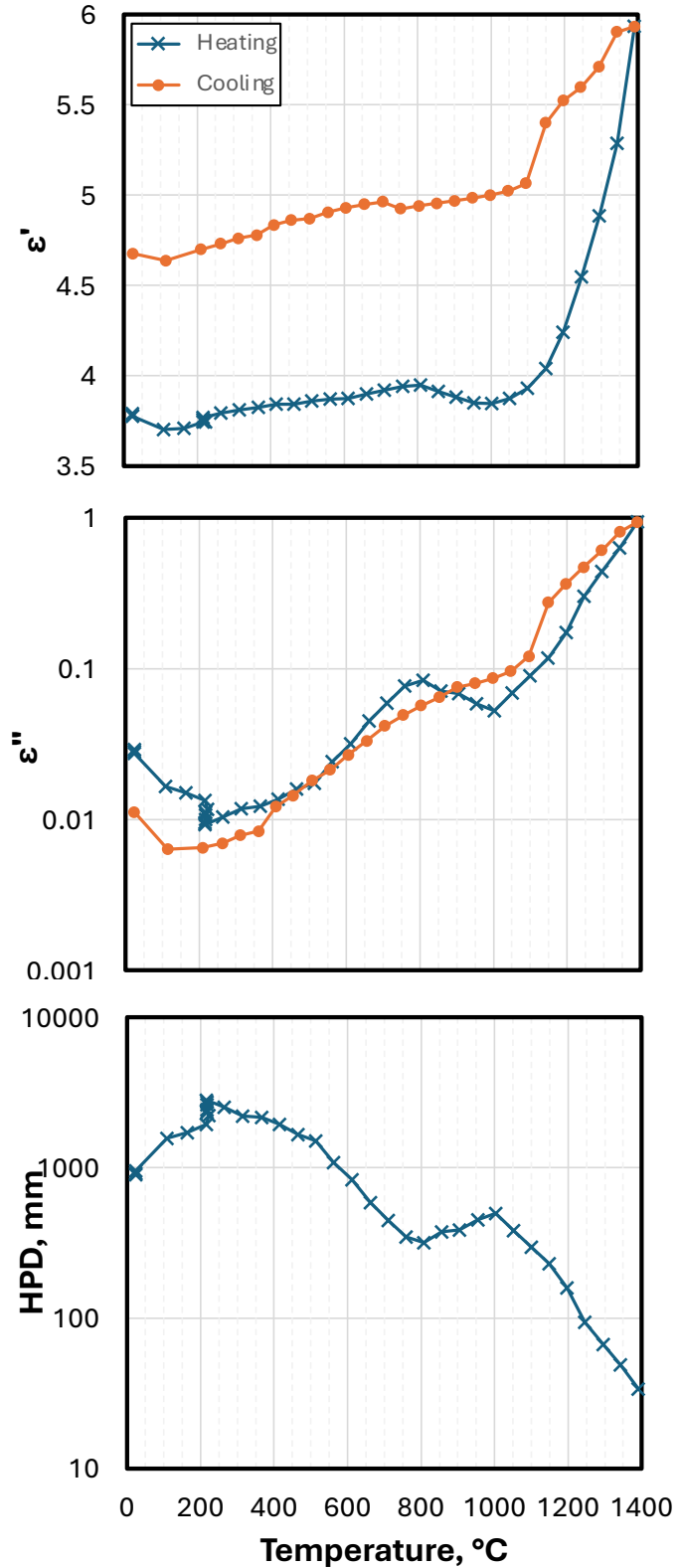


Figure 2.1.1. Heating and cooling legs of ϵ' , ϵ'' , measured for A23, Stillwater anorthosite. The heating leg of HPD is also shown. Values are scaled to a sample density of 1.75 g/cc.

Because the Stillwater anorthosite is the largest single crystalline component in multiple simulants, how its dielectric properties compare to (1) synthetic anorthite produced under the direction of Dr. Holly Shulman, (2) the glass used in NUW-LHT-5M, (3) the NU-LHT-5M simulant, and (4) the Merriam Crater feedstock used in the JSC-1A and CSM-LHT-1G simulants are provided, Figure 2.1.2. More information about all of these additional materials can be found in Rickman et al. (2025). The largest difference found with the Stillwater anorthosite was seen in the Merriam Crater feedstock, which is not surprising as the latter contains substantially higher levels of iron, as well as other significant differences, such as glass composition. The values of NUW-LHT-5M and its glass are relatively close to those for the anorthosite.

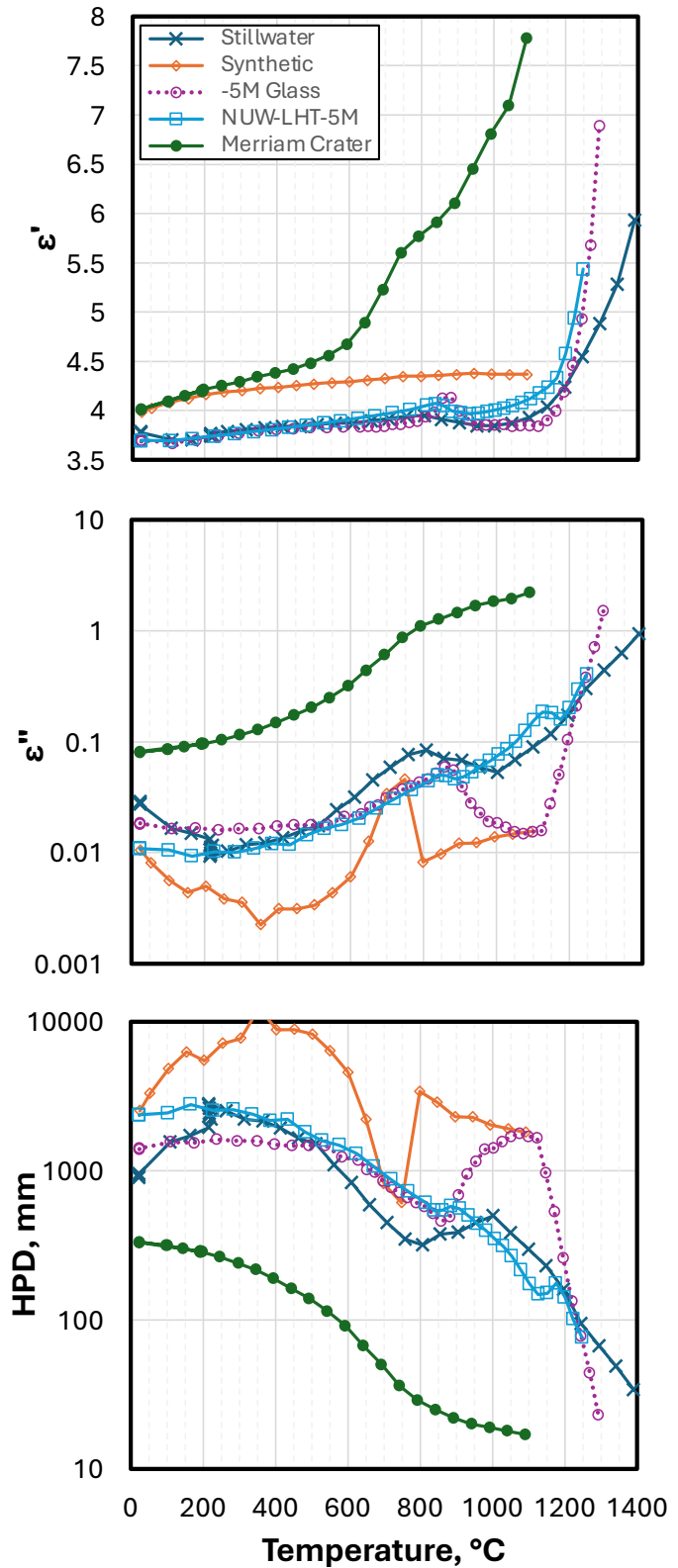


Figure 2.1.2. ϵ' , ϵ'' , and HPD of A23, Stillwater anorthosite, compared to synthetic anorthite, A1; the glass used in NUW-LHT-5M, A22; NUW-LHT-5M simulant, A19; and A14, Merriam Crater feedstock, used in JSC-1A. Only the heating legs are shown.

NUW-LHT-5M is composed of ~38 wt% Stillwater anorthosite and another 40 wt% synthetic glass. Together these are ~ 78 wt% of the simulant. Figure 2.1.3 compares the measurements of the two constituents to the full simulant.

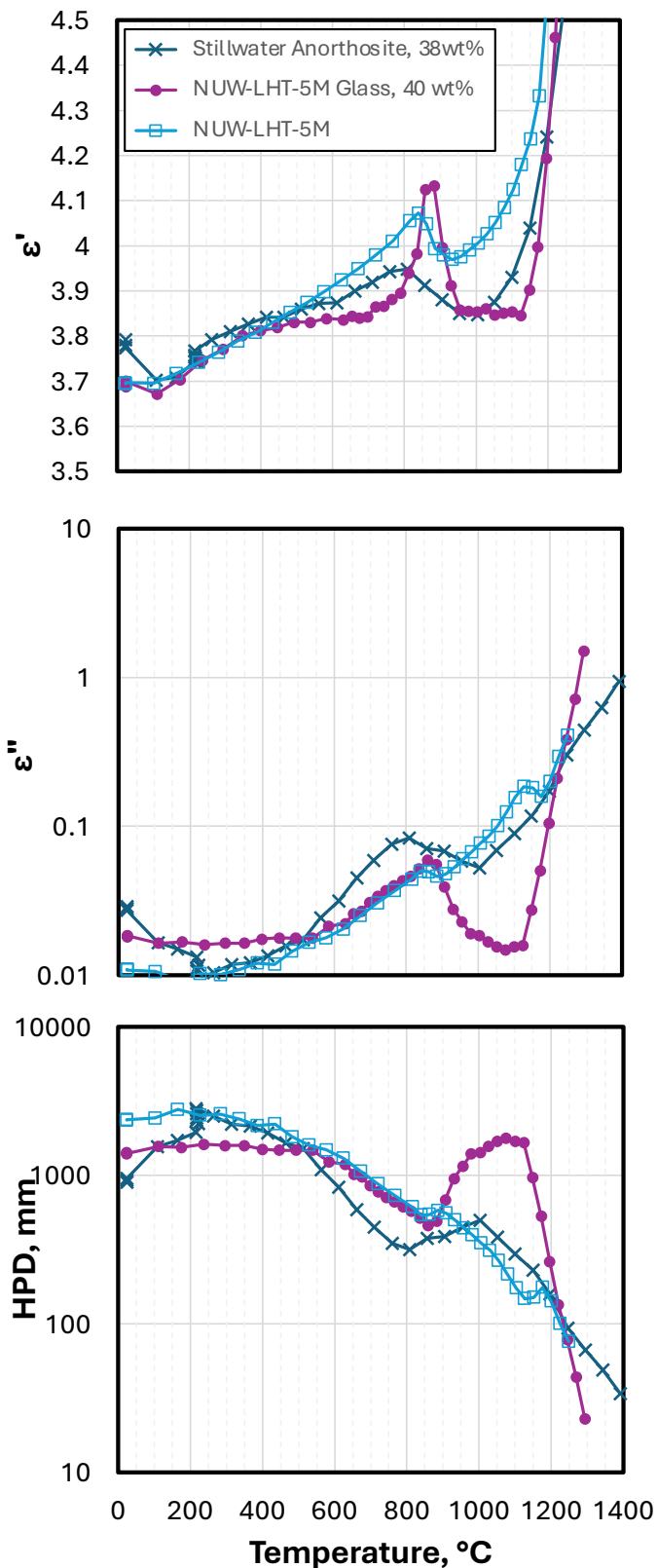


Figure 2.1.3. ϵ' , ϵ'' heating legs, and HPD of Stillwater anorthosite, A23, and A22, NUW-LHT-5M synthetic glass, and A19, NUW-LHT-5M. Weight % of the two components in NUW-LHT-5M are given. Only the heating leg of each run is shown.



Figure 2.1.4. Petrographic thin section of Stillwater Anorthosite. USGS sample ST20D; prepared for Doug Stoeser. Upper image, transmitted light. Lower image, crossed nicols. Colors in the transmitted light have been shifted to aid image interpretation. Patches of sericitic (?) alteration visible.



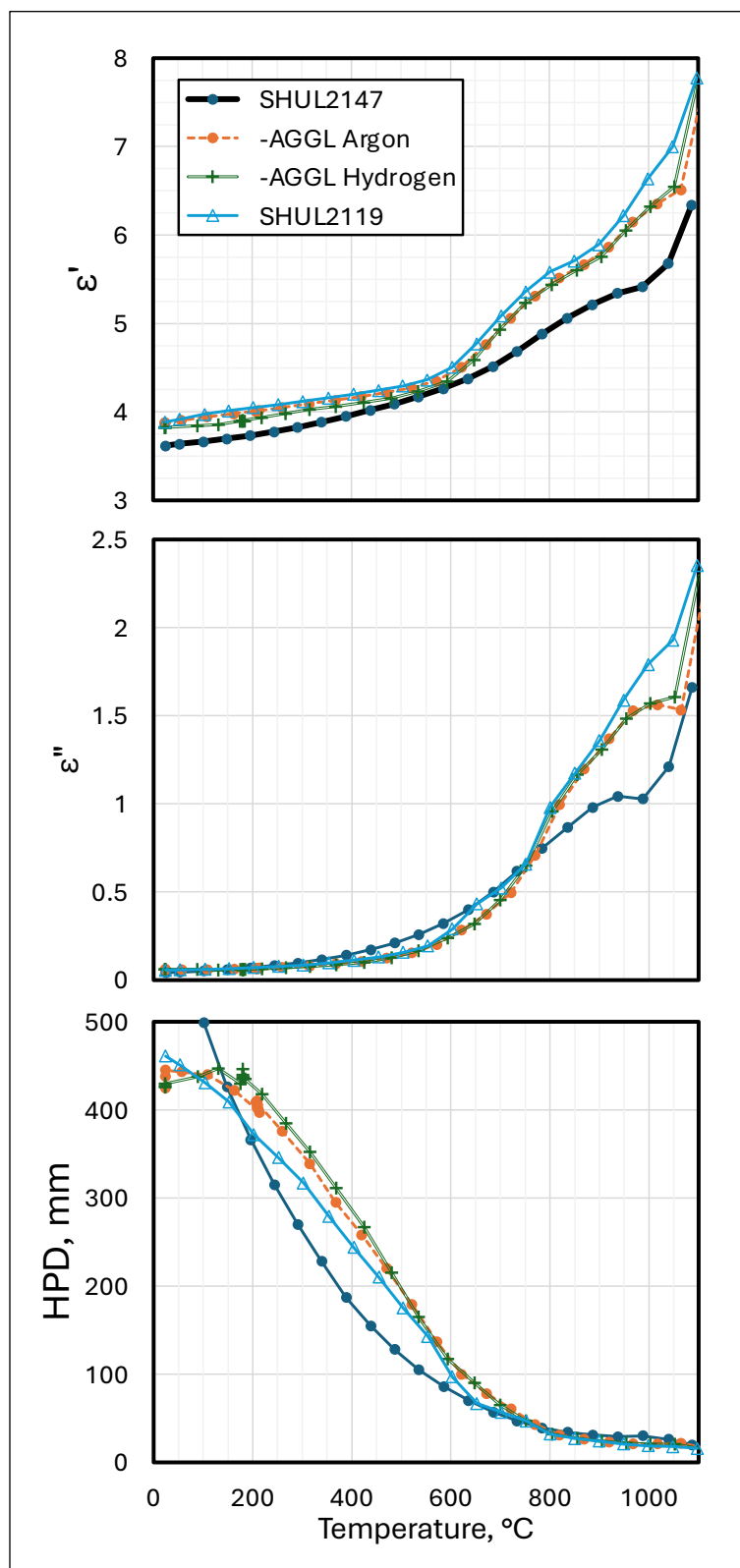
Figure 2.1.5. Petrographic thin section of a Stillwater anorthositic two pyroxene gabbro-norite. USGS sample ST25A; prepared for Doug Stoesser. Upper image, transmitted light. Lower image, crossed nicols. Colors in the transmitted light have been shifted to aid image interpretation. The pyroxenes and the chloritic (?) alteration are typical of some sections of the Stillwater anorthosite used in the simulants.

2.2 JSC-1A-AGGL

With funding by NASA, Orbitec Technologies Corporation of Madison, WI developed a process involving a H₂ environment to alter existing simulants, resulting in the formation of structures very similar to lunar agglutinates (Gustafson et al., 2007). The process was demonstrated to create highly vesicular glasses with significant amounts of micro- and presumably nanoscopic Fe⁰. Simulants processed were JSC-1A, NU-LHT-2M, Chenobi, and OB-1¹; the product of each was renamed by appending the string “-AGGL”. The percentage of the starting material that was converted was not determined; in other words the ending mineralogical content is not known, although the elemental abundances have not shifted.

Two runs were made with JSC-1A-AGGL; A24, used Ultra High Purity (UHP) Argon, and A25 used UHP Argon with 4% H₂. Figure 2.2.1 shows these two runs gave essentially identical results. Data for two other JSC-1A samples, A11, SHUL2147, and A9, SHUL2119, are also shown. A11 was preprocessed with the standard 750 °C back out and the A9 did not receive a comparable pre-treatment.

Figure 2.2.1. ϵ' , and ϵ'' heating legs, and HPD of A24 and A25 compared two JSC-1A samples, A11 and A9. Data scaled to 1.75 g/cc.



¹ Approximately 3 to 5 kg of each simulant was processed. The materials are stored in #10 cans or smaller. If interested in obtaining samples, contact Jennifer.E.Edmunson@nasa.gov.

Additional information about SHUL2147 and SHUL2119 are given in Rickman et al. (2025).

2.3 NU-LHT-2M-AGGL

NU-LHT-2M-AGGL, like the JSC-1A-AGGL, was processed by Orbitec Technologies Corporation to convert some of the simulant into a glass bearing micro- and presumably nano-phase metallic iron. In Figure 2.3.1 the -AGGL version, A26, is compared to the only available data of NU-LHT-2M, A15. As noted in Rickman et al. (2025), the A15 run was terminated due to a problem in the sample at an elevated, but unknown, temperature. These data suggest the problem developed by $T \cong 700\text{ }^{\circ}\text{C}$.

Below $100\text{ }^{\circ}\text{C}$ the difference between the two data sets is unexplained. Typically this difference would be ascribed to differences in H_2O , as water molecules, in the sample; but both of these samples were preheated to remove such water.

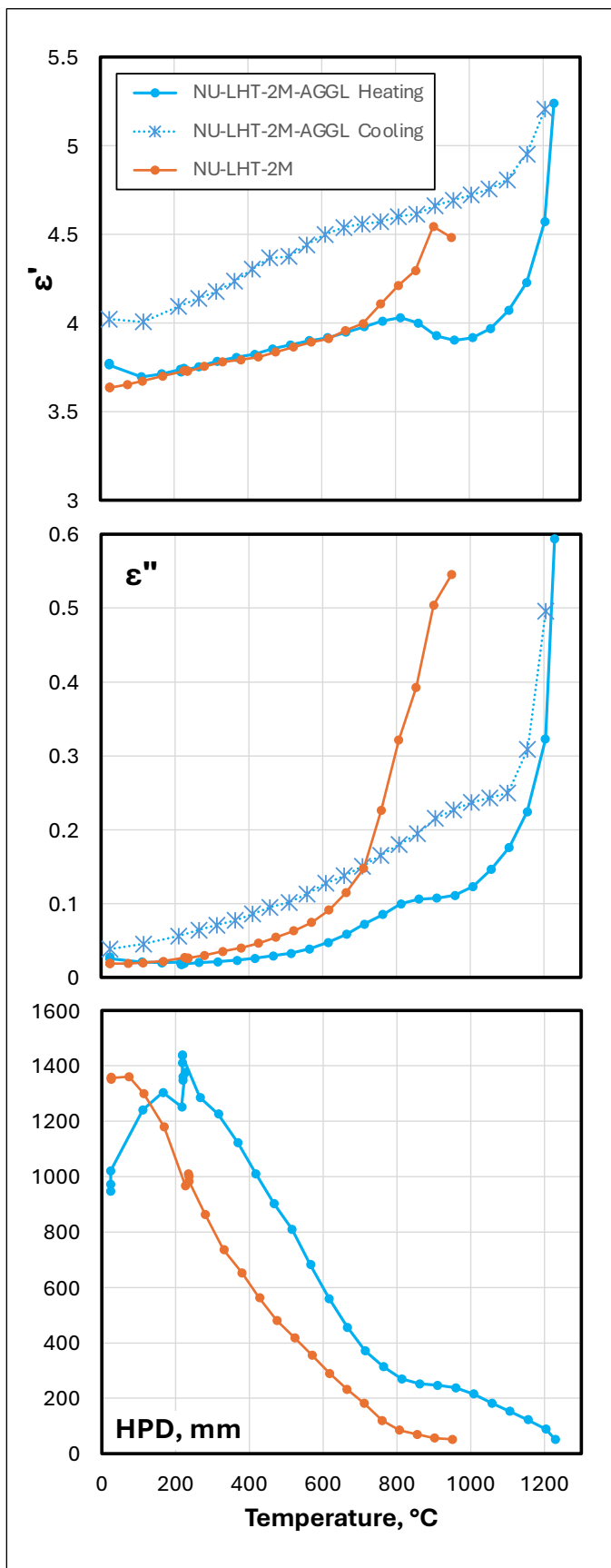


Figure 2.3.1. ϵ' , and ϵ'' , heating and cooling cycles, and HPD of A26 compared to heating leg of A15, NU-LHT-2M.

Figure 2.3.2 compares the available data for NU-LHT-series simulants: NU-LHT-2M, NU-LHT-2M-AGGL, NU-LHT-4M, and NUW-LHT-5M.

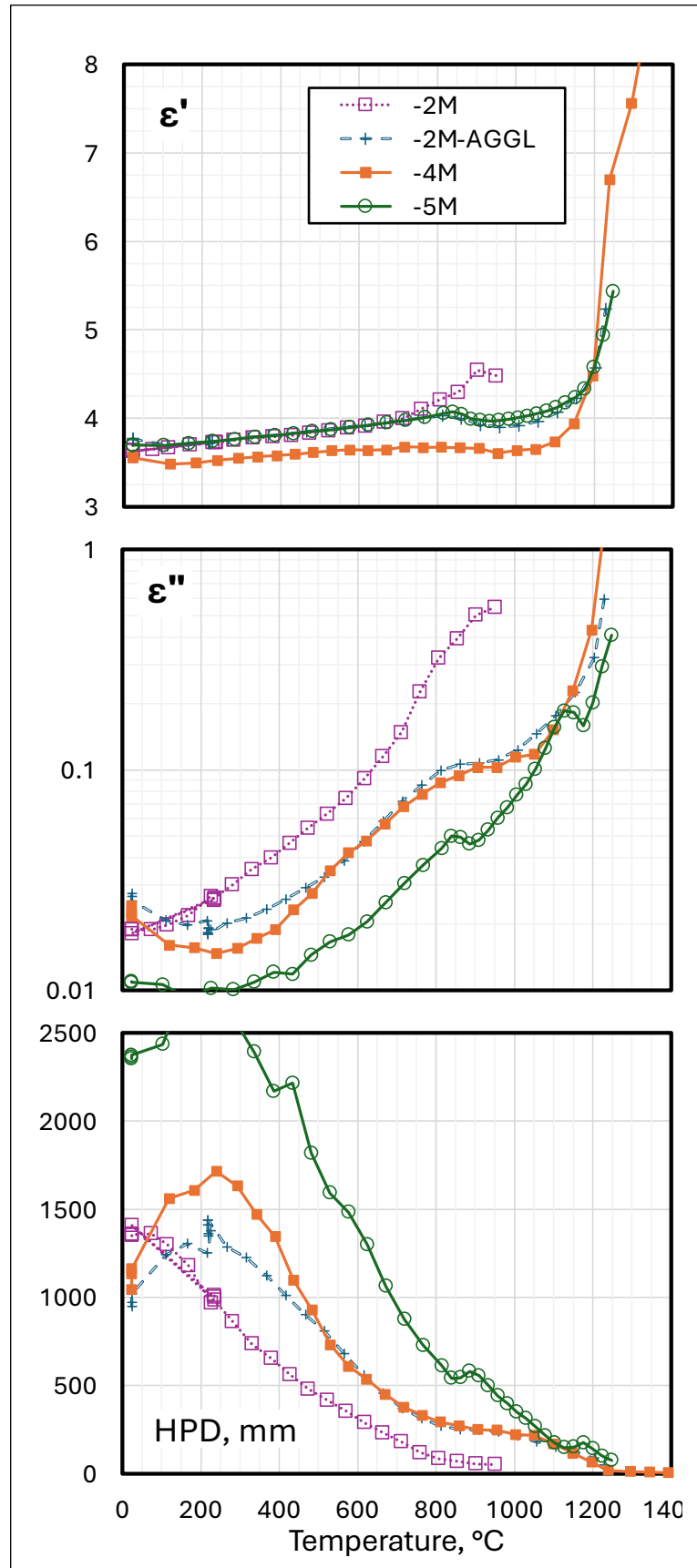


Figure 2.3.2. ϵ' , and ϵ'' , heating cycles, and HPD of A26, NU-LHT-2M-AGGL, compared to heating legs of A15, NU-LHT-2M; A16, NU-LHT-4M; and A19, NUW-LHT-5M.

2.4 Olivines

Dielectric data are shown in Figure 2.4.1 for two high quality olivine samples that were donated to this study by two researchers, John Forster, Microwave Ore Research, Burnaby, BC, V5H 0G8, Canada and Erin R. Bobicki, University of British Columbia, Department of Materials Science and Engineering.

Sample A27, ECERF1437, a commercially sourced olivine, is described in Forster et al. (2018). That document also provides TGA and DSC for this material. That paper also gives the following elemental abundance data for the sample, as shown in Table 2.4. The Fe/Mg ratio for this olivine is close to the target ratio for the NU-LHT-series simulants.

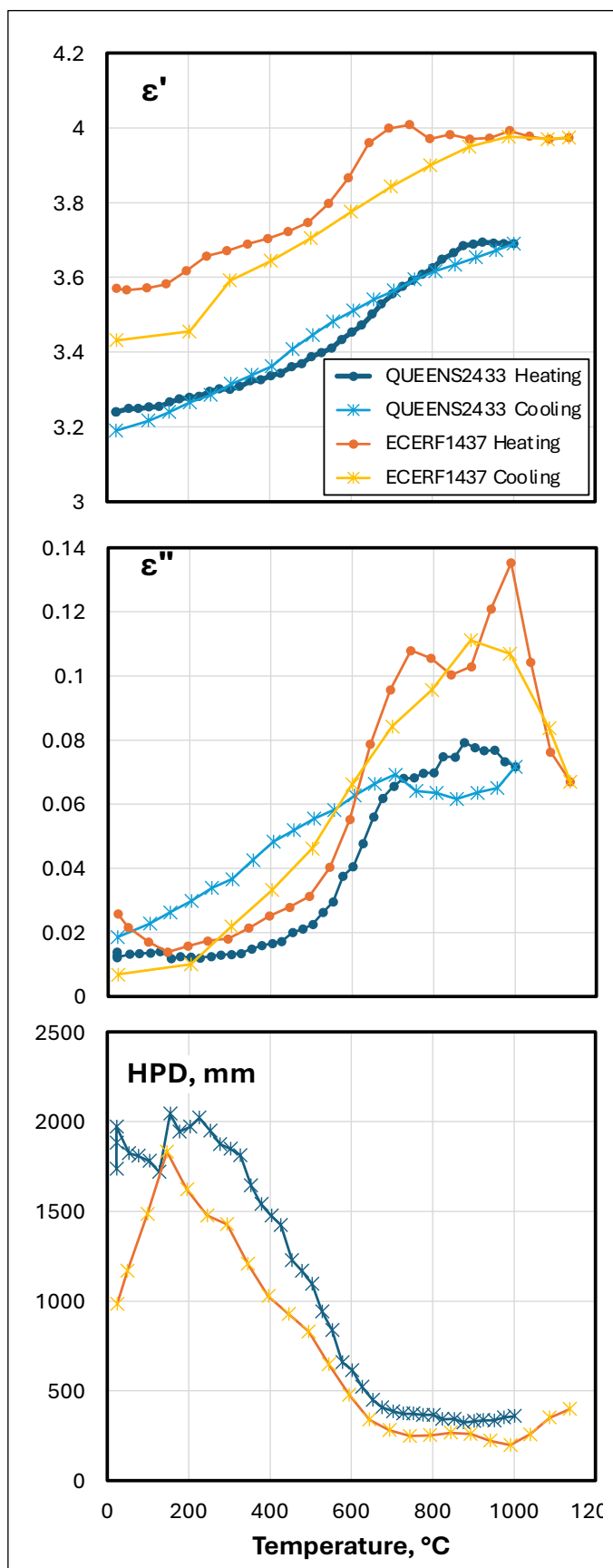
Table 2.4. ICP wt% values for major elements

Al	Ca	Cr
12	0.1	0.43
Fe	Mg	Mn
5.75	29.73	0.09
Ni	S	Si
0.28	0.06	19.18

A27 was run using UHP argon; A28 was run in UHP nitrogen. What impact this difference might have had on the measurements is unknown.

There is no additional information about the olivine used in A28.

Figure 2.4.1. ϵ' , and ϵ'' , heating and cooling cycles, and HPD of two olivine samples, A27 and A28.



The differences between the two olivines are unexplained.

2.5 Ilmenite

In addition to the olivine sample, John Forster also granted access to dielectric data on an ilmenite sample, Figure 2.5.1.

Unlike the other materials in this document and in Rickman et al. (2025), all of which are either a silicate mineral, silica-rich glass, or a mixture of these, ilmenite is an iron – titanium oxide, FeTiO_3 . As a result, this material has very different dielectric properties, with the ϵ' values approximately an order of magnitude higher at high temperature, and the ϵ'' values several orders of magnitude higher than those observed in the silicates. It is clear from these data that the presence of sufficient ilmenite will significantly affect the microwave properties of a lunar regolith simulant containing the mineral. In practice the actual effect of a given amount of ilmenite in any given simulant is complicated, involving questions of how the ilmenite is spatially distributed in the material, Zho et al. (2021).

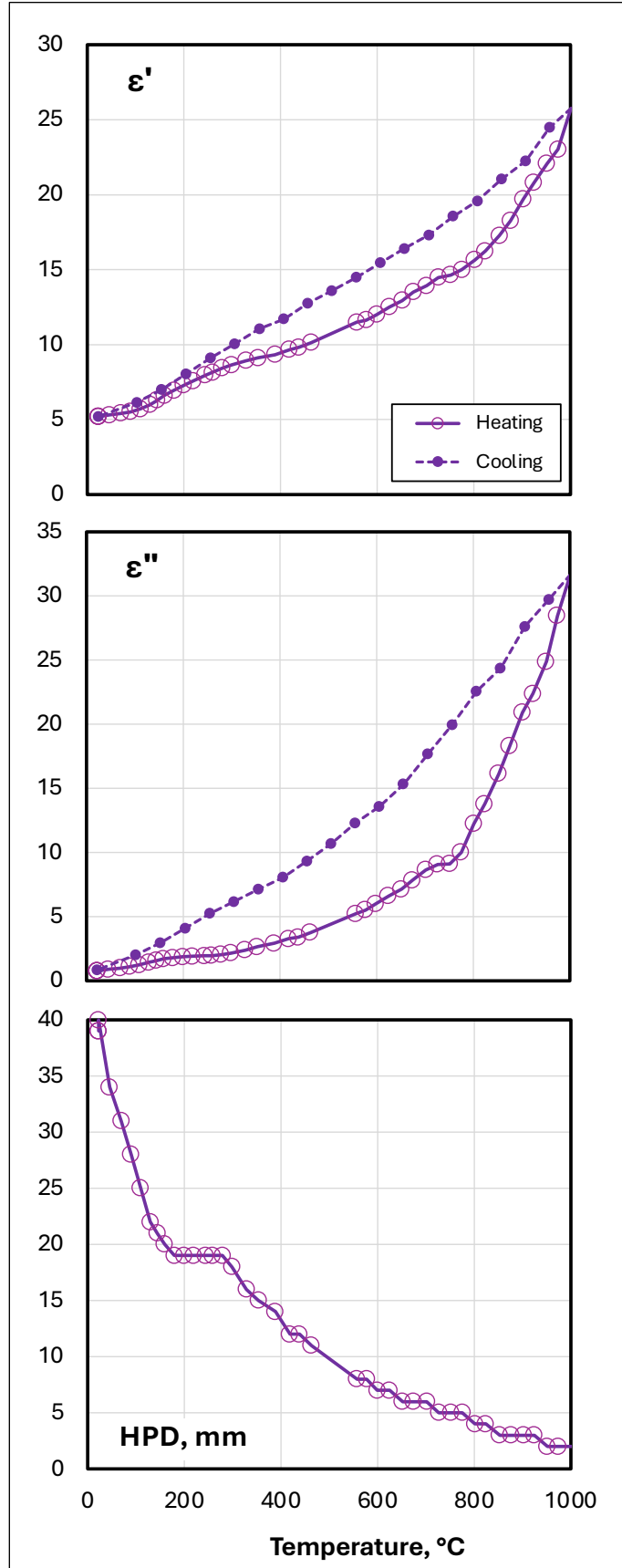


Figure 2.5.1. ϵ' , and ϵ'' , heating and cooling cycles, and HPD of sample A29, ilmenite.

3 Discussion

It has now been demonstrated that during all of the measurements reported here and in Rickman et al. (2025), the samples were oxidized to some degree during the high temperature processing. The influence of the oxidation on the determined values is unknown.

The problem was recognized by the reddening of pellets after processing compared to the initial material. Figure 3.1 contrasts the very black color of JSC-1A powder before processing, with the brick red coloration of the pellets after processing. The specific hue of the post-processed JSC-1A is characteristic of hematite, Fe_2O_3 , being produced. As seen in this figure the amount of oxygen gas flow past the samples is sufficiently large to overcome the reducing atmosphere created by argon with 4% H_2 . Figure 3.2. shows the color shift that occurred with A26, NU-LHT-2M-AGGL, from before to after measurement.

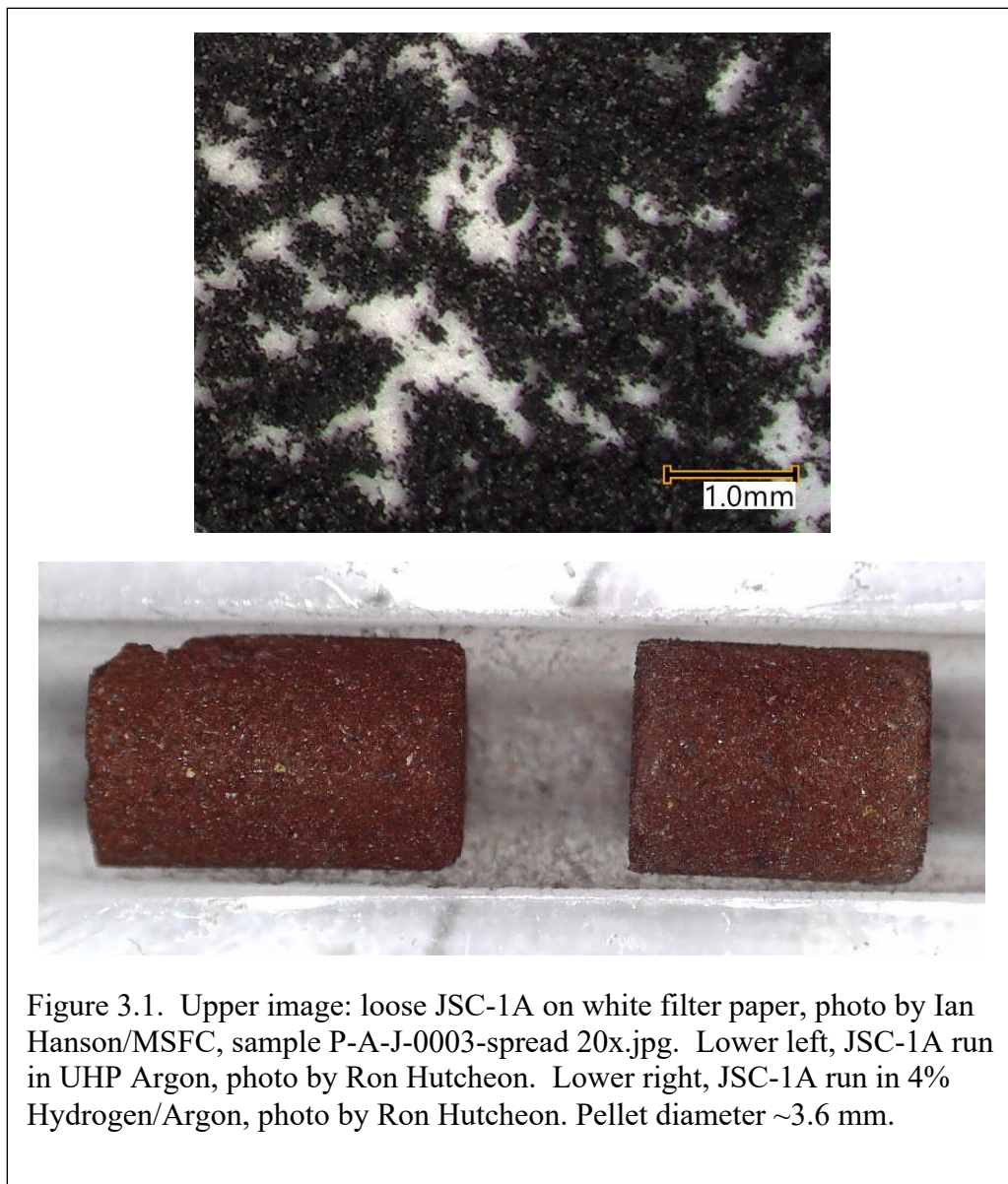




Figure 3.2. Photos of A26, NU-LHT-2M-AGGL, pellet before, upper, and all three pellets after heating to 1225 °C, lower. Pellet diameter ~ 3.6 mm.

The source of the oxygen must be atmospheric, as no other oxygen source is involved in proximity to the measurement system.

Oxygen added to a simulant will increase the weight of the sample. This has been reported in multiple documents, for example see Street et al. (2010), and Ray et al. (2010). For several reasons, such as pellet spalling and the counter acting effect of mass loss due to volatile loss, the weight data provided by MPN does not clearly demonstrate the weight gain.

It was considered possible that oxygen within the simulant might be responsible for the observed reddening. To eliminate this a sample of JSC-1A was run in the lab of Alan Whittington/UTSA by Austin Patridge using the same heating protocol as was used by MPN and with a gas environment of UHP Argon. The reddening, or another color shift, did not occur in that sample.

MPN is currently altering their system to minimize or remove the oxidation.

4 Conclusions

This report, along with Rickman et al. (2025), provides internally consistent data on 29 lunar regolith simulants and related materials. All of the measurements at all frequencies were scaled to a pellet density of 1.75 g/cc, minimizing the effect of differing pellet densities. The data measured at 2466 MHz is provided in Appendix A.

Within the limits of the data, the -AGGL sample JSC-1A-AGGL is not noticeably different compared to the untreated JSC-1A. NU-LHT-2M-AGGL, between 100 °C and $\sim T \cong 700$ °C are functionally identical. Above 700 °C, MPN has stated the NU-LHT-2M data, A15, should not be trusted due to a mechanical problem with the pellets.

As expected, loss values of ϵ'' for the ilmenite are as much as several orders of magnitude different when compared to the silicate minerals, the simulant glasses, or the lunar simulants.

It has been proven that unwanted oxidation of the samples occurs during the high temperature measurements. The significance of the oxidation, in an absolute sense, is unknown. Critically, the plots make it clear that any effect oxidation may have had, it has left the relationships between materials logically reasonable and as expected.

5 Credits

All of the dielectric measurements were made by Microwave Properties North. Samples A23 - A26 were measured under contract with NASA. The senior author did the density scaling, provided knowledge about the simulants, organized the work, and wrote this document.

Permission to use the data for the two olivine samples was kindly given by John Forster john.forster@microwaveoresearch.com, and Erin Bobicki, currently of CURA in Edmonton, Alberta, Canada. Forster also allowed access to the ilmenite data. Access to these three data sets is very much appreciated by the authors.

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Appendix A. Original Measurements and Scaled Values

The following data tables are organized in the order given in Table 1.1. The ϵ' , ϵ'' , measured at 2466 MHz, and the corresponding Half Power Depth values reported by MPN are provided and the same values after scaling the density to 1.75 g/cc. All data measurements, heating and cooling, are included.

Note, there can be small discrepancies between the data shown in the MPN reports and the values shown here. The values used here are from ASCII files provided by MPN to the senior author. Each of the five files reports Index Temperature vs one variables: ϵ' , ϵ'' , HPD, LAPTS, Temp, at all frequencies measured. The ASCII files have more precision than the tables in the reports and can differ slightly from the printed documents. Also, if MPN reprocessed the data to adjust the temperature at which sample density was assumed to shift, the reports were not reissued while the ASCII files were. Both sources of difference can be found in the digital values, but together are too small to make a practical difference in the plots.

The data in the following tables are:

MPN index	- Such as SHUL2149. This links all of the work on a single measurement
MPN document	- Such as "MPN-218_Shulman_2_JSC-1A.docx" Report file by MPN
Index Temp	- A temperature, in degrees centigrade
ϵ'	- Real portion of the relative complex permittivity at frequency 2466 MHz
ϵ''	- Imaginary component of the relative complex permittivity at 2466 MHz
HPD	- Computed Half Power Depth in millimeters.
LAPTS	- Elapsed time in hours
Temp	- Temperature recorded for the specific measurement at the elapsed time.
ϵ' Scaled	- ϵ' scaled to a density of 1.75 g/cc
ϵ'' Scaled	- ϵ'' scaled to a density of 1.75 g/cc
Adjusted HPD	- HPD based on scaled ϵ' and scaled ϵ''

Temp varies with the frequency measured. In our work Index Temp is used rather than the recorded Temp in order that comparisons can be made between the six original difference frequencies. For the frequency report in this document, Index Temp will differ from the "Temp" by an amount that is considered insignificant given other limitations to accuracy in the measurement and the observed rates of change the reported variables with temperature. Study of these data has shown the difference between Index Temp and Temp increase with temperature and are <5% at 1300 °C.

Appendix A. Original Measurements and Scaled Values

NASA2589	MPN-337_NASA_Rickman_Stillwater Anorthosite.docx					Scaled Density 1.75		
Index Temp	e'	e''	HPD	LAPST	Temp	e' Scaled	e'' Scaled	Adjusted HPD
23.65	4.561	0.03865	741.9	0	23.21	3.7914	0.02902	899
23.68	4.545	0.03761	761.2	0.07184	23.43	3.7793	0.02825	922
23.68	4.538	0.03635	787	0.1301	23.43	3.7741	0.0273	954
109.3	4.443	0.02196	1289	0.3589	107.9	3.7027	0.01652	1562
163.9	4.45	0.01997	1418	0.5413	161.7	3.7079	0.01502	1719
216.6	4.497	0.01767	1612	0.707	213.5	3.7433	0.01328	1953
223.1	4.5	0.01552	1835	1.073	220	3.7455	0.01166	2226
217.5	4.503	0.0148	1925	1.438	214.4	3.7478	0.01112	2334
217.7	4.508	0.01424	2002	1.804	214.7	3.7515	0.0107	2427
217.2	4.51	0.01322	2156	2.169	214.1	3.753	0.00993	2616
216.9	4.516	0.01262	2262	2.535	213.8	3.7575	0.00948	2742
215.8	4.529	0.0123	2323	2.901	212.8	3.7673	0.00924	2817
263.9	4.562	0.01381	2077	3.05	260.1	3.7921	0.01037	2518
314.4	4.586	0.01574	1827	3.199	309.8	3.8101	0.01181	2216
366.1	4.607	0.01624	1775	3.364	361.9	3.8259	0.01218	2153
415	4.628	0.01807	1599	3.513	410.1	3.8416	0.01355	1939
464.5	4.629	0.02111	1369	3.661	458.9	3.8424	0.01583	1660
512.7	4.652	0.0232	1248	3.793	506.5	3.8596	0.0174	1514
562	4.669	0.0323	898.2	3.925	555	3.8724	0.02422	1089
611.6	4.671	0.0422	687.7	4.057	603.9	3.8739	0.03164	834
661.8	4.706	0.06005	485.1	4.189	653.3	3.9002	0.045	588
710	4.732	0.07887	370.4	4.304	700.7	3.9197	0.05909	449
759.4	4.762	0.1019	287.6	4.419	749.3	3.9421	0.07631	348
808.3	4.77	0.112	261.8	4.534	797.3	3.9481	0.08387	317
856.6	4.723	0.09432	309.4	4.649	844.8	3.9129	0.07067	375
905.3	4.68	0.09116	318.7	4.765	892.5	3.8807	0.06835	386
954	4.639	0.07789	371.3	4.88	940.2	3.8499	0.05843	450
1003	4.636	0.07018	412	4.995	988	3.8477	0.05265	499
1051	4.673	0.09171	316.5	5.11	1035	3.8754	0.06877	383
1100	4.746	0.1193	245.3	5.225	1083	3.9302	0.08937	297
1149	4.892	0.1565	189.8	5.34	1130	4.0395	0.11701	230
1197	5.162	0.2314	131.9	5.456	1171	4.2412	0.17243	160
1246	5.573	0.4067	77.99	5.571	1211	4.5471	0.30162	94
1295	6.029	0.5987	55.14	5.687	1264	4.8852	0.44191	67
1343	6.573	0.856	40.3	5.802	1311	5.2868	0.6286	49

Appendix A. Original Measurements and Scaled Values

1391	7.454	1.287	28.6	5.918	1349	5.9336	0.93826	34
1343	7.413	1.107	33.11	6.033	1318	5.9026	0.80736	40
1294	7.151	0.831	43.28	6.148	1271	5.7099	0.60735	52
1245	6.997	0.6414	55.43	6.264	1224	5.5965	0.46938	67
1197	6.897	0.4988	70.75	6.38	1177	5.5228	0.36534	86
1149	6.73	0.3729	93.46	6.497	1130	5.4001	0.27351	113
1096	6.275	0.1638	205.4	6.612	1079	5.0653	0.12063	250
1047	6.217	0.1304	256.9	6.727	1031	5.0226	0.09608	312
998.8	6.186	0.1173	284.8	6.844	984	4.9997	0.08646	346
950.3	6.164	0.1085	307.2	6.963	936.5	4.9835	0.07999	374
901.4	6.144	0.1022	325.8	7.085	888.6	4.9688	0.07536	396
852.5	6.125	0.0876	379.4	7.212	840.7	4.9547	0.0646	462
803.6	6.105	0.0772	429.8	7.344	792.7	4.94	0.05694	523
754.7	6.084	0.06647	498.3	7.481	744.7	4.9245	0.04904	606
705.2	6.136	0.05657	588	7.626	696	4.9628	0.04171	716
655.8	6.117	0.04491	739.6	7.779	647.4	4.9488	0.03312	900
605.7	6.092	0.03636	911.5	7.942	598.1	4.9304	0.02682	1110
556.1	6.058	0.02883	1146	8.117	549.3	4.9053	0.02127	1396
507.1	6.01	0.02454	1342	8.305	500.9	4.8698	0.01811	1634
455.3	5.998	0.01947	1689	8.507	449.9	4.861	0.01437	2057
408.7	5.962	0.01643	1995	8.732	403.9	4.8344	0.01213	2430
361.8	5.887	0.01128	2888	8.978	357.6	4.779	0.00833	3519
311.9	5.863	0.01061	3063	9.251	307.4	4.7612	0.00784	3732
264.6	5.822	0.009395	3449	9.578	260.7	4.7309	0.00695	4197
210.1	5.778	0.008766	3682	9.995	207.2	4.6983	0.00648	4486
114.6	5.696	0.008565	3742	11.08	113.1	4.6376	0.00634	4555
24	5.749	0.01508	2135	11.27	23.69	4.6769	0.01116	2598

Appendix A. Original Measurements and Scaled Values

NASA2587	MPN-337_NASA_Rickman_2nd Run NU-LHT-2M-AGGL.docx					Scaled Density 1.75		
Index Temp	e'	e''	HPD	LAPST	Temp	e' Scaled	e'' Scaled	Adjusted HPD
23.94	4.535	0.03659	781.5	0	23.32	3.7718	0.02749	947
23.95	4.532	0.03559	803.2	0.07184	23.61	3.7696	0.02674	973
23.95	4.522	0.0339	842.3	0.1302	23.61	3.7621	0.02547	1021
111	4.433	0.0276	1024	0.359	109.2	3.6951	0.02076	1241
165.3	4.455	0.02634	1076	0.5412	162.5	3.7117	0.01981	1304
216.5	4.49	0.02754	1033	0.7069	212.6	3.738	0.0207	1252
225.8	4.498	0.02507	1136	1.073	221.7	3.744	0.01884	1377
219.7	4.484	0.02555	1113	1.438	215.7	3.7335	0.01921	1348
219.1	4.486	0.02534	1122	1.804	215.1	3.735	0.01905	1360
217.7	4.483	0.02397	1186	2.169	213.8	3.7327	0.01802	1437
217.6	4.473	0.0244	1164	2.535	213.6	3.7252	0.01834	1411
218.1	4.473	0.02392	1187	2.901	214.2	3.7252	0.01798	1439
266.3	4.509	0.02687	1061	3.05	261.3	3.7523	0.02019	1286
316.1	4.551	0.02832	1011	3.199	310.1	3.7838	0.02127	1226
368.7	4.581	0.03104	925.9	3.364	362.9	3.8064	0.0233	1122
417.4	4.602	0.03456	833.7	3.513	410.8	3.8221	0.02594	1010
466.9	4.643	0.03891	743.7	3.661	459.4	3.8529	0.02918	902
515	4.673	0.04346	668	3.793	506.6	3.8754	0.03258	810
565.3	4.706	0.05176	562.9	3.925	555.9	3.9001	0.03879	682
615.7	4.727	0.06316	462.3	4.057	605.3	3.9159	0.04732	560
665.5	4.769	0.07802	375.9	4.188	654.1	3.9474	0.05842	456
713.9	4.809	0.09626	306	4.304	701.4	3.9773	0.07205	371
763.7	4.852	0.114	259.5	4.419	750.1	4.0095	0.08528	314
812.6	4.878	0.1331	222.9	4.534	797.8	4.029	0.09953	270
861.2	4.837	0.1419	208.2	4.649	845.2	3.9983	0.10617	252
910.1	4.742	0.1433	204	4.764	892.8	3.9272	0.10735	247
959	4.708	0.1483	196.5	4.879	940.3	3.9017	0.11115	238
1008	4.728	0.1646	177.4	4.994	988	3.9168	0.12333	215
1057	4.796	0.1954	150.5	5.11	1035	3.9677	0.14627	182
1106	4.933	0.2358	126.5	5.225	1083	4.0703	0.1762	153
1155	5.144	0.3013	101.1	5.34	1130	4.2279	0.22456	122
1204	5.605	0.4354	73.08	5.455	1165	4.5709	0.32279	88
1229	6.507	0.8084	42.46	5.571	1188	5.2381	0.594	51
1205	6.464	0.6743	50.7	5.687	1178	5.2058	0.49568	61
1156	6.12	0.4187	79.39	5.802	1132	4.9516	0.3088	96
1102	5.924	0.3377	96.81	5.917	1080	4.8067	0.24954	117

Appendix A. Original Measurements and Scaled Values

1053	5.853	0.329	98.79	6.032	1032	4.7542	0.24329	120
1004	5.809	0.32	101.2	6.147	984.6	4.7217	0.23674	123
955.7	5.768	0.3068	105.1	6.265	937.2	4.6913	0.22707	127
906.5	5.727	0.2911	110.4	6.387	889.2	4.6609	0.21554	134
857	5.663	0.2628	121.6	6.512	841.1	4.6135	0.19472	147
807.8	5.644	0.2429	131.4	6.643	793.2	4.5993	0.18001	159
758.5	5.605	0.2229	142.7	6.78	745	4.5704	0.16526	173
708.8	5.587	0.2034	156.1	6.924	696.5	4.557	0.15083	189
659.2	5.561	0.1857	170.5	7.076	647.9	4.5377	0.13775	207
608.8	5.509	0.1719	183.3	7.239	598.5	4.4991	0.12758	222
558.8	5.429	0.1523	205.5	7.414	549.6	4.4397	0.11314	249
510	5.342	0.1369	226.7	7.602	501.7	4.375	0.1018	275
458.1	5.33	0.1279	242.4	7.805	450.7	4.3661	0.09512	294
410.8	5.244	0.1155	266.3	8.029	404.3	4.302	0.08598	323
363.4	5.154	0.1037	294	8.277	357.7	4.235	0.07728	357
313.6	5.076	0.09479	319.2	8.549	307.7	4.1768	0.07071	387
265.7	5.024	0.08615	349.4	8.877	260.7	4.138	0.0643	424
211.1	4.963	0.07516	398	9.295	207.3	4.0925	0.05614	483
115.7	4.846	0.06065	487.4	10.38	113.5	4.005	0.04537	591
23.7	4.867	0.05124	578.1	18.72	23.42	4.0207	0.03832	701

Appendix A. Original Measurements and Scaled Values

NASA2583	MPN-337_NASA_Rickman_JSC-1A- AGGL_Argon.docx					Scaled Density 1.75		
Index Temp	e'	e''	HPD	LAPST	Temp	e' Scaled	e'' Scaled	Adjusted HPD
23.94	4.763	0.08508	343.9	0.07181	24.15	3.8809	0.06214	425
23.89	4.758	0.08247	354.6	0.1301	24.02	3.8772	0.06024	438
23.9	4.753	0.08113	360.3	0.331	24.03	3.8736	0.05927	445
56.37	4.796	0.08181	358.9	0.6255	55.88	3.905	0.05972	443
108.8	4.851	0.08285	356.4	0.9517	107.5	3.9451	0.06044	440
163.2	4.902	0.08688	341.7	1.282	161.1	3.9823	0.06333	422
214	4.949	0.09292	321	1.648	211.1	4.0166	0.06769	397
210	4.942	0.09093	327.8	2.013	207.1	4.0115	0.06625	405
209.3	4.942	0.09154	325.6	2.379	206.4	4.0115	0.06669	402
208.4	4.939	0.08978	331.9	2.744	205.5	4.0093	0.06541	410
208.9	4.939	0.09073	328.4	3.11	206	4.0093	0.0661	406
208.5	4.938	0.09071	328.5	3.476	205.6	4.0086	0.06609	406
207	4.935	0.09008	330.7	3.804	204.2	4.0064	0.06563	409
259.1	4.995	0.09839	304.6	4.155	255.4	4.0501	0.07163	376
315.2	5.053	0.1099	274.2	4.439	310.6	4.0923	0.07995	339
367.9	5.11	0.1268	239	4.728	363.7	4.1338	0.09217	295
420	5.167	0.146	208.7	5.012	415	4.1752	0.10605	258
470.2	5.226	0.1724	177.8	5.304	464.6	4.2181	0.12513	220
521.5	5.303	0.2135	144.6	5.555	515.1	4.274	0.15481	179
571.6	5.41	0.2807	111.1	5.809	564.5	4.3517	0.20326	137
621.8	5.622	0.3917	81.22	6.063	613.9	4.5053	0.28292	100
671.5	5.982	0.5214	62.95	6.317	662.9	4.7653	0.37507	78
721.2	6.392	0.691	49.12	6.571	711.7	5.0602	0.49494	61
770.4	6.744	0.9926	35.17	6.825	760.1	5.3135	0.70849	43
819.4	7.028	1.397	25.56	7.082	808.2	5.5188	0.99437	31
869.2	7.233	1.684	21.55	7.34	857.1	5.667	1.19632	26
919	7.509	1.932	19.17	7.594	905.9	5.8651	1.36919	23
967.6	7.907	2.163	17.59	7.851	953.5	6.1487	1.52803	21
1017	8.194	2.217	17.47	8.102	1002	6.3514	1.56294	21
1065	8.425	2.177	18.02	8.353	1049	6.5135	1.53239	22
1113	10.14	3.216	13.44	8.594	1084	7.7228	2.23939	16
1064	9.821	3.24	13.14	8.841	1047	7.5013	2.25984	16
1014	9.271	2.831	14.58	9.098	999.3	7.1132	1.98127	18
962.8	8.825	2.475	16.25	9.345	948.8	6.7973	1.73726	20
914.5	8.468	2.207	17.83	9.599	901.6	6.544	1.55303	22
864.4	8.133	1.951	19.73	9.85	852.4	6.3058	1.37629	24

Appendix A. Original Measurements and Scaled Values

815.2	7.835	1.713	22.03	10.1	804.1	6.0934	1.21121	27
764.9	7.547	1.519	24.38	10.36	754.8	5.8881	1.07654	30
714.4	7.294	1.324	27.47	10.61	705.1	5.7072	0.94036	34
663.8	7.065	1.165	30.69	10.86	655.3	5.5433	0.8291	38
613.8	6.856	1.036	33.98	11.11	606.1	5.3937	0.7387	42
563.8	6.646	0.9262	37.41	11.39	556.8	5.2432	0.66172	46
513.6	6.43	0.8174	41.68	11.69	507.3	5.0881	0.58522	51
463.3	6.219	0.7041	47.56	12.03	457.8	4.9363	0.5052	59
412.7	6.03	0.5859	56.26	12.4	407.9	4.8001	0.42124	69
361.7	5.872	0.4791	67.87	12.83	357.6	4.6859	0.34506	84
310.2	5.739	0.3927	81.84	13.33	305.7	4.5898	0.28326	101
259.4	5.627	0.3294	96.6	13.93	255.7	4.5088	0.23791	119
207.7	5.52	0.2834	111.2	14.72	204.8	4.4313	0.20495	137
155.1	5.407	0.2444	127.6	15.92	153	4.3495	0.17699	158
103.7	5.305	0.2084	148.2	20.33	102.4	4.2755	0.15111	183
24.27	5.158	0.1574	193.5		24.32	4.1687	0.11434	239

Appendix A. Original Measurements and Scaled Values

NASA2591	MPN-337_NASA_Rickman_JSC-1A- AGGL_Hydrogen.docx					Scaled Density 1.75		
Index Temp	e'	e''	HPD	LAPST	Temp	e' Scaled	e'' Scaled	Adjusted HPD
23.76	4.683	0.08399	345.4	0	24.04	3.8224	0.06142	426
23.7	4.693	0.08393	346.1	0.07183	23.86	3.8297	0.06136	427
23.68	4.688	0.08328	348.6	0.1302	23.85	3.8261	0.06089	430
88.71	4.715	0.08214	354.4	0.3589	87.72	3.8458	0.06004	438
131.1	4.729	0.08055	362	0.5411	129.4	3.856	0.05886	447
175.1	4.783	0.08421	348.2	0.7067	172.7	3.8955	0.06149	430
184.3	4.786	0.08332	352	1.072	181.8	3.8977	0.06084	435
180.3	4.788	0.08233	356.3	1.438	177.8	3.8991	0.06011	440
179.8	4.785	0.08127	360.9	1.804	177.4	3.897	0.05934	446
181	4.795	0.08302	353.6	2.169	178.6	3.9043	0.06061	437
179.9	4.791	0.08334	352.1	2.535	177.5	3.9013	0.06085	435
180.1	4.79	0.08301	353.5	2.901	177.7	3.9006	0.06061	437
218.9	4.841	0.08713	338.6	3.05	215.9	3.9378	0.06357	418
266.8	4.9	0.09529	311.5	3.199	263	3.9809	0.06946	385
315.6	4.965	0.1048	285	3.347	312	4.0283	0.07633	352
368.9	5.015	0.1191	252.2	3.496	364.6	4.0647	0.08668	311
425.2	5.07	0.1399	215.8	3.645	420.2	4.1047	0.10175	267
480.6	5.142	0.1748	174	3.776	474.8	4.1571	0.12701	215
534.8	5.245	0.2295	133.8	3.908	528.3	4.232	0.16653	165
593.5	5.404	0.3292	94.71	4.04	586	4.3475	0.2384	117
647.4	5.735	0.4424	72.63	4.172	639.2	4.5871	0.31912	90
699.5	6.218	0.6346	52.75	4.287	690.4	4.9353	0.45535	65
751.7	6.631	0.9119	37.95	4.402	741.7	5.2324	0.6516	47
804.1	6.916	1.343	26.37	4.518	793.2	5.4387	0.9569	32
854.8	7.145	1.642	21.97	4.633	842.9	5.6042	1.16737	27
904.8	7.356	1.845	19.86	4.748	892	5.7559	1.30921	24
954.2	7.772	2.101	17.95	4.863	940.4	6.0528	1.48578	22
1003	8.157	2.227	17.35	4.978	988.4	6.3255	1.57038	21
1052	8.473	2.284	17.24	5.093	1036	6.5483	1.60706	21
1101	10.24	3.298	13.17	5.209	1084	7.7932	2.29518	16
1055	9.493	2.946	14.19	5.324	1039	7.2694	2.05895	17
1002	9.015	2.589	15.71	5.439	986.8	6.9315	1.815	19
952.4	8.626	2.308	17.21	5.554	938.6	6.656	1.6223	21
903.1	8.262	2.051	18.93	5.673	890.4	6.3976	1.44543	23
853.5	7.945	1.814	20.97	5.797	841.7	6.1719	1.28149	26
804	7.637	1.6	23.29	5.925	793.2	5.9524	1.13309	29

Appendix A. Original Measurements and Scaled Values

753.9	7.357	1.392	26.24	6.06	744	5.7524	0.98811	32
702.2	7.133	1.214	29.6	6.203	693.1	5.592	0.86345	36
648.7	6.919	1.069	33.09	6.354	640.4	5.4388	0.76179	41
594.9	6.704	0.9336	37.27	6.515	587.5	5.2846	0.66665	46
542.3	6.503	0.8172	41.92	6.687	535.7	5.1403	0.58467	52
488.4	6.26	0.6873	48.88	6.872	482.6	4.9656	0.49294	60
432.2	6.08	0.5789	57.17	7.071	427.1	4.836	0.41599	70
377	5.889	0.4673	69.68	7.287	372.7	4.6981	0.3365	86
325.1	5.755	0.3923	82.03	7.527	321.4	4.6013	0.28292	101
274.5	5.604	0.3325	95.49	7.795	270.6	4.4922	0.24021	118
227.7	5.456	0.2833	110.6	8.114	224.5	4.385	0.20503	137
177.4	5.352	0.2478	125.2	8.526	175.1	4.3096	0.17957	155
91.82	5.232	0.2053	149.4	9.544	90.78	4.2225	0.149	184
23.67	5.129	0.1656	183.3	10.17	23.85	4.1476	0.12035	226

Appendix A. Original Measurements and Scaled Values

ECERF1437	ECERF_6_mod.doc					Scaled Density 1.75		
Index Temp	e'	e''	HPD	LAPST	Temp	e' Scaled	e'' Scaled	Adjusted HPD
24.07	4.079	0.03186	85	0	23.58	3.5699	0.02576	983
49.2	4.074	0.02678	101	0.2367	47.98	3.5659	0.02165	1169
98.55	4.081	0.02113	128.2	0.4785	95.02	3.5715	0.01708	1483
146.4	4.094	0.01713	158.4	0.7386	140.6	3.582	0.01385	1832
195.8	4.138	0.01946	140.2	0.9546	193.2	3.6176	0.01572	1622
245.3	4.186	0.0215	127.6	1.174	241.8	3.6564	0.01736	1477
294.5	4.204	0.02228	123.4	1.397	290.2	3.6709	0.01799	1428
345.8	4.226	0.02646	104.2	1.575	341.9	3.6887	0.02135	1206
396	4.245	0.03112	88.75	1.749	391.4	3.704	0.02511	1027
445.8	4.268	0.03456	80.14	1.922	440.4	3.7226	0.02788	928
494.6	4.298	0.03878	71.67	2.093	488.5	3.7468	0.03127	830
544.6	4.36	0.0501	55.88	2.263	537.7	3.7968	0.04037	647
594.1	4.446	0.06864	41.19	2.432	586.3	3.8661	0.05526	477
644.3	4.562	0.09789	29.26	2.603	635.5	3.9594	0.07872	339
693.7	4.611	0.119	24.2	2.773	683.9	3.9988	0.09564	280
743.9	4.622	0.1343	21.46	2.945	733	4.0077	0.10793	248
793.4	4.576	0.1313	21.85	3.117	781.4	3.9707	0.10557	253
843.7	4.59	0.1248	23.02	3.289	830.4	3.982	0.10033	266
892.7	4.575	0.128	22.41	3.46	878.1	3.9699	0.10292	259
941.3	4.578	0.1504	19.08	3.631	925.2	3.9724	0.12092	221
990.4	4.602	0.1683	17.09	3.803	972.7	3.9917	0.13528	198
1039	4.584	0.1297	22.14	3.976	1019	3.9772	0.10427	256
1087	4.574	0.09486	30.23	4.152	1066	3.9691	0.07627	350
1136	4.58	0.08345	34.38	4.329	1113	3.9739	0.06709	398
1084	4.575	0.1042	27.53	4.487	1063	3.9699	0.08378	318
988	4.583	0.133	21.59	4.731	970.5	3.9764	0.10693	250
891.1	4.55	0.1382	20.7	4.982	876.5	3.9498	0.11115	239
795.5	4.488	0.1189	23.89	5.285	783.4	3.8999	0.09569	276
698.4	4.417	0.1047	26.91	5.657	688.5	3.8427	0.08433	311
600.2	4.334	0.08224	33.94	6.123	592.3	3.7758	0.0663	393
501.7	4.246	0.05723	48.27	6.712	495.4	3.7048	0.04618	558
402.9	4.171	0.04126	66.37	7.455	398.1	3.6443	0.03332	768
302.9	4.106	0.02703	100.5	8.447	298.5	3.5917	0.02185	1163
203.1	3.937	0.01245	213.7	9.277	200.4	3.455	0.01008	2473
24.11	3.908	0.008548	310.1	9.581	23.88	3.4315	0.00692	3590

Appendix A. Original Measurements and Scaled Values

QUEENS2433	MPN-308_Ravash_QUEENS_Olivine.docx					Scaled Density 1.75		
Index Temp	e'	e''	HPD	LAPST	Temp	e' Scaled	e'' Scaled	Adjusted HPD
22.64	4.227	0.02135	1291	0	23.34	3.2404	0.0139	1736
22.54	4.227	0.0197	1399	0.07176	22.95	3.2404	0.01283	1881
22.57	4.226	0.0188	1466	0.13	22.97	3.2397	0.01224	1972
53.34	4.24	0.02035	1356	0.333	52.99	3.2489	0.01325	1824
76.97	4.24	0.02054	1344	0.4997	76.34	3.2489	0.01337	1808
103.6	4.247	0.02087	1324	0.688	102.7	3.2534	0.01359	1780
127.8	4.248	0.02161	1279	0.8689	126.6	3.2541	0.01407	1719
154.7	4.267	0.01823	1519	1.068	153.1	3.2664	0.01186	2043
177.8	4.279	0.01919	1446	1.255	175.9	3.2743	0.01248	1944
203.3	4.287	0.01894	1465	1.462	201.1	3.2795	0.01232	1971
226.3	4.29	0.01848	1503	1.664	223.9	3.2814	0.01202	2021
253	4.311	0.01922	1448	1.876	250.2	3.2951	0.01249	1949
277	4.321	0.02001	1392	2.077	273.9	3.3016	0.013	1874
303.1	4.32	0.02028	1374	2.286	299.7	3.3009	0.01318	1848
326.8	4.331	0.0207	1348	2.486	323.1	3.3081	0.01345	1813
352.7	4.354	0.02289	1222	2.671	348.7	3.323	0.01486	1645
378.2	4.358	0.02446	1144	2.855	373.8	3.3256	0.01588	1540
403.6	4.376	0.02559	1096	3.039	398.9	3.3373	0.01661	1475
426.6	4.386	0.02655	1058	3.216	421.5	3.3438	0.01723	1423
453.8	4.412	0.03089	911.7	3.407	448.4	3.3607	0.02003	1227
478.7	4.425	0.03249	868.1	3.591	472.9	3.3691	0.02107	1168
503.4	4.454	0.03477	813.7	3.775	497.3	3.3879	0.02253	1095
527.9	4.471	0.0405	700	3.959	521.5	3.3989	0.02623	942
552.8	4.49	0.04556	623.6	4.127	546	3.4112	0.0295	839
577.3	4.525	0.05816	490.4	4.294	570.2	3.4339	0.03763	660
601.9	4.555	0.06261	457	4.462	594.3	3.4533	0.04048	615
626.3	4.584	0.07384	388.7	4.629	618.4	3.4721	0.04772	523
652.7	4.63	0.08673	332.7	4.803	644.4	3.5018	0.05599	448
675.1	4.672	0.0959	302.2	4.964	666.5	3.5289	0.06186	407
702.4	4.713	0.1018	285.9	5.141	693.3	3.5553	0.06561	385
726.7	4.744	0.1057	276.4	5.308	717.2	3.5753	0.06808	372
751.9	4.769	0.106	276.3	5.479	741.9	3.5914	0.06824	372
775.2	4.794	0.1084	270.9	5.643	764.8	3.6075	0.06975	365
801.3	4.822	0.1085	271.3	5.817	790.5	3.6255	0.06977	366
823.4	4.857	0.1164	253.9	5.978	812.2	3.648	0.0748	342
852.5	4.884	0.1163	254.8	6.162	840.7	3.6654	0.0747	343
875.5	4.914	0.1235	240.7	6.326	863.3	3.6847	0.07927	324

Appendix A. Original Measurements and Scaled Values

901.6	4.92	0.121	245.7	6.5	888.9	3.6885	0.07766	331
923.7	4.929	0.1195	249.1	6.66	910.5	3.6943	0.07668	336
950.7	4.925	0.1198	248.3	6.838	937	3.6917	0.07688	335
975.1	4.923	0.1143	260.3	7.002	960.9	3.6904	0.07335	351
1001	4.923	0.1118	266	7.179	986.1	3.6904	0.07175	359
956.5	4.895	0.1014	292.5	7.407	942.7	3.6724	0.06511	394
907.3	4.865	0.09897	298.8	7.654	894.5	3.6532	0.06359	403
856.5	4.835	0.09586	307.5	7.908	844.6	3.6339	0.06163	414
807.2	4.808	0.09883	297.5	8.159	796.3	3.6165	0.06357	401
756.7	4.774	0.09969	293.9	8.413	746.7	3.5946	0.06417	396
706.2	4.728	0.1075	271.3	8.667	697	3.565	0.06926	365
655.5	4.69	0.103	282	8.921	647.1	3.5405	0.06641	380
605.9	4.644	0.09722	297.2	9.172	598.4	3.5108	0.06275	400
556.2	4.599	0.09026	318.5	9.423	549.3	3.4818	0.05831	429
506.3	4.543	0.08593	332.6	9.695	500.2	3.4456	0.05558	447
456.3	4.485	0.08016	354.2	9.998	450.9	3.408	0.05191	476
406.3	4.415	0.07453	378	10.33	401.6	3.3626	0.04834	508
356.1	4.379	0.06559	427.8	10.71	352	3.3393	0.04258	575
305.2	4.342	0.05646	494.8	11.14	301.8	3.3152	0.03668	665
255.1	4.296	0.0522	532.3	11.65	252.3	3.2853	0.03395	716
204.6	4.266	0.04582	604.4	12.26	202.4	3.2658	0.02982	812
153	4.226	0.0404	682.2	13.06	151.5	3.2398	0.02632	917
102.6	4.191	0.03491	786.3	14.27	101.7	3.2169	0.02276	1056
22.91	4.15	0.02838	962.3	19.8	23.24	3.1902	0.01852	1293

Appendix A. Original Measurements and Scaled Values

QUEENS2435	MPN-308_ Ravash_QUEENS_Ilmenite.docx					Scaled Density 1.75		
	Index Temp	e'	e''	HPD	LAPST	Temp	e' Scaled	e'' Scaled Adjusted HPD
22.69	10.95	2.127	20.96	0	23.37	5.2029	0.77402	39
22.62	10.92	2.111	21.09	0.07179	23.01	5.1918	0.76853	39
22.61	10.9	2.098	21.19	0.13	23.01	5.1844	0.76402	40
45.5	11.21	2.462	18.34	0.3257	45.25	5.3008	0.89238	34
69.81	11.53	2.775	16.52	0.4891	69.27	5.42	1.00119	31
89.73	11.82	3.086	15.06	0.6798	88.95	5.5281	1.10884	28
109.7	12.31	3.518	13.5	0.8702	108.6	5.7088	1.25583	25
129.6	13.1	4.086	12.01	1.081	128.3	5.9964	1.44452	22
144.5	13.9	4.526	11.19	1.274	143.1	6.283	1.58592	21
159.4	14.81	4.937	10.59	1.485	157.8	6.6046	1.71406	20
179.4	15.77	5.233	10.31	1.683	177.5	6.9388	1.80092	19
199.3	16.81	5.488	10.15	1.892	197.2	7.2966	1.87227	19
219.2	17.65	5.64	10.11	2.089	216.8	7.5826	1.91165	19
244.1	18.76	5.809	10.11	2.302	241.4	7.9575	1.95322	19
259	19.32	5.867	10.16	2.496	256.2	8.1451	1.96525	19
278.9	20.14	6.167	9.867	2.676	275.8	8.4214	2.05439	19
298.8	20.83	6.5	9.525	2.86	295.5	8.6538	2.15563	18
328.7	21.65	7.276	8.692	3.045	325	8.9336	2.39997	16
353.6	22.16	8.042	7.973	3.221	349.6	9.1111	2.64341	15
388.5	22.81	8.93	7.302	3.412	383.9	9.3358	2.92289	14
418.3	23.76	10.05	6.639	3.598	413.4	9.6605	3.27053	12
438.2	24.21	10.43	6.461	3.786	433	9.8114	3.38573	12
463.1	25.15	11.65	5.918	3.978	457.6	10.1326	3.76135	11
557.6	29.15	16.52	4.541	4.142	550.8	11.4808	5.22746	8
577.5	29.57	17.52	4.327	4.35	570.3	11.6302	5.53106	8
599.3	30.69	19.14	4.049	4.518	591.8	12.0083	6.01179	7
624.8	32.2	21.2	3.762	4.685	616.9	12.5132	6.61651	7
651.9	33.5	22.99	3.55	4.859	643.6	12.946	7.13809	6
674.7	35.17	25.46	3.301	5.02	666	13.5024	7.85466	6
702.2	36.39	28.17	3.055	5.197	693.1	13.9256	8.64668	6
726.7	38.12	29.71	2.967	5.364	717.2	14.4756	9.07264	5
752	38.68	29.87	2.97	5.535	742.1	14.6462	9.10909	5
775.4	39.66	33.01	2.744	5.699	765.1	15.0023	10.02365	5
801.6	41.27	40.69	2.321	5.873	790.8	15.6427	12.25207	4
823.8	42.87	46.07	2.116	6.034	812.6	16.2301	13.78379	4
852.9	45.82	54.53	1.881	6.219	841.1	17.2739	16.15485	3

Appendix A. Original Measurements and Scaled Values

875.9	48.61	62.36	1.718	6.383	863.7	18.249	18.32211	3
902.1	53.04	71.95	1.572	6.557	889.4	19.7165	20.92518	3
924.1	56.46	77.41	1.511	6.718	911	20.7947	22.37552	3
951.2	60.27	86.71	1.408	6.895	937.5	22.0566	24.87383	2
974.3	62.69	99.93	1.275	7.059	960.1	23.0113	28.45777	2
1001	71.77	112.4	1.208	7.236	986.3	25.7518	31.66291	2
956.9	67.66	105	1.252	7.464	943	24.4785	29.73606	2
907.5	60.17	96.67	1.294	7.711	894.7	22.2486	27.61973	2
857	56.71	84.62	1.411	7.965	845.2	21.0249	24.37407	2
807.5	52.05	77.77	1.471	8.216	796.6	19.5728	22.5758	2
757.1	49.21	68.18	1.605	8.47	747	18.5534	19.95328	3
706.7	45.49	59.87	1.739	8.724	697.5	17.3044	17.68749	3
655.9	43.02	51.42	1.934	8.978	647.6	16.3974	15.32673	3
606.4	40.24	45.17	2.106	9.229	598.8	15.445	13.58329	4
556.6	37.29	40.52	2.248	9.48	549.7	14.4717	12.29437	4
506.6	34.76	34.93	2.488	9.752	500.4	13.5898	10.7036	4
456.8	32.34	30.14	2.752	10.05	451.4	12.7516	9.32911	5
406.8	29.25	25.71	3.045	10.39	402.1	11.7092	8.06107	5
356.5	27.36	22.59	3.327	10.77	352.4	11.0544	7.14922	6
305.5	24.4	19.22	3.674	11.2	302.1	10.0528	6.1731	7
255.5	21.66	16.09	4.109	11.7	252.7	9.1101	5.25134	8
204.6	18.65	12.31	4.931	12.31	202.5	8.0461	4.1059	9
153.2	15.74	8.654	6.36	13.11	151.6	6.9944	2.96288	12
102.7	13.4	5.778	8.682	14.3	101.8	6.1315	2.03039	16
22.73	10.93	2.352	18.95	16.76	23.33	5.1982	0.85588	35

Appendix B. Reports from Microwave Properties North

MPN reports for each run are provided below, ordered following the master measurement table, Table 1. Here the reports are reproduced verbatim, and each is 13 to 26 pages long. A report starts with a line giving the report's file name and the date, and ends after the printed ϵ'' data table. The reports contain much more information than is the focus of this paper. All reports include both the ϵ' and the ϵ'' data tables for all frequencies measured, and tables, and graphs of multiple variables needed to understand the data. Many of the reports also have photos of the pellets before and after processing.

35 – 51	Stillwater Anorthosite	MPN-337_NASA_Rickman_Stillwater Anorthosite
52 – 66	JSC-1A-AGGL Ar	MPN-337_NASA_Rickman_JSC-1A-AGGL_Argon
67 – 80	JSC-1A-AGGL H2	MPN-337_NASA_Rickman_JSC-1A- AGGL_4%Hydrogen
81 – 97	NU-LHT-2M-AGGL	MPN-337_NASA_Rickman_NU-LHT-2M-AGGL
98 – 114	Olivine	ECERF_6_mod
115 – 129	Olivine	MPN-308_Ravash_QUEENS_Olivine
130 – 143	Ilmenite	MPN-308_Ravash_QUEENS_Ilmenite

MPN-337_NASA_Rickman_Stillwater Anorthosite Oct. 13, 2025

Stillwater Anorthosite Powder Pellets

Measurements of Complex Dielectric Constant Between 400 and 2985 MHz from Room Temperature to 1400°C to Room Temperature , in 10 sccm Flowing 4% H₂/Argon

Jozef Mouris and Ronald Hutcheon (MPN)

Douglas Rickman of the Space Exploration Division of Amentum (on contract to NASA), requested that MPN measure the complex dielectric properties of pellets of lunar simulant materials which included one of the usual lunar simulant constituents, “Stillwater Anorthosite” .

The powder arrived in a sealed container at MPN on Sept. 4 /2025. The container was first opened on Oct. 10 and three pellets were pressed at ~ 27,000 psi (based on earlier experience with NU-LHT-5M simulant pellet pressing). These pellets seemed to have sufficient strength for handling. Doug had requested an initial density close to the previous runs, and this seemed adequate.

These measurements were done with the pellets in a high purity alumina crucible inside an 8 mm OD fused silica holder, with 4% hydrogen/argon gas mix flowing up past the crucible and out at the top of the holder through the edges around a loose-fitting fused silica plug.

This measurement run was started ~ 8 hours after the pellets were pressed, and the handling of the pellets did not indicate any “fragility”. The pellets retained their integrity during measurement of their dimensions and insertion into the crucible.

The parameters of the initial pellet stack (3 pellets) , were:

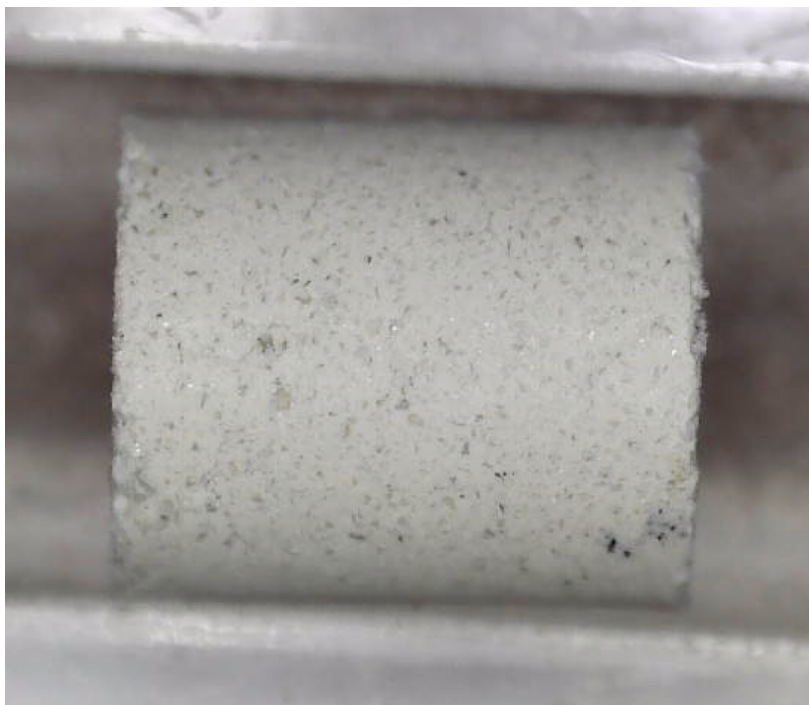
- a) diameter 3.63 +- 0.05 mm
- b) length 14.21 +- 0.10 mm
- c) mass 0.303 +- 0.002 gm
- d) room temperature density 2.06 ± 0.10 gm/cc.
- e) appearance - pellets white/very light grey (see photo of single pellet)

The dielectric properties measurement run consisted of calibration measurements, then three sample measurements at room temperature (RT), then a single measurement at 50C, then 25C steps up to 200C, at which point a 2 hour hold was started, with measurements every 20 minutes. This was to measure the effect of moisture loss (The measurements showed no detectable moisture). The run was then continued in 50C steps to 1400 C, then in -50C steps to 100C, then RT. At the end of the run, the mass of the holder and pellets was measured at room temperature. The pellets had not interacted with the alumina crucible, but had “sintered” into a single rod (see photos) , which came out of the holder easily. Then the empty holder was run to 1250 C to check for contamination. There was no contamination .

The final sample stack properties, at room temperature were :

- a) diameter 3.54 ± 0.05 mm
- b) length 13.54 ± 0.05 mm
- c) mass 0.301 ± 0.002 gm
- d) room temperature density 2.26 ± 0.10 gm/cc.
- e) appearance - light grey rod formed by joining of the three pellets (see photo)

Stillwater Anorthosite

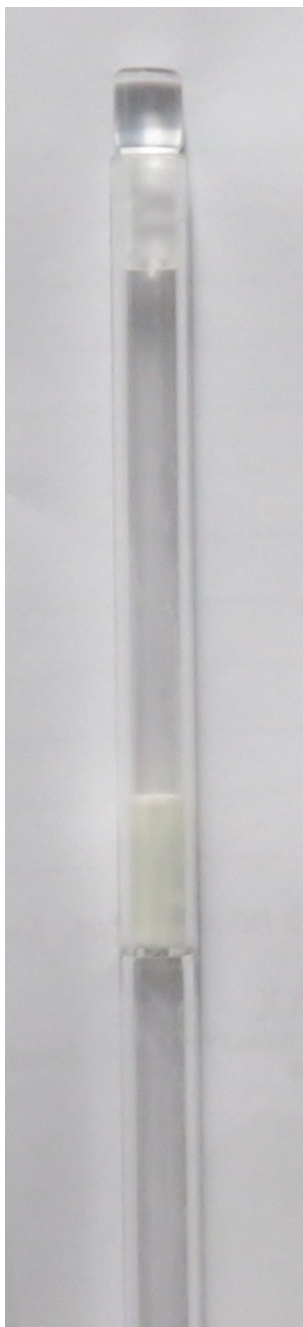


One of the freshly pressed pellets – pressed at $\sim 27,000$ psi .



The final, joined, pellets (after the run to 1400 C in 4% hydrogen/argon).

Stillwater Anorthosite



Measurement setup – with crucible in holder , and
tight fused silica plug in top of holder to reduce/stop air backflow.

Stillwater Anorthosite

The frequency coding is :

Legend for Data Plots :

#	Frequency(MHz)	Symbol
1	397	red diamond, solid line – sometimes the line is omitted!
2	912	blue square, solid line
3	1429	black cross, solid line
4	1948	blue circle, dotted line
5	2466	red cross, dotted line
6	2986	black diamond, dotted line

Comments on the data analysis:

A linear thermal expansion coefficient (CTE) of $0.0 * 10^{-6}/C$ was used.

The ϵ'' values up to 200 C show only a hint of loss of ad/absorbed moisture.

Between 550C and 800 C, some small component melts or dissociates – as indicated by ϵ'' .

The ϵ' values drop slightly between 800C and 1000C

The loss mechanism becomes frequency-dependent starting at ~ 550 C, and indicates disordered structure ionic loss mechanism over the whole range back down to 1100C, where the frequency dependence suddenly disappears ! Recrystallization ?

The rapid increase at ~ 1100 C suggests the influence of melting of some component.

Something happens between 1150C and 1100 C on the way back down in temperature. From my understanding, the sudden decrease in frequency dependence of ϵ'' looks like re-crystallization.

Stillwater Anorthosite

Code Calculates Estimated Sample Dimensions & Volume and Plots Density As a Function of Temperature

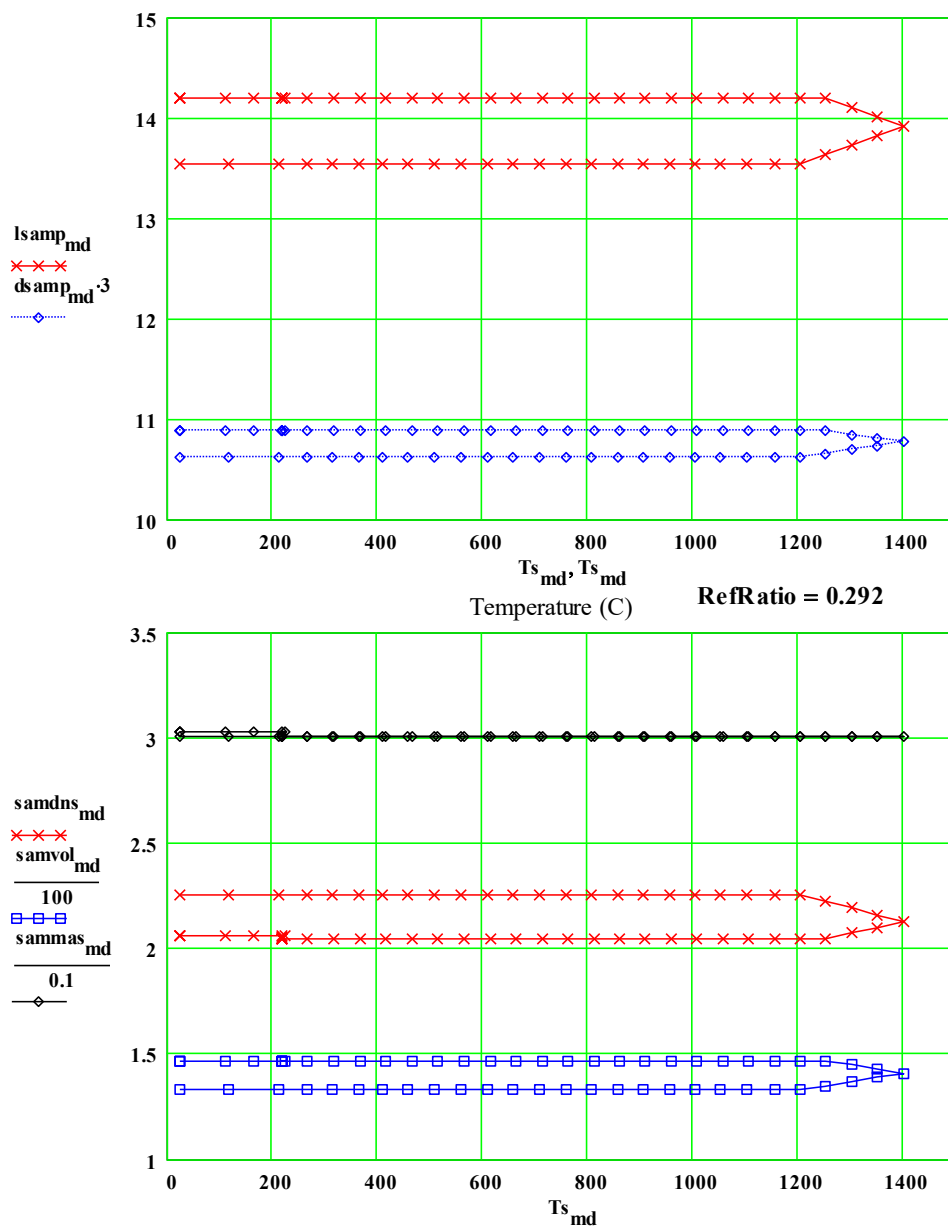
[illegible]

Test = 2025101001

NASA2589.mcd

AnDat = 20251011

Stillwater Anorthosite pellets, Holder + Crucible, RT- 1400C, in flowing 4% Hydrogrn ,D. Rickman, NASA



Stillwater Anorthosite

Test = 2025101001

NASA2589.mcd

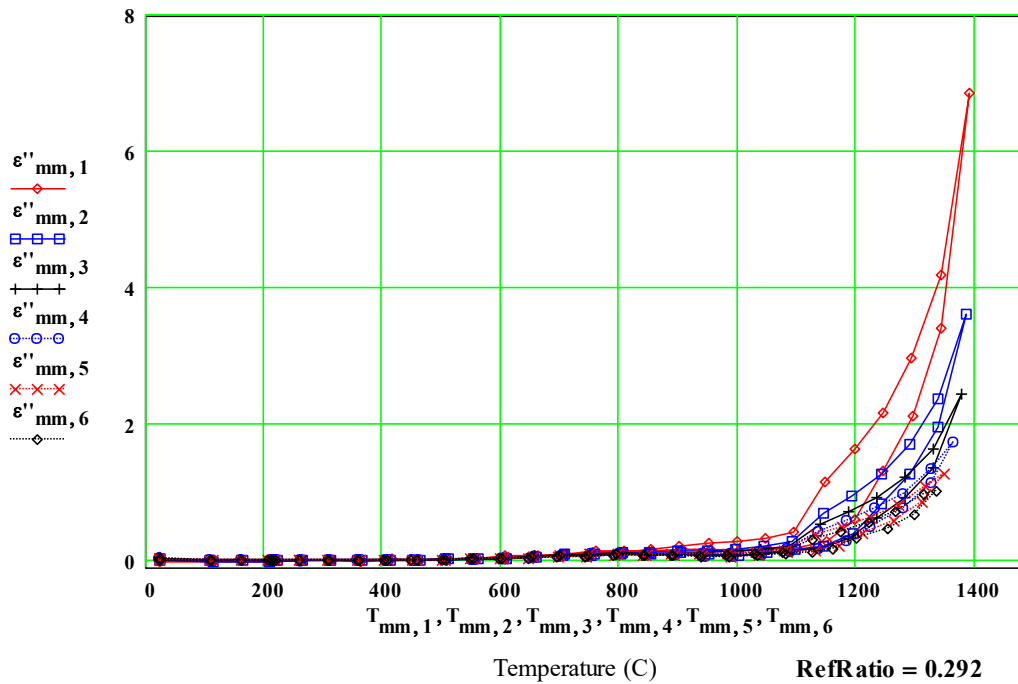
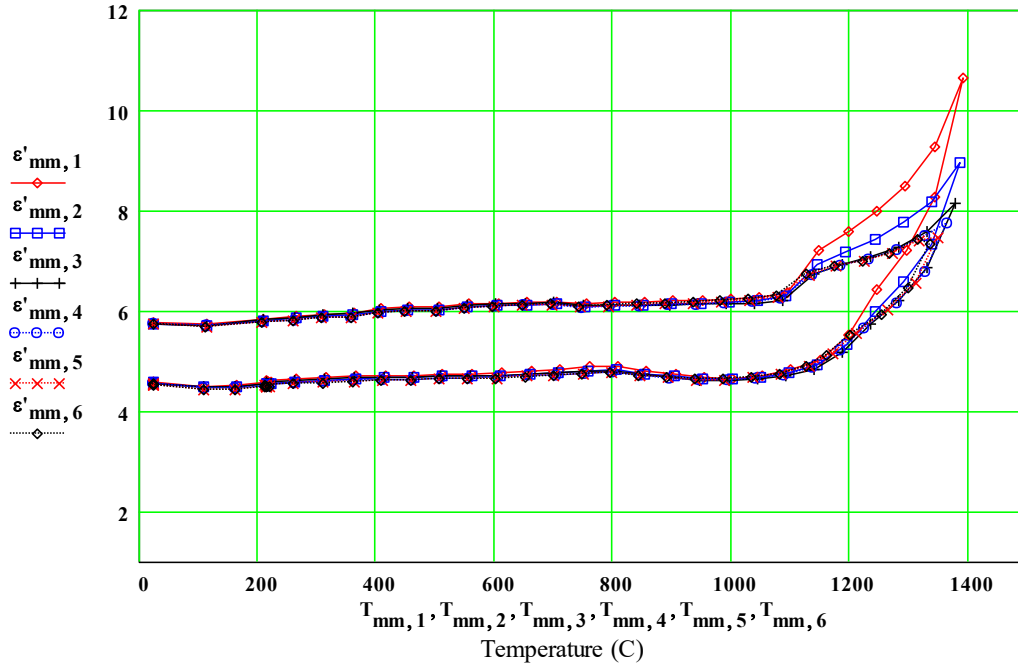
AnDat = 20251012

Stillwater Anorthosite pellets, Holder + Crucible, RT- 1400C, in flowing 4% Hydrogrn ,D. Rickman, NASA

Initial density = $\text{samdns}_{\text{NCal} + 1} = 2.06 \text{ gm/cc}$,

Final density(25C) = $\text{dnsfinal} = 2.26 \text{ gm/cc}$

FracMassChange = 0.993



RefRatio = 0.292

Stillwater Anorthosite

Test = 2025101001

NASA2589.mcd

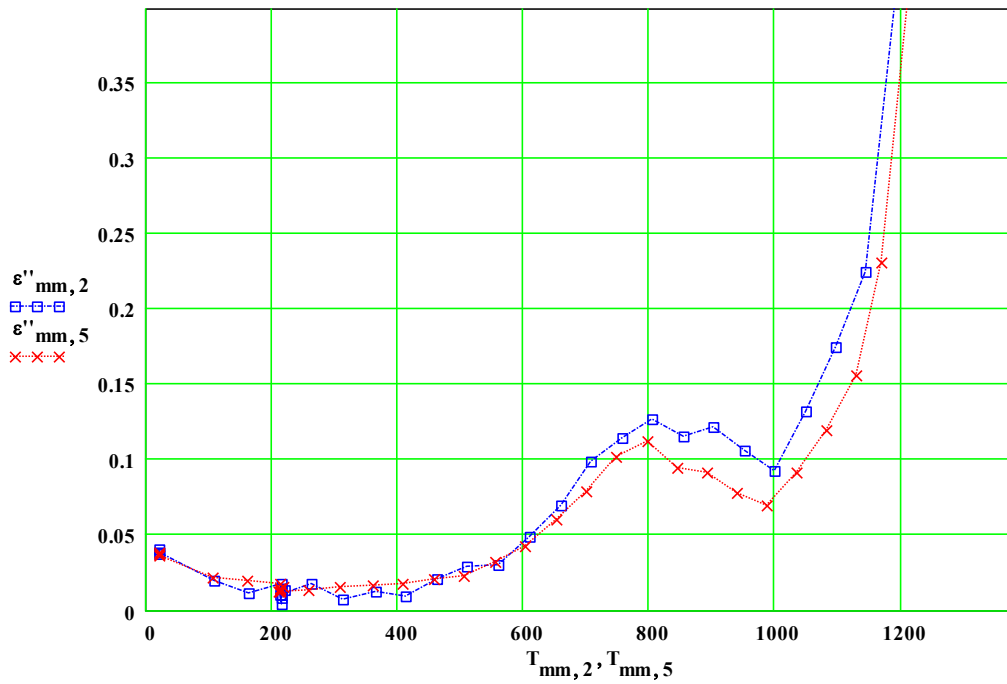
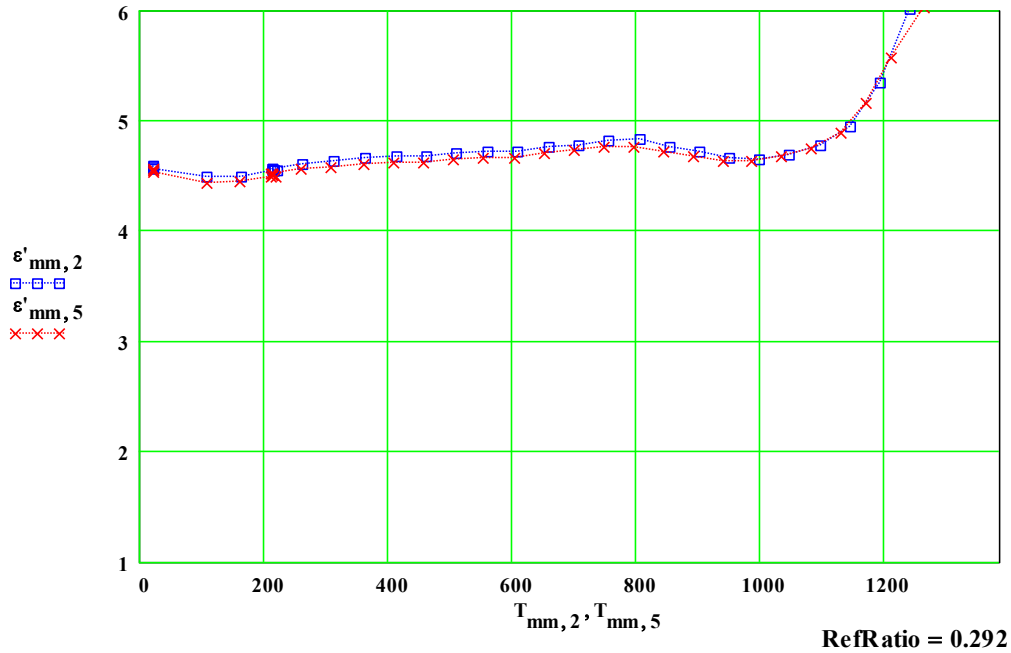
AnDat = 20251012

Stillwater Anorthosite pellets, Holder + Crucible, RT- 1400C, in flowing 4% Hydrogrn ,D. Rickman, NASA

Initial density = $\text{samdns}_{\text{NCal} + 1} = 2.06 \text{ gm/cc}$,

linear thermal expansion

Final density(25C) = $\text{dnsfinal} = 2.26 \text{ gm/cc}$ $\text{FracMassChange} = 0.99$ coef/deg C $\alpha_3 = 0 \cdot 10^{-6}$



Values during ramp-up of temperature.

Stillwater Anorthosite

Test = 2025101001

NASA2589.mcd

AnDat = 20251012

Stillwater Anorthosite pellets, Holder + Crucible, RT- 1400C, in flowing 4% Hydrogen, D. Rickman, NASA

Initial density = $\text{samdns}_{\text{NCal} + 1} = 2.06 \text{ gm/cc}$,

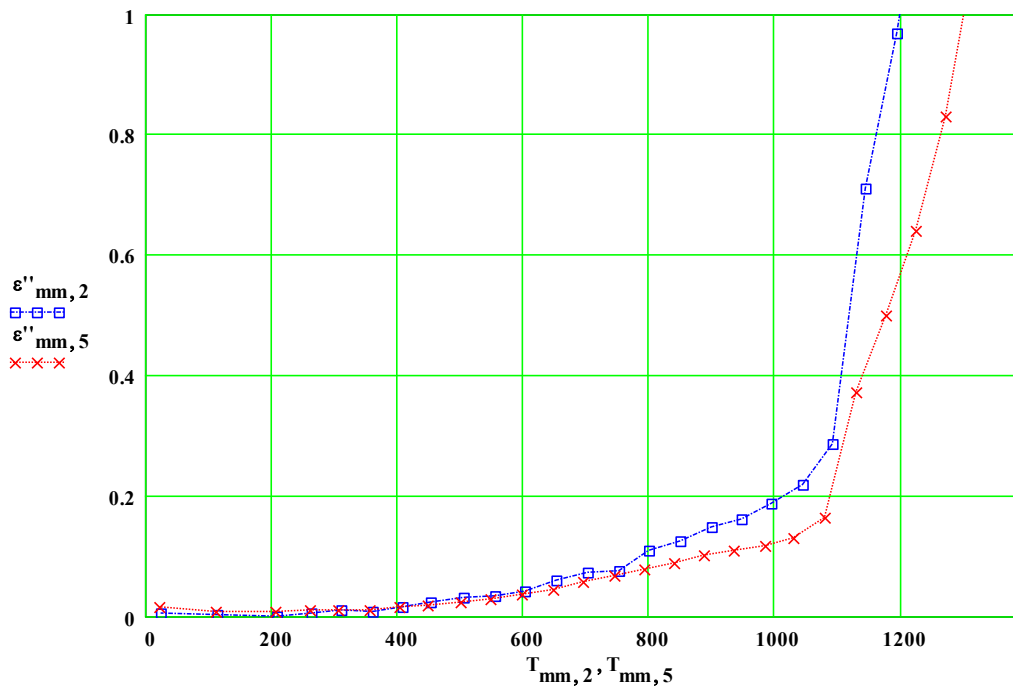
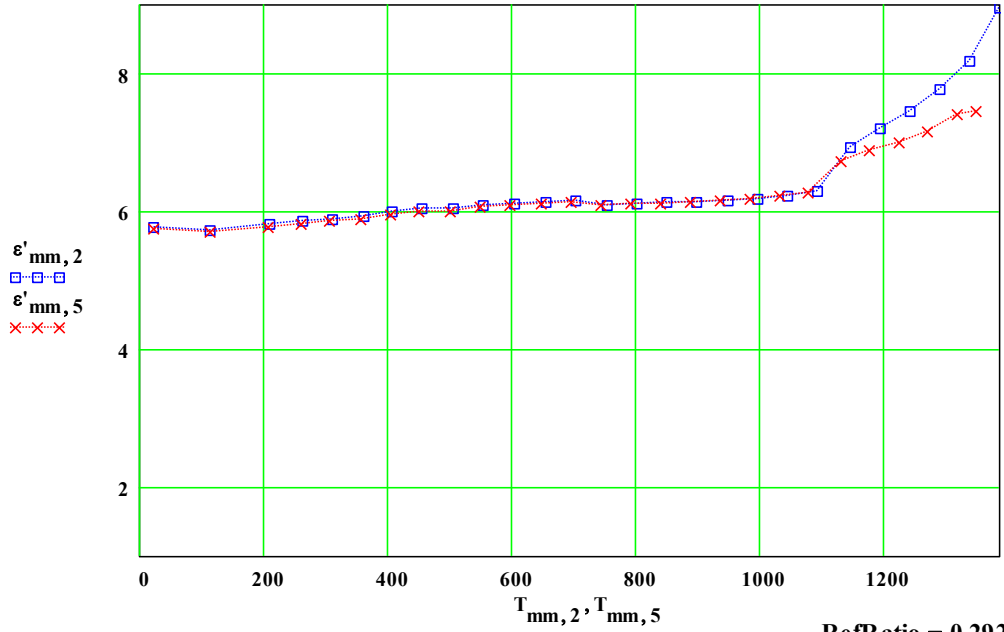
linear thermal expansion

Final density(25C) = $\text{dnsfinal} = 2.26 \text{ gm/cc}$

FracMassChange = 0.99

coef/deg C

$\alpha_3 = 0 \cdot 10^{-6}$



Values during ramp-down of temperature.

Stillwater Anorthosite

Test = 2025101001

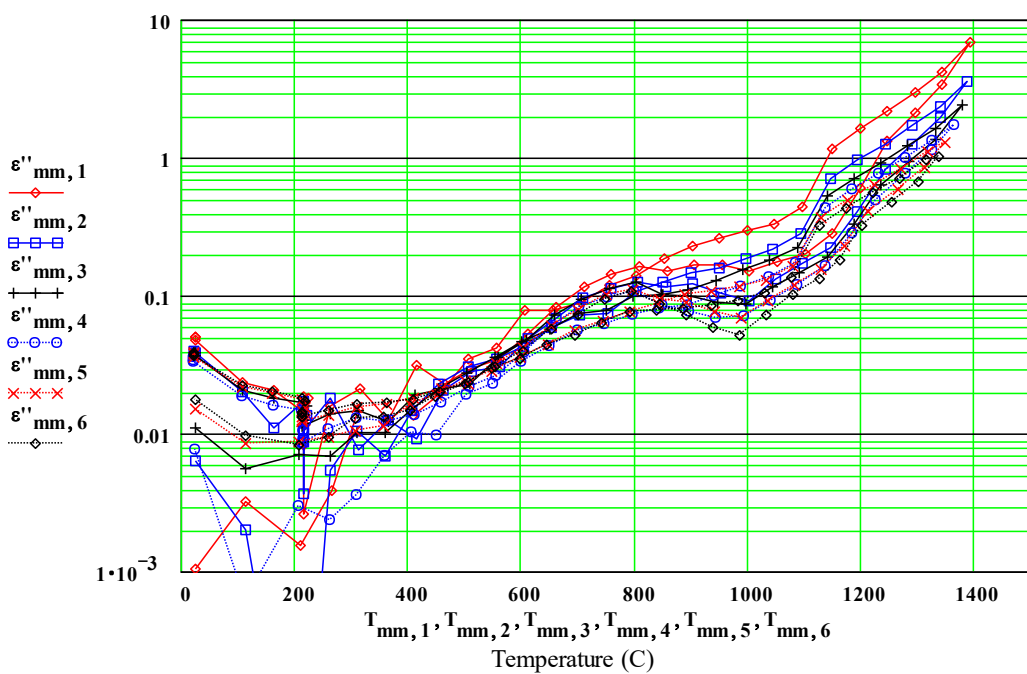
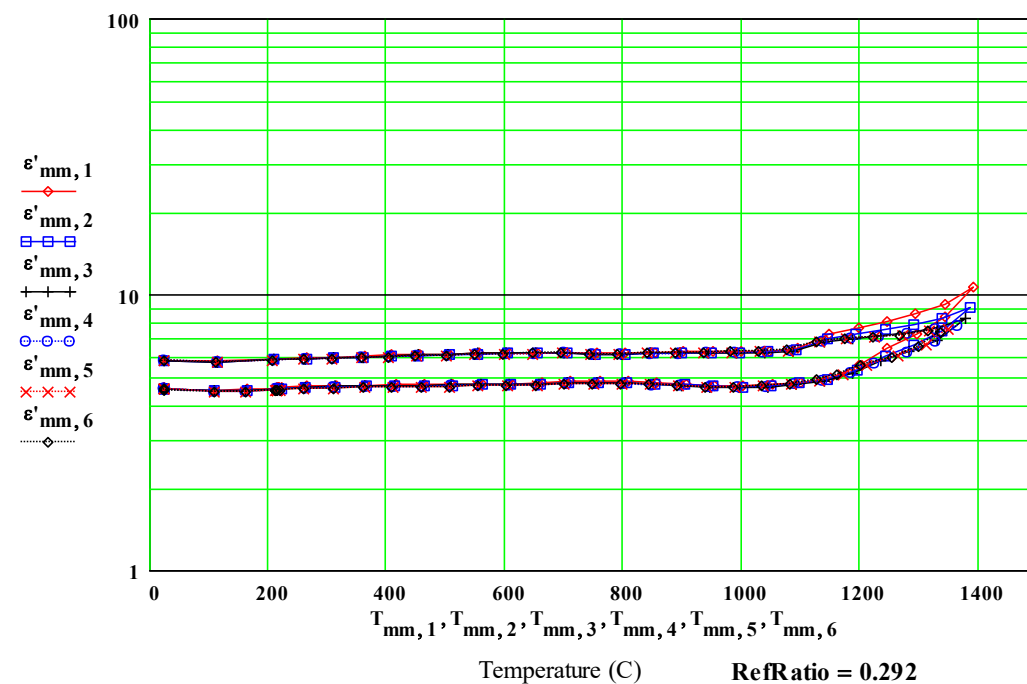
NASA2589.mcd

AnDat = 20251012

Stillwater Anorthosite pellets, Holder + Crucible, RT- 1400C, in flowing 4% Hydrogrn ,D. Rickman, NASA

Initial density = $\text{samdns}_{\text{NCal} + 1} = 2.06 \text{ gm/cc}$, Final density(25C) = $\text{dnsfinal} = 2.26 \text{ gm/cc}$

FracMassChange = 0.99



Stillwater Anorthosite

Test = 2025101001

NASA2589.mcd

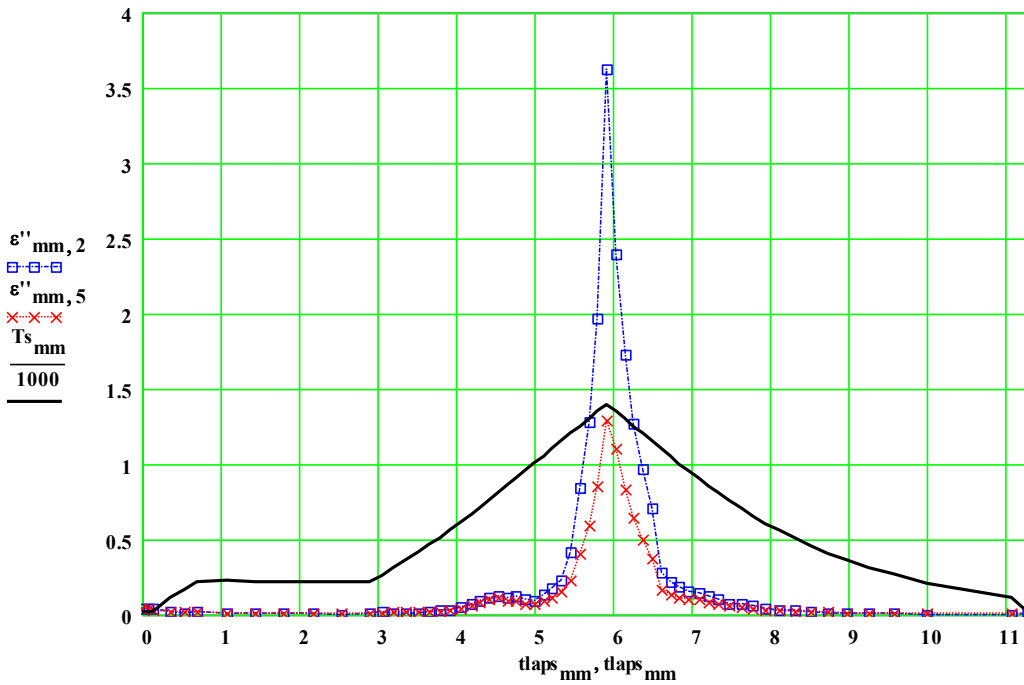
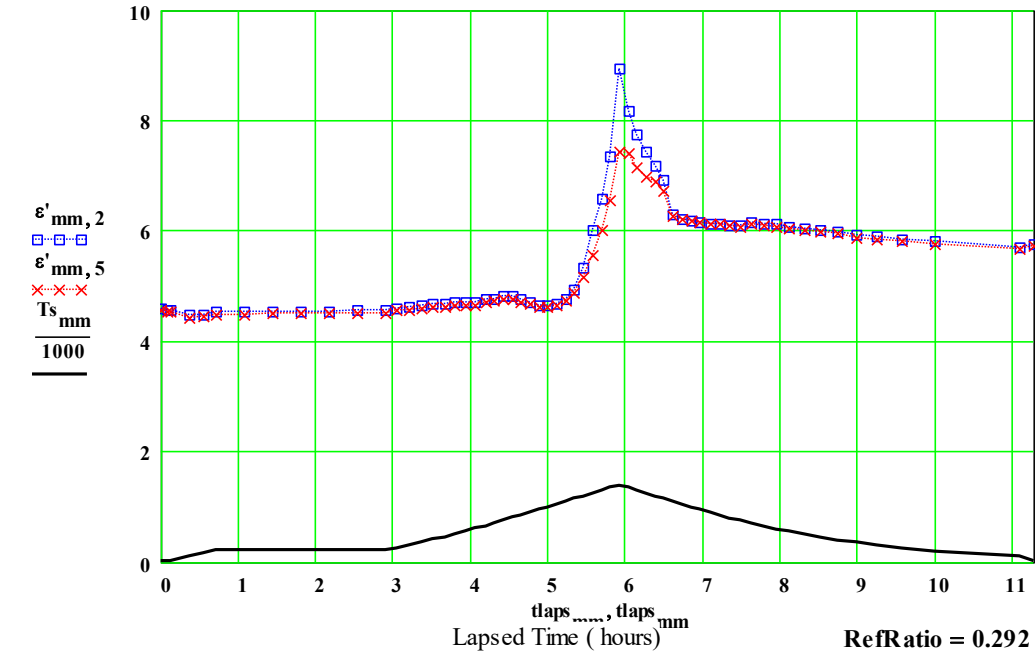
AnDat = 20251012

Stillwater Anorthosite pellets, Holder + Crucible, RT- 1400C, in flowing 4% Hydrogrn ,D. Rickman, NASA

Initial density = $\text{samdns}_{\text{NCal} + 1} = 2.06 \text{ gm/cc}$,

linear thermal expansion

Final density(25C) = $\text{dnsfinal} = 2.26 \text{ gm/cc}$ $\text{FracMassChange} = 0.99$ coef/deg C $\alpha_3 = 0 \cdot 10^{-6}$



Stillwater Anorthosite

Test = 2025101001

NASA2589.mcd

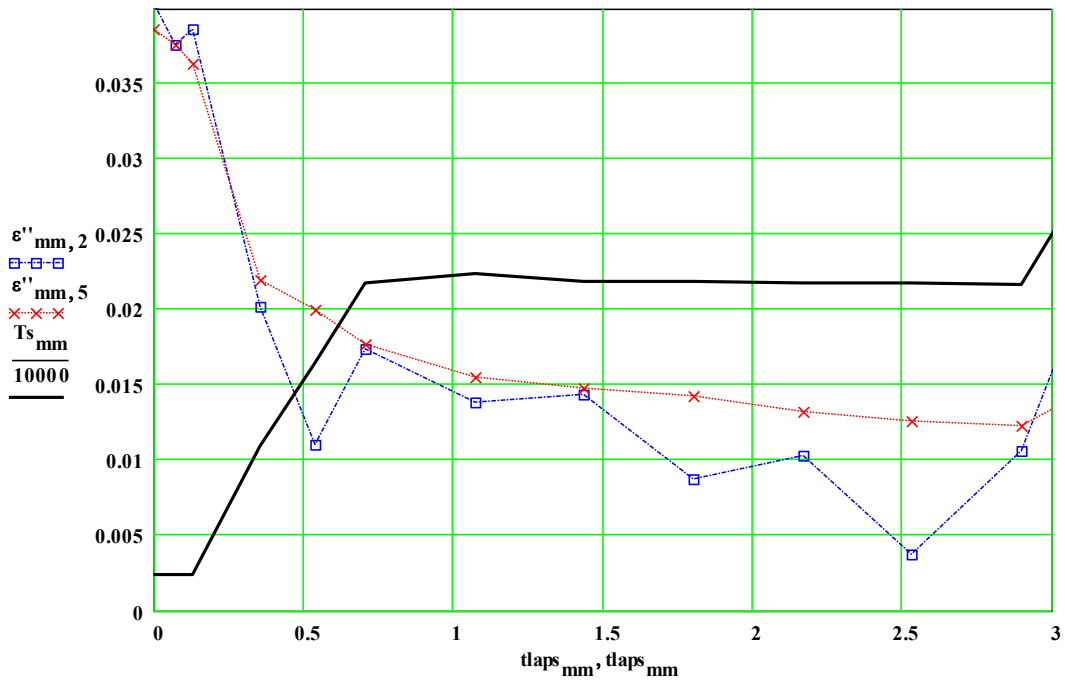
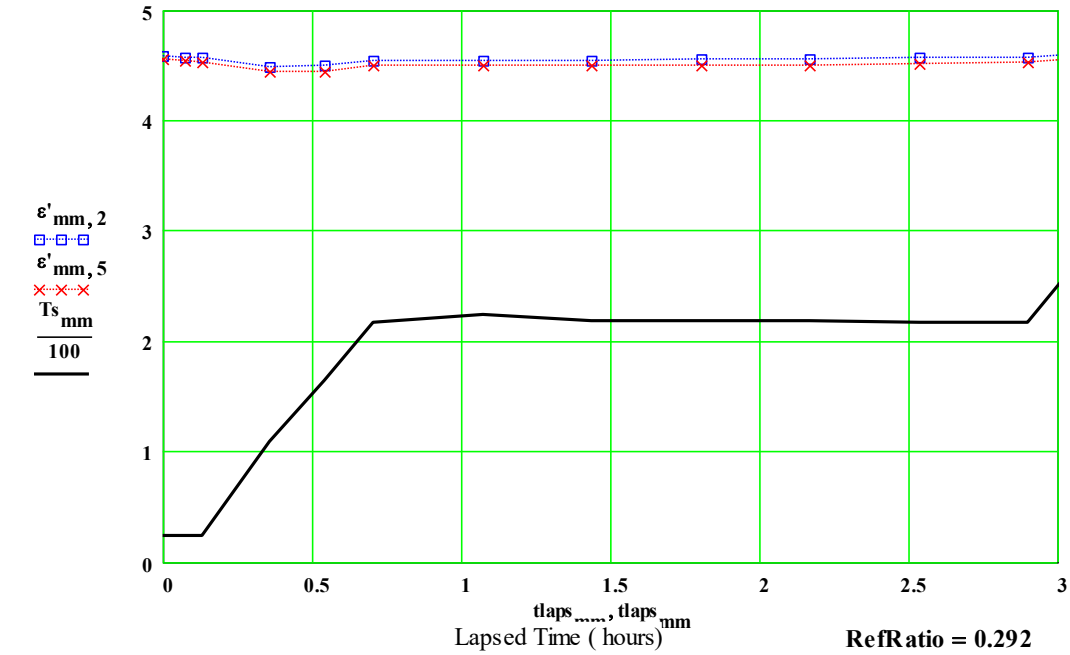
AnDat = 20251012

Stillwater Anorthosite pellets, Holder + Crucible, RT- 1400C, in flowing 4% Hydrogrn ,D. Rickman, NASA

Initial density = $\text{samdns}_{\text{NCal} + 1} = 2.06 \text{ gm/cc}$,

linear thermal expansion

Final density(25C) = $\text{dnsfinal} = 2.26 \text{ gm/cc}$ $\text{FracMassChange} = 0.99$ coef/deg C $\alpha_3 = 0 \cdot 10^{-6}$



There are indications of a small amount of moisture release up to 150C .

Stillwater Anorthosite

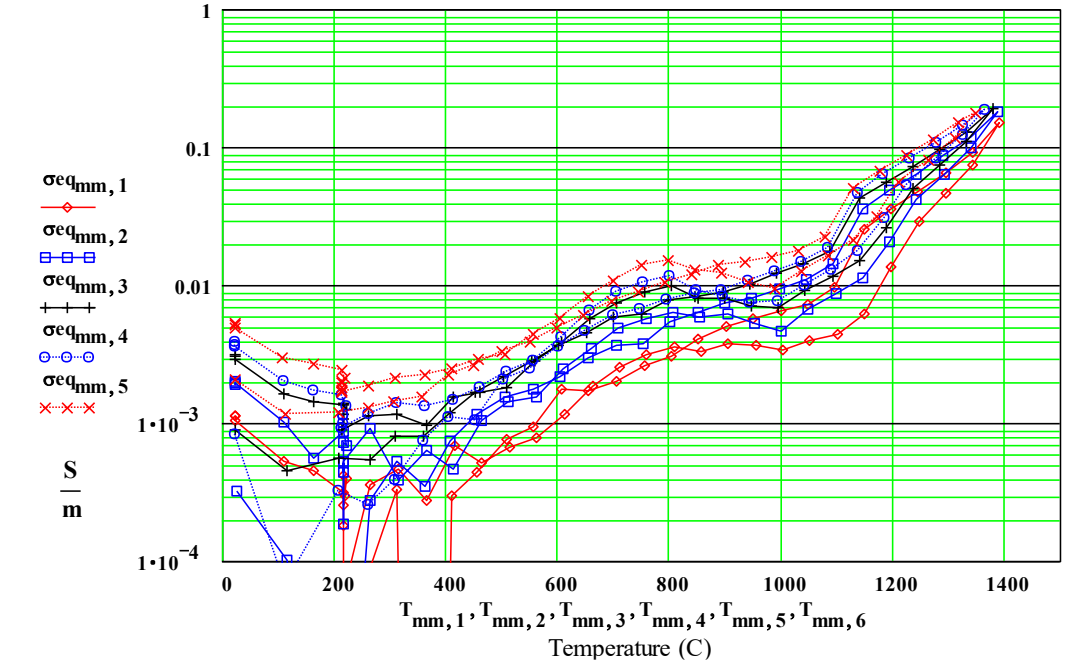
Test = 2025101001

NASA2589.mcd

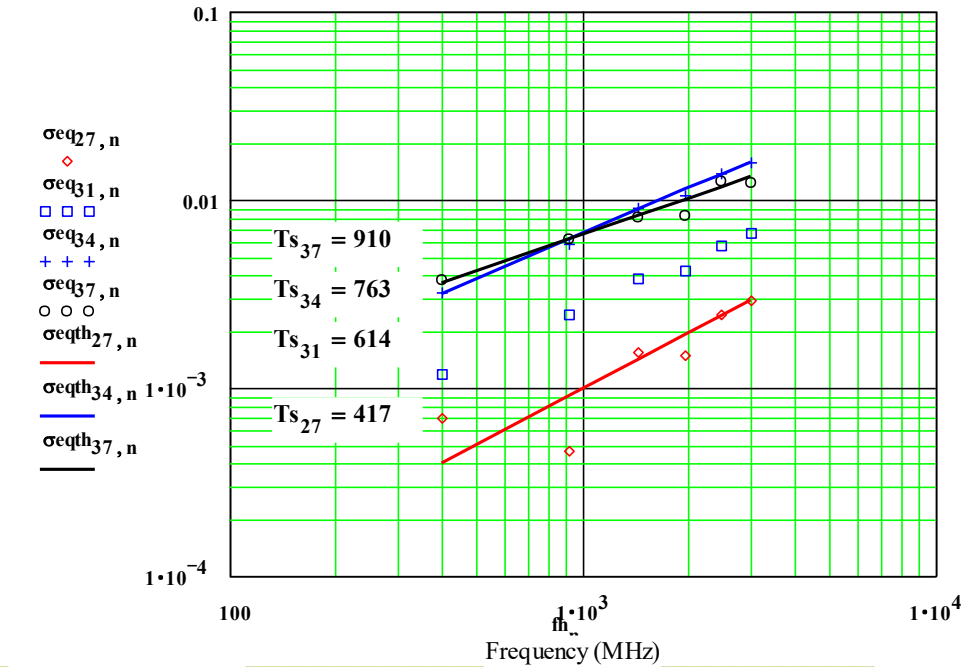
AnDat = 20251012

Stillwater Anorthosite pellets, Holder + Crucible, RT- 1400C, in flowing 4% Hydrogrn ,D. Rickman, NASA

Equivalent Free Electron AC Conductivity (Siemens/metre)



$$\sigma_{eqth_{27,n}} := 0.0004 \cdot \left(\frac{fh_n}{400} \right)^{0.99} \quad \sigma_{eqth_{34,n}} := 0.0032 \cdot \left(\frac{fh_n}{400} \right)^{0.80} \quad \sigma_{eqth_{37,n}} := 0.0036 \cdot \left(\frac{fh_n}{400} \right)^{0.65}$$



Stillwater Anorthosite

Test = 2025101001

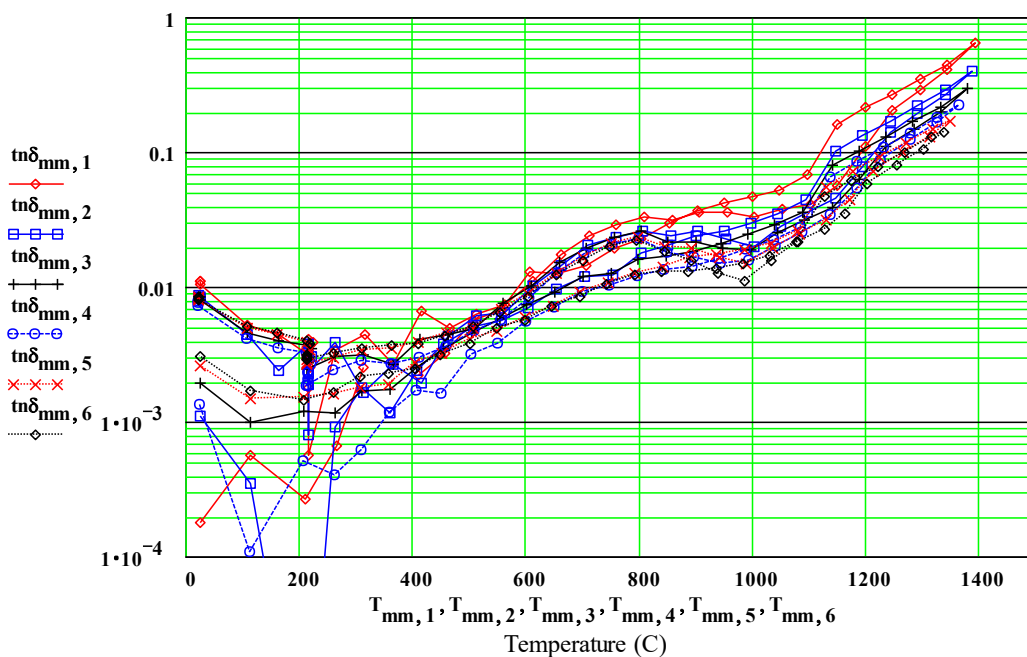
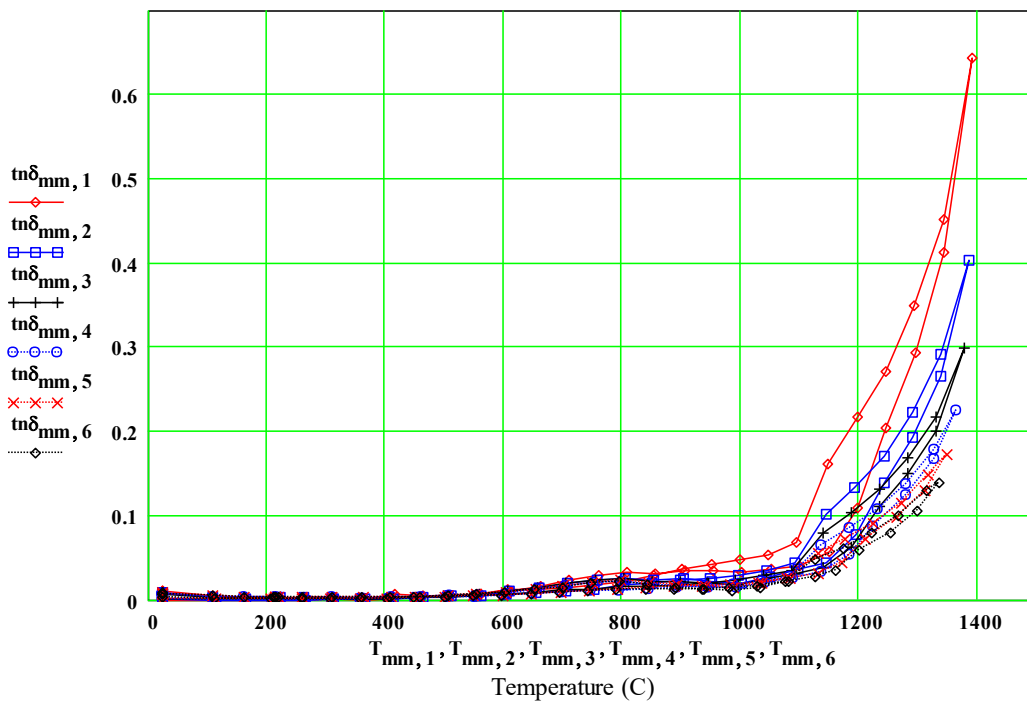
NASA2589.mcd

AnDat = 20251012

Stillwater Anorthosite pellets, Holder + Crucible, RT- 1400C, in flowing 4% Hydrogrn ,D. Rickman, NASA

Initial density = $\text{samdns}_{\text{NCal} + 1} = 2.06 \text{ gm/cc}$,

Final density(25C) = $\text{dnsfinal} = 2.26 \text{ gm/cc}$



Stillwater Anorthosite

Test = 2025101001

NASA2589.mcd

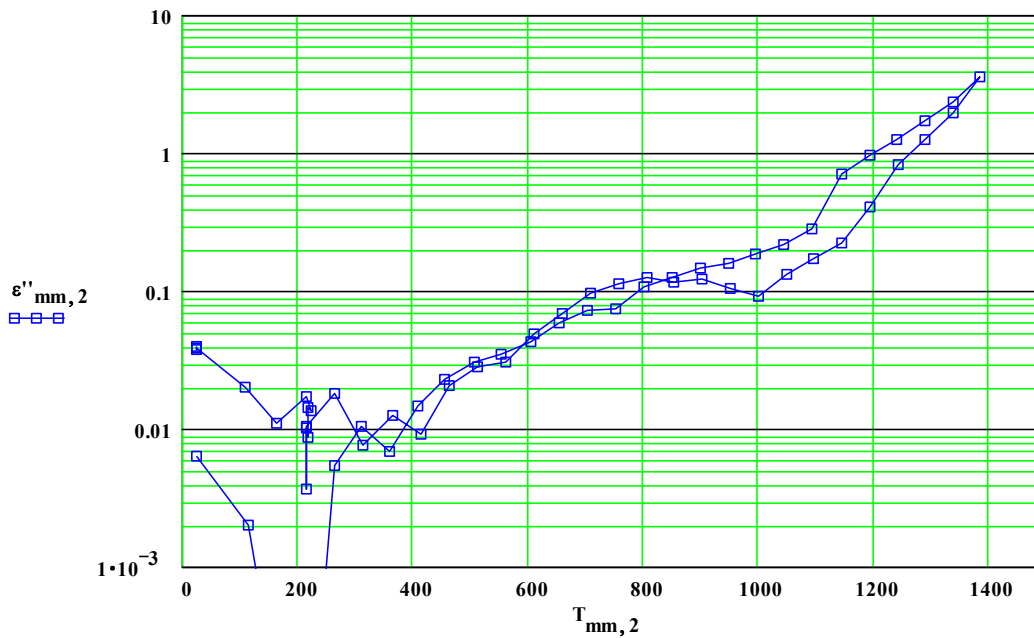
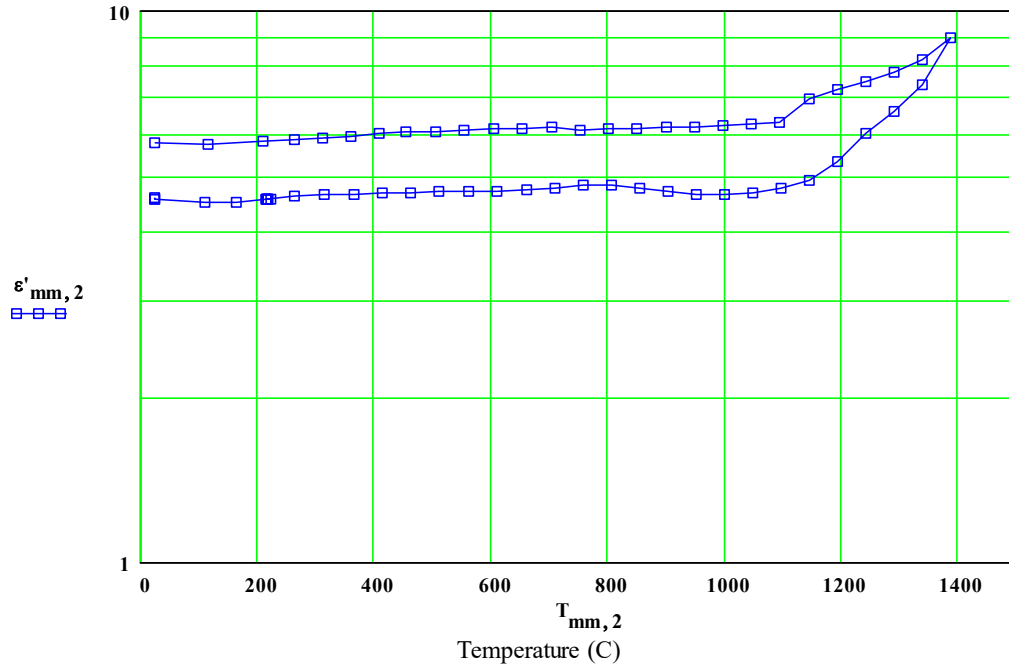
AnDat = 20251012

Stillwater Anorthosite pellets, Holder + Crucible, RT- 1400C, in flowing 4% Hydrogrn ,D. Rickman, NASA

Initial density = $\text{samdens}_{\text{NCal} + 1} = 2.06 \text{ gm/cc}$, Linear thermal exp. coeff. $\alpha_1 = 0$ /deg C

Final density(25C) = $\text{densfinal} = 2.26 \text{ gm/cc}$

Values for 912 MHz



Stillwater Anorthosite

Half-power Depth (millimeters)

$$D_{\text{halfP}}(\text{mm}, n) := \left(\frac{\ln(2)}{2} \right) \cdot (\text{inverse}\alpha_{\text{mm}, n} \cdot 1)$$

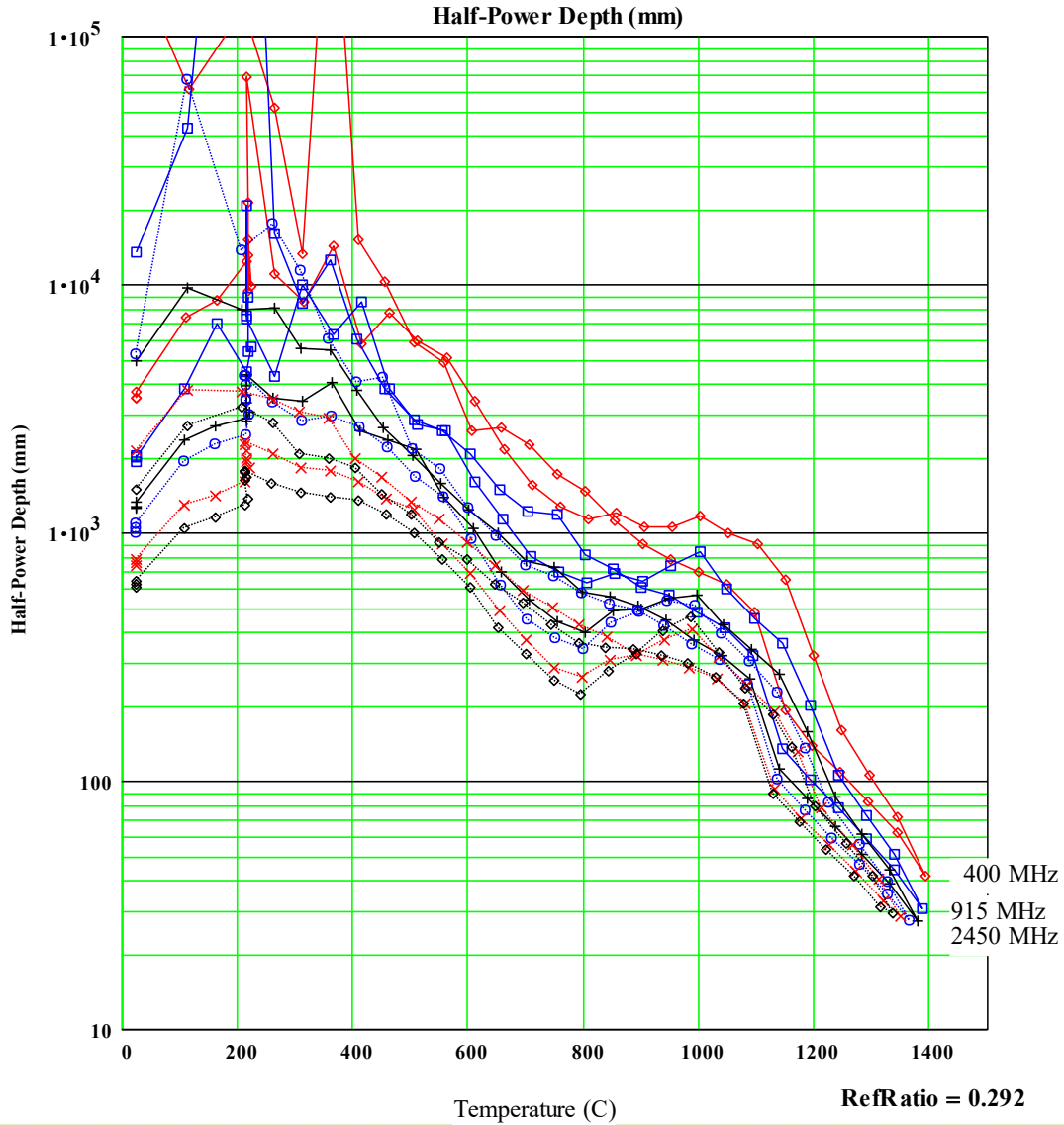
Test = 2025101001

NASA2589.mcd

AnDat = 20251012

Stillwater Anorthosite pellets, Holder + Crucible, RT- 1400C, in flowing 4% Hydrogrn, D. Rickman, NASA

Initial density = $\text{samdns}_{\text{NCal}} + 1 = 2.06$ gm/cc, Final density(25C) = $\text{dnsfinal} = 2.26$ gm/cc



Stillwater Anorthosite

NASA2589.mcd

AnDat = 20251012

Stillwater Anorthosite pellets, Holder + Crucible, RT- 1400C, in flowing 4% Hydrogrn ,D. Rickman, NASA

List of Measured Values of ϵ' and ϵ'' and $\tan\delta$:

Initial density = $\text{samdns}_{\text{NCal} + 1} = 2.06 \text{ gm/cc}$ Final density(25C) = $\frac{\text{dnsfinal}}{\text{Lapsed}} = 2.259 \text{ gm/cc}$

density	index	T(C)	397MHz	912MHz	1429MH	1948MHz	2466MHz	2986MHz	Time (hours)
---------	-------	------	--------	--------	--------	---------	---------	---------	-----------------

sands	mm	T _{mm,1}	ε _{mm,1}	ε _{mm,2}	ε _{mm,3}	ε _{mm,4}	ε _{mm,5}	ε _{mm,6}	tlaps _{mm}	sammass _{mm}
2.06	12	24	4.61	4.59	4.58	4.58	4.56	4.55	0	0.303
2.06	13	24	4.59	4.58	4.56	4.56	4.55	4.54	0.07	0.303
2.06	14	24	4.59	4.57	4.56	4.55	4.54	4.53	0.13	0.303
2.06	15	109	4.51	4.49	4.49	4.46	4.44	4.43	0.36	0.303
2.06	16	164	4.54	4.5	4.5	4.46	4.45	4.44	0.54	0.303
2.06	17	217	4.59	4.55	4.55	4.51	4.5	4.49	0.71	0.303
2.06	18	223	4.6	4.55	4.56	4.51	4.5	4.49	1.07	0.303
2.054	19	217	4.58	4.55	4.56	4.51	4.5	4.49	1.44	0.302
2.047	20	218	4.6	4.55	4.56	4.52	4.51	4.5	1.8	0.301
2.047	21	217	4.59	4.55	4.57	4.52	4.51	4.5	2.17	0.301
2.047	22	217	4.6	4.57	4.57	4.53	4.52	4.51	2.54	0.301
2.047	23	216	4.62	4.57	4.58	4.54	4.53	4.52	2.9	0.301
2.047	24	264	4.66	4.61	4.63	4.57	4.56	4.55	3.05	0.301
2.047	25	314	4.68	4.64	4.65	4.6	4.59	4.58	3.2	0.301
2.047	26	366	4.71	4.66	4.67	4.62	4.61	4.6	3.36	0.301
2.047	27	415	4.72	4.68	4.7	4.63	4.63	4.62	3.51	0.301
2.047	28	464	4.73	4.68	4.7	4.64	4.63	4.62	3.66	0.301
2.047	29	513	4.75	4.7	4.72	4.66	4.65	4.64	3.79	0.301
2.047	30	562	4.76	4.72	4.73	4.67	4.67	4.66	3.92	0.301
2.047	31	612	4.77	4.72	4.73	4.68	4.67	4.67	4.06	0.301
2.047	32	662	4.82	4.76	4.76	4.71	4.71	4.7	4.19	0.301
2.047	33	710	4.86	4.78	4.79	4.73	4.73	4.73	4.3	0.301
2.047	34	759	4.9	4.82	4.81	4.76	4.76	4.76	4.42	0.301
2.047	35	808	4.9	4.84	4.82	4.77	4.77	4.77	4.53	0.301
2.047	36	857	4.82	4.76	4.75	4.71	4.72	4.72	4.65	0.301
2.047	37	905	4.76	4.71	4.69	4.67	4.68	4.69	4.76	0.301
2.047	38	954	4.69	4.66	4.63	4.62	4.64	4.65	4.88	0.301
2.047	39	1003	4.65	4.65	4.62	4.61	4.64	4.65	4.99	0.301
2.047	40	1051	4.72	4.69	4.65	4.65	4.67	4.69	5.11	0.301
2.047	41	1100	4.83	4.78	4.71	4.73	4.75	4.76	5.23	0.301
2.047	42	1149	5.03	4.94	4.86	4.87	4.89	4.91	5.34	0.301
2.047	43	1197	5.55	5.35	5.2	5.21	5.16	5.14	5.46	0.301
2.047	44	1246	6.44	6.01	5.74	5.64	5.57	5.54	5.57	0.301
2.075	45	1295	7.22	6.59	6.21	6.17	6.03	5.95	5.69	0.301
2.105	46	1343	8.29	7.35	6.86	6.78	6.57	6.47	5.8	0.301
2.134	47	1391	10.65	8.96	8.17	7.74	7.45	7.34	5.92	0.301
2.164	48	1343	9.27	8.19	7.61	7.5	7.41	7.44	6.03	0.301
2.195	49	1294	8.51	7.77	7.29	7.22	7.15	7.16	6.15	0.301
2.227	50	1245	8.01	7.45	7.08	7.03	7	7.01	6.26	0.301
2.259	51	1197	7.59	7.2	6.93	6.91	6.9	6.92	6.38	0.301
2.259	52	1149	7.21	6.93	6.74	6.73	6.73	6.75	6.5	0.301
2.259	53	1096	6.38	6.3	6.23	6.24	6.28	6.3	6.61	0.301
2.259	54	1047	6.28	6.22	6.17	6.18	6.22	6.24	6.73	0.301
2.259	55	999	6.25	6.19	6.16	6.15	6.19	6.21	6.84	0.301
2.259	56	950	6.22	6.17	6.15	6.14	6.16	6.19	6.96	0.301
2.259	57	901	6.21	6.14	6.14	6.12	6.14	6.16	7.09	0.301
2.259	58	852	6.19	6.13	6.13	6.1	6.12	6.14	7.21	0.301
2.259	59	804	6.17	6.11	6.12	6.08	6.1	6.12	7.34	0.301
2.259	60	755	6.15	6.1	6.11	6.07	6.08	6.1	7.48	0.301
2.259	61	705	6.2	6.15	6.18	6.12	6.14	6.14	7.63	0.301

mq := 62,63..nd - Nempties

samdas	m _{mq}	T _{mq,1}	ε _{mq,1}	ε _{mq,2}	ε _{mq,3}	ε _{mq,4}	ε _{mq,5}	ε _{mq,6}	tlaps _{mq}	sammas _{mq}
2.259	62	656	6.19	6.14	6.16	6.11	6.12	6.12	7.78	0.301
2.259	63	606	6.17	6.12	6.15	6.09	6.09	6.1	7.94	0.301
2.259	64	556	6.16	6.09	6.12	6.06	6.06	6.06	8.12	0.301
2.259	65	507	6.09	6.05	6.08	6.01	6.01	6.01	8.31	0.301
2.259	66	455	6.1	6.04	6.07	6	6	6	8.51	0.301
2.259	67	409	6.06	6	6.03	5.96	5.96	5.96	8.73	0.301
2.259	68	362	5.97	5.93	5.95	5.89	5.89	5.89	8.98	0.301
2.259	69	312	5.94	5.9	5.93	5.87	5.86	5.86	9.25	0.301
2.259	70	265	5.91	5.86	5.88	5.83	5.82	5.82	9.58	0.301
2.259	71	210	5.86	5.81	5.83	5.79	5.78	5.78	9.99	0.301
2.259	72	115	5.75	5.72	5.73	5.7	5.7	5.69	11.08	0.301
2.259	73	24	5.77	5.76	5.75	5.76	5.75	5.75	11.27	0.301

Stillwater Anorthosite

Test = 2025101001 NASA2589.mcd AnDat = 20251012

Stillwater Anorthosite pellets, Holder + Crucible, RT- 1400C, in flowing 4% Hydrogrn ,D. Rickman, NASA

List of Measured Values of ϵ' and ϵ'' and $\tan\delta$:
 ~~~~~~

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.06$  gm/cc Final density(25C) =  $\text{dnsfinal} = 2.259$  gm/cc  
 Lapsed

| density | index | T(C) | 397MHz                     | 912MHz                     | 1429MH                     | 1948MHz                    | 2466MHz                    | 2986MHz                    | Time<br>(hours) |        |
|---------|-------|------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|-----------------|--------|
| samdns  | mm    | T    | $\epsilon''_{\text{mm},1}$ | $\epsilon''_{\text{mm},2}$ | $\epsilon''_{\text{mm},3}$ | $\epsilon''_{\text{mm},4}$ | $\epsilon''_{\text{mm},5}$ | $\epsilon''_{\text{mm},6}$ | tlaps           | sammas |
| mm      | mm    | mm   | mm                         | mm                         | mm                         | mm                         | mm                         | mm                         | mm              | mm     |
| 2.06    | 12    | 24   | 0.051                      | 0.04                       | 0.039                      | 0.036                      | 0.039                      | 0.039                      | 0               | 0.303  |
| 2.06    | 13    | 24   | 0.051                      | 0.038                      | 0.039                      | 0.035                      | 0.038                      | 0.038                      | 0.07            | 0.303  |
| 2.06    | 14    | 24   | 0.048                      | 0.039                      | 0.037                      | 0.033                      | 0.036                      | 0.037                      | 0.13            | 0.303  |
| 2.06    | 15    | 109  | 0.024                      | 0.02                       | 0.021                      | 0.019                      | 0.022                      | 0.023                      | 0.36            | 0.303  |
| 2.06    | 16    | 164  | 0.021                      | 0.011                      | 0.018                      | 0.016                      | 0.02                       | 0.02                       | 0.54            | 0.303  |
| 2.06    | 17    | 217  | 0.014                      | 0.017                      | 0.017                      | 0.015                      | 0.018                      | 0.018                      | 0.71            | 0.303  |
| 2.06    | 18    | 223  | 0.018                      | 0.014                      | 0.016                      | 0.012                      | 0.016                      | 0.017                      | 1.07            | 0.303  |
| 2.054   | 19    | 217  | 0.012                      | 0.014                      | 0.017                      | 0.01                       | 0.015                      | 0.014                      | 1.44            | 0.302  |
| 2.047   | 20    | 218  | 0.014                      | 0.009                      | 0.015                      | 0.011                      | 0.014                      | 0.014                      | 1.8             | 0.301  |
| 2.047   | 21    | 217  | 0.019                      | 0.01                       | 0.014                      | 0.009                      | 0.013                      | 0.013                      | 2.17            | 0.301  |
| 2.047   | 22    | 217  | 0.008                      | 0.004                      | 0.013                      | 0.008                      | 0.013                      | 0.013                      | 2.54            | 0.301  |
| 2.047   | 23    | 216  | 0.003                      | 0.011                      | 0.011                      | 0.008                      | 0.012                      | 0.013                      | 2.9             | 0.301  |
| 2.047   | 24    | 264  | 0.016                      | 0.018                      | 0.014                      | 0.011                      | 0.014                      | 0.015                      | 3.05            | 0.301  |
| 2.047   | 25    | 314  | 0.021                      | 0.008                      | 0.015                      | 0.013                      | 0.016                      | 0.016                      | 3.2             | 0.301  |
| 2.047   | 26    | 366  | 0.013                      | 0.013                      | 0.012                      | 0.012                      | 0.016                      | 0.017                      | 3.36            | 0.301  |
| 2.047   | 27    | 415  | 0.031                      | 0.009                      | 0.019                      | 0.014                      | 0.018                      | 0.018                      | 3.51            | 0.301  |
| 2.047   | 28    | 464  | 0.023                      | 0.021                      | 0.021                      | 0.017                      | 0.021                      | 0.02                       | 3.66            | 0.301  |
| 2.047   | 29    | 513  | 0.03                       | 0.029                      | 0.023                      | 0.022                      | 0.023                      | 0.024                      | 3.79            | 0.301  |
| 2.047   | 30    | 562  | 0.035                      | 0.031                      | 0.036                      | 0.026                      | 0.032                      | 0.031                      | 3.92            | 0.301  |
| 2.047   | 31    | 612  | 0.053                      | 0.049                      | 0.049                      | 0.039                      | 0.042                      | 0.04                       | 4.06            | 0.301  |
| 2.047   | 32    | 662  | 0.084                      | 0.07                       | 0.073                      | 0.06                       | 0.06                       | 0.058                      | 4.19            | 0.301  |
| 2.047   | 33    | 710  | 0.117                      | 0.099                      | 0.095                      | 0.083                      | 0.079                      | 0.074                      | 4.3             | 0.301  |
| 2.047   | 34    | 759  | 0.145                      | 0.114                      | 0.115                      | 0.099                      | 0.102                      | 0.095                      | 4.42            | 0.301  |
| 2.047   | 35    | 808  | 0.162                      | 0.127                      | 0.127                      | 0.109                      | 0.112                      | 0.108                      | 4.53            | 0.301  |
| 2.047   | 36    | 857  | 0.153                      | 0.116                      | 0.103                      | 0.086                      | 0.094                      | 0.087                      | 4.65            | 0.301  |
| 2.047   | 37    | 905  | 0.171                      | 0.122                      | 0.101                      | 0.077                      | 0.091                      | 0.074                      | 4.76            | 0.301  |
| 2.047   | 38    | 954  | 0.169                      | 0.106                      | 0.091                      | 0.069                      | 0.078                      | 0.059                      | 4.88            | 0.301  |
| 2.047   | 39    | 1003 | 0.154                      | 0.093                      | 0.088                      | 0.072                      | 0.07                       | 0.052                      | 4.99            | 0.301  |
| 2.047   | 40    | 1051 | 0.18                       | 0.133                      | 0.117                      | 0.094                      | 0.092                      | 0.073                      | 5.11            | 0.301  |
| 2.047   | 41    | 1100 | 0.202                      | 0.175                      | 0.148                      | 0.122                      | 0.119                      | 0.102                      | 5.23            | 0.301  |
| 2.047   | 42    | 1149 | 0.286                      | 0.225                      | 0.19                       | 0.166                      | 0.157                      | 0.133                      | 5.34            | 0.301  |
| 2.047   | 43    | 1197 | 0.613                      | 0.415                      | 0.332                      | 0.285                      | 0.231                      | 0.183                      | 5.46            | 0.301  |
| 2.047   | 44    | 1246 | 1.318                      | 0.842                      | 0.643                      | 0.498                      | 0.407                      | 0.328                      | 5.57            | 0.301  |
| 2.075   | 45    | 1295 | 2.122                      | 1.279                      | 0.937                      | 0.764                      | 0.599                      | 0.481                      | 5.69            | 0.301  |
| 2.105   | 46    | 1343 | 3.432                      | 1.964                      | 1.383                      | 1.136                      | 0.856                      | 0.682                      | 5.8             | 0.301  |
| 2.134   | 47    | 1391 | 6.867                      | 3.627                      | 2.45                       | 1.746                      | 1.287                      | 1.027                      | 5.92            | 0.301  |
| 2.164   | 48    | 1343 | 4.201                      | 2.394                      | 1.655                      | 1.341                      | 1.107                      | 0.975                      | 6.03            | 0.301  |
| 2.195   | 49    | 1294 | 2.982                      | 1.729                      | 1.24                       | 0.992                      | 0.831                      | 0.72                       | 6.15            | 0.301  |
| 2.227   | 50    | 1245 | 2.175                      | 1.272                      | 0.932                      | 0.765                      | 0.641                      | 0.556                      | 6.26            | 0.301  |
| 2.259   | 51    | 1197 | 1.646                      | 0.968                      | 0.717                      | 0.59                       | 0.499                      | 0.427                      | 6.38            | 0.301  |
| 2.259   | 52    | 1149 | 1.165                      | 0.711                      | 0.539                      | 0.435                      | 0.373                      | 0.323                      | 6.5             | 0.301  |
| 2.259   | 53    | 1096 | 0.44                       | 0.286                      | 0.225                      | 0.175                      | 0.164                      | 0.135                      | 6.61            | 0.301  |
| 2.259   | 54    | 1047 | 0.334                      | 0.219                      | 0.18                       | 0.137                      | 0.13                       | 0.105                      | 6.73            | 0.301  |
| 2.259   | 55    | 999  | 0.298                      | 0.187                      | 0.154                      | 0.118                      | 0.117                      | 0.092                      | 6.84            | 0.301  |
| 2.259   | 56    | 950  | 0.264                      | 0.161                      | 0.129                      | 0.1                        | 0.109                      | 0.086                      | 6.96            | 0.301  |
| 2.259   | 57    | 901  | 0.229                      | 0.148                      | 0.112                      | 0.086                      | 0.102                      | 0.081                      | 7.09            | 0.301  |
| 2.259   | 58    | 852  | 0.185                      | 0.125                      | 0.104                      | 0.081                      | 0.088                      | 0.08                       | 7.21            | 0.301  |
| 2.259   | 59    | 804  | 0.141                      | 0.109                      | 0.1                        | 0.073                      | 0.077                      | 0.076                      | 7.34            | 0.301  |
| 2.259   | 60    | 755  | 0.119                      | 0.076                      | 0.078                      | 0.063                      | 0.066                      | 0.064                      | 7.48            | 0.301  |
| 2.259   | 61    | 705  | 0.091                      | 0.074                      | 0.075                      | 0.057                      | 0.057                      | 0.052                      | 7.63            | 0.301  |

m<sub>q</sub> := 62,63,..,nd - Nempties

| samdns | mmmq | T <sub>mq,1</sub> | ε'' <sub>mq,1</sub> | ε'' <sub>mq,2</sub> | ε'' <sub>mq,3</sub> | ε'' <sub>mq,4</sub> | ε'' <sub>mq,5</sub> | ε'' <sub>mq,6</sub> | tlaps <sub>mq</sub> | sammas <sub>mq</sub> |
|--------|------|-------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|----------------------|
| 2.259  | 62   | 656               | 0.078               | 0.06                | 0.057               | 0.043               | 0.045               | 0.044               | 7.78                | 0.301                |
| 2.259  | 63   | 606               | 0.08                | 0.043               | 0.046               | 0.033               | 0.036               | 0.035               | 7.94                | 0.301                |
| 2.259  | 64   | 556               | 0.043               | 0.035               | 0.036               | 0.023               | 0.029               | 0.03                | 8.12                | 0.301                |
| 2.259  | 65   | 507               | 0.035               | 0.031               | 0.028               | 0.019               | 0.025               | 0.023               | 8.31                | 0.301                |
| 2.259  | 66   | 455               | 0.02                | 0.023               | 0.021               | 0.01                | 0.019               | 0.019               | 8.51                | 0.301                |
| 2.259  | 67   | 409               | 0.014               | 0.015               | 0.015               | 0.01                | 0.016               | 0.015               | 8.73                | 0.301                |
| 2.259  | 68   | 362               | -0                  | 0.007               | 0.01                | 0.007               | 0.011               | 0.013               | 8.98                | 0.301                |
| 2.259  | 69   | 312               | 0.015               | 0.011               | 0.01                | 0.004               | 0.011               | 0.013               | 9.25                | 0.301                |
| 2.259  | 70   | 265               | 0.004               | 0.005               | 0.007               | 0.002               | 0.009               | 0.01                | 9.58                | 0.301                |
| 2.259  | 71   | 210               | 0.002               | 0                   | 0.007               | 0.003               | 0.009               | 0.008               | 9.99                | 0.301                |
| 2.259  | 72   | 115               | 0.003               | 0.002               | 0.006               | 0.001               | 0.009               | 0.01                | 11.08               | 0.301                |
| 2.259  | 73   | 24                | 0.001               | 0.006               | 0.011               | 0.008               | 0.015               | 0.018               | 11.27               | 0.301                |

## MPN-337\_NASA\_Rickman\_JSC-1A-AGGL\_Argon Oct. 18, 2025

### JSC-1A AGGL Lunar Simulant Pellets

#### Measurements of Complex Dielectric Constant Between 400 and 2985 MHz from Room Temperature to 1100°C to Room Temperature , in 10 sccm Flowing UHP Argon

Jozef Mouris and Ronald Hutcheon ( MPN)

Douglas Rickman of the Space Exploration Division of Amentum ( on contract to NASA), requested that MPN measure the complex dielectric properties of pellets of lunar simulants which included special “agglutinates” which are considered to have favourable properties simulating the iron content of lunar regolith. The first of these was JSC-1A-AGGL , based on the oldest, best known “mare” simulant but with components processed at very high temperatures to emulate the known elemental iron content of lunar regolith.

The powder arrived in a sealed container at MPN on Sept. 4 /2025. The container was first opened on Sept. 25 and a pellet was pressed at ~ 20,000 psi which seemed to have sufficient strength for handling. Doug had requested an initial density close to the previous runs, and this seemed adequate – at ~ 2.1 g/cc . The 20,000 psi required was a bit lower than that used for achieving strong enough pellets with the old JSC-1A material.

The parameters of the initial pellet stack ( 2 pellets) , were:

- a) diameter 3.62 +- 0.05 mm
- b) length 12.50 +- 0.05 mm
- c) mass 0.269 +- 0.002 gm
- d) room temperature density 2.09 ± 0.09 gm/cc.
- e) appearance - grey/dark brown pellets ( see photo)
- f) resistivity end-to-end > 30 Mohm
- g) very slight attraction to a strong magnet

The dielectric properties measurement run consisted of calibration measurements, then three sample measurements at room temperature (RT), then a single measurements at 50C, then 25C steps up to 200C, at which points a 2 hour hold was started, with measurements every 20 minutes. This was to measure the effect of moisture loss ( The measurements showed no detectable moisture). The run was then continued in 50C steps to 1100C, then in -50C steps to 100C, then RT. At the end of the run, the mass of the holder and pellets was measured at room temperature. It was noted that the pellets had some grit between them and the holder wall, which made the pellets difficult to remove. This was accomplished, however, with the pellets intact. It was later established that they were very strong, and difficult to break! Good landing pad material.

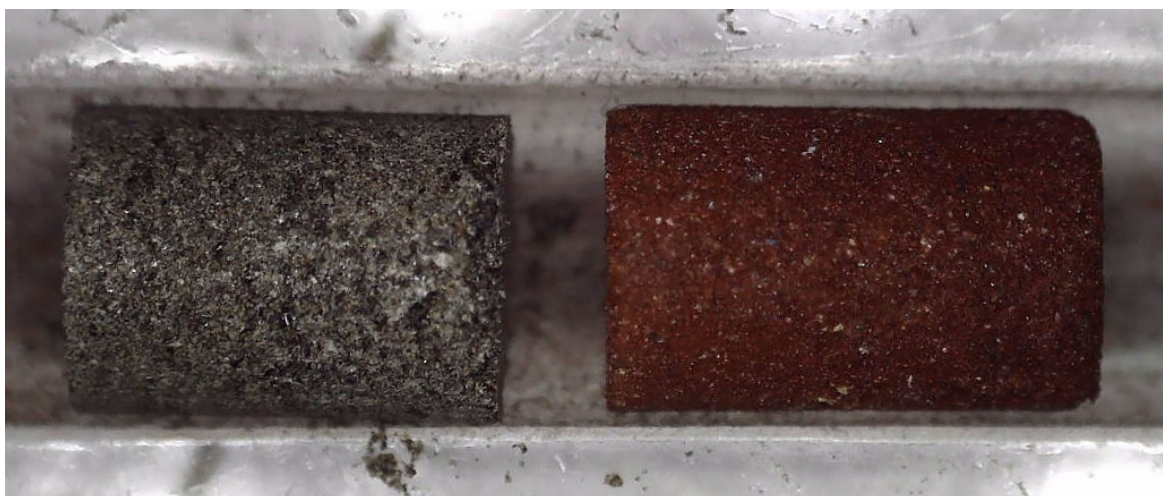
Then the empty holder was run to 1100C to check for contamination. There was no contamination .

The final sample stack properties, at room temperature were :

- a) diameter 3.58 ± 0.05 mm
- b) length 12.60 ± 0.05 mm
- c) mass 0.269 ± 0.002 gm
- f) room temperature density 2.12 ± 0.09 gm/cc.
- g) appearance - a dark, reddish-orange rod (see photos)
- f) resistivity end-to-end > 30 Mohm
- g) very slight attraction to a strong magnet



One initial pellet – at ~ 20,000 psi .



Comparison of initial and final pellet appearance.



The two final pellets. The lighting is different ( stronger here ).



A picture of the surface of the shipped powder in its shipping jar. Approximately the same magnification as the pellet views.



End-on view of one of the final pellets.



Cut faces of the “cut” final pellet



Side view of the cut ( final) pellet

Clearly the whole final pellet was permeated with the “red” colour. Experience suggests that the few ppm of oxygen in the UHP argon would not permeate both pellets completely.

The frequency coding is :

Legend for Data Plots :

| # | Frequency(MHz) |
|---|----------------|
| 1 | 397            |
| 2 | 912            |
| 3 | 1429           |
| 4 | 1948           |
| 5 | 2466           |
| 6 | 2986           |

Symbol

red diamond, solid line – sometimes the line is omitted!  
 blue square, solid line  
 black cross, solid line  
 blue circle, dotted line  
 red cross, dotted line  
 black diamond, dotted line

Comments on the data analysis:

A linear thermal expansion coefficient (CTE) of  $0.0 \times 10^{-6}/\text{C}$  was used.

There  $\epsilon''$  values up to 200 C show only a hint of absorbed moisture.

The loss mechanism is frequency-dependent starting just above 400C, and indicates some amount of disordered structure ionic loss mechanism over the whole range back down to 250C .

The rapid increase between 1050 C and 1100 C suggests the influence of melting of some component.

## JSC-1A-AGGL Argon

Code Calculates Estimated Sample Dimensions &amp; Volume and Plots Density As a Function of Temperature

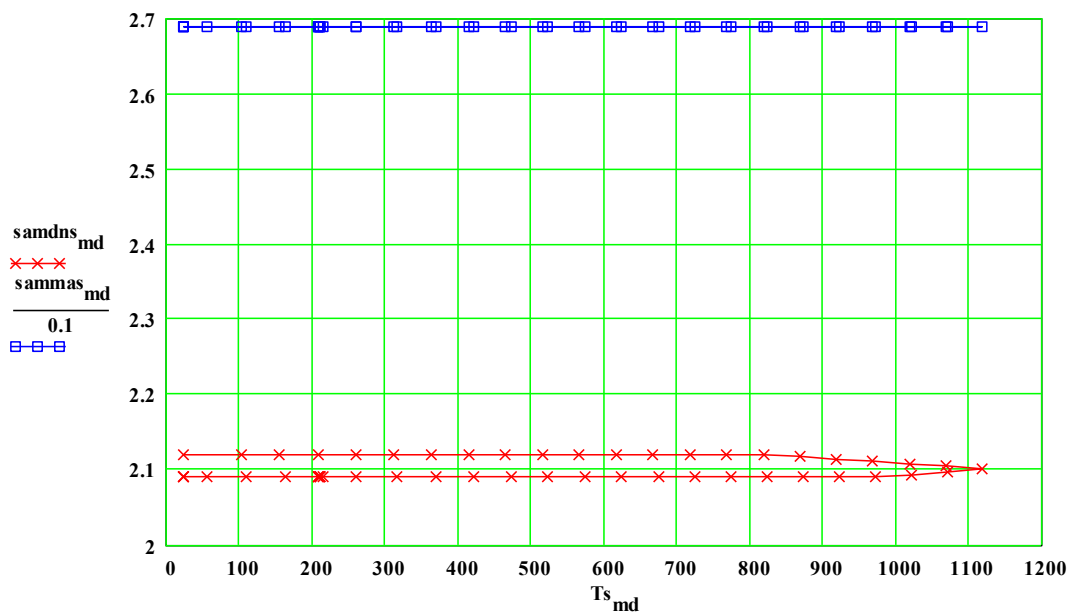
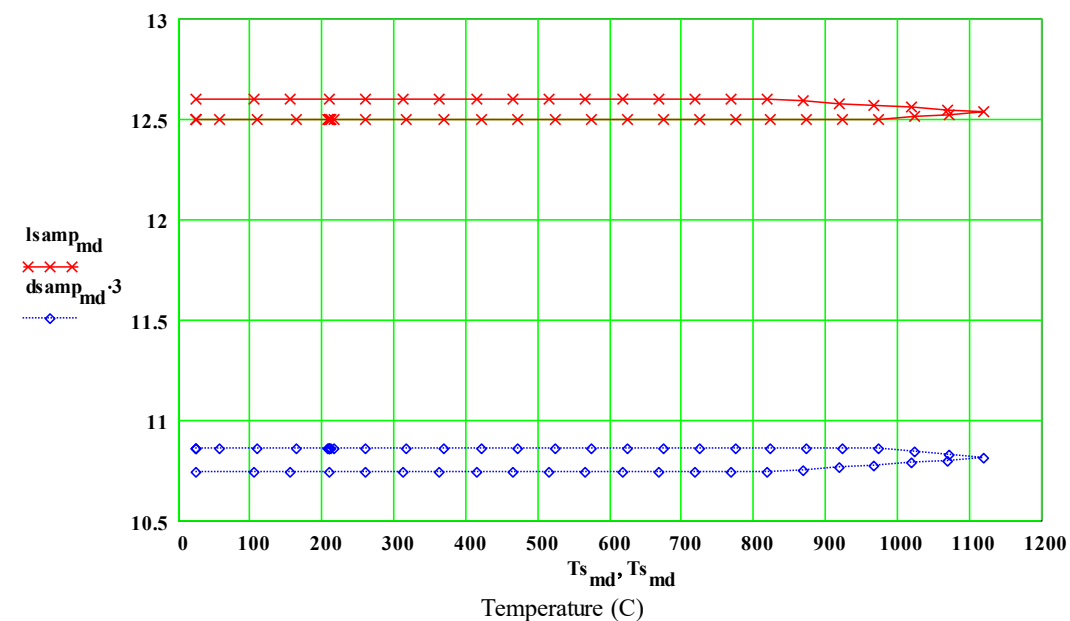
Test = 2025092701

NASA2583 TM685.mcd

**AnDat = 20250930**

JSC-1A-AGGL , RT to 1100C to RT, in 10 sccm argon, for D. Rickman, Amentum (NASA consultant)

Assumed Effective Dimensions (mm) and Density (gm/cc) as a Function of Temperature for Solid



# JSC-1A-AGGL Argon

Test = 2025092701

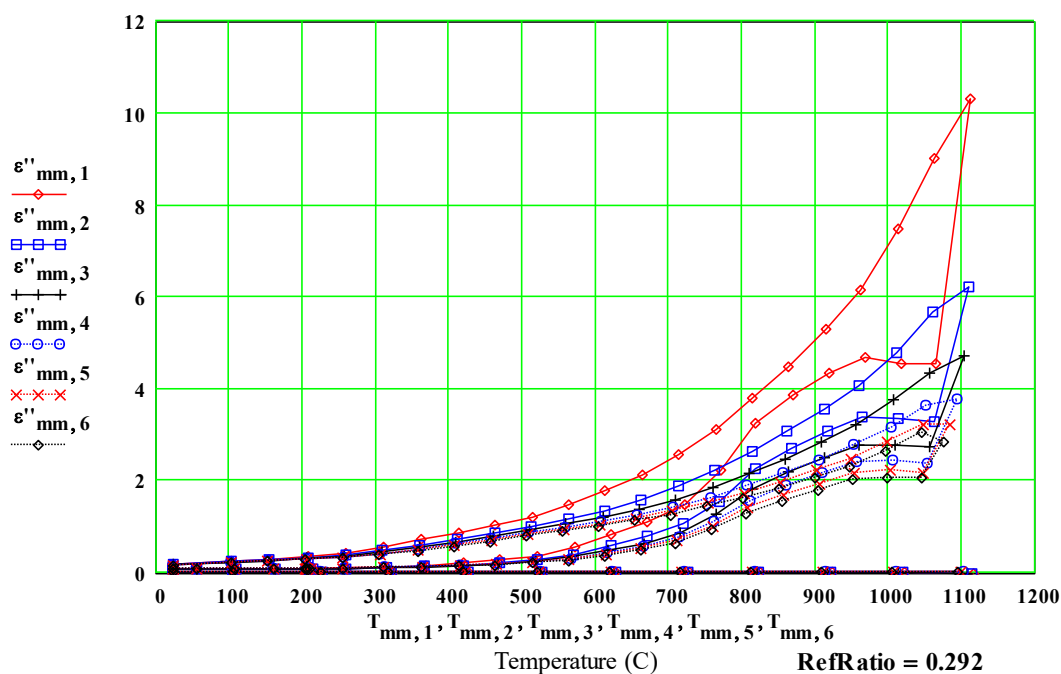
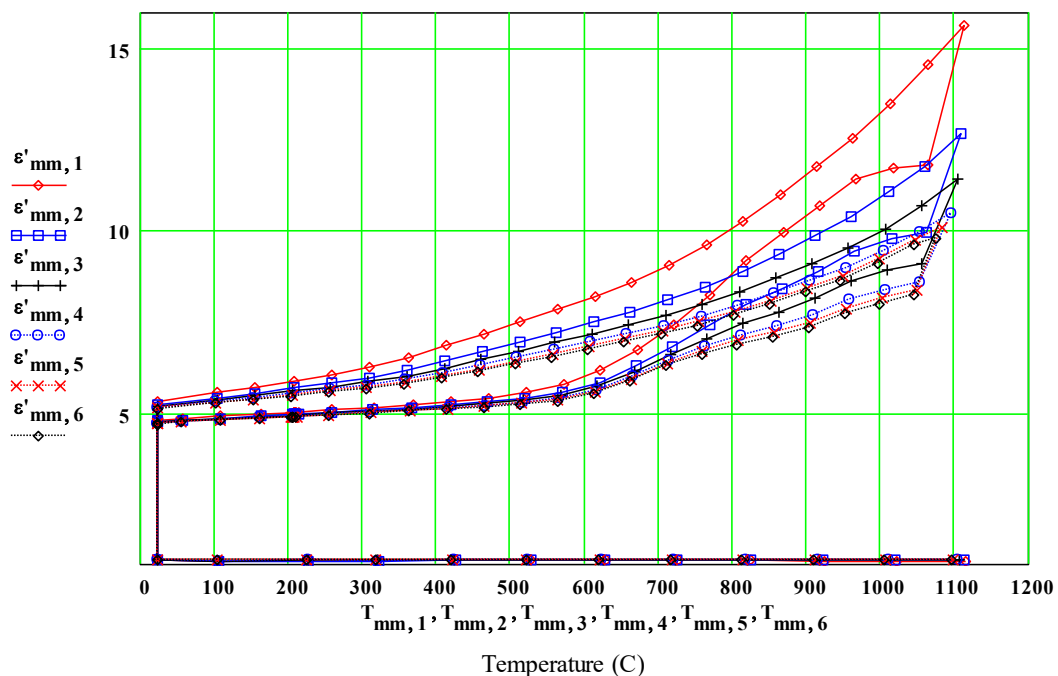
NASA2583\_TM685.mcd

AnDat = 20250930

JSC-1A-AGGL , RT to 1100C to RT, in 10 sccm argon, for D. Rickman, Amentum (NASA consultant)

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.09 \text{ gm/cc}$ ,

Final density(25C) =  $\text{dnsfinal} = 2.12 \text{ gm/cc}$



# JSC-1A-AGGL Argon

Test = 2025092701

NASA2583\_TM685.mcd

AnDat = 20250930

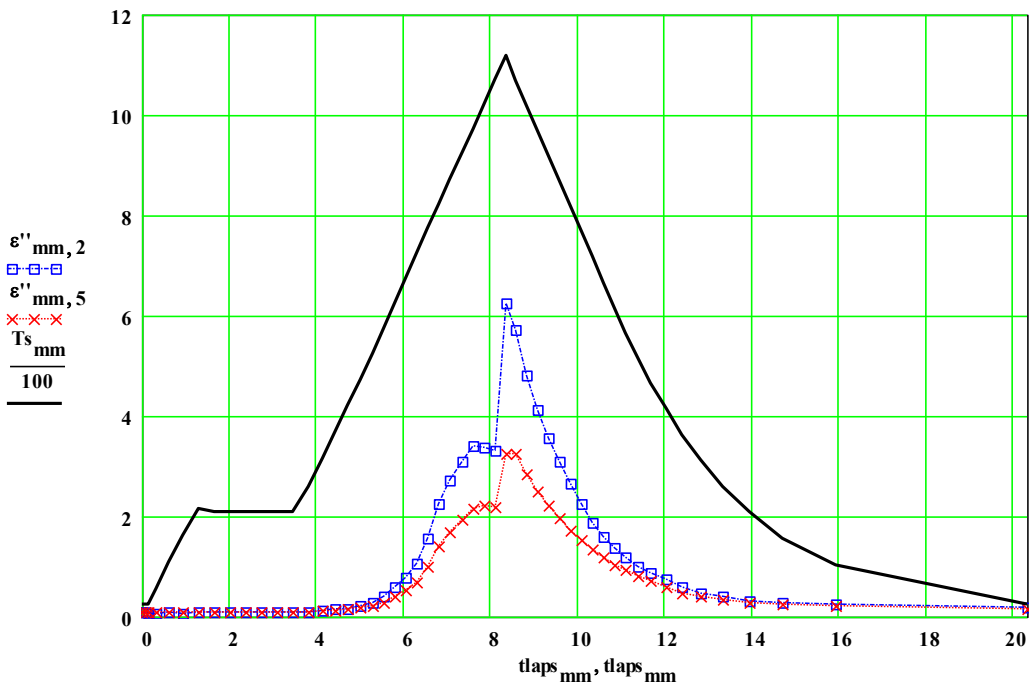
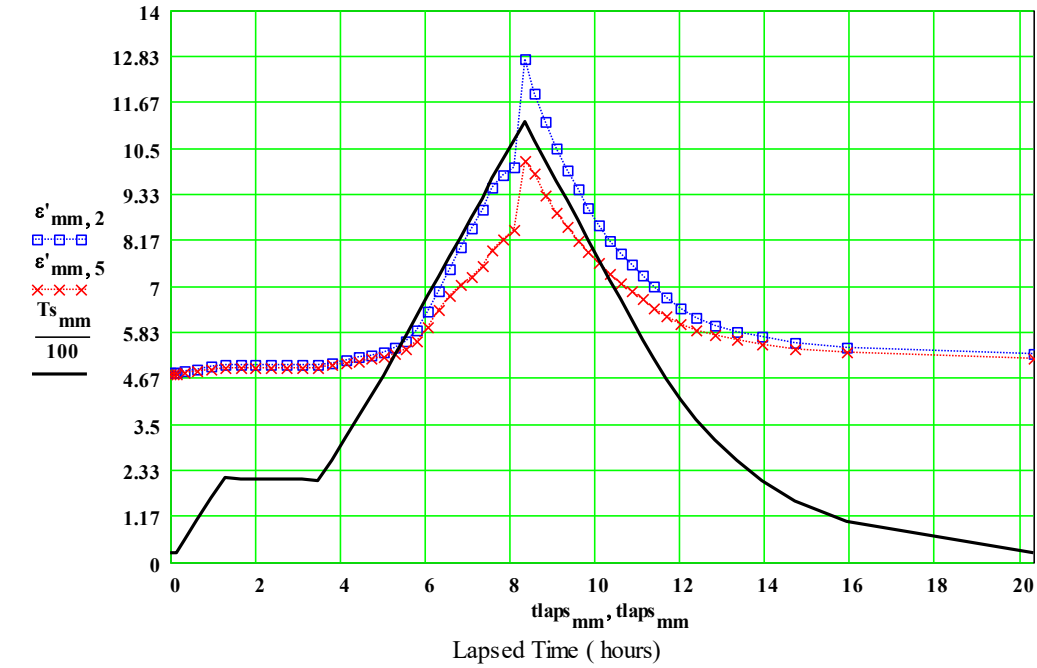
JSC-1A-AGGL , RT to 1100C to RT, in 10 sccm argon, for D. Rickman, Amentum (NASA consultant)

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.09 \text{ gm/cc}$ ,

Thermal exp. coeff.

Final density(25C) =  $\text{dnsfinal} = 2.12 \text{ gm/cc}$  FracMassChange = 1

$\alpha_1 = 0$



# JSC-1A-AGGL Argon

Test = 2025092701

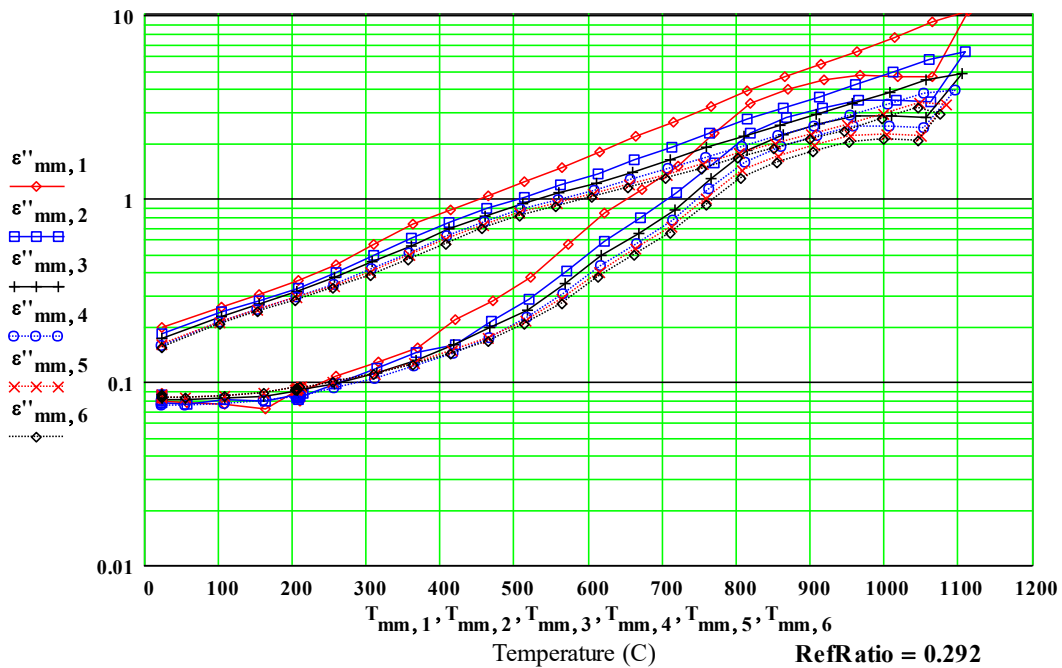
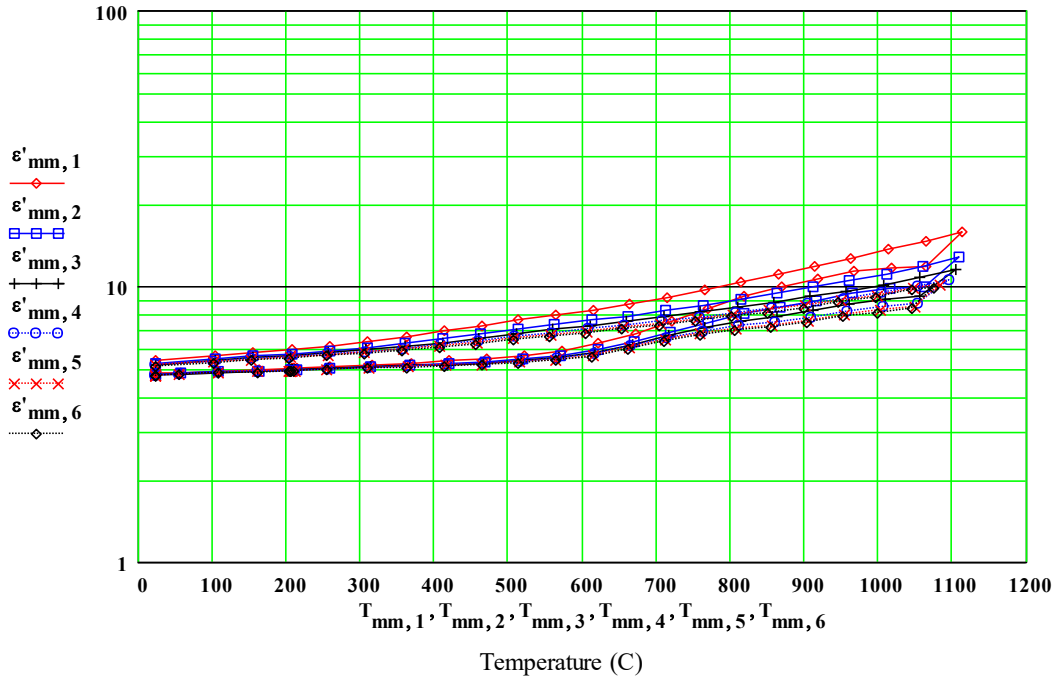
NASA2583\_TM685.mcd

AnDat = 20250930

JSC-1A-AGGL , RT to 1100C to RT, in 10 sccm argon, for D. Rickman, Amentum (NASA consultant)

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.09 \text{ gm/cc}$ ,

Final density(25C) =  $\text{dnsfinal} = 2.12 \text{ gm/cc}$



# JSC-1A-AGGL Argon

Test = 2025092701

NASA2583\_TM685.mcd

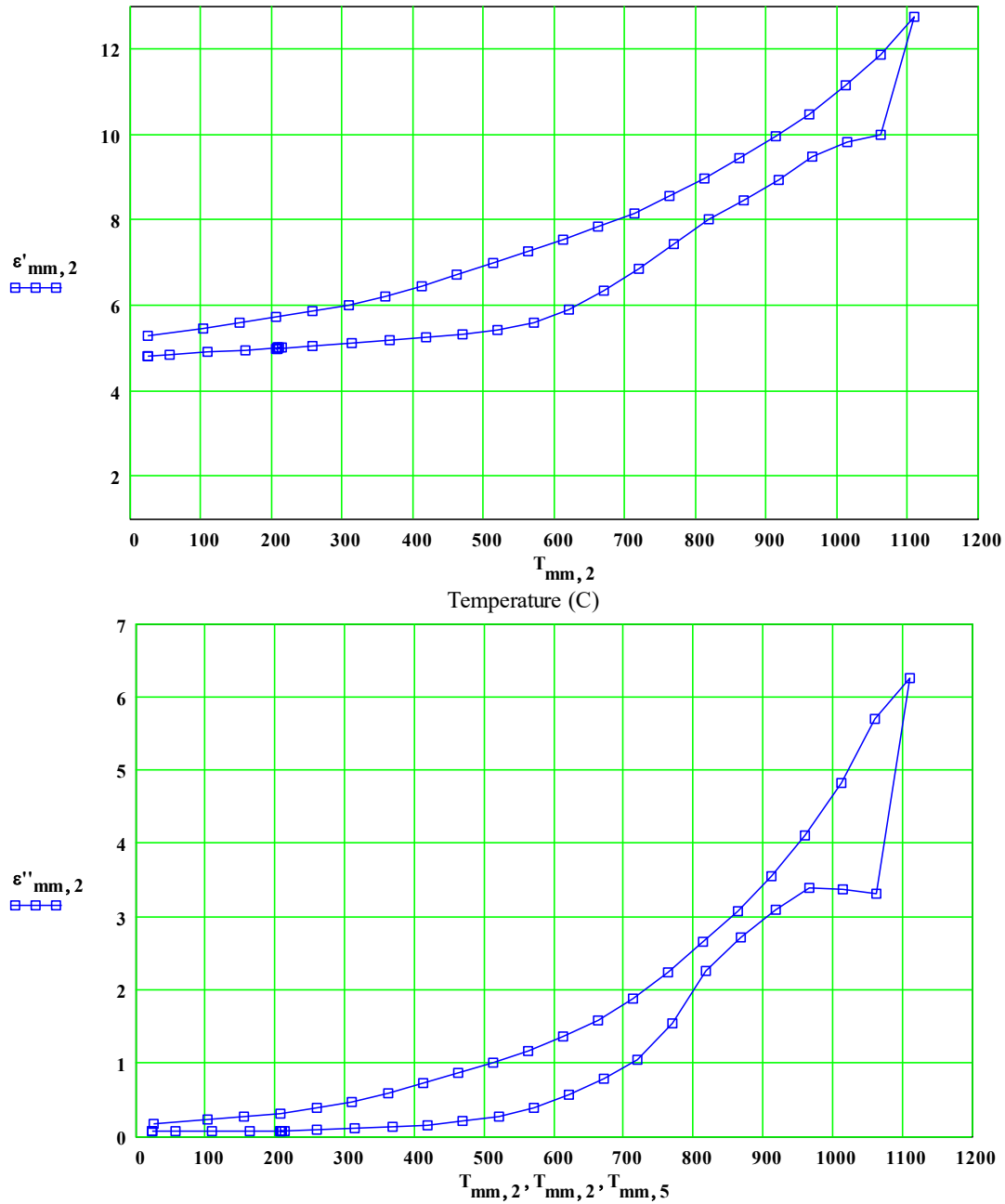
AnDat = 20250930

JSC-1A-AGGL , RT to 1100C to RT, in 10 sccm argon, for D. Rickman, Amentum (NASA consultant)

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.09 \text{ gm/cc}$ , Thermal exp. coeff.  $\alpha_1 = 0$

Final density(25C) =  $\text{dnsfinal} = 2.12 \text{ gm/cc}$

## Values for 912 MHz



# JSC-1A-AGGL Argon

Test = 2025092701

NASA2583\_TM685.mcd

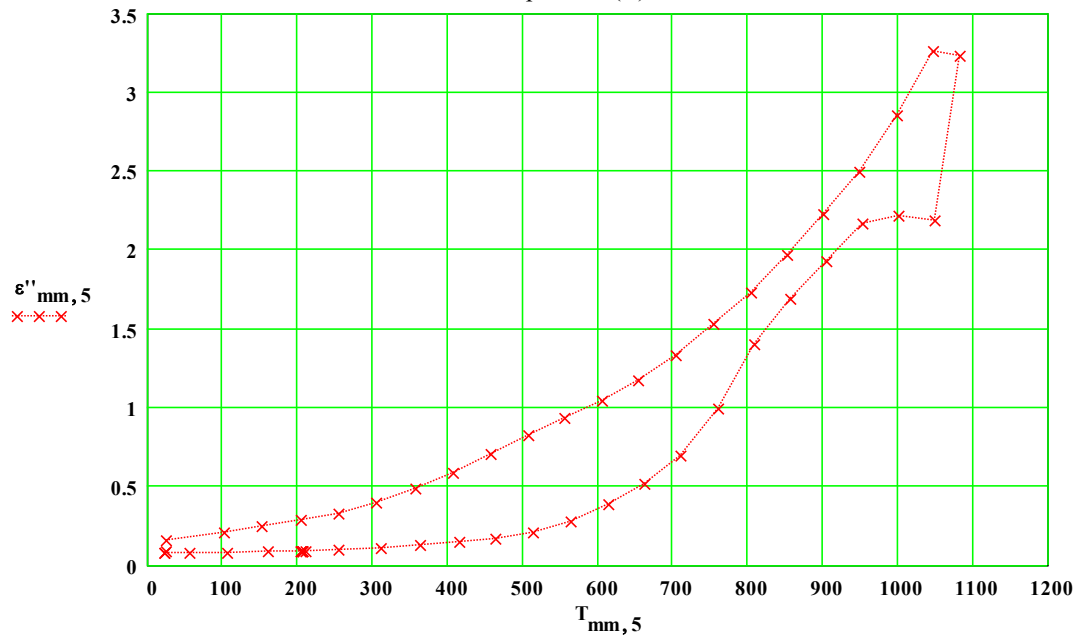
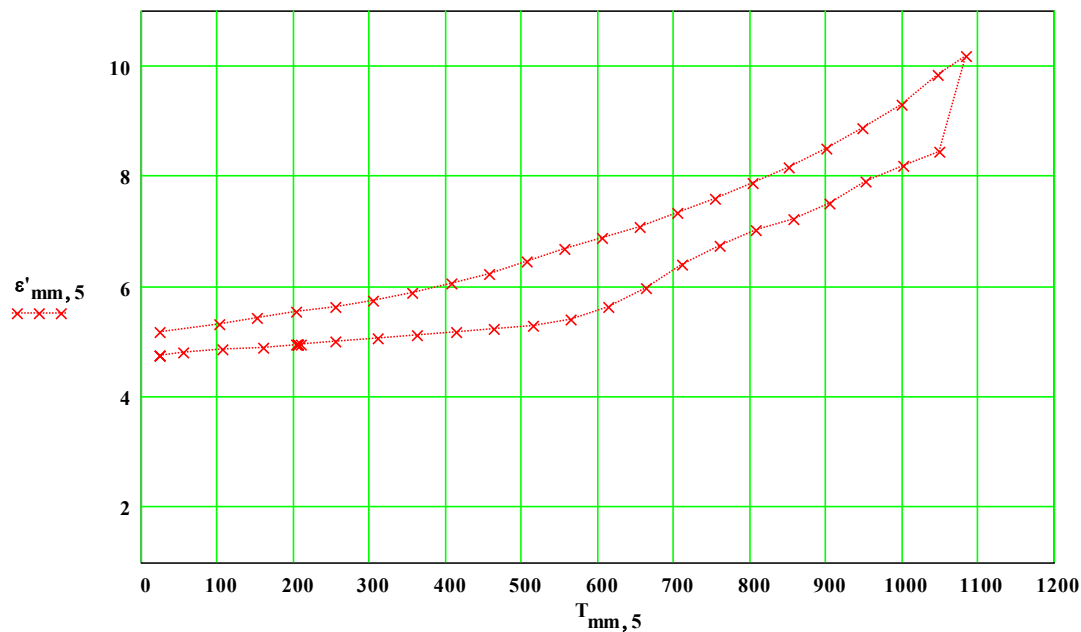
AnDat = 20250930

JSC-1A-AGGL , RT to 1100C to RT, in 10 sccm argon, for D. Rickman, Amentum (NASA consultant)

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.09$  gm/cc, Thermal exp. coeff  $\alpha_1 = 0$

Final density(25C) =  $\text{dnsfinal} = 2.12$  gm/cc

## Values for 2465 MHz



# JSC-1A-AGGL Argon

Test = 2025092701

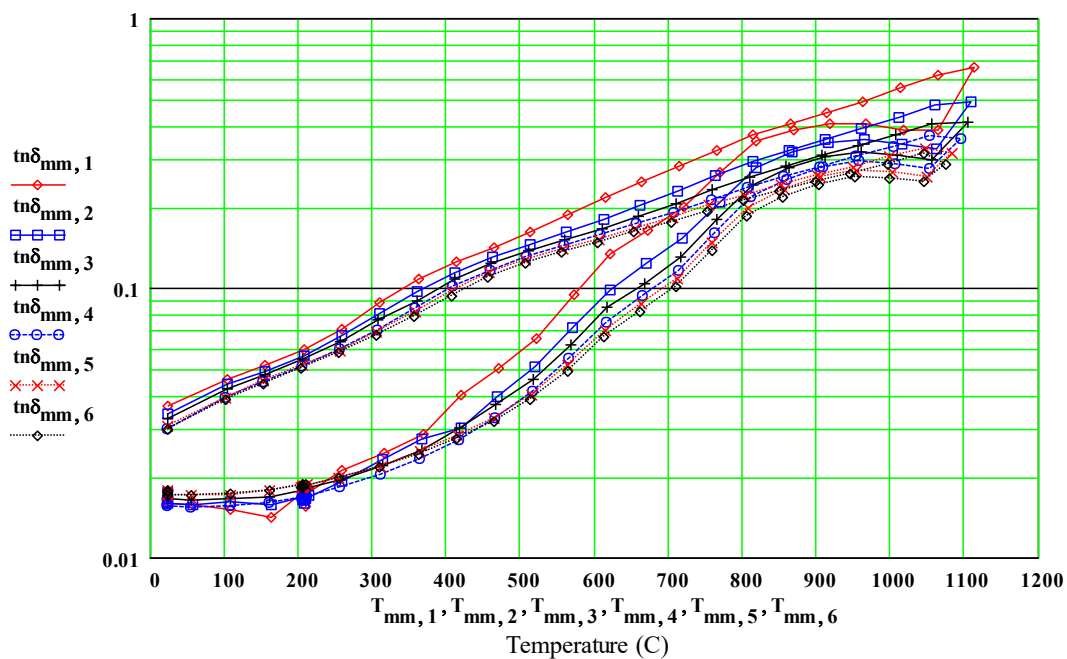
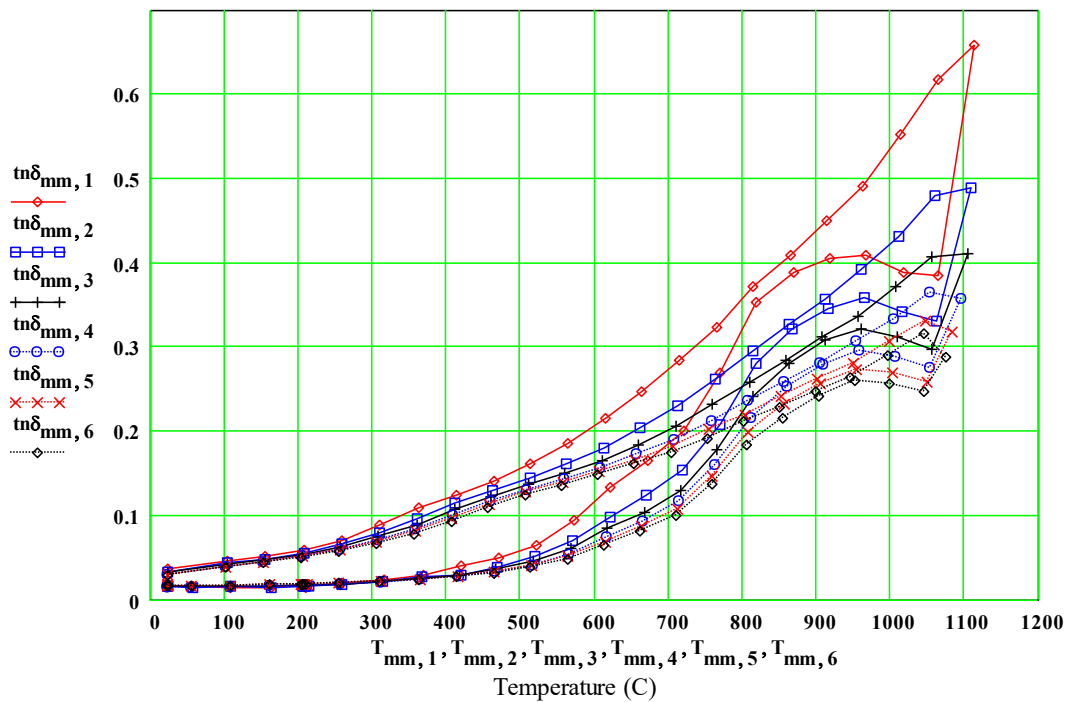
THDR2582\_TM684.mcd

AnDat = 20250930

T4P02 Brick Test Sample , RT to 1050C to RT, in air, for Andreas Bluml, TH-Deggendorf

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.09 \text{ gm/cc}$ ,

Final density(25C) =  $\text{dnsfinal} = 2.12 \text{ gm/cc}$



# JSC-1A-AGGL Argon

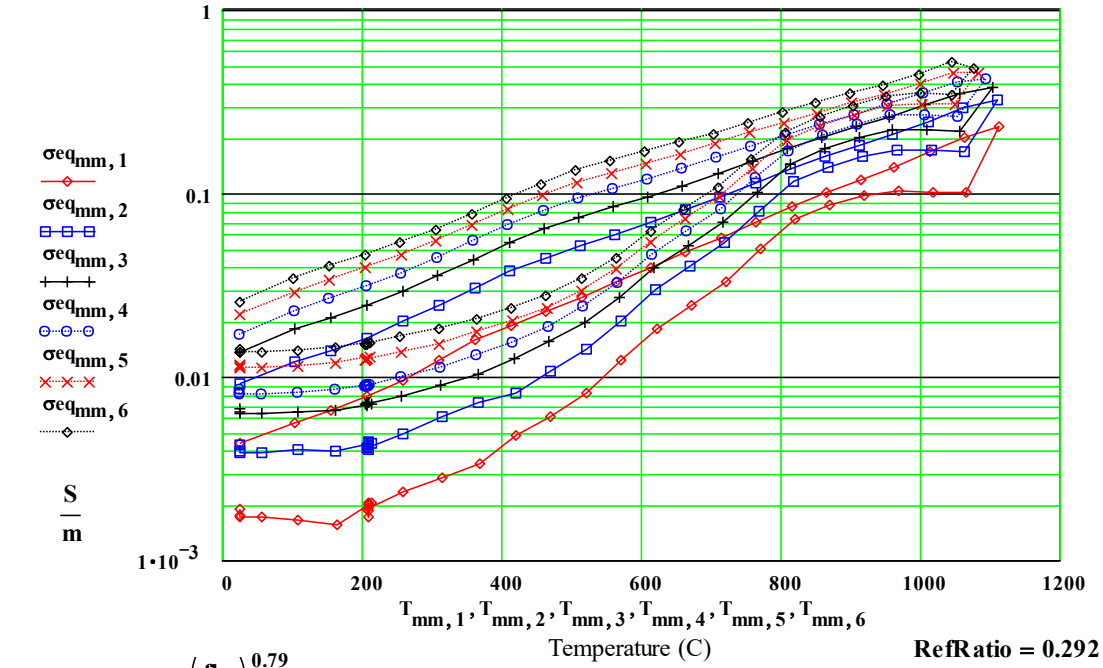
Test = 2025092701

NASA2583\_TM685.mcd

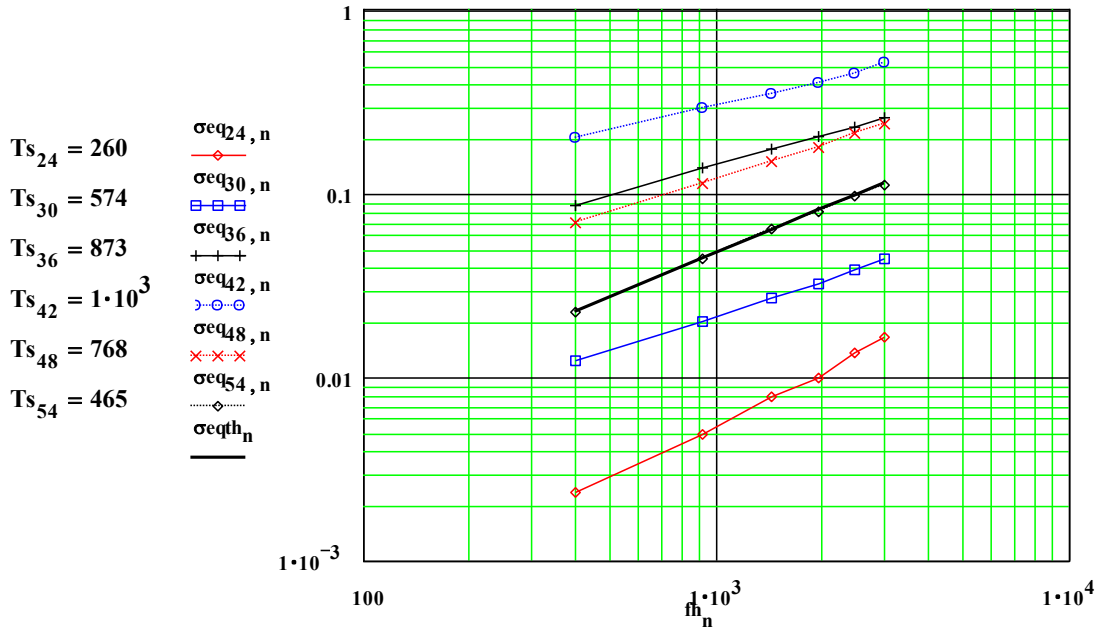
AnDat = 20250930

JSC-1A-AGGL , RT to 1100C to RT, in 10 sccm argon, for D. Rickman, Amentum (NASA consultant)

Equivalent Free Electron Conductivity ( Siemens/metre)



$$\sigma_{eqth_n} := 0.023 \cdot \left( \frac{fh_n}{400} \right)^{0.79} \quad \text{for } T = 465 \text{ on ramp down}$$



## JSC-1A-AGGL Argon

NASA2583\_TM685.mcd

**AnDat = 20251018**

JSC-1A-AGGL , RT to 1100C to RT, in 10 sccm UHP argon, for D. Rickman, Amentum (NASA consultant)

List of Measured Values of  $\varepsilon'$  and  $\varepsilon''$  :

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.091 \text{ gm/cc}$

Lapsed

density index T(C) 397MHz 912MHz 1429MH 1948MHz2466MHz 2986MHz

Time  
(1999)

(hours)

samdns<sub>mm</sub> T<sub>mm,1</sub> ε'<sub>mm,1</sub> ε'<sub>mm,2</sub> ε'<sub>mm,3</sub> ε'<sub>mm,4</sub> ε'<sub>mm,5</sub> ε'<sub>mm,6</sub> tlaps<sub>mm</sub> sammas<sub>mm</sub>

|       |    |      |       |       |       |       |       |      |       |       |
|-------|----|------|-------|-------|-------|-------|-------|------|-------|-------|
| 2.091 | 11 | 24   | 4.87  | 4.83  | 4.8   | 4.78  | 4.76  | 4.75 | 0     | 0.269 |
| 2.091 | 12 | 24   | 4.86  | 4.82  | 4.79  | 4.77  | 4.76  | 4.74 | 0.07  | 0.269 |
| 2.091 | 13 | 24   | 4.85  | 4.81  | 4.79  | 4.77  | 4.75  | 4.74 | 0.13  | 0.269 |
| 2.091 | 14 | 56   | 4.9   | 4.85  | 4.83  | 4.81  | 4.8   | 4.78 | 0.33  | 0.269 |
| 2.091 | 15 | 109  | 4.95  | 4.91  | 4.89  | 4.86  | 4.85  | 4.84 | 0.63  | 0.269 |
| 2.091 | 16 | 163  | 5.01  | 4.97  | 4.94  | 4.91  | 4.9   | 4.89 | 0.95  | 0.269 |
| 2.091 | 17 | 214  | 5.07  | 5.02  | 4.99  | 4.96  | 4.95  | 4.94 | 1.28  | 0.269 |
| 2.091 | 18 | 210  | 5.06  | 5.01  | 4.99  | 4.96  | 4.94  | 4.93 | 1.65  | 0.269 |
| 2.091 | 19 | 209  | 5.06  | 5.01  | 4.98  | 4.96  | 4.94  | 4.93 | 2.01  | 0.269 |
| 2.091 | 20 | 208  | 5.06  | 5     | 4.98  | 4.95  | 4.94  | 4.93 | 2.38  | 0.269 |
| 2.091 | 21 | 209  | 5.06  | 5.01  | 4.98  | 4.95  | 4.94  | 4.93 | 2.74  | 0.269 |
| 2.091 | 22 | 208  | 5.06  | 5     | 4.98  | 4.95  | 4.94  | 4.92 | 3.11  | 0.269 |
| 2.091 | 23 | 207  | 5.05  | 5     | 4.98  | 4.95  | 4.94  | 4.92 | 3.48  | 0.269 |
| 2.091 | 24 | 259  | 5.13  | 5.06  | 5.04  | 5.01  | 5     | 4.98 | 3.8   | 0.269 |
| 2.091 | 25 | 315  | 5.2   | 5.13  | 5.1   | 5.07  | 5.05  | 5.04 | 4.16  | 0.269 |
| 2.091 | 26 | 368  | 5.29  | 5.19  | 5.17  | 5.13  | 5.11  | 5.09 | 4.44  | 0.269 |
| 2.091 | 27 | 420  | 5.37  | 5.27  | 5.23  | 5.19  | 5.17  | 5.15 | 4.73  | 0.269 |
| 2.091 | 28 | 470  | 5.46  | 5.34  | 5.3   | 5.25  | 5.23  | 5.21 | 5.01  | 0.269 |
| 2.091 | 29 | 521  | 5.61  | 5.45  | 5.39  | 5.33  | 5.3   | 5.28 | 5.3   | 0.269 |
| 2.091 | 30 | 572  | 5.83  | 5.6   | 5.52  | 5.45  | 5.41  | 5.38 | 5.55  | 0.269 |
| 2.091 | 31 | 622  | 6.21  | 5.89  | 5.77  | 5.67  | 5.62  | 5.58 | 5.81  | 0.269 |
| 2.091 | 32 | 672  | 6.76  | 6.34  | 6.18  | 6.05  | 5.98  | 5.93 | 6.06  | 0.269 |
| 2.091 | 33 | 721  | 7.46  | 6.88  | 6.64  | 6.48  | 6.39  | 6.33 | 6.32  | 0.269 |
| 2.091 | 34 | 770  | 8.29  | 7.44  | 7.09  | 6.87  | 6.74  | 6.66 | 6.57  | 0.269 |
| 2.091 | 35 | 819  | 9.24  | 8.01  | 7.51  | 7.18  | 7.03  | 6.92 | 6.82  | 0.269 |
| 2.091 | 36 | 869  | 9.98  | 8.46  | 7.82  | 7.42  | 7.23  | 7.12 | 7.08  | 0.269 |
| 2.091 | 37 | 919  | 10.72 | 8.94  | 8.18  | 7.71  | 7.51  | 7.38 | 7.34  | 0.269 |
| 2.091 | 38 | 968  | 11.46 | 9.5   | 8.66  | 8.13  | 7.91  | 7.76 | 7.59  | 0.269 |
| 2.095 | 39 | 1017 | 11.74 | 9.82  | 8.96  | 8.42  | 8.19  | 8.05 | 7.85  | 0.269 |
| 2.098 | 40 | 1065 | 11.84 | 10    | 9.17  | 8.66  | 8.43  | 8.29 | 8.1   | 0.269 |
| 2.102 | 41 | 1113 | 15.69 | 12.74 | 11.49 | 10.55 | 10.14 | 9.87 | 8.35  | 0.269 |
| 2.106 | 42 | 1064 | 14.64 | 11.85 | 10.75 | 10.03 | 9.82  | 9.69 | 8.59  | 0.269 |
| 2.109 | 43 | 1014 | 13.55 | 11.14 | 10.12 | 9.51  | 9.27  | 9.15 | 8.84  | 0.269 |
| 2.112 | 44 | 963  | 12.57 | 10.45 | 9.59  | 9.03  | 8.82  | 8.7  | 9.1   | 0.269 |
| 2.115 | 45 | 915  | 11.78 | 9.92  | 9.15  | 8.66  | 8.47  | 8.35 | 9.35  | 0.269 |
| 2.118 | 46 | 864  | 11.01 | 9.41  | 8.75  | 8.31  | 8.13  | 8.02 | 9.6   | 0.269 |
| 2.121 | 47 | 815  | 10.29 | 8.94  | 8.38  | 8     | 7.84  | 7.72 | 9.85  | 0.269 |
| 2.121 | 48 | 765  | 9.66  | 8.52  | 8.03  | 7.7   | 7.55  | 7.45 | 10.1  | 0.269 |
| 2.121 | 49 | 714  | 9.09  | 8.13  | 7.72  | 7.43  | 7.29  | 7.2  | 10.36 | 0.269 |
| 2.121 | 50 | 664  | 8.62  | 7.8   | 7.45  | 7.19  | 7.07  | 6.98 | 10.61 | 0.269 |
| 2.121 | 51 | 614  | 8.21  | 7.52  | 7.21  | 6.97  | 6.86  | 6.77 | 10.86 | 0.269 |
| 2.121 | 52 | 564  | 7.85  | 7.25  | 6.97  | 6.75  | 6.65  | 6.56 | 11.11 | 0.269 |
| 2.121 | 53 | 514  | 7.52  | 6.98  | 6.73  | 6.53  | 6.43  | 6.36 | 11.39 | 0.269 |
| 2.121 | 54 | 463  | 7.19  | 6.7   | 6.48  | 6.31  | 6.22  | 6.15 | 11.69 | 0.269 |
| 2.121 | 55 | 413  | 6.87  | 6.44  | 6.25  | 6.1   | 6.03  | 5.98 | 12.03 | 0.269 |
| 2.121 | 56 | 362  | 6.55  | 6.2   | 6.05  | 5.93  | 5.87  | 5.83 | 12.4  | 0.269 |
| 2.121 | 57 | 310  | 6.29  | 6     | 5.88  | 5.79  | 5.74  | 5.7  | 12.83 | 0.269 |
| 2.121 | 58 | 259  | 6.07  | 5.85  | 5.75  | 5.67  | 5.63  | 5.59 | 13.33 | 0.269 |
| 2.121 | 59 | 208  | 5.9   | 5.71  | 5.63  | 5.55  | 5.52  | 5.49 | 13.93 | 0.269 |
| 2.121 | 60 | 155  | 5.73  | 5.57  | 5.5   | 5.44  | 5.41  | 5.38 | 14.72 | 0.269 |

$$mq := 61, 62 \dots nd - N_{\text{empties}}$$

| samdns | mcmq | T <sub>mq, 1</sub> | ε <sup>1</sup> <sub>mq, 1</sub> | ε <sup>1</sup> <sub>mq, 2</sub> | ε <sup>1</sup> <sub>mq, 3</sub> | ε <sup>1</sup> <sub>mq, 4</sub> | ε <sup>1</sup> <sub>mq, 5</sub> | ε <sup>1</sup> <sub>mq, 6</sub> | tlaps <sub>mq</sub> | sammms <sub>mq</sub> |
|--------|------|--------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------|----------------------|
| 2.121  | 61   | 104                | 5.58                            | 5.44                            | 5.38                            | 5.33                            | 5.31                            | 5.29                            | 15.92               | 0.269                |
| 2.121  | 62   | 24                 | 5.36                            | 5.27                            | 5.21                            | 5.18                            | 5.16                            | 5.14                            | 20.33               | 0.269                |

# JSC-1A-AGGL Argon

Test = 2025092701

NASA2583\_TM685.mcd

AnDat = 20251018

JSC-1A-AGGL , RT to 1100C to RT, in 10 sccm UHP argon, for D. Rickman, Amentum (NASA consultant)

List of Measured Values of  $\epsilon'$  and  $\epsilon''$  :

^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^

Initial density = samdns<sub>NCal + 1</sub> = 2.091 gm/cc

Lapsed

density index T(C) 397MHz 912MHz 1429MH 1948MHz2466MHz 2986MHz

Time

(hours)

| samdns | mmmm | T <sub>mm,1</sub> | $\epsilon'$ <sub>mm,1</sub> | $\epsilon''$ <sub>mm,2</sub> | $\epsilon''$ <sub>mm,3</sub> | $\epsilon''$ <sub>mm,4</sub> | $\epsilon''$ <sub>mm,5</sub> | $\epsilon''$ <sub>mm,6</sub> | tlaps <sub>mm</sub> | sammas <sub>mm</sub> |
|--------|------|-------------------|-----------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|---------------------|----------------------|
| 2.091  | 11   | 24                | 0.086                       | 0.085                        | 0.085                        | 0.078                        | 0.085                        | 0.085                        | 0                   | 0.269                |
| 2.091  | 12   | 24                | 0.08                        | 0.078                        | 0.081                        | 0.075                        | 0.082                        | 0.083                        | 0.07                | 0.269                |
| 2.091  | 13   | 24                | 0.078                       | 0.076                        | 0.08                         | 0.074                        | 0.081                        | 0.081                        | 0.13                | 0.269                |
| 2.091  | 14   | 56                | 0.078                       | 0.076                        | 0.08                         | 0.073                        | 0.082                        | 0.082                        | 0.33                | 0.269                |
| 2.091  | 15   | 109               | 0.075                       | 0.08                         | 0.081                        | 0.075                        | 0.083                        | 0.084                        | 0.63                | 0.269                |
| 2.091  | 16   | 163               | 0.071                       | 0.078                        | 0.083                        | 0.078                        | 0.087                        | 0.087                        | 0.95                | 0.269                |
| 2.091  | 17   | 214               | 0.093                       | 0.086                        | 0.09                         | 0.084                        | 0.093                        | 0.093                        | 1.28                | 0.269                |
| 2.091  | 18   | 210               | 0.089                       | 0.083                        | 0.091                        | 0.081                        | 0.091                        | 0.092                        | 1.65                | 0.269                |
| 2.091  | 19   | 209               | 0.079                       | 0.082                        | 0.091                        | 0.082                        | 0.092                        | 0.091                        | 2.01                | 0.269                |
| 2.091  | 20   | 208               | 0.085                       | 0.088                        | 0.09                         | 0.083                        | 0.09                         | 0.09                         | 2.38                | 0.269                |
| 2.091  | 21   | 209               | 0.092                       | 0.08                         | 0.091                        | 0.082                        | 0.091                        | 0.091                        | 2.74                | 0.269                |
| 2.091  | 22   | 208               | 0.094                       | 0.087                        | 0.088                        | 0.081                        | 0.091                        | 0.09                         | 3.11                | 0.269                |
| 2.091  | 23   | 207               | 0.086                       | 0.082                        | 0.09                         | 0.082                        | 0.09                         | 0.09                         | 3.48                | 0.269                |
| 2.091  | 24   | 259               | 0.108                       | 0.097                        | 0.098                        | 0.091                        | 0.098                        | 0.099                        | 3.8                 | 0.269                |
| 2.091  | 25   | 315               | 0.128                       | 0.119                        | 0.112                        | 0.103                        | 0.11                         | 0.11                         | 4.16                | 0.269                |
| 2.091  | 26   | 368               | 0.153                       | 0.143                        | 0.131                        | 0.12                         | 0.127                        | 0.124                        | 4.44                | 0.269                |
| 2.091  | 27   | 420               | 0.216                       | 0.16                         | 0.159                        | 0.142                        | 0.146                        | 0.142                        | 4.73                | 0.269                |
| 2.091  | 28   | 470               | 0.275                       | 0.212                        | 0.196                        | 0.172                        | 0.172                        | 0.166                        | 5.01                | 0.269                |
| 2.091  | 29   | 521               | 0.367                       | 0.28                         | 0.247                        | 0.221                        | 0.214                        | 0.204                        | 5.3                 | 0.269                |
| 2.091  | 30   | 572               | 0.556                       | 0.399                        | 0.34                         | 0.297                        | 0.281                        | 0.265                        | 5.55                | 0.269                |
| 2.091  | 31   | 622               | 0.832                       | 0.583                        | 0.49                         | 0.421                        | 0.392                        | 0.368                        | 5.81                | 0.269                |
| 2.091  | 32   | 672               | 1.114                       | 0.787                        | 0.644                        | 0.563                        | 0.521                        | 0.486                        | 6.06                | 0.269                |
| 2.091  | 33   | 721               | 1.495                       | 1.057                        | 0.868                        | 0.753                        | 0.691                        | 0.642                        | 6.32                | 0.269                |
| 2.091  | 34   | 770               | 2.235                       | 1.557                        | 1.271                        | 1.099                        | 0.993                        | 0.919                        | 6.57                | 0.269                |
| 2.091  | 35   | 819               | 3.272                       | 2.258                        | 1.818                        | 1.552                        | 1.397                        | 1.281                        | 6.82                | 0.269                |
| 2.091  | 36   | 869               | 3.876                       | 2.721                        | 2.201                        | 1.879                        | 1.684                        | 1.539                        | 7.08                | 0.269                |
| 2.091  | 37   | 919               | 4.355                       | 3.102                        | 2.52                         | 2.149                        | 1.932                        | 1.778                        | 7.34                | 0.269                |
| 2.091  | 38   | 968               | 4.685                       | 3.404                        | 2.786                        | 2.414                        | 2.163                        | 2.014                        | 7.59                | 0.269                |
| 2.095  | 39   | 1017              | 4.55                        | 3.367                        | 2.795                        | 2.432                        | 2.217                        | 2.064                        | 7.85                | 0.269                |
| 2.098  | 40   | 1065              | 4.556                       | 3.304                        | 2.732                        | 2.381                        | 2.177                        | 2.049                        | 8.1                 | 0.269                |
| 2.102  | 41   | 1113              | 10.261                      | 6.217                        | 4.717                        | 3.762                        | 3.216                        | 2.835                        | 8.35                | 0.269                |
| 2.106  | 42   | 1064              | 8.985                       | 5.657                        | 4.35                         | 3.645                        | 3.24                         | 3.048                        | 8.59                | 0.269                |
| 2.109  | 43   | 1014              | 7.43                        | 4.779                        | 3.75                         | 3.147                        | 2.831                        | 2.641                        | 8.84                | 0.269                |
| 2.112  | 44   | 963               | 6.114                       | 4.07                         | 3.218                        | 2.753                        | 2.475                        | 2.293                        | 9.1                 | 0.269                |
| 2.115  | 45   | 915               | 5.254                       | 3.527                        | 2.842                        | 2.428                        | 2.207                        | 2.064                        | 9.35                | 0.269                |
| 2.118  | 46   | 864               | 4.461                       | 3.055                        | 2.471                        | 2.14                         | 1.951                        | 1.833                        | 9.6                 | 0.269                |
| 2.121  | 47   | 815               | 3.788                       | 2.632                        | 2.15                         | 1.876                        | 1.713                        | 1.625                        | 9.85                | 0.269                |
| 2.121  | 48   | 765               | 3.105                       | 2.217                        | 1.852                        | 1.624                        | 1.519                        | 1.427                        | 10.1                | 0.269                |
| 2.121  | 49   | 714               | 2.563                       | 1.865                        | 1.583                        | 1.406                        | 1.324                        | 1.254                        | 10.36               | 0.269                |
| 2.121  | 50   | 664               | 2.126                       | 1.581                        | 1.369                        | 1.232                        | 1.165                        | 1.119                        | 10.61               | 0.269                |
| 2.121  | 51   | 614               | 1.764                       | 1.351                        | 1.194                        | 1.086                        | 1.036                        | 1                            | 10.86               | 0.269                |
| 2.121  | 52   | 564               | 1.46                        | 1.167                        | 1.047                        | 0.965                        | 0.926                        | 0.89                         | 11.11               | 0.269                |
| 2.121  | 53   | 514               | 1.213                       | 1.005                        | 0.922                        | 0.848                        | 0.817                        | 0.786                        | 11.39               | 0.269                |
| 2.121  | 54   | 463               | 1.012                       | 0.868                        | 0.794                        | 0.732                        | 0.704                        | 0.67                         | 11.69               | 0.269                |
| 2.121  | 55   | 413               | 0.853                       | 0.736                        | 0.673                        | 0.613                        | 0.586                        | 0.558                        | 12.03               | 0.269                |
| 2.121  | 56   | 362               | 0.71                        | 0.597                        | 0.541                        | 0.497                        | 0.479                        | 0.458                        | 12.4                | 0.269                |
| 2.121  | 57   | 310               | 0.555                       | 0.481                        | 0.445                        | 0.404                        | 0.393                        | 0.377                        | 12.83               | 0.269                |
| 2.121  | 58   | 259               | 0.429                       | 0.391                        | 0.365                        | 0.335                        | 0.329                        | 0.321                        | 13.33               | 0.269                |
| 2.121  | 59   | 208               | 0.35                        | 0.32                         | 0.306                        | 0.284                        | 0.283                        | 0.276                        | 13.93               | 0.269                |
| 2.121  | 60   | 155               | 0.295                       | 0.273                        | 0.262                        | 0.243                        | 0.244                        | 0.238                        | 14.72               | 0.269                |

mq := 61,62..nd - Nempties

| samdns <sub>mq</sub> | mmmq | T <sub>mq,1</sub> | $\epsilon''$ <sub>mq,1</sub> | $\epsilon''$ <sub>mq,2</sub> | $\epsilon''$ <sub>mq,3</sub> | $\epsilon''$ <sub>mq,4</sub> | $\epsilon''$ <sub>mq,5</sub> | $\epsilon''$ <sub>mq,6</sub> | tlaps <sub>mq</sub> | sammas <sub>mq</sub> |
|----------------------|------|-------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|---------------------|----------------------|
| 2.121                | 61   | 104               | 0.255                        | 0.238                        | 0.227                        | 0.209                        | 0.208                        | 0.205                        | 15.92               | 0.269                |
| 2.121                | 62   | 24                | 0.196                        | 0.18                         | 0.171                        | 0.155                        | 0.157                        | 0.153                        | 20.33               | 0.269                |

## **MPN-337\_NASA\_Rickman\_JSC-1A-AGGL\_4%Hydrogen Oct. 18, 2025**

### **JSC-1A AGGL Lunar Simulant Pellets**

#### **Measurements of Complex Dielectric Constant Between 400 and 2985 MHz from Room Temperature to 1100°C to Room Temperature , in 10 sccm Flowing 4% Hydrogen in Argon**

Jozef Mouris and Ronald Hutcheon ( MPN)

Douglas Rickman of the Space Exploration Division of Amentum ( on contract to NASA), requested that MPN measure the complex dielectric properties of pellets of lunar simulants which included special “agglutinates” which are considered to have favourable properties simulating the iron content of lunar regolith. The first of these was JSC-1A-AGGL , based on the oldest, best known “mare” simulant but with components processed at very high temperatures to emulate the known elemental iron content of lunar regolith.

The powder arrived in a sealed container at MPN on Sept. 4 /2025. The container was first opened on Sept. 25, and re-sealed after pellet making. The pellets for this run were made on Oct. 15, and were again pressed at ~ 20,000 psi which seemed to have sufficient strength for handling. Doug had requested an initial density close to the previous runs

The parameters of the initial pellet stack ( 3 pellets) , were:

- a) diameter 3.64 +- 0.05 mm
- b) length 13.68 +- 0.05 mm
- c) mass 0.289 +- 0.002 gm
- h) room temperature density 2.03 ± 0.09 gm/cc.
- i) appearance - grey pellets ( see photo)
- j) resistivity end-to-end > 30 Mohm
- k) very slight attraction to a strong magnet

The dielectric properties measurement run consisted of calibration measurements, then three sample measurements at room temperature (RT), then a single measurements at 50C, then 25C steps up to 200C, at which points a 2 hour hold was started, with measurements every 20 minutes. This was to measure the effect of moisture loss ( The measurements showed no detectable moisture). The run was then continued in 50C steps to 1100C, then in -50C steps to 100C, then RT. At the end of the run, the mass of the holder and pellets was measured at room temperature. It was noted that the pellets had some grit between them and the holder wall, which made the pellets difficult to remove. This was accomplished, however, with the pellets intact. It was later established that they were very strong, and difficult to break! Good landing pad material.

Then the empty holder was run to 1100C to check for contamination. There was no contamination .

The final sample stack properties, at room temperature were :

- a) diameter 3.60 ± 0.05 mm
- b) length 13.56 ± 0.05 mm
- c) mass 0.288 ± 0.002 gm
- h) room temperature density 2.09 ± 0.09 gm/cc.
- i) appearance - a dark, reddish-orange rod (see photos)
- f) resistivity end-to-end > 30 Mohm
- g) very slight attraction to a strong magnet



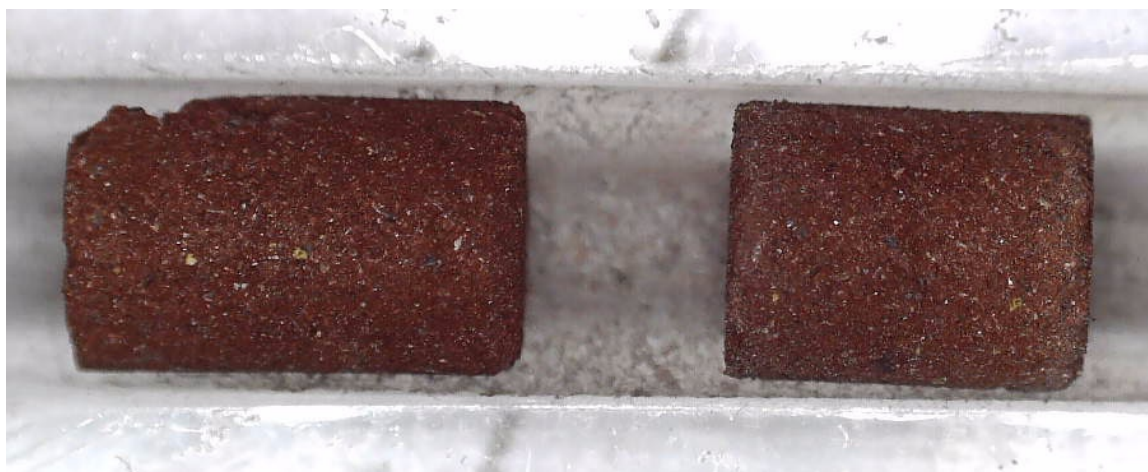
One initial pellet – at ~ 20,000 psi .



Comparison of the colour of the initial powder with that of the final pellets after the run to 1100 C in 4% hydrogen/Argon.



The final pellets of the 4% Hydrogen run. The lighting is slightly different .



A comparison of the appearance of the final pellets of the two separate JSC-1A-AGGL runs in different atmospheres to 1100 C .

The left hand pellet (NASA2583 ) was run in UHP Argon .

The right hand pellet (NASA2591) was run in 4% Hydrogen/Argon.

The frequency coding is :

Legend for Data Plots :

| # | <u>Frequency(MHz)</u> | <u>Symbol</u>                                            |
|---|-----------------------|----------------------------------------------------------|
| 1 | 397                   | red diamond, solid line – sometimes the line is omitted! |
| 2 | 912                   | blue square, solid line                                  |
| 3 | 1429                  | black cross, solid line                                  |
| 4 | 1948                  | blue circle, dotted line                                 |
| 5 | 2466                  | red cross, dotted line                                   |
| 6 | 2986                  | black diamond, dotted line                               |

Comments on the data analysis:

A linear thermal expansion coefficient ( CTE) of  $0.0 * 10^{-6}/C$  was used.

There  $\epsilon''$  values up to 200 C show only a hint of absorbed moisture.

The loss mechanism is frequency-dependent starting just above 400C, and indicates some amount of disordered structure ionic loss mechanism over the whole range back down to 250C .

The rapid increase between 1050 C and 1100 C suggests the influence of melting of some component.



# JSC-1A-AGGL Argon w/4% H<sub>2</sub>

Test = 2025191501

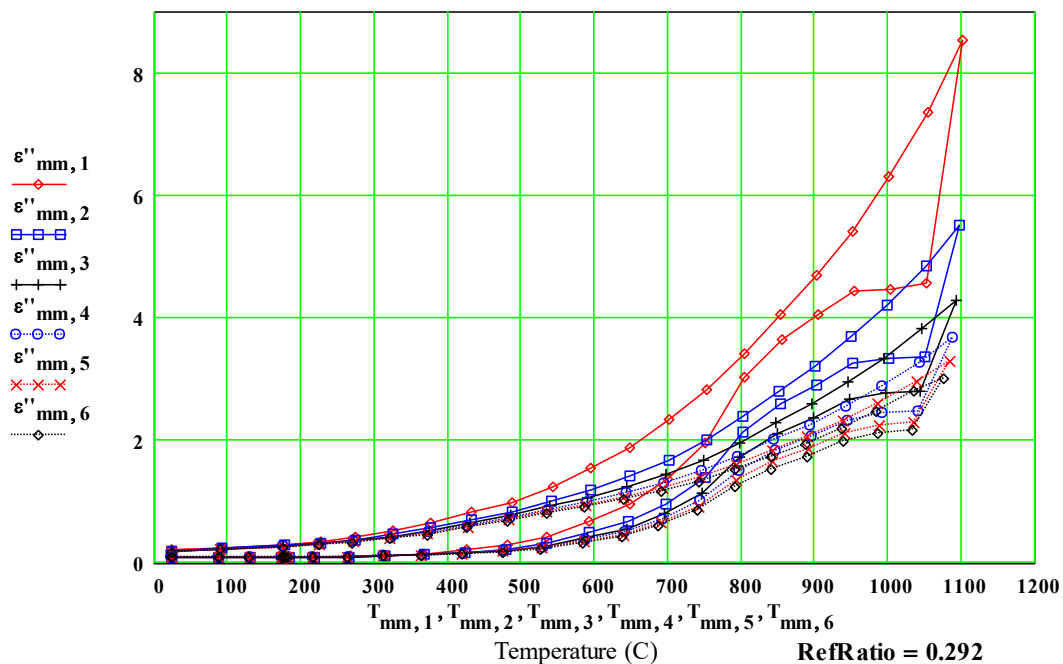
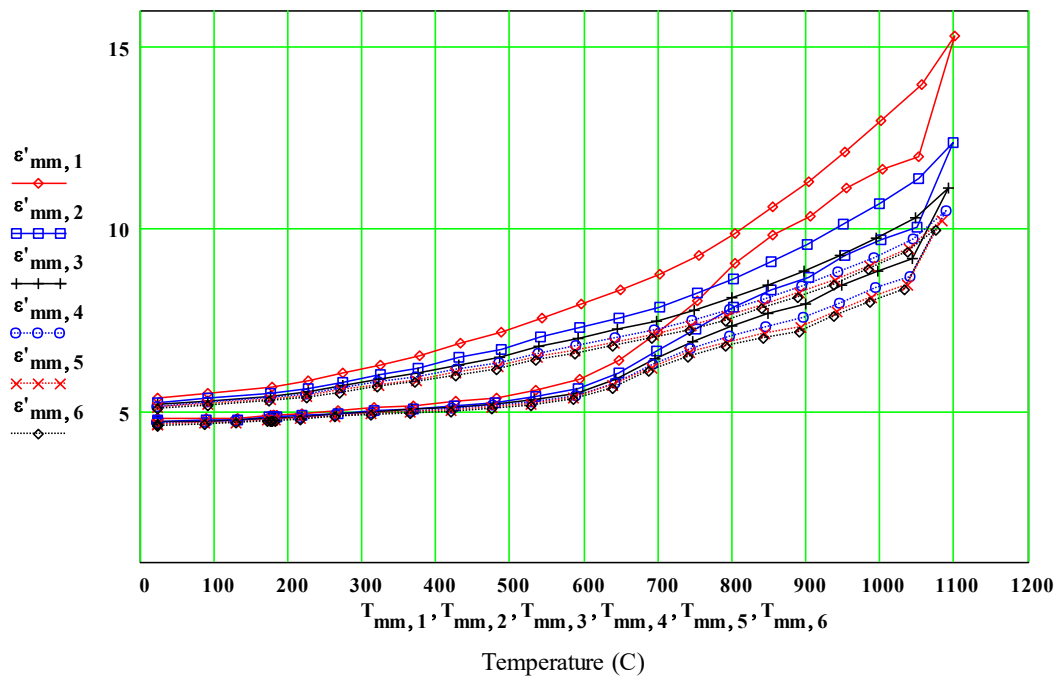
NASA2591\_TM685.mcd

AnDat = 20251016

JSC-1A-AGGL, RT to 1100C to RT, in 10 sccm 4% Hydrogen/Argon, D. Rickman, Amentum (NASA consultant)

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.03 \text{ gm/cc}$ ,

Final density(25C) =  $\text{dnsfinal} = 2.09 \text{ gm/cc}$



RefRatio = 0.292

# JSC-1A-AGGL Argon w/4% H<sub>2</sub>

Test = 2025191501

NASA2591\_TM685.mcd

AnDat = 20251018

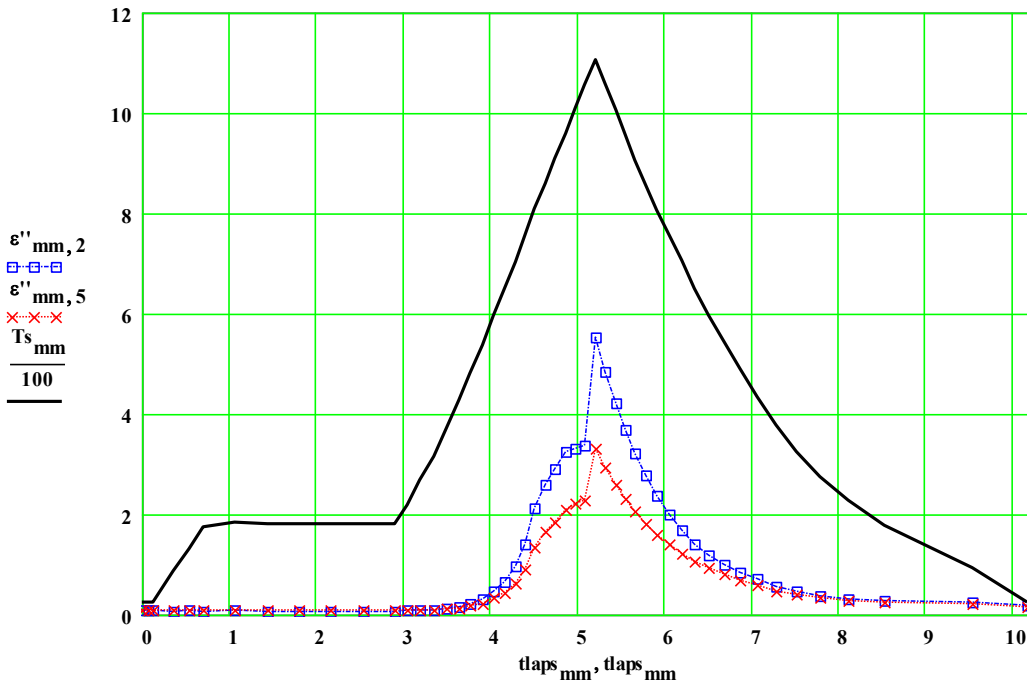
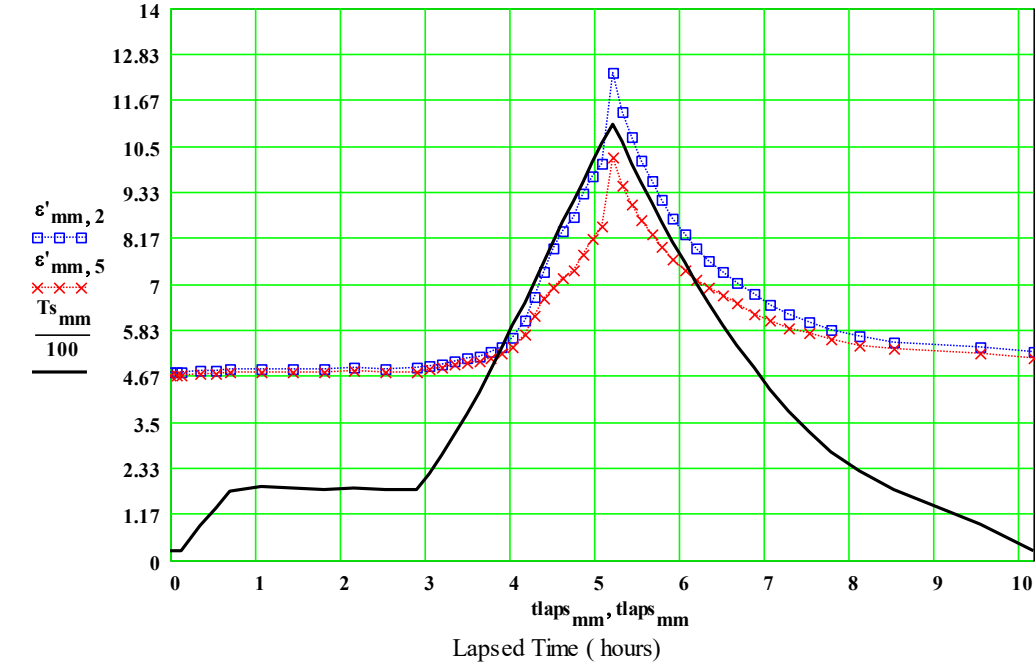
JSC-1A-AGGL, RT to 1100C to RT, in 10 sccm 4% Hydrogen/Argon, D. Rickman, Amentum (NASA consulta

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.03 \text{ gm/cc}$ ,

Thermal exp. coeff.

Final density(25C) =  $\text{dnsfinal} = 2.09 \text{ gm/cc}$  FracMassChange = 1

$\alpha_1 = 0$



# JSC-1A-AGGL Argon w/4% H<sub>2</sub>

Test = 2025191501

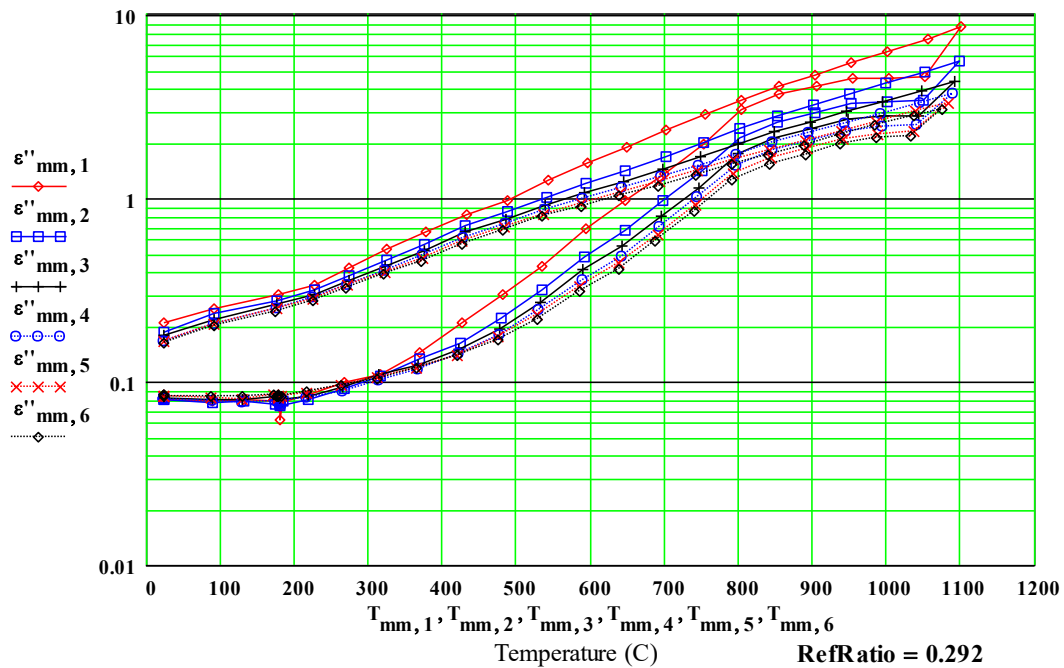
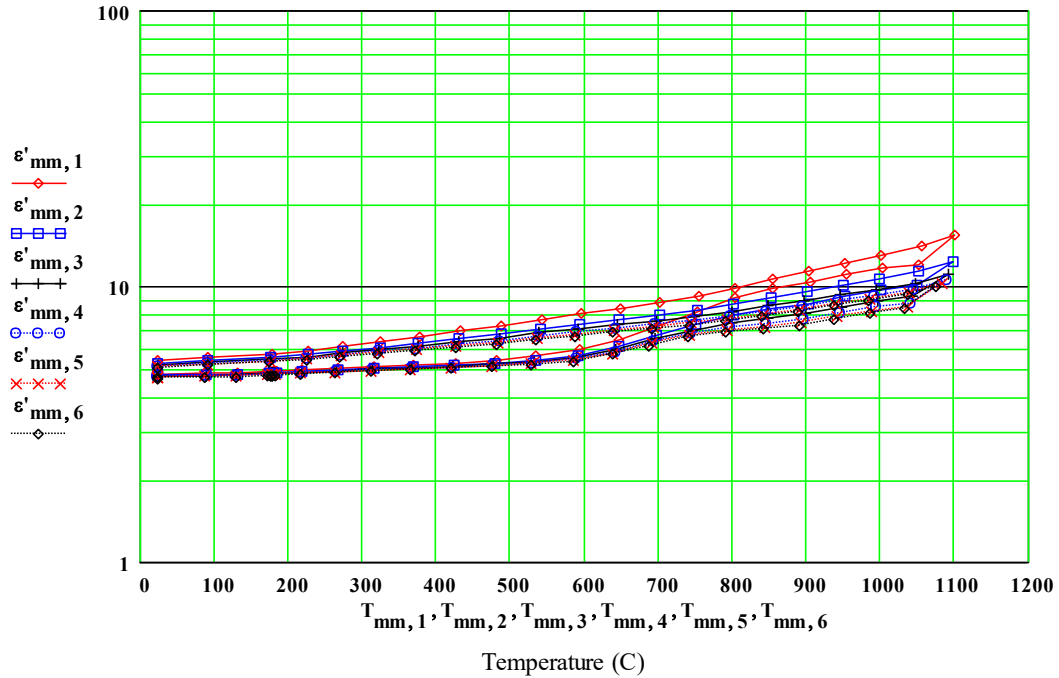
NASA2591\_TM685.mcd

AnDat = 20251018

JSC-1A-AGGL, RT to 1100C to RT, in 10 sccm 4% Hydrogen/Argon, D. Rickman, Amentum (NASA consultant)

Initial density =  $\text{samdns}_{\text{NCal}} + 1 = 2.03$  gm/cc,

Final density(25C) =  $\text{dnsfinal} = 2.09$  gm/cc



RefRatio = 0.292

# JSC-1A-AGGL Argon w/4% H<sub>2</sub>

Test = 2025191501

NASA2591\_TM685.med

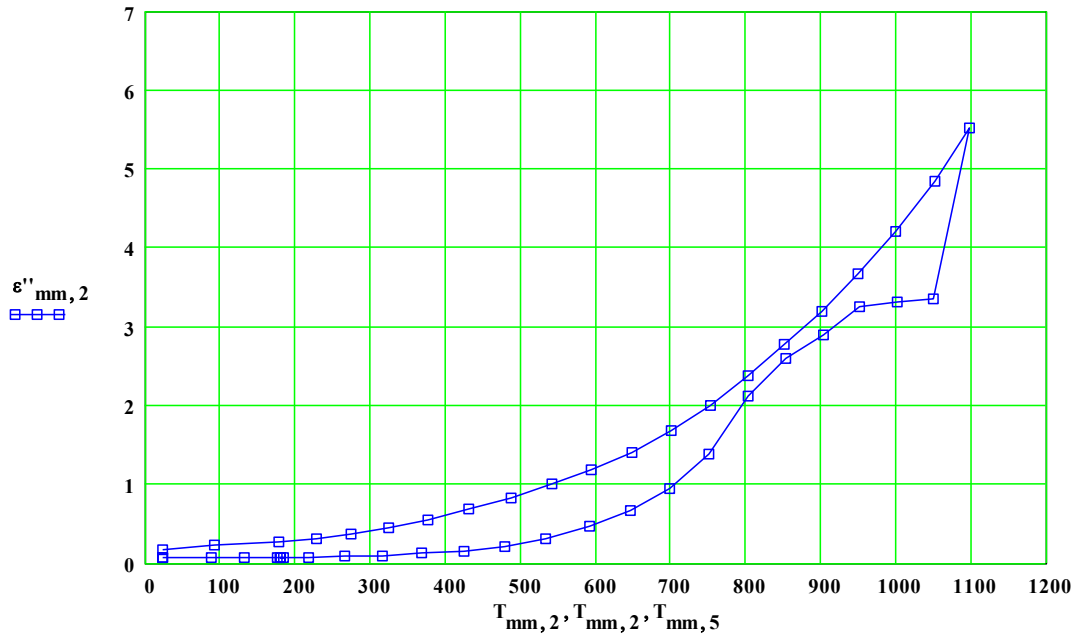
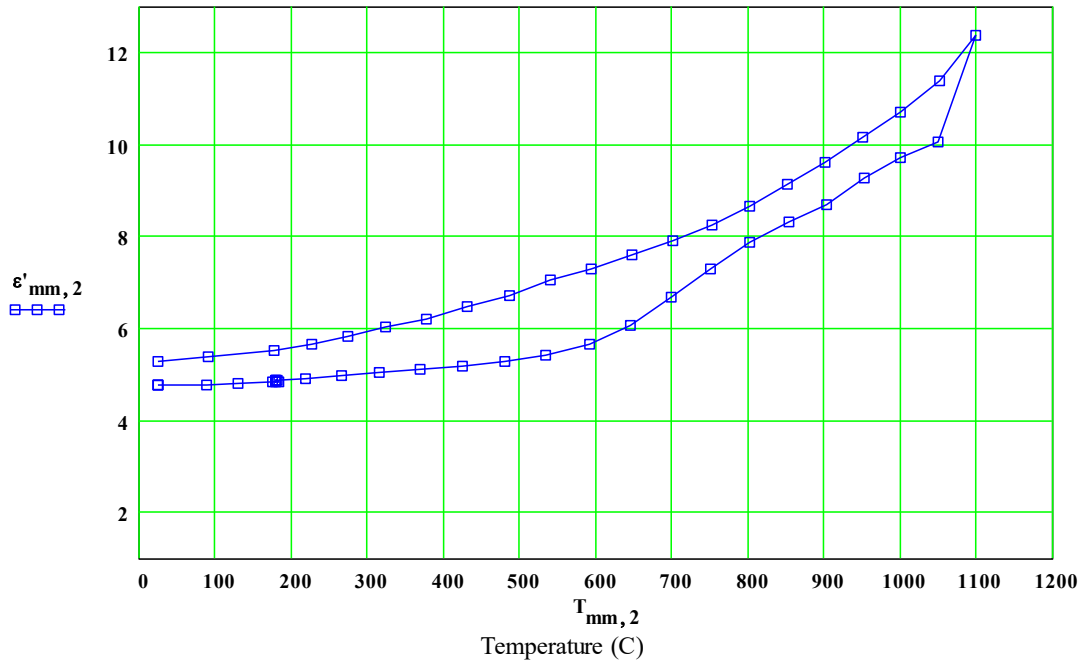
AnDat = 20251018

JSC-1A-AGGL , RT to 1100C to RT, in 10 sccm 4% Hydrogen/Argon, D. Rickman, Amentum (NASA consultant)

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.03$  gm/cc, Thermal exp. coeff.  $\alpha_1 = 0$

Final density(25C) =  $\text{dnsfinal} = 2.09$  gm/cc

## Values for 912 MHz



# JSC-1A-AGGL Argon w/4% H<sub>2</sub>

Test = 2025191501

NASA2591\_TM685.mcd

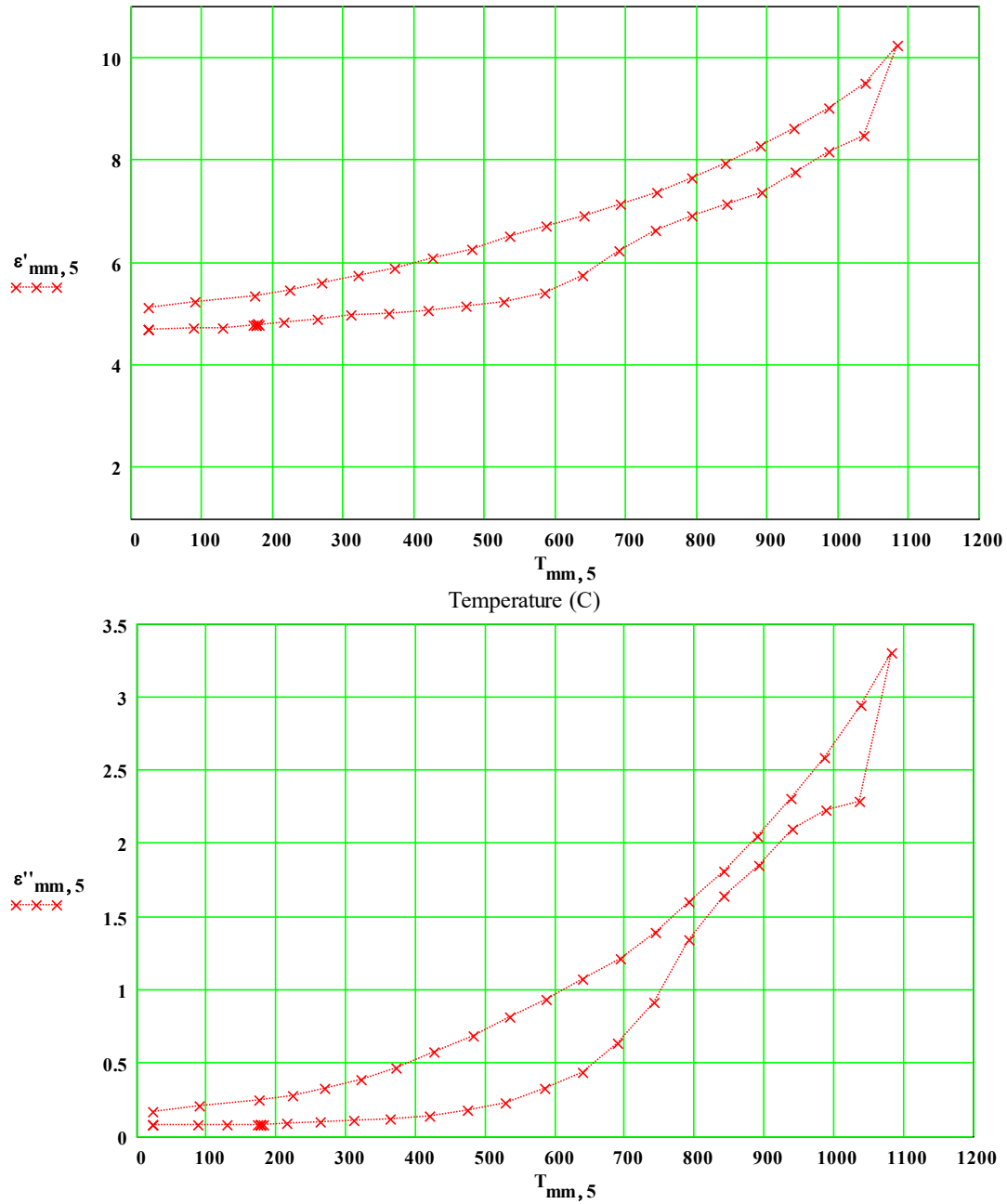
AnDat = 20251018

JSC-1A-AGGL, RT to 1100C to RT, in 10 sccm 4% Hydrogen/Argon, D. Rickman, Amentum (NASA consultant)

Initial density =  $\text{sam dns}_{\text{NCal} + 1} = 2.03$  gm/cc, Thermal exp. coeff  $\alpha_1 = 0$

Final density(25C) =  $\text{dns final} = 2.09$  gm/cc

## Values for 2465 MHz



# JSC-1A-AGGL Argon w/4% H<sub>2</sub>

Test = 2025191501

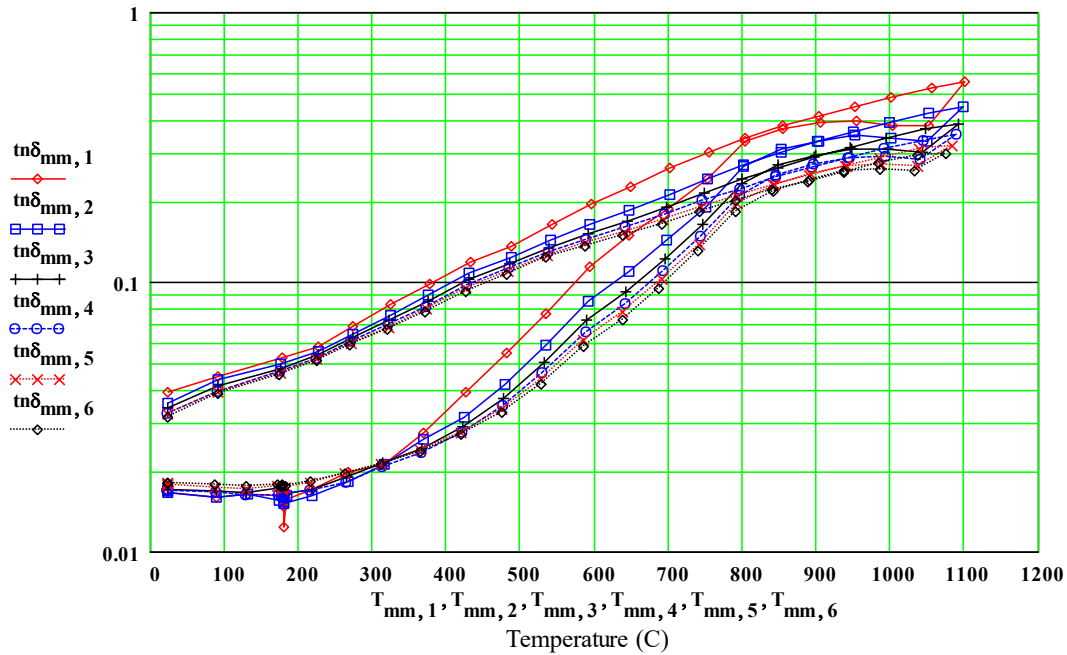
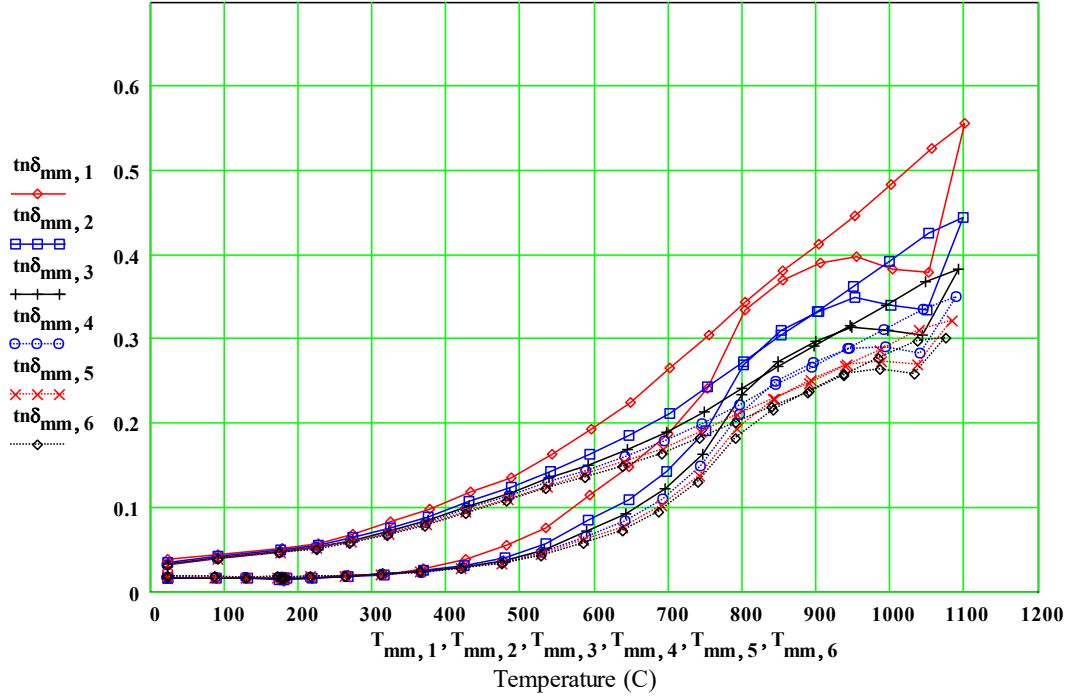
NASA2591\_TM685.mcd

AnDat = 20251018

JSC-1A-AGGL, RT to 1100C to RT, in 10 sccm 4% Hydrogen/Argon, D. Rickman, Amentum (NASA consult)

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.03 \text{ gm/cc}$ ,

Final density(25C) =  $\text{dnsfinal} = 2.09 \text{ gm/cc}$



# JSC-1A-AGGL Argon w/4% H<sub>2</sub>

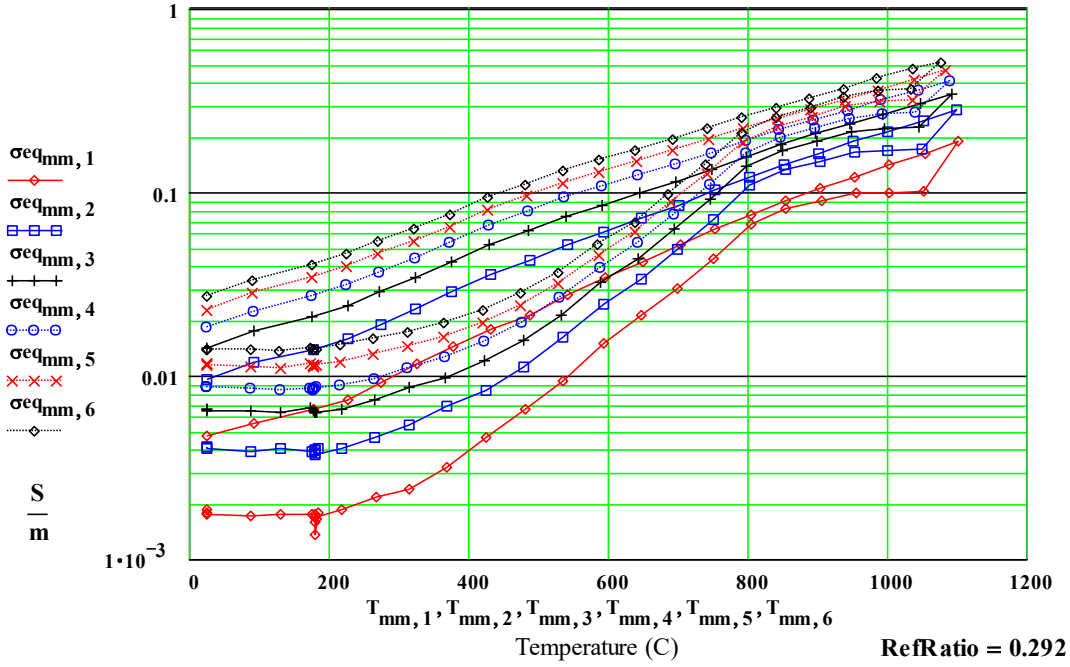
Test = 2025191501

NASA2591\_TM685.mcd

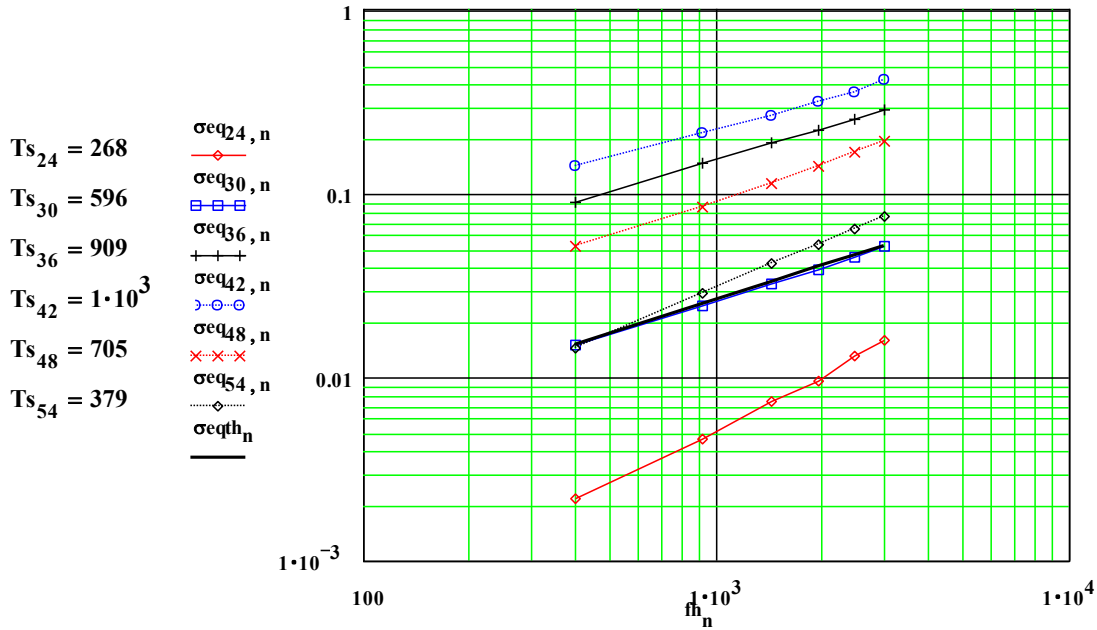
AnDat = 20251018

JSC-1A-AGGL, RT to 1100C to RT, in 10 sccm 4% Hydrogen/Argon, D. Rickman, Amentum (NASA consulta

Equivalent Free Electron Conductivity ( Siemens/metre)



$$\sigma_{eqth_n} := 0.015 \cdot \left( \frac{fh_n}{400} \right)^{0.62} \quad \text{for } T = 596 \text{ on ramp up}$$



JSC-1A-AGGL Argon w/4% H<sub>2</sub>

**Test = 2025191501**

NASA2591 TM685.mcd

**AnDat = 20251018**

JSC-1A-AGGL, RT to 1100C to RT, in 10 sccm 4% Hydrogen/Argon, D. Rickman, Amentum (NASA consult)

List of Measured Values of  $\varepsilon'$  and  $\varepsilon''$  :

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.03 \text{ gm/cc}$

Lapsed

density index T(C) 397MHz 912MHz 1429MH 1948MHz2466MHz 2986MHz

Time  
(hours)

| samdns | mm | T <sub>mm,1</sub> | ε <sub>mm,1</sub> | ε <sub>mm,2</sub> | ε <sub>mm,3</sub> | ε <sub>mm,4</sub> | ε <sub>mm,5</sub> | ε <sub>mm,6</sub> | tlaps <sub>mm</sub> | sammas <sub>mm</sub> |
|--------|----|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|---------------------|----------------------|
| 2.03   | 11 | 24                | 4.83              | 4.78              | 4.74              | 4.71              | 4.68              | 4.65              | 0                   | 0.289                |
| 2.03   | 12 | 24                | 4.84              | 4.78              | 4.75              | 4.72              | 4.69              | 4.66              | 0.07                | 0.289                |
| 2.03   | 13 | 24                | 4.83              | 4.78              | 4.74              | 4.71              | 4.69              | 4.65              | 0.13                | 0.289                |
| 2.029  | 14 | 89                | 4.86              | 4.8               | 4.77              | 4.74              | 4.71              | 4.69              | 0.36                | 0.289                |
| 2.029  | 15 | 131               | 4.86              | 4.81              | 4.78              | 4.75              | 4.73              | 4.7               | 0.54                | 0.289                |
| 2.028  | 16 | 175               | 4.92              | 4.87              | 4.84              | 4.8               | 4.78              | 4.75              | 0.71                | 0.289                |
| 2.027  | 17 | 184               | 4.92              | 4.87              | 4.84              | 4.81              | 4.79              | 4.76              | 1.07                | 0.289                |
| 2.026  | 18 | 180               | 4.93              | 4.87              | 4.84              | 4.81              | 4.79              | 4.76              | 1.44                | 0.288                |
| 2.025  | 19 | 180               | 4.92              | 4.87              | 4.84              | 4.8               | 4.79              | 4.76              | 1.8                 | 0.288                |
| 2.025  | 20 | 181               | 4.93              | 4.88              | 4.85              | 4.81              | 4.8               | 4.77              | 2.17                | 0.288                |
| 2.024  | 21 | 180               | 4.93              | 4.87              | 4.85              | 4.81              | 4.79              | 4.76              | 2.53                | 0.288                |
| 2.023  | 22 | 180               | 4.93              | 4.87              | 4.84              | 4.81              | 4.79              | 4.76              | 2.9                 | 0.288                |
| 2.023  | 23 | 219               | 4.99              | 4.93              | 4.9               | 4.86              | 4.84              | 4.81              | 3.05                | 0.288                |
| 2.023  | 24 | 267               | 5.05              | 4.99              | 4.96              | 4.92              | 4.9               | 4.87              | 3.2                 | 0.288                |
| 2.023  | 25 | 316               | 5.14              | 5.06              | 5.03              | 4.99              | 4.97              | 4.93              | 3.35                | 0.288                |
| 2.023  | 26 | 369               | 5.2               | 5.12              | 5.08              | 5.04              | 5.01              | 4.98              | 3.5                 | 0.288                |
| 2.023  | 27 | 425               | 5.3               | 5.19              | 5.15              | 5.09              | 5.07              | 5.03              | 3.64                | 0.288                |
| 2.023  | 28 | 481               | 5.42              | 5.29              | 5.24              | 5.17              | 5.14              | 5.11              | 3.78                | 0.288                |
| 2.023  | 29 | 535               | 5.6               | 5.43              | 5.36              | 5.28              | 5.25              | 5.2               | 3.91                | 0.288                |
| 2.023  | 30 | 593               | 5.91              | 5.66              | 5.55              | 5.46              | 5.4               | 5.35              | 4.04                | 0.288                |
| 2.023  | 31 | 647               | 6.43              | 6.07              | 5.92              | 5.8               | 5.73              | 5.67              | 4.17                | 0.288                |
| 2.023  | 32 | 700               | 7.21              | 6.69              | 6.46              | 6.31              | 6.22              | 6.12              | 4.29                | 0.288                |
| 2.023  | 33 | 752               | 8.07              | 7.3               | 6.97              | 6.75              | 6.63              | 6.54              | 4.4                 | 0.288                |
| 2.023  | 34 | 804               | 9.08              | 7.9               | 7.38              | 7.08              | 6.92              | 6.8               | 4.52                | 0.288                |
| 2.023  | 35 | 855               | 9.85              | 8.34              | 7.7               | 7.33              | 7.14              | 7.02              | 4.63                | 0.288                |
| 2.023  | 36 | 905               | 10.38             | 8.71              | 7.98              | 7.57              | 7.36              | 7.21              | 4.75                | 0.288                |
| 2.023  | 37 | 954               | 11.17             | 9.29              | 8.47              | 7.99              | 7.77              | 7.64              | 4.86                | 0.288                |
| 2.023  | 38 | 1003              | 11.66             | 9.74              | 8.89              | 8.4               | 8.16              | 8.02              | 4.98                | 0.288                |
| 2.039  | 39 | 1052              | 11.99             | 10.08             | 9.21              | 8.7               | 8.47              | 8.34              | 5.09                | 0.288                |
| 2.055  | 40 | 1101              | 15.32             | 12.38             | 11.17             | 10.49             | 10.24             | 10                | 5.21                | 0.288                |
| 2.07   | 41 | 1055              | 13.98             | 11.39             | 10.32             | 9.73              | 9.49              | 9.39              | 5.32                | 0.288                |
| 2.087  | 42 | 1002              | 13                | 10.72             | 9.78              | 9.24              | 9.02              | 8.9               | 5.44                | 0.288                |
| 2.087  | 43 | 952               | 12.13             | 10.16             | 9.33              | 8.84              | 8.63              | 8.51              | 5.55                | 0.288                |
| 2.087  | 44 | 903               | 11.34             | 9.61              | 8.89              | 8.46              | 8.26              | 8.15              | 5.67                | 0.288                |
| 2.087  | 45 | 854               | 10.63             | 9.14              | 8.51              | 8.12              | 7.94              | 7.83              | 5.8                 | 0.288                |
| 2.087  | 46 | 804               | 9.9               | 8.68              | 8.14              | 7.8               | 7.64              | 7.52              | 5.93                | 0.288                |
| 2.087  | 47 | 754               | 9.29              | 8.26              | 7.81              | 7.51              | 7.36              | 7.25              | 6.06                | 0.288                |
| 2.087  | 48 | 702               | 8.79              | 7.91              | 7.53              | 7.26              | 7.13              | 7.03              | 6.2                 | 0.288                |
| 2.087  | 49 | 649               | 8.36              | 7.61              | 7.28              | 7.04              | 6.92              | 6.82              | 6.35                | 0.288                |

# JSC-1A-AGGL Argon w/4% H<sub>2</sub>

Test = 2025191501

NASA2591\_TM685.mcd

AnDat = 20251018

JSC-1A-AGGL, RT to 1100C to RT, in 10 sccm 4% Hydrogen/Argon, D. Rickman, Amentum (NASA consult)

List of Measured Values of  $\epsilon'$  and  $\epsilon''$  :

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.03$  gm/cc

density index T(C) 397MHz 912MHz 1429MH 1948MHz2466MHz 2986MHz Lapsed Time (hours)

| samdns | mm | T    | $\epsilon''$ mm, 1 | $\epsilon''$ mm, 2 | $\epsilon''$ mm, 3 | $\epsilon''$ mm, 4 | $\epsilon''$ mm, 5 | $\epsilon''$ mm, 6 | tlaps | sammas |
|--------|----|------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------|--------|
| mm     | mm | mm   | mm                 | mm                 | mm                 | mm                 | mm                 | mm                 | mm    | mm     |
| 2.03   | 11 | 24   | 0.084              | 0.082              | 0.083              | 0.08               | 0.084              | 0.084              | 0     | 0.289  |
| 2.03   | 12 | 24   | 0.082              | 0.081              | 0.083              | 0.08               | 0.084              | 0.084              | 0.07  | 0.289  |
| 2.03   | 13 | 24   | 0.08               | 0.08               | 0.081              | 0.08               | 0.083              | 0.083              | 0.13  | 0.289  |
| 2.029  | 14 | 89   | 0.078              | 0.077              | 0.08               | 0.079              | 0.082              | 0.083              | 0.36  | 0.289  |
| 2.029  | 15 | 131  | 0.08               | 0.079              | 0.08               | 0.077              | 0.081              | 0.083              | 0.54  | 0.289  |
| 2.028  | 16 | 175  | 0.079              | 0.076              | 0.084              | 0.078              | 0.084              | 0.085              | 0.71  | 0.289  |
| 2.027  | 17 | 184  | 0.081              | 0.079              | 0.079              | 0.079              | 0.083              | 0.084              | 1.07  | 0.289  |
| 2.026  | 18 | 180  | 0.061              | 0.078              | 0.08               | 0.077              | 0.082              | 0.083              | 1.44  | 0.288  |
| 2.025  | 19 | 180  | 0.081              | 0.075              | 0.081              | 0.076              | 0.081              | 0.084              | 1.8   | 0.288  |
| 2.025  | 20 | 181  | 0.076              | 0.078              | 0.08               | 0.078              | 0.083              | 0.084              | 2.17  | 0.288  |
| 2.024  | 21 | 180  | 0.072              | 0.078              | 0.079              | 0.077              | 0.083              | 0.083              | 2.53  | 0.288  |
| 2.023  | 22 | 180  | 0.077              | 0.074              | 0.08               | 0.078              | 0.083              | 0.083              | 2.9   | 0.288  |
| 2.023  | 23 | 219  | 0.085              | 0.079              | 0.083              | 0.082              | 0.087              | 0.088              | 3.05  | 0.288  |
| 2.023  | 24 | 267  | 0.099              | 0.091              | 0.094              | 0.089              | 0.095              | 0.095              | 3.2   | 0.288  |
| 2.023  | 25 | 316  | 0.109              | 0.107              | 0.109              | 0.102              | 0.105              | 0.104              | 3.35  | 0.288  |
| 2.023  | 26 | 369  | 0.144              | 0.134              | 0.122              | 0.117              | 0.119              | 0.118              | 3.5   | 0.288  |
| 2.023  | 27 | 425  | 0.208              | 0.164              | 0.151              | 0.141              | 0.14               | 0.138              | 3.64  | 0.288  |
| 2.023  | 28 | 481  | 0.298              | 0.22               | 0.195              | 0.18               | 0.175              | 0.168              | 3.78  | 0.288  |
| 2.023  | 29 | 535  | 0.427              | 0.317              | 0.269              | 0.243              | 0.229              | 0.218              | 3.91  | 0.288  |
| 2.023  | 30 | 593  | 0.677              | 0.48               | 0.405              | 0.355              | 0.329              | 0.309              | 4.04  | 0.288  |
| 2.023  | 31 | 647  | 0.962              | 0.667              | 0.546              | 0.482              | 0.442              | 0.411              | 4.17  | 0.288  |
| 2.023  | 32 | 700  | 1.358              | 0.961              | 0.789              | 0.694              | 0.635              | 0.583              | 4.29  | 0.288  |
| 2.023  | 33 | 752  | 1.954              | 1.396              | 1.142              | 1.001              | 0.912              | 0.851              | 4.4   | 0.288  |
| 2.023  | 34 | 804  | 3.034              | 2.129              | 1.727              | 1.484              | 1.343              | 1.242              | 4.52  | 0.288  |
| 2.023  | 35 | 855  | 3.651              | 2.596              | 2.114              | 1.826              | 1.642              | 1.517              | 4.63  | 0.288  |
| 2.023  | 36 | 905  | 4.065              | 2.901              | 2.37               | 2.054              | 1.845              | 1.722              | 4.75  | 0.288  |
| 2.023  | 37 | 954  | 4.448              | 3.252              | 2.659              | 2.314              | 2.101              | 1.972              | 4.86  | 0.288  |
| 2.023  | 38 | 1003 | 4.462              | 3.326              | 2.77               | 2.441              | 2.227              | 2.115              | 4.98  | 0.288  |
| 2.039  | 39 | 1052 | 4.559              | 3.368              | 2.806              | 2.469              | 2.284              | 2.164              | 5.09  | 0.288  |
| 2.055  | 40 | 1101 | 8.533              | 5.519              | 4.293              | 3.674              | 3.298              | 3.015              | 5.21  | 0.288  |
| 2.07   | 41 | 1055 | 7.368              | 4.849              | 3.814              | 3.267              | 2.946              | 2.788              | 5.32  | 0.288  |
| 2.087  | 42 | 1002 | 6.304              | 4.211              | 3.34               | 2.874              | 2.589              | 2.473              | 5.44  | 0.288  |
| 2.087  | 43 | 952  | 5.419              | 3.686              | 2.96               | 2.551              | 2.308              | 2.186              | 5.55  | 0.288  |
| 2.087  | 44 | 903  | 4.694              | 3.206              | 2.597              | 2.247              | 2.051              | 1.931              | 5.67  | 0.288  |
| 2.087  | 45 | 854  | 4.062              | 2.793              | 2.274              | 1.994              | 1.814              | 1.716              | 5.8   | 0.288  |
| 2.087  | 46 | 804  | 3.402              | 2.383              | 1.964              | 1.727              | 1.6                | 1.515              | 5.93  | 0.288  |
| 2.087  | 47 | 754  | 2.834              | 2.01               | 1.678              | 1.501              | 1.392              | 1.319              | 6.06  | 0.288  |
| 2.087  | 48 | 702  | 2.337              | 1.681              | 1.435              | 1.298              | 1.214              | 1.155              | 6.2   | 0.288  |
| 2.087  | 49 | 649  | 1.885              | 1.415              | 1.232              | 1.126              | 1.069              | 1.019              | 6.35  | 0.288  |
| 2.087  | 50 | 595  | 1.547              | 1.197              | 1.062              | 0.978              | 0.934              | 0.898              | 6.51  | 0.288  |
| 2.087  | 51 | 542  | 1.241              | 1.012              | 0.919              | 0.856              | 0.817              | 0.79               | 6.69  | 0.288  |
| 2.087  | 52 | 488  | 0.976              | 0.837              | 0.768              | 0.717              | 0.687              | 0.662              | 6.87  | 0.288  |
| 2.087  | 53 | 432  | 0.818              | 0.704              | 0.648              | 0.603              | 0.579              | 0.558              | 7.07  | 0.288  |
| 2.087  | 54 | 377  | 0.652              | 0.562              | 0.519              | 0.483              | 0.467              | 0.452              | 7.29  | 0.288  |
| 2.087  | 55 | 325  | 0.523              | 0.457              | 0.428              | 0.403              | 0.392              | 0.382              | 7.53  | 0.288  |
| 2.087  | 56 | 275  | 0.418              | 0.376              | 0.358              | 0.338              | 0.333              | 0.324              | 7.8   | 0.288  |
| 2.087  | 57 | 228  | 0.338              | 0.315              | 0.301              | 0.286              | 0.283              | 0.277              | 8.11  | 0.288  |
| 2.087  | 58 | 177  | 0.3                | 0.275              | 0.262              | 0.25               | 0.248              | 0.243              | 8.53  | 0.288  |
| 2.087  | 59 | 92   | 0.248              | 0.234              | 0.22               | 0.207              | 0.205              | 0.2                | 9.54  | 0.288  |
| 2.087  | 60 | 24   | 0.211              | 0.187              | 0.178              | 0.167              | 0.166              | 0.161              | 10.17 | 0.288  |

**MPN-337\_NASA\_Rickman\_NU-LHT-2M-AGGL      Oct. 11, 2025**

**NU-LHT-2M-AGGL Lunar Simulant Pellets – 2nd Run**  
**Measurements of Complex Dielectric Constant Between 400 and 2985 MHz**  
**from Room Temperature to 1225°C to Room Temperature ,**  
**in 10 sccm Flowing 4% H<sub>2</sub>/Argon**

Jozef Mouris and Ronald Hutcheon ( MPN)

Douglas Rickman of the Space Exploration Division of Amentum ( on contract to NASA), requested that MPN measure the complex dielectric properties of pellets of lunar simulants which included special “agglutinates” which are considered to have favourable properties simulating the iron content of lunar regolith. The second of these was NU-LHT-2M-AGGL , based on the oldest, highlands simulant but with the additional processing step of laser-induced high temperature irradiation in high vacuum - to produce the known micro and nano particle size elemental iron content of lunar regolith.

The powders arrived in a sealed container at MPN on Sept. 4 /2025. The NU-LHT-2M-AGGL container was first opened on Oct. 1 and three pellets were pressed at ~ 32,000 psi ( based on earlier experience with NU-LHT-5M simulant pellet pressing). These pellets seemed to have sufficient strength for handling. Doug had requested an initial density close to the previous runs, and this seemed adequate – at ~ 2.1 g/cc . The 32,000 psi required is substantially higher than that used for achieving strong enough pellets with the old JSC-1A material.

These measurements were done with the pellets in a high purity alumina crucible inside an 8 mm OD fused silica holder, with 4% hydrogen/argon gas mix flowing up past the crucible and out at the top of the holder through the edges around a loose-fitting fused silica plug.

**Run #2 :NU-LHT-2M-AGGL Lunar Simulant Pellets**

This measurement run was started ~ 6 hours after the pellets were pressed, and the handling of the pellets did not indicate any “fragility”. The pellets retained their integrity during measurement of their dimensions and insertion into the crucible.

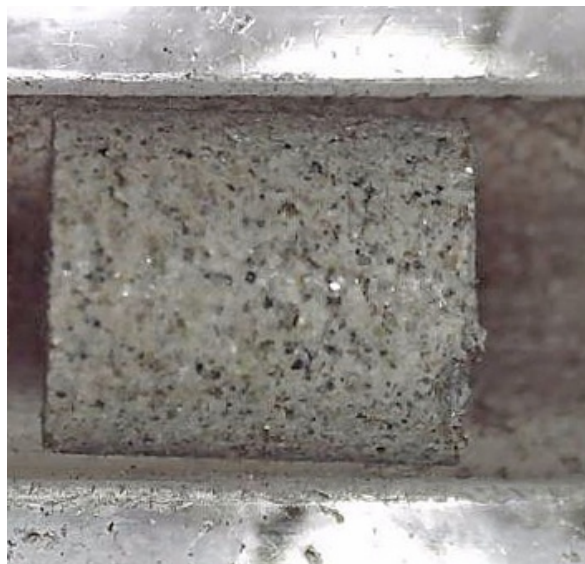
The parameters of the initial pellet stack ( 3 pellets ) , were:

- a) diameter 3.63 +- 0.05 mm
- b) length 12.67 +- 0.10 mm
- c) mass 0.270 +- 0.002 gm
- d) room temperature density  $2.06 \pm 0.10$  gm/cc.
- e) appearance - light grey/off white pellets ( see photo of single pellet)

The dielectric properties measurement run consisted of calibration measurements, then three sample measurements at room temperature (RT), then a single measurement at 50C, then 25C steps up to 200C, at which points a 2 hour hold was started, with measurements every 20 minutes. This was to measure the effect of moisture loss ( The measurements showed no detectable moisture). The run was then continued in 50C steps to 1225 C, then in -50C steps to 100C, then RT. At the end of the run, the mass of the holder and pellets was measured at room temperature. The pellets had not interacted with the alumina crucible, and “poured” out easily for removal. Then the empty holder was run to 1250 C to check for contamination. There was no contamination .

The final sample stack properties, at room temperature were :

- a) diameter  $3.61 \pm 0.05$  mm
- b) length  $12.50 \pm 0.05$  mm
- c) mass  $0.266 \pm 0.002$  gm
- j) room temperature density  $2.08 \pm 0.10$  gm/cc.
- k) appearance - mottled brown/black surfaces (see photos)

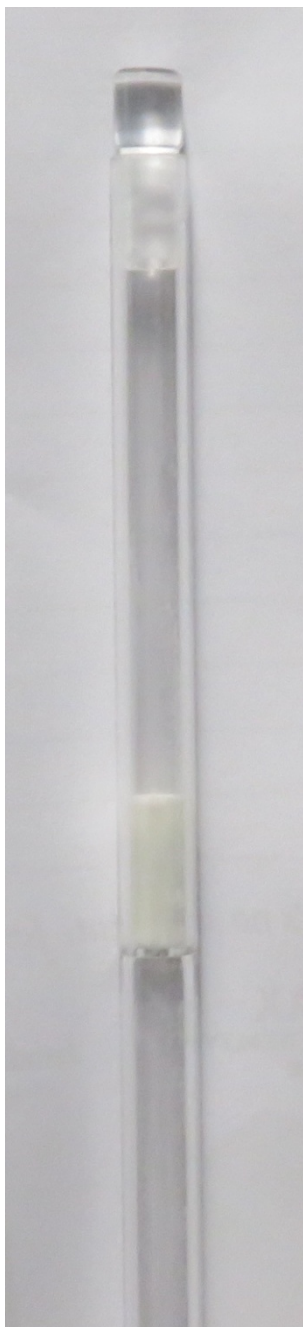


## NU-LHT-2M-AGGL

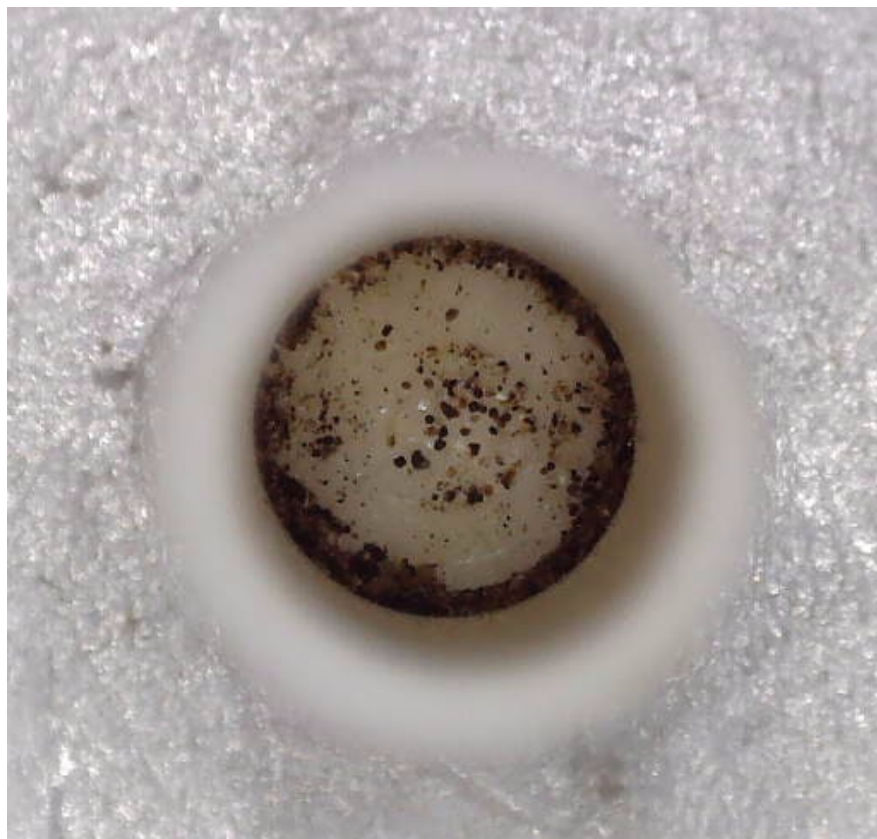
One of the freshly pressed pellets – pressed at  $\sim 27,000$  psi .



The final pellets ( after the run to 1225 C in 4% hydrogen/argon).



Measurement setup – with crucible in holder , and  
tight fused silica plug in top of holder to stop air backflow.



A view down into the crucible interior after the pellets were gently “poured” out. The final sample mass included the small bits of sample “powder” seen in the bottom.

The frequency coding is :

Legend for Data Plots :

| # | <u>Frequency(MHz)</u> | <u>Symbol</u>                                            |
|---|-----------------------|----------------------------------------------------------|
| 1 | 397                   | red diamond, solid line – sometimes the line is omitted! |
| 2 | 912                   | blue square, solid line                                  |
| 3 | 1429                  | black cross, solid line                                  |
| 4 | 1948                  | blue circle, dotted line                                 |
| 5 | 2466                  | red cross, dotted line                                   |
| 6 | 2986                  | black diamond, dotted line                               |

Comments on the data analysis:

A linear thermal expansion coefficient (CTE) of  $0.0 \times 10^{-6}/\text{C}$  was used.

The  $\epsilon''$  values up to 200 C show only a hint of loss of ad/absorbed moisture.

The loss mechanism becomes frequency-dependent starting at  $\sim 780$  C, and indicates some amount of disordered structure ionic loss mechanism over the whole range back down to 500C .

The rapid increase above 1100 C suggests the influence of melting of some component.

## NU-LHT-2M-AGGL

Code Calculates Estimated Sample Dimensions &amp; Volume and Plots Density As a Function of Temperature

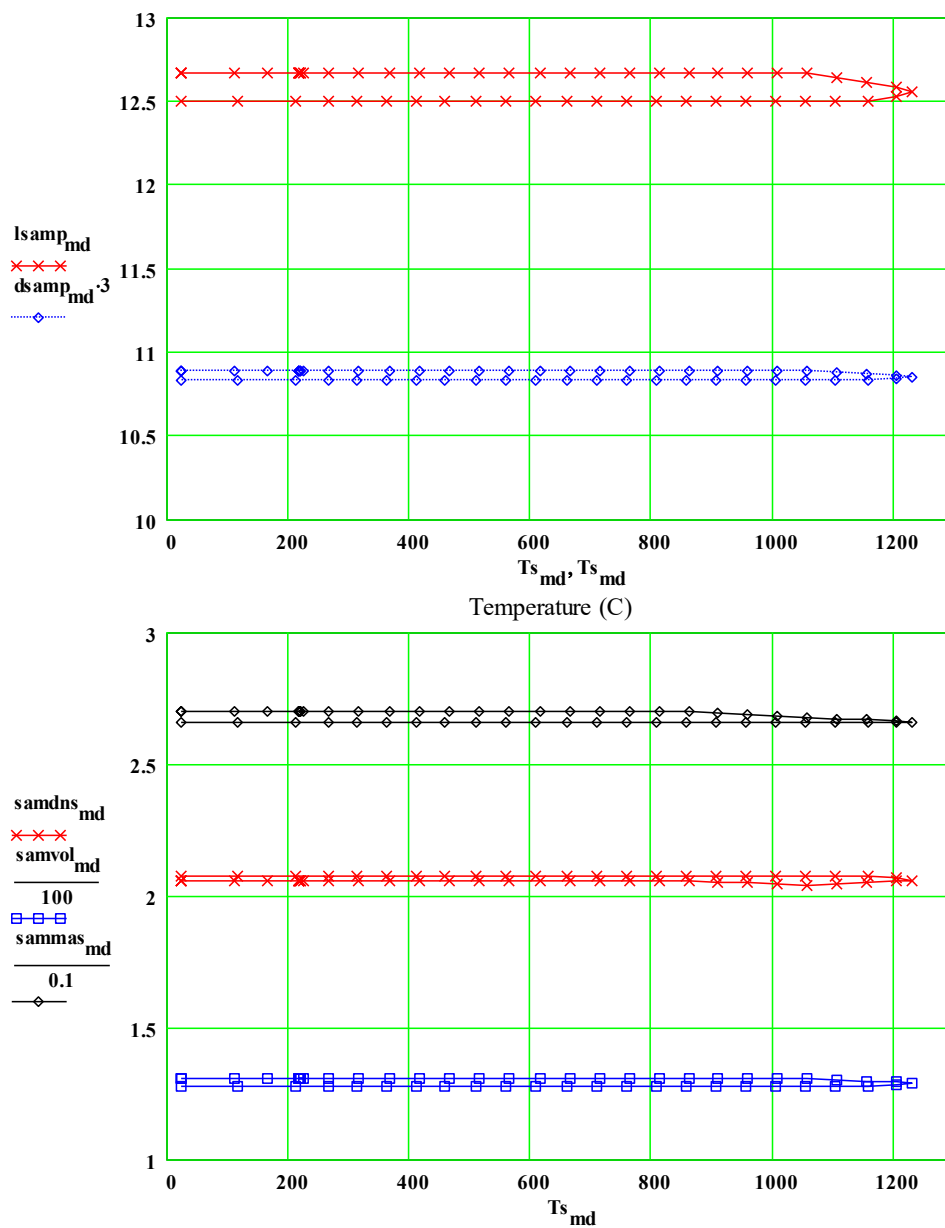
[illegible]

**Test = 2025100701**

NASA2587.mcd

**AnDat = 20251009**

2nd run : NU-LHT-2M-AGGL pellets, Holder + Crucible, RT- 1225C, in flowing 4% Hydrogrn ,D. Rickman, NAS



# NU-LHT-2M-AGGL

Test = 2025100701

NASA2587.mcd

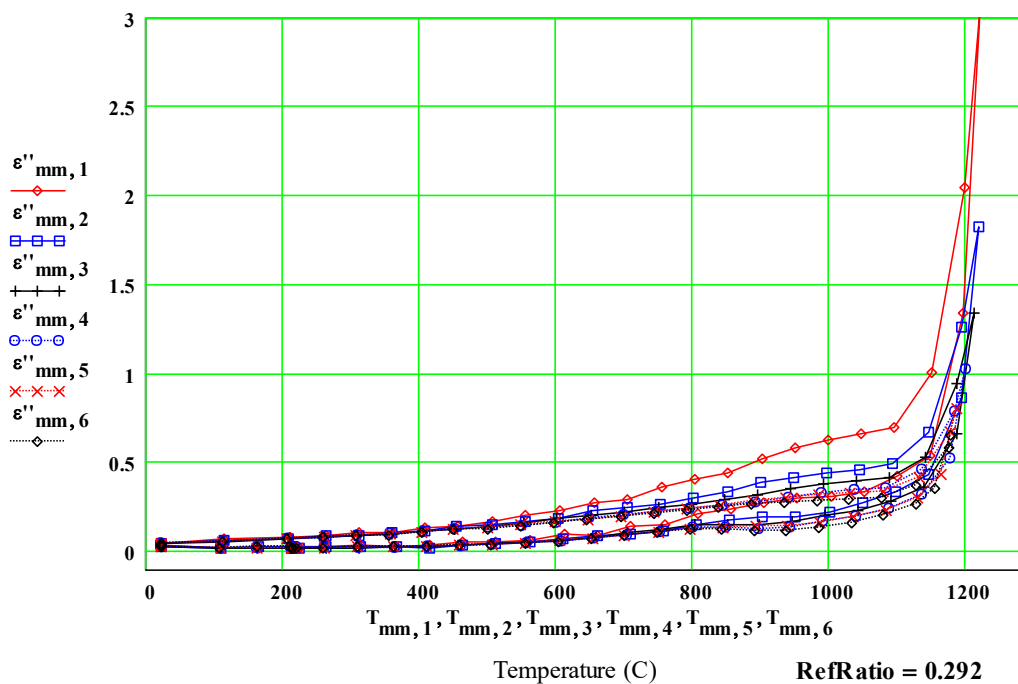
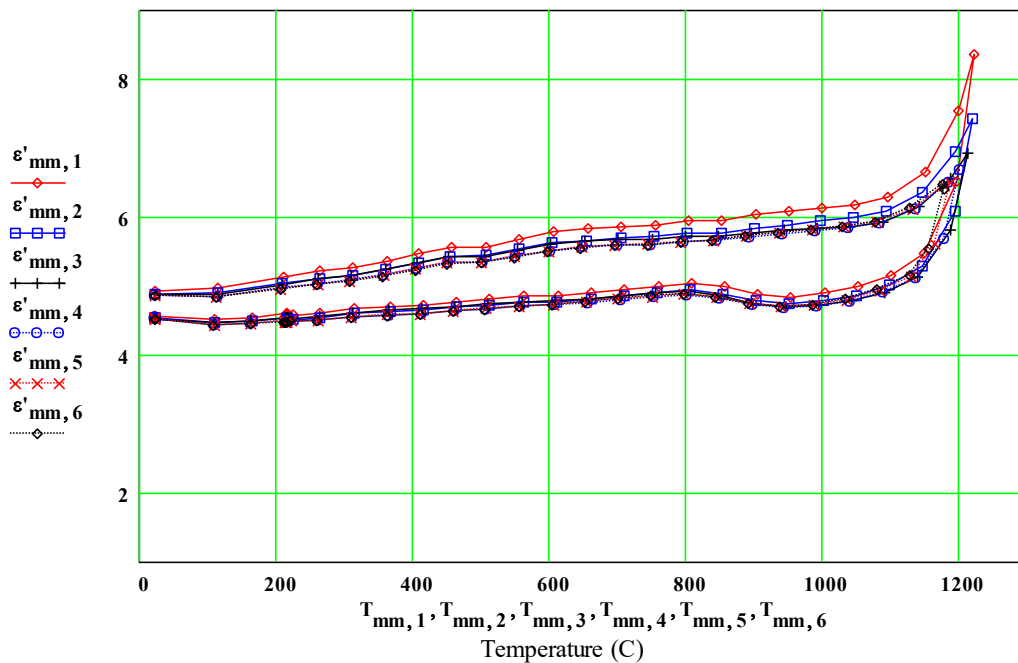
AnDat = 20251010

2nd Run NU-LHT-2M-AGGL pellets, Holder + Crucible, RT- 1225C, in flowing 4% Hydrogrn ,D. Rickman, NAS

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.06 \text{ gm/cc}$ ,

Final density(25C) =  $\text{dnsfinal} = 2.08 \text{ gm/cc}$

FracMassChange = 0.985



RefRatio = 0.292

# NU-LHT-2M-AGGL

Test = 2025100701

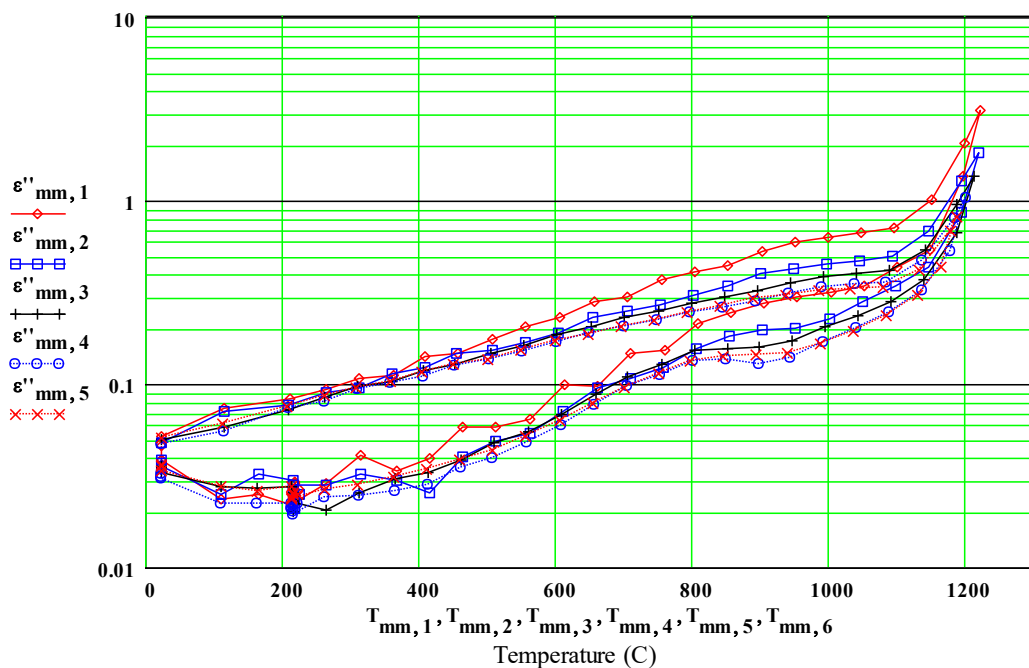
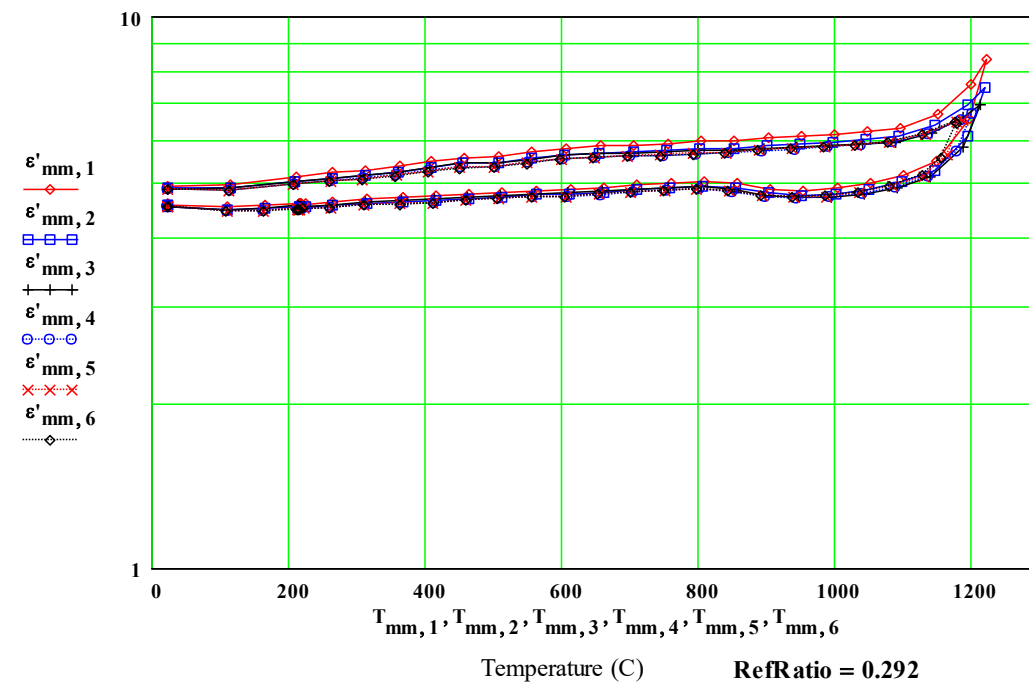
NASA2587.mcd

AnDat = 20251010

2nd Run: NU-LHT-2M-AGGL pellets, Holder + Crucible, RT- 1225C, in flowing 4% Hydrogrn ,D. Rickman, NAS

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.06 \text{ gm/cc}$ , Final density(25C) =  $\text{dnsfinal} = 2.08 \text{ gm/cc}$

FracMassChange = 0.99



# NU-LHT-2M-AGGL

Test = 2025100701

NASA2587.mcd

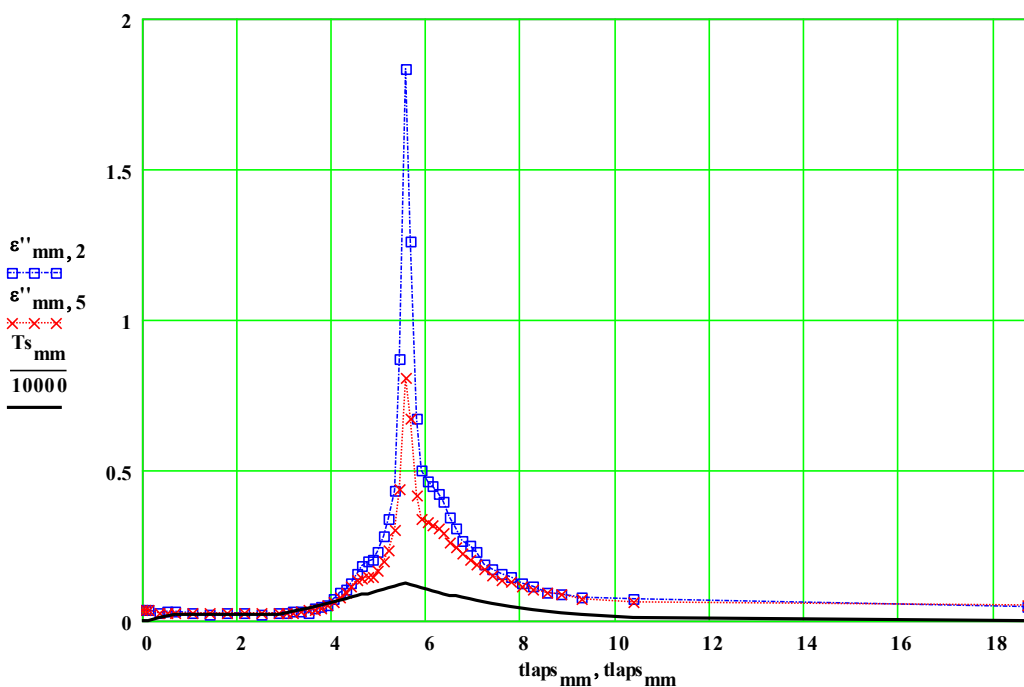
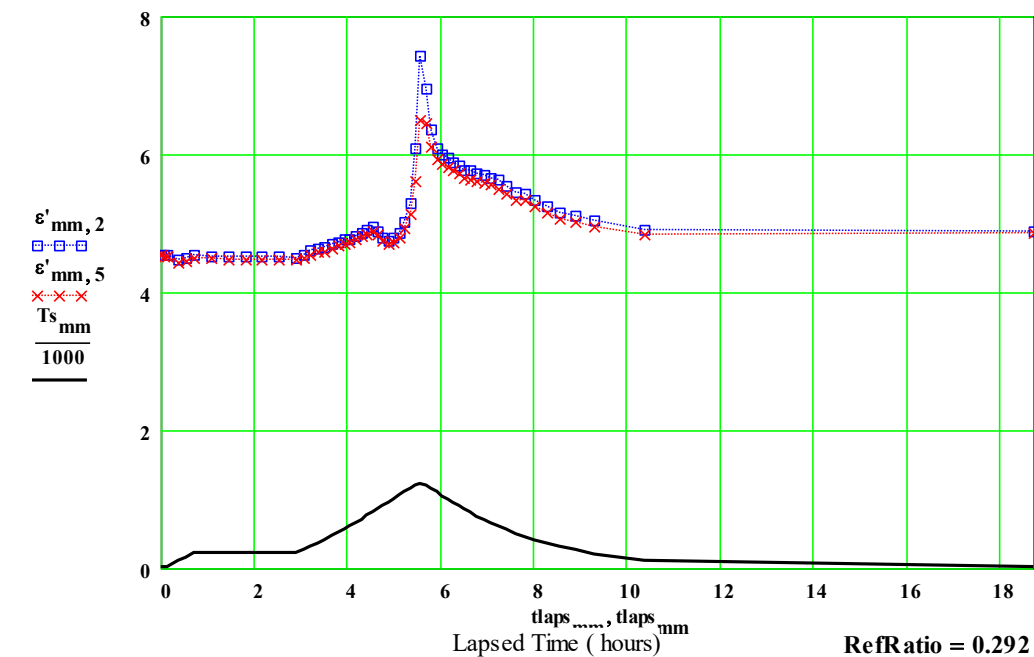
AnDat = 20251010

2nd Run NU-LHT-2M-AGGL pellets, Holder + Crucible, RT- 1225C, in flowing 4% Hydrogrn ,D. Rickman, NAS.

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.06 \text{ gm/cc}$ ,

linear thermal expansion

Final density(25C) =  $\text{dnsfinal} = 2.08 \text{ gm/cc}$   $\text{FracMassChange} = 0.99$   $\text{coef/deg C}$   $\alpha_3 = 0 \cdot 10^{-6}$



# NU-LHT-2M-AGGL

Test = 2025100701

NASA2587.mcd

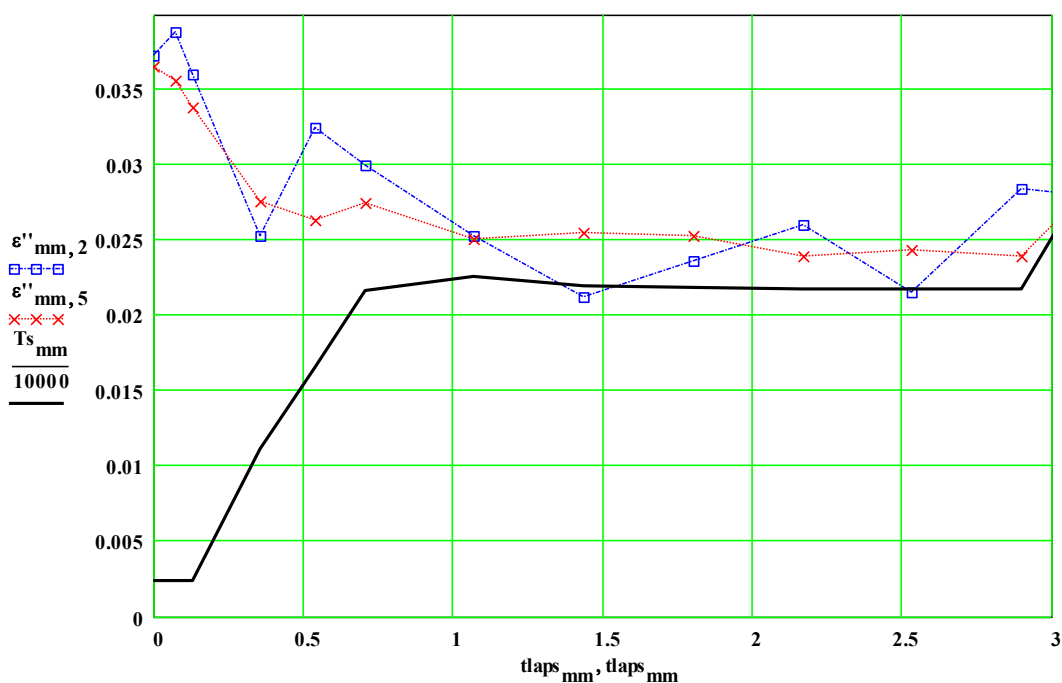
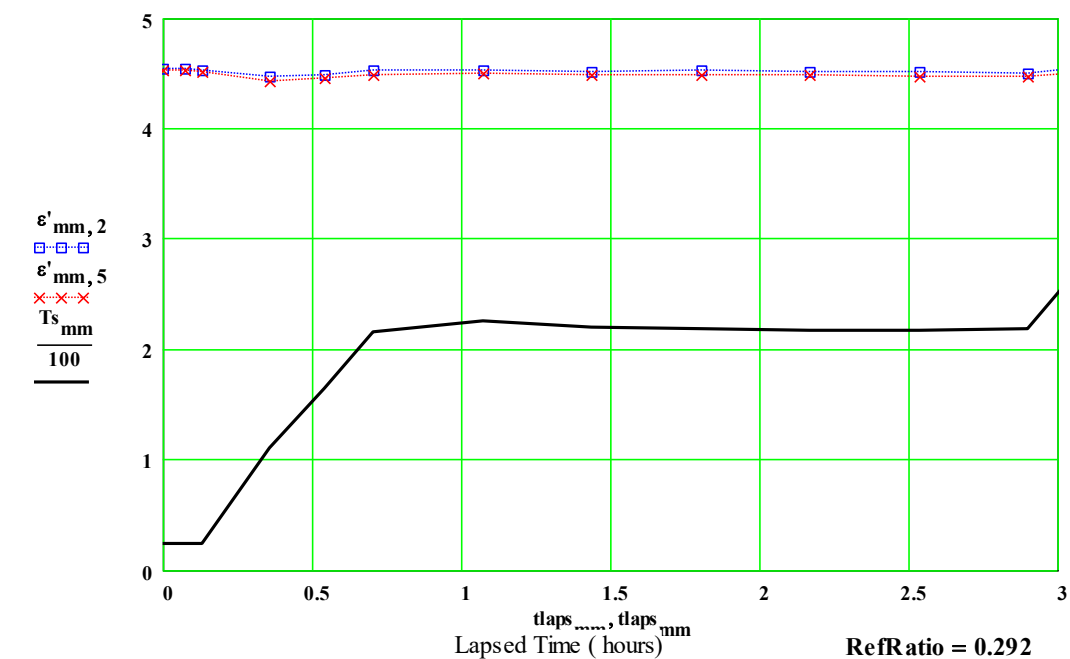
AnDat = 20251010

2nd Run NU-LHT-2M-AGGL pellets, Holder + Crucible, RT- 1225C, in flowing 4% Hydrogen, D. Rickman, NAS.

Initial density =  $\text{samdens}_{\text{NCal} + 1} = 2.06 \text{ gm/cc}$ ,

linear thermal expansion

Final density(25C) =  $\text{densfinal} = 2.08 \text{ gm/cc}$   $\text{FracMassChange} = 0.99$  coef/deg C  $\alpha_3 = 0 \cdot 10^{-6}$



There are indications of a small amount of moisture release up to 200C .

# NU-LHT-2M-AGGL

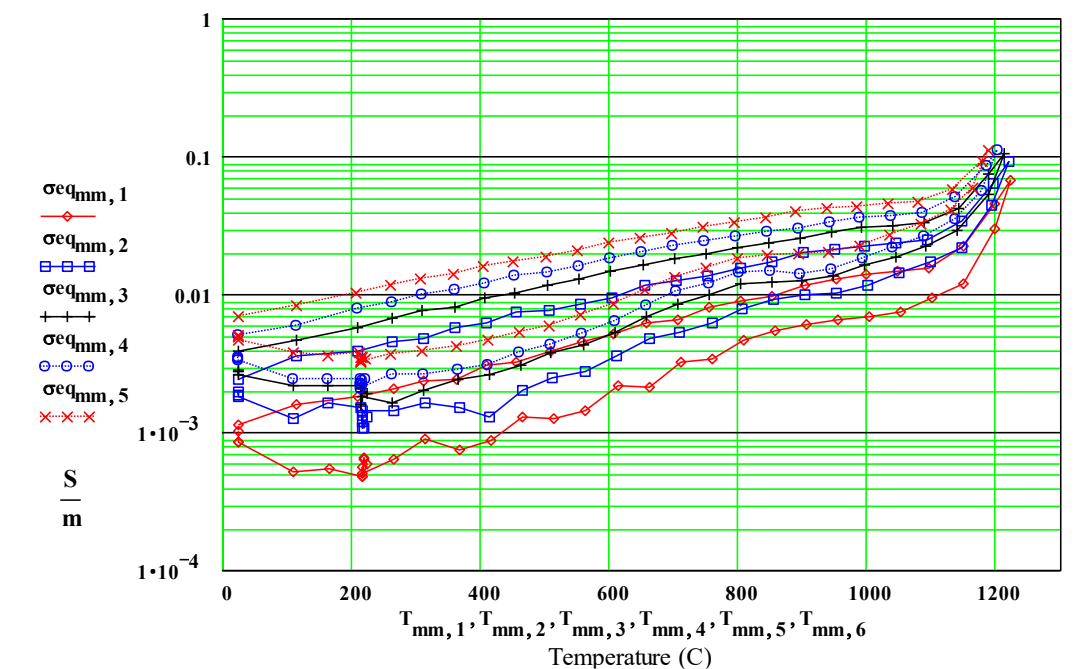
Test = 2025100701

NASA2587.mcd

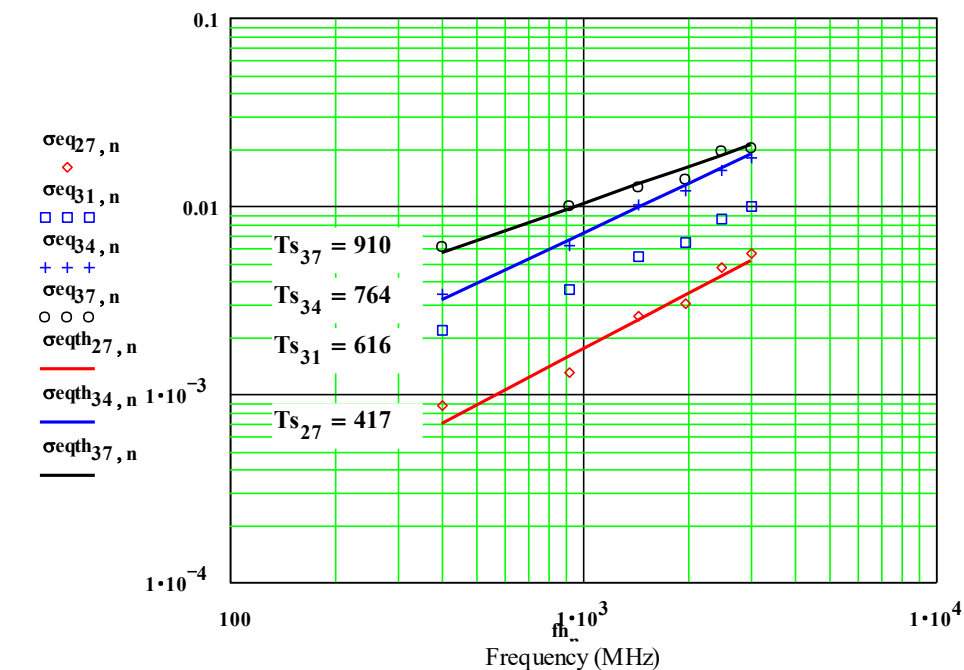
AnDat = 20251010

2nd Run: NU-LHT-2M-AGGL pellets, Holder + Crucible, RT- 1225C, in flowing 4% Hydrogrn ,D. Rickman, NAS

Equivalent Free Electron AC Conductivity ( Siemens/metre)



$$\sigma_{eqth_{27,n}} := 0.0007 \cdot \left( \frac{fh_n}{400} \right)^{0.99} \quad \sigma_{eqth_{34,n}} := 0.0032 \cdot \left( \frac{fh_n}{400} \right)^{0.88} \quad \sigma_{eqth_{37,n}} := 0.0056 \cdot \left( \frac{fh_n}{400} \right)^{0.66}$$



# NU-LHT-2M-AGGL

Test = 2025100701

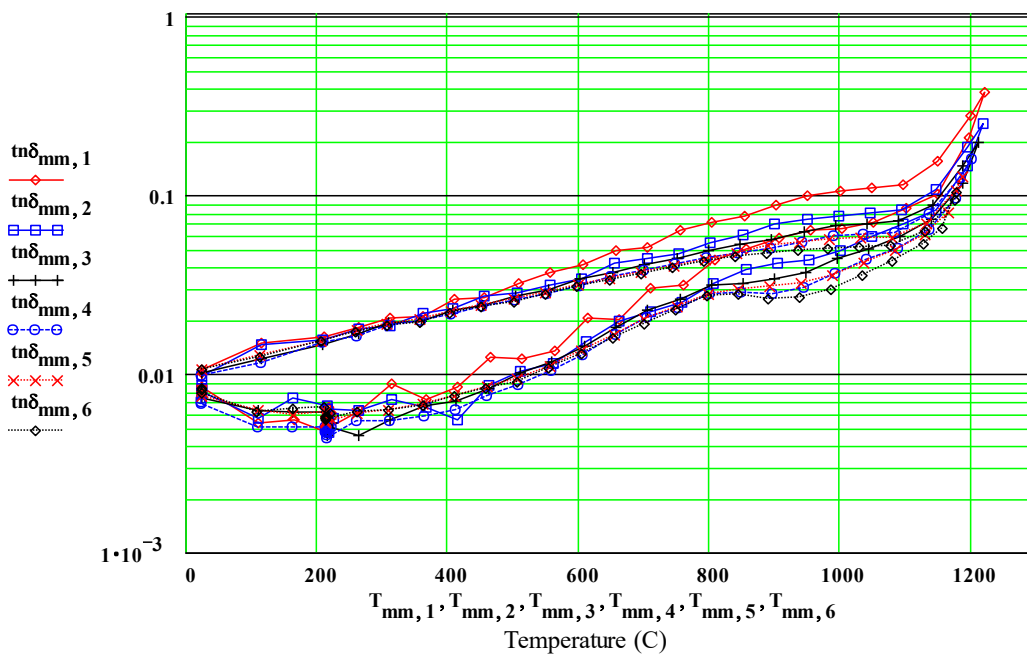
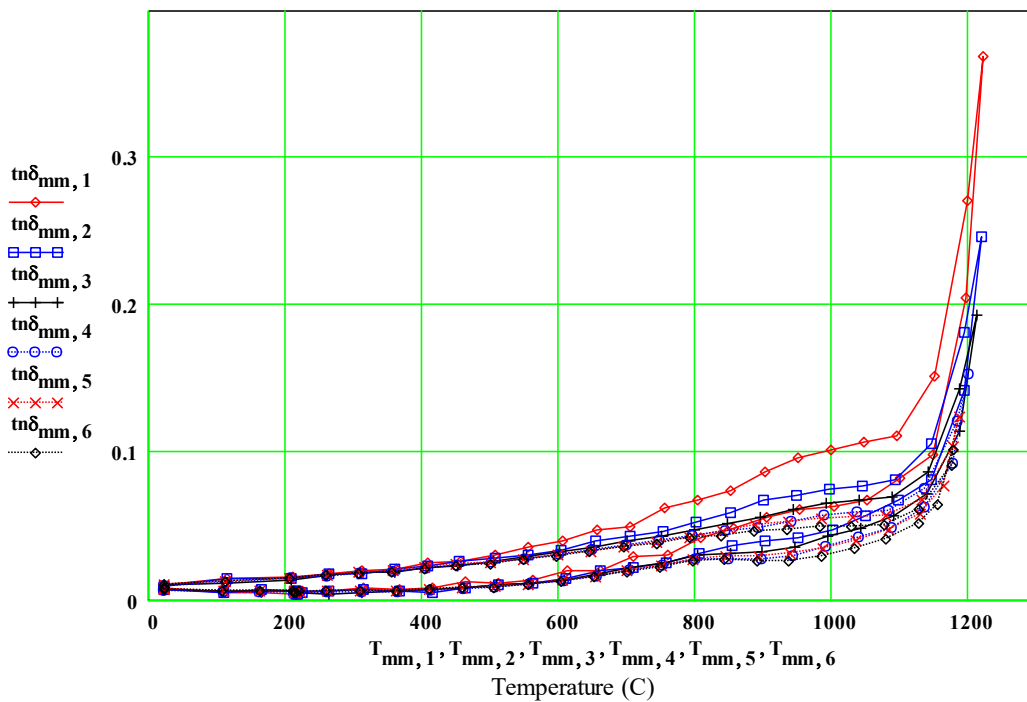
NASA2587.mcd

AnDat = 20251010

2nd Run: NU-LHT-2M-AGGL pellets, Holder + Crucible, RT- 1225C, in flowing 4% Hydrogrn ,D. Rickman, NAS

Initial density =  $\text{sam} \text{dns}_{\text{NCal} + 1} = 2.06 \text{ gm/cc}$ ,

Final density(25C) =  $\text{dnsfinal} = 2.08 \text{ gm/cc}$



# NU-LHT-2M-AGGL

Half-power Depth (millimeters)

$$D_{\text{halfP}}(\text{mm}, n) := \left( \frac{\ln(2)}{2} \right) \cdot (\text{inverse}\alpha_{\text{mm}, n} \cdot 1)$$

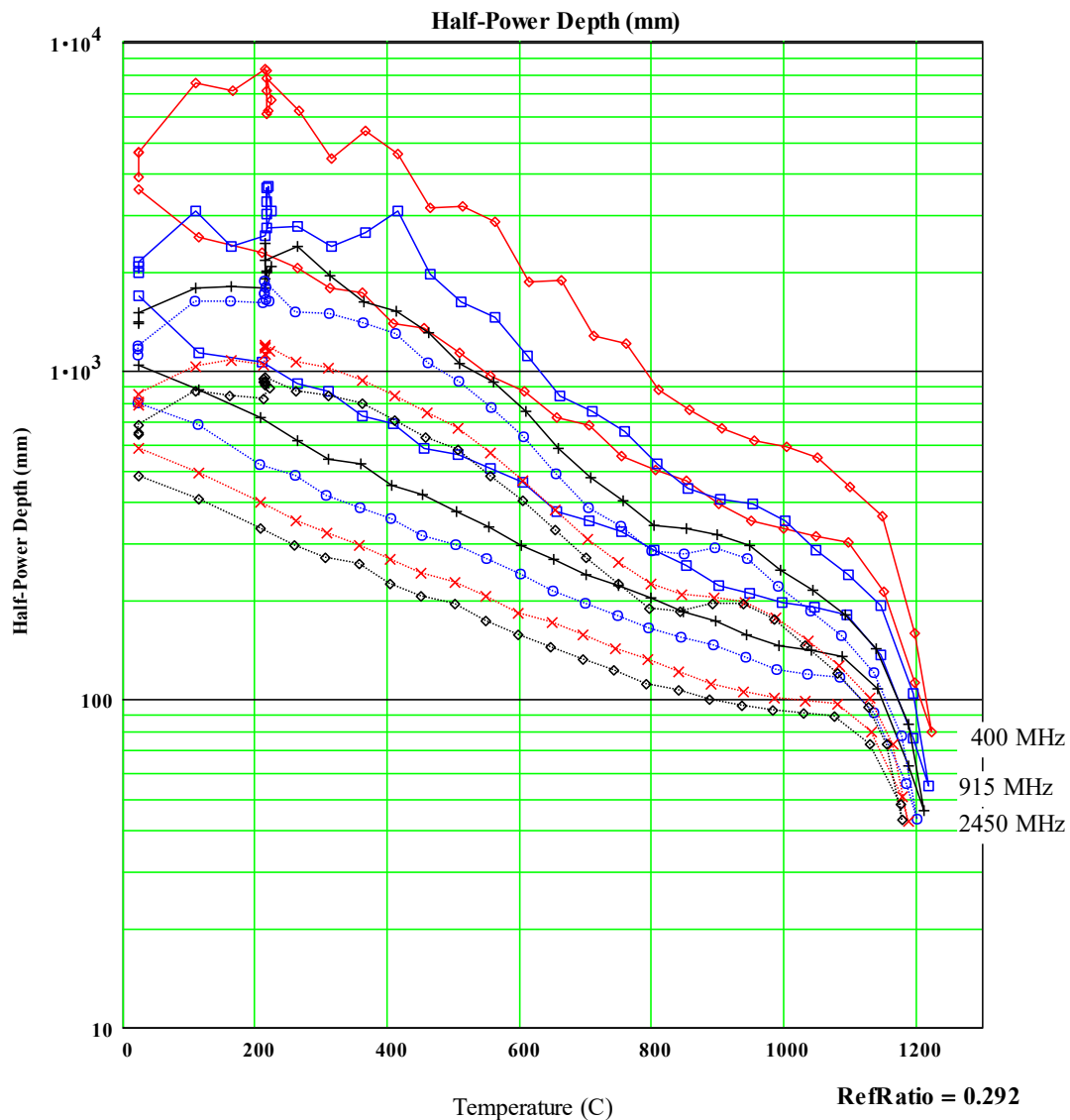
Test = 2025100701

NASA2587.mcd

AnDat = 20251010

2nd Run NU-LHT-2M-AGGL pellets, Holder + Crucible, RT- 1225C, in flowing 4% Hydrogrn, D. Rickman, NASA

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.06$  gm/cc, Final density(25C) =  $\text{dnsfinal} = 2.08$  gm/cc



# NU-LHT-2M-AGGL

Test = 2025100701

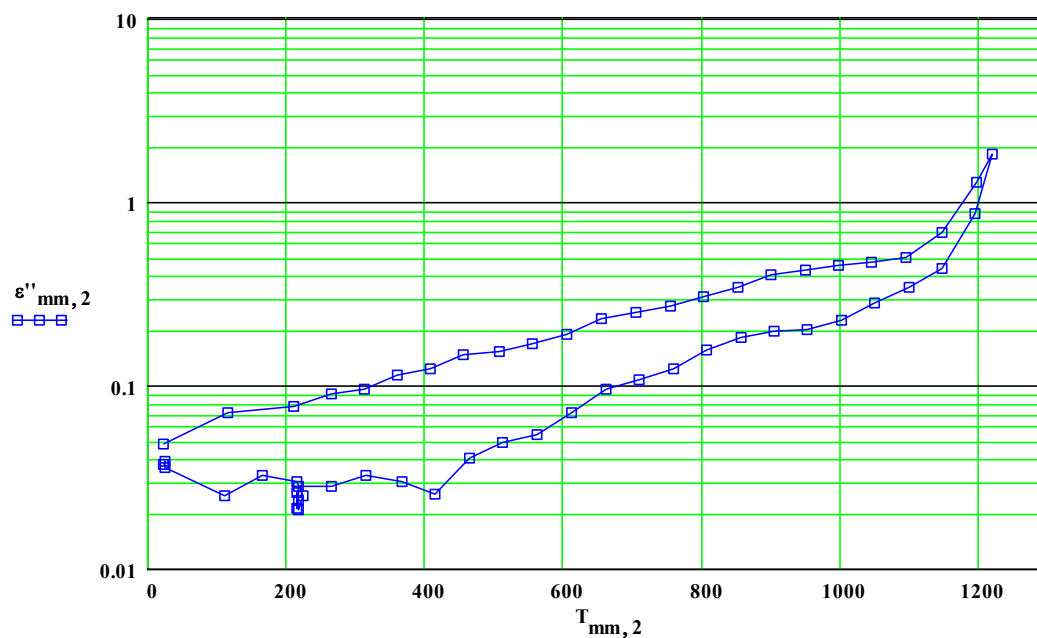
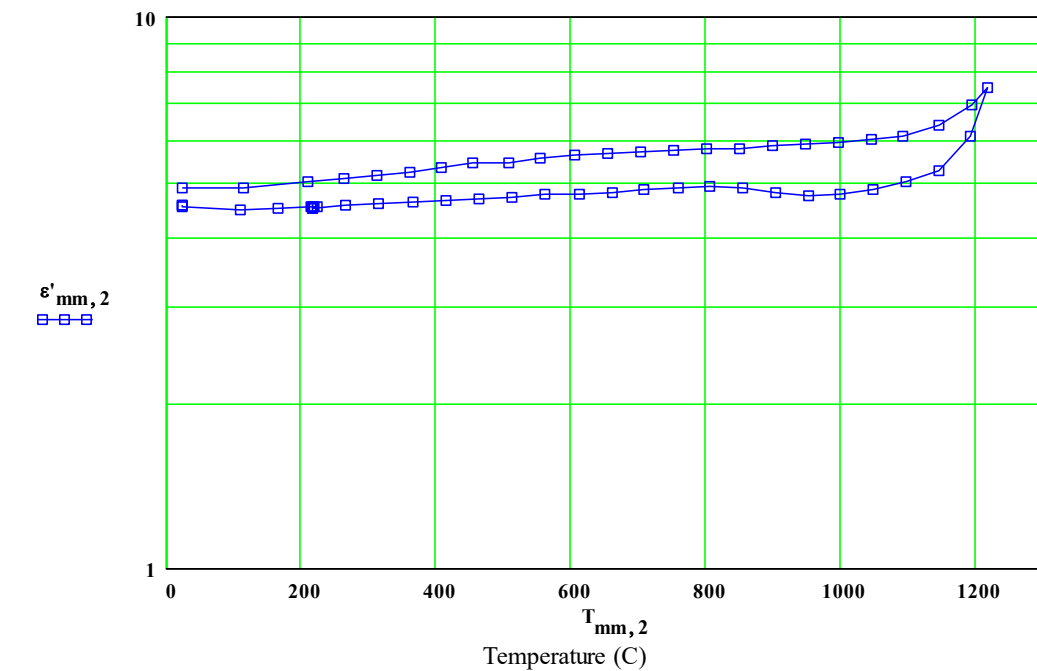
NASA2587.mcd

AnDat = 20251011

2nd Run: NU-LHT-2M-AGGL pellets, Holder + Crucible, RT- 1225C, in flowing 4% Hydrogrn ,D. Rickman, NAS.

Initial density =  $\text{samdms}_{\text{NCal} + 1} = 2.06 \text{ gm/cc}$ , Linear thermal exp. coeff.  $\alpha_1 = 0$  /deg C

## Values for 912 MHz



## NU-LHT-2M-AGGL

Test = 2025100701 NASA2587.mcd AnDat = 20251011

NU-LHT-2M-AGGL pellets, Holder + Crucible, RT- 1225C, in flowing 4% Hydrogen, D. Rickman, NASA

List of Measured Values of  $\epsilon'$  and  $\epsilon''$  and  $\tan\delta$  :

Initial density =  $\frac{\text{sam} \text{ dns}_{\text{NCal} + 1}}{\text{I}_{\text{air}}}$  = 2.059 gm/cc      Final density(25C) =  $\frac{\text{dns}_{\text{final}}}{\text{I}_{\text{air}}}$  = 2.079 gm/cc

|               |      |        |        |        |         |         |         |                           |
|---------------|------|--------|--------|--------|---------|---------|---------|---------------------------|
| density index | T(C) | 397MHz | 912MHz | 1429MH | 1948MHz | 2466MHz | 2986MHz | Eapsed<br>Time<br>(hours) |
|---------------|------|--------|--------|--------|---------|---------|---------|---------------------------|

| samdn <sub>mm</sub> | mm | T <sub>mm,1</sub> | ε <sub>mm,1</sub> | ε <sub>mm,2</sub> | ε <sub>mm,3</sub> | ε <sub>mm,4</sub> | ε <sub>mm,5</sub> | ε <sub>mm,6</sub> | (taps) <sub>mm</sub> | sammas <sub>mm</sub> |
|---------------------|----|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|----------------------|----------------------|
| 2.059               | 12 | 24                | 4.58              | 4.55              | 4.54              | 4.54              | 4.53              | 4.53              | 0                    | 0.27                 |
| 2.059               | 13 | 24                | 4.58              | 4.55              | 4.54              | 4.54              | 4.53              | 4.53              | 0.07                 | 0.27                 |
| 2.059               | 14 | 24                | 4.56              | 4.54              | 4.53              | 4.52              | 4.52              | 4.52              | 0.13                 | 0.27                 |
| 2.059               | 15 | 111               | 4.52              | 4.47              | 4.47              | 4.43              | 4.43              | 4.43              | 0.36                 | 0.27                 |
| 2.059               | 16 | 165               | 4.55              | 4.49              | 4.5               | 4.45              | 4.46              | 4.45              | 0.54                 | 0.27                 |
| 2.059               | 17 | 216               | 4.61              | 4.54              | 4.55              | 4.49              | 4.49              | 4.48              | 0.71                 | 0.27                 |
| 2.059               | 18 | 225               | 4.59              | 4.53              | 4.55              | 4.49              | 4.5               | 4.5               | 1.07                 | 0.27                 |
| 2.059               | 19 | 219               | 4.58              | 4.52              | 4.54              | 4.48              | 4.48              | 4.48              | 1.44                 | 0.27                 |
| 2.059               | 20 | 218               | 4.6               | 4.52              | 4.54              | 4.48              | 4.49              | 4.49              | 1.8                  | 0.27                 |
| 2.059               | 21 | 217               | 4.59              | 4.52              | 4.53              | 4.48              | 4.48              | 4.48              | 2.17                 | 0.27                 |
| 2.059               | 22 | 217               | 4.58              | 4.51              | 4.53              | 4.47              | 4.47              | 4.47              | 2.53                 | 0.27                 |
| 2.059               | 23 | 217               | 4.57              | 4.51              | 4.52              | 4.47              | 4.47              | 4.47              | 2.9                  | 0.27                 |
| 2.059               | 24 | 265               | 4.62              | 4.55              | 4.57              | 4.5               | 4.51              | 4.5               | 3.05                 | 0.27                 |
| 2.059               | 25 | 315               | 4.68              | 4.6               | 4.62              | 4.55              | 4.55              | 4.55              | 3.2                  | 0.27                 |
| 2.059               | 26 | 367               | 4.71              | 4.64              | 4.65              | 4.58              | 4.58              | 4.57              | 3.36                 | 0.27                 |
| 2.059               | 27 | 416               | 4.74              | 4.67              | 4.68              | 4.6               | 4.6               | 4.6               | 3.51                 | 0.27                 |
| 2.059               | 28 | 465               | 4.78              | 4.7               | 4.71              | 4.64              | 4.64              | 4.64              | 3.66                 | 0.27                 |
| 2.059               | 29 | 513               | 4.81              | 4.73              | 4.74              | 4.67              | 4.67              | 4.67              | 3.79                 | 0.27                 |
| 2.059               | 30 | 563               | 4.85              | 4.77              | 4.78              | 4.7               | 4.71              | 4.7               | 3.92                 | 0.27                 |
| 2.059               | 31 | 613               | 4.87              | 4.78              | 4.79              | 4.72              | 4.73              | 4.72              | 4.06                 | 0.27                 |
| 2.059               | 32 | 663               | 4.9               | 4.82              | 4.83              | 4.76              | 4.77              | 4.77              | 4.19                 | 0.27                 |
| 2.059               | 33 | 711               | 4.95              | 4.87              | 4.86              | 4.8               | 4.81              | 4.81              | 4.3                  | 0.27                 |
| 2.059               | 34 | 760               | 4.99              | 4.92              | 4.91              | 4.84              | 4.85              | 4.85              | 4.42                 | 0.27                 |
| 2.059               | 35 | 809               | 5.04              | 4.95              | 4.92              | 4.86              | 4.88              | 4.88              | 4.53                 | 0.27                 |
| 2.059               | 36 | 857               | 5                 | 4.89              | 4.87              | 4.82              | 4.84              | 4.84              | 4.65                 | 0.27                 |
| 2.055               | 37 | 906               | 4.88              | 4.8               | 4.76              | 4.72              | 4.74              | 4.75              | 4.76                 | 0.27                 |
| 2.052               | 38 | 954               | 4.84              | 4.75              | 4.71              | 4.68              | 4.71              | 4.71              | 4.88                 | 0.269                |
| 2.048               | 39 | 1003              | 4.9               | 4.79              | 4.72              | 4.7               | 4.73              | 4.73              | 4.99                 | 0.269                |
| 2.044               | 40 | 1051              | 5                 | 4.87              | 4.79              | 4.77              | 4.8               | 4.81              | 5.11                 | 0.268                |
| 2.048               | 41 | 1100              | 5.16              | 5.02              | 4.92              | 4.91              | 4.93              | 4.94              | 5.22                 | 0.268                |
| 2.053               | 42 | 1149              | 5.48              | 5.28              | 5.13              | 5.12              | 5.14              | 5.16              | 5.34                 | 0.267                |
| 2.057               | 43 | 1197              | 6.53              | 6.1               | 5.81              | 5.68              | 5.61              | 5.56              | 5.46                 | 0.267                |
| 2.062               | 44 | 1222              | 8.35              | 7.43              | 6.94              | 6.67              | 6.51              | 6.41              | 5.57                 | 0.266                |
| 2.071               | 45 | 1198              | 7.56              | 6.94              | 6.58              | 6.5               | 6.46              | 6.47              | 5.69                 | 0.266                |
| 2.079               | 46 | 1150              | 6.67              | 6.36              | 6.16              | 6.12              | 6.12              | 6.13              | 5.8                  | 0.266                |
| 2.079               | 47 | 1097              | 6.29              | 6.08              | 5.93              | 5.91              | 5.92              | 5.94              | 5.92                 | 0.266                |
| 2.079               | 48 | 1048              | 6.19              | 5.99              | 5.87              | 5.83              | 5.85              | 5.86              | 6.03                 | 0.266                |
| 2.079               | 49 | 999               | 6.14              | 5.94              | 5.84              | 5.79              | 5.81              | 5.82              | 6.15                 | 0.266                |
| 2.079               | 50 | 951               | 6.08              | 5.89              | 5.81              | 5.75              | 5.77              | 5.77              | 6.26                 | 0.266                |
| 2.079               | 51 | 902               | 6.05              | 5.85              | 5.78              | 5.71              | 5.73              | 5.73              | 6.39                 | 0.266                |
| 2.079               | 52 | 853               | 5.96              | 5.78              | 5.72              | 5.65              | 5.66              | 5.66              | 6.51                 | 0.266                |
| 2.079               | 53 | 804               | 5.96              | 5.77              | 5.72              | 5.64              | 5.64              | 5.64              | 6.64                 | 0.266                |
| 2.079               | 54 | 755               | 5.88              | 5.73              | 5.68              | 5.6               | 5.61              | 5.6               | 6.78                 | 0.266                |
| 2.079               | 55 | 706               | 5.86              | 5.7               | 5.67              | 5.59              | 5.59              | 5.58              | 6.92                 | 0.266                |
| 2.079               | 56 | 656               | 5.83              | 5.67              | 5.65              | 5.56              | 5.56              | 5.55              | 7.08                 | 0.266                |
| 2.079               | 57 | 606               | 5.79              | 5.63              | 5.61              | 5.51              | 5.51              | 5.5               | 7.24                 | 0.266                |
| 2.079               | 58 | 556               | 5.68              | 5.54              | 5.53              | 5.43              | 5.43              | 5.42              | 7.41                 | 0.266                |
| 2.079               | 59 | 508               | 5.57              | 5.45              | 5.44              | 5.35              | 5.34              | 5.33              | 7.6                  | 0.266                |
| 2.079               | 60 | 456               | 5.56              | 5.43              | 5.43              | 5.33              | 5.33              | 5.32              | 7.81                 | 0.266                |
| 2.079               | 61 | 409               | 5.48              | 5.34              | 5.34              | 5.25              | 5.24              | 5.23              | 8.03                 | 0.266                |

mq := 62,63..nd - Nempties

| sandms | nm <sub>sq</sub> | T <sub>mq, 1</sub> | ε <sub>mq, 1</sub> | ε <sub>mq, 2</sub> | ε <sub>mq, 3</sub> | ε <sub>mq, 4</sub> | ε <sub>mq, 5</sub> | ε <sub>mq, 6</sub> | flaps <sub>mq</sub> | sammas <sub>mq</sub> |
|--------|------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|---------------------|----------------------|
| 2.079  | 62               | 362                | 5.36               | 5.24               | 5.24               | 5.16               | 5.15               | 5.15               | 8.28                | 0.266                |
| 2.079  | 63               | 312                | 5.28               | 5.17               | 5.17               | 5.08               | 5.08               | 5.07               | 8.55                | 0.266                |
| 2.079  | 64               | 265                | 5.22               | 5.11               | 5.11               | 5.03               | 5.02               | 5.02               | 8.88                | 0.266                |
| 2.079  | 65               | 210                | 5.14               | 5.04               | 5.03               | 4.97               | 4.96               | 4.95               | 9.3                 | 0.266                |
| 2.079  | 66               | 115                | 4.98               | 4.9                | 4.89               | 4.85               | 4.85               | 4.84               | 10.38               | 0.266                |
| 2.079  | 67               | 24                 | 4.94               | 4.89               | 4.88               | 4.87               | 4.87               | 4.87               | 18.72               | 0.266                |

# NU-LHT-2M-AGGL

Test = 2025100701      NASA2587.mcd      AnDat = 20251011

2nd Run: NU-LHT-2M-AGGL pellets, Holder + Crucible, RT- 1225C, in flowing 4% Hydrogrn ,D. Rickman, NAS

List of Measured Values of  $\epsilon'$  and  $\epsilon''$  and  $\tan\delta$  :  
 ~~~~~

Initial density = **samdns**_{mm} **NCal + 1** = **2.059** gm/cc Final density(25C) = **dnsfinal** = **2.079** gm/cc
 Lapsed

density index T(C) 397MHz 912MHz 1429MH 1948MHz 2466MHz 2986MHz
 Time (hours)

| amands | mm | T mm,1 | ε'' mm,1 | ε'' mm,2 | ε'' mm,3 | ε'' mm,4 | ε'' mm,5 | ε'' mm,6 | tlaps mm | sammas mm |
|--------|----|--------|----------|----------|----------|----------|----------|----------|----------|-----------|
| 2.059 | 12 | 24 | 0.046 | 0.037 | 0.036 | 0.033 | 0.037 | 0.037 | 0 | 0.27 |
| 2.059 | 13 | 24 | 0.039 | 0.039 | 0.035 | 0.031 | 0.036 | 0.036 | 0.07 | 0.27 |
| 2.059 | 14 | 24 | 0.039 | 0.036 | 0.033 | 0.03 | 0.034 | 0.035 | 0.13 | 0.27 |
| 2.059 | 15 | 111 | 0.024 | 0.025 | 0.028 | 0.022 | 0.028 | 0.027 | 0.36 | 0.27 |
| 2.059 | 16 | 165 | 0.025 | 0.032 | 0.027 | 0.022 | 0.026 | 0.028 | 0.54 | 0.27 |
| 2.059 | 17 | 216 | 0.022 | 0.03 | 0.028 | 0.023 | 0.028 | 0.029 | 0.71 | 0.27 |
| 2.059 | 18 | 225 | 0.027 | 0.025 | 0.024 | 0.022 | 0.025 | 0.027 | 1.07 | 0.27 |
| 2.059 | 19 | 219 | 0.029 | 0.021 | 0.025 | 0.02 | 0.026 | 0.026 | 1.44 | 0.27 |
| 2.059 | 20 | 218 | 0.03 | 0.024 | 0.025 | 0.022 | 0.025 | 0.026 | 1.8 | 0.27 |
| 2.059 | 21 | 217 | 0.022 | 0.026 | 0.026 | 0.021 | 0.024 | 0.025 | 2.17 | 0.27 |
| 2.059 | 22 | 217 | 0.025 | 0.022 | 0.02 | 0.021 | 0.024 | 0.025 | 2.53 | 0.27 |
| 2.059 | 23 | 217 | 0.023 | 0.028 | 0.023 | 0.019 | 0.024 | 0.025 | 2.9 | 0.27 |
| 2.059 | 24 | 265 | 0.029 | 0.028 | 0.021 | 0.024 | 0.027 | 0.027 | 3.05 | 0.27 |
| 2.059 | 25 | 315 | 0.041 | 0.033 | 0.026 | 0.025 | 0.028 | 0.028 | 3.2 | 0.27 |
| 2.059 | 26 | 367 | 0.034 | 0.03 | 0.031 | 0.026 | 0.031 | 0.03 | 3.36 | 0.27 |
| 2.059 | 27 | 416 | 0.04 | 0.026 | 0.033 | 0.028 | 0.035 | 0.034 | 3.51 | 0.27 |
| 2.059 | 28 | 465 | 0.059 | 0.04 | 0.039 | 0.035 | 0.039 | 0.038 | 3.66 | 0.27 |
| 2.059 | 29 | 513 | 0.058 | 0.049 | 0.048 | 0.04 | 0.043 | 0.042 | 3.79 | 0.27 |
| 2.059 | 30 | 563 | 0.065 | 0.055 | 0.055 | 0.048 | 0.052 | 0.051 | 3.92 | 0.27 |
| 2.059 | 31 | 613 | 0.099 | 0.072 | 0.068 | 0.059 | 0.063 | 0.06 | 4.06 | 0.27 |
| 2.059 | 32 | 663 | 0.098 | 0.095 | 0.088 | 0.077 | 0.078 | 0.074 | 4.19 | 0.27 |
| 2.059 | 33 | 711 | 0.146 | 0.107 | 0.109 | 0.098 | 0.096 | 0.09 | 4.3 | 0.27 |
| 2.059 | 34 | 760 | 0.154 | 0.123 | 0.128 | 0.112 | 0.114 | 0.109 | 4.42 | 0.27 |
| 2.059 | 35 | 809 | 0.213 | 0.156 | 0.152 | 0.134 | 0.133 | 0.13 | 4.53 | 0.27 |
| 2.059 | 36 | 857 | 0.246 | 0.184 | 0.155 | 0.136 | 0.142 | 0.133 | 4.65 | 0.27 |
| 2.055 | 37 | 906 | 0.277 | 0.196 | 0.159 | 0.129 | 0.143 | 0.124 | 4.76 | 0.27 |
| 2.052 | 38 | 954 | 0.301 | 0.201 | 0.172 | 0.139 | 0.148 | 0.124 | 4.88 | 0.269 |
| 2.048 | 39 | 1003 | 0.314 | 0.229 | 0.205 | 0.169 | 0.165 | 0.139 | 4.99 | 0.269 |
| 2.044 | 40 | 1051 | 0.343 | 0.282 | 0.236 | 0.202 | 0.195 | 0.167 | 5.11 | 0.268 |
| 2.048 | 41 | 1100 | 0.429 | 0.34 | 0.284 | 0.243 | 0.236 | 0.206 | 5.22 | 0.268 |
| 2.053 | 42 | 1149 | 0.541 | 0.433 | 0.369 | 0.321 | 0.301 | 0.267 | 5.34 | 0.267 |
| 2.057 | 43 | 1197 | 1.343 | 0.867 | 0.666 | 0.527 | 0.435 | 0.358 | 5.46 | 0.267 |
| 2.062 | 44 | 1222 | 3.082 | 1.831 | 1.344 | 1.024 | 0.808 | 0.653 | 5.57 | 0.266 |
| 2.071 | 45 | 1198 | 2.051 | 1.263 | 0.946 | 0.792 | 0.674 | 0.591 | 5.69 | 0.266 |
| 2.079 | 46 | 1150 | 1.012 | 0.674 | 0.536 | 0.464 | 0.419 | 0.375 | 5.8 | 0.266 |
| 2.079 | 47 | 1097 | 0.701 | 0.498 | 0.419 | 0.356 | 0.338 | 0.305 | 5.92 | 0.266 |
| 2.079 | 48 | 1048 | 0.665 | 0.466 | 0.401 | 0.346 | 0.329 | 0.296 | 6.03 | 0.266 |
| 2.079 | 49 | 999 | 0.629 | 0.45 | 0.387 | 0.334 | 0.32 | 0.289 | 6.15 | 0.266 |
| 2.079 | 50 | 951 | 0.588 | 0.422 | 0.357 | 0.307 | 0.307 | 0.279 | 6.26 | 0.266 |
| 2.079 | 51 | 902 | 0.525 | 0.397 | 0.323 | 0.281 | 0.291 | 0.267 | 6.39 | 0.266 |
| 2.079 | 52 | 853 | 0.443 | 0.342 | 0.299 | 0.262 | 0.263 | 0.25 | 6.51 | 0.266 |
| 2.079 | 53 | 804 | 0.409 | 0.306 | 0.274 | 0.246 | 0.243 | 0.238 | 6.64 | 0.266 |
| 2.079 | 54 | 755 | 0.367 | 0.268 | 0.249 | 0.224 | 0.223 | 0.215 | 6.78 | 0.266 |
| 2.079 | 55 | 706 | 0.296 | 0.248 | 0.23 | 0.207 | 0.203 | 0.199 | 6.92 | 0.266 |
| 2.079 | 56 | 656 | 0.279 | 0.231 | 0.206 | 0.19 | 0.186 | 0.182 | 7.08 | 0.266 |
| 2.079 | 57 | 606 | 0.232 | 0.189 | 0.187 | 0.167 | 0.172 | 0.166 | 7.24 | 0.266 |
| 2.079 | 58 | 556 | 0.207 | 0.17 | 0.163 | 0.149 | 0.152 | 0.15 | 7.41 | 0.266 |
| 2.079 | 59 | 508 | 0.175 | 0.154 | 0.146 | 0.135 | 0.137 | 0.132 | 7.6 | 0.266 |
| 2.079 | 60 | 456 | 0.146 | 0.146 | 0.129 | 0.125 | 0.128 | 0.125 | 7.81 | 0.266 |
| 2.079 | 61 | 409 | 0.141 | 0.122 | 0.12 | 0.11 | 0.115 | 0.114 | 8.03 | 0.266 |

mq := 62,63..nd - Nempties

| samdns | | T | ϵ'' | ϵ'' | ϵ'' | ϵ'' | ϵ'' | ϵ'' | tlaps | sammas |
|--------|----|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-------|--------|
| mq | mq | mq ₁ | mq ₁ | mq ₂ | mq ₃ | mq ₄ | mq ₅ | mq ₆ | mq | mq |
| 2.079 | 62 | 362 | 0.112 | 0.114 | 0.102 | 0.101 | 0.104 | 0.098 | 8.28 | 0.266 |
| 2.079 | 63 | 312 | 0.108 | 0.095 | 0.098 | 0.093 | 0.095 | 0.092 | 8.55 | 0.266 |
| 2.079 | 64 | 265 | 0.093 | 0.09 | 0.086 | 0.08 | 0.086 | 0.085 | 8.88 | 0.266 |
| 2.079 | 65 | 210 | 0.083 | 0.077 | 0.072 | 0.074 | 0.075 | 0.075 | 9.3 | 0.266 |
| 2.079 | 66 | 115 | 0.073 | 0.071 | 0.059 | 0.055 | 0.061 | 0.06 | 10.38 | 0.266 |
| 2.079 | 67 | 24 | 0.052 | 0.048 | 0.05 | 0.047 | 0.051 | 0.051 | 18.72 | 0.266 |

ECERF_6_mod**June 28, 2017**Pure Olivine

The test material arrived as a powder. The measurement sample was formed by making pellets in a custom uniaxial press, to form cylindrical pellets of ~ 3.6 mm diameter and ~ 4.5 mm long. Three of these pellets were stacked in our 4 mm ID quartz sample holder to form the measurement sample. The temperature during the run went up to 1150C and then back to room temperature (RT), all in a 10 sccm flow of UHP argon.

The initial sample parameters were:

- a) diameter 3.61 +/- 0.05
- b) length 14.07 +/- 0.05 mm
- c) mass 0.318 +/- 0.002 gm
- l) room temperature density 2.21 ± 0.09 gm/cc.
- m) appearance - 3 stacked light blue-grey pellets
- n) no attraction to a strong permanent magnet

The dielectric properties measurements were performed at RT, 50°C, and then 50°C steps to 1150°C, then to 1100C, then in -100°C steps back down to 100°C, then room temperature. The empty holder was measured at a few points up to 1100°C, and was found uncontaminated.

The final sample properties, at room temperature were:

- a) diameter 3.61 +/- 0.05
- b) length 13.94 +/- 0.05 mm
- c) mass 0.314 +/- 0.002 gm
- l) room temperature density 2.20 ± 0.09 gm/cc.
- m) appearance - 3 stacked pellets -- bottom pellet was light orange-beige with core of blue-grey – lower half of mid pellet outer surface is half beige-orange, half light grey. Top pellet is light grey. This suggests a change in a surface layer induced by the very slight oxygen contamination in out UHP argon (~ 10 ppm ?).

The final pellets were not attracted to a strong magnet. At room temperature the resistance from end to end of each pellet was > 30 Mohms – the material was a good insulator! The very small initial drop in ϵ'' values is likely due to loss of adsorbed moisture.

The frequency coding is :

Legend for Data Plots :

| # | <u>Frequency(MHz)</u> | <u>Symbol</u> |
|---|-----------------------|--|
| 1 | 397 | red diamond, solid line – sometimes the line is omitted! |
| 2 | 912 | blue square, solid line |
| 3 | 1429 | black cross, solid line |
| 4 | 1948 | blue circle, dotted line |
| 5 | 2466 | red cross, dotted line |
| 6 | 2986 | black diamond, dotted line |

Discussion of Olivine and Comments on Data :

Olivine can have the form of :

Forsterite (Mg_2SiO_4) (mp = 1900C, density 3.21 to 3.33 g/cc) or

Fayalite (Fe_2SiO_4) (mp = 1200C) or

solid solutions where Mg^{++} and Fe^{++} substitute for each other in the structure.

All forms are pure ordered crystalline structures, and, without impurities, would be expected to have low dielectric loss.

The detailed chemical composition of this material is not known.

Experience suggests the initial decrease in ϵ'' values from room temperature up to 200C was caused by a small amount of adsorbed water, as it was gone on the return down in temperature.

The ϵ'' values up to 500C reflect a modest thermally activated loss mechanism, likely caused by impurity ions in the material. The frequency dependence eliminated electron conductivity as the mechanism! The activation energy for the increasing loss is ~ 0.2 eV, suggesting the ions causing the loss are not resident interstitially in the structure, but are at grain boundaries where the binding energy is small.

At higher temperatures, both ϵ' and ϵ'' show small peaks at 700C and 980C, which need to be interpreted. They may be the result of phase transitions, or just the change in some small impurity at crystalline boundaries.

In any case, the values of ϵ'' at 1150C are 40% lower than the peak values at 975C.

The return down in temperature shows only a single, broader, peak, which may be something different – or a merging of the two peaks for some reason.

The room temperature values of ϵ'' return to a low value of $\epsilon'' \sim 0.01$, very reasonable for a dry crystalline powder.

Olivine ECERF_6

Code Calculates Estimated Sample Dimensions & Volume and Plots Density As a Function of Temperature
 ~~~~~

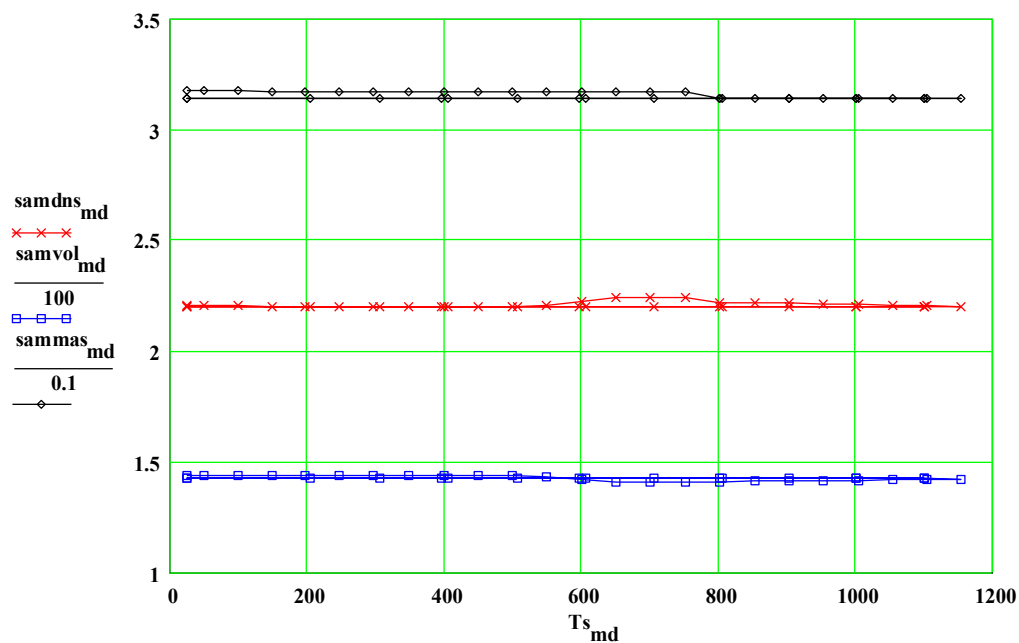
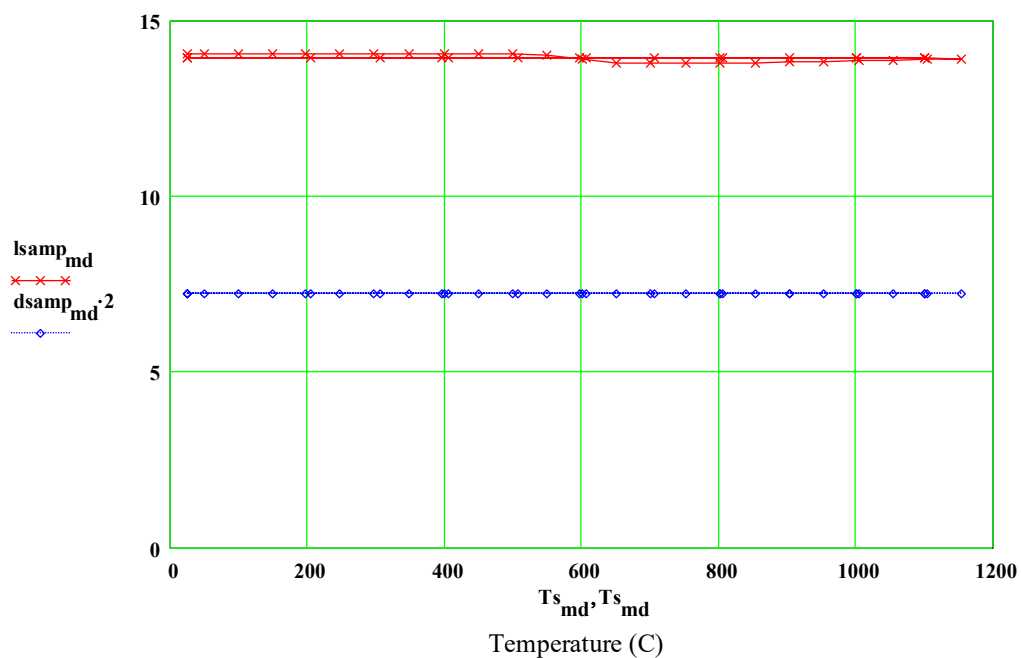
Test = 2014052801

ECERF1437.mcd

AnDat = 20140529

Pure Olivine, pellets , RT - 1150C, in 10 sccm flowing UHP Argon, for Erin Bobicki, ECERF

Assumed Effective Dimensions (mm) and Density (gm/cc) as a Function of Temperature for Solid





Final serpentine and olivine pellets.



Final Olivine pellets. Bottom pellet had brown/orange exterior. Mid pellet partially brow.

Initial pellets were all blue-grey.

Test = 2014052801

ECERF1437\_HTnew.mcd

AnDat = 20140529

Pure Olivine, pellets , RT - 1150C, in 10 sccm flowing UHP Argon, for Erin Bobicki, ECERF

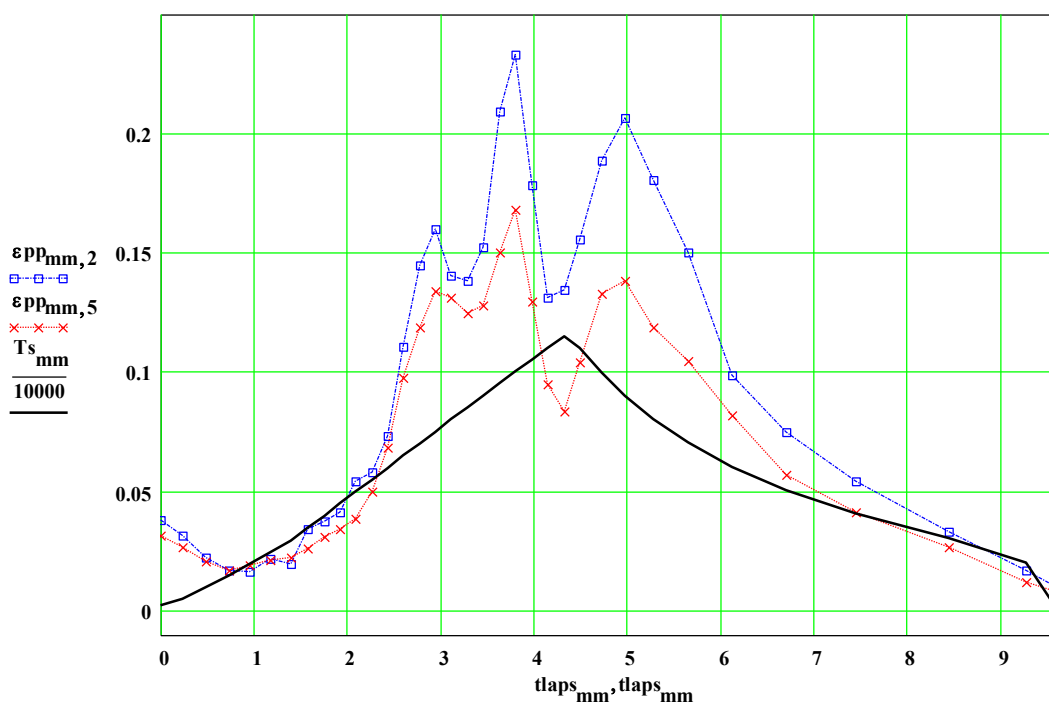
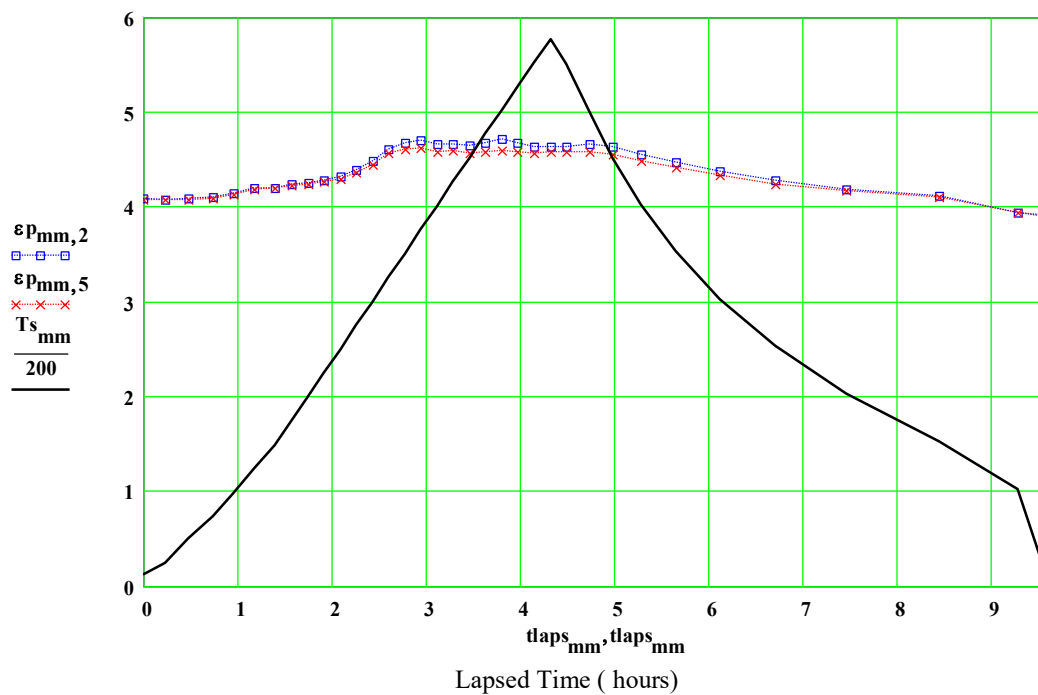
Initial density =  $\text{samdens}_{\text{NCal} + 1} = 2.21$  gm/cc,

Thermal exp. coeff.

Final density(25C) =  $\text{densfinal} = 2.2$  gm/cc

FracMassChange = 0.99

$\alpha_1 = 0$



# Olivine ECERF\_6

Test = 2014052801

ECERF1437\_HTnew.mcd

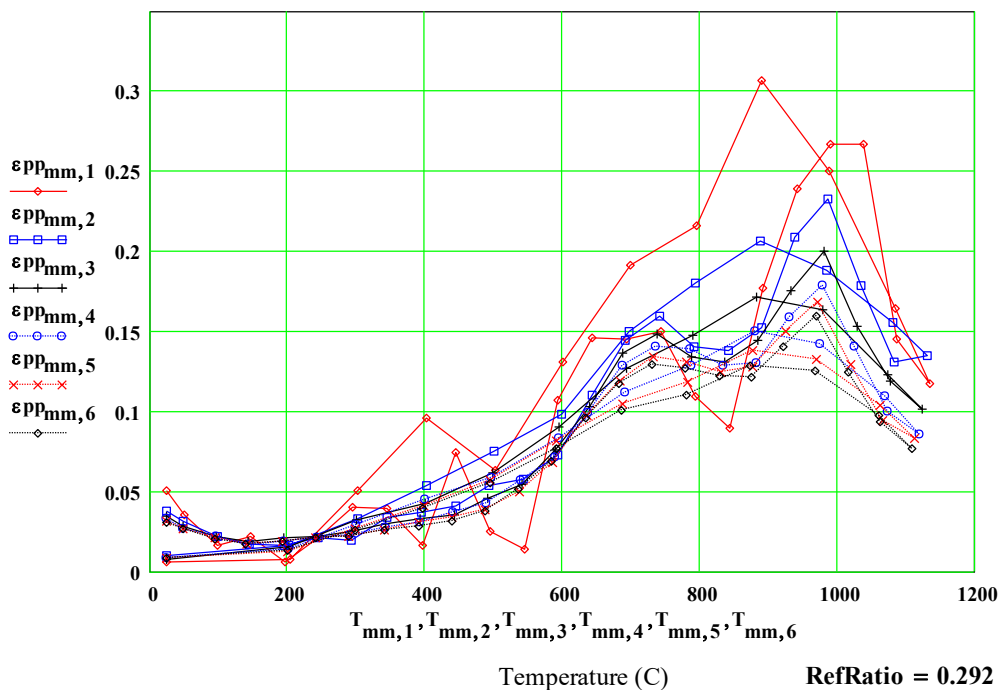
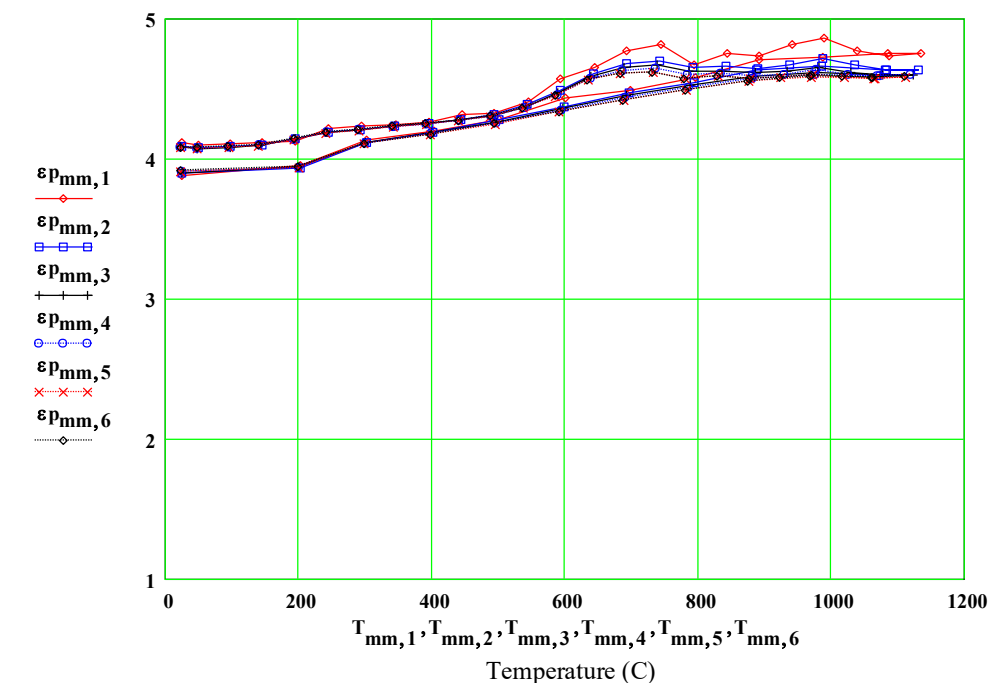
AnDat = 20140529

Pure Olivine, pellets , RT - 1150C, in 10 sccm flowing UHP Argon, for Erin Bobicki, ECERF

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.21$  gm/cc,  $\text{FracMassChange} = 0.987$   $\alpha_1 = 0 \cdot 10^{-6}$

Final density(25C) =  $\text{dnsfinal} = 2.2$  gm/cc

thermal expansion coef /deg C below  $T_i$



# Olivine ECERF\_6

Test = 2014052801

ECERF1437\_IncreasingTemp\_HTnew.mcd

AnDat = 20170628

Pure Olivine, pellets , RT - 1150C, in 10 sccm flowing UHP Argon, for Erin Bobicki, ECERF

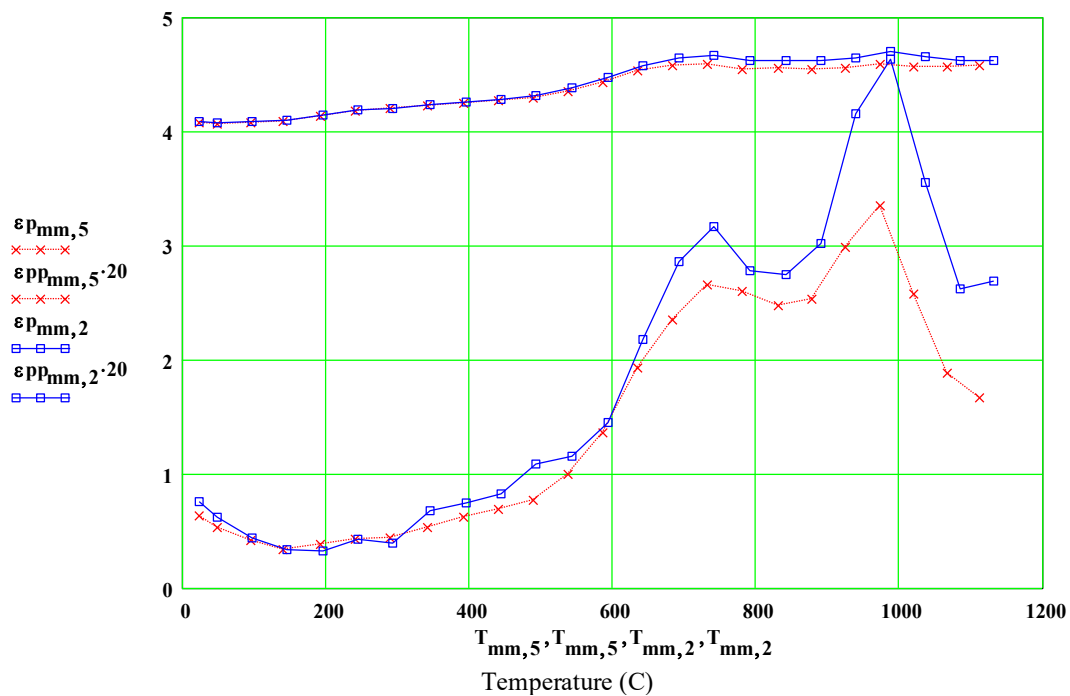
Initial density =  $\text{sam} \text{ dns}_{\text{NCal} + 1} = 2.21$  gm/cc,

Thermal exp. coeff.

Final density(25C) =  $\text{dns}_{\text{final}} = 2.2$  gm/cc

FracMassChange = 0.99

$\alpha_1 = 0$



# Olivine ECERF\_6

Test = 2014052801

ECERF1437\_DecreasingTemp\_HTnew.mcd

AnDat = 20170628

Pure Olivine, pellets , RT - 1150C, in 10 sccm flowing UHP Argon, for Erin Bobicki, ECERF

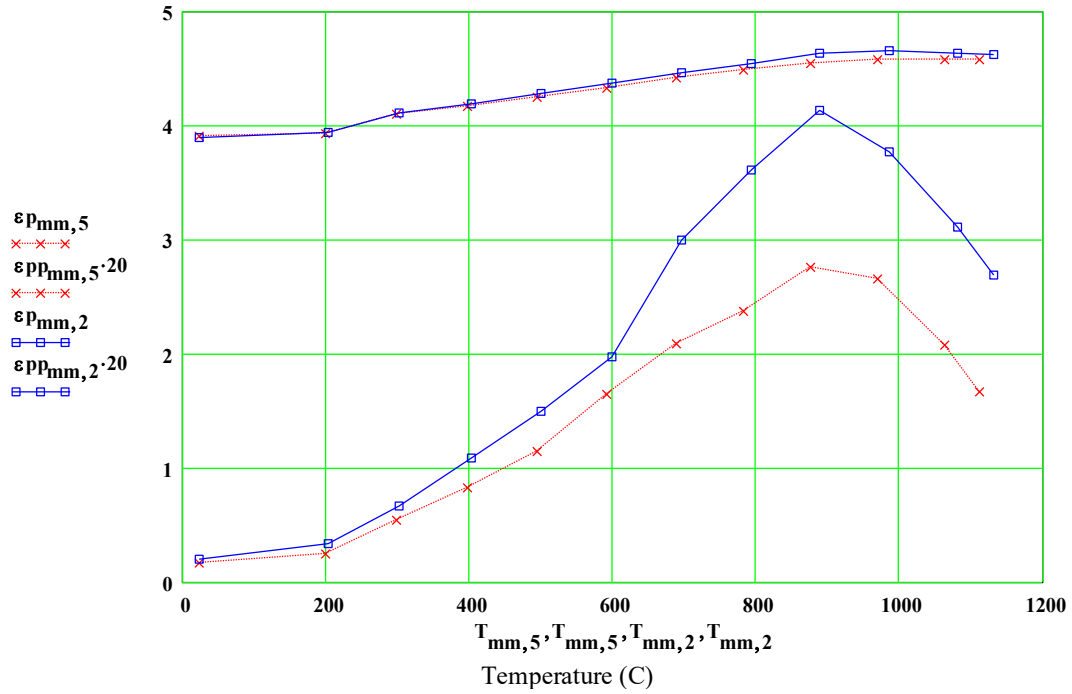
Initial density =  $\text{sam} \text{dns}_{\text{NCal} + 1} = 2.21$  gm/cc,

Thermal exp. coeff.

Final density(25C) =  $\text{dns}_{\text{final}} = 2.2$  gm/cc

FracMassChange = 0.99

$\alpha_1 = 0$



# Olivine ECERF\_6

Test = 2014052801

ECERF1437\_HTnew.mcd

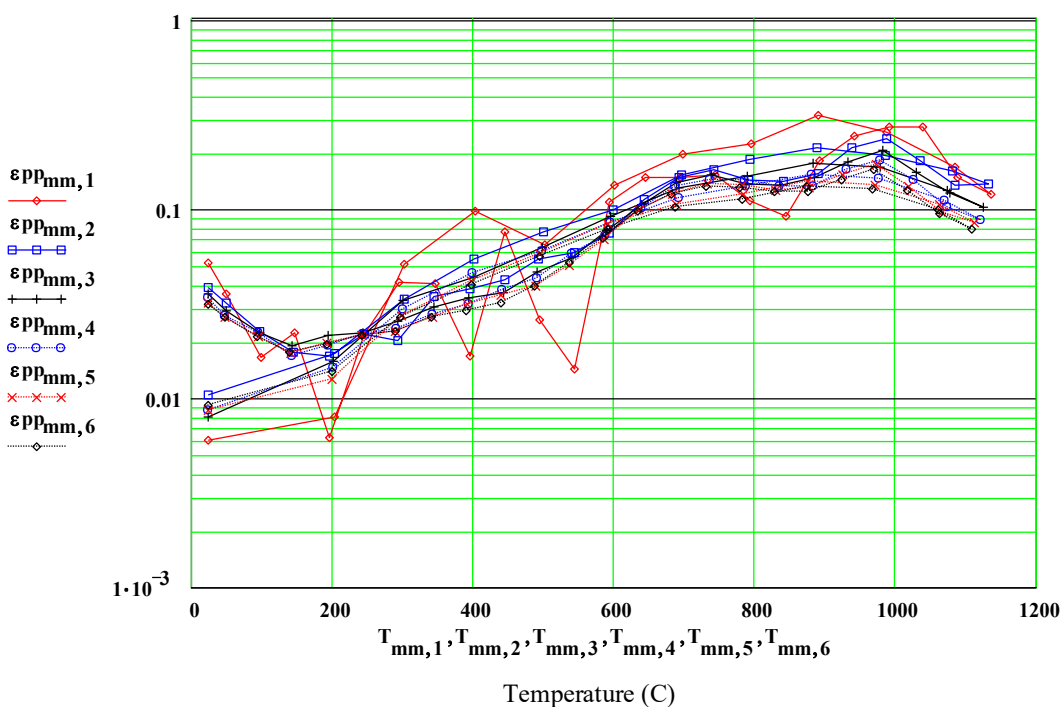
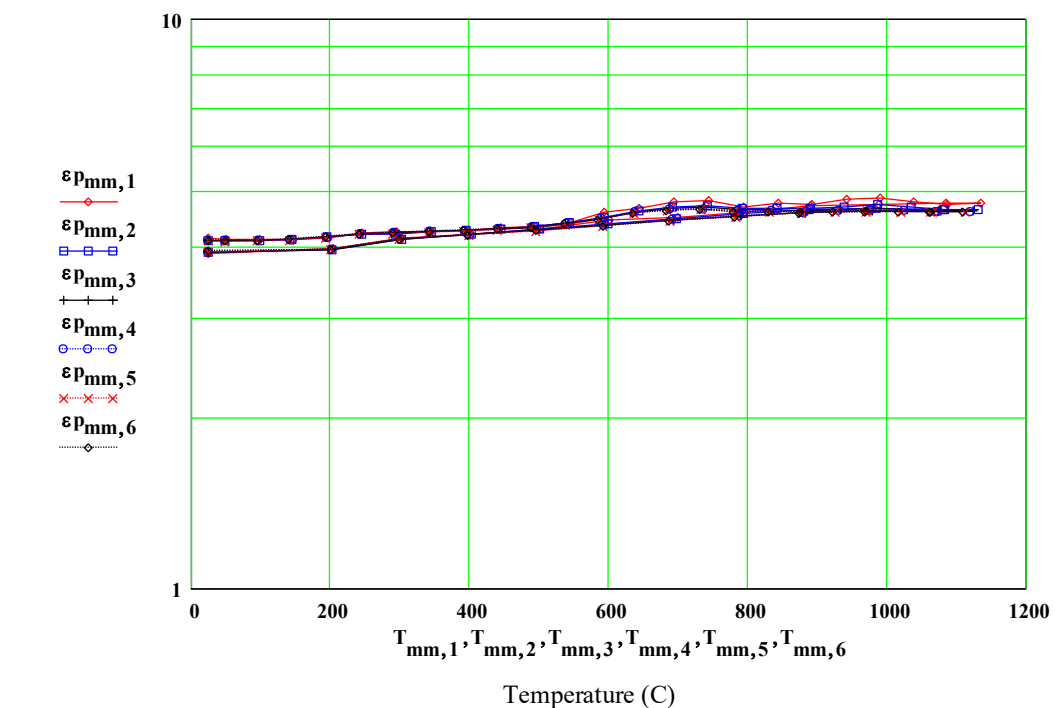
AnDat = 20140529

Pure Olivine, pellets , RT - 1150C, in 10 sccm flowing UHP Argon, for Erin Bobicki, ECERF

Initial density =  $\text{sam dns}_{\text{NCal} + 1} = 2.21 \text{ gm/cc}$ , Final density(25C) =  $\text{dnsfinal} = 2.2 \text{ gm/cc}$

FracMassChange = 0.99

$\alpha_1 = 0$  /C



# Olivine ECERF\_6

Test = 2014052801

ECERF1437\_HTnew.mcd

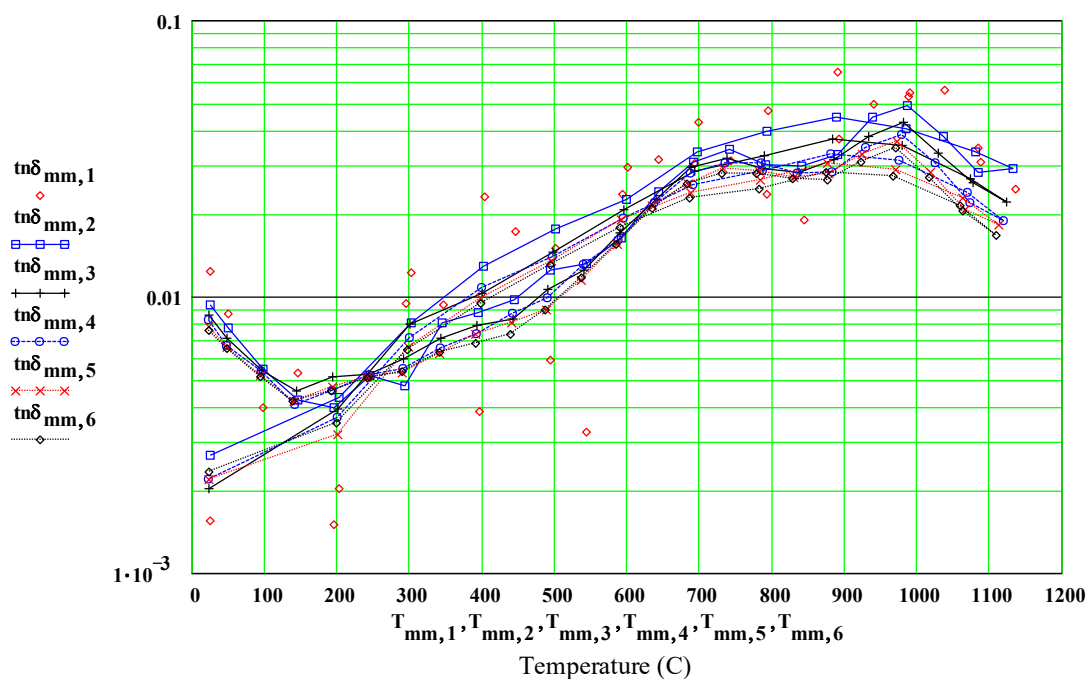
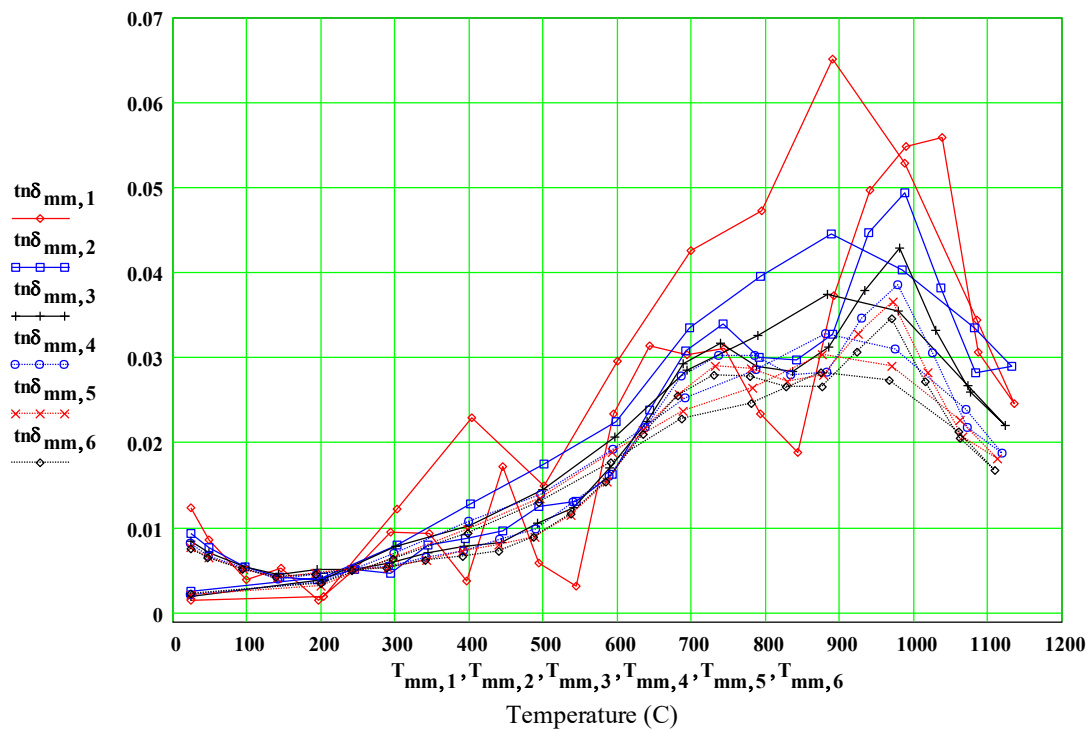
AnDat = 20140529

Pure Olivine, pellets , RT - 1150C, in 10 sccm flowing UHP Argon, for Erin Bobicki, ECERF

Initial density =  $\text{samdens}_{\text{NCal} + 1} = 2.21$  gm/cc,

FracMassChange = 0.987

Final density(25C) =  $\text{dnsfinal} = 2.2$  gm/cc



Code Calculates the Half-Power Depth at each Temperature for each Frequency

[illegible]

Half-power Depth (centimeters)

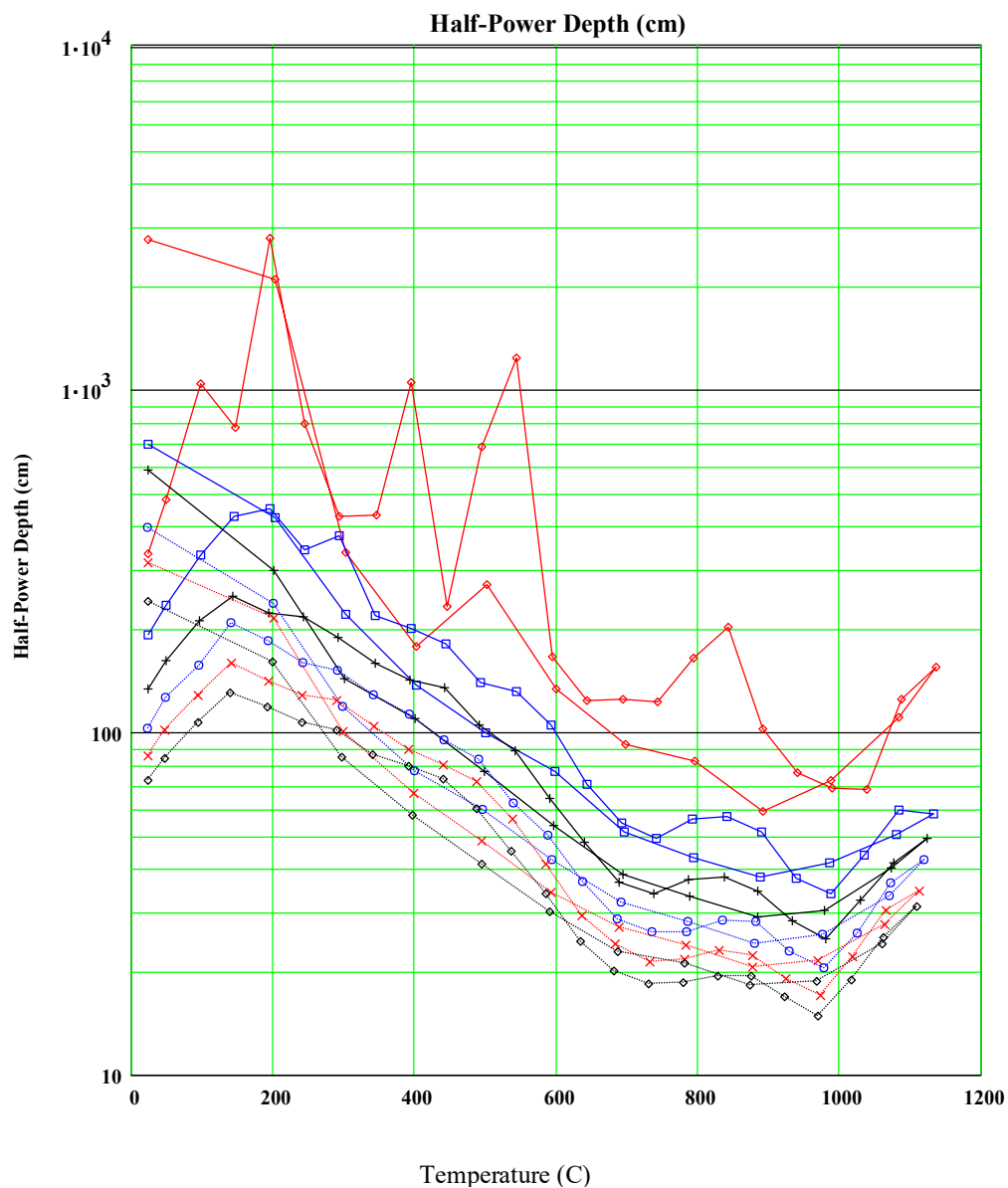
$$\mathbf{D\_halfP}_{(mm,n)} := \left( \frac{\ln(2)}{2} \right) \cdot (\text{inverse}\alpha_{mm,n} \cdot 100)$$

**Test = 2014052801**

ECERF1437\_HTnew.mcd

**AnDat = 20140529**

Pure Olivine, pellets , RT - 1150C, in 10 sccm flowing UHP Argon, for Erin Bobicki, ECERF



# Olivine ECERF\_6

Test = 2014052801

ECERF1437\_HTnew.mcd

AnDat = 20170628

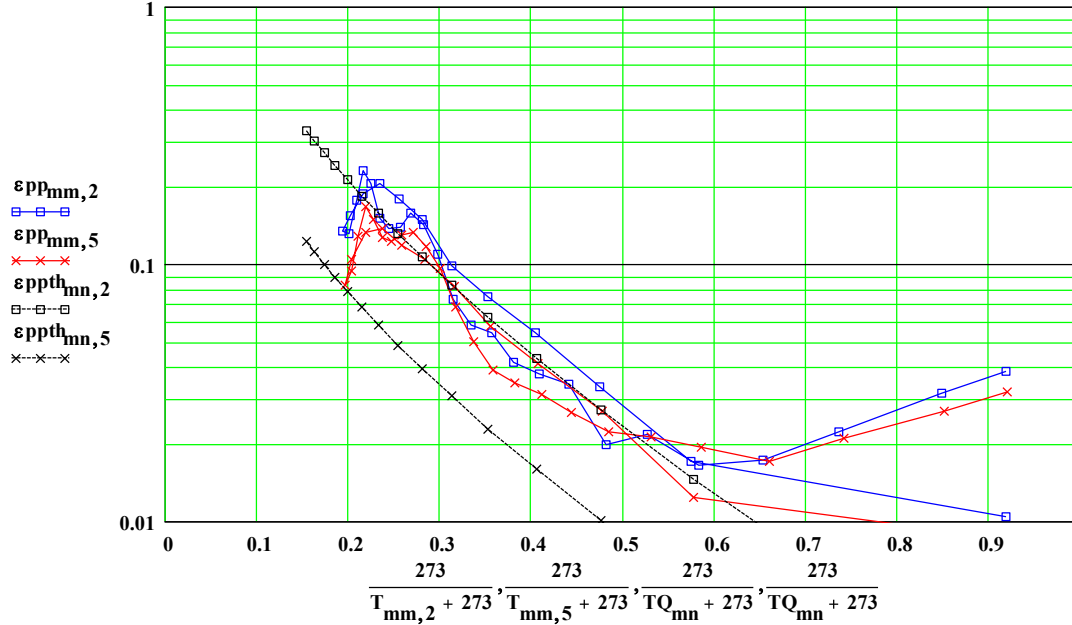
Pure Olivine, pellets , RT - 1150C, in 10 sccm flowing UHP Argon, for Erin Bobicki, ECERF

Initial density =  $\text{samdns}_7 = 2.21$  gm/cc, Final density(25C) =  $\text{dnsfinal} = 2.2$  gm/cc

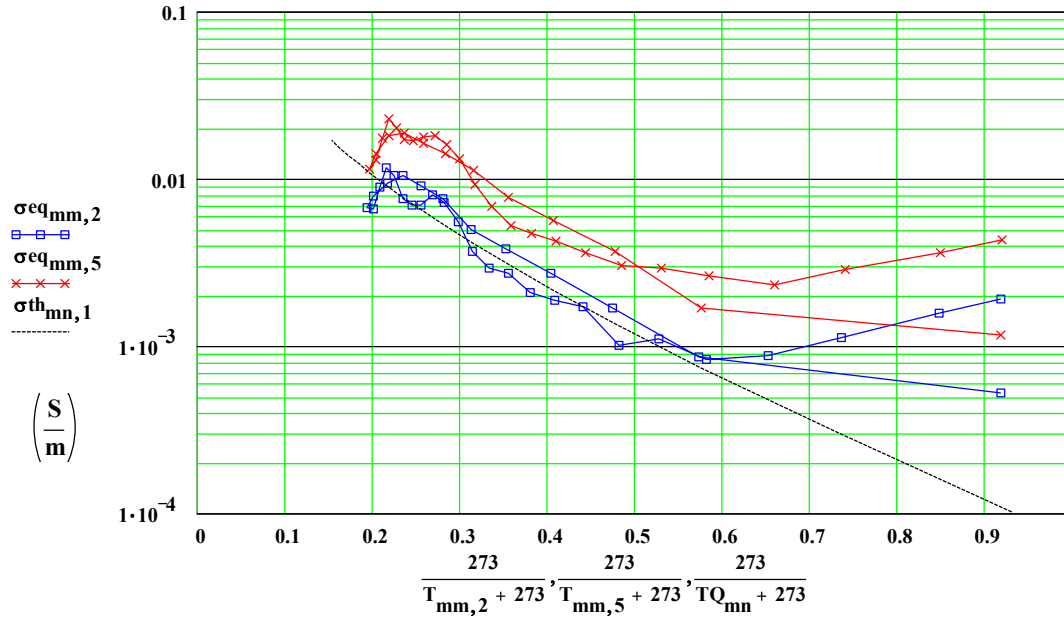
$E_g = 0.2$  eV

$\sigma_{\text{int}} = 5 \cdot 10^{-3}$

Siemens/metre



Equivalent Free Electron Conductivity ( Siemens/metre)



$$\rho_{eqmm,n} := \frac{1}{\sigma_{eqmm,n}}$$

$$\rho_{thmn,n} := \frac{1}{\sigma_{thmn,n}}$$

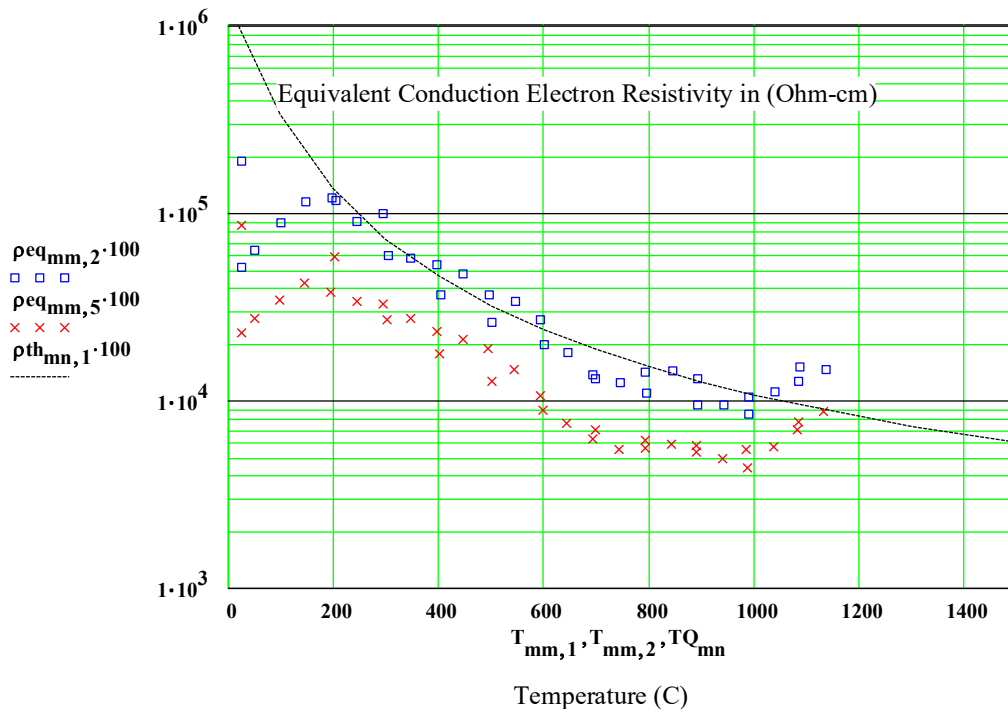
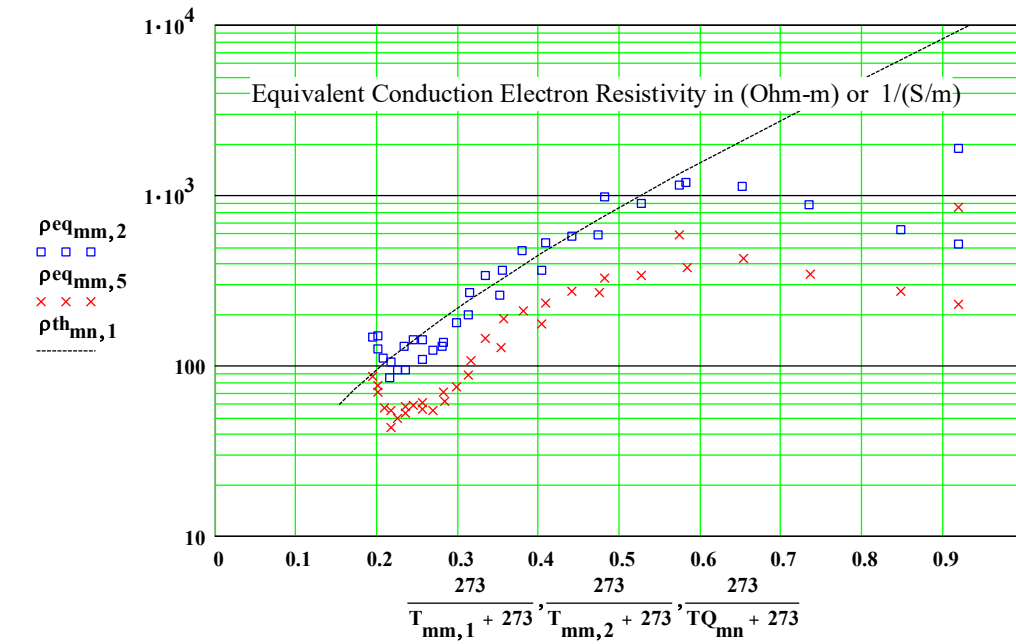
# Olivine ECERF\_6

Test = 2014052801

ECERF1437\_HTnew.mcd

AnDat = 20170628

Pure Olivine, pellets , RT - 1150C, in 10 sccm flowing UHP Argon, for Erin Bobicki, ECERF





## Olivine ECERF 6

**Test = 2014052801**

ECERF1437 HTnew.mcd

**AnDat = 20140529**

Pure Olivine, pellets , RT - 1150C, in 10 sccm flowing UHP Argon, for Erin Bobicki, ECERF

List of Measured Values of  $\epsilon'$  and  $\epsilon''$  and  $\tan\delta$  :

AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA

Initial density = **samdns<sub>NCal + 1</sub>** = **2.208** gm/cc      Final density(25C) = **dnsfinal** = **2.201** gm/cc

Lapsed

| density | index | T(C) | 397MHz | 912MHz | 1499MH | 1977MHz | 2466MHz | 2986MHz | Time<br>(hours) |
|---------|-------|------|--------|--------|--------|---------|---------|---------|-----------------|
|---------|-------|------|--------|--------|--------|---------|---------|---------|-----------------|

(hours)

| samdn <sub>s</sub> | h <sub>mm</sub> | T <sub>mm,1</sub> | ε <sub>mm,1</sub> | ε <sub>mm,2</sub> | ε <sub>mm,3</sub> | ε <sub>mm,4</sub> | ε <sub>mm,5</sub> | ε <sub>mm,6</sub> | tlaps <sub>mm</sub> | sammas <sub>mm</sub> |
|--------------------|-----------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|---------------------|----------------------|
| 2.208              | 7               | 24                | 4.12              | 4.1               | 4.09              | 4.08              | 4.08              | 4.08              | 0                   | 0.318                |
| 2.208              | 8               | 49                | 4.1               | 4.08              | 4.08              | 4.08              | 4.07              | 4.08              | 0.24                | 0.318                |
| 2.206              | 9               | 99                | 4.11              | 4.09              | 4.08              | 4.08              | 4.08              | 4.09              | 0.48                | 0.318                |
| 2.201              | 10              | 146               | 4.12              | 4.1               | 4.1               | 4.1               | 4.09              | 4.1               | 0.74                | 0.317                |
| 2.201              | 11              | 196               | 4.13              | 4.15              | 4.14              | 4.14              | 4.14              | 4.14              | 0.95                | 0.317                |
| 2.201              | 12              | 245               | 4.22              | 4.19              | 4.19              | 4.19              | 4.19              | 4.19              | 1.17                | 0.317                |
| 2.201              | 13              | 294               | 4.24              | 4.21              | 4.21              | 4.21              | 4.2               | 4.21              | 1.4                 | 0.317                |
| 2.201              | 14              | 346               | 4.25              | 4.24              | 4.23              | 4.23              | 4.23              | 4.23              | 1.58                | 0.317                |
| 2.201              | 15              | 396               | 4.27              | 4.26              | 4.26              | 4.25              | 4.24              | 4.25              | 1.75                | 0.317                |
| 2.201              | 16              | 446               | 4.31              | 4.28              | 4.28              | 4.27              | 4.27              | 4.28              | 1.92                | 0.317                |
| 2.201              | 17              | 495               | 4.33              | 4.32              | 4.31              | 4.3               | 4.3               | 4.31              | 2.09                | 0.317                |
| 2.209              | 18              | 545               | 4.41              | 4.39              | 4.38              | 4.37              | 4.36              | 4.37              | 2.26                | 0.317                |
| 2.225              | 19              | 594               | 4.57              | 4.49              | 4.47              | 4.46              | 4.45              | 4.45              | 2.43                | 0.317                |
| 2.244              | 20              | 644               | 4.65              | 4.61              | 4.59              | 4.58              | 4.56              | 4.56              | 2.6                 | 0.317                |
| 2.244              | 21              | 694               | 4.77              | 4.68              | 4.65              | 4.63              | 4.61              | 4.61              | 2.77                | 0.317                |
| 2.244              | 22              | 744               | 4.81              | 4.7               | 4.67              | 4.64              | 4.62              | 4.62              | 2.94                | 0.317                |
| 2.223              | 23              | 793               | 4.68              | 4.66              | 4.63              | 4.6               | 4.58              | 4.58              | 3.12                | 0.314                |
| 2.22               | 24              | 844               | 4.76              | 4.66              | 4.63              | 4.61              | 4.59              | 4.59              | 3.29                | 0.314                |
| 2.217              | 25              | 893               | 4.74              | 4.65              | 4.62              | 4.59              | 4.57              | 4.57              | 3.46                | 0.314                |
| 2.215              | 26              | 941               | 4.82              | 4.67              | 4.63              | 4.6               | 4.58              | 4.58              | 3.63                | 0.314                |
| 2.212              | 27              | 990               | 4.87              | 4.72              | 4.66              | 4.63              | 4.6               | 4.6               | 3.8                 | 0.314                |
| 2.209              | 28              | 1039              | 4.77              | 4.67              | 4.62              | 4.6               | 4.58              | 4.59              | 3.98                | 0.314                |
| 2.206              | 29              | 1087              | 4.73              | 4.63              | 4.6               | 4.59              | 4.57              | 4.58              | 4.15                | 0.314                |
| 2.203              | 30              | 1136              | 4.75              | 4.63              | 4.6               | 4.6               | 4.58              | 4.59              | 4.33                | 0.314                |
| 2.201              | 31              | 1084              | 4.76              | 4.64              | 4.6               | 4.59              | 4.58              | 4.58              | 4.49                | 0.314                |
| 2.201              | 32              | 988               | 4.73              | 4.66              | 4.62              | 4.6               | 4.58              | 4.59              | 4.73                | 0.314                |
| 2.201              | 33              | 891               | 4.71              | 4.63              | 4.59              | 4.57              | 4.55              | 4.55              | 4.98                | 0.314                |
| 2.201              | 34              | 795               | 4.58              | 4.55              | 4.52              | 4.51              | 4.49              | 4.49              | 5.29                | 0.314                |
| 2.201              | 35              | 698               | 4.49              | 4.47              | 4.45              | 4.43              | 4.42              | 4.42              | 5.66                | 0.314                |
| 2.201              | 36              | 600               | 4.43              | 4.37              | 4.36              | 4.35              | 4.33              | 4.34              | 6.12                | 0.314                |
| 2.201              | 37              | 502               | 4.28              | 4.28              | 4.27              | 4.25              | 4.25              | 4.25              | 6.71                | 0.314                |
| 2.201              | 38              | 403               | 4.2               | 4.19              | 4.19              | 4.18              | 4.17              | 4.18              | 7.46                | 0.314                |
| 2.201              | 39              | 303               | 4.14              | 4.12              | 4.12              | 4.11              | 4.11              | 4.11              | 8.45                | 0.314                |
| 2.201              | 40              | 203               | 3.95              | 3.94              | 3.94              | 3.94              | 3.94              | 3.94              | 9.28                | 0.314                |
| 2.201              | 41              | 24                | 3.89              | 3.9               | 3.9               | 3.91              | 3.91              | 3.91              | 9.58                | 0.314                |

## Olivine ECERF 6

**Test = 2014052801**

ECERF1437 HTnew.mcd

**AnDat = 20140529**

Pure Olivine, pellets, RT - 1150C, in 10 sccm flowing UHP Argon, for Erin Bobicki, ECERF

List of Measured Values of  $\epsilon'$  and  $\epsilon''$  and  $\tan\delta$  :

[illegible]

Initial density = **samdns<sub>NCal + 1</sub> = 2.208** gm/cc      Final density(25C) = **dnsfinal = 2.201** gm/cc

Lapsed

| density | index | T(C) | 397MHz | 912MHz | 1499MH | 1977MHz | 2466MHz | 2986MHz |
|---------|-------|------|--------|--------|--------|---------|---------|---------|
|---------|-------|------|--------|--------|--------|---------|---------|---------|

Time  
(hours)
$$\text{samd}_{\text{ns}} \quad \text{mm} \quad \text{T}_{\text{mm},1} \quad \varepsilon_{\text{pp}_{\text{mm},1}} \quad \varepsilon_{\text{pp}_{\text{mm},2}} \quad \varepsilon_{\text{pp}_{\text{mm},3}} \quad \varepsilon_{\text{pp}_{\text{mm},4}} \quad \varepsilon_{\text{pp}_{\text{mm},5}} \quad \varepsilon_{\text{pp}_{\text{mm},6}} \quad \text{tlaps}_{\text{mm}} \quad \text{samm}_{\text{as}} \quad \text{mm}$$

|       |    |      |       |       |       |       |       |       |      |       |
|-------|----|------|-------|-------|-------|-------|-------|-------|------|-------|
| 2.208 | 7  | 24   | 0.051 | 0.038 | 0.035 | 0.034 | 0.032 | 0.031 | 0    | 0.318 |
| 2.208 | 8  | 49   | 0.036 | 0.031 | 0.029 | 0.027 | 0.027 | 0.027 | 0.24 | 0.318 |
| 2.206 | 9  | 99   | 0.016 | 0.022 | 0.022 | 0.022 | 0.021 | 0.021 | 0.48 | 0.318 |
| 2.201 | 10 | 146  | 0.022 | 0.017 | 0.019 | 0.017 | 0.017 | 0.017 | 0.74 | 0.317 |
| 2.201 | 11 | 196  | 0.006 | 0.017 | 0.021 | 0.019 | 0.019 | 0.019 | 0.95 | 0.317 |
| 2.201 | 12 | 245  | 0.022 | 0.022 | 0.022 | 0.022 | 0.022 | 0.021 | 1.17 | 0.317 |
| 2.201 | 13 | 294  | 0.04  | 0.02  | 0.025 | 0.023 | 0.022 | 0.023 | 1.4  | 0.317 |
| 2.201 | 14 | 346  | 0.04  | 0.034 | 0.03  | 0.027 | 0.026 | 0.027 | 1.58 | 0.317 |
| 2.201 | 15 | 396  | 0.017 | 0.037 | 0.034 | 0.031 | 0.031 | 0.029 | 1.75 | 0.317 |
| 2.201 | 16 | 446  | 0.074 | 0.042 | 0.036 | 0.037 | 0.035 | 0.031 | 1.92 | 0.317 |
| 2.201 | 17 | 495  | 0.026 | 0.054 | 0.046 | 0.043 | 0.039 | 0.039 | 2.09 | 0.317 |
| 2.209 | 18 | 545  | 0.014 | 0.058 | 0.055 | 0.057 | 0.05  | 0.051 | 2.26 | 0.317 |
| 2.225 | 19 | 594  | 0.108 | 0.073 | 0.077 | 0.072 | 0.069 | 0.069 | 2.43 | 0.317 |
| 2.244 | 20 | 644  | 0.146 | 0.111 | 0.104 | 0.1   | 0.098 | 0.096 | 2.6  | 0.317 |
| 2.244 | 21 | 694  | 0.146 | 0.145 | 0.137 | 0.129 | 0.119 | 0.118 | 2.77 | 0.317 |
| 2.244 | 22 | 744  | 0.15  | 0.16  | 0.148 | 0.141 | 0.134 | 0.13  | 2.94 | 0.317 |
| 2.223 | 23 | 793  | 0.11  | 0.141 | 0.134 | 0.14  | 0.131 | 0.128 | 3.12 | 0.314 |
| 2.22  | 24 | 844  | 0.09  | 0.139 | 0.132 | 0.129 | 0.125 | 0.122 | 3.29 | 0.314 |
| 2.217 | 25 | 893  | 0.177 | 0.153 | 0.145 | 0.13  | 0.128 | 0.122 | 3.46 | 0.314 |
| 2.215 | 26 | 941  | 0.24  | 0.209 | 0.176 | 0.159 | 0.15  | 0.14  | 3.63 | 0.314 |
| 2.212 | 27 | 990  | 0.267 | 0.233 | 0.2   | 0.179 | 0.168 | 0.16  | 3.8  | 0.314 |
| 2.209 | 28 | 1039 | 0.267 | 0.179 | 0.154 | 0.141 | 0.13  | 0.125 | 3.98 | 0.314 |
| 2.206 | 29 | 1087 | 0.145 | 0.131 | 0.119 | 0.1   | 0.095 | 0.094 | 4.15 | 0.314 |
| 2.203 | 30 | 1136 | 0.118 | 0.135 | 0.102 | 0.086 | 0.083 | 0.077 | 4.33 | 0.314 |
| 2.201 | 31 | 1084 | 0.164 | 0.156 | 0.123 | 0.11  | 0.104 | 0.098 | 4.49 | 0.314 |
| 2.201 | 32 | 988  | 0.25  | 0.189 | 0.164 | 0.143 | 0.133 | 0.126 | 4.73 | 0.314 |
| 2.201 | 33 | 891  | 0.307 | 0.207 | 0.172 | 0.15  | 0.138 | 0.129 | 4.98 | 0.314 |
| 2.201 | 34 | 795  | 0.217 | 0.18  | 0.148 | 0.129 | 0.119 | 0.111 | 5.29 | 0.314 |
| 2.201 | 35 | 698  | 0.192 | 0.15  | 0.127 | 0.112 | 0.105 | 0.101 | 5.66 | 0.314 |
| 2.201 | 36 | 600  | 0.131 | 0.099 | 0.091 | 0.084 | 0.082 | 0.077 | 6.12 | 0.314 |
| 2.201 | 37 | 502  | 0.064 | 0.075 | 0.062 | 0.059 | 0.057 | 0.055 | 6.71 | 0.314 |
| 2.201 | 38 | 403  | 0.096 | 0.054 | 0.043 | 0.045 | 0.041 | 0.04  | 7.46 | 0.314 |
| 2.201 | 39 | 303  | 0.051 | 0.033 | 0.033 | 0.029 | 0.027 | 0.027 | 8.45 | 0.314 |
| 2.201 | 40 | 203  | 0.008 | 0.017 | 0.016 | 0.014 | 0.012 | 0.014 | 9.28 | 0.314 |
| 2.201 | 41 | 24   | 0.006 | 0.01  | 0.008 | 0.009 | 0.009 | 0.009 | 9.58 | 0.314 |

# Olivine ECERF\_6

Test = 2014052801

ECERF1437\_HTnew.mcd

AnDat = 20140529

Pure Olivine, pellets , RT - 1150C, in 10 sccm flowing UHP Argon, for Erin Bobicki, ECERF

List of Measured Values of  $\epsilon'$  and  $\epsilon''$  and  $\tan\delta$  :

~~~~~

Initial density = $\text{samdns}_{\text{NCal} + 1} = 2.208$ gm/cc Final density(25C) = $\text{dnsfinal} = 2.201$ gm/cc

density index T(C) 397MHz 912MHz 1499MH 1977MHz2466MHz 2986MHz
Lapsed
Time
(hours)

| samdns _{mm} | T _{mm,1} | tn δ _{mm,1} | tn δ _{mm,2} | tn δ _{mm,3} | tn δ _{mm,4} | tn δ _{mm,5} | tn δ _{mm,6} | tlaps _{mm} |
|----------------------|-------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|---------------------|
| 2.208 | 7 | 24 | 0.012 | 0.009 | 0.009 | 0.008 | 0.008 | 0 |
| 2.208 | 8 | 49 | 0.009 | 0.008 | 0.007 | 0.007 | 0.007 | 0.24 |
| 2.206 | 9 | 99 | 0.004 | 0.005 | 0.005 | 0.005 | 0.005 | 0.48 |
| 2.201 | 10 | 146 | 0.005 | 0.004 | 0.005 | 0.004 | 0.004 | 0.74 |
| 2.201 | 11 | 196 | 0.001 | 0.004 | 0.005 | 0.005 | 0.005 | 0.95 |
| 2.201 | 12 | 245 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 1.17 |
| 2.201 | 13 | 294 | 0.01 | 0.005 | 0.006 | 0.005 | 0.005 | 1.4 |
| 2.201 | 14 | 346 | 0.009 | 0.008 | 0.007 | 0.006 | 0.006 | 1.58 |
| 2.201 | 15 | 396 | 0.004 | 0.009 | 0.008 | 0.007 | 0.007 | 1.75 |
| 2.201 | 16 | 446 | 0.017 | 0.01 | 0.008 | 0.009 | 0.008 | 1.92 |
| 2.201 | 17 | 495 | 0.006 | 0.013 | 0.011 | 0.01 | 0.009 | 2.09 |
| 2.209 | 18 | 545 | 0.003 | 0.013 | 0.013 | 0.013 | 0.011 | 2.26 |
| 2.225 | 19 | 594 | 0.024 | 0.016 | 0.017 | 0.016 | 0.015 | 2.43 |
| 2.244 | 20 | 644 | 0.031 | 0.024 | 0.023 | 0.022 | 0.021 | 2.6 |
| 2.244 | 21 | 694 | 0.03 | 0.031 | 0.029 | 0.028 | 0.026 | 2.77 |
| 2.244 | 22 | 744 | 0.031 | 0.034 | 0.032 | 0.03 | 0.029 | 2.94 |
| 2.223 | 23 | 793 | 0.024 | 0.03 | 0.029 | 0.03 | 0.029 | 3.12 |
| 2.22 | 24 | 844 | 0.019 | 0.03 | 0.028 | 0.028 | 0.027 | 3.29 |
| 2.217 | 25 | 893 | 0.037 | 0.033 | 0.031 | 0.028 | 0.028 | 3.46 |
| 2.215 | 26 | 941 | 0.05 | 0.045 | 0.038 | 0.035 | 0.033 | 3.63 |
| 2.212 | 27 | 990 | 0.055 | 0.049 | 0.043 | 0.039 | 0.037 | 3.8 |
| 2.209 | 28 | 1039 | 0.056 | 0.038 | 0.033 | 0.031 | 0.028 | 3.98 |
| 2.206 | 29 | 1087 | 0.031 | 0.028 | 0.026 | 0.022 | 0.021 | 4.15 |
| 2.203 | 30 | 1136 | 0.025 | 0.029 | 0.022 | 0.019 | 0.018 | 4.33 |
| 2.201 | 31 | 1084 | 0.035 | 0.034 | 0.027 | 0.024 | 0.023 | 4.49 |
| 2.201 | 32 | 988 | 0.053 | 0.04 | 0.036 | 0.031 | 0.029 | 4.73 |
| 2.201 | 33 | 891 | 0.065 | 0.045 | 0.037 | 0.033 | 0.03 | 4.98 |
| 2.201 | 34 | 795 | 0.047 | 0.04 | 0.033 | 0.029 | 0.026 | 5.29 |
| 2.201 | 35 | 698 | 0.043 | 0.034 | 0.029 | 0.025 | 0.024 | 5.66 |
| 2.201 | 36 | 600 | 0.03 | 0.023 | 0.021 | 0.019 | 0.019 | 6.12 |
| 2.201 | 37 | 502 | 0.015 | 0.018 | 0.015 | 0.014 | 0.013 | 6.71 |
| 2.201 | 38 | 403 | 0.023 | 0.013 | 0.01 | 0.011 | 0.01 | 7.46 |
| 2.201 | 39 | 303 | 0.012 | 0.008 | 0.008 | 0.007 | 0.007 | 8.45 |
| 2.201 | 40 | 203 | 0.002 | 0.004 | 0.004 | 0.004 | 0.003 | 9.28 |
| 2.201 | 41 | 24 | 0.002 | 0.003 | 0.002 | 0.002 | 0.002 | 9.58 |

MPN-308_Ravash_QUEENS_Olivine**Mar. 28, 2024**

Olivine Ref., RD57, V03369C, Pressed Asymmetric Pellet Sample
Complex Dielectric Constant
Cycle from Room Temperature to 1000°C to Room Temperature,
in 10 sccm UHP Nitrogen

John Forster and Ravash Mehr decided that they would choose very specific “single mineral” specimens from the large collection of de Beers rocks, and crush these and use them as reference values when considering the response of mixed mineral samples. To avoid possible problems due to sample levitation caused by pellet swelling, Microwave Properties North used an asymmetric punch/die to make pellets with a flat down one side which would allow gas flow even if some expansion occurred. The pellets were pressed at ~ 33,000 psi. Thus a measurement of the complex dielectric properties, up to 1000C and back to room temperature, was done in 10 sccm flowing UHP nitrogen. The test sample pellets were not baked to ensure dryness.

The initial sample parameters were:

- a) effective diameter 3.633 +- 0.02 mm
- b) length 12.65 +- 0.05 mm
- c) mass 0.295 +- 0.002 gm
- o) room temperature density 2.25 ± 0.08 gm/cc.
- p) appearance - 2 stacked grey pellets (see photo of single initial pellet)

The dielectric properties measurements were performed three times at RT, and then the temperature was ramped up to 1000C in 25C steps, then the temperature was brought back down to 100C in -50C steps, then RT.

The holder was removed from the apparatus and the final sample was weighed. The final empty sample holder measurements showed no contamination.

The final sample properties, at room temperature were :

- a) effective diameter 3.633 ± 0.05 mm
- b) length 12.60 ± 0.05 mm
- c) mass 0.291 ± 0.002 gm
- n) room temperature density 2.23 ± 0.08 g/cc
- o) appearance - orange-tipped pellets (see photo)

Note: The percent mass loss was $\sim 1.5 \pm 1.0$ % .

The frequency coding is :

Legend for Data Plots :

| # | Frequency(MHz) | Symbol |
|---|----------------|--|
| 1 | 397 | red diamond, solid line – sometimes the line is omitted! |
| 2 | 912 | blue square, solid line |
| 3 | 1429 | black cross, solid line |
| 4 | 1948 | blue circle, dotted line |

Olivine QUEENS2433

| | | |
|---|------|----------------------------|
| 5 | 2466 | red cross, dotted line |
| 6 | 2986 | black diamond, dotted line |

A thermal expansion coefficient (CTE) of $0.0 * 10^{-6}/C$ was used.





One initial pellet
in flowing UHP nitrogen.

Final two pellets after run to 1000C

We think the dark surface on the initial pellet is due to abrasion of the stainless steel die – a thin surface coating of steel.

The thin orange coating on the final pellets is likely due to the small amount of oxygen impurity (< 10 ppm) in the nitrogen,

Which converts the thin steel coating to oxide (hematite).

Comments on the data analysis:

The olivine sample is very low loss, and the influence of transformations is very small. There is evidence of a small dissociation transition starting at 700C, but this might be a small impurity.

Olivine QUEENS2433

Estimated Sample Dimensions & Volume and Plots Density As a Function of Temperature

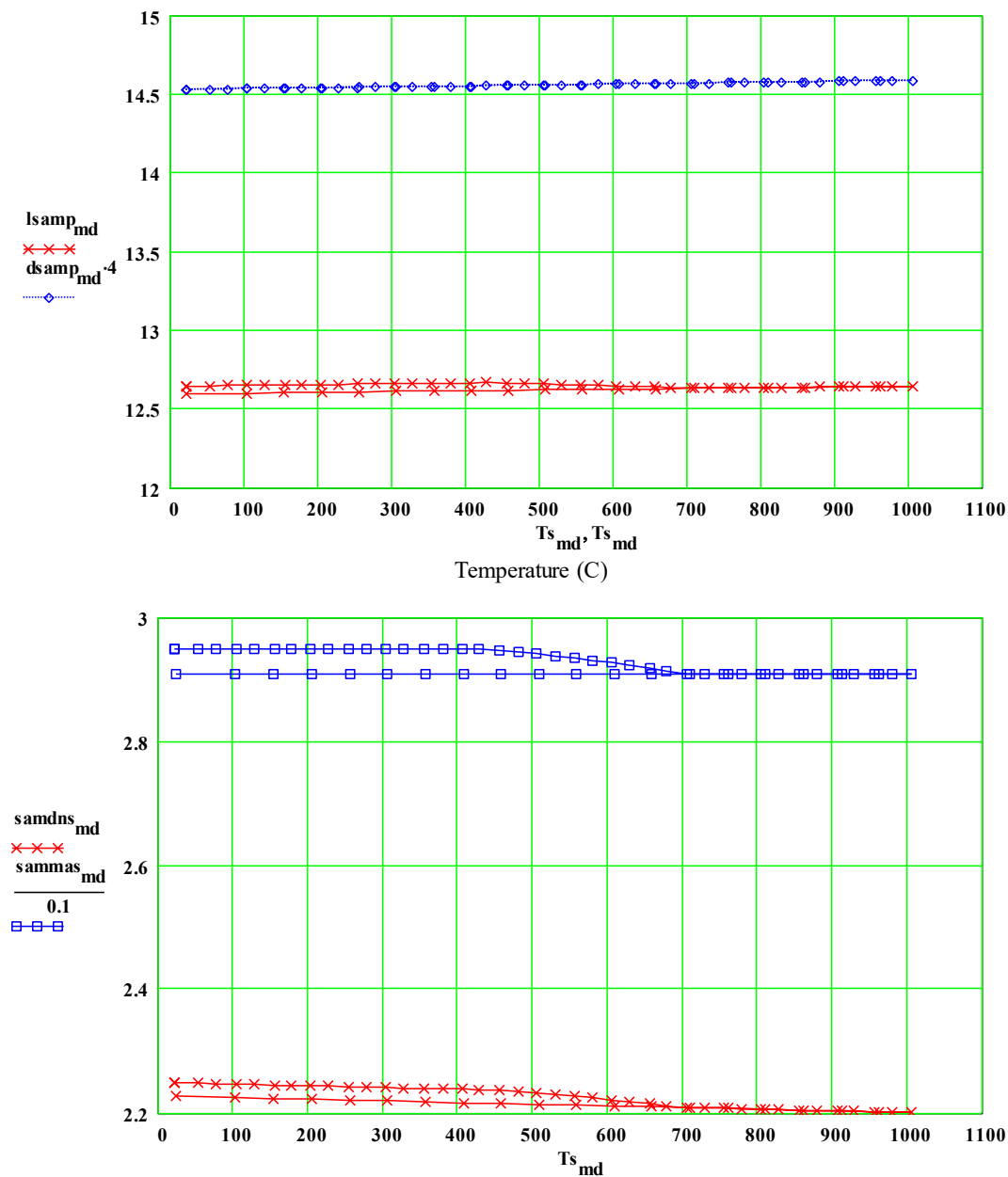
Test = 2024032601

QUEENS2433.mcd

AnDat = 20240328

Olivine Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Quee

Assumed Effective height, Diameter (mm) and Density (gm/cc) as a Function of Temperature for Powder Plug



Upper Plot : sample length and diameter : Lower Plot : sample density and mass

Olivine QUEENS2433

Test = 2024032601

QUEENS2433.mcd

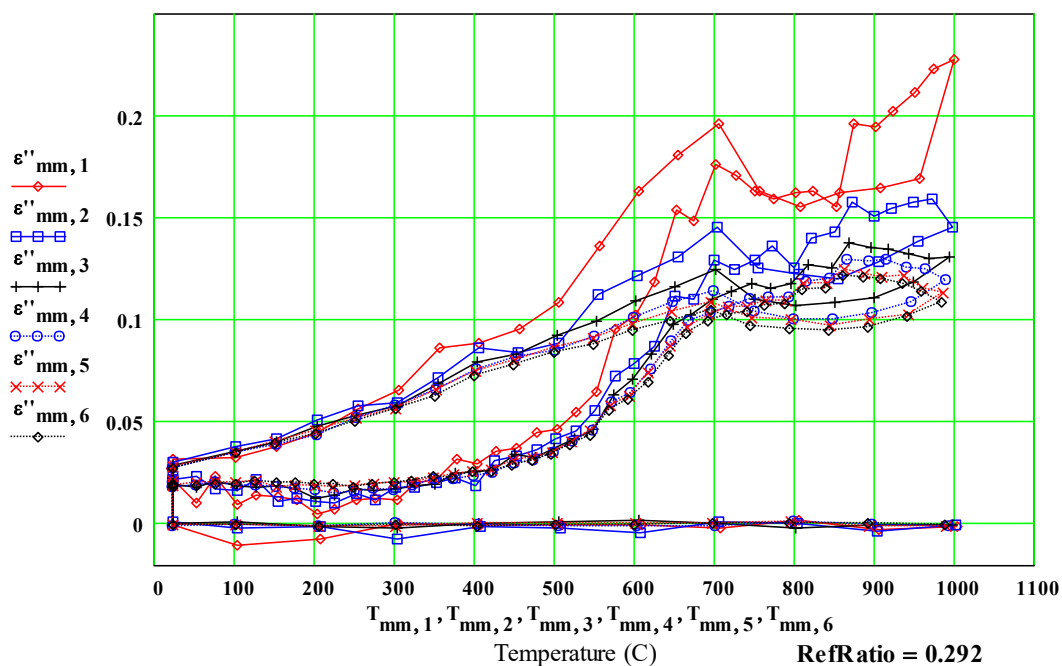
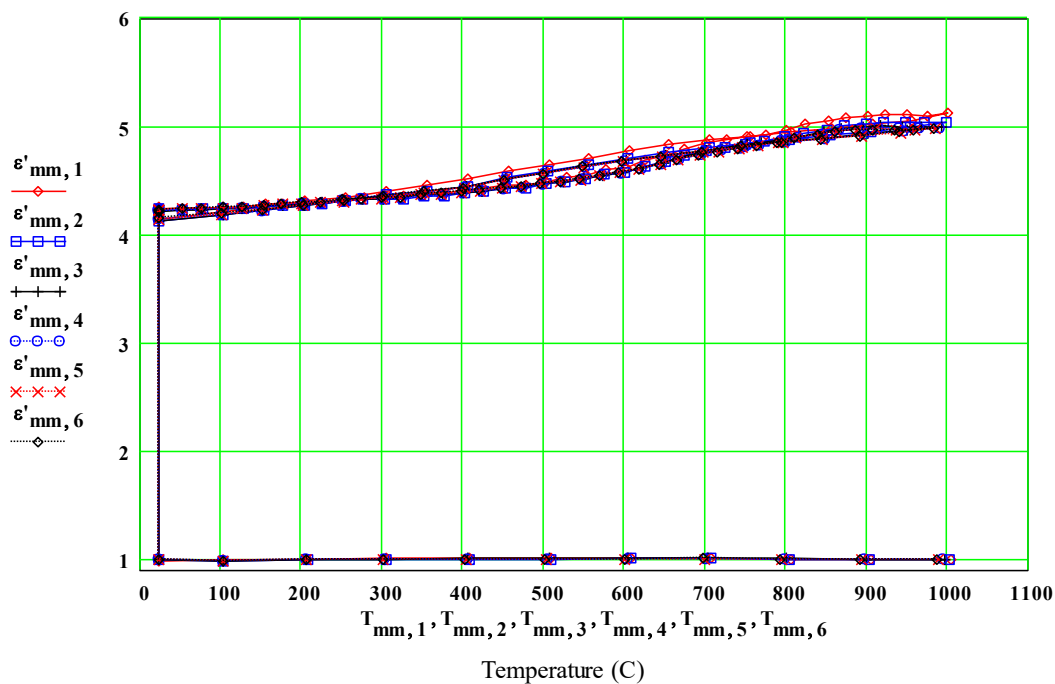
AnDat = 20240328

Olivine Ref, RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Queen

Initial density = $\text{samdns}_{\text{NCal} + 1} = 2.25 \text{ gm/cc}$,

Final density(25C) = $\text{dnsfinal} = 2.23 \text{ gm/cc}$

Final_over_Initial_mass = 0.986



Olivine QUEENS2433

Test = 2024032601

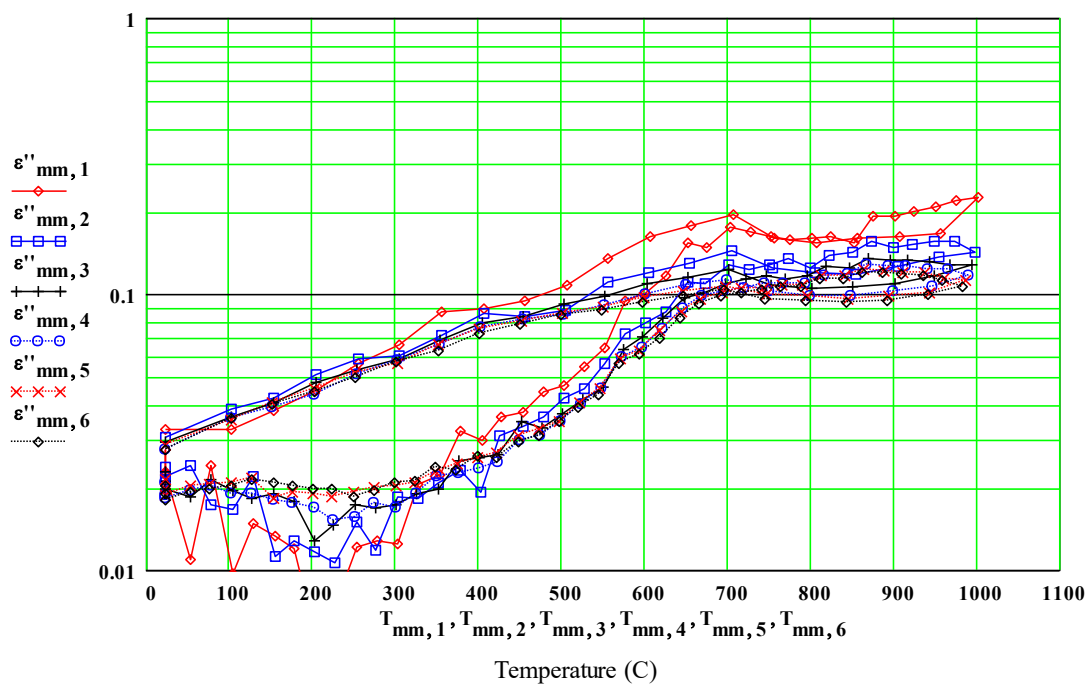
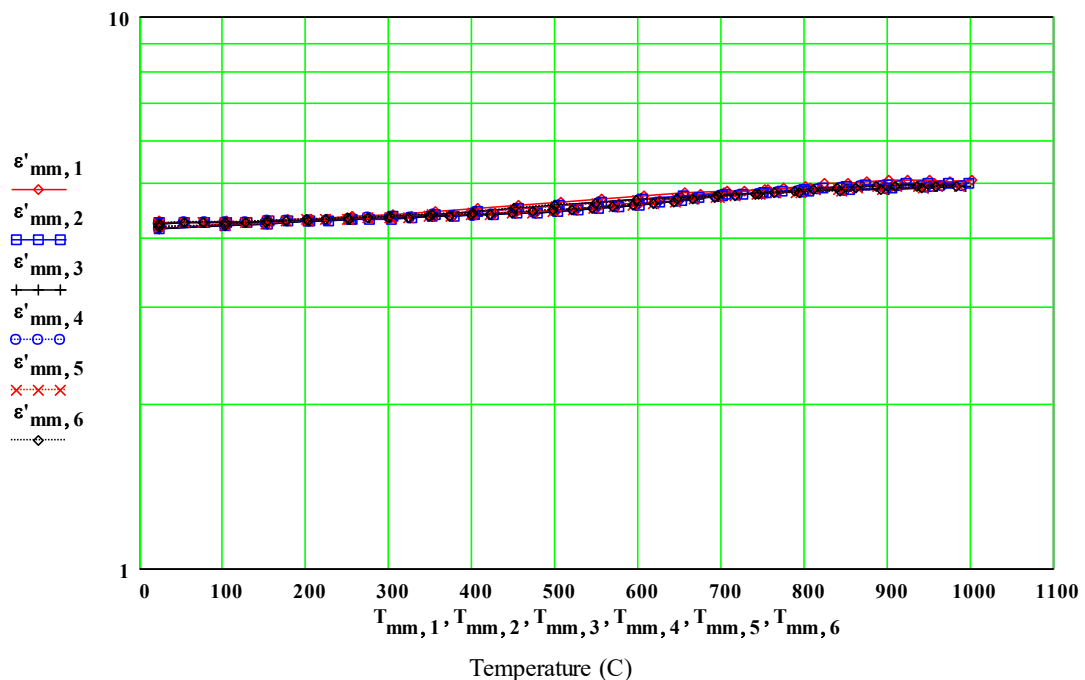
QUEENS2433.mcd

AnDat = 20240328 T

Olivine Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Queen

Initial density = $\text{samdns}_{\text{NCal} + 1} = 2.25 \text{ gm/cc}$, Final density(25C) = $\text{dnsfinal} = 2.23 \text{ gm/cc}$ I

FracMassChange = 0.99 $\alpha_1 = 4 \cdot 10^{-6} \text{ /C}$ $\alpha_2 = 0 \text{ /C}$ F



Olivine QUEENS2433

Test = 2024032601

QUEENS2433.mcd

AnDat = 20240328

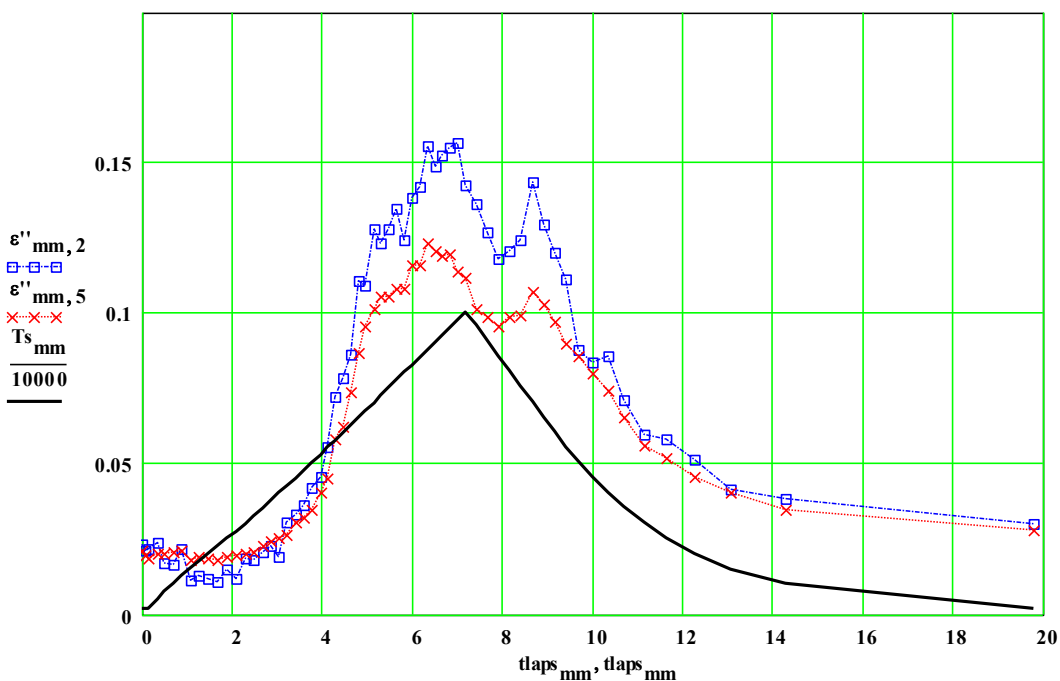
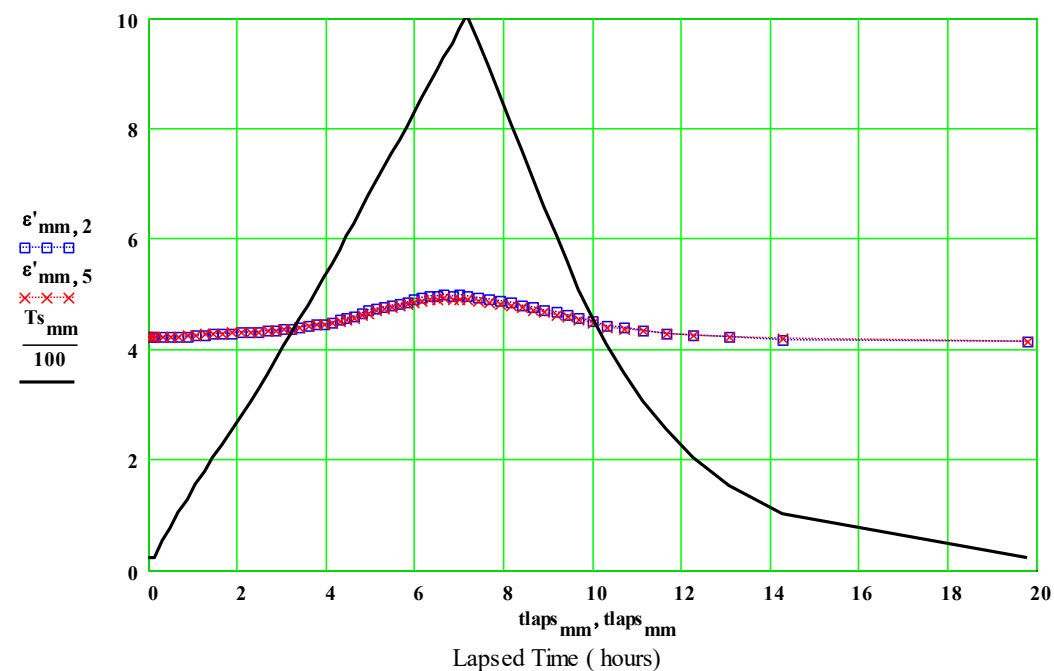
Olivine Ref, RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Quee

Initial density = $\text{samdns}_{\text{NCal} + 1} = 2.25 \text{ gm/cc}$, Solid Test Sample

Thermal exp. coeff.

Final density(25C) = $\text{dnsfinal} = 2.23 \text{ gm/cc}$ FracMassChange = 0.99

$\alpha_1 = 4 \cdot 10^{-6}$



Olivine QUEENS2433

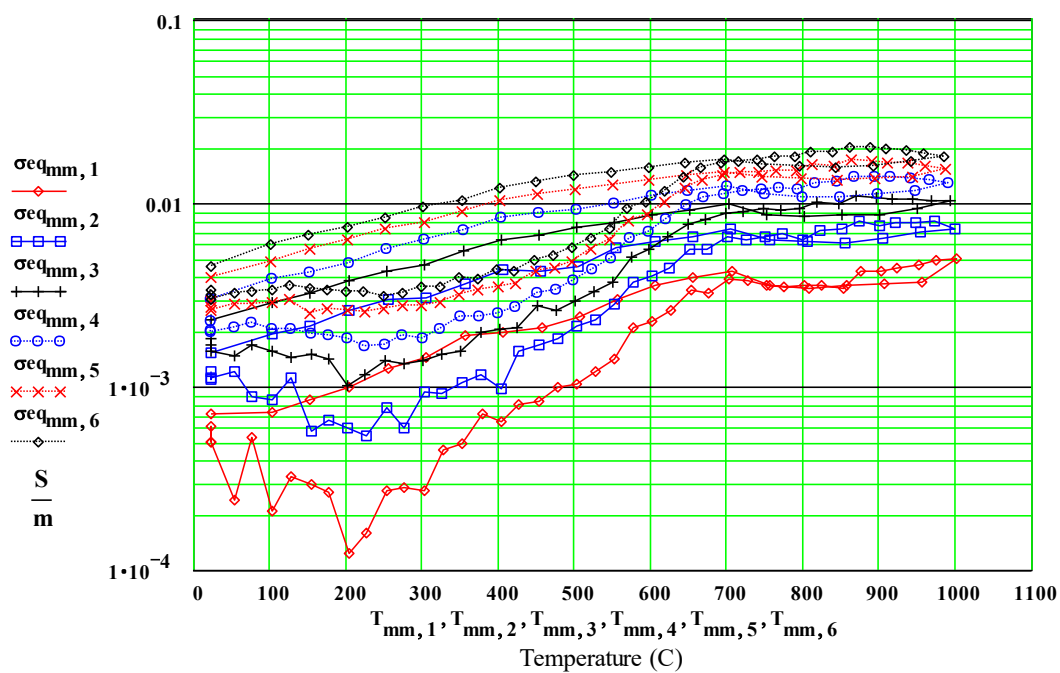
Test = 2024032601

QUEENS2433.mcd

AnDat = 20240328

Olivine Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Quee

Equivalent Free Electron AC Conductivity (Siemens/metre)



Olivine QUEENS2433

Test = 2024032601

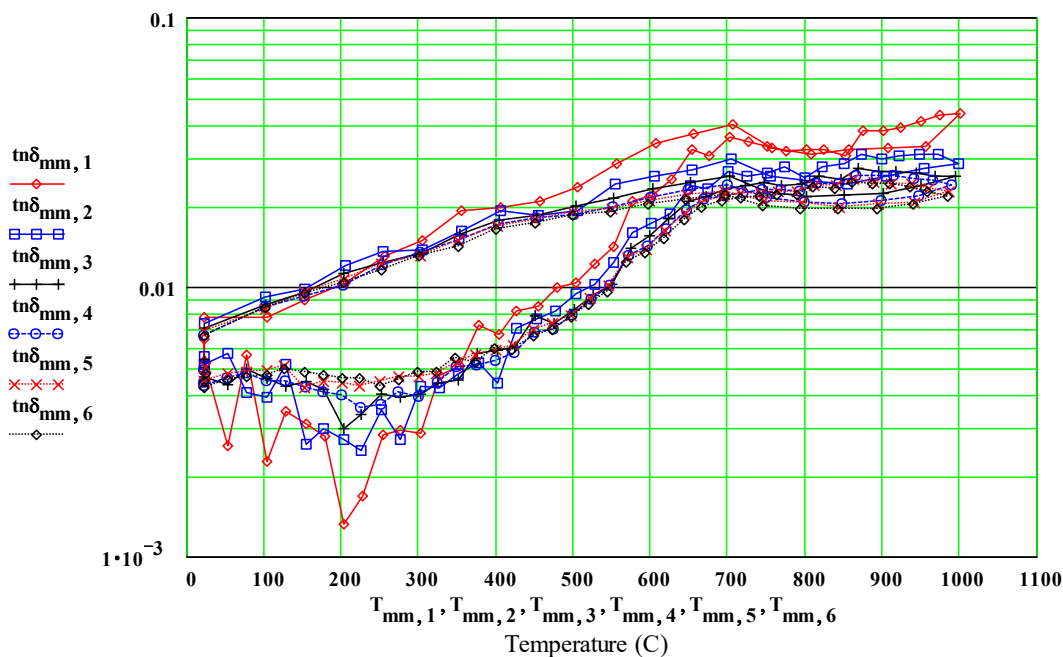
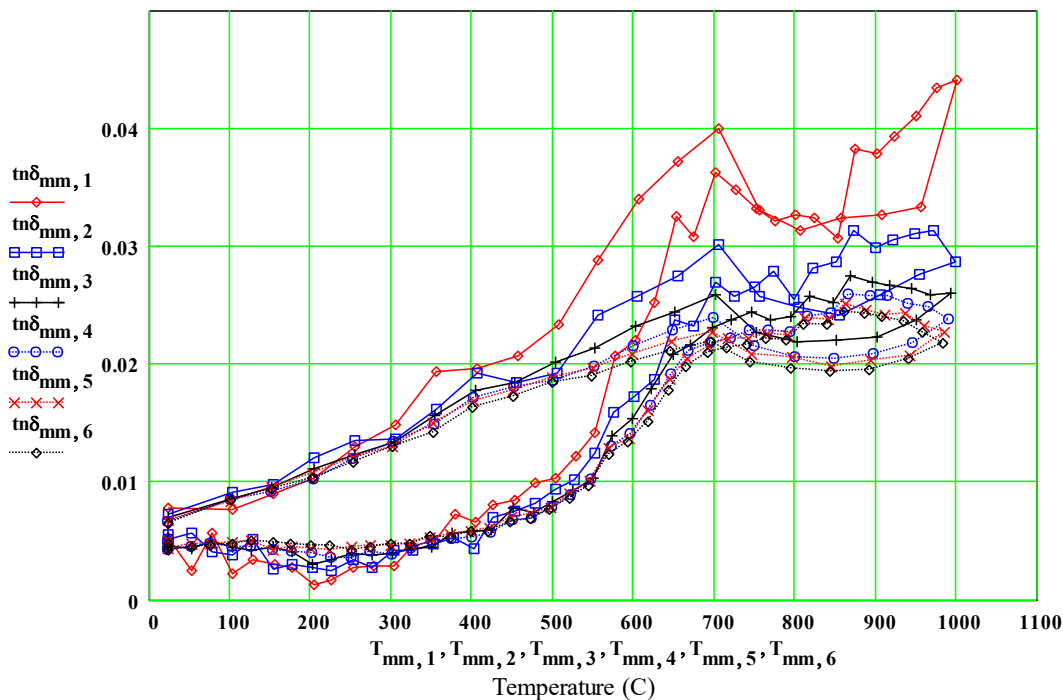
QUEENS2433.mcd

AnDat = 20240328

Olivine Ref, RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Quee

Initial density = $\text{samdns}_{\text{NCal} + 1} = 2.25 \text{ gm/cc}$,

Final density(25C) = $\text{dnsfinal} = 2.23 \text{ gm/cc}$



Olivine QUEENS2433

Test = 2024032601

QUEENS2433.mod

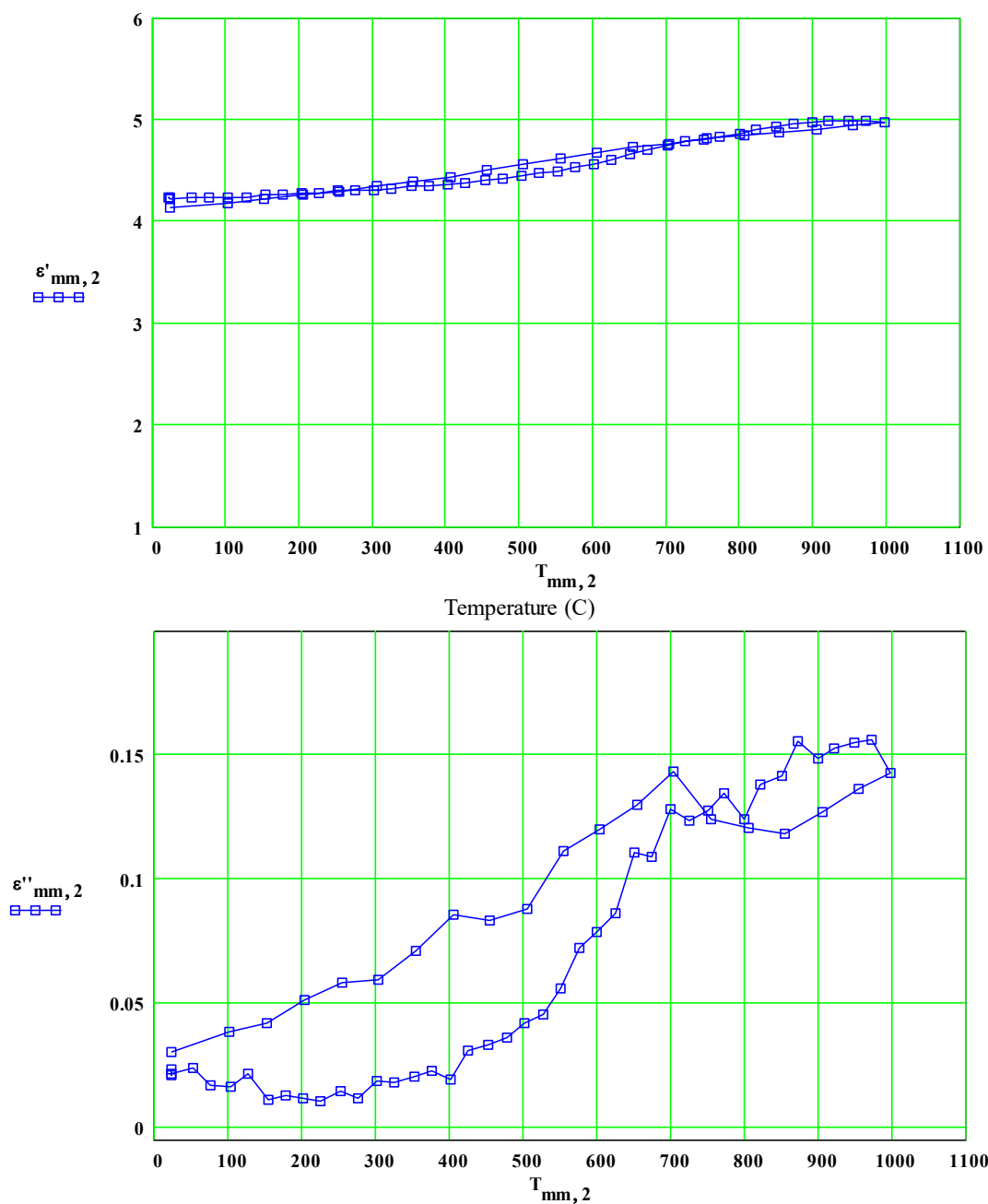
AnDat = 20240328

Olivine Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Queen

Initial density = $\text{samdns}_{\text{NCal} + 1} = 2.25 \text{ gm/cc}$, Thermal exp. coeff. $\alpha_1 = 4 \cdot 10^{-6}$

Final density(25C) = $\text{dnsfinal} = 2.23 \text{ gm/cc}$

Values for 912 MHz



Olivine QUEENS2433

Half-power Depth (millimeters)

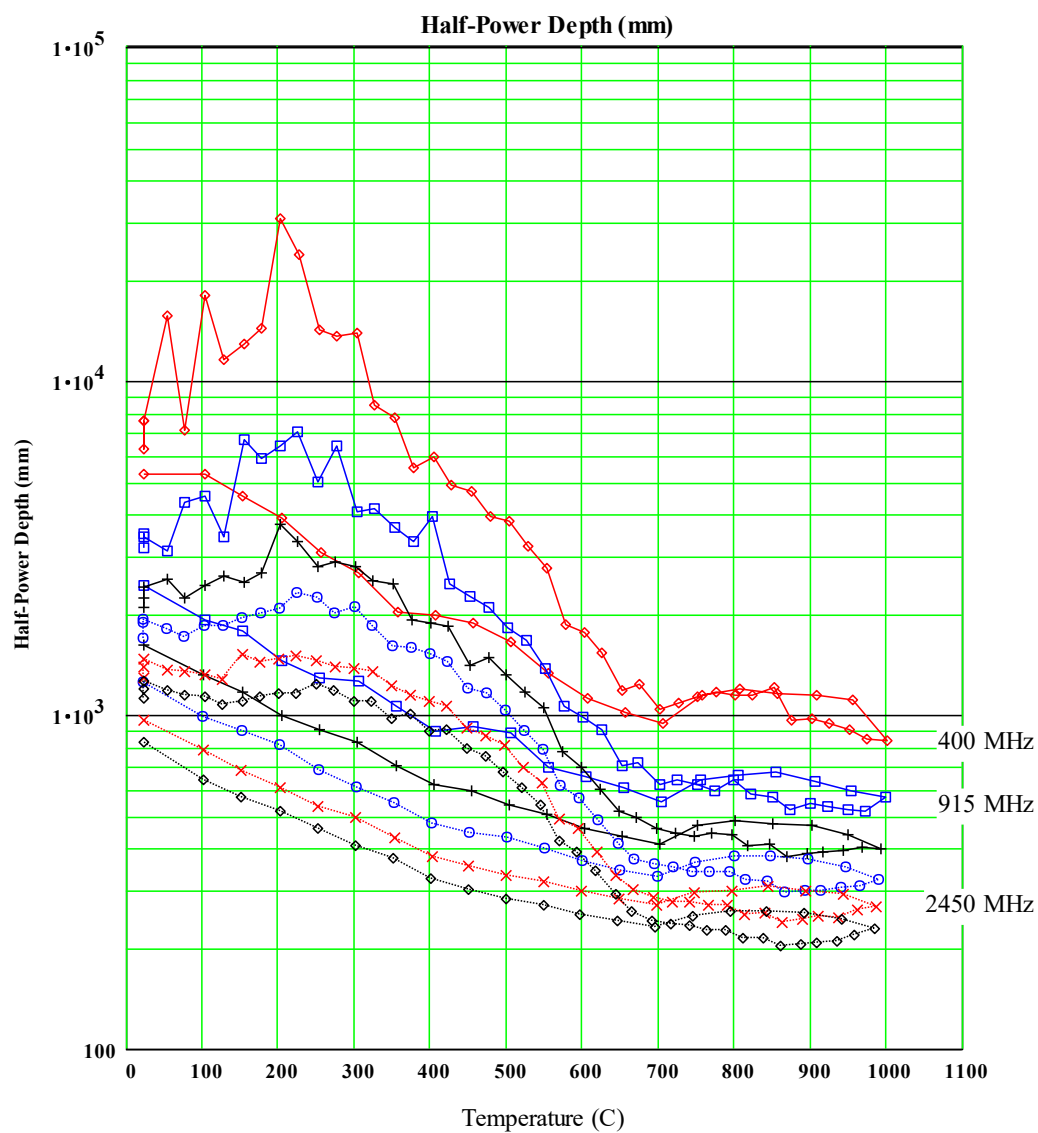
$$D_{\text{halfP}}(\text{mm}, n) := \left(\frac{\ln(2)}{2} \right) \cdot (\text{inverse}\alpha_{\text{mm}, n} \cdot 1)$$

Test = 2024032601

QUEENS2433.mcd

AnDat = 20240328

Olivine Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Quee



Olivine QUEENS2433

Test = 2024032601 QUEENS2433.mcd AnDat = 20240328
Olivine Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Quee

List of Measured Values of ϵ' and ϵ'' :
~~~~~

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.25$  gm/cc Final density(25C) =  $\text{dnsfinal} = 2.228$  gm/cc  
Lapsed  
Time

| density              | index | T(C)              | 397MHz                      | 912MHz                      | 1429MH                      | 1948MHz                     | 2466MHz                     | 2986MHz                     | Time<br>(hours)     |                      |
|----------------------|-------|-------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|---------------------|----------------------|
| samdns <sub>mm</sub> | mm    | T <sub>mm,1</sub> | $\epsilon'$ <sub>mm,1</sub> | $\epsilon'$ <sub>mm,2</sub> | $\epsilon'$ <sub>mm,3</sub> | $\epsilon'$ <sub>mm,4</sub> | $\epsilon'$ <sub>mm,5</sub> | $\epsilon'$ <sub>mm,6</sub> | tlaps <sub>mm</sub> | sammas <sub>mm</sub> |
| 2.25                 | 11    | 23                | 4.26                        | 4.24                        | 4.23                        | 4.23                        | 4.23                        | 4.22                        | 0                   | 0.295                |
| 2.25                 | 12    | 23                | 4.24                        | 4.23                        | 4.23                        | 4.23                        | 4.23                        | 4.23                        | 0.07                | 0.295                |
| 2.25                 | 13    | 23                | 4.25                        | 4.23                        | 4.23                        | 4.22                        | 4.23                        | 4.23                        | 0.13                | 0.295                |
| 2.249                | 14    | 53                | 4.25                        | 4.24                        | 4.24                        | 4.24                        | 4.24                        | 4.24                        | 0.33                | 0.295                |
| 2.248                | 15    | 77                | 4.24                        | 4.24                        | 4.24                        | 4.23                        | 4.24                        | 4.24                        | 0.5                 | 0.295                |
| 2.247                | 16    | 104               | 4.26                        | 4.24                        | 4.24                        | 4.24                        | 4.25                        | 4.25                        | 0.69                | 0.295                |
| 2.247                | 17    | 128               | 4.25                        | 4.24                        | 4.25                        | 4.24                        | 4.25                        | 4.25                        | 0.87                | 0.295                |
| 2.246                | 18    | 155               | 4.28                        | 4.26                        | 4.26                        | 4.26                        | 4.27                        | 4.27                        | 1.07                | 0.295                |
| 2.245                | 19    | 178               | 4.29                        | 4.27                        | 4.27                        | 4.27                        | 4.28                        | 4.29                        | 1.25                | 0.295                |
| 2.245                | 20    | 203               | 4.3                         | 4.28                        | 4.28                        | 4.28                        | 4.29                        | 4.29                        | 1.46                | 0.295                |
| 2.244                | 21    | 226               | 4.3                         | 4.29                        | 4.29                        | 4.29                        | 4.29                        | 4.3                         | 1.66                | 0.295                |
| 2.243                | 22    | 253               | 4.33                        | 4.3                         | 4.31                        | 4.3                         | 4.31                        | 4.32                        | 1.88                | 0.295                |
| 2.243                | 23    | 277               | 4.33                        | 4.31                        | 4.32                        | 4.31                        | 4.32                        | 4.33                        | 2.08                | 0.295                |
| 2.242                | 24    | 303               | 4.33                        | 4.31                        | 4.32                        | 4.32                        | 4.32                        | 4.33                        | 2.29                | 0.295                |
| 2.241                | 25    | 327               | 4.35                        | 4.33                        | 4.33                        | 4.32                        | 4.33                        | 4.34                        | 2.49                | 0.295                |
| 2.241                | 26    | 353               | 4.37                        | 4.35                        | 4.36                        | 4.35                        | 4.35                        | 4.36                        | 2.67                | 0.295                |
| 2.24                 | 27    | 378               | 4.38                        | 4.35                        | 4.36                        | 4.35                        | 4.36                        | 4.37                        | 2.86                | 0.295                |
| 2.239                | 28    | 404               | 4.39                        | 4.37                        | 4.38                        | 4.37                        | 4.38                        | 4.39                        | 3.04                | 0.295                |
| 2.239                | 29    | 427               | 4.41                        | 4.38                        | 4.38                        | 4.38                        | 4.39                        | 4.39                        | 3.22                | 0.295                |
| 2.237                | 30    | 454               | 4.44                        | 4.41                        | 4.42                        | 4.41                        | 4.41                        | 4.42                        | 3.41                | 0.295                |
| 2.236                | 31    | 479               | 4.45                        | 4.42                        | 4.43                        | 4.42                        | 4.43                        | 4.44                        | 3.59                | 0.295                |
| 2.233                | 32    | 503               | 4.48                        | 4.45                        | 4.46                        | 4.45                        | 4.45                        | 4.46                        | 3.78                | 0.294                |
| 2.231                | 33    | 528               | 4.51                        | 4.47                        | 4.48                        | 4.47                        | 4.47                        | 4.48                        | 3.96                | 0.294                |
| 2.228                | 34    | 553               | 4.53                        | 4.49                        | 4.5                         | 4.49                        | 4.49                        | 4.5                         | 4.13                | 0.294                |
| 2.225                | 35    | 577               | 4.59                        | 4.54                        | 4.53                        | 4.52                        | 4.52                        | 4.53                        | 4.29                | 0.293                |
| 2.222                | 36    | 602               | 4.6                         | 4.56                        | 4.56                        | 4.55                        | 4.55                        | 4.56                        | 4.46                | 0.293                |
| 2.219                | 37    | 626               | 4.67                        | 4.61                        | 4.6                         | 4.59                        | 4.58                        | 4.59                        | 4.63                | 0.292                |
| 2.216                | 38    | 653               | 4.71                        | 4.66                        | 4.65                        | 4.63                        | 4.63                        | 4.63                        | 4.8                 | 0.292                |
| 2.213                | 39    | 675               | 4.77                        | 4.71                        | 4.69                        | 4.68                        | 4.67                        | 4.68                        | 4.96                | 0.291                |
| 2.209                | 40    | 702               | 4.82                        | 4.75                        | 4.74                        | 4.72                        | 4.71                        | 4.72                        | 5.14                | 0.291                |
| 2.209                | 41    | 727               | 4.85                        | 4.79                        | 4.77                        | 4.75                        | 4.74                        | 4.75                        | 5.31                | 0.291                |
| 2.209                | 42    | 752               | 4.87                        | 4.81                        | 4.79                        | 4.77                        | 4.77                        | 4.77                        | 5.48                | 0.291                |
| 2.208                | 43    | 775               | 4.9                         | 4.84                        | 4.82                        | 4.8                         | 4.79                        | 4.8                         | 5.64                | 0.291                |
| 2.207                | 44    | 801               | 4.93                        | 4.87                        | 4.85                        | 4.83                        | 4.82                        | 4.82                        | 5.82                | 0.291                |
| 2.207                | 45    | 823               | 4.98                        | 4.91                        | 4.88                        | 4.86                        | 4.86                        | 4.86                        | 5.98                | 0.291                |
| 2.206                | 46    | 852               | 5.01                        | 4.93                        | 4.91                        | 4.89                        | 4.88                        | 4.89                        | 6.16                | 0.291                |
| 2.205                | 47    | 875               | 5.05                        | 4.96                        | 4.94                        | 4.92                        | 4.91                        | 4.91                        | 6.33                | 0.291                |
| 2.205                | 48    | 902               | 5.05                        | 4.98                        | 4.95                        | 4.93                        | 4.92                        | 4.92                        | 6.5                 | 0.291                |
| 2.204                | 49    | 924               | 5.06                        | 4.99                        | 4.96                        | 4.94                        | 4.93                        | 4.93                        | 6.66                | 0.291                |
| 2.203                | 50    | 951               | 5.06                        | 4.98                        | 4.95                        | 4.94                        | 4.92                        | 4.93                        | 6.84                | 0.291                |
| 2.203                | 51    | 975               | 5.05                        | 4.99                        | 4.95                        | 4.94                        | 4.92                        | 4.92                        | 7                   | 0.291                |
| 2.202                | 52    | 1001              | 5.06                        | 4.98                        | 4.95                        | 4.93                        | 4.92                        | 4.93                        | 7.18                | 0.291                |
| 2.203                | 53    | 957               | 5                           | 4.94                        | 4.92                        | 4.9                         | 4.89                        | 4.9                         | 7.41                | 0.291                |
| 2.204                | 54    | 907               | 4.97                        | 4.91                        | 4.89                        | 4.87                        | 4.86                        | 4.87                        | 7.65                | 0.291                |
| 2.206                | 55    | 856               | 4.93                        | 4.88                        | 4.86                        | 4.84                        | 4.83                        | 4.84                        | 7.91                | 0.291                |
| 2.207                | 56    | 807               | 4.9                         | 4.84                        | 4.83                        | 4.81                        | 4.81                        | 4.81                        | 8.16                | 0.291                |
| 2.208                | 57    | 757               | 4.88                        | 4.81                        | 4.79                        | 4.78                        | 4.77                        | 4.78                        | 8.41                | 0.291                |
| 2.21                 | 58    | 706               | 4.85                        | 4.77                        | 4.75                        | 4.73                        | 4.73                        | 4.73                        | 8.67                | 0.291                |
| 2.211                | 59    | 655               | 4.8                         | 4.73                        | 4.71                        | 4.69                        | 4.69                        | 4.69                        | 8.92                | 0.291                |
| 2.212                | 60    | 606               | 4.75                        | 4.68                        | 4.67                        | 4.65                        | 4.64                        | 4.65                        | 9.17                | 0.291                |

mq := 61,62..nd - Nempties

| samdns <sub>mq</sub> |    | T <sub>mq,1</sub> | $\epsilon'_{\text{mq},1}$ | $\epsilon'_{\text{mq},2}$ | $\epsilon'_{\text{mq},3}$ | $\epsilon'_{\text{mq},4}$ | $\epsilon'_{\text{mq},5}$ | $\epsilon'_{\text{mq},6}$ | tlaps <sub>mq</sub> | sammas <sub>mq</sub> |
|----------------------|----|-------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------|----------------------|
| 2.214                | 61 | 556               | 4.68                      | 4.62                      | 4.61                      | 4.6                       | 4.6                       | 4.6                       | 9.42                | 0.291                |
| 2.215                | 62 | 506               | 4.62                      | 4.57                      | 4.56                      | 4.54                      | 4.54                      | 4.55                      | 9.7                 | 0.291                |
| 2.216                | 63 | 456               | 4.57                      | 4.51                      | 4.5                       | 4.49                      | 4.48                      | 4.49                      | 10                  | 0.291                |
| 2.218                | 64 | 406               | 4.5                       | 4.44                      | 4.43                      | 4.41                      | 4.42                      | 4.42                      | 10.33               | 0.291                |
| 2.219                | 65 | 356               | 4.45                      | 4.4                       | 4.39                      | 4.38                      | 4.38                      | 4.39                      | 10.71               | 0.291                |
| 2.22                 | 66 | 305               | 4.4                       | 4.36                      | 4.35                      | 4.34                      | 4.34                      | 4.35                      | 11.14               | 0.291                |
| 2.222                | 67 | 255               | 4.34                      | 4.3                       | 4.3                       | 4.29                      | 4.3                       | 4.3                       | 11.65               | 0.291                |
| 2.223                | 68 | 205               | 4.31                      | 4.27                      | 4.27                      | 4.26                      | 4.27                      | 4.27                      | 12.26               | 0.291                |
| 2.224                | 69 | 153               | 4.26                      | 4.23                      | 4.22                      | 4.23                      | 4.23                      | 4.23                      | 13.06               | 0.291                |
| 2.226                | 70 | 103               | 4.22                      | 4.19                      | 4.19                      | 4.19                      | 4.19                      | 4.2                       | 14.27               | 0.291                |
| 2.228                | 71 | 23                | 4.15                      | 4.14                      | 4.13                      | 4.14                      | 4.15                      | 4.16                      | 19.8                | 0.291                |

# Olivine QUEENS2433

Test = 2024032601

QUEENS2433.mcd

AnDat = 20240328

Olivine Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Quee

List of Measured Values of  $\epsilon'$  and  $\epsilon''$  :

Initial density =  $\text{samdns}_{\text{NCal}+1} = 2.25$  gm/cc Final density(25C) =  $\text{dnsfinal} = 2.228$  gm/cc

density index T(C) 397MHz 912MHz 1429MH 1948MHz2466MHz 2986MHz Time (hours)

| sands | mm |      | T  | $\epsilon''_{\text{mm},1}$ | $\epsilon''_{\text{mm},2}$ | $\epsilon''_{\text{mm},3}$ | $\epsilon''_{\text{mm},4}$ | $\epsilon''_{\text{mm},5}$ | $\epsilon''_{\text{mm},6}$ | tlaps | samm  |
|-------|----|------|----|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|-------|-------|
|       |    |      | mm |                            |                            |                            |                            |                            |                            | mm    | mm    |
| 2.25  | 11 | 23   |    | 0.023                      | 0.024                      | 0.023                      | 0.021                      | 0.021                      | 0.02                       | 0     | 0.295 |
| 2.25  | 12 | 23   |    | 0.027                      | 0.021                      | 0.021                      | 0.019                      | 0.02                       | 0.019                      | 0.07  | 0.295 |
| 2.25  | 13 | 23   |    | 0.023                      | 0.022                      | 0.02                       | 0.018                      | 0.019                      | 0.018                      | 0.13  | 0.295 |
| 2.249 | 14 | 53   |    | 0.011                      | 0.024                      | 0.019                      | 0.019                      | 0.02                       | 0.019                      | 0.33  | 0.295 |
| 2.248 | 15 | 77   |    | 0.024                      | 0.017                      | 0.021                      | 0.02                       | 0.021                      | 0.02                       | 0.5   | 0.295 |
| 2.247 | 16 | 104  |    | 0.01                       | 0.017                      | 0.019                      | 0.019                      | 0.021                      | 0.02                       | 0.69  | 0.295 |
| 2.247 | 17 | 128  |    | 0.015                      | 0.022                      | 0.018                      | 0.019                      | 0.022                      | 0.021                      | 0.87  | 0.295 |
| 2.246 | 18 | 155  |    | 0.013                      | 0.011                      | 0.019                      | 0.018                      | 0.018                      | 0.021                      | 1.07  | 0.295 |
| 2.245 | 19 | 178  |    | 0.012                      | 0.013                      | 0.018                      | 0.017                      | 0.019                      | 0.02                       | 1.25  | 0.295 |
| 2.245 | 20 | 203  |    | 0.006                      | 0.012                      | 0.013                      | 0.017                      | 0.019                      | 0.02                       | 1.46  | 0.295 |
| 2.244 | 21 | 226  |    | 0.007                      | 0.011                      | 0.015                      | 0.015                      | 0.018                      | 0.02                       | 1.66  | 0.295 |
| 2.243 | 22 | 253  |    | 0.012                      | 0.015                      | 0.017                      | 0.016                      | 0.019                      | 0.019                      | 1.88  | 0.295 |
| 2.243 | 23 | 277  |    | 0.013                      | 0.012                      | 0.017                      | 0.018                      | 0.02                       | 0.02                       | 2.08  | 0.295 |
| 2.242 | 24 | 303  |    | 0.012                      | 0.019                      | 0.017                      | 0.017                      | 0.02                       | 0.021                      | 2.29  | 0.295 |
| 2.241 | 25 | 327  |    | 0.02                       | 0.018                      | 0.019                      | 0.019                      | 0.021                      | 0.021                      | 2.49  | 0.295 |
| 2.241 | 26 | 353  |    | 0.022                      | 0.021                      | 0.02                       | 0.022                      | 0.023                      | 0.024                      | 2.67  | 0.295 |
| 2.24  | 27 | 378  |    | 0.032                      | 0.023                      | 0.025                      | 0.022                      | 0.024                      | 0.023                      | 2.86  | 0.295 |
| 2.239 | 28 | 404  |    | 0.029                      | 0.019                      | 0.026                      | 0.023                      | 0.026                      | 0.026                      | 3.04  | 0.295 |
| 2.239 | 29 | 427  |    | 0.036                      | 0.031                      | 0.026                      | 0.025                      | 0.027                      | 0.026                      | 3.22  | 0.295 |
| 2.237 | 30 | 454  |    | 0.038                      | 0.034                      | 0.035                      | 0.03                       | 0.031                      | 0.029                      | 3.41  | 0.295 |
| 2.236 | 31 | 479  |    | 0.045                      | 0.036                      | 0.033                      | 0.031                      | 0.032                      | 0.031                      | 3.59  | 0.295 |
| 2.233 | 32 | 503  |    | 0.047                      | 0.042                      | 0.037                      | 0.035                      | 0.035                      | 0.035                      | 3.78  | 0.294 |
| 2.231 | 33 | 528  |    | 0.055                      | 0.046                      | 0.042                      | 0.04                       | 0.04                       | 0.039                      | 3.96  | 0.294 |
| 2.228 | 34 | 553  |    | 0.064                      | 0.056                      | 0.046                      | 0.046                      | 0.046                      | 0.043                      | 4.13  | 0.294 |
| 2.225 | 35 | 577  |    | 0.095                      | 0.073                      | 0.063                      | 0.059                      | 0.058                      | 0.056                      | 4.29  | 0.293 |
| 2.222 | 36 | 602  |    | 0.102                      | 0.079                      | 0.071                      | 0.064                      | 0.063                      | 0.061                      | 4.46  | 0.293 |
| 2.219 | 37 | 626  |    | 0.118                      | 0.087                      | 0.083                      | 0.075                      | 0.074                      | 0.069                      | 4.63  | 0.292 |
| 2.216 | 38 | 653  |    | 0.153                      | 0.111                      | 0.097                      | 0.089                      | 0.087                      | 0.082                      | 4.8   | 0.292 |
| 2.213 | 39 | 675  |    | 0.147                      | 0.109                      | 0.102                      | 0.099                      | 0.096                      | 0.093                      | 4.96  | 0.291 |
| 2.209 | 40 | 702  |    | 0.175                      | 0.128                      | 0.109                      | 0.103                      | 0.102                      | 0.099                      | 5.14  | 0.291 |
| 2.209 | 41 | 727  |    | 0.169                      | 0.124                      | 0.113                      | 0.106                      | 0.106                      | 0.102                      | 5.31  | 0.291 |
| 2.209 | 42 | 752  |    | 0.162                      | 0.128                      | 0.117                      | 0.109                      | 0.106                      | 0.103                      | 5.48  | 0.291 |
| 2.208 | 43 | 775  |    | 0.158                      | 0.135                      | 0.115                      | 0.11                       | 0.108                      | 0.106                      | 5.64  | 0.291 |
| 2.207 | 44 | 801  |    | 0.161                      | 0.125                      | 0.117                      | 0.11                       | 0.109                      | 0.107                      | 5.82  | 0.291 |
| 2.207 | 45 | 823  |    | 0.161                      | 0.138                      | 0.126                      | 0.117                      | 0.116                      | 0.114                      | 5.98  | 0.291 |
| 2.206 | 46 | 852  |    | 0.154                      | 0.142                      | 0.124                      | 0.119                      | 0.116                      | 0.114                      | 6.16  | 0.291 |
| 2.205 | 47 | 875  |    | 0.193                      | 0.156                      | 0.136                      | 0.128                      | 0.123                      | 0.12                       | 6.33  | 0.291 |
| 2.205 | 48 | 902  |    | 0.192                      | 0.149                      | 0.134                      | 0.127                      | 0.121                      | 0.12                       | 6.5   | 0.291 |
| 2.204 | 49 | 924  |    | 0.199                      | 0.153                      | 0.133                      | 0.127                      | 0.119                      | 0.119                      | 6.66  | 0.291 |
| 2.203 | 50 | 951  |    | 0.208                      | 0.155                      | 0.131                      | 0.124                      | 0.12                       | 0.116                      | 6.84  | 0.291 |
| 2.203 | 51 | 975  |    | 0.22                       | 0.157                      | 0.128                      | 0.123                      | 0.114                      | 0.112                      | 7     | 0.291 |
| 2.202 | 52 | 1001 |    | 0.224                      | 0.143                      | 0.129                      | 0.117                      | 0.112                      | 0.107                      | 7.18  | 0.291 |
| 2.203 | 53 | 957  |    | 0.167                      | 0.137                      | 0.117                      | 0.107                      | 0.101                      | 0.1                        | 7.41  | 0.291 |
| 2.204 | 54 | 907  |    | 0.163                      | 0.127                      | 0.109                      | 0.102                      | 0.099                      | 0.095                      | 7.65  | 0.291 |
| 2.206 | 55 | 856  |    | 0.16                       | 0.118                      | 0.107                      | 0.099                      | 0.096                      | 0.094                      | 7.91  | 0.291 |
| 2.207 | 56 | 807  |    | 0.154                      | 0.121                      | 0.106                      | 0.099                      | 0.099                      | 0.094                      | 8.16  | 0.291 |
| 2.208 | 57 | 757  |    | 0.161                      | 0.124                      | 0.109                      | 0.103                      | 0.1                        | 0.096                      | 8.41  | 0.291 |
| 2.21  | 58 | 706  |    | 0.194                      | 0.144                      | 0.123                      | 0.113                      | 0.107                      | 0.104                      | 8.67  | 0.291 |
| 2.211 | 59 | 655  |    | 0.179                      | 0.13                       | 0.116                      | 0.108                      | 0.103                      | 0.099                      | 8.92  | 0.291 |
| 2.212 | 60 | 606  |    | 0.162                      | 0.12                       | 0.109                      | 0.1                        | 0.097                      | 0.094                      | 9.17  | 0.291 |

mq := 61,62...nd - Nempties

| samdns | $\epsilon'_{\text{mq},1}$ | $\epsilon'_{\text{mq},1}$ | $\epsilon'_{\text{mq},2}$ | $\epsilon'_{\text{mq},3}$ | $\epsilon'_{\text{mq},4}$ | $\epsilon'_{\text{mq},5}$ | $\epsilon'_{\text{mq},6}$ | tlaps <sub>mq</sub> | sammas <sub>mq</sub> |       |
|--------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------|----------------------|-------|
| 2.214  | 61                        | 556                       | 0.135                     | 0.112                     | 0.099                     | 0.091                     | 0.09                      | 0.088               | 9.42                 | 0.291 |
| 2.215  | 62                        | 506                       | 0.108                     | 0.088                     | 0.092                     | 0.085                     | 0.086                     | 0.084               | 9.7                  | 0.291 |
| 2.216  | 63                        | 456                       | 0.095                     | 0.084                     | 0.083                     | 0.081                     | 0.08                      | 0.078               | 10                   | 0.291 |
| 2.218  | 64                        | 406                       | 0.089                     | 0.086                     | 0.079                     | 0.076                     | 0.075                     | 0.072               | 10.33                | 0.291 |
| 2.219  | 65                        | 356                       | 0.086                     | 0.071                     | 0.069                     | 0.065                     | 0.066                     | 0.062               | 10.71                | 0.291 |
| 2.22   | 66                        | 305                       | 0.066                     | 0.06                      | 0.058                     | 0.058                     | 0.056                     | 0.057               | 11.14                | 0.291 |
| 2.222  | 67                        | 255                       | 0.057                     | 0.058                     | 0.053                     | 0.052                     | 0.052                     | 0.05                | 11.65                | 0.291 |
| 2.223  | 68                        | 205                       | 0.045                     | 0.051                     | 0.048                     | 0.043                     | 0.046                     | 0.045               | 12.26                | 0.291 |
| 2.224  | 69                        | 153                       | 0.038                     | 0.042                     | 0.041                     | 0.039                     | 0.04                      | 0.04                | 13.06                | 0.291 |
| 2.226  | 70                        | 103                       | 0.033                     | 0.039                     | 0.036                     | 0.035                     | 0.035                     | 0.035               | 14.27                | 0.291 |
| 2.228  | 71                        | 23                        | 0.032                     | 0.03                      | 0.029                     | 0.027                     | 0.028                     | 0.027               | 19.8                 | 0.291 |

**MPN-308\_Ravash\_QUEENS\_Ilmenite****April 1, 2024**

Ilmenite Ref., RD57, Pressed Asymmetric Pellet Sample  
Complex Dielectric Constant  
Cycle from Room Temperature to 1000°C to Room Temperature,  
in 10 sccm UHP Nitrogen

John Forster and Ravash Mehr decided that they would choose very specific “ single mineral “ specimens from the large collection of de Beers rocks, and crush these and use them as reference values when considering the response of mixed mineral samples. To avoid possible problems due to sample levitation caused by pellet swelling, Microwave Properties North used an asymmetric punch/die to make pellets with a flat down one side which would allow gas flow even if some expansion occurred. The pellets were pressed at ~ 33,000 psi. Thus a measurement of the complex dielectric properties, up to 1000C and back to room temperature, was done in 10 sccm flowing UHP nitrogen. The test sample pellets were not baked to ensure dryness.

The initial sample parameters were:

- a) effective diameter 3.635 +- 0.02 mm
- b) length 12.78 +- 0.05 mm
- c) mass 0.387 +- 0.002 gm
- q) room temperature density  $2.92 \pm 0.14$  gm/cc.
- r) appearance - 2 stacked grey pellets

The dielectric properties measurements were performed three times at RT, and then the temperature was ramped up to 1000C in 25C steps , then the temperature was brought back down to 100C in -50C steps, then RT .

The holder was removed from the apparatus and the final sample was weighed. The final empty sample holder measurements showed no contamination.

The final sample properties, at room temperature were :

- a) effective diameter  $3.634 \pm 0.05$  mm
- b) length  $12.77 \pm 0.05$  mm
- c) mass  $0.377 \pm 0.002$  gm
- p) room temperature density  $2.85 \pm 0.13$  g/cc
- q) appearance - orange colouration on bottom pellet ( see photo)

Note: The percent mass loss was  $\sim 2.6 \pm 1.0$  % .

The frequency coding is :

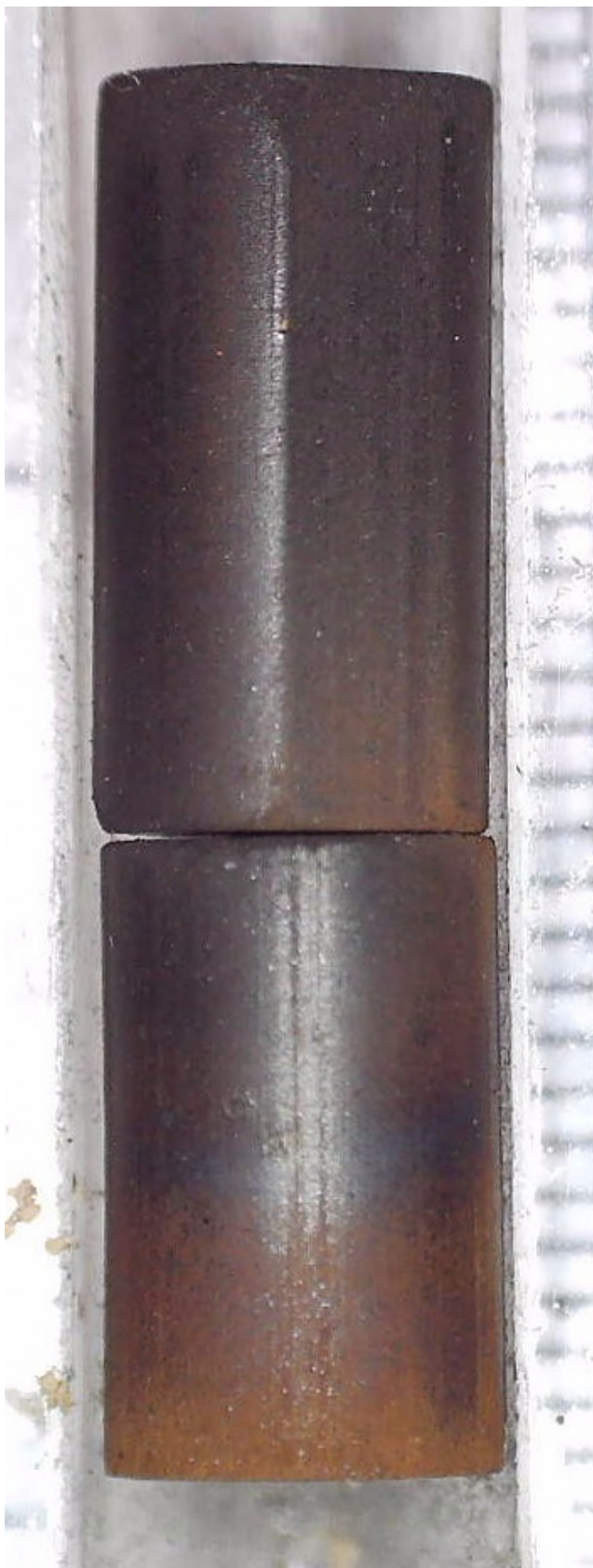
Legend for Data Plots :

| # | Frequency(MHz) | Symbol                                                   |
|---|----------------|----------------------------------------------------------|
| 1 | 397            | red diamond, solid line – sometimes the line is omitted! |
| 2 | 912            | blue square, solid line                                  |
| 3 | 1429           | black cross, solid line                                  |
| 4 | 1948           | blue circle, dotted line                                 |

## Ilmenite QUEENS2435

|   |      |                            |
|---|------|----------------------------|
| 5 | 2466 | red cross, dotted line     |
| 6 | 2986 | black diamond, dotted line |

A thermal expansion coefficient (CTE) of  $4.0 \times 10^{-6}/\text{C}$  was used.



## Ilmenite QUEENS2435

Final two pellets after run to 1000C in flowing UHP nitrogen.

The thin orange coating on the bottom of the final pellets is likely due to the small amount of oxygen impurity ( $< 10$  ppm) in the nitrogen, which converts some small component to ferrous oxide (hematite).

Comments on the data analysis:

The measurement system lost the 2985 MHz peak above 750C due to the very large peak width reducing the peak height to background noise level.

The ilmenite sample has large dielectric loss, apparently of the ionic conduction type, as evidenced by the large frequency dispersion of the high temperature values

.  
The Half-Power Depth above 700C is smaller than the test sample diameter, so the accuracy of our calculated values is decreased greatly due to the theory's assumption of uniform electric field in the test sample!

There is evidence of a transition to pseudorutile starting at ~ 700C, producing a highly defected ( and thus disordered ) structure.

# Ilmenite QUEENS2435

Estimated Sample Dimensions & Volume and Plots Density As a Function of Temperature

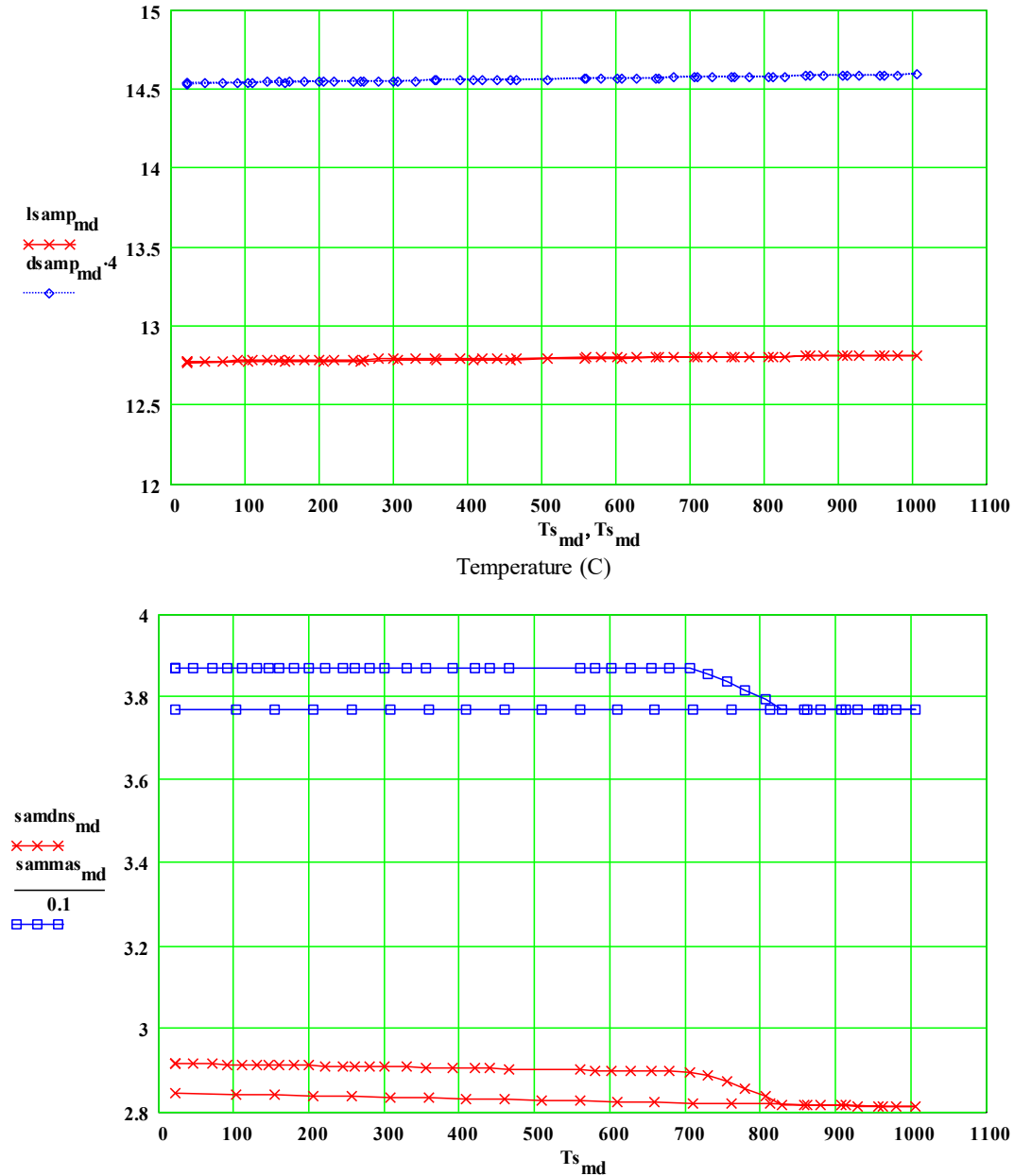
Test = 2024032901

QUEENS2435.mcd

AnDat = 20240331

Ilmenite Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Quee

Assumed Effective height, Diameter (mm) and Density (gm/cc) as a Function of Temperature for Pellets



Upper Plot : sample length and diameter : Lower Plot : sample density and mass

# Ilmenite QUEENS2435

Test = 2024032901

QUEENS2435.mcd

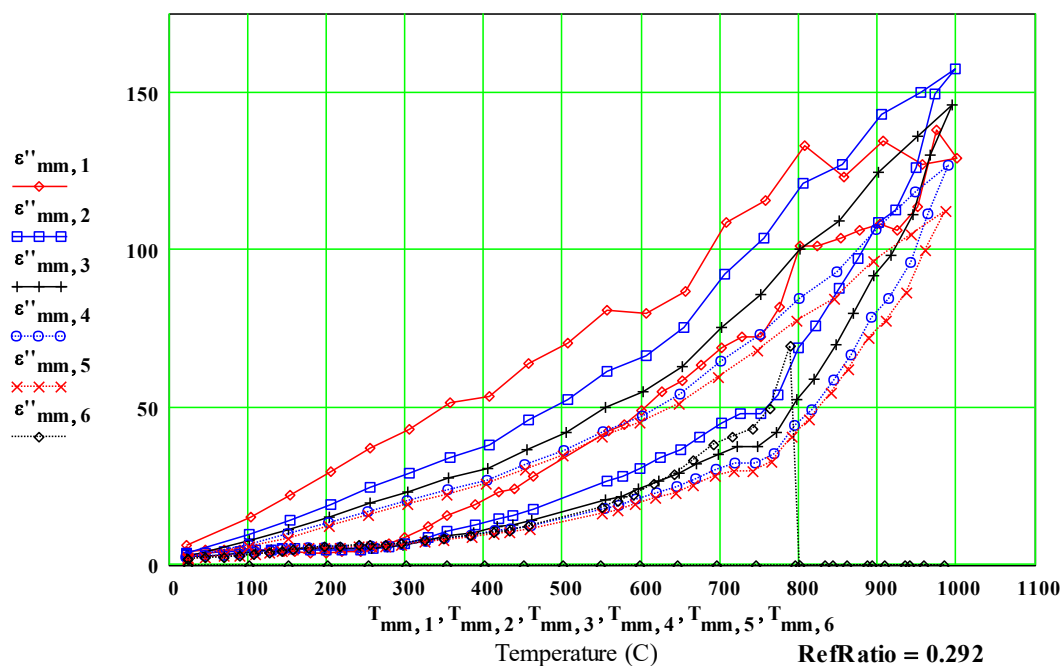
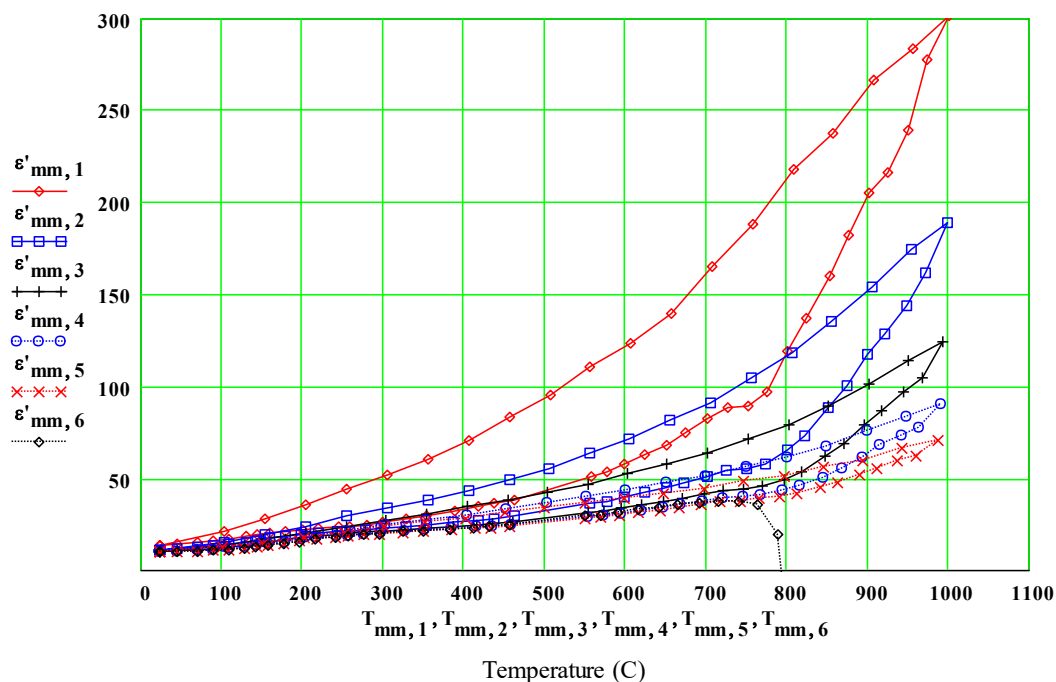
AnDat = 20240331

Ilmenite Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Quee

Initial density =  $\text{samdns}_{\text{NCal}} + 1 = 2.92 \text{ gm/cc}$ ,

Final density(25C) =  $\text{dnsfinal} = 2.85 \text{ gm/cc}$

Final\_over\_Initial\_mass = 0.974



RefRatio = 0.292

# Ilmenite QUEENS2435

Test = 2024032901

QUEENS2435.mcd

AnDat = 20240331

Ilmenite Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Quee

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.92$  gm/cc,

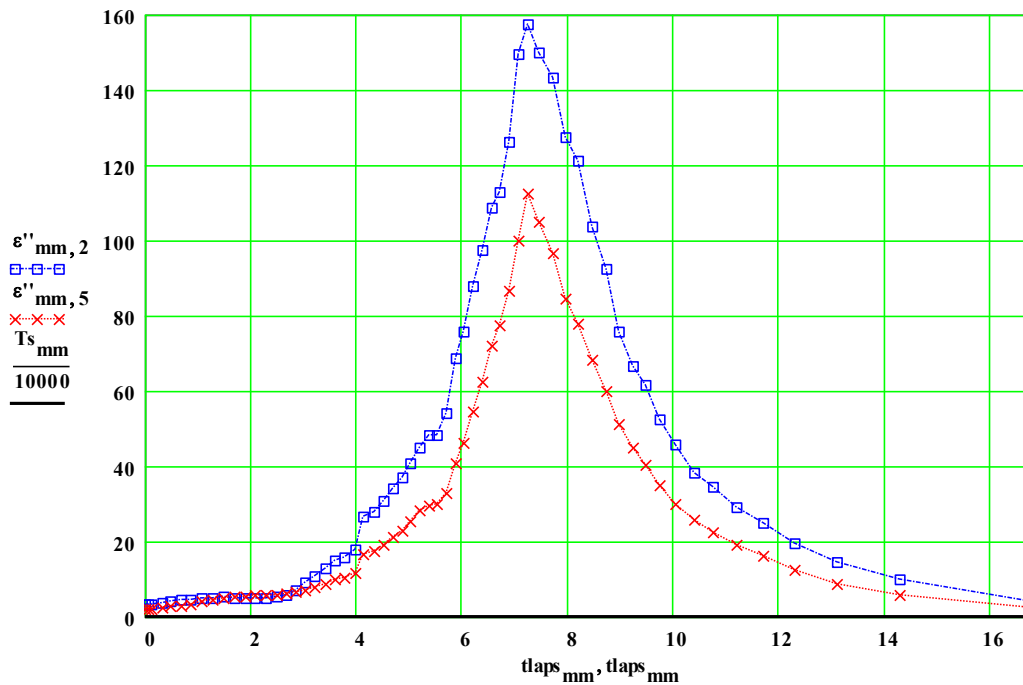
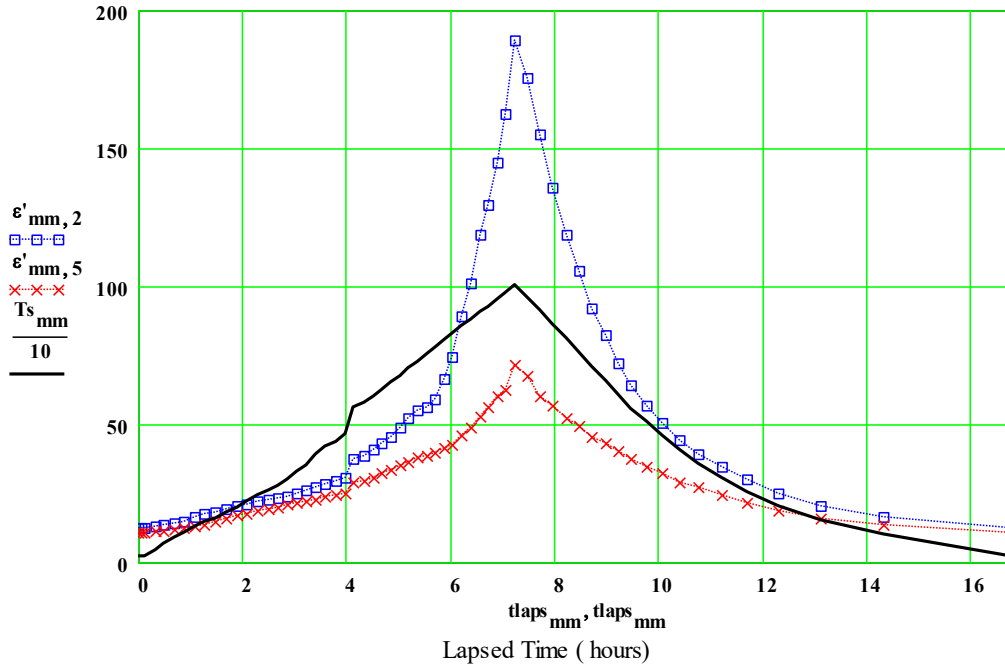
Solid Test Sample

Thermal exp. coeff.

Final density(25C) =  $\text{dnsfinal} = 2.85$  gm/cc

FracMassChange = 0.97

$\alpha_1 = 4 \cdot 10^{-6}$



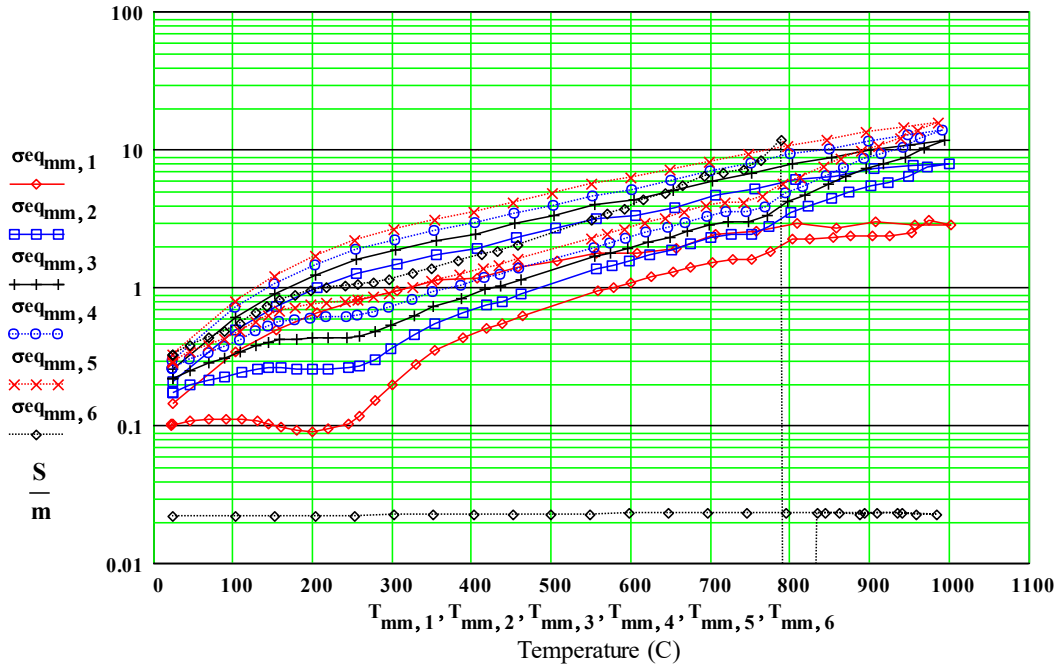
# Ilmenite QUEENS2435

Test = 2024032901

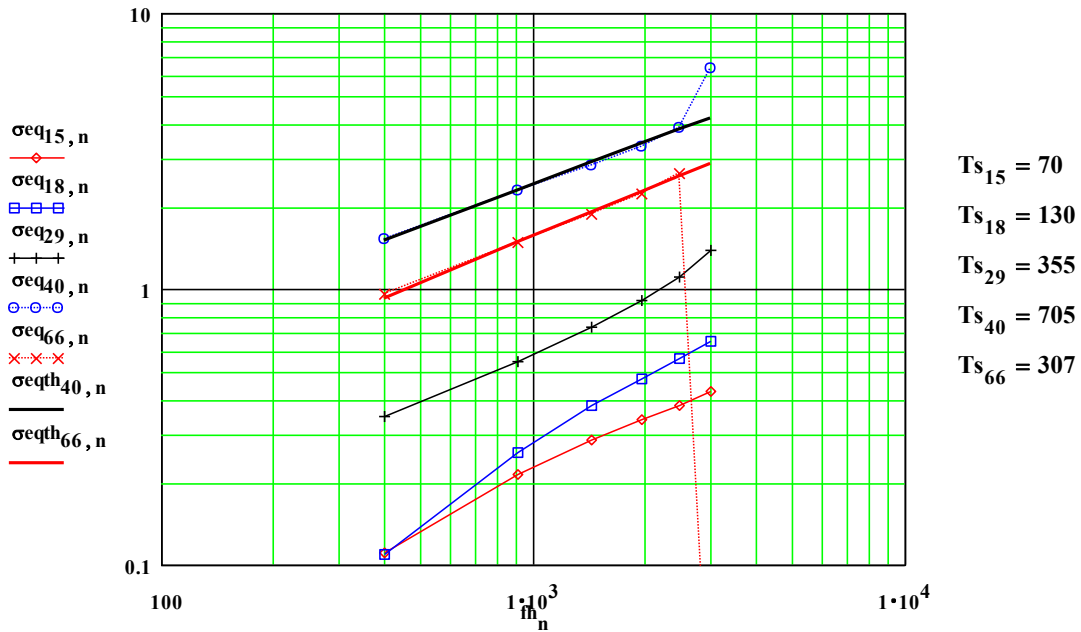
QUEENS2435.mod

AnDat = 20240331

Ilmenite Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Quee  
Equivalent Free Electron AC Conductivity ( Siemens/metre)



$$Ts_{66} = 307 \quad \sigma_{eqth_{66,n}} := 0.93 \cdot \left( \frac{fh_n}{400} \right)^{0.56} + 0.0 \quad Ts_{40} = 705 \quad \sigma_{eqth_{40,n}} := 1.5 \cdot \left( \frac{fh_n}{400} \right)^{0.51} + 0.0$$



$Ts_{15} = 70$   
 $Ts_{18} = 130$   
 $Ts_{29} = 355$   
 $Ts_{40} = 705$   
 $Ts_{66} = 307$

# Ilmenite QUEENS2435

Test = 2024032901

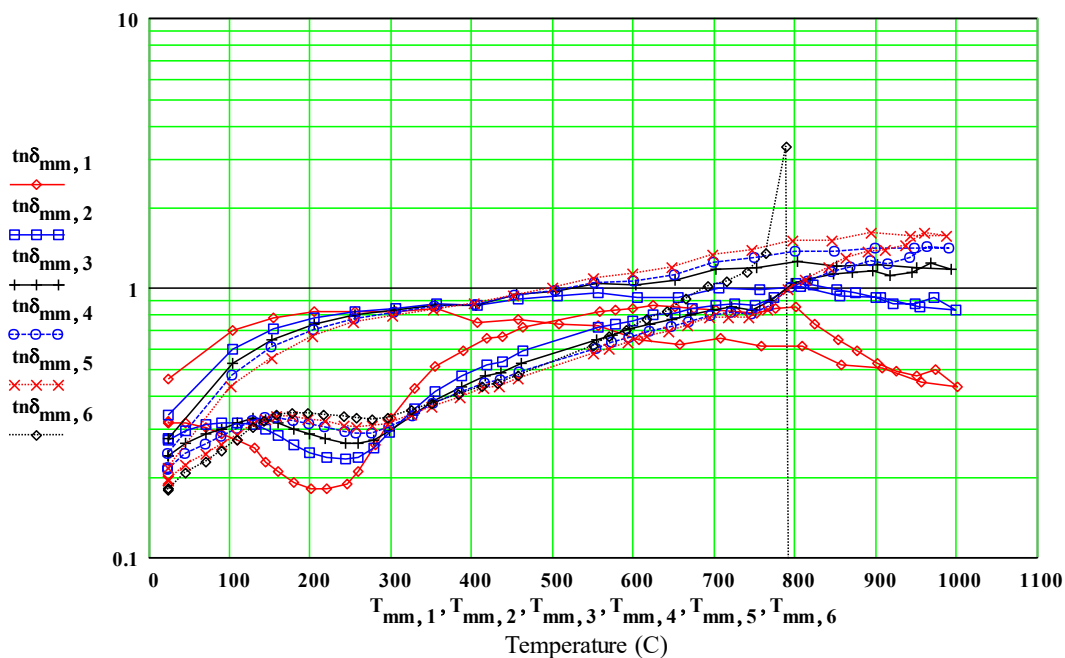
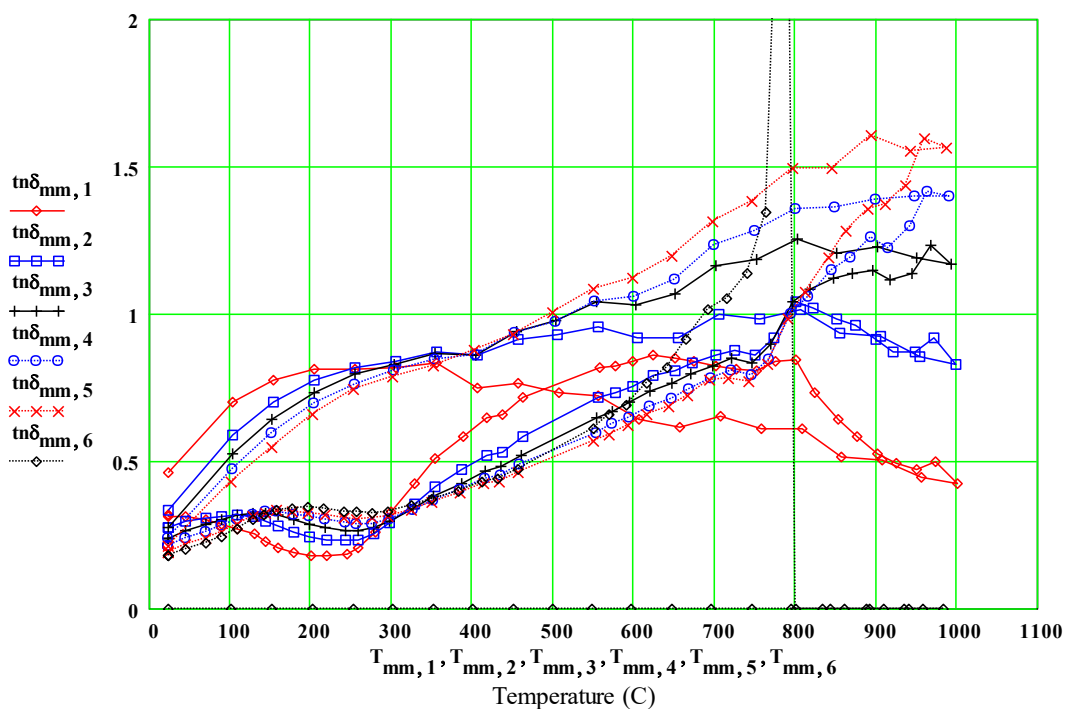
QUEENS2435.mcd

AnDat = 20240331

Ilmenite Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Quee

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.92 \text{ gm/cc}$ ,

Final density(25C) =  $\text{dnsfinal} = 2.85 \text{ gm/cc}$



# Ilmenite QUEENS2435

Test = 2024032901

QUEENS2435.mod

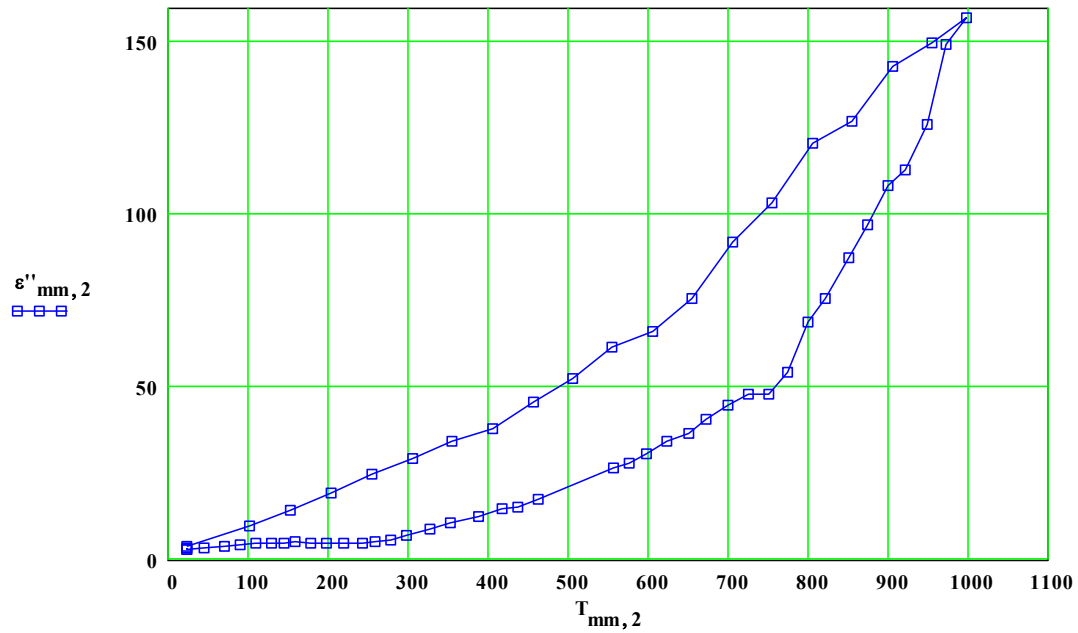
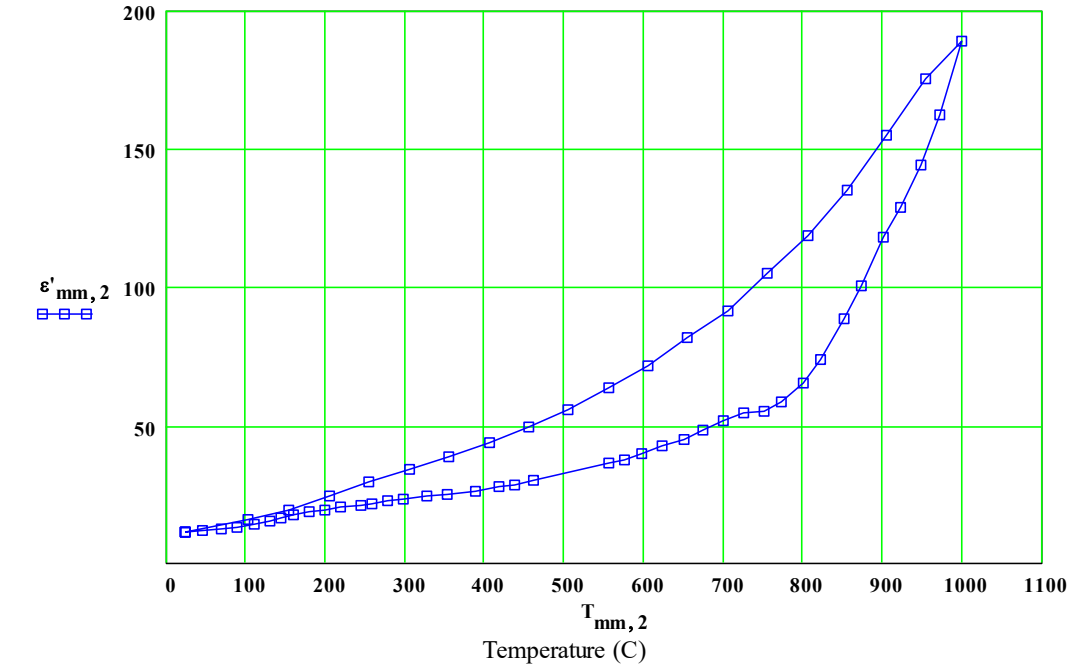
AnDat = 20240331

Ilmenite Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 scem nitrogen, for Ravash, Quee

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.92 \text{ gm/cc}$ , Thermal exp. coeff.  $\alpha_1 = 4 \cdot 10^{-6}$

Final density(25C) =  $\text{dnsfinal} = 2.85 \text{ gm/cc}$

## Values for 912 MHz



# Ilmenite QUEENS2435

Half-power Depth (millimeters)

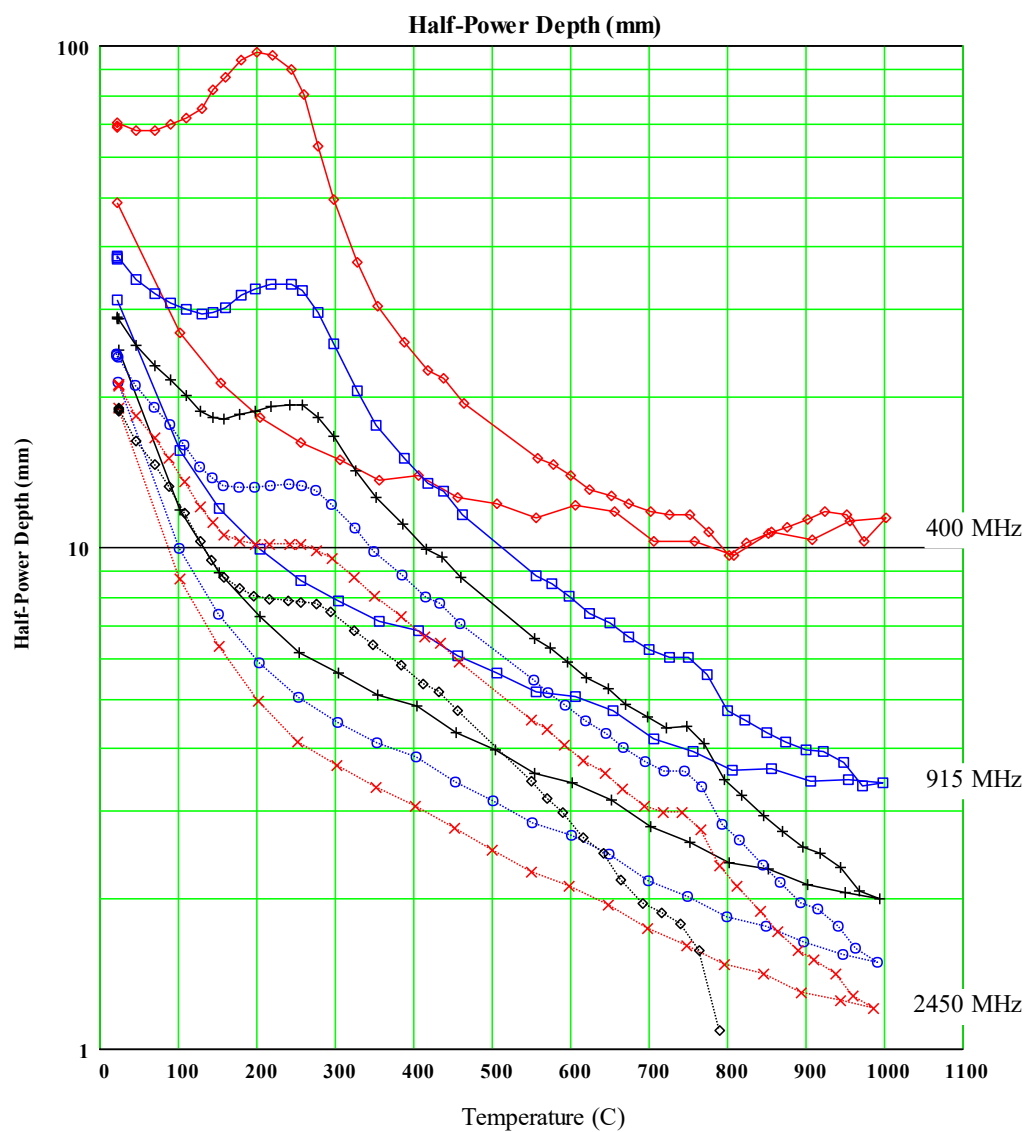
$$D_{\text{halfP}}(\text{mm}, n) := \left( \frac{\ln(2)}{2} \right) \cdot \left( \text{inverse}\alpha_{\text{mm}, n} \cdot 1 \right)$$

Test = 2024032901

QUEENS2435.mcd

AnDat = 20240331

Ilmenite Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Quee



# Ilmenite QUEENS2435

Test = 2024032901 QUEENS2435.mcd AnDat = 20240331  
 Ilmenite Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Quee

List of Measured Values of  $\epsilon'$  and  $\epsilon''$  :  
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^

Initial density =  $\text{samdns}_{\text{NCal} + 1} = 2.918$  gm/cc Final density(25C) =  $\text{dnsfinal} = 2.846$  gm/cc  
 Lapsed

density index T(C) 397MHz 912MHz 1429MHz 1948MHz2466MHz 2986MHz  
 Time

(hours)  
 $\text{samdns}_{\text{mm}}$   $T_{\text{mm},1}$   $\epsilon'_{\text{mm},1}$   $\epsilon'_{\text{mm},2}$   $\epsilon'_{\text{mm},3}$   $\epsilon'_{\text{mm},4}$   $\epsilon'_{\text{mm},5}$   $\epsilon'_{\text{mm},6}$   $\text{tlaps}_{\text{mm}}$   $\text{sammas}_{\text{mm}}$

|       |    |      |        |        |        |       |       |        |      |       |
|-------|----|------|--------|--------|--------|-------|-------|--------|------|-------|
| 2.918 | 11 | 23   | 14.63  | 12.39  | 11.59  | 11.19 | 10.95 | 10.87  | 0    | 0.387 |
| 2.918 | 12 | 23   | 14.58  | 12.34  | 11.54  | 11.15 | 10.92 | 10.84  | 0.07 | 0.387 |
| 2.918 | 13 | 23   | 14.55  | 12.32  | 11.52  | 11.14 | 10.9  | 10.83  | 0.13 | 0.387 |
| 2.917 | 14 | 45   | 15.61  | 12.98  | 11.98  | 11.5  | 11.21 | 11.13  | 0.33 | 0.387 |
| 2.916 | 15 | 70   | 16.49  | 13.6   | 12.44  | 11.87 | 11.53 | 11.45  | 0.49 | 0.387 |
| 2.916 | 16 | 90   | 17.27  | 14.18  | 12.88  | 12.2  | 11.82 | 11.71  | 0.68 | 0.387 |
| 2.915 | 17 | 110  | 18.21  | 15.05  | 13.57  | 12.76 | 12.31 | 12.19  | 0.87 | 0.387 |
| 2.914 | 18 | 130  | 19.53  | 16.3   | 14.62  | 13.65 | 13.1  | 12.96  | 1.08 | 0.387 |
| 2.914 | 19 | 144  | 20.48  | 17.37  | 15.6   | 14.52 | 13.9  | 13.73  | 1.27 | 0.387 |
| 2.914 | 20 | 159  | 21.39  | 18.46  | 16.68  | 15.52 | 14.81 | 14.66  | 1.48 | 0.387 |
| 2.913 | 21 | 179  | 22.06  | 19.42  | 17.7   | 16.51 | 15.77 | 15.61  | 1.68 | 0.387 |
| 2.913 | 22 | 199  | 22.98  | 20.45  | 18.78  | 17.6  | 16.81 | 16.71  | 1.89 | 0.387 |
| 2.912 | 23 | 219  | 23.59  | 21.17  | 19.61  | 18.44 | 17.65 | 17.56  | 2.09 | 0.387 |
| 2.911 | 24 | 244  | 24.5   | 22.15  | 20.64  | 19.51 | 18.76 | 18.7   | 2.3  | 0.387 |
| 2.911 | 25 | 259  | 25.03  | 22.62  | 21.17  | 20.09 | 19.32 | 19.27  | 2.5  | 0.387 |
| 2.91  | 26 | 279  | 26.05  | 23.35  | 21.9   | 20.86 | 20.14 | 20.15  | 2.68 | 0.387 |
| 2.91  | 27 | 299  | 27.37  | 24.08  | 22.56  | 21.52 | 20.83 | 20.94  | 2.86 | 0.387 |
| 2.909 | 28 | 329  | 29.31  | 25.17  | 23.41  | 22.32 | 21.65 | 21.86  | 3.04 | 0.387 |
| 2.908 | 29 | 354  | 30.95  | 26.05  | 24.01  | 22.83 | 22.16 | 22.51  | 3.22 | 0.387 |
| 2.907 | 30 | 388  | 33.14  | 27.14  | 24.82  | 23.54 | 22.81 | 23.29  | 3.41 | 0.387 |
| 2.906 | 31 | 418  | 35.76  | 28.59  | 25.88  | 24.47 | 23.76 | 24.34  | 3.6  | 0.387 |
| 2.906 | 32 | 438  | 37.33  | 29.31  | 26.45  | 24.89 | 24.21 | 24.78  | 3.79 | 0.387 |
| 2.905 | 33 | 463  | 39.63  | 30.72  | 27.47  | 25.81 | 25.15 | 25.93  | 3.98 | 0.387 |
| 2.902 | 34 | 558  | 52.15  | 37.33  | 32.41  | 30.02 | 29.15 | 30.43  | 4.14 | 0.387 |
| 2.901 | 35 | 577  | 54.41  | 38.39  | 33.11  | 30.46 | 29.57 | 30.9   | 4.35 | 0.387 |
| 2.901 | 36 | 599  | 58.81  | 40.63  | 34.59  | 31.76 | 30.69 | 32.42  | 4.52 | 0.387 |
| 2.9   | 37 | 625  | 63.75  | 43.25  | 36.45  | 33.41 | 32.2  | 33.94  | 4.68 | 0.387 |
| 2.899 | 38 | 652  | 68.76  | 45.67  | 38.09  | 34.64 | 33.5  | 34.86  | 4.86 | 0.387 |
| 2.899 | 39 | 675  | 75.75  | 48.97  | 40.29  | 36.54 | 35.17 | 36.44  | 5.02 | 0.387 |
| 2.898 | 40 | 702  | 83.37  | 52.29  | 42.82  | 38.52 | 36.39 | 37.6   | 5.2  | 0.387 |
| 2.888 | 41 | 727  | 89.15  | 55.07  | 44.6   | 39.73 | 38.12 | 38.59  | 5.36 | 0.386 |
| 2.874 | 42 | 752  | 89.84  | 56.05  | 45.37  | 40.78 | 38.68 | 37.98  | 5.54 | 0.384 |
| 2.857 | 43 | 775  | 97.7   | 58.96  | 47.01  | 41.7  | 39.66 | 36.75  | 5.7  | 0.382 |
| 2.839 | 44 | 802  | 119.54 | 66.27  | 50.61  | 43.99 | 41.27 | 20.95  | 5.87 | 0.38  |
| 2.819 | 45 | 824  | 137.73 | 74.36  | 54.79  | 46.65 | 42.87 | -28.23 | 6.03 | 0.377 |
| 2.818 | 46 | 853  | 160.9  | 89.05  | 62.67  | 51.17 | 45.82 | -60.89 | 6.22 | 0.377 |
| 2.817 | 47 | 876  | 182.5  | 101.21 | 70.08  | 56.1  | 48.61 | -60.94 | 6.38 | 0.377 |
| 2.817 | 48 | 902  | 205.96 | 118.6  | 80.06  | 62.27 | 53.04 | -61    | 6.56 | 0.377 |
| 2.816 | 49 | 924  | 216.51 | 129.46 | 87.89  | 68.93 | 56.46 | -61.05 | 6.72 | 0.377 |
| 2.815 | 50 | 951  | 239.33 | 144.73 | 97.53  | 74.09 | 60.27 | -61.11 | 6.89 | 0.377 |
| 2.814 | 51 | 974  | 277.8  | 162.64 | 105.57 | 78.61 | 62.69 | -61.17 | 7.06 | 0.377 |
| 2.813 | 52 | 1001 | 302.06 | 189.33 | 124.93 | 90.77 | 71.77 | -61.23 | 7.24 | 0.377 |
| 2.815 | 53 | 957  | 283.58 | 175.47 | 114.67 | 84.66 | 67.66 | -61.13 | 7.46 | 0.377 |
| 2.816 | 54 | 908  | 267.16 | 155.17 | 101.7  | 76.46 | 60.17 | -61.01 | 7.71 | 0.377 |
| 2.818 | 55 | 857  | 237.64 | 135.67 | 90.37  | 68.38 | 56.71 | -60.9  | 7.96 | 0.377 |
| 2.82  | 56 | 808  | 218.48 | 119.03 | 79.86  | 62.44 | 52.05 | -60.79 | 8.22 | 0.377 |
| 2.821 | 57 | 757  | 188.72 | 105.55 | 72.56  | 56.95 | 49.21 | -60.68 | 8.47 | 0.377 |
| 2.823 | 58 | 707  | 166.16 | 92.21  | 64.71  | 52.08 | 45.49 | -60.57 | 8.72 | 0.377 |
| 2.825 | 59 | 656  | 140.57 | 82.25  | 59.12  | 48.45 | 43.02 | -60.46 | 8.98 | 0.377 |
| 2.827 | 60 | 606  | 123.75 | 72.36  | 53.4   | 44.45 | 40.24 | -60.36 | 9.23 | 0.377 |

$\text{mq} = 61, 62, \dots, \text{nd}$  - Nempties

| samdns |    | $T_{mq,1}$ | $\epsilon'_{mq,1}$ | $\epsilon'_{mq,2}$ | $\epsilon'_{mq,3}$ | $\epsilon'_{mq,4}$ | $\epsilon'_{mq,5}$ | $\epsilon'_{mq,6}$ | tlaps <sub>mq</sub> | sammas <sub>mq</sub> |
|--------|----|------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|---------------------|----------------------|
| 2.828  | 61 | 557        | 111.81             | 64.47              | 48.03              | 40.65              | 37.29              | -60.26             | 9.48                | 0.377                |
| 2.83   | 62 | 507        | 95.78              | 56.64              | 43.17              | 37.3               | 34.76              | -60.15             | 9.75                | 0.377                |
| 2.832  | 63 | 457        | 83.86              | 50.29              | 39.07              | 33.89              | 32.34              | -60.05             | 10.05               | 0.377                |
| 2.833  | 64 | 407        | 71.39              | 44.44              | 35.73              | 31.08              | 29.25              | -59.95             | 10.39               | 0.377                |
| 2.835  | 65 | 356        | 61.55              | 39.46              | 31.83              | 28.14              | 27.36              | -59.85             | 10.77               | 0.377                |
| 2.837  | 66 | 306        | 53.12              | 34.87              | 28.47              | 25.34              | 24.4               | -59.76             | 11.2                | 0.377                |
| 2.838  | 67 | 256        | 45.39              | 30.36              | 24.97              | 22.45              | 21.66              | -59.66             | 11.7                | 0.377                |
| 2.84   | 68 | 205        | 36.48              | 25.16              | 21.2               | 19.22              | 18.65              | -59.57             | 12.31               | 0.377                |
| 2.842  | 69 | 153        | 28.66              | 20.5               | 17.67              | 16.23              | 15.74              | -59.47             | 13.11               | 0.377                |
| 2.844  | 70 | 103        | 21.92              | 16.61              | 14.71              | 13.8               | 13.4               | -59.38             | 14.3                | 0.377                |
| 2.846  | 71 | 23         | 14.36              | 12.26              | 11.52              | 11.16              | 10.93              | -59.24             | 16.76               | 0.377                |

# Ilmenite QUEENS2435

Test = 2024032901

QUEENS2435.mcd

AnDat = 20240331

Ilmenite Ref., RD-57, V03369C, De Beers, asymmetric pellets, RT to 1000C, in 10 sccm nitrogen, for Ravash, Que

List of Measured Values of  $\epsilon'$  and  $\epsilon''$  :  
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^

Initial density = **samdns**<sub>NCal + 1</sub> = **2.918** gm/cc Final density(25C) = **dnsfinal** = **2.846** gm/cc

density index T(C) 397MHz 912MHz 1429MH 1948MHz2466MHz 2986MHz Lapsed Time (hours)

| samdns | mm | T     | $\epsilon'$ | $\epsilon''$ | $\epsilon'$ | $\epsilon''$ | $\epsilon'$ | $\epsilon''$ | $\epsilon'$ | $\epsilon''$ | $\epsilon'$ | $\epsilon''$ | taps | sammas |
|--------|----|-------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|------|--------|
| mm     | mm | mm, 1 | mm, 1       | mm, 2        | mm, 3       | mm, 4        | mm, 5       | mm, 6        | mm          | mm           | mm          | mm           | mm   | mm     |
| 2.918  | 11 | 23    | 4.694       | 3.421        | 2.78        | 2.392        | 2.127       | 1.964        | 0           | 0.387        |             |              |      |        |
| 2.918  | 12 | 23    | 4.634       | 3.397        | 2.761       | 2.376        | 2.111       | 1.947        | 0.07        | 0.387        |             |              |      |        |
| 2.918  | 13 | 23    | 4.583       | 3.375        | 2.738       | 2.358        | 2.098       | 1.934        | 0.13        | 0.387        |             |              |      |        |
| 2.917  | 14 | 45    | 4.906       | 3.851        | 3.184       | 2.765        | 2.462       | 2.278        | 0.33        | 0.387        |             |              |      |        |
| 2.916  | 15 | 70    | 5.04        | 4.23         | 3.57        | 3.105        | 2.775       | 2.576        | 0.49        | 0.387        |             |              |      |        |
| 2.916  | 16 | 90    | 4.997       | 4.489        | 3.885       | 3.423        | 3.086       | 2.892        | 0.68        | 0.387        |             |              |      |        |
| 2.915  | 17 | 110   | 4.987       | 4.783        | 4.296       | 3.842        | 3.518       | 3.333        | 0.87        | 0.387        |             |              |      |        |
| 2.914  | 18 | 130   | 4.954       | 5.089        | 4.783       | 4.392        | 4.086       | 3.927        | 1.08        | 0.387        |             |              |      |        |
| 2.914  | 19 | 144   | 4.635       | 5.207        | 5.082       | 4.779        | 4.526       | 4.4          | 1.27        | 0.387        |             |              |      |        |
| 2.914  | 20 | 159   | 4.461       | 5.227        | 5.301       | 5.13         | 4.937       | 4.931        | 1.48        | 0.387        |             |              |      |        |
| 2.913  | 21 | 179   | 4.185       | 5.079        | 5.321       | 5.309        | 5.233       | 5.34         | 1.68        | 0.387        |             |              |      |        |
| 2.913  | 22 | 199   | 4.129       | 5.048        | 5.417       | 5.502        | 5.488       | 5.737        | 1.89        | 0.387        |             |              |      |        |
| 2.912  | 23 | 219   | 4.244       | 5.008        | 5.417       | 5.576        | 5.64        | 5.969        | 2.09        | 0.387        |             |              |      |        |
| 2.911  | 24 | 244   | 4.615       | 5.139        | 5.499       | 5.685        | 5.809       | 6.197        | 2.3         | 0.387        |             |              |      |        |
| 2.911  | 25 | 259   | 5.252       | 5.336        | 5.597       | 5.795        | 5.867       | 6.321        | 2.5         | 0.387        |             |              |      |        |
| 2.91   | 26 | 279   | 6.801       | 5.994        | 6.01        | 6.047        | 6.167       | 6.538        | 2.68        | 0.387        |             |              |      |        |
| 2.91   | 27 | 299   | 8.959       | 7.07         | 6.669       | 6.55         | 6.5         | 6.893        | 2.86        | 0.387        |             |              |      |        |
| 2.909  | 28 | 329   | 12.409      | 8.994        | 7.954       | 7.48         | 7.276       | 7.713        | 3.04        | 0.387        |             |              |      |        |
| 2.908  | 29 | 354   | 15.783      | 10.745       | 9.187       | 8.439        | 8.042       | 8.339        | 3.22        | 0.387        |             |              |      |        |
| 2.907  | 30 | 388   | 19.474      | 12.844       | 10.607      | 9.552        | 8.93        | 9.351        | 3.41        | 0.387        |             |              |      |        |
| 2.906  | 31 | 418   | 23.147      | 14.929       | 12.17       | 10.805       | 10.053      | 10.481       | 3.6         | 0.387        |             |              |      |        |
| 2.906  | 32 | 438   | 24.538      | 15.665       | 12.784      | 11.27        | 10.433      | 10.919       | 3.79        | 0.387        |             |              |      |        |
| 2.905  | 33 | 463   | 28.524      | 17.894       | 14.375      | 12.595       | 11.647      | 12.264       | 3.98        | 0.387        |             |              |      |        |
| 2.902  | 34 | 558   | 42.735      | 26.738       | 20.97       | 17.855       | 16.524      | 18.573       | 4.14        | 0.387        |             |              |      |        |
| 2.901  | 35 | 577   | 44.885      | 28.088       | 22.106      | 19.085       | 17.518      | 20.447       | 4.35        | 0.387        |             |              |      |        |
| 2.901  | 36 | 599   | 49.319      | 30.74        | 24.282      | 20.655       | 19.144      | 22.445       | 4.52        | 0.387        |             |              |      |        |
| 2.9    | 37 | 625   | 55.045      | 34.369       | 26.909      | 22.926       | 21.198      | 25.957       | 4.68        | 0.387        |             |              |      |        |
| 2.899  | 38 | 652   | 58.507      | 36.977       | 29.095      | 24.779       | 22.991      | 28.583       | 4.86        | 0.387        |             |              |      |        |
| 2.899  | 39 | 675   | 63.753      | 40.954       | 32.216      | 27.229       | 25.459      | 33.353       | 5.02        | 0.387        |             |              |      |        |
| 2.898  | 40 | 702   | 68.891      | 45.145       | 35.385      | 30.174       | 28.173      | 38.184       | 5.2         | 0.387        |             |              |      |        |
| 2.888  | 41 | 727   | 72.457      | 48.211       | 37.948      | 32.057       | 29.713      | 40.64        | 5.36        | 0.386        |             |              |      |        |
| 2.874  | 42 | 752   | 72.453      | 48.25        | 37.858      | 32.308       | 29.868      | 43.146       | 5.54        | 0.384        |             |              |      |        |
| 2.857  | 43 | 775   | 82.227      | 54.321       | 42.312      | 35.371       | 33.008      | 49.529       | 5.7         | 0.382        |             |              |      |        |
| 2.839  | 44 | 802   | 101.371     | 68.923       | 52.886      | 44.098       | 40.686      | 69.795       | 5.87        | 0.38         |             |              |      |        |
| 2.819  | 45 | 824   | 101.221     | 75.969       | 59.375      | 49.39        | 46.073      | - 0          | 6.03        | 0.377        |             |              |      |        |
| 2.818  | 46 | 853   | 103.77      | 87.839       | 70.239      | 58.893       | 54.533      | 0.139        | 6.22        | 0.377        |             |              |      |        |
| 2.817  | 47 | 876   | 106.5       | 97.485       | 79.814      | 66.805       | 62.36       | 0.139        | 6.38        | 0.377        |             |              |      |        |
| 2.817  | 48 | 902   | 108.541     | 108.744      | 92.186      | 78.475       | 71.95       | 0.137        | 6.56        | 0.377        |             |              |      |        |
| 2.816  | 49 | 924   | 106.624     | 113.09       | 98.321      | 84.302       | 77.414      | 0.138        | 6.72        | 0.377        |             |              |      |        |
| 2.815  | 50 | 951   | 113.788     | 126.189      | 111.186     | 95.971       | 86.708      | 0.139        | 6.89        | 0.377        |             |              |      |        |
| 2.814  | 51 | 974   | 138.274     | 149.451      | 130.316     | 111.143      | 99.928      | 0.137        | 7.06        | 0.377        |             |              |      |        |
| 2.813  | 52 | 1001  | 129.163     | 157.424      | 145.95      | 126.771      | 112.379     | 0.137        | 7.24        | 0.377        |             |              |      |        |
| 2.815  | 53 | 957   | 127.406     | 149.953      | 136.383     | 118.313      | 105.044     | 0.138        | 7.46        | 0.377        |             |              |      |        |
| 2.816  | 54 | 908   | 134.893     | 143.407      | 124.988     | 106.26       | 96.666      | 0.14         | 7.71        | 0.377        |             |              |      |        |
| 2.818  | 55 | 857   | 123.046     | 127.362      | 109.177     | 93.095       | 84.621      | 0.139        | 7.96        | 0.377        |             |              |      |        |
| 2.82   | 56 | 808   | 133.276     | 121.12       | 100.371     | 84.629       | 77.77       | 0.139        | 8.22        | 0.377        |             |              |      |        |
| 2.821  | 57 | 757   | 115.671     | 103.825      | 86.049      | 73.093       | 68.18       | 0.139        | 8.47        | 0.377        |             |              |      |        |
| 2.823  | 58 | 707   | 108.878     | 92.447       | 75.518      | 64.374       | 59.873      | 0.139        | 8.72        | 0.377        |             |              |      |        |
| 2.825  | 59 | 656   | 86.976      | 75.775       | 63.088      | 54.218       | 51.418      | 0.138        | 8.98        | 0.377        |             |              |      |        |
| 2.827  | 60 | 606   | 79.886      | 66.46        | 54.979      | 47.011       | 45.174      | 0.139        | 9.23        | 0.377        |             |              |      |        |

mq = 61,62..nd - Nempties

| samdns | mq | T     | $\epsilon'$ | $\epsilon''$ | $\epsilon'$ | $\epsilon''$ | $\epsilon'$ | $\epsilon''$ | $\epsilon'$ | $\epsilon''$ | taps | sammas |
|--------|----|-------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|------|--------|
| mq     | mq | mq, 1 | mq, 1       | mq, 2        | mq, 3       | mq, 4        | mq, 5       | mq, 6        | mq          | mq           | mq   | mq     |
| 2.828  | 61 | 557   | 81.062      | 61.814       | 50.067      | 42.387       | 40.52       | 0.137        | 9.48        | 0.377        |      |        |
| 2.83   | 62 | 507   | 70.543      | 52.649       | 42.179      | 36.296       | 34.929      | 0.137        | 9.75        | 0.377        |      |        |
| 2.832  | 63 | 457   | 64.277      | 46.009       | 36.889      | 31.74        | 30.137      | 0.136        | 10.05       | 0.377        |      |        |
| 2.833  | 64 | 407   | 53.472      | 38.203       | 30.799      | 26.795       | 25.706      | 0.137        | 10.39       | 0.377        |      |        |
| 2.835  | 65 | 356   | 51.48       | 34.441       | 27.63       | 23.853       | 22.59       | 0.135        | 10.77       | 0.377        |      |        |
| 2.837  | 66 | 306   | 43.383      | 29.324       | 23.565      | 20.447       | 19.217      | 0.135        | 11.2        | 0.377        |      |        |
| 2.838  | 67 | 256   | 37.024      | 24.833       | 19.976      | 17.102       | 16.093      | 0.134        | 11.7        | 0.377        |      |        |
| 2.84   | 68 | 205   | 29.657      | 19.521       | 15.523      | 13.352       | 12.309      | 0.134        | 12.31       | 0.377        |      |        |
| 2.842  | 69 | 153   | 22.22       | 14.417       | 11.384      | 9.701        | 8.654       | 0.133        | 13.11       | 0.377        |      |        |
| 2.844  | 70 | 103   | 15.332      | 9.833        | 7.721       | 6.502        | 5.778       | 0.131        | 14.3        | 0.377        |      |        |
| 2.846  | 71 | 23    | 6.616       | 4.137        | 3.2         | 2.69         | 2.352       | 0.132        | 16.76       | 0.377        |      |        |