Making Unique Samples for the Cosmochemistry Community

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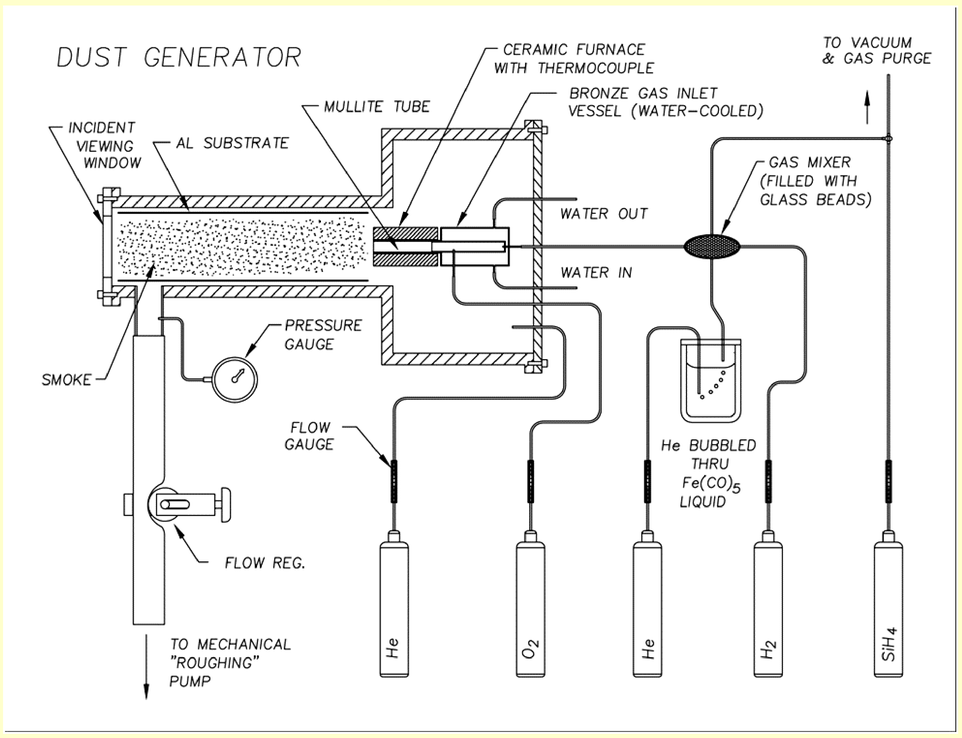
Summary

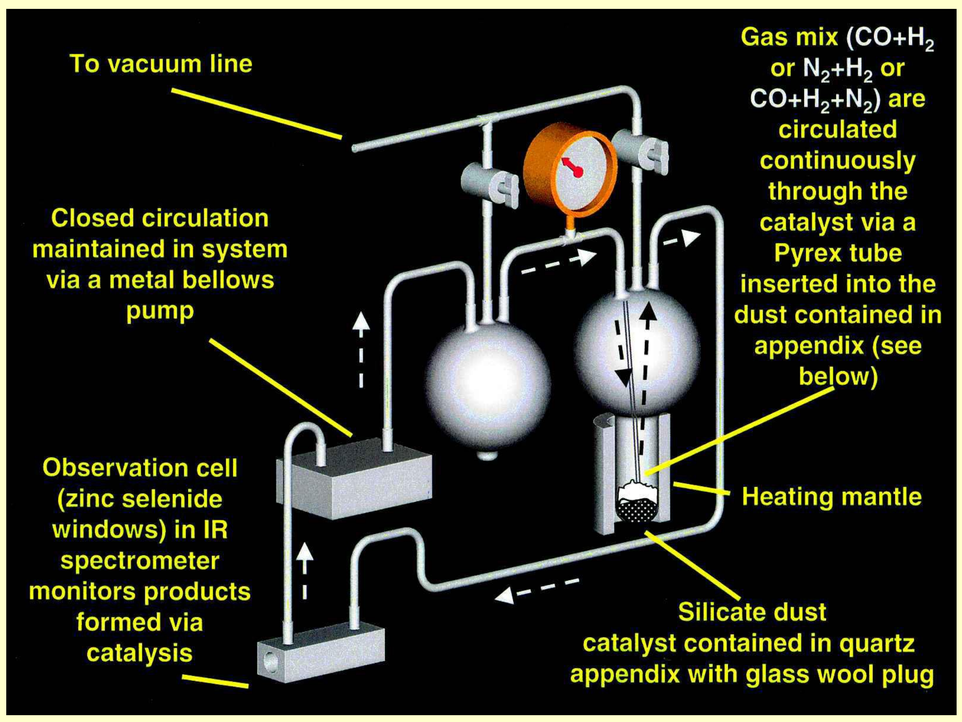
Condensates formed in astrophysical environments are difficult to access as starting materials for laboratory studies of processes that might occur in protostellar nebulae. While micrograms of such materials might be found in the heart of rare, unprocessed, primitive meteorites such as Acfer 094, much larger quantities of material are required in order to conduct multiple experiments at a variety of temperatures and pressures. To solve that problem we manufacture several different varieties of "natural" simulants from flowing hydrogen gas seeded with appropriate metals and exposed to a hydrogen-oxygen flame. These samples range from simple SiO_x smoke, to more complex Fe_aSiO_x, Mg_aSiO_x and $Fe_aMg_bSiO_x$ smokes that mimic the reactivity and spectral properties of fresh, vapor-phase condensates such as those that might form in circumstellar outflows or from vaporized materials formed by energetic processes in protostellar nebulae. In addition, we also make carbonaceous samples formed from a flowing stream of CO on the surfaces of various catalysts during surface mediated reactions in an excess of hydrogen and in the presence of N_2. Carbon deposits do not form continuous coatings on the catalytic surfaces, but instead form extremely high surface area per unit volume "filamentous" structures. While these structures will form slowly but over longer times in protostellar nebulae than in our experiments due to the lower CO pressure, such fluffy coatings on the surfaces of chondrules or CAIs could promote grain-grain sticking during low velocity collisions and might provide carbonaceous feedstock for the synthesis of interesting biochemical precursors to life during metamorphism on meteorite parent bodies. Both silicate smokes as well as carbonaceous solids have been made available to the scientific community for use in their own cosmochemical experiments.

Making Silicate Smokes



Schematic diagram of the dust generator used to manufacture 10 nm scale smoke particles *via* the combustion of hydrogen gas containing small amounts of silane, iron pentacarbonyl, trimethyl aluminum, titanium tetrachloride and metal vapors such as magnesium, calcium, sodium and potassium. Molecular oxygen is typically used as the oxidant. The reaction occurs across a flame front within a resistively heated furnace at temperatures between 500 and 1500 K. Condensates are rapidly quenched and are collected on an aluminum substrate downstream of the furnace at temperatures below 350 K.

Making Carbonaceous Solids



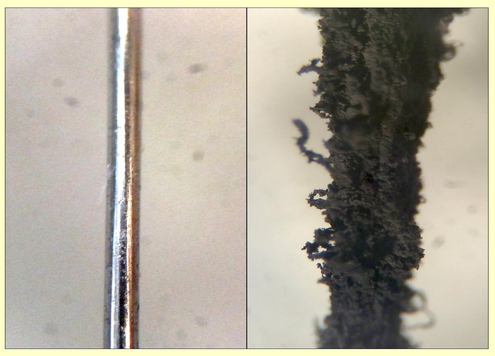
The catalyst is in the bottom of a quartz finger (attached to a 2–L Pyrex bulb) that can be heated to a controlled temperature. A Pyrex tube brings reactive gas to the bottom of the finger. The gas passes through the catalyst into the upper reservoir of the bulb and flows through a stainless steel tube at room temperature to a glass-walled cell (ZnSe windows) in an FTIR spectrometer. A metal bellows pump returns the gas via to the bottom of the catalyst finger to start the cycle over again. We have ten identical experimental systems: the total volume of each system is 4.7 +/- 0.1 liters.

Surface Mediated Reactions and Carbonaceous Dust

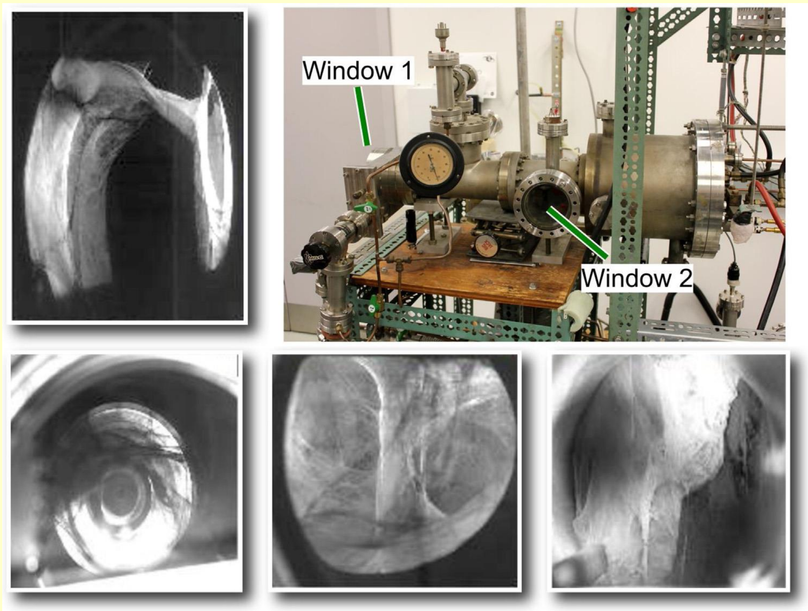
We are not claiming here that surface mediated reactions constitute the single – or even the most important - mechanism that forms the full distribution of organic molecules in asteroids or comets or that are found in meteorites or IDPs. There are many different processes that can be important sources for particular compounds in many different meteorite types. However, we do believe that surface mediated reactions are a very efficient mechanism for converting nebular CO or CO_2 into solid carbonaceous materials. Such solids should be easy to incorporate into planetesimals and these carbonaceous grains could then serve as the feed stock that is transformed by various thermal or hydrothermal processes on parent bodies into the myriad organic molecules found in natural sources.

In addition, while we use various industrial reactions as models of nebular processes; e.g., the Fischer-Tropsch reaction: $CO + 3H_2 \Rightarrow CH_4 + H_2O$; the Haber-Bosch reaction: $N_2 + 3H_2 \Rightarrow 2NH_3$; the water-gas shift reaction: $CO + H_2O \Rightarrow CO_2 + H_2$; or the Boudouard Reaction: $2CO \Rightarrow CO_2 + C_{solid}$; natural reactions on grain surfaces in protostellar nebulae are much more complex. For this reason it can be extremely misleading to discuss a specific model reaction in isolation when describing natural reactions that might occur on the surfaces of grains in the Solar Nebula. Hereafter we will simply discuss measurements of *surface mediated reactions*.

Two Interesting Oddities Found While Making Samples



Below: An optical microscope image of iron wire (.009" Diam.) before (left) and after (right) use as the catalyst for a single 873K run of CO + N_2 + H_2 => products



Above: Views of iron "spider webs" produced in the smoke generator. Top right: the generator showing locations of the viewing/illumination windows. Top left: light in Window2, view from Window 1; bottom left: light in Window 1, view from Window 1; bottom middle: light in Window 1, view from Window 2; bottom right: light in Window 2,view from Window 2.

Individual researchers who have requested, and been sent, samples

8/24/18	Maria Gritsevich	no	FeSiO smoke (Summer	-	n/a	stock		small black v	unreacted FeSiO smoke (Summer 2017 batch) Si:O2=30; H2=100; T~450C, P~80 torr
		no	MgSiO smoke (Fall 201	-	n/a	stock		small black v	unreacted MgSiO smoke (Fall 2012 batch) Si:O2=30; H2=100; T~440C, P~75-85 torr
		no	silica smoke (1/31/02)	-	n/a			small black v	unreacted Si-O smoke (generated 1/31/02 by Nuth/Hill) H2=0; He=150-300; O2=125; SiH4=25; T=500-734C (smudgy blue marker on lid)
		no	Fe/MgSiO smoke (1/4/0	-	n/a			small black v	generated 1/4/00, small grains, black color
3/6/18	Westphal, Andrew (UC	no	FeSiO smoke (5Mar201	-	n/a			20ml vial	unreacted FeSiO catalyst (starting material, generated 3/5/18), packed by Joe directly from collector
		no	FeSiO smoke (Summer	-	n/a			med green v	unreacted FeSiO smoke (Summer 2017 batch) Si:O2=30; H2=100; T~450C, P~80 torr
8/10/17	Elena Dobrica	no	Fe-silcate smoke (Sum	-	n/a	stock		~100mg (tiny	unreacted FeSiO smoke (Summer 2017) Fe:Si:O2=30; H2=100; T~450C, P~80-85 torr, 4 runs consolidated
		yes	organics from reacted F	450C	1 run	Frank's run, 20		~15mg (tiny l	solid organics from 450C FTT reacted Fe wire run from long tube furnace (Frank Ferguson operator)
12/21/16	Devin Schrader	no	FeSiO smoke (Dec 2016)		n/a		~2.5 g		unreacted FeSiO smoke (Dec 2016) Fe:Si:O2=30; H2=100; T~450C, P~80-85 torr; the entire batch of two runs (11/23 and 12/7)
11/2/16	Devin Schrader	no	MgSiO smoke (Oct 2016)		n/a		~5 g		unreacted MgSiO smoke (Oct 2016) Si:O2=30; H2=100; T~400C, P~75-85 torr; the entire batch of all two runs
3/10/16	Chizmadia-Fuson, Lysa	no	MgSiO (2/22/12), unconsolidated		n/a		~2000mg		unreacted MgSiO smoke (generated 2/22/12) Si:O2=30; H2=100, T~405C, P~65torr, Johnson/Nuth, (1 of 2 vials)
		no	MgSiO (2/22/12), unconsolidated		n/a		~2200mg		unreacted MgSiO smoke (generated 2/22/12) Si:O2=30; H2=100, T~405C, P~65torr, Johnson/Nuth, (2 of 2 vials)
		no	Fe/Mg silicate (1/5/00) GC		n/a		~1410mg		unreacted Fe/Mg silicate smoke (generated 1/5/00), by GC, (3 of 3 vials)
		no	Fe Silicate smoke (8/9/01)		n/a		~1900mg		unreacted FeSiO smoke (generated 8/9/01) Si:30, O2:30, Fe:50, H2:100, T~620C (1 of 2 vials)
		no	Fe Silicate smoke (8/9/01)		n/a		~2100mg		unreacted FeSiO smoke (generated 8/9/01) Si:30, O2:30, Fe:50, H2:100, T~620C (2 of 2 vials)
2/5/16	Neyda Abreu	yes	iron wire, 12 inches	600C	1	13-Jan-16		small length v	about an inch of reacted iron wire w/associated carbonaceous deposit, FTT run by FFerguson
		yes	iron wire, 12 inches	500C	1	29-Dec-15		small length v	about an inch of reacted iron wire w/associated carbonaceous deposit, FTT run by Fferguson
8/13/15	Getty, Stephanie	no	FeSiO smoke (Fall 200	-	n/a	stock		small black v	pulled from 'stock' of unreacted sample from Mkopstein stockpile
	Rick Arevalo	yes	Hydrated FeSiO smoke	313C	65hrs		3/5/04	small black v	from Hydrated FeSiO (Sept 2003) 03/05/04 ~313C, ~1506psi, 65 hrs
		yes	Hydrated FeSiO smoke	312C	9d, 17h		3/12/04	small black v	from Hydrated FeSiO (Sept 2003) 03/12/04, 312C ~1506psi, 9 d, 17 hrs
		yes	FeSiO (Fall 2009) react	550C	11 (27d)	summer 2010		small black v	from MKopstein runs, Summer 2010
		yes	Hydrated FTT-FeSiO s	400C	??		Jun-00	small black v	from Hill/Nuth, hydrated FeSiO sample FESIL121599 following FTT at 400C
2/11/15	Blacksberg, Jordana (J	no	MgSiO smoke (Fall 201	-	n/a	stock		~500mg (20r	unreacted MgSiO smoke (Fall 2012 batch) Si:O2=30; H2=100; T~440C, P~75-85 torr
		no	FeSiO smoke (Oct 200	-	n/a	stock		~500mg (20r	unreacted FeSiO catalyst (starting material, generated Oct 2003) Si:O2:Fe=30; H2=125; T~500C; P~80 torr
10/17/14	Westphal, Andrew (UC	no	FeSiO smoke (Sept 20	-	n/a			50 mg, small	unreacted FeSiO catalyst (starting material, generated Sept 2003)
	Zack Gainsforth	no	MgSiO smoke (Fall 201	-	n/a			50 mg, small	unreacted MgSiO smoke (Fall 2012 batch) Si:O2=30; H2=100; T~440C, P~75-85 torr
4/18/14	Locke, Darren (JSC)	yes	Fe - 40 mesh	600C	20a	20130715		170mg	A:
		yes	Fe - 40 mesh?	500C	9a	20130606		150mg	B:
		yes	Fe - 40 mesh?	400C	2a	20130725		160mg	C:
		yes	Fe - 40 mesh?	600C	1a (24hr)	20130320		280mg	D:
		yes	Fe3O4 325 mesh	600C	20a	20130716		62mg	E:
		yes	Fe3O4 325 mesh	400C	20a	20130717		65mg	F:
		yes	Fe3O4 325 mesh	400C	1a (48hr)	20120615		300mg	G:
		yes	Fe3O4 325 mesh	300C	1c (72hr)	20130321		300mg	H:
		yes	FeSiO reacted w/NG	600C	18	2/20/09		12mg	I:
		yes	FeSiO smoke (Sept 200	300C	9	Jan-07		9mg	J:
4/9/14	De Gregorio, Brad	no	Fe - 40 mesh	-	n/a			grains	Fe (40 mesh, <420 microns) powder grains
	Rhonda Stroud	no	Fe3O4 325 mesh					grains	Fe3O4 (325 mesh, <44 microns) powder grains, magnetite
		no	FeSiO smoke unreacted					grains	FeSiO smoke (20-50nm). amorphous grains produced in our lab
		no	MgSiO smoke unreacted					grains	MgSiO smoke (20-50nm). amorphous grains produced in our lab
		yes	Fe	600C	20a			grains	Fe @ 600C, 20 cycles
		yes	Fe3O4	600C	20a			grains	Fe3O4 @ 600C, 20 cycles
		yes	Fe3O4	400C	20a			grains	Fe3O4 @ 400C, 20 cycles
		yes	FeSiO reacted	600C	18			grains	FeSiO smoke @ 600C, 18 cycles
		yes	FeSiO reacted	300C	9			grains	FeSiO smoke @ 300C, 9 cycles
		yes	graphite powder	600C	18			grains	Graphite @ 600C, 18 cycles
4/7/13	McGregor, James	no	Fe Silicate		n/a		8/13/01	basic white v	unreacted Fe silicate smoke, Al collector, Si:O2:30; Fe:50; H2:100; T ~610C, Joe's handwriting on label
	University of Sheffield, UK		FeSiO (9/29/03)		n/a		9/29/03	basic white v	unreacted FeSiO catalyst (starting material, generated 9/29/03); beige color caused by Fe(CO)5 running low
4/2/13	Tsu-Chien Weng (SLAC	no	MgSiO smoke (8/24/12)		n/a			basic white v	unreacted MgSiO smoke (generated 8/24/12) Si:O2=30; H2=100, T~440C, Johnson&Nuth (1 of 1 vial), appears that a portion was given to S.Getty
	Julia Lee (Harvard)	yes	Hydrated Mg Silicate sn	400C	??		Jul-00	basic white v	brown-red grains; texture is slightly clumpy/cohesive, not uniform in color
	Conel Alexander	no	mag silicate		n/a		5/7/97	0.2626g, talk	very fine, homogenous, light brown powder
		no	MgSiOx		n/a		4/9/97	small nalgen	light, dirty brown, fluffy powder (handwritten label)
		no	Al/Fe/SiO smoke		n/a		9/2/86	green jar w/b	T~520C, P~110torr, 100amps
1/10/13	Blacksberg, Jordana (J	no	MgSiO smoke (Fall 201	-	n/a	stock		~500mg (20r	unreacted MgSiO smoke (Fall 2012 batch) Si:O2=30; H2=100; T~440C, P~75-85 torr
		no	FeSiO smoke (Oct 200	-	n/a	stock		~500mg (20r	unreacted FeSiO catalyst (starting material, generated Oct 2003) Si:O2:Fe=30; H2=125; T~500C; P~80 torr
		no	silica smoke (1/31/02)	-	n/a			215mg (20m	unreacted Si-O smoke (generated 1/31/02 by Nuth/Hill) H2=0; He=150-300; O2=125; SiH4=25; T=500-734C (smudgy blue marker on lid)
5/31/13	Hadamcik, Edith	no	graphite powder	-	n/a	-		tiny black ca	technical grade, B. Preiser Company, Inc. (lot info?: 5# T 409)
		yes	graphite reacted (botton	600C	18		10/24/08	93 mg (tiny b	reacted graphite powder from base of reaction finger
		yes	FeSiO (Fall 2009) react	550C	15	summer 2010		21 mg (tiny b	MKopstein rxn; 15 cycles completed (final, from reaction finger, sample from 20ml while vial)
		yes	FeSiO (Fall 2009) react	550C	8	summer 2010		20 mg (tiny b	MKopstein rxn; 8 cycles completed (~20 days)
		no	FeSiO smoke (Fall 200	-	n/a	stock		~100mg (tiny	unreacted FeSiO catalyst (starting material, generated Fall 2009) Si:O2:Fe=30; H2=125; T~500C; P~80 torr
		no	MgSiO smoke (Fall 201	-	n/a	stock		~100mg (tiny	unreacted MgSiO smoke (Fall 2012 batch) Si:O2=30; H2=100; T~440C, P~75-85 torr
3/1/13	Hadamcik, Edith	no	graphite powder	-	n/a	-		tiny black ca	technical grade, B. Preiser Company, Inc. (lot info?: 5# T 409)
	not received	yes	graphite reacted (botton	600C	18		10/24/08	75 mg (tiny b	reacted graphite powder from base of reaction finger
		yes	FeSiO (Fall 2009) react	550C	15	summer 2010		21 mg (tiny b	MKopstein rxn; 15 cycles completed (final, from reaction finger, sample from 20ml while vial)
		yes	FeSiO (Fall 2009) react	550C	7	summer 2010		10.3 mg (tiny	MKopstein rxn; 7 cycles completed (~20 days)
		no	FeSiO smoke (Fall 200	-	n/a	stock		~100mg (gre	unreacted FeSiO catalyst (starting material, generated Fall 2009) Si:O2:Fe=30; H2=125; T~500C; P~80 torr
		no	MgSiO smoke (Fall 201	-	n/a	stock		~100mg (gre	unreacted MgSiO smoke (Fall 2012 batch) Si:O2=30; H2=100; T~440C, P~75-85 torr
2/20/13	Perera, Thushara	no	FeSiO smoke (Fall 200	-	n/a	stock		380mg (20m	unreacted FeSiO catalyst (starting material, generated Fall 2009) Si:O2:Fe=30; H2=125; T~500C; P~80 torr
		no	MgSiO smoke (Fall 201	-	n/a	stock		340mg (20m	unreacted MgSiO smoke (Fall 2012 batch) Si:O2=30; H2=100; T~440C, P~75-85 torr
2/14/13	Chizmadia-Fuson, Lysa	no	FeSiO smoke (Fall 200	-	n/a	stock		1.0g (20ml w	unreacted FeSiO catalyst (starting material, generated Fall 2009) Si:O2:Fe=30; H2=125; T~500C; P~80 torr
1/15/13	Hoffman, Eugene	no	MgSiO smoke (Fall 201	-	n/a	stock		0.8g (20ml w	unreacted MgSiO smoke (Fall 2012 batch) Si:O2=30; H2=100; T~440C, P~75-85 torr
12/15/11	Getty, Stephanie	no	FeSiO smoke (Sept 200	-	-	-		tiny black ca	unreacted FeSiO catalyst (starting material, generated Sept 2003)
12/15/11		yes	FeSiO reacted	300C				tiny black ca	reacted FeSiO catalysts
12/15/11		yes	FeSiO reacted	600C	18		6/20/09	tiny black ca	reacted FeSiO catalysts
3/31/11	Chizmadia-Fuson, Lysa	no	Fe/Mg Silicate (1/5/00) GK					basic white v	unreacted Fe/Mg silicate smoke (generated 1/5/00) run by GK (1 of 3?) vials
3/31/11		no	FeSiO (Fall 2009)					~750mg	unreacted FeSiO catalyst (starting material, generated Fall 2009) Si:O2:Fe=30; H2=125; T~500C; P~80 torr
3/31/11		no	SiOx (3/1/11) Nuth					~650mg	unreacted SiOx smoke (generated 3/1/11 by Nuth) beige
3/31/11		no	FeSiO smoke (?) (3/29/11)					2 basic white	unreacted FeSiO smoke (generated 3/29/11 by Johnson/Nuth); helium ran out during run; unclear how much iron, if any, was incorporated)
12/17/10	Brucato, John Robert	no	MgSiO smoke (8/8/01)	-	-	-		basic white v	unreacted MgSiO smoke (generated 8/8/01) Si:O2=30; H2=125, T~503C
12/17/10		no	FeSiO (Fall 2009)	-	-	-		basic white v	unreacted FeSiO catalyst (starting material, generated Fall 2009) Si:O2:Fe=30; H2=125; T~500C; P~80 torr
7/12/10	Rummeli, Mark	no	glass wool	-	-	-		dime sized	glass wool placed in taped weigh paper 'envelope'
7/12/10		no	graphite powder	-	-	-		tiny black ca	technical grade, B. Preiser Company, Inc. (lot info?: 5# T 409)
7/12/10		yes	graphite reacted (top)	600C	18		10/24/08	tiny black ca	reacted graphite powder from glass wool
7/12/10		yes	graphite reacted (botton	600C	18		10/24/08	tiny black ca	reacted graphite powder from base of reaction finger
5/26/10	Bradley, John	no	FeSiO (Fall 2009)	-	-	-		tiny black ca	unreacted FeSiO catalyst (starting material, generated Fall 2009) Si:O2:Fe=30; H2=125; T~500C; P~80 torr
5/26/10		no	MgSiO smoke (8/8/01)	-	-	-		tiny black ca	unreacted MgSiO smoke (generated 8/8/01) Si:O2=30; H2=125, T~503C
5/18/10	Chizmadia-Fuson, Lysa	no	Si-O (1/31/02)	-				200mg	unreacted Si-O smoke (generated 1/31/02 by Nuth/Hill) H2=0; H2=150-300; O2=125; SiH4=25; T=500-734C (smudgy blue marker on lid)
5/18/10		no	Mg-Fe silicate (1/4/00)					350mg	unreacted Mg-Fe silicate (generated 1/4/00)
5/18/10		no	MgSiO smoke (8/8/01)					300mg	unreacted MgSiO smoke (generated 8/8/01) Si:O2=30; H2=125, T~503C
5/18/10		no	Mg-Al silicate (5/14/02)					1370mg	unreacted Mg-Al silicate (generated 5/14/02) Si:O2:Al=30; H2=125; T~675C
5/18/10		no	FeSiO smoke (Oct 2003)					2000mg	unreacted FeSiO catalyst (starting material, generated Oct 2003) Si:O2:Fe=30; H2=125; T~500C; P~80 torr
5/18/10		no	FeSiO (Fall 2009)					1000mg	unreacted FeSiO catalyst (starting material, generated Fall 2009) Si:O2:Fe=30; H2=125; T~500C; P~80 torr
5/18/10		no	FeSiO (9/29/03)					1360mg	unreacted FeSiO catalyst (starting material, generated 9/29/03) bottle 9 of 29; beige color caused by Fe(CO)5 running low
3/3/10	Hussaini, Razi	no	graphite powder	-				~25cm^3	technical grade, B. Preiser Company, Inc. (lot info?: 5# T 409)
3/3/10	Hussaini, Razi	yes	FeSiO reacted	600C	16		2/20/09	~200mg	reacted FeSiO catalysts
3/3/10	Hussaini, Razi	no	FeSiO (Fall 2009)	-	-			~100mg	unreacted FeSiO catalyst (starting material, generated Fall 2009)