A-968

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GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

12 December 1966

U. S. Army Missile Command
LANCE Project Office
Redstone Arsenal, Alabama

Attention: AMCPM-LCE

Subject: Monthly Progress Letter No. 1
Project A-968
"Neutralizer for Hot Gas-IRFNA System"
Covering the Period from 1 August to 30 September 1966
Contract No. DAAH01-67-C-0077

Gentlemen:

All tests conducted during the reporting period are summarized in Table I, and include tests with various combinations of Purple K, water, a 30% calcium chloride-water solution, as well as a few tests without neutralizer.

The tests conducted without the addition of IRFNA to the system were used to estimate the temperature level recorded by the thermocouples without reaction. These tests are summarized in Table II and plotted on Figure 1 as indicated temperature (thermocouple reading) versus grams neutralizer. It is noted that since fresh fuel-gas is being fed into the reactor, past the fast thermocouple, during piston movement, the reading of this thermocouple probably responds to the temperature of the incoming gas mixed with the chamber gas. Consequently, the other (slower) thermocouple is believed to be more indicative of the situation in the reactor chamber.

A number of different combinations of the Purple K neutralizer with other materials (water, calcium chloride solution, etc,) were subjected to preliminary examination. These tests are reported in Table III, in order of increasing quantity of IRFNA.

The data from Table III is plotted in Figure 2 as indicated temperature versus weight of neutralizer. The different quantities of IRFNA and the different types of neutralizer are shown in the coded information for each point. There does not appear to be any distinct trend indicated.

A few tests were run with injection of the IRFNA starting at 0.3 seconds rather than at 1.3 seconds, with a three second duration of injection. These data are tabulated in Table IV.

TABLE I

SUMMARY OF DATA

Run No.	Mix Tank		Htr. Temp.	$T_{gas_{in}}$	Neutralizer	IRFNA Residual	IRFNA Inj. Rate	IRFNA Dip	Inject Start	Time End	Time Stroke End	$P_{g_{max}}$ psi	θP_{max} sec	P_{H_2O} max	Fast TC °F	Fast TC θ	Slow TC °F	Slow TC θ	Rate of Rise Initial	Rate of Rise Due to Injec	Remarks
8-8	1280	950	2160	1830	14 gm PK + 2.3 cc H_2O	2	2.3	24.0 (8.7)	1.86	5.02	5.85	1086/1172	0.55/8.75	1043	791	9.15	808	9.5	6220		
	1020	650	2190		Polyethylene	2	2.3	(8.4)	1.09	4.27		838	0.35	800	693	4.75	497	2.0	5440		
8-9	1300	920	2140	1810		2	2.2	10.6 (8.6)	1.10	4.27	5.34	1075	0.55	1034	735	0.5	563	1.35	5980		
	950	665	2140	1790		2	2.3	0.0 (10)	1.10	4.27	6.16	776	0.3	766	793	0.4	585	1.5	5440		
8-10	1300	940	2220	1885		2	2.1	8.0 (8.2)	1.05	4.23	5.31	1086	0.5	1053	968	0.45	735	1.10	6000		
	1000	750	2210	1860		2	2.2	24.0 (9.0)	1.09	4.27	5.95	842	0.35	808	1485	3.2	1772	4.40	5280		
8-11	1300	1000	2290	1940		2	2.1	10.6 (7.1)	1.10	4.27	5.55	1079	0.51	1058	1091	2.85	1934	3.75	6220		
	1080	730	2290	1925		2	2.2	21.2 (10.8)	1.11	4.29	6.21	889	0.3	855	1011	0.35	884	0.55	6820		
8-12	1300	985	2265	1940	14 gm PK + 2.3 cc H_2O	2	2.1	15.9 (8.2)	1.02	4.20	5.26	1086/1300	0.5/5.85	1062/1250	1158	5.85	1286	5.85	6040		
	1070	665	2170	1840	in chamber void	2	2.2	10.6 (5.5)	1.06	4.24	5.91	892/1070	0.3/3.26	860/1043	1116	3.91	1330	3.95	6980	1420	Barksdale Valve open @ start of test
8-16	1300	930	2240	1915	14 gm PK	2	2.4	(8.8)	1.12	4.27	5.40	1020/1474	0.69/6.04	1001/1419	1424	7.54	1659	6.89			$(\frac{dP}{d\theta}$ = 1240 @ bottom), Fast TC out
	1050	710	2170	1825		2	2.3		1.08	4.19	5.95	850	0.5	827			385	2.5	3480		
8-17	1300	1000	2260	1920	2.3 gm H_2O above piston	2	2.1	15.9 (7.1)	1.02	4.17	5.26	1075	0.7	1043	998	0.62	1556	4.62	5000		
	1080	685	2180	1840	2.3 gm H_2O above piston	2		MT* tank on at start		4.22	5.83	931	0.45	907	2257	1.33	1394	3.07	5820		IRFNA valve open @ start of run
8-18	1300	940	2150		14 gm PK							1071	0.55	1034	757	0.6	431	3.1	3690		
	1060	730	2150	1805							5.85	869	0.35	851	658	0.6	386	5.85	3000		
8-19	1300	950	2180	1850	14 gm PK, 2.3 cc H_2O (above						5.36		0.45	1034	820	0.45	400	5.36	3880		
	1010	690	2180	1830	piston - Polyethylene)						6.08	823	0.35	808	650	0.35	350	6.08	4100		
8-22	1300	920	2240		14 gm PK						Const. Vol.	962	0.76		1116	0.38	565	3.0	3480		Ablative Test - Constant Volume
	970	670	2140									695	0.45		1074	0.32	563	3.0	2960		
8-24	1250	860	2270		14 gm PK		2.1	8.0 (6.7)	1.07	4.23	Const. Vol.	920	0.6		1137	0.32	735	0.65	3660		Ablative Material - Constant Volume
	885	615	2210				1.9	10.6 (6.3)	1.05	4.2		632	0.32		1074	0.25	563	0.81	3340		
8-25	1300	800	2210								Const. Vol.	951	0.4		1154	0.3	735	0.66	3800		Ablative Material - Constant Volume
	1010	671	2190									745	0.4		1116	0.28	714	0.60	3500		
8-26	1300	900	2150				2.2	0.0 (7.2)	1.12	4.29	Const. Vol	962	0.5		1137	0.31	727	0.76	4640		Ablative Test - Constant Volume
	930	650	2175				2.0	? (6.3)	1.1	4.26		679	0.37		1137	0.32	791	2.23	2960		
8-29	1300	910	2220				2.2	2.1 (7.1)	1.12	4.27	Const. Vol.	962	0.45		1235	0.37	714	0.75	4120		Ablative Test - Constant Volume
	930		2205				1.5	? (4.9)	1.08	4.24		648	0.4		1137	0.37	863	5.0	3120		
8-30	1300	910	2140				1.8	2.1 (6.1)	1.07	4.24	Const. Vol.	873	0.5		1167	0.3	752	0.93	4440		Ablative Material Test - Constant Volume
	1050		2140				2.3	? (7.1)	1.12		Const. Vol.	585	0.4		1137	0.3	563/1053	0.75/4.75	3100		Ablative Material Test - Constant Volume
8-31	1300		2210		14 gms PK; 2.3 cc 30% $CaCl_2$		3.1	(10.8)		4.26		884		1034	726	4.5	363	2.0	6220		
9-1	1300	930	2220		14 gms PK; 3.4 cc 30% $CaCl_2$	2	2.0	0				958		1062	744	5.25	363	5.25	6440		Doubtful injection
9-2	1300	830	2285		14 gms PK; 4.3 cc 30% $CaCl_2$	2		(7.3)						1039	748	5.0	-	-			Chamber pressure gage polarity reversed
	960		2260			2	2.6	(7.6)				780		757	484	5.0	300	2.0	6200		

*Empty

(Continued)

TABLE I

SUMMARY OF DATA

Run No.	Mix Tank		Htr. Temp.	$T_{gas_{in}}$	Neutralizer	IRFNA Residual	IRFNA Inj. Rate	IRFNA Dip	Inject. Start	Time End	Time Stroke End	$P_{g_{max}}$ psi	$\theta_{P_{max}}$ sec	$P_{H_2O_{max}}$	Fast TC °F	Fast TC θ	Slow TC °F	Slow TC θ	Rate of Rise Initial	Rate of Rise Due to Injec.	Remarks
9-6	1300	920	2230		14 gm PK; 4.3 cc 30% $CaCl_2$	2	2.2	34.0	(8.2) 1.08	4.24		1083	0.5	1043	497	6.0	297	6.02	6200		
	970	660	2210			2	2.2		(7.8) 1.08	4.26		815	0.4	790	383		497		5960		
9-7	1300	830	2220	1930	14 gms PK; 4.3 cc 30% $CaCl_2$	4	2.4	31.0	(8.5) 1.05	4.23	6.52	1044	0.47		310	3.5	296	1.57	7000		
	910	600	2200	1835		4	2.2	0.0	(7.4) 1.07	4.24	7.59	776	0.28		383	7.59	287	3.25	6360		
9-8	1300	890	2240	1890	14 gms PK; 4.3 cc 30% $CaCl_2$	4	2.3	10.6	(8.4) 1.05	4.25	6.29	1086	0.4		1099	5.1	290	2.72	6980		
	860	400	2300	1910		4	2.2	10.6	(7.8) 1.12	4.30	7.75	714	0.27		633	4.5	260	1.66	5820		
9-9	1300	890	2200	1860	14 gms PK; 4.3 cc 30% $CaCl_2$	6	2.9		1.1	4.30	6.0	1086	0.57		799	3.75	296	2.77	6140	Neg.	Injection questionable
	960	560	2210	1835		6		5.3	(9.7) 1.12	4.29	7.84	737	0.3		639	7.0	274	7.84	5740		
9-12	1300	920	2260	1900	14 gms PK; 4.3 cc $CaCl_2$	6	2.5	0.0	(8.6) 2.46	5.66	6.27	1044	1.22		938	5.8	431	3.15			Barksdale valve cracked open @ start of test
9-13	1300	900	2280	1930	14 gms PK; 4.3 cc 30% $CaCl_2$	6		0 ?			6.03	1110	0.58	1072	701	5.0	400	5.0	6980		Bkdle Valve cracked open @ start of test, doubtful injection
9-14	1300	940	2320	1960	14 gms PK; 4.3 cc 30% $CaCl_2$	6		5.3 ?	2.57	4.30	6.07	1105	0.45	1048	735	4.25	458	0.75			Ch. press. pen did not write
9-15	1300	890	2340	1980	14 gms PK; 4.3 cc 30% $CaCl_2$	6		5.3			6.20	1125	0.4	1072	735	3.5	466	2.5			Mkr ckt not operating properly, P_{ch} pen not inking
	920	640	2240	1860		6		5.3	(8.9) 1.25	4.25	7.63	768	0.4	729	628	4.64	386	1.0			P_{ch} pen not inking
9-19	1300	890	2260	1910	14 gms PK; 4.3 cc 30% $CaCl_2$	6	2.8	10.6	(9.6) 1.11	4.25	5.94	1086	0.4	1058	761	4.5	386	6.0			Slight lk @ gas inlet of RC, P_{ch} pen not inking
	940	630	2215	1860		6	2.6	0.0	(9.0) 1.08	4.23	6.13	776	0.4	752	563	5.35	386	1.2			Slight lk @ spark plug, P_{ch} pen not inking
9-20	1300	830	2325	1975	14 gms PK; 4.3cc 30% $CaCl_2$	6	2.6	15.9	(9.6) 0.42	3.63	5.43	1086	0.4	1048	812	0.4	431	1.0	6980		
	1020	630	2190	1830		6	2.5	5.3	(9.4) 0.38	3.58	6.84	854	0.4	832	537	4.0	475	1.0	6980		Slight leak @ spark plug
9-22	1300	990	2265	1925	14 gms PK ; 4.3 cc 30% $CaCl_2$	6	0.9	0.0	(3.9) 0.37	3.58	5.77	1156	1.25	1105	out	out	2675	2.0	7680		
			2220	1870		6	1.7	0.0	(4.8) 0.40	3.61	6.32	954	1.75	917	out	out	2144	3.61	6740		
9-23	1300	930	2265	1925	14 gms PK; 4.3 cc 30% $CaCl_2$	6	1.9	16.6	(2.5) 0.40	3.61	5.94	1086/1214	1.15/1.35	1048/1175	1637	3.51	1957	2.7	7060	640	
	1040		2235	1870		6	2.0	29.0	(8.0) 0.35	3.56	7.01	854	0.4	827	654	5.18	409	7.01	6280		
9-26	1300	940	2280	1930	14 gms PK	6	2.0	10.6	(4.0) 0.65	3.56	6.2	1078/1249	0.65/2.11	1048/1208	1550	3.55	1627	3.4	6280	1780	
	1000	700	2200	1850		6	2.0	10.6	(3.0) 0.37	3.59	6.7	815/989	0.35/1.92	799/945	1762	3.15	no print		5660	1460	TC_2 indicated ΔT, did not ink
9-27	1300	940	2230	1900	12.6 gms PK; 7 cc 30% $CaCl_2$	6	2.0	5.3	(4.4) 0.37	3.57	5.76	1079/1257	0.37/2.02	1048/1222	1430	3.7	1685	2.8	6140	1330	
	1030	710	2220	1860		6	-				6.7	881	0.27	846	528	6.7	377	2.5			Mkr ckt not operating
9-28	1300	900	2230	1875	12.6 gms PK: 7 cc 30% $CaCl_2$	6		5.3			6.02	1079	0.5	1034	662	6.02	475	1.25			Mkr ckt not operating
	950	680	2240	1880		6	1.8	21.2	(3.5) 0.38	3.6	6.63	778/958	0.38/2.17	663/926	1503	3.9	981	4.5	5880		
9-29	1300	970	2240	1870	12.6 gms PK; 7cc 30% $CaCl_2$	4	2.0	5.3	(4.4) 0.36	3.64	5.23	1078/1207	0.4/1.65	1039/1152	1685	3.52	1158	5.23	6620	600	
	1000	720	2230	1890		4	1.3	5.3	(2.8) 0.37	3.62	6.79	854/1203	0.37/2.30	827/1161	1350	3.9	1636	4.15	7100	5450	
9-30	1180	830	2210	1890	12.6 gms PK; 7 cc 30% $CaCl_2$ solution	2	2.3		(1.8) 0.35	1.12	5.76	954/1389	0.36/2.80	940/1344	1305	3.8	no print		3840	2400	
10-4	1300	935	2210	1860	12.6 gms PK; 7 cc 30% $CaCl_2$	2	2.0	5.3	0.33	3.53	8.11	1136	0.4	1105	650	4.0	453	3.0			
	1000	660	2220	1840		2		8.0	0.37	3.6	9.57	838	0.4	813	554	7.0	363	0.75			

(continued)

TABLE I

SUMMARY OF DATA

Run No.	Mix	Tank	Htr. Temp.	$T_{gas_{in}}$	Neutralizer	IRFNA Residual	IRFNA Inj. Rate	IRFNA Dip	Inject Time Start	Inject Time End	Time Stroke End	$P_{g_{max}}$ psi	$\theta_{P_{max}}$ sec	P_{H_2O} max	Fast TC °F	Fast TC θ	Slow TC °F	Slow TC θ	Rate of Rise Initial	Rate of Rise Due to Inj.	Remarks
10-7	1120		2220		12.6 gms PK; 7 cc 30% $CaCl_2$ Sol'n		2.0		0.3	3.62		1017	0.45	959	968	3.98	926	4.55			
10-10	1240	945			12.6 gms PK; 7 cc 30% $CaCl_2$		2.0	2.7	0.32	3.62	7.98	1121	0.55	1081	1286	3.35	1695	3.85			
	930	695						2.7	0.33	3.63	9.28	811	0.32	780	2014	3.69	2081	3.80			
10-11	1300	1050			12.6 gms PK (only)		2.0	15.9	0.29	3.59	5.37	1125	0.34	1081	1503	2.37	1717	3.07			
	1050	790						10.6	0.34	3.65	8.82	923	0.34	879	2062	3.45	2144	3.25			
10-12	1300	960			14 gms PK (only)		2.0	15.9	0.31	3.61	8.09	1125	0.31	1081	1569	3.5	1658	3.66			(1) Approximately 6 gms PK remaining in basket
	1000	660						15.9	0.31	3.62	9.77	861	0.31	832	692	7.5	497	1.0			
10-13	1300	920			14 gms PK + 7.6 gm in and behind		2.9	10.6	0.33	3.63	8.08	1106/1211	0.55/2.15	1062	1925	3.50	1864	3.7			6.4 gms PK left behind finger (1)
	920	630			basket			8.9	0.31	3.62	(bottom)	683/1141	0.32/2.32	649	1459	3.0	1372	3.35			Piston inadvertantly at bottom at start
8-1	1300	710	2320		14 gms basket, 4.67 W, Poly on piston		3.1	(10.0)	1.1	4.22	-4.81	970/1292	0.4/4.39	970	1179	4.9	1031	6.0	4100	1660	Piston bottomed prior to injection, Barksdale valve open at start
8-2	1300	600	2360	1995	14 gms basket, 4.67 W, Poly on piston		2.1	(10.9)	1.09	4.83	5.82	1086	0.33	1043	947	2.85	585	1.5	5820		
8-3	1300	975	2100	1805	14 gms basket, 4.67 W, Poly on piston		2.3	(5.8)	1.12	4.30	5.22	1195	3.22	1161	1201	4.82	1307	5.17	5900	1450	
	970	610	2080	1735			2.3	(8.2)	1.09	4.27	6.65	787	0.31	761	755	0.35	541	1.5	5820		
8-4	1300	920	2220	1880	14 gms basket, 4.76 W, Poly on piston	2	2.1	(8.2)	1.07	4.26	5.81	1079	0.75	1039	837	0.75	572	1.75	6520		
	930	690	2210	1860		2	2.3	(5.9)	1.09	4.22	5.14	745/861	0.37/2.73	719/831	1416	3.67	1503	4.62	5440	465	
8-5	1300	925	2150	1825	14 gms basket, 4.76 W, Poly on piston	2	2.0	(8.1)	1.05	4.23	5.26	1086	0.45	1043	757	0.55	572	1.4	6600		
	1000	675	2100	1830			2.2	(8.1)	1.05	4.25	6.59	826	0.4	790	658	3.35	489	1.35	6140		

The data from Table IV is shown plotted in Figure 3. Again, no significant trend is apparent. It is noted that the quantities of residual and injected IRFNA, converting to full scale via the 100 times volume scale are shown below:

	Georgia Tech	Full Scale
Residual IRFNA	2 cc	12.2 in^3
	4 cc	24.4 in^3
	6 cc	36.3 in^3
Injection Rate	2 cc/sec	0.692 #/sec

The quantities of IRFNA used in these tests are somewhat more than expected in the full scale unit. However, if the neutralizer won't handle 12.2 in^3 of IRFNA, then little or no safety factor appears to exist.

It is further noted that with the quantity of IRFNA used as residual, the reaction system is initially oxidizer rich by a large factor. Experience with the constant volume reactor has shown that heavily oxidizer rich fuel gas reactions are relatively insensitive to the neutralizer.

Six tests were conducted for the purpose of testing the coating material on the piston seal. These tests were run under constant volume conditions with the specimen located both in the input gas stream and at a point where the injected IRFNA impacted on the samples. (The specimen have been subsequently sent to the sponsor). These tests are summarized in Table V.

Future Program

It is expected that the experimental work during the coming month will continue the studies of the mixed neutralizer (Purple K and calcium chloride solution).

Preparation for the low temperature (-40° F) studies and the seal material studies is well underway.

Respectfully submitted,

J. F. Kinney
Project Director

JFK/jw

TABLE II

NO IRFNA TESTS

Run No.	Neutralizer	TC_1 °F	TC_1 θ, sec	TC_2 °F	TC_2 θ, sec	Rate of P. Rise Initial	Remarks
2-23		922	0.60	692	0.65	7700	
		871	0.55	580	0.70	7400	
8-25		1154	0.3	735	0.66	3800	Constant volume
		1116	0.28	714	0.6	2500	
8-18	14 gms Purple K	759	0.6	431	3.1	3690	
		658	0.6	386	5.85	3000	
8-19	14 gms Purple K	820	0.45	400	5.36	3880	
	2.3 cc H_2O (Piston)	650	0.35	350	6.08	4100	
7-5	68 gms Purple K (on piston)	777		377			Barksdale Valve open @ start, recorder on slow speed
8-24	14 gms Purple K	1137	0.32	735	0.65	3660	Inj.@ 1.07 sec (Vol = C)
		1074	0.25	563	0.81	3340	Inj.@ 1.05 sec (Vol = C)

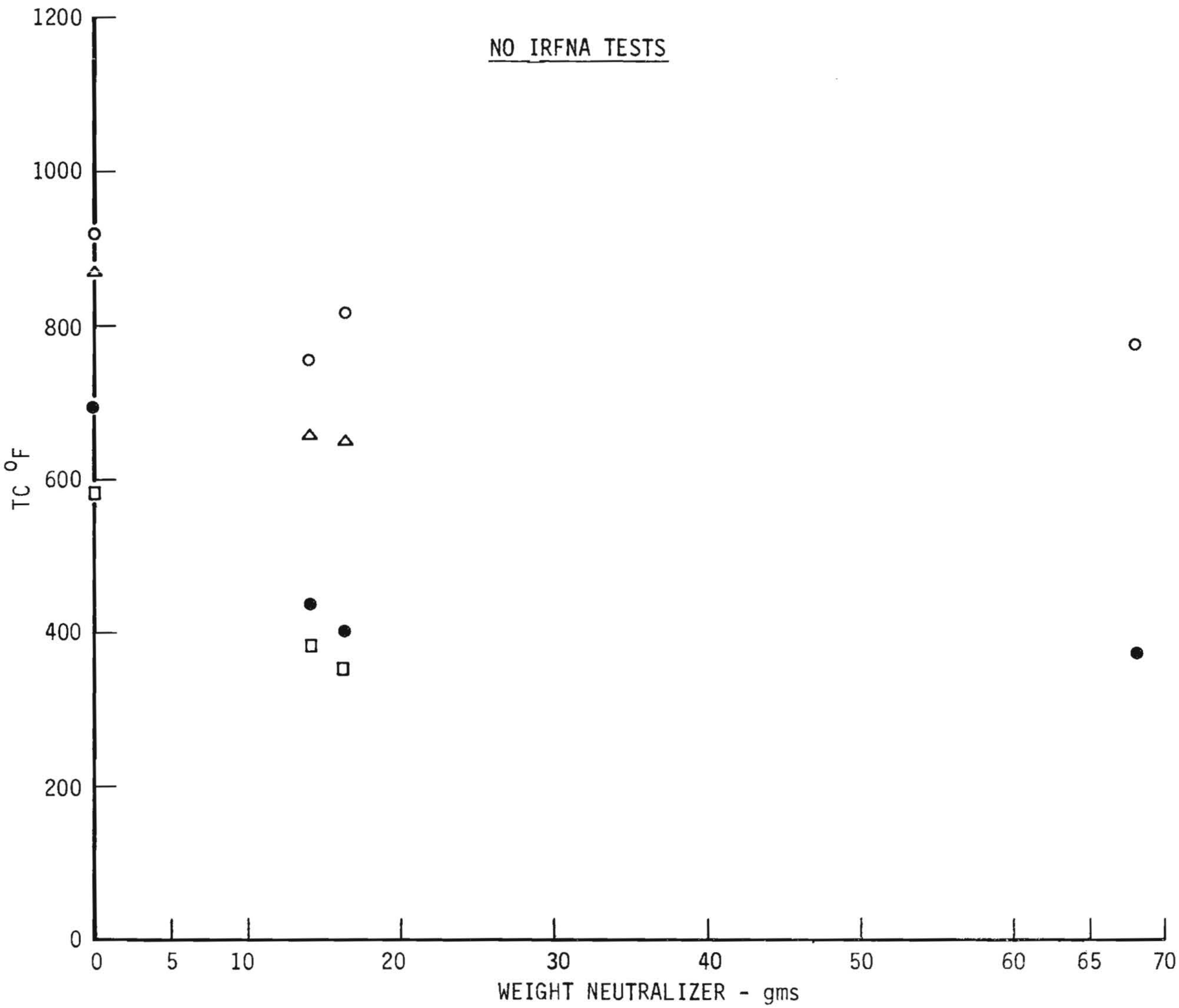

Figure 1. Indicated Temperature vs Weight Neutralizer.

TABLE III

HOT GAS-IRFNA TESTS WITH VARIOUS NEUTRALIZERS

Run No.	Residual cc	Injected cc/sec	Neutralizer	TC 1 °F	TC 1 Sec	TC 2 °F	TC 2 Sec
8-5	2	2		757	0.55	572	1.4
				658	3.35	489	1.35
8-9	2	2		735	0.5	563	1.35
				799	0.4	585	1.5
8-10	2	2		968	0.45	735	1.1
				1485	3.2	1772	4.4
8-11	2	2		1091	2.85	1934	3.75
				1011	0.35	884	0.55
8-17	2	2	2.3 cc H_2O (Piston)	998	0.62	1556	4.62
				2257	1.33	1394	3.07
8-16	2	2	14 gms Purple K	1424	7.54	1659	6.89
						385	2.5
8-12			14 gms Purple K + 1 cc H_2O	1158	5.85	1286	5.85
			(on piston)	1116	3.91	1330	3.95
8-8	2	2	14 gms Purple K + 2.3 gms	791	9.15	808	9.5
			H_2O in Polyeth.	693	4.75	497	2.0
9-1	2	2	14 gms Purple K + 3.4 cc	744	3.25	363	5.25
			30% $CaCl_2$ solution				
9-2	2	2	14 gms Purple K + 4.3 cc	748	5.0		
			30% $CaCl_2$ solution	484	5.0	300	2.0
9-6	2	2	14 gms Purple K + 4.3 cc	497	6.0	297	6.02
			30% $CaCl_2$ solution	386		492	
8-4	2	2	14 gms Purple K + 4.67 cc	837	0.75	572	1.75
			H_2O in Polyeth. (piston)	1416	3.67	1503	4.62
9-7	4	2	14 gms Purple K + 4.3 cc	310	6.5	296	1.57
			30% $CaCl_2$ solution	386	7.59	287	3.25
9-8	4	2	14 gms Purple K + 4.3 cc	1099	5.1	290	2.72
			30% $CaCl_2$ Solution	663	4.5	260	1.66
9-9	6	2	14 gms Purple K + 4.3 cc	799	3.75	296	2.77
			30% $CaCl_2$ Solution	639	7.0	274	7.84
9-12	6	2	14 gms Purple K + 4.3 cc	968	5.8	431	3.15
			$CaCl_2$ Solution				
9-13	6	2	14 gms Purple K + 4.3 cc	701	5.0	400	5.0
			$CaCl_2$ Solution				
9-14	6	2	14 gms Purple K + 4.3 cc	735	4.25	458	0.75
			$CaCl_2$ Solution				
9-19	6	2	14 gms Purple K + 4.3 cc	761	4.5	386	6.0
			$CaCl_2$ Solution	563	5.35	386	1.2
9-15	6	2	14 gms Purple K + 4.3 cc	735	3.5	466	2.5
			$CaCl_2$ Solution	628	4.64	386	1.0

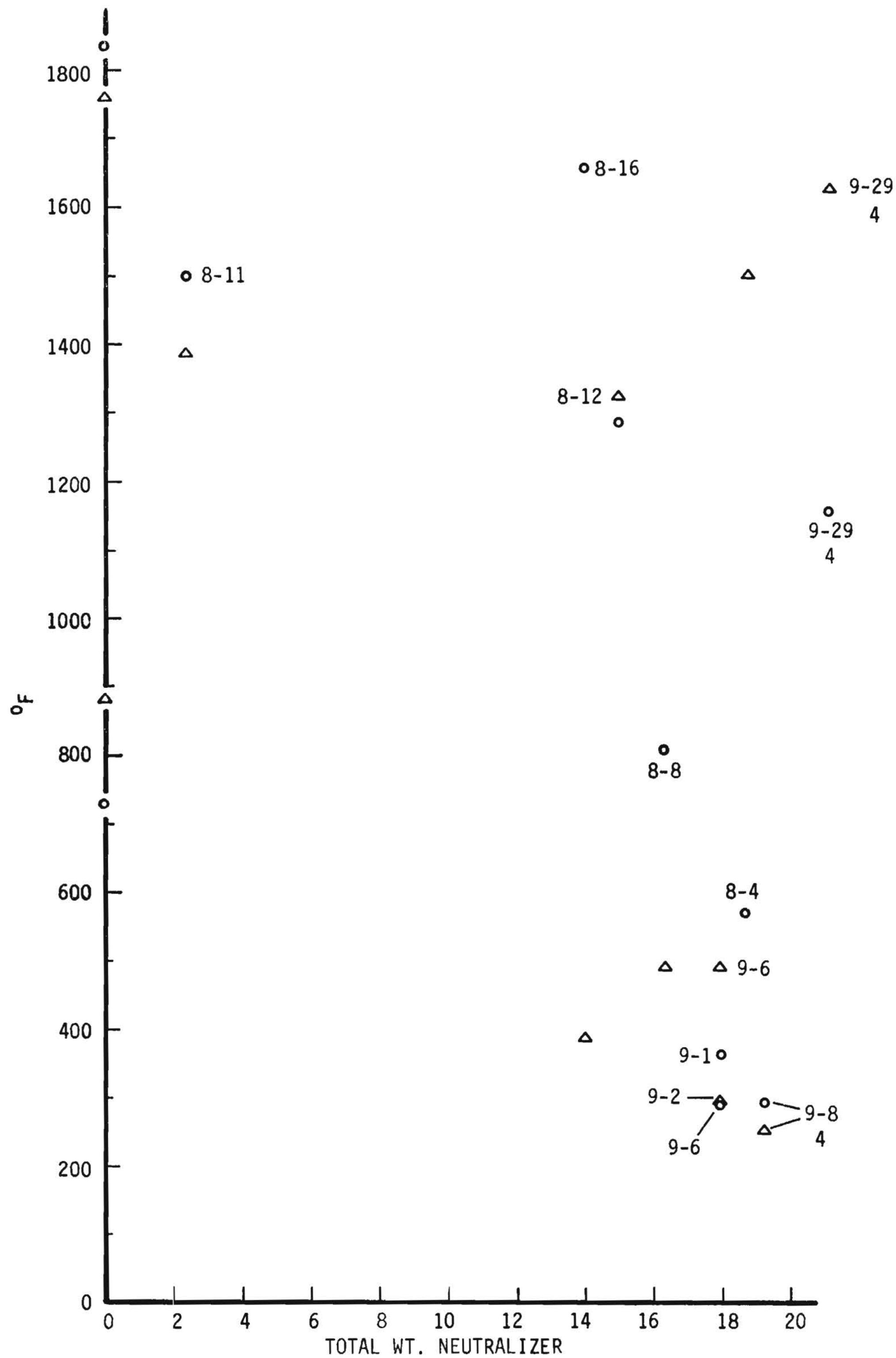

Figure 2. Indicated Temperature vs Total Weight Neutralizer.

TABLE IV

SUMMARY OF DATA FOR TESTS WITH EARLY INJECTION

Run No.	Residual cc	Injected cc/sec	Σ	Neutralizer	TC_1 °F	TC_1 sec	TC_2 °F	TC_2 sec
9-30	2	2.3	1.75	12.6 gms Purple K + 7.0 cc $CaCl_2$ Solution	1305	3.8		
9-29	4	2.0	4.4	12.6 gms Purple K + 7 cc	1685	3.52	1158	5.23
	4	1.3	2.8	$CaCl_2$ Solution	1350	3.9	1636	4.15
9-26	6	2.0	4.0	14 gms Purple K	1550	3.55	1627	3.4
	6	2.0	3.0		1760	3.15	--out--	
9-20	6	2.6	9.6	14 gms Purple K + 4.3 cc	812	0.4	431	1.0
	6	2.5	9.4	30% $CaCl_2$	637	4.0	475	1.0
9-22	6	0.9	3.8	14 gm Purple K + 4.3 cc	--out--		2675	2.0
	6	1.7	4.8	30% $CaCl_2$	--out--		2144	3.61
9-23	6	1.9	2.5	14 gm Purple K + 4.3 cc	1667	3.51	1957	2.7
	6	2.0	8.0	30% $CaCl_2$	659	5.18	409	7.01
9-27	6	2.0	4.4	12.6 gms Purple K + 7 cc	1460	3.7	1685	2.8
	6			30% $CaCl_2$	528	6.7	377	2.5
9-28	6			12.6 gms Purple K + 7 cc	662	6.02	475	1.25
	6	1.8	3.5	30% $CaCl_2$	1503	3.9	981	4.5

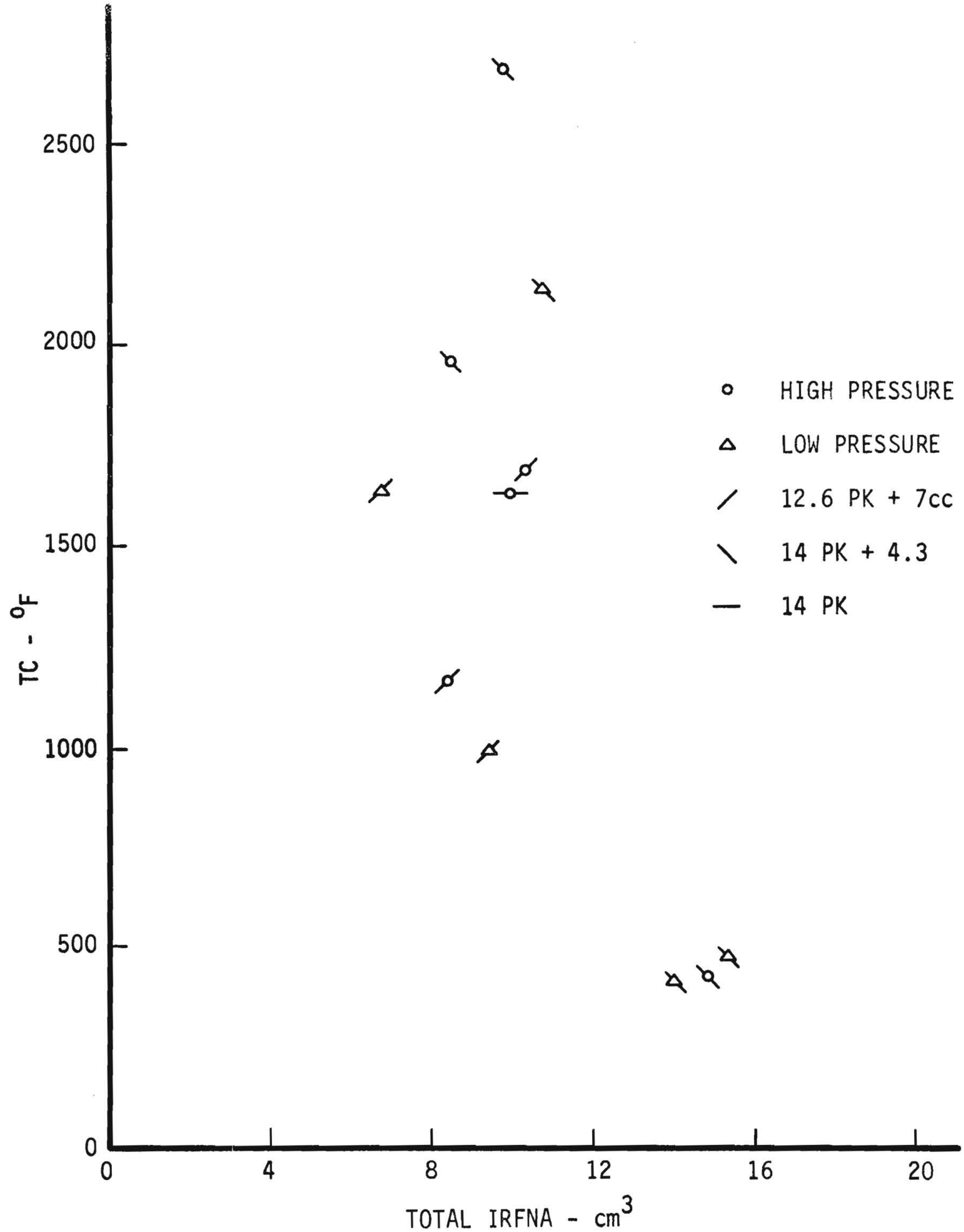

Figure 3. Early Injection Thermocouple Couple Reading vs Total IRFNA.

TABLE V

MATERIAL TESTS OF ABLATIVE

Run No.	Neutralizer	IRFNA		TC_1		TC_2	
		cc/sec	total	°F	sec	°F	sec
8-22	14 gms Purple K	--		1116	0.38	565	3.0
				1074	0.32	563	3.0
8-24	14 gms Purple K	2.1	6.7	1137	0.32	735	0/65
		1.9	6.3	1074	0.25	563	0.81
8-25	--	--		1154	0.3	735	0.66
				1116	0.28	714	0.60
8-26	--	2.2	7.2	1137	0.31	727	0.71
		2.0	6.3	1137	0.32	791	2.2
8-29	--	2.2	7.1*	1235	0.37	714	0.75
		1.5	4.9	1137	0.37	863	5.0
8-30	--	1.8	6.1*	1167	0.3	752	0.9
		2.3	7.1	1137	0.3	563/1053	0.75/4.75

*Injection time estimated

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA 30332

5 January 1967

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U. S. Missile Command
LANCE Project Office
Redstone Arsenal, Ala.

Attention: AMCPM-LCE

Subject: Monthly Progress Letter Report No. 2
Project A-963
"Continuation of Hot Gas-IRFNA Studies"
Covering the Period from October 1 to October 31, 1966
Contract No. DAAHO1-67-C-0077

Gentlemen:

During the month of October 1966, work continued on investigating the use of a combination of 30% $CaCl_2$ solution with "Purple K" as a neutralizer. As a comparison, runs were made with only "Purple K".

In addition, six no neutralizer runs were made with no residual and an approximate 2 cc/sec injection rate. Reaction did not occur on several of the no neutralizer runs. It was found that the mix tank pressure gauge and the injection pressure gauge were inaccurate, thus erroneously indicating a ΔP across the injection orifice when none actually existed. In addition, the IRFNA injection valve operation was marginal, resulting in questionable injection even when the proper ΔP was present. The valve was subsequently replaced and the gauges recalibrated.

Due to the inaccuracy of the gauges and marginal valve operation, data taken during the latter part of the month is of questionable value.

The data for the neutralizer tests have been plotted in Figure 1 as ΔT versus Total IRFNA and in Figure 2 as ΔT versus Initial Injection Rate. Only one no-neutralizer value has been plotted as a result of the problem with the gauges and the valve. The ΔT is based on the slow thermocouple and is

$$\Delta T = TC_{test} - TC_{st'd.}$$

REVIEW

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SUMMARY OF DATA TAKEN IN OCTOBER

Run No.	Mix Tank Start psi	Mix Tank End psi	Heater Temp. °F	Neutralizer gms	IRFNA R cc	IRFNA Inj. cc	IRFNA I. Rate cc/sec	Gas P_{Max} psi	Gas $\theta_{P_{Max}}$ sec
10-4	1300	935	2300	12.6 P.K. and 7 cc	0	5.4	2.7	1136	0.4
	1000	660	2340	30% $CaCl_2$	0	7.1	1.6	838	0.4
10-7	1120	845	2240	12.6 P.K. and 7 cc 30% $CaCl_2$	0	?		1017	0.45
10-10	1240	945	2375	12.6 P.K. and 7 cc	0	<1.0	0.00	1121	0.55
	930	695	2475	30% $CaCl_2$	0	4.5	1.0	811	0.32
10-11	1300	1050	2435	12.6 P.K.	0	3.6	0.8	1125	0.34
	1050	790	2390	12.6 P.K.	0	2.7	0.4	923	0.34
10-12	1300	960	2440	14.0 P.K. --	0	1.9	0.6	1125	0.31
	1000	660	2390	in basket	0	5.1	1.1	861	0.31
10-13	1300	630	2320	14 P.K. and 7.6 P.K. in	0	4.1	1.5	1211	1.75
	920	630	2320	polyethylene bag behind basket	0	4.4		1141	2.32
10-14	1300	940	2350	14 P.K. + 7.6 P.K. in bag	0	6.9	2.5	1227	1.75
	1060	745	2345	behind basket	0	5.8	2.3	1163	3.12
10-17	1300	1000	2300	No Neutralizer	0			1148	0.44
	930	695	2375	No Neutralizer	0	4.6		939	3.64
10-18*	1300	1000	2350	No Neutralizer	0	1.0		1132	0.50
	910	620	2340	No Neutralizer	0	1.0		896	1.4
10-20*	1300	955	2340	No Neutralizer	0	<1.0	1.6	1280	2.8
	1000	710	2355	No Neutralizer	0	7.8	2.0	970	1.10
10-21*	1280	895	2310	No Neutralizer	0	0.5		1171	1.01
	920	630	2375	No Neutralizer	0	3.2	1.9	833	1.0
10-24*	1300	887	2300	No Neutralizer	0	10.1		1163	0.70
	890	620	2325	No Neutralizer	0	7.7	2.2	977	0.38
10-25*	1300	933	2320	No Neutralizer	0	7.0	2.1	1094	0.64
	970	620	2485	No Neutralizer	0	6.9	1.7	822	0.30
10-26*	897	2355	2355	No Neutralizer	2	7.4	2.3	703	1.50
10-28	1300	905	2344	No Neutralizer	0	5.8	2.0	1064	0.6
10-30	1275	805	2350	No Neutralizer	0	6.5	1.8		

*IRFNA injection of questionable reliability

SUMMARY OF DATA TAKEN IN OCTOBER

Run No.	Inlet TC T_{Max} °F	Inlet TC $\theta_{T_{Max}}$ sec	TC T_{Max} °F	TC $\theta_{T_{Max}}$	Rate of Rise psi/sec	ΔT_2 °F	Remarks
10-4	650	4.0	453	3.0	7760	13	
	554	7.0	364	0.75	6210	36	
10-7	968	3.98	926	4.55	9540	376	Not enough pressure for low pressure run
10-10	1286	3.35	1695	3.85	6210	1165	
	2014	3.69	2081	3.80	6210	1641	
10-11	1503	2.37	1717	3.07	8540	1277	
	2062	3.45	2 44	3.25	6210	1704	
10-12	1569	3.50	1658	3.66	7760	1128	6 gms P.K. in basket after Run No. 1
	692	7.50	497	1.00	6210	67	
10-13	1925	3.50	1864	3.70	7360	1334	6.4 gms P.K. in basket after Run No. 1
	1450	3.00	1372	3.35	3870	932	
10-14	1864	3.70	1725	3.70	6980	1295	Plastic bag w/7.6 gms P.K. did not break on Run 1
	1481	4.42	1459	6.20	6980	1009	
10-17	777	0.45	714	0.55	7760	234	Cleaned intake pipe prior to Run No. 1
	1795	1.57	2452	3.64	6980	2012	
10-18*	757	0.48	715	0.55	7760	235	New inj. N_2 gauge
	632	0.57	541	0.55	5810	231	
10-20*	921	1.80			8540		Changed mix tank pressure gauge prior to run
	1521	4.15	1158	3.5	6590	728	
10-21*	888	0.32	536	0.70	8540	36	
	641	5.00	386	0.30	6210	106	
10-24*	854	1.07			6600		TC did not print } - First run with
	563	2.50			6990		TC did not print new IRFNA
10-25*	1006	0.45	563	3.70	6990	33	
	829	0.40	735	1.90	6990	285	
10-26*	1804	4.95	1257	5.87	1166	727	Leak at head gasket
10-28	1014	0.4	1014	4.75			Cold Box
10-30	888	0.9	735	4.65			Cold Box Marker Ckt. inoperative

*IRFNA injection of questionable reliability.

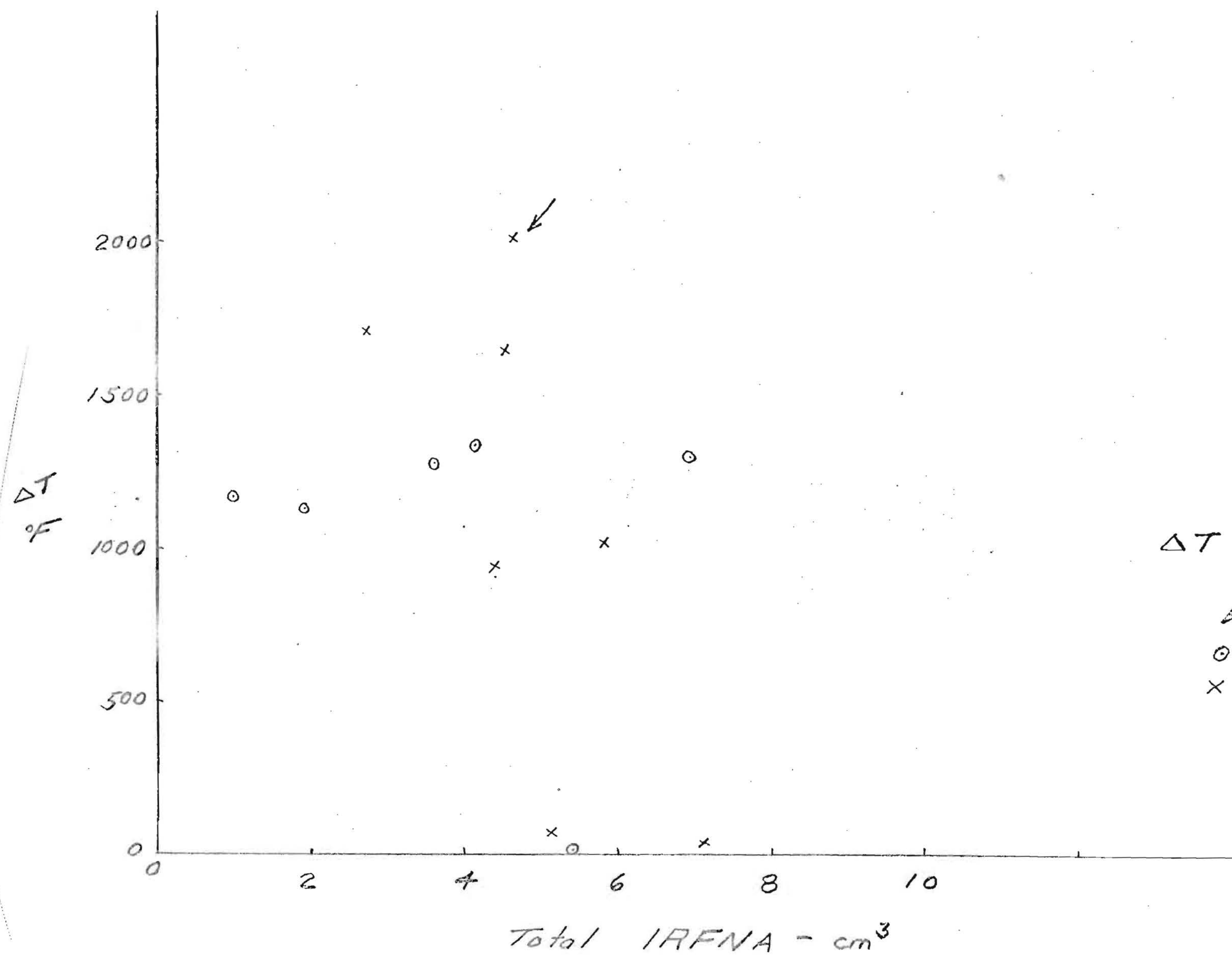
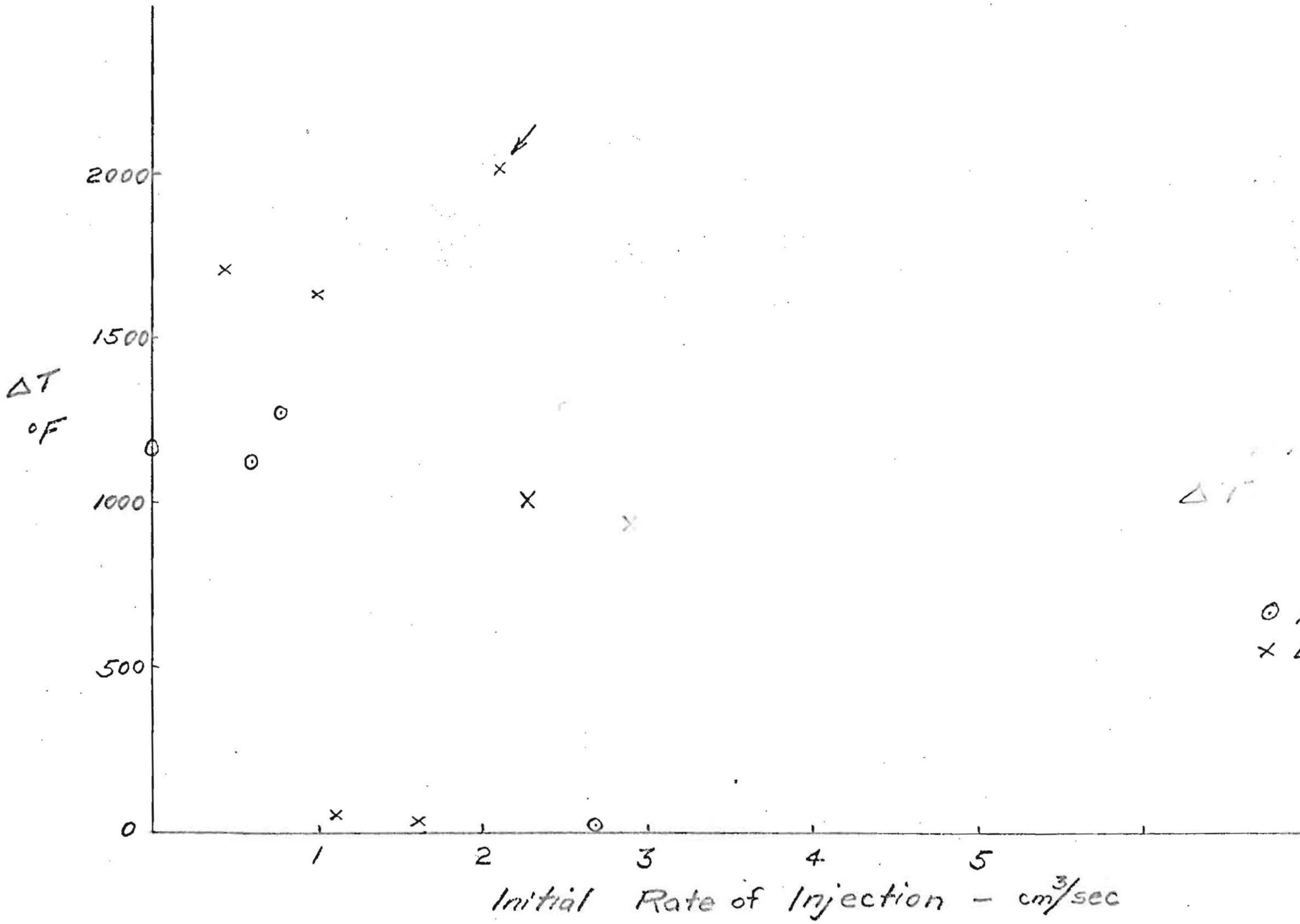


FIGURE 1

ΔT vs Total IRFNA

↙ No Neutralizer
⊙ High Pressue
× Low Pressure



URE 2

ΔT

No Neutralizer

⊙ High Pressure

× Low Pressure

where TC_{test} = thermocouple reading at $\theta_{T_{max}}$ (time of maximum temperature indication for test)

$TC_{st'd.}$ = thermocouple reading at $\theta_{T_{max}}$ for standard test with no-acid and 14 gms PK neutralizer

FUTURE PROGRAM

Work will begin in November using a "cold box" surrounding the reaction chamber and neutralizer basket to test the effect of the neutralizer on the reaction at an ambient temperature of -40° F. "Purple K" and "Purple K" plus 30% $CaCl_2$ solution will be used as neutralizers.

Respectfully submitted,

J. F. Kinney
Project Director

A-968

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA 30332

9 January 1967

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U.S. Army Missile Command
LANCE Project Office
Redstone Arsenal, Alabama

Attention: AMCPM-LCE

Subject: Monthly Progress Letter No. 3
Project A-968
"Continuation of Hot Gas-IRFNA Neutralizer Studies"
Covering Period 1 November 1966 to 1 December 1966
Contract No. DAAH01-67-C-0077

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Gentlemen:

All tests in November were made with a cold box surrounding the reaction chamber and neutralizer package. The ambient temperature and temperature of the reaction chamber were adjusted to approximately -40° F.

In addition to several tests made with no neutralizer, tests were made using 14 gms "Purple K" and 12.6 gms "Purple K" plus 7 cc 30% $CaCl_2$ solution as neutralizers (See Table I). The $CaCl_2$ solution was contained in a polyethylene bag and located immediately downstream of the neutralizer basket.

All tests were made with an approximate 2 cc/sec injection rate and either 0,1,2, or 4 cc of residual IRFNA (see Table I).

No neutralizer tests

Figure 1 shows a trend of increasing T_{max} with increasing total volume of IRFNA for no neutralizer tests.

Tests using 14 gms "Purple K" as neutralizer

Neutralization was not accomplished with 14 gms "Purple K". It can be observed in Figure 1 that most tests using 14 gms "Purple K" exhibited higher maximum temperature than those where no "Purple K" was used.

TABLE NO. I

RUNS FOR NOVEMBER 1966

	Mix Tank			IRFNA					Gas	
Run No. (Date)	Start (psi)	End (psi)	Htr. Temp. °F	Residual (cc)	Injected Volume (cc)	Initial Inj. Rate (cc/sec)	Average Rate (cc/sec)	Dip	P_{Max} (psi)	$\theta_{P_{Max}}$ (sec)
No Neutralizer										
11-1-66	1255	842	2355	0	6.89	1.89	2.09	3/16"	1088	0.85
11-2-66	1210	845	2310	0	4.88	0.95	1.49	1/16"	1041	0.37
11-3-66	1310	897	2320	0	5.63	1.62	1.70	1/16"	1116	0.65
11-28-66	1300	880	2365	1	5.89	1.52	1.825	1/16"	1101	0.28
	925	600	2345	1	Gas press. did not print			-	-	-
11-29-66	825	600	2375	1	Gas press. did not print			3/8"	-	-
11-30-66	1225	845	2280	1	4.20	1.059	1.29	0	1052	0.58
11-4-66	1280	905	2355	2	5.725	1.18	1.74	1/4"	1104	0.33
11-7-66	1310	905	2300	4	5.57	1.38	1.96	1/4"	1112	0.45
11-8-66	1285	900	2325	4	7.93	2.16	2.40	1/16"	1072	0.51
	895	595	2345	4	7.25	2.04	2.19	1/8"	741	0.33
Neutralizer: 14 gm P.K.										
11-14-66	1275	895	2366	0	5.68	1.50	1.75	1/8"	1082	0.47
11-15-66	1295	1095	2390	0	5.09	1.10	1.59	1/8"	1113	0.42
	1095	695	2331	0	8.27	1.89	2.53	3/16"	863	0.35
11-21-66	1200	0	2340	1	-	-	-	-	-	-
11-22-66	1275	850	2380	1	4.14	0.71	1.25	3/16"	1072	0.48
11-11-66	1300	960	2370	2	4.46	0.88	1.36	3/16"	1131	0.45
	1000	655	2366	2	9.64	2.42	2.97	-	788	0.30
11-9-66	1255	945	2365	4	10.1	2.86	3.07	3/16"	1068	0.75
	965	610	2327	4	8.84	2.00	2.68	1/16"	792	0.50
11-10-66	1275	895	2366	4	5.84	1.44	1.81	1/8"	1049	0.49
Neutralizer: 12.6 gm P.K. + 7 cc $CaCl_2$ Solution										
11-16-66	1300	755	2333	0	7.76	1.62	2.36	1/4"	1101	0.33
	770	500	2350	0	5.31	1.81	1.61	-	632	0.32
11-23-66	1285	885	2360	1	6.63	1.53	2.07	-	1088	0.30
11-17-66	1300	895	2332	2	5.66	1.90	1.72	3/16"	1039	0.53
11-18-66	1300	890	2390	4	6.53	1.20	1.98	1/4"	1116	0.50
	815	550	2375	4	4.60	1.49	1.39	1/16"	684	0.29

TABLE NO. I

RUNS FOR NOVEMBER 1966

Run No. (Date)	Inlet T.C. T_{Max} °F	Inlet T.C. $\theta_{T_{Max}}$ (sec)	T.C. T_{Max} °F	T.C. $\theta_{T_{Max}}$ (sec)	Rate of Rise (psi/sec)	Remarks
No Neutralizer						
11-1-66	905	0.50	880	3.10	5580	
11-2-66	981	0.45	675	4.45	6547	
11-3-66	Did not print		777	5.05	8923	
11-28-66	1929	2.30	1269	2.85	7440	
	519	0.30	278	0.30	-	
11-29-66	1892	3.00	1312	4.75	-	
11-30-66	879	3.60	1065	3.78	8930	
11-4-66	998	0.45	1040	1.27	9660	
11-7-66	1048	0.57	2237	1.37	8560	
11-8-66	989	0.50	820	1.40	8930	Leak at O-rings
	1591	2.15	1503	1.25	6330	Pressure Leak
Neutralizer: 14 gm P.K.						
11-14-66	Burned out		1808	1.98	7070	
11-15-66	837	1.60	1708	2.38	7070	
	666	4.88	368	0.82	5580	
11-21-66	-	-	-	-	-	Gasket blew out at Neut. Flanges
11-22-66	2217	1.60	2109	2.08	7440	
11-11-66	1006	1.56	1808	1.77	6700	
	684	3.47	386	0.93	5580	
11-9-66	2042	1.02	1326	4.81	7076	Leak at O-rings
	623	3.82	216	3.16	5580	-31°F Ambient on Run No. 2
11-10-66	1600	1.96	2052	2.36	7070	
Neutralizer: 12.6 gm P.K. + 7 cc $CaCl_2$ Solution						
11-16-66	597	5.05	378	6.40	7070	
	448	4.00	199	3.30	5960	
11-23-66	2379	3.58	1260	4.70	8930	
11-17-66	649	6.88	413	8.62	7070	
11-18-66	2338	3.97	519	7.10	9660	
	493	5.10	350	5.90	6700	

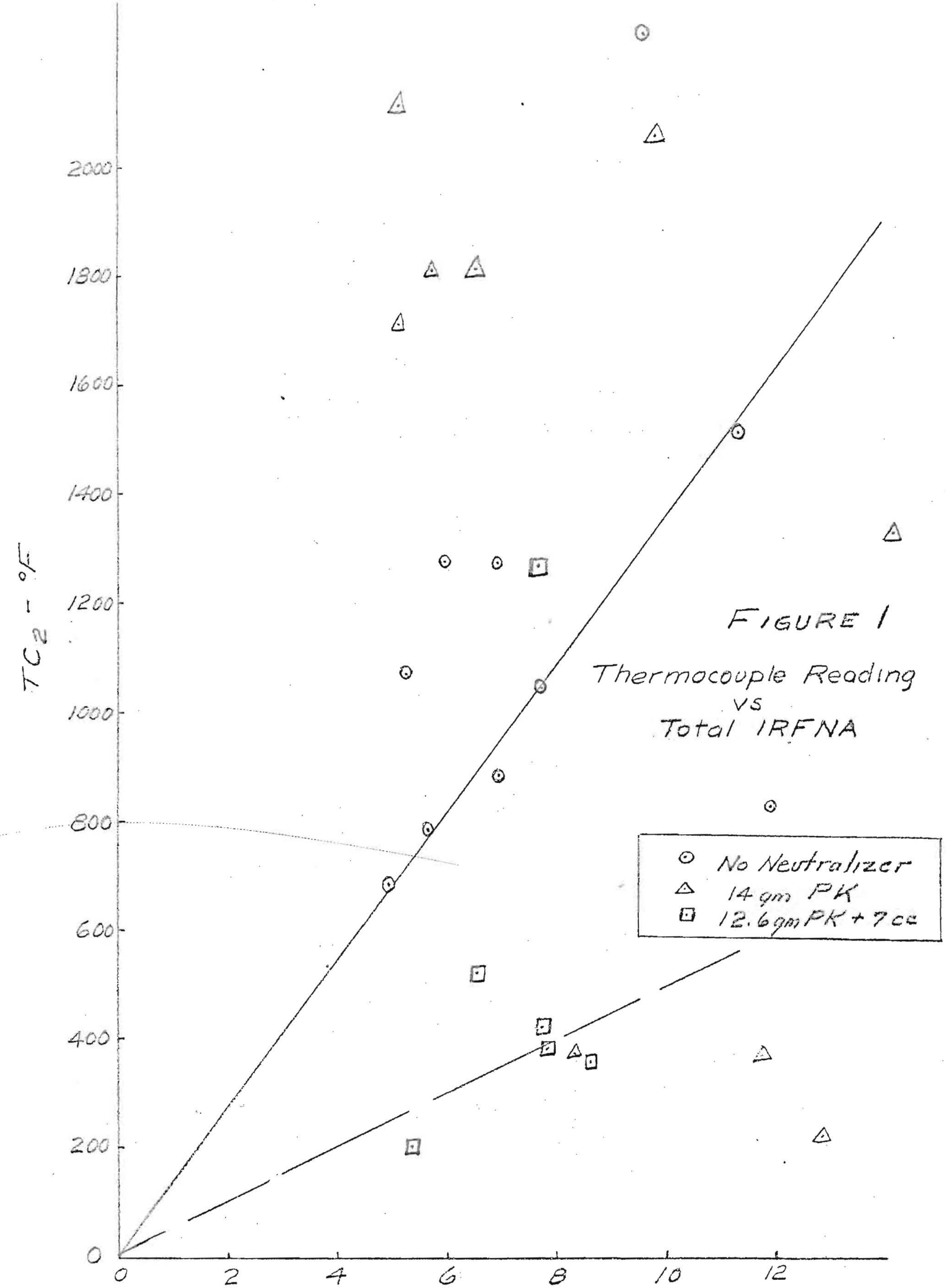

FIGURE 1
Thermocouple Reading
vs
Total IRFNA
No Neutralizer
14 gm PK
12.6 gm PK + 7 cc
TC_2 - °F
Total IRFNA --- cm^3
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2
4
6
8
10
12

Tests using 12.6 gms "Purple K" + 7 cc 30% $CaCl_2$ solution

Better neutralization was obtained using the combination neutralizer than those tests where 14 gms "Purple K" only was used. Neutralization was not accomplished for the tests made on 23 November and 18 November.

Respectfully submitted,

J. F. Kinney
Project Director

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

9 January 1967

U. S. Army Missile Command
LANCE Project Office
Redstone Arsenal, Ala.

Attention: AMCPM-LCE

Subject: Monthly Progress Letter No. 4
Project A-968
"Continuation of Hot Gas-IRFNA Neutralizer Studies
Covering the Period 1 December 1966 to 1 January 1967
Contract No. DAAHO1-67-C-0077

Gentlemen:

In the month of December, work was continued on tests with the cold box surrounding the reaction chamber and neutralizer basket. All tests using neutralizer were made without pressure tubes with the exception of the run made on 12-19-66. The data are summarized in Table I.

Two no-neutralizer tests were made, one being a reference test in which no acid was used. The other no-neutralizer test was a repeat of a November test in order to verify the results obtained previously.

Best neutralization was obtained by using a combination of 12.6 gms "Purple K" plus 7 cc, 30% $CaCl_2$ solution rather than the single component neutralizer, 14 gms "Purple K".

Comparison of the recorded temperature (slow thermocouple) with that of a reference (no acid) test, is tabulated in Table II, and includes all "cold-box" data to date. These data are plotted in Figures 1, 2, and 3 versus total quantity of IRFNA.

Respectfully submitted,

J. F. Kinney
Project Director

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TABLE NO. I

RUNS FOR DECEMBER 1966

Run No. (Date)	Mix Tank Start (psi)	Mix Tank End (psi)	Htr. Temp. °F	IRFNA Residual (cc)	IRFNA Injected Volume (cc)	IRFNA Initial Inj. Rate (cc/sec)	Avg. Rate (cc/sec)	Dip	Gas P_{Max} (psi)	Gas $\theta_{P_{Max}}$ (sec)
No Neutralizer										
12-29-66	1200	800		0	0	0	0	0	1030	0.55
12-30-66	1215	825		0	5.25	1.38	1.59	-	1032	0.50
Neutralizer - 14 gm P.K. without pressure tubes										
12-16-66	1300	885	2250	0	0	0	0	0	1109	0.35
12-8-66	1245	815	2360	1	6.73	2.21	2.20		996	0.80
12-2-66	1300	605	2380	2					-	-
12-6-66	1300	906	2345	2	6.94	2.39	2.19		848	0.54
Neutralizer - 12.6 gm P.K. + 7 cc 30% $CaCl_2$										
12-19-66	1300	900	2257	0	0	0	0	0	1082	0.56
12-9-66	1300	978	2300	2	-	-	-	-	-	-
12-12-66	1275	885		2	Injected all IRFNA in reservoir					-
12-15-66	1300	915	2270	2	5.05	1.29	1.51	1/16"	1101	0.42

TABLE NO. I

RUNS FOR DECEMBER 1966

Run No. (Date)	Intake TC T_{Max} °F	Intake TC $\theta_{T_{Max}}$ (sec)	TC T_{Max} °F	TC $\theta_{T_{Max}}$ (sec)	Rate of Rise (psi/sec)	ΔTC_2 °F	Remarks
No Neutralizer							
12-29-66	829	0.55	422	0.55	7440	-	Inlet TC was in off
12-30-66	-	-	998	3.93	5960	635	position during run
Neutralizer - 14 gm P.K. without pressure tubes							
12-16-66	632	4.60	359	1.88	6330	-	
12-8-66	1149	1.42	1485	3.20	>440	1165	
12-2-66	-	-	-	-	-	-	Blew cylinder
12-6-66	1175	3.32	1863	3.53	6330	1543	
Neutralizer - 12.6 gm P.K. + 7 cc 30% CaCl2							
12-19-66	482	5.50	359	5.45	-	-	With pressure tubes
12-9-66	-	-	-	-	-		Recorder paper slipping + Ambient not -40°
12-12-66	-	-	-	-	-	-	Without pressure tubes
12-15-66	649	0.70	769	4.50	6660	449	Without pressure tubes

TABLE II

COLD BOX DATA FOR NOVEMBER AND DECEMBER

Run No.	Σ	ΔT_2
No Neutralizer (ΔT referred to test 12-29-66)		
11-1-66	6.9	515
11-2-66	4.9	305
11-3-66	5.6	427
11-28-66	6.9	899
11-29-66		
11-30-66	5.2	695
11-4-66	7.7	640
11-7-66	9.6	1847
11-8-66	11.9	435
	11.3	
12-29-66	0	ref
12-30-66	5.3	623
Neutralizer: 14 gm P.K. (ΔT referred to test 12-16-66)		
11-14-66	5.7	1458
11-15-66	5.1	1373
	8.3	
11-21-66		
11-22-66	5.1	1759
11-11-66	6.5	1458
	11.7	
11-9-66	14.1	1006
	12.8	
11-10-66	9.8	1702
12-16-66	0	ref
12-8-66	7.7	1165
12-2-66	2	
12-6-66	8.9	1533
Neutralizer: 12.6 + 7 (ΔT referred to test 12-19-66)		
11-16-66	7.8	38
	5.3	
11-23-66	7.6	910
11-17-66	7.7	138
11-18-66	10.5	204
	8.6	
12-19-66	0	ref
12-9-66	2	
12-12-66		
12-15-66	7.1	14

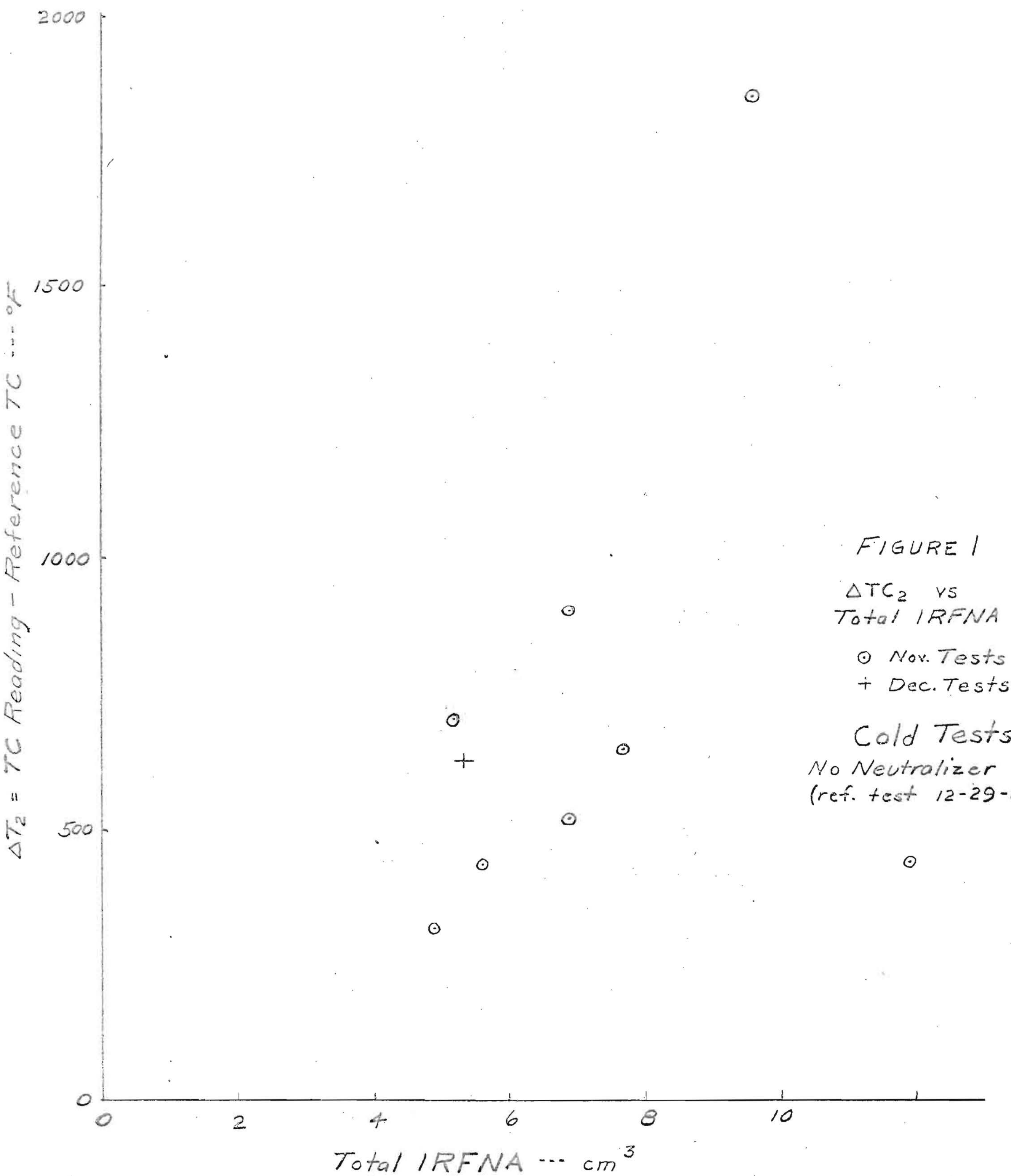

FIGURE 1

ΔTC_2 VS Total IRFNA

Cold Tests

No Neutralizer

(ref. test 12-29-66)

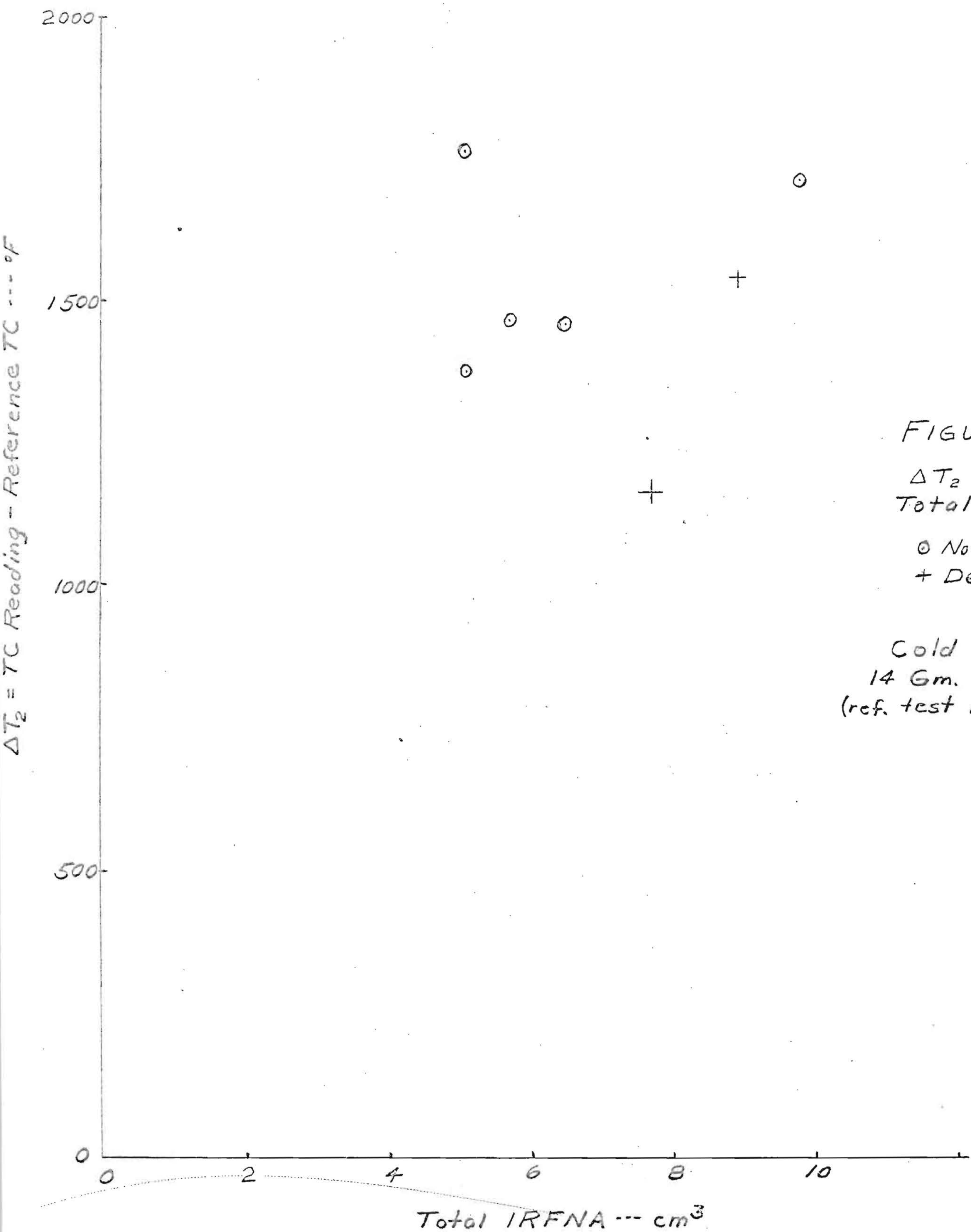

FIGURE 2

ΔT_2 VS
Total IRFNA

⊙ Nov. Tests
+ Dec. Tests

Cold Tests
14 Gm. P.K.
(ref. test 12-16-66)

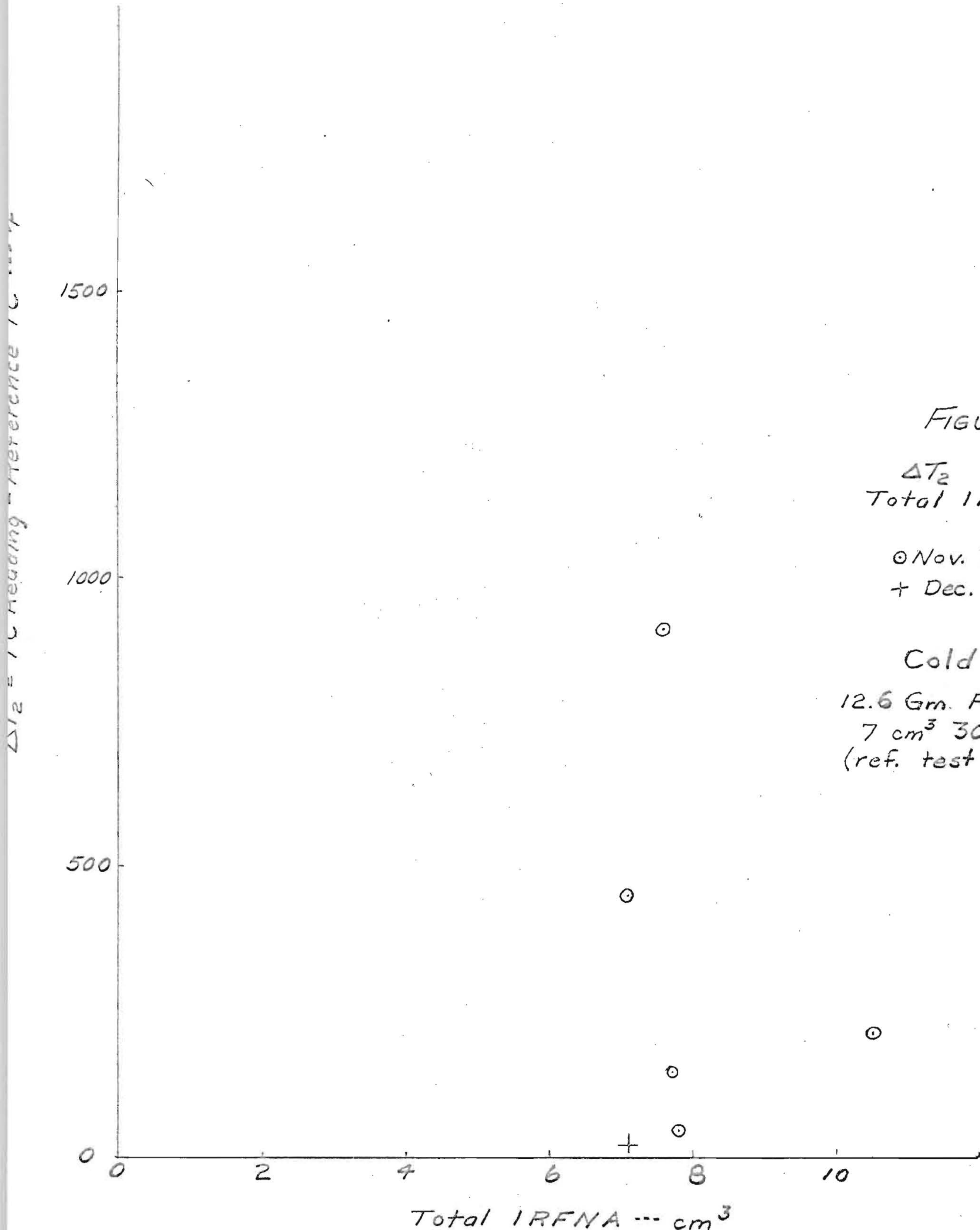

FIGURE 3

ΔT_2 VS
Total IRFNA

⊙ Nov. Tests
+ Dec. Tests

Cold Tests

12.6 Gm. P.K. +
7 cm^3 30% $CaCl_2$
(ref. test 12-19-66)

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

17 February 1967

U. S. Army Missile Command
LANCE Project Office
Redstone Arsenal, Alabama

Attention: AMCPM-LCE

Subject: Monthly Progress Letter No. 5
Project A-968
"Neutralizer for Hot Gas-IRFNA System"
Covering Period from 1 January 1967 to 1 February 1967
Contract No. DAAH01-67-C-0077

COPY

Gentlemen:

During the month of January 1967 testing was started to determine the effects of the IRFNA-Hot Gas reaction on piston seal material. The method consisted of injecting IRFNA along the edge of a flexed sample of the piston material while inside the reaction chamber and exposed to hot gas.

No Neutralizer runs

Several no neutralizer tests were made using 0, 2, and 4 cc residual IRFNA. In addition, on two of the tests (1-16 and 1-23), IRFNA was injected from the top of the reaction chamber (regular IRFNA injection). See Table I.

Two seal samples showed relatively severe signs of burning (1-10 and 1-23). The thermocouples indicated a definite reaction on both of these tests.

Slight indications of burning of the seal samples were observed on the tests made on 1-11 and 1-12. Neither of these tests exhibited significant increase in temperature.

All other samples used in the no neutralizer tests showed no visible signs of burning.

Neutralizer Runs

The neutralizer used for all neutralizer tests was a combination of 12.6 gms of Purple K plus 7 cc of a 30% $CaCl_2$ solution.

Two tests were made using 2 cc residual IRFNA, the rest were run without residual. Injected IRFNA was used on three of the tests. Neutralization occurred on all of the tests with the exception of those made on 1-26 and 1-27. None of the samples used in the neutralizer tests showed signs of burning.

The seal studies will continue in February in order to determine if seal sample burning can be made to occur without a temperature rise being indicated on the thermocouples.

Respectfully submitted,

J. F. Kinney
Project Director

JFK/h

TABLE I

SUMMARY OF DATA FOR JANUARY

Run No. 1967	Mix Tank Start psi	Mix Tank End psi	Htr. Temp. °F	IRFNA Residual cc	IRFNA Initial Inj. Rate cc/sec	IRFNA Avg. Inj. Rate cc/sec	IRFNA Injected Volume cc	Dip	Gas P_{max} psi	Gas $\theta_{P_{max}}$ sec	Inlet TC T_{max} °F	Inlet TC $\theta_{T_{max}}$ sec	TC T_{max} °F	TC $\theta_{T_{max}}$ sec	Rate of Rise psi/sec
No neutralizer															
1-10	Blew gasket in R. C.														
1-11	1300	765	2350	4	--	--	--	--	Polaroty reversed		1158	0.30	921	0.50	--
1-12	1300	880	2300	4	--	--	--	--	977	0.40	1106	0.25	580	0.85	4070
	885	--	2340	4	--	--	--	--	629	0.35	1244	0.20	632	1.00	3330
1-16	1300	800	2250	0	3.21	3.77	12.5	5/16	969	0.40	1032	0.30	457	0.60	3700
1-17	1300	750	2400	0	--	--	--	--	958	0.42	1082	0.32	457	0.92	3700*
1-19	1200	590	--	0	--	--	--	--	--	--	Incorrect scale used on TC's				
1-20	1300	--	2280	0	--	--	--	--	918	0.47	989	0.32	377	1.22	3552
1-23	1225	825	2150	2	4.04	3.60	8.55	1/16	999	1.57	1346	2.97	905	5.43	3478
Neutralizer -- 12.6 gms P.K. + 7 cc 30% C_2Cl Solution															
1-18	1300	790	2375	0	--	--	--	--	955	0.47	1048	0.27	536	1.07	3700
1-24	1300	--	2200	2	4.50	4.37	14.3	3/16	866	0.60	649	0.55	404	1.05	2960
1-26	1265	850	2360	2	4.35	2.83	9.44	1/16	1006	1.35	1699	3.25	989	4.80	3700
1-27	1300	--	2380	0	4.22	1.71	5.74	1/16	1088	2.00	1433	2.65	896	4.30	3552
1-30	1300	--	2390	0	--	--	--	--	969	0.45	1158	0.30	510	2.15	3700
1-31	1300	--	2300	0	--	--	--	--	962	0.40	1158	0.35	475	1.60	3700

*Micro-injection did not occur

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13 April 1976

1967

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U. S. Army Missile Command
LANCE Project Office
Redstone Arsenal, Alabama

Attention: AMCPM-LCE

Subject: Monthly Progress Letter No. 6
Project A-968
"Neutralizer for Hot Gas-IRFNA System"
Covering Period from 1 February 1967 through 28 February 1967
Contract No. DAAH01-67-C-0077

Gentlemen:

Five tests with neutralizer (12.6 gm Purple "K" compound and 7 cc, 30% $CaCl_2$ solution) and seven tests with no neutralizer were conducted during the month of February. These tests were all conducted with the temperature in the reaction chamber in the vicinity of -40° F, and were for the purpose of testing the effect of IRFNA leakage on the seal material.

In each test, the seal, under stress, was placed against the end of a hypodermic needle and against an aluminum stress plate such that the IRFNA passing through the needle had to flow past a stressed section of the seal, with TR-69 coated face of the seal toward the hot synthetic SPGG gas.

These tests are summarized in the attached table, with a general comment on the seal condition after the test (four catagories).

These seal tests are expected to continue for another month in an effort to detail those conditions which lead to the more severe action on the seal material.

Respectfully submitted,

J. F. Kinney
Project Director

JFK/h

FEBRUARY 1967 DATA SHEET

Run No. Date	Mix Tank Start psi	Htr Temp. °F	IRFNA Residual cc	IRFNA Initial Inj. Rate cc/sec	IRFNA Avg. Inj. Rate cc/sec	IRFNA Injected Volume cc	IRFNA Dip cc	Gas P_{max} psi	Gas $\theta_{P_{max}}$ sec	Inlet TC T_{max} °F	Inlet TC $\theta_{T_{max}}$ sec	Slow TC T_{max} °F	Slow TC $\theta_{T_{max}}$ sec	Sample TC T_{max} °F	Sample TC $\theta_{T_{max}}$ sec	Remarks
No Neutralizer																
2-1	1300	2390	1	3.10	1.31	4.33	--	1017	2.00	1441	2.30	718	5.50			14 ga needle -- SB
2-8	1300	2360	0	4.46	0.78	2.56	37	1102	1.50	1808	2.77	1398	4.90			#14 needle* -- SB
2-9	1254	2400	0	0	0	0	0	921	0.55	Not operating		457	3.00			IRFNA froze, 18 ga needle* -- NO
2-10	1285	2360	0	4.21	2.91	9.55	15	913	0.75	1116	0.30	404	1.35			#18 needle*, inj. not indicate -- NO
2-13	1300	2360	0	3.33	1.77	6.25	6	954	0.50	1150	0.35	386	2.45			14 ga needle* -- SB
2-14	1270	2380	0	1.91	0.83	2.74	--	1032	2.40	1235	3.30	650	5.25			14 ga needle* -- S
2-16	1300	2380	0	1.93	1.43	4.72	5	969	0.45	1158	0.30	475	2.75			*
Neutralizer -- 12.6 g P K + 7 cc 30% $CaCl_2$																
2-2	1300	2340	0	--	--	--	--	962	0.50	1090	0.35	475	1.10			Bottom piston injection only -- NO
2-3	1310	2350	0	--	--	--	--	932	0.50	1116	0.35	475	1.15			Bottom piston injection only -- NO
2-20	1200	2020	0	12.7	3.21	10.6	15	869	0.60	1158	3.00	692	4.85	Wrong scale setting off scale		Began before gas entered RC -- S
2-22	1220	2400	0	4.91	1.43	4.91	10	925	0.50	1158	0.35	422	2.10	1681	3.75	*
2 24	1300	2130	0	8.4	3.0	9.9	10	844	0.6	1137	0.4	533	2.4	1010	1.0	*

SB - Wire show
S - Subst.
B - Burn indicated
NO - No burn indicated

*Pressure injection from bottom

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May 19, 1967

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U. S. Army Missile Command
LANCE Project Office
Redstone Arsenal, Alabama

Attention: AMCPM-LCE

Subject: Monthly Progress Letter No. 7
Project A-968
"Neutralizer for Hot Gas-IRFNA System"
Covering Period from 1 March 1967 through 31 March 1967
Contract No. DAAH01-67-C-0077

Gentlemen:

Work continued on the studies of the compatibility of the seal material with IRFNA flowing past the seal into the hot gases. These tests show that severe burning of the seal material may be obtained with little or no indication on the thermocouple located at the top of the reaction chamber, but not directly in the flow path of the inlet gas (similar to the thermocouple location in the dead space above the Lance oxidizer piston). It is hoped that photographs (now being processed for inclusion in a forthcoming special report) will show the extent of this burning.

In addition, two tests were conducted to examine the effect of hot gas flowing past the seal interface into an IRFNA-rich atmosphere. In both cases, the effect of the gas flow was apparent.

The second test ruptured the small stainless steel box, possibly at the time the reaction chamber pressure was released by the blow-down operation. The seal acting as a flapper, closed the box tightly when the pressure inside the box exceeded the chamber pressure on the outside of the box. However, a hot gas-IRFNA vapor reaction would also have produced an excess pressure inside the box. The seal material was burned on the inside face to a greater extent on the second test than on the first test. But no surge of pressure, as produced by a rupture, was observed during the recording period of the test. Thus, the time of rupture of the box is unknown.

It is planned to try to conclude the seal studies during the coming month in order that the other phases of the work may be completed prior to the end of the contract.

Respectifully submitted,

J. F. Kinney
Project Director

JFK/kh

MARCH 1967 DATA SHEET

Run No.	Mix Psi	Tank Psi	Htr Temp. °F	Neutralizer	IRFNA Residual cc	init. Rate cc/sec	Avg. Rate cc/sec	init. Vol. cc	Dip cc	Gas P Max Psi	Gas θ sec	Intet TC T Max °F	Intet TC θ sec.	Slow TC T Max °F	Slow TC θ sec.	Rate of P. Rise	Remarks
3-1	1243	872		12.6 + 7cc (bot. ing #14 needle)					0	984	0.38	1244	0.32 (smple)	550 1061	2.5 1.08		
3-2	1290		2255 (2030)	(1/32" IRFNA in box w/ seal matl)						937	0.95	1222	0.5 (smple)	541 892	1.85 0.70		
3-8	1250	900	2210	12.6 + 7 cc (146) (TC over smpl)		8.3	2.33	7.66	2.76	890	0.55	1157	0.45 (820 @ 4.25)	528	1.45		
3-9	1280			12.6 + 7cc (166) (TC under smpl)		Mtd	IRFNA	tank	prior	1020	0.25	2150	1.65 (1887 @ .04 sec. ?)	1795	.53		
3-10	1280	790	2090	12.6 + 7 14G Box -						875	0.55	1158	0.35	542	2.3		
3-14	1260			12.6 + 7 14G (TC under smpl)		5.2	1.9	6.4	5.52			TC	scale gain	mis set			
3-15	1300	950	2220	12.6 + 7 14G (TC under smpl)		9.98	3.42	7.95	11	930	0.26	1158	0.45	820	3.52		
3-16	1280	940	2270	12.6 + 7 14G (TC under smpl)	(2014 al) .050	10.2	2.49	8.03	5.5	940	0.5	1158	0.44 (2477 @ 3.25)	520	2.45		
3-17	1300		2250	12.6 + 7 14G (TC under smpl)	(2014 al) .030	6.5	2.18	7.09		930	0.45	1050	0.28 (1350 @ 2.15)	520	2.0		
3-20	1300	850	2210	12.6 + 14G TC under with al/gl					0	915	0.4	1137	0.35 (820 @1.20)	470	2.45		No injection
3-21	1750		2250	12.6 + 7 14G (TC under w/al -gl	.015	4.0	2.3	8.24	5.3	877	0.36	1185	0.33 (1704 @ 3.31)	490	3.0		Al melted
3-22	1300		2270	12.6 + 7 Box						950	0.43	1158	0.41 (981 @ 0.95	572	2.7		
3-28	1220			12.6 + 7 al sand. w/insul.		9.9	6.44	16.5	58.4	1804	3.45	1770	5.0 (burn-out @3.58 sec.	795	6.4		Bkd/V oper @ 2.2 sec.
3-30	1275		2270	12.6 + 7 al sand. w/insul.		11.3	2.72	6.8	3.19	1440	1.95	out	1.6	2148 (2148 2.48			
3-31	1210		2270	seal sand					0	818	0.8	1074	0.69 (563 @ 1.8)	409	2.74		no inj.

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22 May 1967

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U. S. Army Missile Command
LANCE Project Office
Redstone Arsenal, Alabama

Attention: AMCPM-LCE

Subject: Monthly Progress Letter No. 8
Project A-968
"Neutralizer for Hot Gas-IRFNA System"
Covering Period from 1 April 1967, through 28 April 1967
Contract No. DAAH01-67-C-0077

Gentlemen:

The month of April was utilized in studying the effect of IRFNA leakage on the TR-69 material at ambient temperature.

The initial test produced a violent reaction, bursting the rupture disc, deforming the bottom flange of the reaction chamber (requiring a new flange assembly), and physically stripping the threads of the pressure cell mount in the reaction chamber. (Apparently only two threads of this cell were engaged during the test, thus, this failure was not necessarily the cause of the TR-69--IRFNA reaction; any pressure of 1200 psi or so may have stripped the threads).

Subsequent tests have shown that large amounts of IRFNA injected fairly rapidly produce enough heat capacity to inhibit the violent reaction. Physically attaching the TR-69 to an aluminum backing of 1/32 or 3/16 inch thickness also produces enough heat absorption capacity that no apparent violent reaction occurs. However, the quantity of aluminum required to inhibit the violent reaction is at present unknown.

In addition, it was shown that multiple (successive) injections of small amounts of IRFNA leads to a more favorable condition for violent reaction. Thus, a small continuous trickle of IRFNA is believed to be more likely to react severely than a large surge of IRFNA.

It is planned to make a few tests with this IRFNA--TR-69 system at elevated temperatures during the coming month.

Respectfully submitted,

[illegible]
Project Director

APRIL 1967 DATA SHEET

Run No.	Condition	IFRNA	Gas P_{Max} psi	Gas θ_{Max} sec	Inlet TC T_{Max} °F	STC T_{Max} °F	NTC T_{Max} °F	Remarks
4-7	Ambient - Air in RC	16 cc @ 10 min. intervals 3(inj.) 100 cc @ 30 min. interval (burst diaphram out 17 min. later)						inj. orif 0.018 86 gm TR - 69 ∇P=400
4-13	" " " "	2 min. 40 sec. after 1st 16cc injection	?		1351	799	TC 2348	86 gm TR ∇P=50
4-14	" " " "	3 X 16cc @ 10min. int. 100cc after 30 min. 45 sec. after first inj.	(350)		1457	1658	TC 2197	∇P=400
4-17	" " " "	3 X 16cc @ 10min. int. 100cc after 30 min. 50 sec. after first inj.	220		1011	1459	TC 1726	∇P=400
4-18	" " " "	3 X 16cc @ 10min. int. 100cc after 30 min. (no apparent reaction)						Butyl Seal w/silicone strp (10" secter) ∇P=400
4-19	" " " "	3 X 16 @ 10 min. int. 100cc after 30 min. (no apparent reaction)						TR 69 coated 180° RC top to bottom ∇P=400
4-20	" " " "	3 X 16 @ 10 min. int. 3 X 100cc at 30 min. int. 8 min 10 sec. after 1st 100cc inj.	60		burn out		TC 2150	TR-69 strips-∇P=400 0.1875" D orif in blowdown
4-21	" " " "	3 X 16 @ 10 min. int. 3 X 100cc @ 30 min. int. no apparent reaction						15-4X1X3/16 Al w/TR-69 (90 gms)
4-24	" " " "	no apparent reaction						TR-69 strips 9" 3in once
4-25 (1)	" " " "	no apparent reaction						4 1/2 ^{3} TR-69 strips
4-25 (2)	" " " "	no apparent reaction						2 1/4 ^{3} TR-69 strips
4-26	" " " "	3 min. after 1st inj. 2 min. 13 sec. after total of 73 cc inj'd	10 off scale		130 1934		TC 143 TC 75200	1 1/8 in ^{3} TR-69 strips
4-27	" " " "	500cc @ start (no other)	5	end				86 gm cured in bottom sides - 5/8" strip up
4-28	" " " "	4cc @ 1min. interval Σ=30 inj. ∇P=400	> 350	45 sec. aft. 9th inj.	2525 @reaction	1840 @ reaction		4cc @ 1 min. intervals 86 gms TR - 69 strips
5-1	" " " "	16cc @5 min. intervals DP=4cc ∇P=400 (total of 10 inj.)	5	end				16cc @ 5 min. int. 86 gms on 60 in. of 1/32 Al.
5-2	" " " "	28 injs. - 2cc @ 1 min. int. ∇P=400	300	25 sec. aft. 28th inj.	7250	burn out @reaction		2cc @ 1 min. intervals 86 gms TR-69 strips (blew rupture disc)

FINAL REPORT

PROJECT A-968

NEUTRALIZER FOR HOT GAS-IRFNA SYSTEM

J. F. KINNEY

Contract No. DAAHO1-67-C-0077

July 1968

Prepared for
Army Missile Command
LANCE Project Office
Redstone Arsenal, Alabama

1968

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

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Engineering Experiment Station
Atlanta, Georgia

FINAL REPORT

PROJECT A-968

NEUTRALIZER FOR HOT GAS-IRFNA NEUTRALIZER

By

J. F. KINNEY

CONTRACT NO. DAAHO1-67-C-0077

JULY 1968

Performed for
ARMY MISSILE COMMAND
LANCE PROJECT OFFICE
REDSTONE ARSENAL, ALABAMA

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I. SUMMARY

The LANCE system uses an aluminum piston to separate the propellants from the hot fuel-rich pressurized gas generated by a solid propellant gas generator (SPGG). Leakage of the oxidant (IRFNA) past the piston may result in excessive temperature levels in the missile.

Experimental studies of this system utilizing a hot synthetic gas (composition similar to the AGJ-SPGG gas) - IRFNA reaction have been conducted in a 195 cubic inch constant volume reactor at temperature levels of the order of 1800 degrees and at pressures up to 1200 psig.

In addition to studying facets of the neutralizer-IRFNA-hot-AGJ gas system, various materials studies were also conducted during the contract period. Since IRFNA irreversibly decomposes on temperature cycling to liberate significant quantities of oxygen, oxygen was added to the AGJ-IRFNA-neutralizer system studies late in the program.

A. Conclusions

It is concluded that:

1. The addition of oxygen in significant quantities to the hot AGJ gas-IRFNA system complicates the neutralization problem--providing an additional oxidant which was present previously only in small quantities.

2. The "Purple K" material has limited usefulness as a neutralizer with AGJ-type gases if a significant quantity of gaseous oxygen is present in the AGJ-IRFNA system.

3. The combination of "Purple K" with 30 percent calcium chloride solution may provide improved neutralization in the AGJ gas-IRFNA system over "Purple K" alone. This improvement, if present, does not appear to be sufficient to provide neutralization under all conditions pertinent to LANCE operation if significant quantites of gaseous oxygen are present.

4. "Purple K" requires some finite time in the hot gas atmosphere to become effective.

5. The liquid in the combination neutralizer ("Purple K" with $CaCl_2$ solution) appears to help during the early phase because of the fine (spray) dispersal of the liquid, presenting a larger surface area for heat transfer.

6. The effect of very large surface area (fine particle size) has not been determined to date for this system (with either liquid or solid-type neutralizers).

7. The mechanism of neutralization of the IRFNA--or the IRFNA-O_2-AGJ fuel gas system is not understood to date.

8. The hot AGJ-type gases will deteriorate the butyl seal material.

9. The TR-69 ablative material may under certain conditions react with IRFNA with severe pressure and temperature rises.

B. Recommendations

It is recommended that:

1. Effort be continued on the neutralization study to provide some criteria for suppression of the unwanted reaction in the event of IRFNA leakage past the seal in the LANCE system.

2. Additional work be initiated to further the understanding of neutralization of HNO_3, NO_2, NO, O_2 reactions with H_2, CO, and CH_4.

3. The effect of surface area be determined both in regards to liquids and solids, since if the effect is the same, the primary effect may be that of a heat sink.

4. The use of other neutralizing agents be investigated further, particularly the oxalates and alums with particular reference to the use of heavier metals (cesium and rubidium in the place of potassium) in the salts.

5. Faster responding thermocouples be surveyed which will stand-up under the hot, acid, oxidizing as well as reducing atmospheres.

II. INTRODUCTION

The propellant tanks in the LANCE missile are pressurized with a Solid Propellant Gas Generator (SPGG) gas which is rich in both carbon monoxide and hydrogen. A piston separates the liquid propellant from the hot SPGG gases.

Oxidizer (IRFNA) leakage past the piston may react with the hot SPGG gases, resulting in hazardous temperature rises in the volume above the piston. Previous work has shown that temperature rises due to the hot gas/ IRFNA reaction may exceed 1000 degrees Fahrenheit above the design temperature level in the oxidizer tank.

Experimental studies of the effect of various neutralizers with the hot synthetic gas * - IRFNA reaction were conducted in a 195 cubic inch constant volume reactor at temperatures of 1200 to 1800 degrees Fahrenheit and pressures up to 1200 PSIG. An interim neutralizer was recommended early in the program consisting of a $KHCO_3$ - H_2O slurry. Subsequent tests suggested that the pure $KHCO_3$ is a more efficient neutralizer and has been recommended for use with the Army's LANCE system. In the LANCE system, after ignition the hot fuel gases force the piston down the chamber expelling IRFNA and creating an increased gas volume above the piston, this constant influx of fresh hot SPGG gases is occuring during flight. This causes the reactor volume (the volume of gases above the piston) to continually increase from some initial value of the order of 200 cubic inches to something of the order of

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* Composition similar to the AGJ Solid Propellant Gas Generator Gas at 1000 psia and 2100° F:

Gas	mf
CH_4	0.013
CO	0.485
CO_2	0.042
H_2	0.316
H_2O	0.062
N_2	0.081

20,000 cubic inches, a factor of 100. Thus, a changing volume system occurs in the missile and should also be utilized in studying the neutralizer effectiveness in the model studies. A 180 cubic inch changing volume reactor with a ratio of maximum volume to initial volume of approximately 110 was constructed at Georgia Tech to study the effect of the neutralizer on the hot gas/IRFNA reaction in the changing volume reactor.

The early work with the changing volume reactor was difficult to correlate because of long test times (on the order of 7 seconds) and because the hot gases flowing into the reactor are flowing at a much lower rate which provided some additional time for cooling of the gases before they reach the reactor. However, some correlation was obtained suggesting that the test data appears to be reproducible.

Subsequent to the work described above, work under the contract* covered by this report was initiated to attempt to characterize the neutralizer in addition to studying a number of facets of the compatibility problem: Seal compatibility with both IRFNA and hot gases flowing across the seal, as well as just hot gases flowing across the seal, and compatibility of the TR-69 ablative material with IRFNA were experimentally tested.

In addition to these studies, two tests were conducted directly impinging the hot AGJ gases on IRFNA (direct expulsion). Late in the year the system was changed somewhat to include the oxygen produced by the irreversible decomposition of IRFNA on thermal cycling such that not only IRFNA but gaseous oxygen in the system produces oxidizer requirements on the neutralizer or flame-quenching material.

* September 1, 1966 to October 31, 1967

III. EXPERIMENTAL EQUIPMENT

The experimental equipment used in the previous work* was used in the work under this contract with only slight modifications.

Initially, a solenoid-driven syringe was used to attempt injection of small quantities of IRFNA past the seal into the hot gases. The design was such that 1300 psi was developed in the syringe barrel for purposes of injection. This would provide a Δp (across the needle) in excess of 100 pounds for all conditions of normal operation in the reaction chamber. However, because of varying injection times, and consequently varying pressure, particularly in the early phases of the test cycle where a high rate of hot gas flow across the sample is obtained, the Δp varied considerably, varying both the amount of injection and the rate of injection. In addition, it was difficult to estimate the exact quantity of injection because of the small quantities of IRFNA utilized and the difficulty in dis-assembly after the tests to measure the remaining quantity of liquid in the barrel.

Consequently, the test equipment was modified to utilize pressure injection from the regular injection system used previously, except that a hyperdermic needle was utilized for the process. This system worked very well although larger quantities of IRFNA were used; essentially all of the tests reported herein were operated with this system. This technique was also less time consuming as far as assembly and dis-assembly were concerned.

The arrangement of the seal material clamped and under stress in the bottom of the constant volume reacion chamber is shown in Figure 1 with the hyperdermic needle passing through the bottom flange of the reactor and subsequently attached to the pressure injection system.

In order to test for hot gas leaking past the seal and into an IRFNA-

* See References.

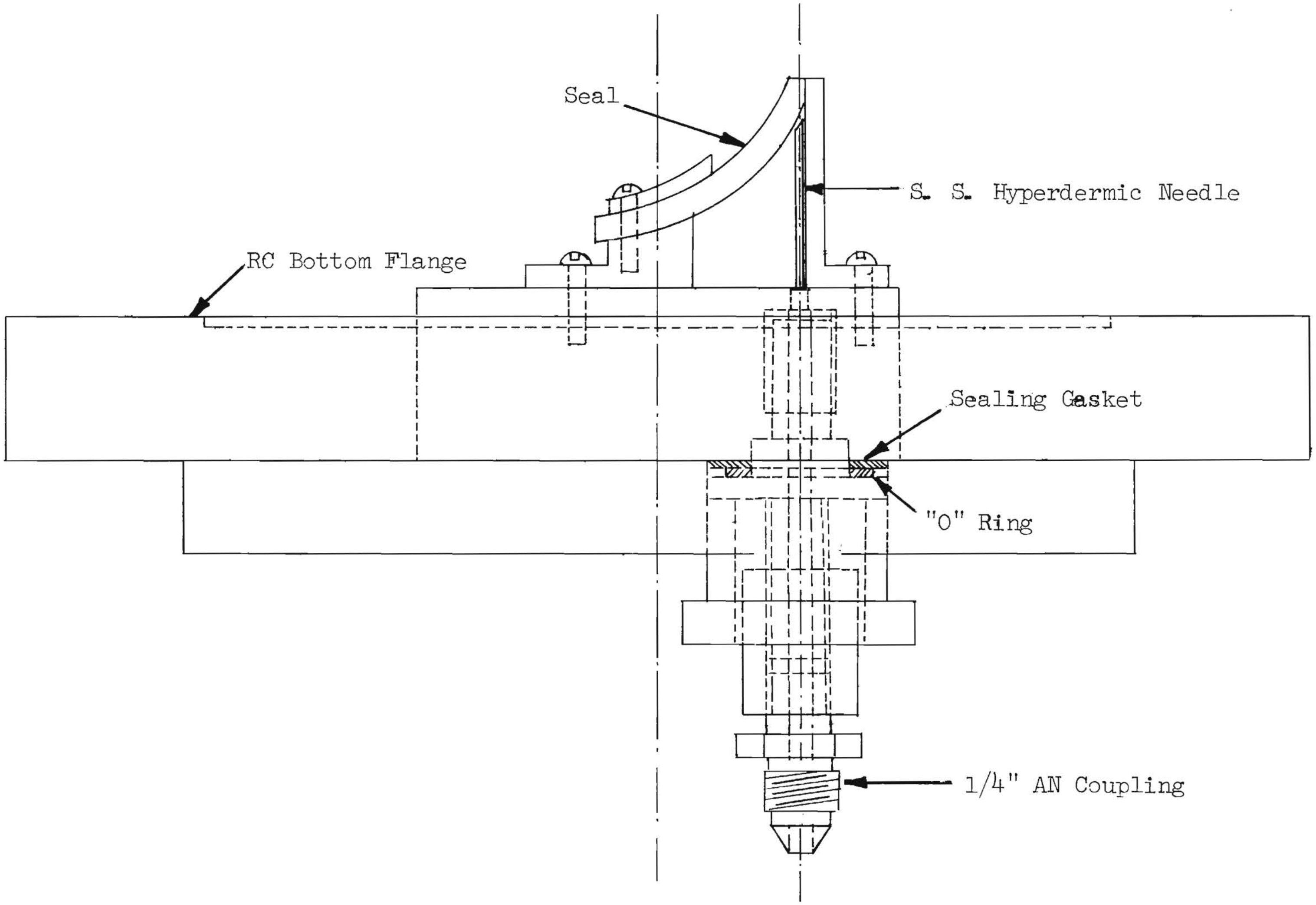


Figure 1. Sketch of Injection (Needle) Arrangement

rich atmosphere a small stainless steel box was constructed with an opening in the top approximately 1 inch wide and $1\frac{1}{2}$ inches long with a fixture attached such that a section of the seal could be attached either to the top or to the bottom of this opening, sealing the opening with the force from a seal-contained spring holding the opening closed, Figure 2. In this way leakage past the seal into the IRFNA-rich atmosphere could be obtained. This container was located on a pedestal in the center of the reaction chamber and directly in the flow of the hot gases from the inlet port.

A six channel Offner recorder was obtained to increase the monitoring capability of the instrumentation. While the equipment initially worked satisfactorily, it soon developed a malfunction which caused a number of the heat-recording stylii to burn out and subsequently was not fully operative during the remainder of the contract period. It has not been possible during the course of this contract to obtain the fully instrumented system originally planned.

IV. EXPERIMENTAL WORK

The experimental work has been quite varied during the period covered by this report and included studies of the neutralizer characteristics utilizing the "Purple K" neutralizer alone, "Purple K" with water, and "Purple K" with a 30 percent calcium chloride solution. Tests were also conducted with the reactor at -40° and tests were conducted using a combination of oxygen and IRFNA as the oxidizing agent for the hot fuel gas. In addition, a number of material's studies were conducted both on the piston seal material and some of the coating materials such as TR-69 (which is used on the piston as an ablative compound). Tests were also conducted with unsymmetrical dimethyl hydrazine (UDMH) and trichloro ethylene (TCE) as additives to the system.

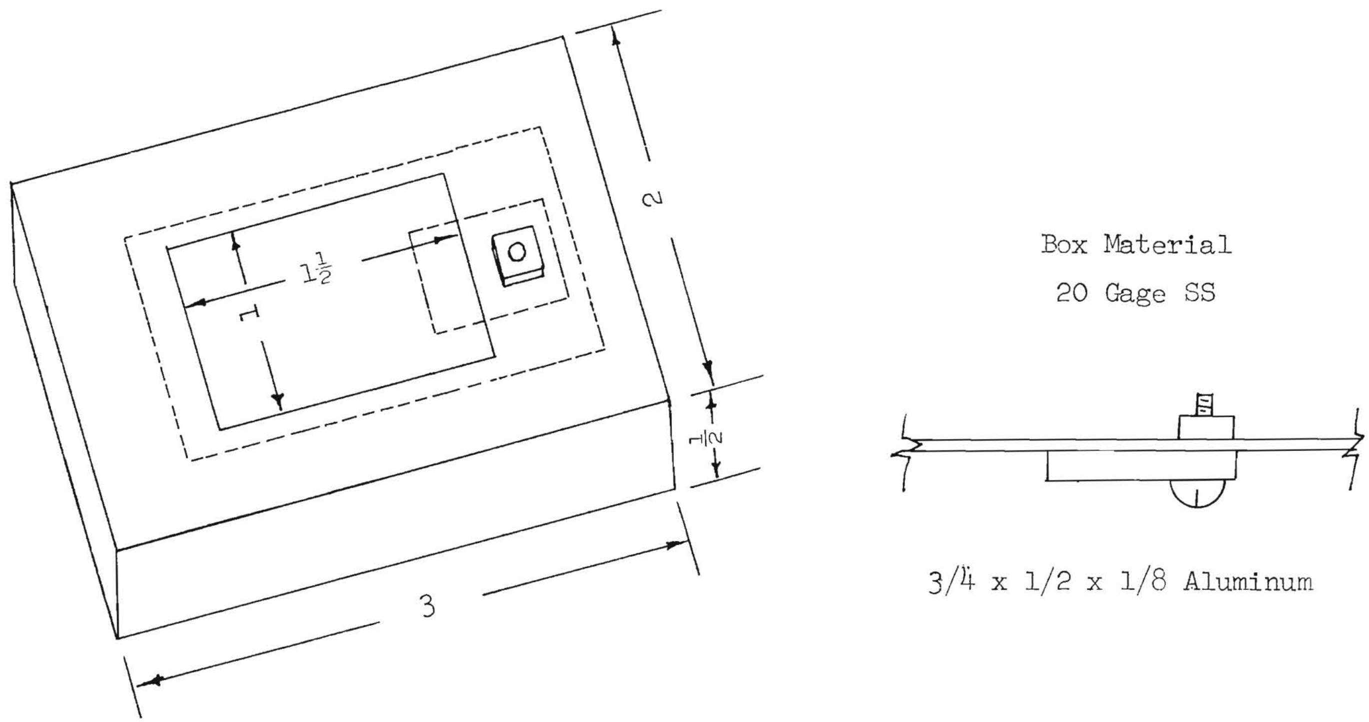


FIGURE 2

Sketch of Aluminum Box for Seal Studies

The data for all tests are summarized in Table VIII, Appendix A, according to the date of the tests. These data have been grouped into categories in Tables I through VII for purposes of comparing the data from similar tests.

A. No Neutralizer Tests

More than 59 tests were conducted with the no-neutralizer series. The tests varied in both time of injection, temperature of the reactor, type of oxidizer, etc. The data presented in Table I has been extracted from that which is presented in Appendix A.

B. ("Purple K" only)

A total of 36 tests were conducted with "Purple K" as the only neutralizer. Part of these tests were with the piston and part were conducted in a constant volume reactor. These tests are summarized in Table II, the data for which has been extracted from Appendix A.

C. "Purple K" with 30 percent Calcium Chloride Solution

A total of 89 tests were conducted with the combination of "Purple K" and 30 percent calcium chloride solution. These tests are summarized in Table III, with the data extracted from Appendix A.

D. Residual IRFNA with Oxygen as the Oxidizer

More than 24 tests were conducted utilizing residual IRFNA and injected oxygen as the oxidizer for the fuel gas reaction. These tests, in the main, were conducted at ambient temperature both with and without neutralizer under both constant volume and changing volume reaction conditions. The data are assembled together in Table IV, which has been extracted from that which is presented in Appendix A.

TABLE I

SUMMARY OF TESTS WITH NO NEUTRALIZER
CONSTANT VOLUME REACTOR

			Acid		Reactor						
Date	Mix Tank psig	Htr. Temp. ° F	Residual cc	Injected cc	Pressure Max psig	Inlet Temp. Max ° F	Temp. (Slow TC) Max ° F	Temp. (Bot. TC) Max ° F	Reactor Temp. ° F	Injection Time	Remarks
8-25-66	1300	2210			951	1154	735		Ambient		Ablative Test
	1010	2190			745	1116	714		Ambient		Ablative Test
8-26-66	1300	2150		7.2	962	1137	727		Ambient	Late	Ablative Test
	930	2175		6.3	679	1137	791		Ambient	Late	Ablative Test
8-29-66	1300	2220		7.1	962	1235	714		Ambient	Late	Ablative Test
	930	2205		4.9	648	1137	863		Ambient	Late	Ablative Test
8-30-66	1300	2140		6.1	873	1167	752		Ambient	Late	Ablative Test
	1050	2140		7.1	585	1137	1053		Ambient	Late	Ablative Test
1-12-67	1300	2300	4.0	?	977	1106	580		Ambient	Late	
	885	2340	4.0	?	629	1244	632		Ambient	Late	
1-16-67	1300	2250		?	969	1032	457		-40	Early	
1-17-67	1300	2400			958	1082	457		-40	Early	
1-20-67	1300	2280		?	918	989	377		-40	Early	
1-23-67	1225	2150	2.0	8.6	999	1346	905		-40	Early	
2-1-67	1300	2390	1.0	5.3	1017	1441	718		-40	Early	
2-8-67	1300	2360		2.6	1102	1808	1398		-40	Early	
2-10-67	1285	2360		?	913	1116	404		-40	Early	
2-13-67	1300	2360		6.3	954	1150	386		-40	Early	
2-14-67	1270	2380		2.7	1032	1235	650		-40	Early	
2-16-67	1300	2380		4.7	969	1158	475		-40	Early	
3-2-67	1290	2255			937	1222	541	892	-40		
8-7-67	990	2200			577	734	563		Ambient		Blank
	670	2200			409	593	364		Ambient		Blank
8-9-67					740	900	658		Ambient		Dry air flush of RC
8-10-67	1280		28.7		993	918	1890	BO	Ambient		10.1 gm O_2 injected (NO_2)
8-15-67	1300	2200			818	1044	801	1161	Ambient		Dry air in RC
					578	1032	650	905	Ambient		Dry air in RC
8-16-67	1250	2200		14.0	837	1733	1800	1431	Ambient	Early	4.4 cc UDMH Residual
8-18-67	1300	2200		14.0	893	1683	1534	2500	Ambient	Early	4.4 cc UDMH Residual
9-22-67(1)	1300	2000			841	778	296		Ambient		Blank

Table I Continued

TABLE I (Continued)

SUMMARY OF TESTS WITH NO NEUTRALIZER
CHANGING VOLUME REACTOR

Date	Mix Tank psig	Htr. Temp. °F	Acid Residual cc	Acid Injected cc	Reactor Pressure Max psig	Reactor Inlet Temp. Max °F	Reactor Temp. (Slow TC) Max °F	Reactor Temp. (Bot. TC) Max °F	Reactor Temp. °F	Injection Time	Remarks
8-9-66	1300	2140	2	10.6	1075	735	563		Ambient	Early	
	950	2140	2	12.0	776	799	585		Ambient	Early	
8-10-66	1300	1885	2	10.2	1086	968	735		Ambient	Early	
	1000	1860	2	11.0	842	1485	1772		Ambient	Early	
8-11-66	1300	2290	2	9.1	1079	1091	1934		Ambient	Early	
	1080	2290	2	12.8	889	1011	884		Ambient	Early	
10-17-66	1300	2300		8.8	1148	777	714		Ambient		
	930	2375		4.6	939	1795	2452		Ambient		
10-28-66	1300	2340		5.8	1064	1014	1014		Ambient		
10-30-66	1275	2350		6.5	1063	888	735		Ambient		
11-1-66	1255	2355		6.9	1088	905	880		-40		
11-2-66	1210	2310		4.9	1041	981	675		-40		
11-3-66	1310	2320		5.6	1116		777		-40		
11-4-66	1280	2355	2	5.7	1104	998	1040		-40		
11-7-66	1310	2300	4	5.6	1112	1048	2237		-40		
11-8-66	1285	2325	4	7.9	1072	989	820		-40		
	895	2345	4	7.3	741	1591	1503		-40		
11-28-66	1300	2365	1	5.9	1101	1929	1269		-40		
	925	2345	1	?		519	278		-40		
11-29-66	825	2375	1	?		1892	1312		-40		
11-30-66	1225	2280	1	4.2	1052	879	1065		-40		
12-29-66	1200				1030	829	422		-40		
12-30-66	1215			5.3	1032		998		-40		
7-24-67	1240	2200				2197	BO		Ambient	Early	14 gm O_2 injected (NO_2)
7-26-67	1175	2200			960	2510	1821		Ambient	Early	12.1 gm O_2 Injected (NO_2)
8-21-67	1300	2200	2950		919	2367	2228		Ambient		DIRECT EXPULSION
8-22-67	1300	2200	2950		915	>2500	1525		Ambient		DIRECT EXPULSION

TABLE II

SUMMARY OF TESTS WITH "PURPLE K"
CHANGING VOLUME REACTOR

Date	Mix Tank psig	Htr. Temp. °F	Oxident* Residual cc	Oxident* Injected cc	Reactor Pressure Max psig	Reactor Inlet Temp. Max °F	Reactor (Slow TC) Max °F	Wt. PK gms	Reactor Temp.	Injection Time	Remarks
8-16-66	1300	2240	2.0	6.8	1474	1424	1057	14.0	Ambient	Late	Neutralizer in basket
	1050	2170	2.3	0.0	850		385	14.0	Ambient		Neutralizer in basket
8-18-66	1300	2150			1071	757	431	14.0	Ambient		Neutralizer in basket
	1060	2150			869	658	386	14.0	Ambient		Neutralizer in basket
9-23-66	1300	2280	6.0	4.0	1240	1550	1629	14.0	Ambient	Early	
	1000	2200	6.0	3.0	989	1762		14.0	Ambient	Early	
10-11-66	1300	2435	0.0	15.9	1125	1503	1717	12.6	Ambient	Early	
	1050	2390	0.0	10.6	923	2062	2144	12.6	Ambient	Early	
10-12-66	1300	2440	0.0	15.9	1125	1569	1658	14.0	Ambient	Early	
	1000	2390	0.0	15.9	861	692	497	14.0	Ambient	Early	
10-13-66(1)	1300	2320	0.0	4.1	1211	1925	1864	21.6	Ambient	Early	
10-14-66(1)	1300	2350	0.0	6.9	1227	1864	1725	14.0	Ambient	Early	
(2)	1060	2345	0.0	5.8	1163	1481	1459	21.6	Ambient	Early	
11-9-66(1)	1255	2365	4.0	10.1	1068	2042	1326	14.0	-40	Early	R @ -40° F
(2)	965	2327	4.0	4.8	792	623	216	14.0	-40	Early	R @ -40° F
11-11-66(1)	1300	2370	2.0	4.5	1131	1006	1808	14.0	-40	Early	R @ -40° F
(2)	1000	2366	2.0	9.6	788	684	386	14.0	-40	Early	R @ -40° F
11-14-66	1275	2366	0.0	5.7	1082		1808	14.0	-40	Early	R @ -40° F
11-15-66	1295	2390	0.0	5.1	1113	839	1708	14.0	-40	Early	R @ -40° F
	1095	2331	0.0	8.3	863	666	368	14.0	-40	Early	R @ -40° F
11-22-66	1275	2380	1.0	4.1	1072	2217	2109	14.0	-40	Early	
12-6-66	1300	2345	2.0	6.9	848	1175	1863	14.0	-40	Early	
12-8-66	1245	2360	1.0	6.7	1109	1149	1485	14.0	-40	Early	
12-16-66	1300	2250			996	632	359	14.0	-40		
7-11-67	1240	2100	0.0	4.7	912	1957	1887	19.6	Ambient	Early	10 cc TCE Residual
7-12-67	1270	2300	0.0	11.4	844	714	341	29.6	Ambient	Early	
7-18-67	1145	2200	0.0	2.6	874	585	230*	12.6	Ambient	Early	
10-27-67	1350	1900	3.0	5.6 gm O_2	1121	612	405	12.7	Ambient	Late	Barksdale valve open at start
10-30-67	1290	1930	3.0	5.6 gm O_2	1137	675	441	12.7	Ambient		
10-31-67	1250	1640	3.0	5.6 gm O_2	1104	486	405	12.7	Ambiant	Early	

* IRFNA unless noted
** 20 Gage TC in Slow TC position

Table II Continued

TABLE II (Continued)

SUMMARY OF TESTS WITH "PURPLE K"
CONSTANT VOLUME REACTOR

Date	Mix Tank psig	Htr. Temp. °F	Oxident* Residual cc	Oxident* Injected cc	Reactor Pressure Max psig	Reactor Inlet Temp. Max °F	Reactor (Slow TC) Max °F	Reactor (Bot TC) Max °F	Wt. PK gms	Reactor Temp.	Injection Time	Remarks
8-22-66	1300	2240			962	1116	565		14.0	Ambient		Basket
	970	2140			695	1074	563		14.0	Ambient		Basket
8-14-66	1300				766	1076	1256	855	12.6	Ambient		Dry air in reactor
8-24-66	1250	2270	0	6.7	920	1137	735		14.0	Ambient	Late	Basket
	885	2210	0	6.3	632	1074	563		14.0	Ambient	Late	Basket
6-9-67	1200	2320	0	8.0	974	1416	1459		21.6	Ambient	Late	
10-13-67	1300	2320	0	4.4	1141	1459	1372		21.6	Ambient	Early	
8-11-67	1300		28.7	11.3 gms O_2	967	2430	2540	2408	12.6	Ambient	Early	
			28.7	13.5 gms O_2	818	2340	BO	1890	12.6	Ambient	Early	
9-8-67	1300	1800	30.0	8.5 gms O_2	1078	1329	BO		120.0	Ambient	Early	Blew
7-3-67	1160	2200	0	5.3	669	1074	778	650	19.6	-40	Late	
7-5-67	1245	2200	0	10.6	811		990	BO	19.6	-40	Late	
7-6-67	1270	2200	0	8.0	691	990	606	585	19.6	-40	Late	

*IRFNA unless noted

TABLE III

SUMMARY OF TESTS WITH "PURPLE K" AND 30% CALCIUM CHLORIDE SOLUTION
CONSTANT VOLUME REACTOR

			Acid		Reactor				Neutralizer Wt.				
Date	Mix Tank psig	Htr. Temp. °F	Residual cc	Injected cc	Pressure Max psig	Inlet Temp. Max °F	(Slow TC) Max °F	(Bot. TC) Max °F	PK gms	Sol'n. gms	Reactor Temp. °F	Injection Time	Remarks
8-31-66	1300	2210		10.8	884	726	363		14.0	2.9	Ambient	Late	Injection doubtful
9-1-66	1300	2220	2	?	958	744	363		14.0	4.4	Ambient	Late	
9-2-66	1300	2285	2	7.3		748			14.0	5.5	Ambient	Late	
	960	2260	2	7.6	780	484	300		14.0	5.5	Ambient	Late	
9-6-66	1300	2230	2	8.6	1083	497	297		14.0	5.5	Ambient	Late	
	970	2210							14.0	5.5	Ambient	Late	
4-6-67	1200	2300		7.0	792	1010	395	475	12.6	9.0	-40	Late	
4-4-67	1300	2315			837	1074	431	628	12.6	9.0	-40		Frozen injection line - no injection
4-3-67	1270	2360			865	1054	409	650	12.6	9.0	-40		Frozen injection line - no injection
1-18-67	1300	2375			955	1048	536		12.6	9.0	-40		
3-10-67	1280	2090		Box	875	1158	542		12.6	9.0	-40		Aluminum box with IRFNA and seal
3-20-67	1300	2210			915	1137	470	820	12.6	9.0	-40		
3-22-67	1300	2270		Box	950	1158	572	981	12.6	9.0	-40		Aluminum box with IRFNA and seal
1-24-67	1300	2200	2	14.3	866	649	404		12.6	9.0	-40	Early	
1-26-67	1265	2360	2	9.4	1006	1699	989		12.6	9.0	-40	Early	
1-27-67	1300	2380	2	5.7	1088	1433	896			9.0	-40	Early	
1-30-67	1300	2390		?	969	1158	510		12.6	9.0	-40	Early	
1-31-67	1300	2300		?	962	1158	475		12.6	9.0	-40	Early	
2-2-67	1300	2340		?	962	1090	475		12.6	9.0	-40	Early	
2-3-67	1310	2350		?	932	1116	475		12.6	9.0	-40	Early	
2-20-67	1200	2020		10.6	869	1158	692		12.6	9.0	-40	Early	
2-22-67	1220	2400		4.9	925	1158	422		12.6	9.0	-40	Early	
2-24-67	1300	2130		9.9	844	1137	533		12.6	9.0	-40	Early	
8-17-67	1300	2200		5.3	910	1643	1418	BO	12.6	9.0	Ambient	Early	8.8 cc UDMH Residual
3-1-67	1243			5.5	984	1244	550	1061	12.6	9.0	-40	Early	
3-8-67	1250	2210		6.8	890	1157	528	820	12.6	9.0	-40	Early	
3-9-67	1280			2.0	1020	2150	1795	BO	12.6	9.0	-40	Early	Pre-injection of IRFNA
3-15-67	1300	2220		7.1	930	1158	820	2550(BO)	12.6	9.0	-40	Early	
3-16-67	1280	2270		7.2	940	1158	520	2477	12.6	9.0	-40	Early	
3-17-67	1300	2250		6.3	930	1050	520	1350	12.6	9.0	-40	Early	
3-21-67	1250	2250		7.3	877	1185	490	1704	12.6	9.0	-40	Early	

(Continued)

TABLE III (Continued)

SUMMARY OF TESTS WITH "PURPLE K" AND 30% CALCIUM CHLORIDE SOLUTION
WITH CONSTANT VOLUME REACTOR

Date	Mix Tank psig	Htr. Temp °F	Acid Residual cc	Acid Injected cc	Reactor Pressure Max psig	Reactor Inlet Temp. Max °F	Reactor (Slow TC) Max °F	Reactor (Bot. TC) Max °F	Neutralizer Wt. PK gms	Neutralizer Wt. Sol'n. gms	Reactor Temp.	Injection Time	Remarks
3-28-67	1220			7.5	950	1158	572	981	12.6	9.0	-40	Early	Barksdale valve open at start
3-30-67	1275	2270		7.1	1804	1770	795	BO	12.6	9.0	-40	Early	
3-31-67	1210	2270			818	1074		563	12.6	9.0	-40		
7-7-67	1200	2300			696	947	563	650	12.6	9.0	-40		10 cc Residual TCE
8-31-67		1200	30						12.6	9.0			3.6 gms O_2 Injected
9-11-67	1300	1800	30		810	1547	250		120.0	95.0	Ambient	Early	3.2 gms O_2 injected
9-18-67	1300	1800	30		1034	810	315		120.0	95.0	Ambient	Early	11.3 gms O_2 injected
9-19-67	1300	2000	30		900	778	628		120.0	95.0	Ambient	Early	11.3 gms O_2 injected
9-22-67 (2)	1300	2000	30		880	820	341		120.0	95.0	Ambient	Early	12.4 gms O_2 injected
9-25-67	1190	2000	30		731	819	333		120.0	95.0	Ambient	Early	12.4 gms O_2 injected
10-17-67	1230	1810	6		1295	1283	1305		12.7	11.0	Ambient	Early	1.2 gms O_2 injected
10-9-67	1130	1800	30		896	1863			256.0	136.0	Ambient	Early	12.3 gms O_2 injected
10-16-67	1195	1990	60		929				105.0	90.0	Ambient	Early	12.3 gms O_2 injected

(Continued

TABLE III (Continued)

SUMMARY OF TESTS WITH "PURPLE K" AND 30% CALCIUM CHLORIDE SOLUTION
CHANGING VOLUME REACTOR

Date	Mix Tank psig	Htr. Temp	Acid Residual cc	Acid Injected cc	Reactor Pressure Max psig	Reactor Inlet Temp. Max °F	Reactor (Slow TC) Max °F	Reactor (Bot. TC) Max °F	Neutralizer Wt. PK gms	Neutralizer Wt. Sol'n. gms	Remarks
9-7-66	1300	2220	4	8.5	1044	310	296		14.0	5.5	Late injection
	910	2200	4	7.4	776	383	287		14.0	5.5	Late injection
9-8-66	1300	2240	4	8.4	1086	1099	290		14.0	5.5	Late injection
	860	2300	4	7.8	714	663	266		14.0	5.5	Late injection
9-9-66	1300	2200	6		1086	792	296		14.0	5.5	Late injection
	960	2210	6	9.7	737	639	274		14.0	5.5	Late injection
9-12-66	1300	2260	6	8.6	1044	968	431		14.0	5.5	Barksdale valve leaked--late injection
9-13-66	1300	2280	6		1110	701	400		14.0	5.5	Barksdale Valve leaked--late injection
9-14-66	1300	2320	6		1105	735	458		14.0	5.5	Late injection
9-15-66	1300	2340	6		1125	735	466		14.0	5.5	Late injection
	920	2240	6	8.9	768	628	386		14.0	5.5	Late injection
9-19-66	1300	2260	6	9.6	1086	761	386		14.0	5.5	Leak at RC inlet
	940	2215	6	9.0	776	563	386		14.0	5.5	Leak at RC spark plug
9-20-66	1300	2325	6	9.6	1086	812	431		14.0	5.5	Early injection, leak at RC spark plug
	1020	2190	6	9.4	854	637	475		14.0	5.5	Early injection, leak at RC spark plug
9-22-66	1300	2265	6	3.9	1156		2675		14.0	5.5	Early injection
		2220	6	4.8	954		2144		14.0	5.5	Early injection
9-23-66	1300	2265	6	2.5	1214	1667	1957		14.0	5.5	Early injection
	1040	2235	6	8.0	854	654	409		14.0	5.5	Early injection
9-27-66	1300	2230	6	4.4	1257	1460	1685		12.6	9.0	Early injection
	1030	2220	6		881	846	377		12.6	9.0	Early injection
9-28-66	1300	2230	6		1079	662	475		12.6	9.0	Early injection
	950	2240	6	9.5	958	1503	981		12.6	9.0	Early injection
9-29-66	1300	2240	4	4.4	1207	1685	1158		12.6	9.0	Early injection
	1000	2230	4	2.8	1203	1350	1636		12.6	9.0	Early injection
9-30-66	1180	2210	2	1.8	1389	1305			12.6	9.0	Early injection
10-4-66	1300	2210	0	5.4	1136	650	453		12.6	9.0	Early injection
	1000	2220	0	7.1	838	554	363		12.6	9.0	Early injection
10-7-66	1120	2220	0	<0.1	1017	968	926		12.6	9.0	Early injection
10-10-66	1240	2375	0	0.6	1121	1286	1695		12.6	9.0	Early injection
	930	2475	0	4.5	811	2014	2081		12.6	9.0	Early injection
7-9-67	1210	2200	0	6.2	1042	1053	990*		12.6	9.0	Early injection

*No. 20 gage TC on slow TC

(Continued)

TABLE III (Continued)

SUMMARY OF TESTS WITH "PURPLE K" AND 30% CALCIUM CHLORIDE SOLUTION
CHANGING VOLUME REACTOR

Date	Mix Tank psig	Htr. Temp. ° F	Acid Residual cc	Acid Injected cc	Reactor Pressure Max psig	Reactor Inlet Temp Max ° F	Reactor (Slow TC) Max ° F	Reactor (Bot. TC) Max ° F	Neutralizer Wt. PK gms	Neutralizer Wt. Sol'n. gms	Remarks
11-16-66	1300	2333	0	7.8	1101	597	378		12.6	9.0	RC @ -40F, early injection
	770	2350	0	5.3	632	448	199		12.6	9.0	
11-17-66	1300	2330	2	5.7	1037	649	413		12.6	9.0	
11-18-66	1300	2390	4	6.5	1116	2338	519		12.6	9.0	
	815	2375	4	4.6	684	493	350		12.6	9.0	
11-23-66	1285	2360	1	5.6	1088	2379	1260		12.6	9.0	
12-15-66	1300	2270	2	5.1	1101	649	769		12.6	9.0	
12-19-66	1300	2257	0	0	1082	482	359		12.6	9.0	
10-2-67	1460	1830	3	0*	1113	828	675		16.0	7.9	AGJ into O_2 (10 gms O_2)
10-3-67	945	2050	3	0**	813	519	386		16.0	7.9	** 1
10-18-67	1170	2070	6	0*	1469	2048	BO		12.7	7.9	Pre-injection O_2 (100gms O_2) Blew Neutralizer into heater exit
10-26	1360	1950	6	0*	1121	720			12.7	7.9	~ 6.7 gms O_2

*O_2 injection

**Timer over-ran stop-injected O_2 2nd time -- blew chamber

TABLE IV

SUMMARY OF TESTS WITH RESIDUAL IRFNA AND INJECTED OXYGEN

Date	Mix Tank	Htr. Temp.	Acid: Residual IRFNA	Acid: Injected O_2	Reactor: Pressure Max	Reactor: Inlet Temp. Max	Reactor: (Slow TC) Max	Reactor: (Bot. TC) Max	Neutralizer Wt.: PK	Neutralizer Wt.: Sol'n.	Remarks
	psig	°F	cc	gms	psig	°F	°F	°F	gms	gms	
7-13-67		2200		23.7	931	1730	1630	1887	12.6	9.0	Constant volume
7-14-67	1285	2220		9.2	1049	1780	1550	2150			Constant volume
8-10-67	1280	2200	28.7	10.6	993	918	1890	BO			Constant volume
8-11-67	1300		28.7	11.3	967	2430	2540	2408	12.6		Constant volume
	600		28.7	13.5	818	2370	BO	1890	12.6		Constant volume
9-8-67	1300	1800	30.0	8.5	1098	1329	BO		120.0		Constant volume
9-11-67	1300	1800	30.0		810	1547	252		120.0	95.0	Constant volume -- Barksdale valve leaked
9-18-67	1300	1800	30.0	11.3	864				120.0	95.0	Constant volume
9-19-67	1300	2000	30.0	11.3	900	778	628		120.0	95.0	Constant volume
9-22-67(2)	1300	2000	30.0	12.4	880	820	340		120.0	95.0	Constant volume
9-25-67	1190	2000	30.0	12.4	731	819	333		120.0	95.0	Constant volume -- Neutralizer in 2 PE bags at inlet
10-9-67	1130			8.5		1818					Constant volume -- heater out after test
10-16-67	1195		6.0	27.6	929			105	105.0	90.0	Constant volume -- Neutralizer in 2 PE bags at inlet
10-17-67	1230		6.0	9.9	1295	1283	1305		12.7	11.0	Constant volume -- Neutralizer in 2 PE bags at inlet
7-24-67	1240	2200	14.2			BO	2197				Changing volume
7-26-67	1175	2200	26.2		960	2510	1821				Changing volume
10-2-67	1460	1830	3.0	38.9	1113	828	675		16.0	8.0	Changing Volume -- Neutralizer in PE bag at inlet (RC)
10-3-67	945	2050	3.0		813	519	386		16.0	8.0	Changing volume -- Neutralizer in PE bag at inlet (RC)
					Rupture	BO	BO	Timer over-ran injected O_2 2nd time			Changing volume -- Neutralizer solution in RC first Pre-injected O_2 (Htr. out after test)
10-18-67	1170		6.0	(99)	1469	2048	BO		12.7	8.0	Changing volume -- Neutralizer solution in RC first
10-26-67		1950	6.0	6.7	1121	720			12.7	8.0	Changing volume -- Neutralizer solution in RC first
10-27-67		1900	3.0	5.7	112;	612	405		12.7		Changing volume -- Question inj. ? PK in after bskt.
10-30-67		1930	3.0	5.7	1137	675	441		12.7		Changing volume -- Question Inj'n. ? PK in after bskt.
10-31-67		1640	3.0	5.3	1104	486	405		12.7		Changing volume -- Question Inj'n. ? PK in after bskt.

Note: PK < 100 gms were placed in PE bag and hung over hot-gas entrance in reactor

E. Materials Tests

Twenty-seven tests were conducted for materials study purposes, on other than the TR-69 ablative material tests which are listed separately. These data are summarized in Table V.

F. TR-69 Tests

Some 24 tests were conducted with various configurations of TR-69 placed in the chamber with IRFNA to test compatibility of these two components. TR-69 is an ablative coating which is placed on top of the piston in the LANCE design. The data are extracted from Appendix A and located in Table VI.

G. Miscellaneous Tests

A number of miscellaneous tests were conducted during the period covered by the contract utilizing UDMH and TCE. These data are listed in Table VII, extracted from Appendix A.

A number of tests have been duplicated in Tables I through VII, appearing in two or more tables for the simple reason that the specific characteristic being examined in one table occurred under conditions which may have appeared in another table. Consequently, some double and even triple entries will be observed. In addition, a few of the tests were not considered as realistic tests from a standpoint of either instrumentation or other equipment failure and have not been listed in Tables I through VII.

TABLE V

SUMMARY OF TESTS - MATERIALS STUDIES

Date	Mix Tank psig	Htr. Temp. °F	Oxidizer Residual cc	Oxidizer Injected cc	Reactor Pressure Max psig	Reactor Inlet Temp. Max °F	Reactor (Slow TC) Max °F	Reactor (Bot. TC) Max °F	Reactor Temp.	Injection Time	Reactor Type	Neutralizer Wt. PK gms	Neutralizer Wt. Sol'n. gms	Remarks
2-1-67	1300	2390	1	4.3	1017	1441	718		-40	Early	Const. Vol.			14 gage needle -- SB
2-8-67	1300	2360		2.6	1102	1808	1398		-40	Early	Const. Vol.			14 gage needle -- SB*
2-9-67	1254	2400			921		457		-40	Early	Const. Vol.			-- NO*
2-10-67	1285	2360		9.5	913	1116	404		-40	Early	Const. Vol.			18 gage needle -- NO*
2-13-67	1300	2360		6.3	954	1150	386		-40	Early	Const. Vol.			14 gage needle -- SB*
2-14-67	1270	2380		2.7	1032	1235	650		-40	Early	Const. Vol.			14 gage needle -- S*
2-16-67	1300	2380		4.7	969	1158	475		-40	Early	Const. Vol.			*
2-2-67	1300	2340			962	1090	475		-40	Early	Const. Vol.	12.6	9	NO
2-3-67	1310	2350			932	1116	475		-40	Early	Const. Vol.	12.6	9	NO
2-20-67	1200	2020		10.6	869	1158	692		-40	Early	Const. Vol.	12.6	9	Pre-injection -- S
2-22-67	1220	2400		4.91	925	1158	422	1681	-40	Early	Const. Vol.	12.6	9	*
2-24-67	1300	2130		9.9	844	1137	533	1010	-40	Early	Const. Vol.	12.6	9	*
3-1-67	1243				984	1244	550	1061			Const. Vol.	12.6	9	NO
3-8-67	1250	2210		7.7	890	1157	528	820			Const. Vol.	12.6	9	TC over sample -- S
3-9-67	1280			(180)	1020	2150	1795	1887			Const. Vol.	12.6	9	Emptied IRFNA Tank -- TC under Sample -- SB
3-14-67	1260			6.4	Gains mis-sets						Const. Vol.	12.6	9	SB
3-15-67	1300	2220		8.0	930	1158	820	2550			Const. Vol.	12.6	9	TC under sample -- SB
3-16-67	1280	2270		8.0	940	1158	520	2477			Const. Vol.	12.6	9	TC under sample -- S, 0.05" Al.
3-17-67	1300	2250		7.1	930	1050	520	1350			Const. Vol.	12.6	9	TC under sample -- SB, 0.03" Al.
3-20-67	1300	2210			915	1137	470	820			Const. Vol.	12.6	9	TC under sample
3-21-67	1750	2250		8.2	877	1185	490	1704			Const. Vol.	12.6	9	TC under sample w/Al-glass sandwich, Al melted, SB, 0.015 Al.
3-28-67	1220			16.5	1804	1770	795	BO		Late	Const. Vol.	12.6	9	Pre-injection -- Al. sandwich with insulation -- SB
3-30-67	1275	2270		6.8	1440	BO	2148	2148		Late	Const. Vol.	12.6	9	Al. sandwich w/insulation -- S
3-31-67	1210	2270			818	1074	409	563			Const. Vol.	12.6	9	Al. sandwich w/insulation -- NO
3-2-67			3.1		937	1222	541	892			Const. Vol.	12.6	9	Box with seal material -- S
3-10-67					875	1158	542				Const. Vol.	12.6	9	Box with seal material - S
3-22-67					950	1158	572	981			Const. Vol.	12.6	9	Box w. seal mat'l. -- box parted -- S

*Pressure injection from bottom

TABLE VI

SUMMARY OF TESTS WITH TR-69 MATERIAL

Date	Reactor Initial Temp.	Oxidizer Amount cc	Oxidizer Interval time	Pressure Max psig	Reactor Inlet Temp. Max °F	Reactor (Slow TC) Max °F	Reactor (Bot. TC) Max °F	Orifice ΔP	Remarks
4-7-67	Ambient	16 100	10 min. (3) 30 min.					400	86 gm. TR-69; burst diaphragm out @ 47 minutes
4-13-67	Ambient	16			1351	799	2348	50	86 gm. TR-69; 2 min. 40 sec.
4-14-67	Ambient	16 100	10 min. (3) 30 min.	(350)	1457	1658	2197	400	86 gm. TR-69; 30 min. 45 sec.
4-17-67	Ambient	16 100	10 min. (3) 30 min.	220	1011	1459	1726	400	10 in. sector--buty seal w/silicon strip; 30 min. 50 sec.
4-18-67	Ambient	16 100	10 min. (3) 30 min.					400	No. apparent reaction; 86 gm. TR-69
4-19-67	Ambient	16 100	10 min. (3) 30 min.					400	TR-69 coated 180° of RC, top to bottom; no apparent reaction
4-20-67	Ambient	16 100	10 min. (3) 30 min. (3)	60	BO		2150	400	86 gm. TR-69 (0.1875" D orif. in blow-down; 38 min. 10 sec.
4-21-67	Ambient	16 100	10 min. (3) 30 min. (3)						90 gm. TR-69 on Alum. 15 strips 4x1x3/16; no apparent reaction
4-24-67	Ambient	150	(1)						86 gm. TR-69; no apparent reaction
4-25-67(1)	Ambient	75 25	(1) 60 min. (1)						86 gm. TR-69; no apparent reaction
(2)	Ambient	37.5	(1)						86 gm. TR-69; no apparent reaction
4-26-67	Ambient	*	@ 3 min. @ ~ 20 min.	60 off scale	130 1934		143 >2500		86 gm. TR-69 2 min. 13 sec. after total of 73 cc injected
4-27-67	Ambient	500	(1)						86 gms. TR-69 cured on bottom + 5/8" up sides of RC
4-28-67	Ambient	4	1 min. (30)	>350	2525	1840		400	86 gm. TR-69; values are for 45 sec. after 9th injection
5-1-67	Ambient	16	5 min. (10)	5				400	86 gm. TR-69 on 1/32" thick aluminum
5-2-67	Ambient	2	1 min. (28)	300	>2500	BO		400	86 gm. TR-69 strips, blew rupture disc 25 sec. after 28th injection
5-8-67	Ambient	1	1min. (47)		>2500		BO	400	86 gm. TR-69 strips, reaction at 42.5 min.
5-9-67	Ambient	2	1 min.(42)					400	86 gm. TR-69 strips on 3/16" aluminum
5-16-67(1)	Ambient	2	1 min.					400	84 gm. TR-69 on 60 in^2 1 mil aluminum; no significant reaction
5-16-67(2)	Ambient	2	1 min.					400	84 gm. TR-69 on 60 in^2 3/16" aluminum, no significant reaction
5-17-67	Ambient	2	1 min.					400	86 gm. TR-69 on 6"x1", 1 mil aluminum strip, no significant reaction
5-18-67	150° F	2	1 min. (59)	off scale	2500		BO	400	86 gm. TR-69 on 15 4"x1" alum. foil strips, reaction @ 22.5 min.
5-22-67	150° F	2	1 min. (59)				Out (acid)	400	86 gm. TR-69 on 60 in^2 3/16" aluminum, no apparent reaction
5-23-67	150° F	2	1 min. (59)				Out	400	Reaction @ 50 min. 86 gm. TR-69 on 60 in^2 0.008 aluminum
5-24-67	150° F	2	1 min. (59)					400	86 gm. TR-69 on 60 in^2 0.040 aluminum, NO_2 release only
5-25-67	150° F	2	1 min. (59)				BO	400	Reaction @ ~ 6 sec -- 86 gm. TR-69 on 60 in^2 0.016 aluminum

*18.8 cc initially
16 cc at 5 minute intervals (20)
4.65 cc at 5 minute intervals (1)
4.65 cc at 1 minute intervals

TABLE VII

SUMMARY OF MISCELLANEOUS TESTS

Date	Mix Tank psig	Htr. Temp. °F	Oxidizer Residual cc	Oxidizer Injected cc	Reactor Pressure Max psig	Reactor Inlet Temp. Max °F	Reactor Temp. (Slow TC) Max °F	Reactor Temp. (Bot. TC) Max °F	Reaction Temp.	Injection Times	Reactor Type	Neutralizer PK gms	Neutralizer Liquid gms	Remarks
8-17-66	1300	2260	2	7.1	1075	998	1556		Ambient	Late	Changing Volume		2.3 H_2O	
	1080	2180	2	(180)	931	2257	1394		Ambient	Late	Changing Volume		2.3 H_2O	IRFNA valve open at start
8-8-66	1280	2160	2	8.7	1172	791	808		Ambient	Late	Changing Volume	14	2.3 H_2O	
	1020	2190	2	8.4	838	693	497		Ambient	Late	Changing Volume	14	2.3 H_2O	
8-12-66	1300	2265	2	8.2	1300	1158	1286		Ambient	Late	Changing Volume	14	2.3 H_2O	
	1070	2170	2	5.5	1070	1116	1330		Ambient	Late	Changing Volume	14	2.3 H_2O	
8-19-66	1300	2180				820	400		Ambient	Late	Changing Volume	14		
	1010	2180			823	650	350		Ambient	Late	Changing Volume	14	2.3 H_2O	
7-7-67	1200	2300			696	941	563					12.6	9 sol'n	10 cc Tri-chloroethylene residual
7-10-67	1240	2200			844	714	341					12.6	9 sol'n	10 cc Tri-chloroethylene residual
8-2-67	1450	2200			990	1053	786				Const. Vol.			10 cc residual UDMH
	1317	2190			714	1035	296				Const. Vol.			100 cc residual UDMH
	700	2190			346	900	208				Const. Vol			100 cc residual UDMH
8-4-67	1275				878	888	585				Const. Vol.			10 cc after basket, 5 cc basket , UDMH
8-16-67	1250	2200			837	1733	1800	1431						4.4 cc UDMH residual
8-17-67	1300	2200			911	1643	1418	BO						8.8 cc UDMH residual
8-18-67	1300	2200			893	1683	1534	2500						4.4 cc UDMH residual

V. RESULTS

A. General Discussion

The hot fuel gas utilized in these tests is a synthetic gas made up to match the equilibrium composition of the AGJ-SPGG gas used in the LANCE system and nominally has some 32% hydrogen and 48% carbon monoxide as the major fuel constituents. However, this gas composition changes considerably with temperature and to some extent with pressure. Consequently, the gas entering the heater may be 32% hydrogen and 48% carbon monoxide and after passing through the heater set for 1600° F or less, this exit composition should be roughly the same. With an 1800° F heater, only minor changes in hot gas composition will occur because of the reaction time required to make composition changes, and residence time in the heater is short compared to the rates of reaction. On the other hand, if the heater is at 2400° F, it is entirely possible that the hydrogen and the carbon monoxide fractions will exceed these percentages, with consequent reduction in the other species. Reaction rates in the vicinity of 2200 to 2400 are quite rapid for these chemical changes and consequently it might be assumed that they occur within the time that the gas is in residence within the heater. Further, as the chemical species change so will the number of gas moles/gram of gas change, (change in pseudo-molecular weight), such that more gas moles are produced per unit weight of inlet gas for the higher temperature heater settings.

Along with changes in chemical composition, additional changes may occur in the heat transfer characteristics because of the variation in the quantity of multi-atomic species of the gas as well as changes in temperature level. This plays a major part in the thermocouple indications that are observed in the reaction chamber with or without reaction.

In addition to the chemical changes that occur, small leaks that are either undetectable or practically liveable-with occur in the system from time to time which result in slight variations of the data. This, in the main, is reflected in the pressure obtained in the reaction chamber system, but also plays a secondary part in the thermocouple response that is indicated during a test.

The test system, as has been noted previously, has a mix-tank, two valves in line with the heater, and a reaction chamber which is monitored for temperature and pressure. Opening the two valves initiates a test which starts the mix-tank gases (synthetic AGJ gas) through the heater and into the reaction chamber. The rate of gas transfer is in the main, pressure controlled. The Barksdale valve has a finite opening rate, effictively creating an orifice in the line which provides acoustic flow at this point in the system during the initial phases of the test. With acoustic flow in the valve, gas flow rate is primarily controlled by the pressure in the mix-tank. The quilibrium pressure developed in the system is the result of expansion of the mix-tank gases through the orifice, the heater and in the reactor. Maximum pressure will be a function not only of the temperature and pressure in the mix-tank but also early reaction that might occur in the reactor. Maximum pressure with no chemical reaction is roughly that which would be obtained in the mix-tank following the increase in volume from approximately 900 cubic inches to 1200 cubic inches.

The attainment of reaction in the system also would appear to be dependent upon a number of characteristics: (1) the F/O ratio (whether it is in the reactive area), (2) the mixture composition, (3) the dispersion or rate of distribution of the injection material, normally liquid IRFNA, but in some cases an oxygen-NO_2 mixture, (4) the dispersion of the neutralizer if one is used (how well the neutralizer is mixed with the gases, the time associated with the mixing process is also relevant), (5) in many reactions, there is an incubation period, such that the rate of heat transfer to the reactor walls could be sufficient to have cooled the reacting mixture below the point at which significant reaction will be observed. With Oxygen and NO_2, the incubation period is relatively short, but liquid IRFNA and solid or liquid coolants complicate the system severely.

It is further noted that it is quite possible with the neutralizer, liquid or solid, that the rate of dispersion is critical as far as the time required to provide any coolant or neutralizing action. In other words, if the particulate matter is broken up in spheres the order of a micron or two in diameter, the surface area presented is one hundred times the surface area for heat transfer of particulate matter which has a diameter of 100 microns. This is true of not only solid coolants or neutralizers but also the liquid calcium chloride solution or pure water. If the particles are broken up into a very fine mist the heat transfer and the effective cooling action will be much faster than if it is in large globules and droplets.

The transducers used in this work are fairly typical of the type that are used in other work of this nature. BLH pressure cells produce a voltage representative of the pressure in the reacting system. This pressure is only representative of that which is in front of the gauge. This does not necessarily reflect a buildup or overall pressure unless it is occuring over a period of a number of tens of milliseconds. However, the rate of change in pressure with time in most of the work has been of the order of tens of milliseconds for significant changes. Consequently, it is believed that in the main, the transducers are seeing general buildup of pressure rather than an instantaneous wave type pressure generation.

The thermocouples are 24 gauge chromel-alumel (in the main). One thermocouple (TC) is in the hot gas stream entering the reaction chamber and has a fairly high heat transfer coefficient and a resultant fairly low time constant for the period during which the gas enters the reaction chamber at the initial part of the test. Subsequent to that time, the rate of heat transfer drops significantly and the thermocouple time constant increases for chemical reactions or subsequent temperature changes in the reaction chamber.

Another thermocouple generally referred to as the slow thermocouple is located in a corner of the reaction chamber and has a relatively low heat transfer coefficient and is closely surrounded by cool reaction chamber walls, both of which produce a longer time constant thermocouple under all conditions. A third thermocouple has been used in many instances, which is located in the bottom of the reaction chamber but has the hot gases blowing directly on it. The heat transfer coefficient to this thermocouple is probably less than that of the thermocouple located in the incoming gas stream its response would be expected to be intermediate between the other two thermocouples.

In general, after initial pressurization the temperature of the gases in the reaction chamber is continuously being reduced by heat transfer to the walls. Consequently, the gas temperature is decreasing as an exponential function. The thermocouples are exposed to an increase in temperature during the initial phase of the test for a period of time that is not much longer, if as long, as the time constant of the thermocouple itself. And from that time on, the thermocouples are exposed to a gradually decreasing gas temperature, which means that the thermocouple never indicates the full temperature and never really significantly approaches the gas temperature except when there is a reaction occurring and the flame or the gas from the flame passes directly across the thermocouple proper in which case it is quite possible that the thermocouple may approach the gas temperature after the combustion processes but not the temperature achieved in the combustion process.

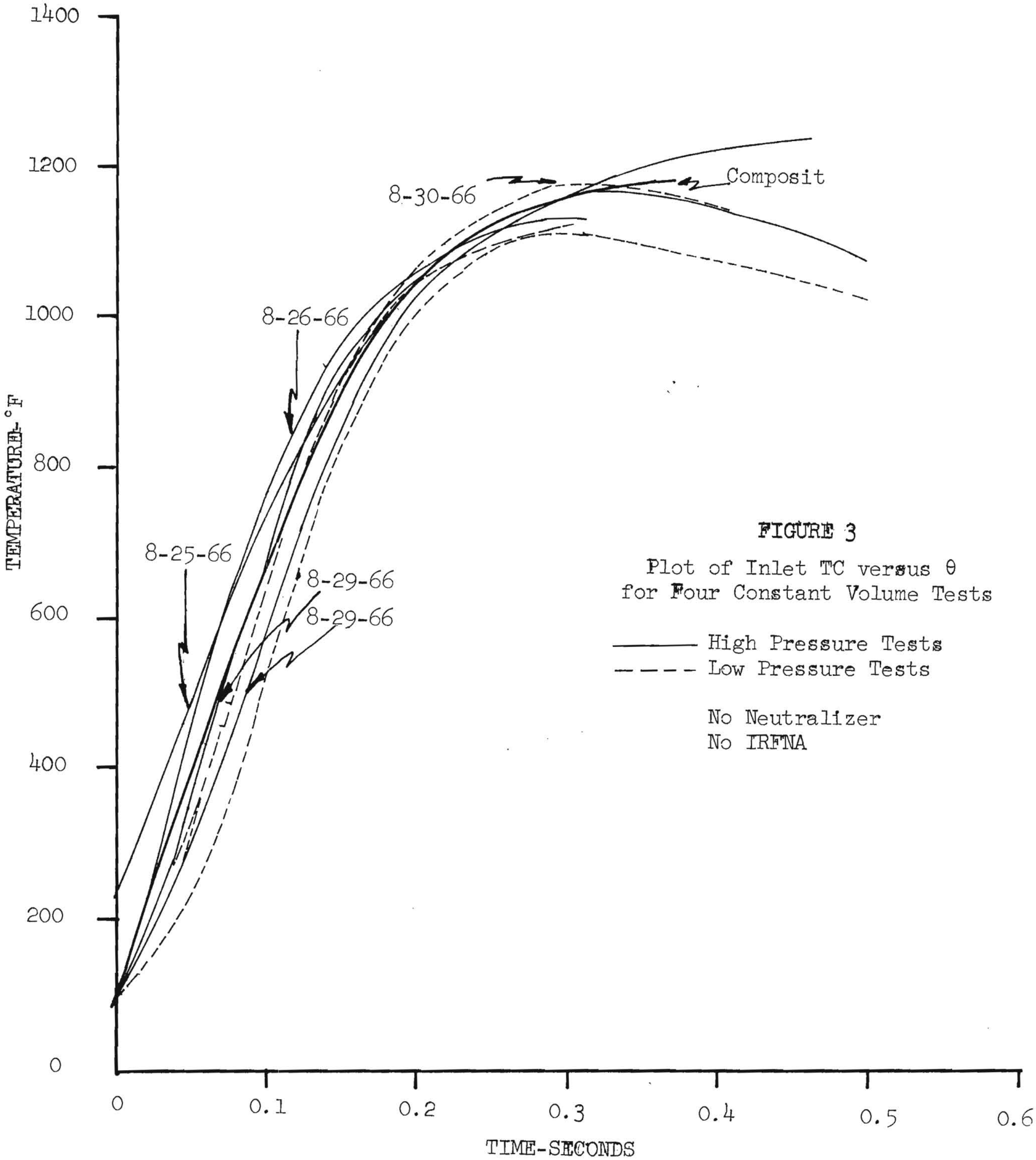
It is necessary to consider these characteristics of the system in order to evaluate some of the results that have been obtained in the test work.

Analysis of the Data for the Nō-Neutralizer Tests

Primarily, the tests utilizing no-neutralizer were performed to check the operation of the equipment and to provide a reference for evaluation of the neutralizer under the test conditions. A few of these tests were conducted in the process of examining the effects of hot gases or IRFNA on the physical properties of the piston seal or other material. These data are summarized in Table I.

The thermocouple outputs have been plotted for four of these tests in Figures 3, and 4 and pressure in Figure 5, as a function of time for the purpose of comparing near-duplication tests. Shown also is a composit or average value of P or T as a function of time, which will be used in the next four figures for comparison purposes. Figure 6 is a plot of the composits above with the results of another "no-neutralizer" run with somewhat different mix-tank pressures, primarily for the purpose of showing the effect of themix-tank on the temperature and pressure recorded as a function of the time. The lower driving pressure produce slower mass flow rates with the result that the temperatures and pressure are slower in reaching their peak values, with lower peak values.

In Figure 7, the composit referred to above is plotted along with the sensors reporting of a test operated under near equal conditions but at -40 initial reactor temperature. It may be observed that, with the exception of


1400
1200
1000
800
600
400
200
0
TEMPERATURE-°F
0
0.1
0.2
0.3
0.4
0.5
0.6
TIME-SECONDS
8-30-66
Composit
8-26-66
8-25-66
8-29-66
8-29-66
FIGURE 3
Plot of Inlet TC versus θ
for Four Constant Volume Tests
High Pressure Tests
Low Pressure Tests
No Neutralizer
No IRFNA

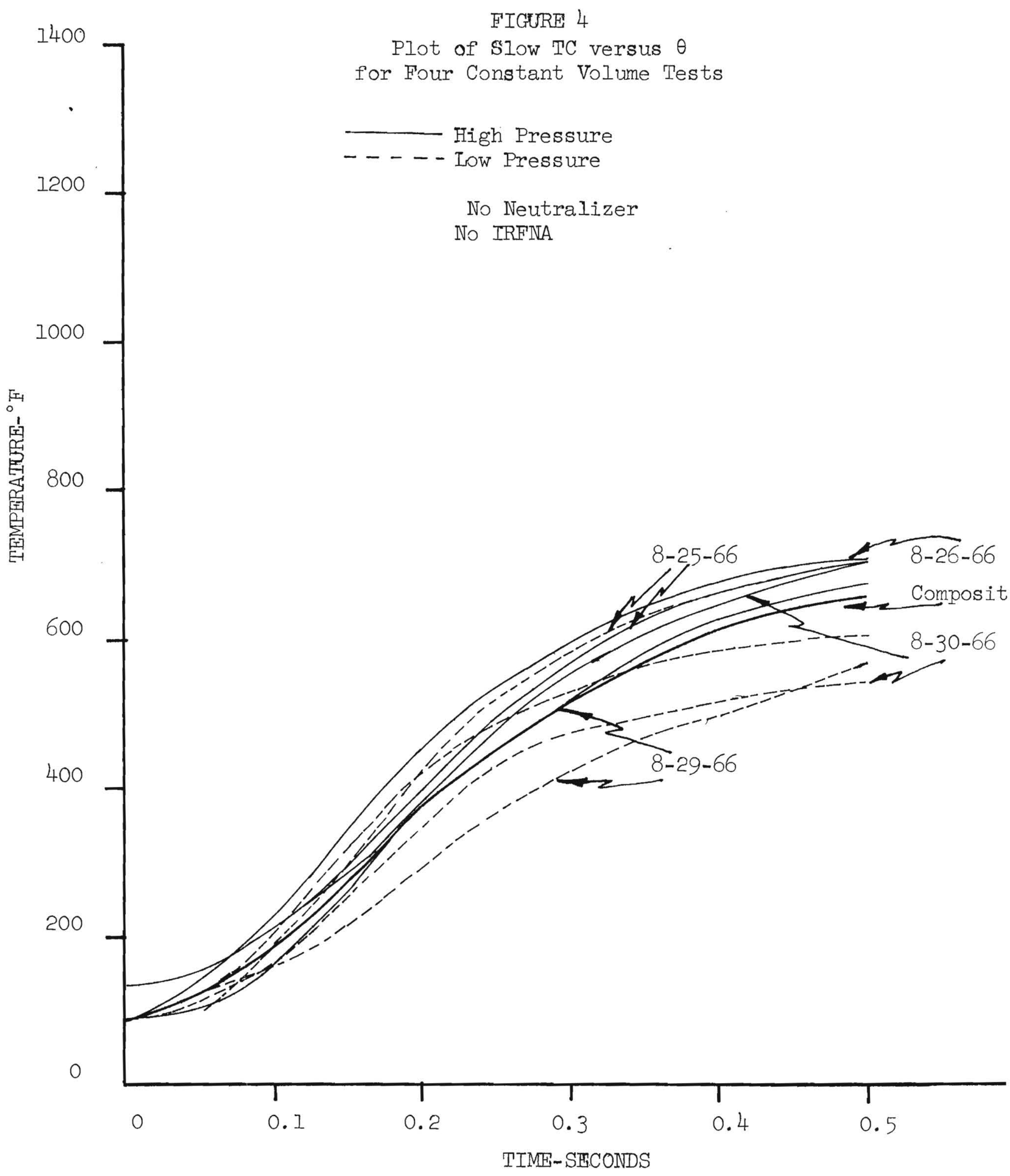


FIGURE 4
Plot of Slow TC versus θ
for Four Constant Volume Tests
High Pressure
Low Pressure
No Neutralizer
No IRFNA
1400
1200
1000
800
600
400
200
0
TEMPERATURE-°F
8-25-66
8-26-66
Composit
8-30-66
8-29-66
0
0.1
0.2
0.3
0.4
0.5
TIME-SECONDS

FIGURE 5

Plot of P_{ch} versus θ
for Four Constant Volume Tests

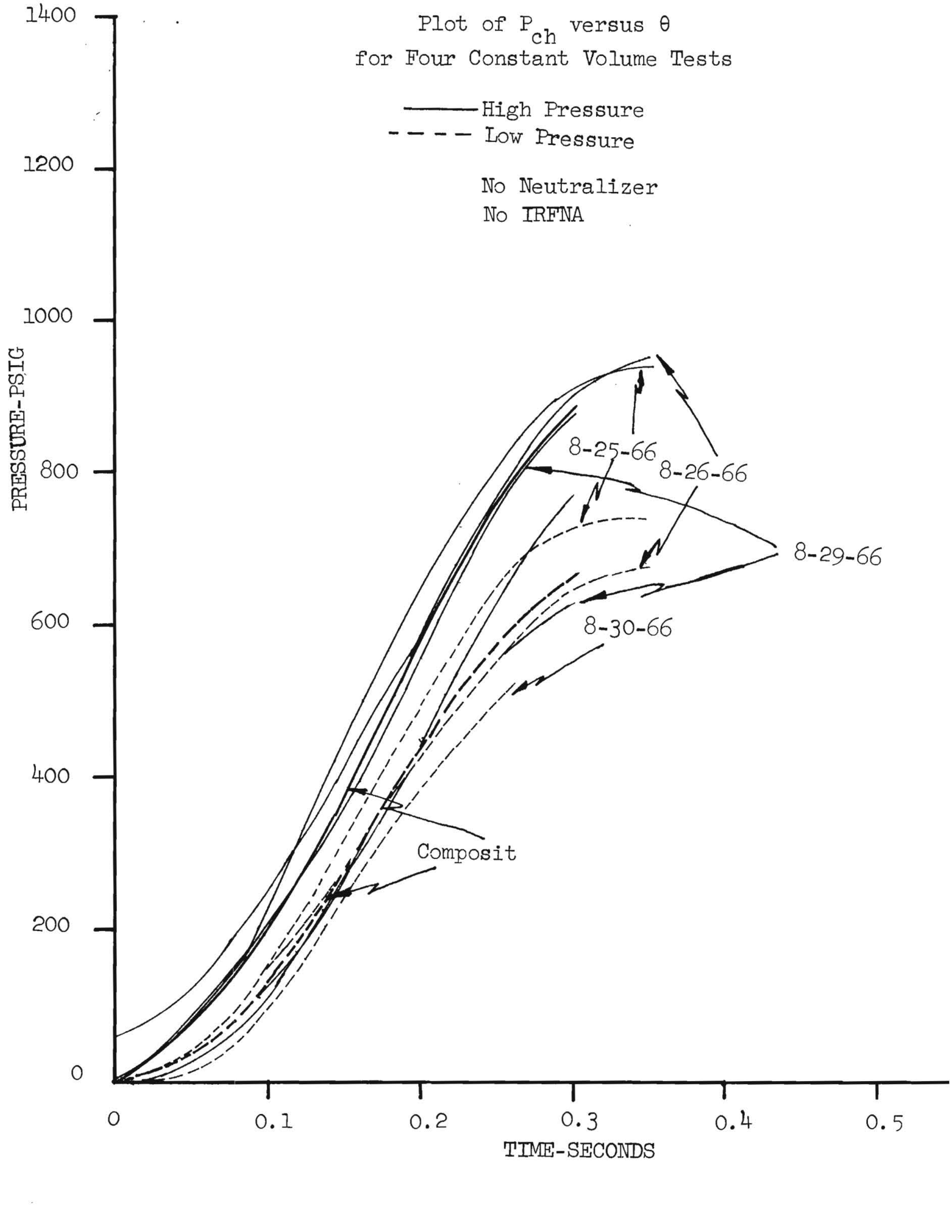
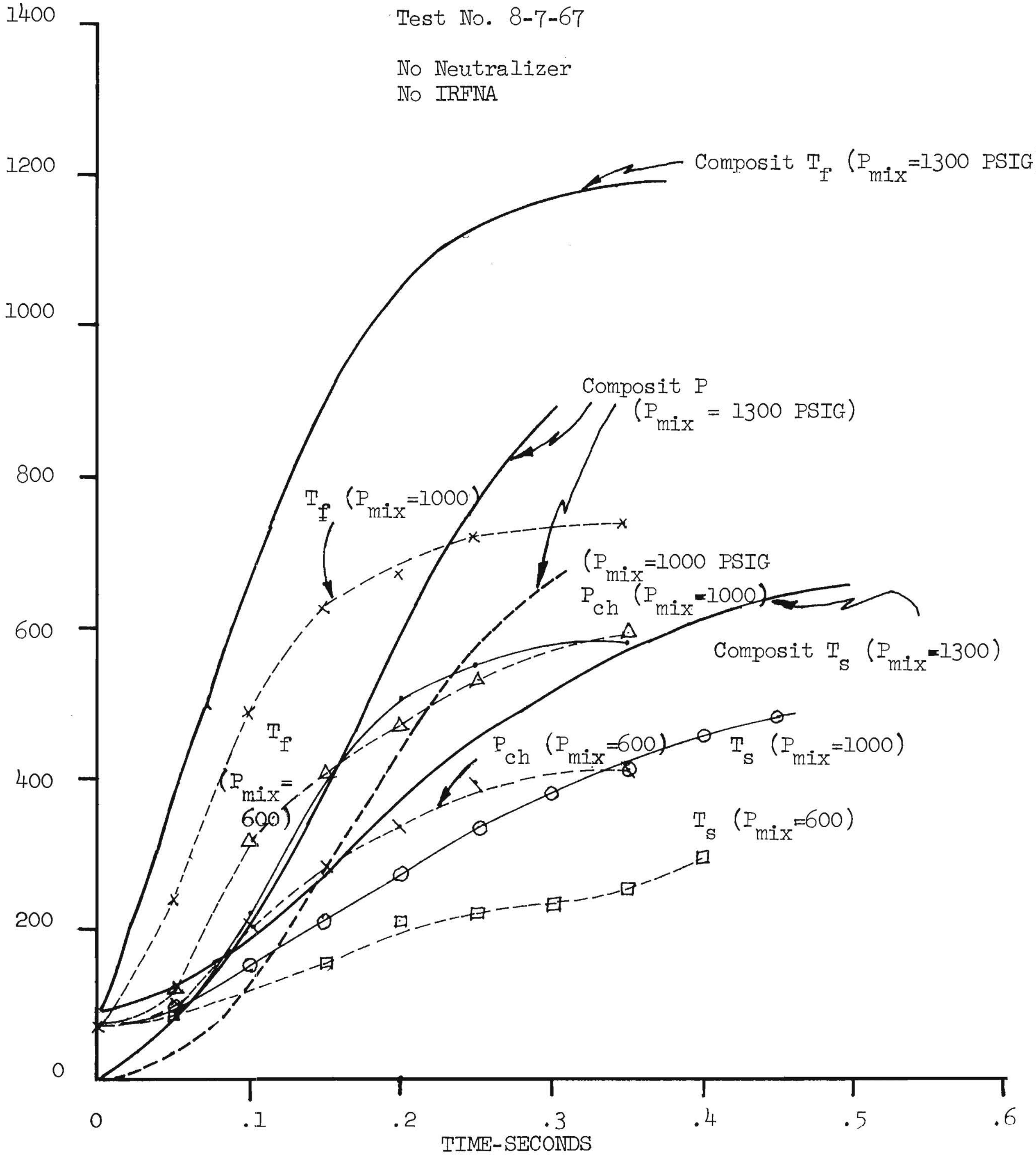


FIGURE 6

Plot Showing Effect of P_{mix} on T_f, T_s, and P_{ch}



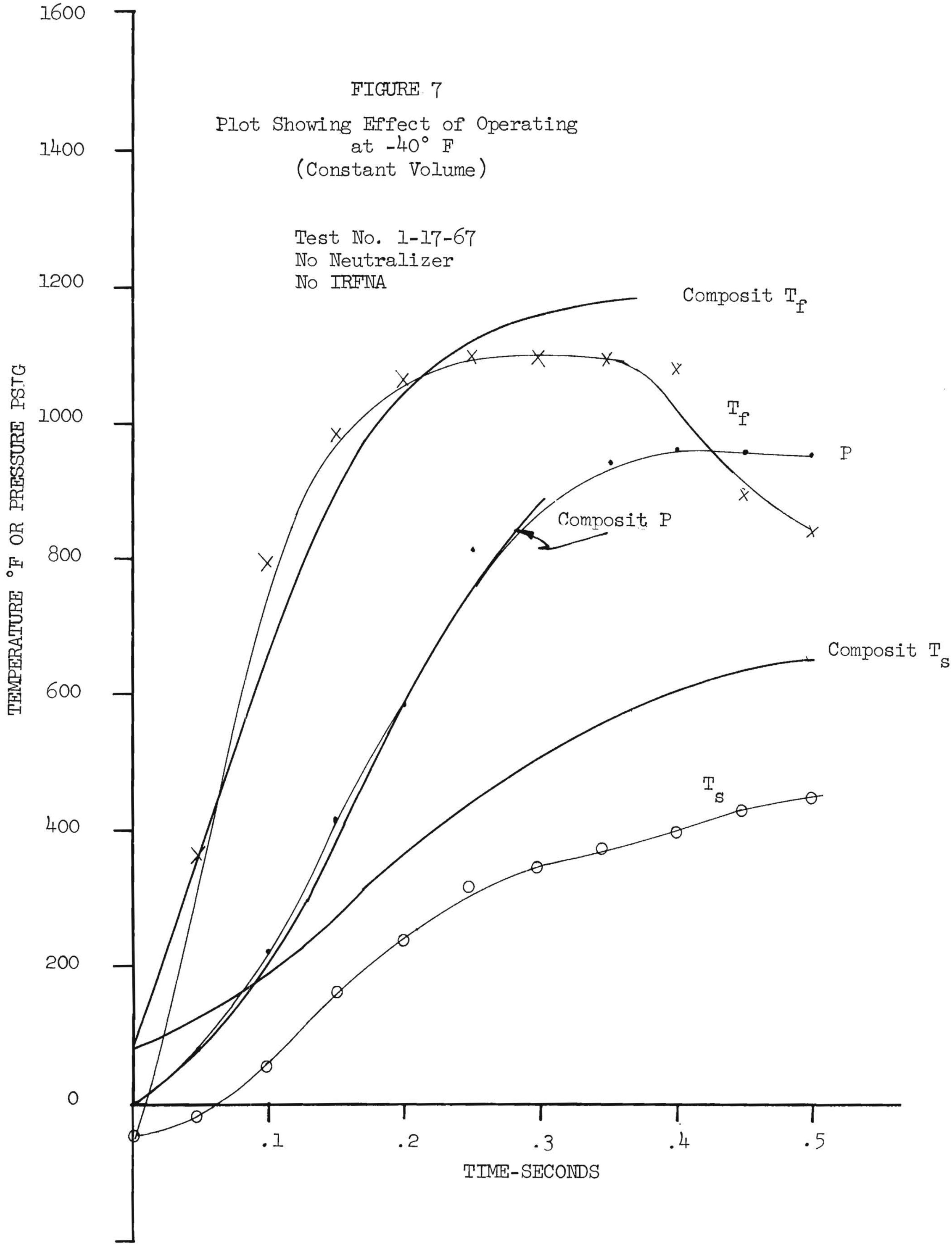


FIGURE 7
Plot Showing Effect of Operating at -40° F (Constant Volume)
Test No. 1-17-67
No Neutralizer
No IRFNA
Composit T_f
T_f
P
Composit P
Composit T_s
T_s
1600
1400
1200
1000
800
600
400
200
0
.1
.2
.3
.4
.5
TEMPERATURE °F OR PRESSURE PSIG
TIME-SECONDS

the initial 50ms or so the fast thermocouple is responding almost identically to the room temperature tests, as might be expected because of the high heat transfer rates. This is not the case with the slow thermocouple. The pressure appears to rise at a slightly faster rate, however this is probably not significant.

The composit above is plotted along with the two thermocouples and pressure indicators for a test having initial residual IRFNA inthe reactor in Figure 8. It may be observed here that all sensors seem to be responding faster as a result of some reaction with IRFNA (or its products of decomposition) even in the early phases of the hot gases entering the reacting system.

In Figure 9 the composites as well as temperature and pressure signals are plotted as a function of time for a test with only dry air in the reactor initially. Here, again the sensors appear to be responding slightly faster, possibly due to reaction of the hot gases with the dry air. It may also be observed here that the bottom thermocouple response for the dry air test is intermediate between the fast thermocouple and the slow thermocouple and probably gives a better indication of conditions in the reactor as a whole than either of the other two.

Tests of the changing volume system utilizing amoving piston during the reaction test are much more difficult to analyze because, in addition to the variabilities of heat transfer, mix-tank pressure, gas composition, thermocouple response, dispersion, etc., a changing volume condition exists which is not regular even as a function of the integral of the pressure-time curve above the piston, and the rate of water ejection from the orifice below the piston. However, some comparisons may be made.

The no-neutralizer, no-IRFNA condition is shown in Figure 10, as a function of time. This is the only no-neutralizer-no-IRFNA test that was

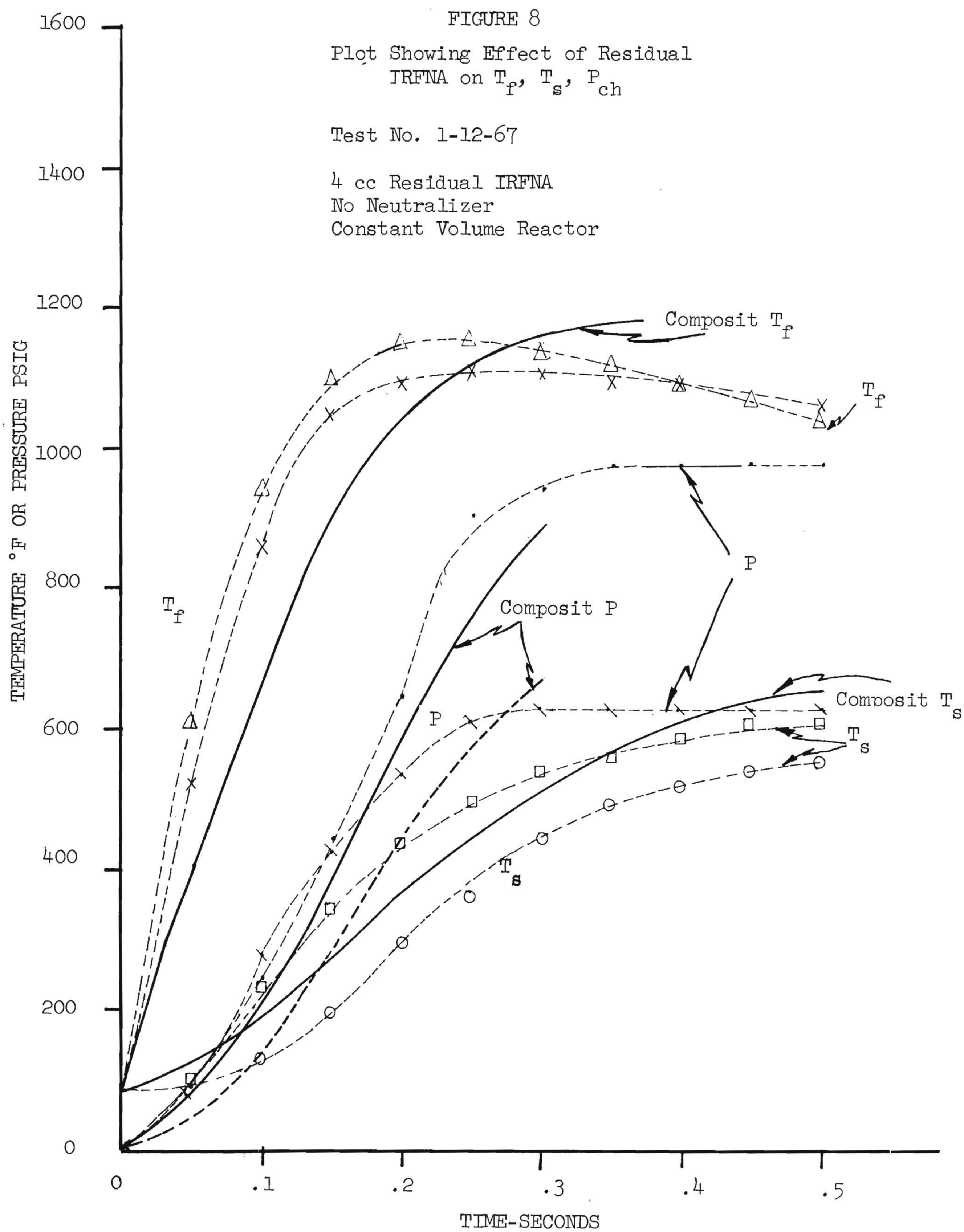


FIGURE 8
Plot Showing Effect of Residual IRFNA on T_f, T_s, P_{ch}
Test No. 1-12-67
4 cc Residual IRFNA
No Neutralizer
Constant Volume Reactor
1600
1400
1200
1000
800
600
400
200
0
TEMPERATURE °F OR PRESSURE PSIG
Composit T_f
T_f
T_f
P
Composit P
P
Composit T_s
T_s
T_s
0
.1
.2
.3
.4
.5
TIME-SECONDS

FIGURE 9

Plot Showing Effect of
Dry Air in Reactor

No Neutralizer
No IRFNA
Constant Volume Reactor

Test No. 8-15-67

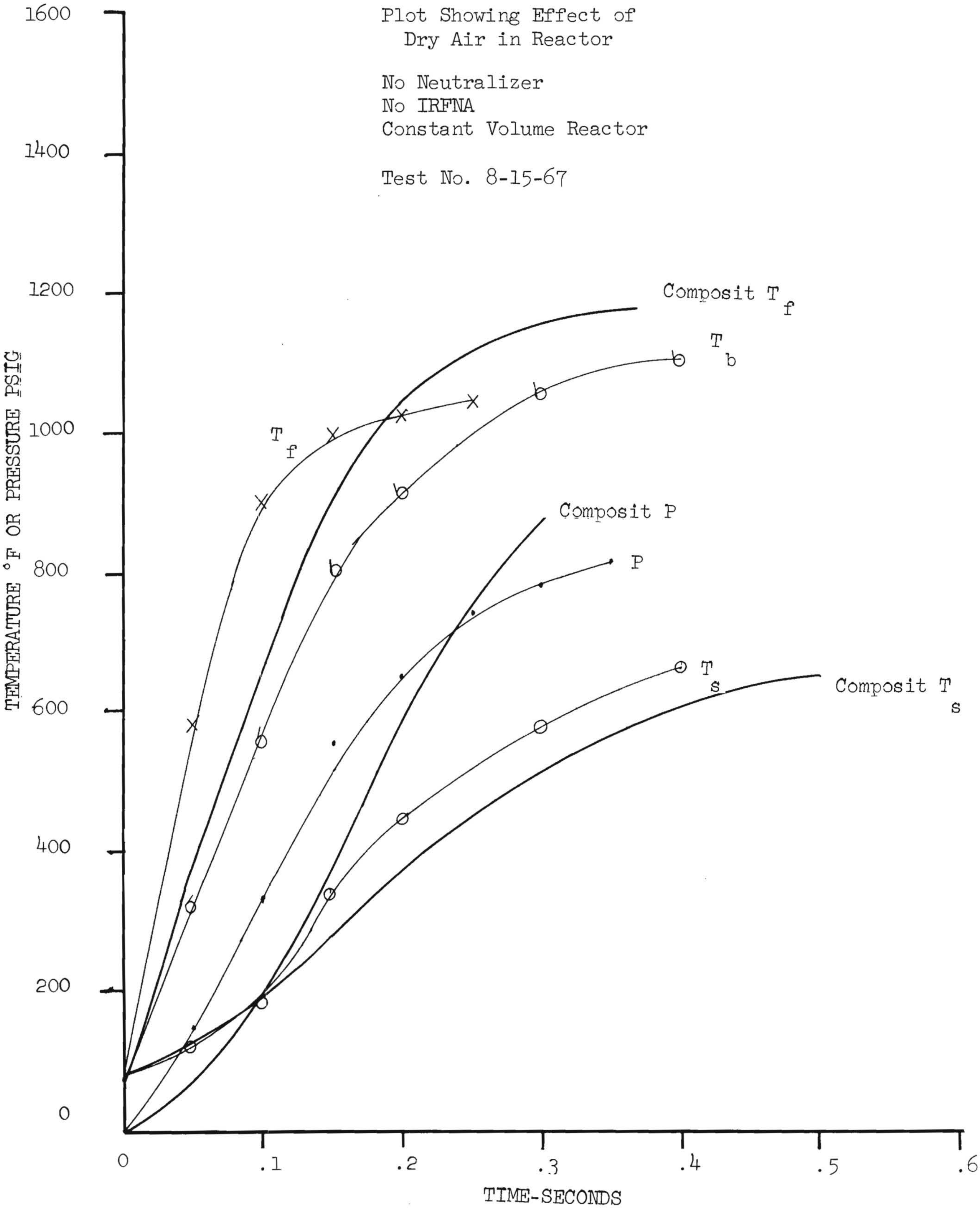
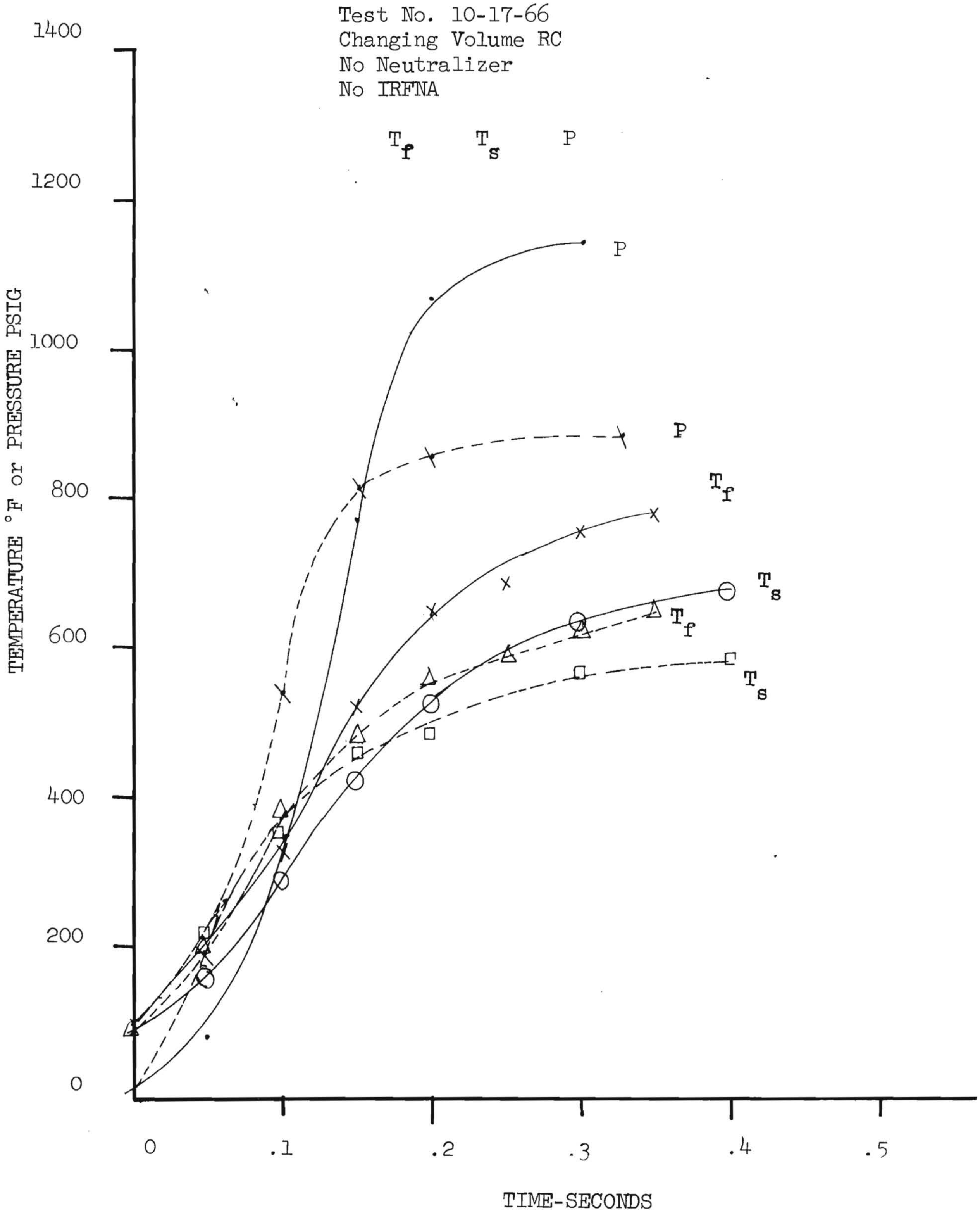


FIGURE 10

Plot Showing T_f, T_s, and P vs. θ

Test No. 10-17-66
Changing Volume RC
No Neutralizer
No IRFNA



conducted during the contract period on this system. Plotted in Figure 11 is the basic information on Figure 10, of two tests using 2 cc. of residual IRFNA above the piston and it may be observed that the fast thermocouple, even though it would appear to be shielded by the incoming gas appears to respond faster in the situation where residual IRFNA is present.

Figure 12 is a plot of the two direct expulsion tests where IRFNA was directly expelled by the hot synthetric AGJ gases without benefit of a separating piston. The fast thermocouple again, although supposedly shielded by the incoming gases, does reveal some increase in temperature in the early stages of the tests with the increased quantity of IRFNA present in the direct expulsion tests. The pressure rises faster but stabilizes at a lower level than in the tests using small amounts of residual IRFNA.

Figure 13 is a plot of the early phases of a test utilizing oxygen injection at 0.1 seconds. It may be observed that both pressure and temperature rise faster, the temperatures go to a higher level, and the pressure is stabilized at a slightly lower level than the tests using residual IRFNA.

These tests, although indicating some comparisons are not truly quantitative from a standpoint that the direct comparison of any particular set of conditions can not be accurately duplicated. There are always slight variations in mixture, slight variations in temperatures, slight variations in dispersing, which alter to some little degree the individual signals obtained from the temperature and pressure elements. The reactor is in a transient state with heat transfer occurring continuously, but not steadily. Slow or fast chemical reactions are occurring during this transient operation, thermocouples, by their nature, are not instantaneously responding and consequently lag the actual condition in the reactor. Finally, the system is heterogeneous, that is, more than one phase, in which non-uniformity of its heterogeneity is the

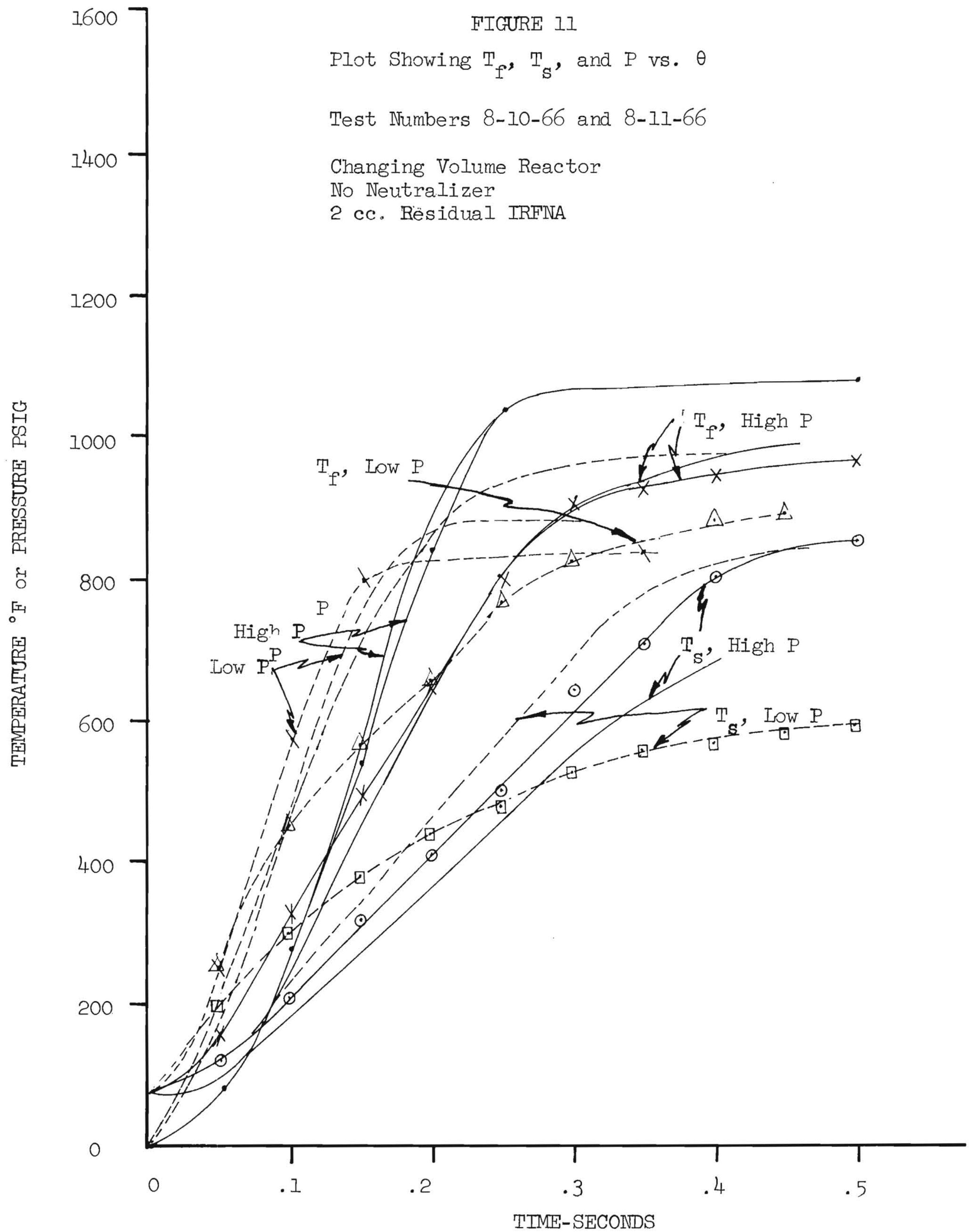


FIGURE 11
Plot Showing T_f, T_s, and P vs. θ
Test Numbers 8-10-66 and 8-11-66
Changing Volume Reactor
No Neutralizer
2 cc. Residual IRFNA
1600
1400
1200
1000
800
600
400
200
0
TEMPERATURE °F or PRESSURE PSIG
T_f, High P
T_f, Low P
P
High P
Low P
P
T_s, High P
T_s, Low P
0
.1
.2
.3
.4
.5
TIME-SECONDS

FIGURE 12

Plot Showing T_f, T_s, P vs. θ

for Direct Expulsion Tests

Test Nos. 8-22-67   8-21-67

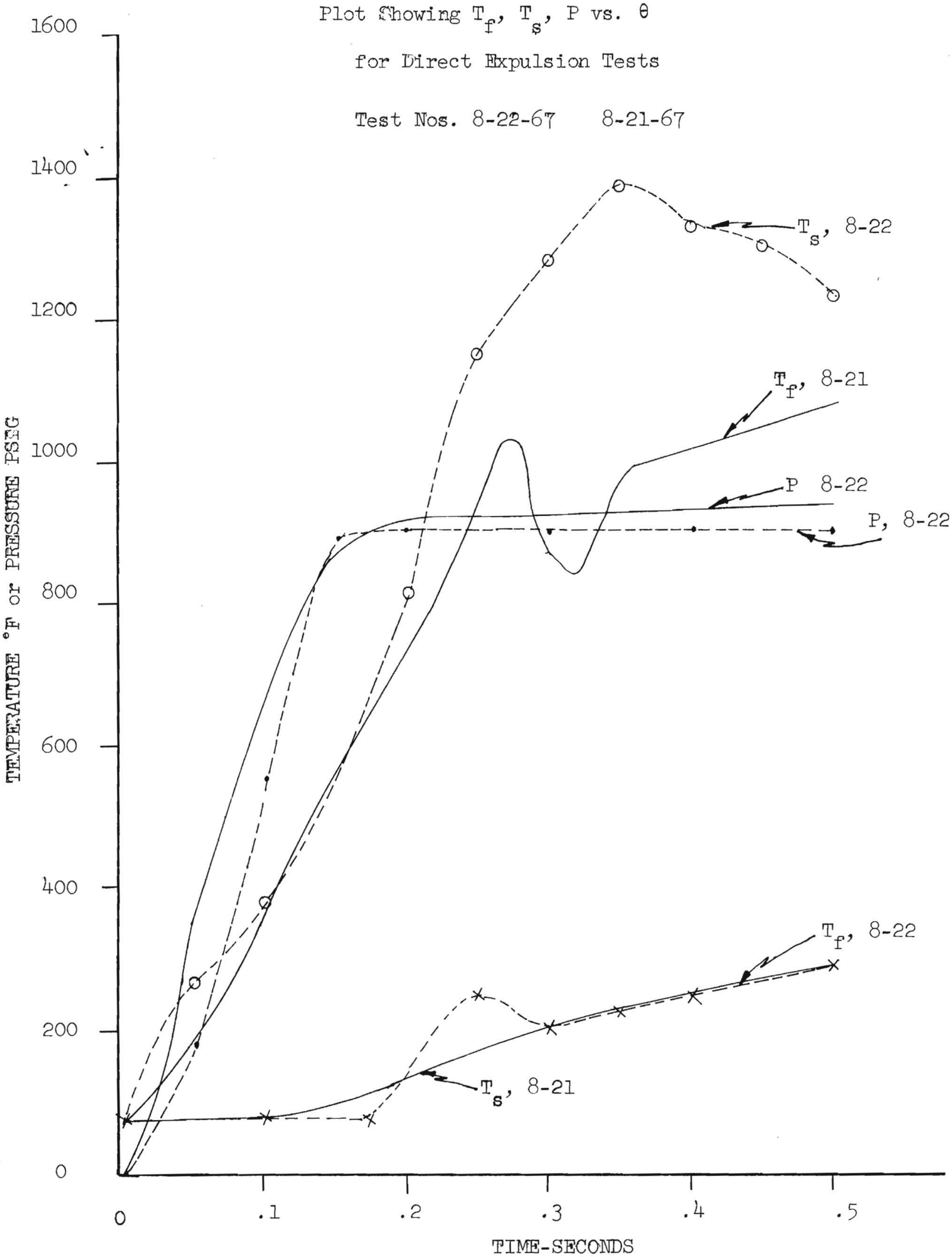
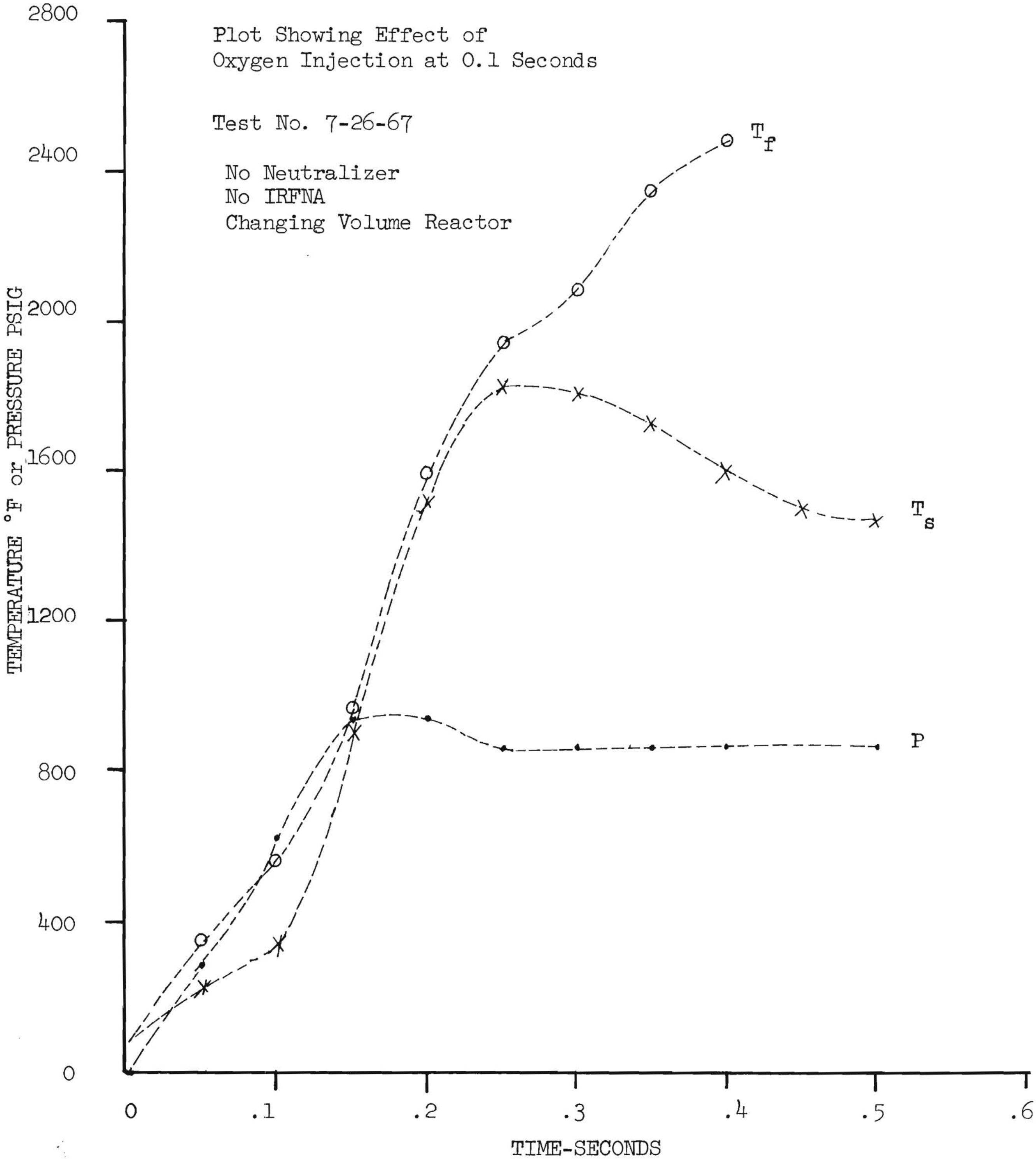


FIGURE 13



2800
2400
2000
1600
1200
800
400
0
TEMPERATURE °F or PRESSURE PSIG
Plot Showing Effect of
Oxygen Injection at 0.1 Seconds
Test No. 7-26-67
No Neutralizer
No IRFNA
Changing Volume Reactor
T_f
T_s
P
0
.1
.2
.3
.4
.5
.6
TIME-SECONDS

principal generalization which can be made. The non-uniformity is readily shown by examination of the data during which 3 thermocouples were located in the reactor in a constant volume test. Figure 14 shows the plotted indicated-temperatures for the three thermocouples, inlet, slow and bottom. The inlet thermocouple and the slow thermocouple indicated essentially normal, non-or near-non-reacting conditions in the reactor. However, the bottom thermocouple approximately 0.7 second after the injection started indicated a rapidly increasing temperature and actually burned-out about 1.2 seconds later. Thus, it is possible for the two thermocouples, inlet and slow to read near normal conditions and still have a severe reaction occur within the heterogeneous type reactor. It should be mentioned that the inlet thermocouple is shielded by the incoming gas during the first half second or so during a test. Subsequent to that time, it sees the same type of situation that the slow thermocouple sees, which is in a recessed portion of the reactor near one of the corners, and which is similar to the thermocouple location in a LANCE missile. Consequently, these thermocouples can be indicating near normal operation and still have a severe reaction occur in a one-fifth scale reactor. The heterogeneity in the missile would be expected to be even more pronounced.

B. Neutralizer Studies

1. Tests with "Purple K" Neutralizer

While "Purple K" has looked fairly good in earlier tests as a neutralizer for limited quantities of IRFNA injected into the hot fuel gas, modification of the conditions rapidly changed this picture. Apparently some finite amount of time is required for the "Purple K" to become effective. This is, in all probability of the order of a second or more after the "Purple K" is contacted with the hot gases. Early injection, that is, at times 0.2 to 0.5

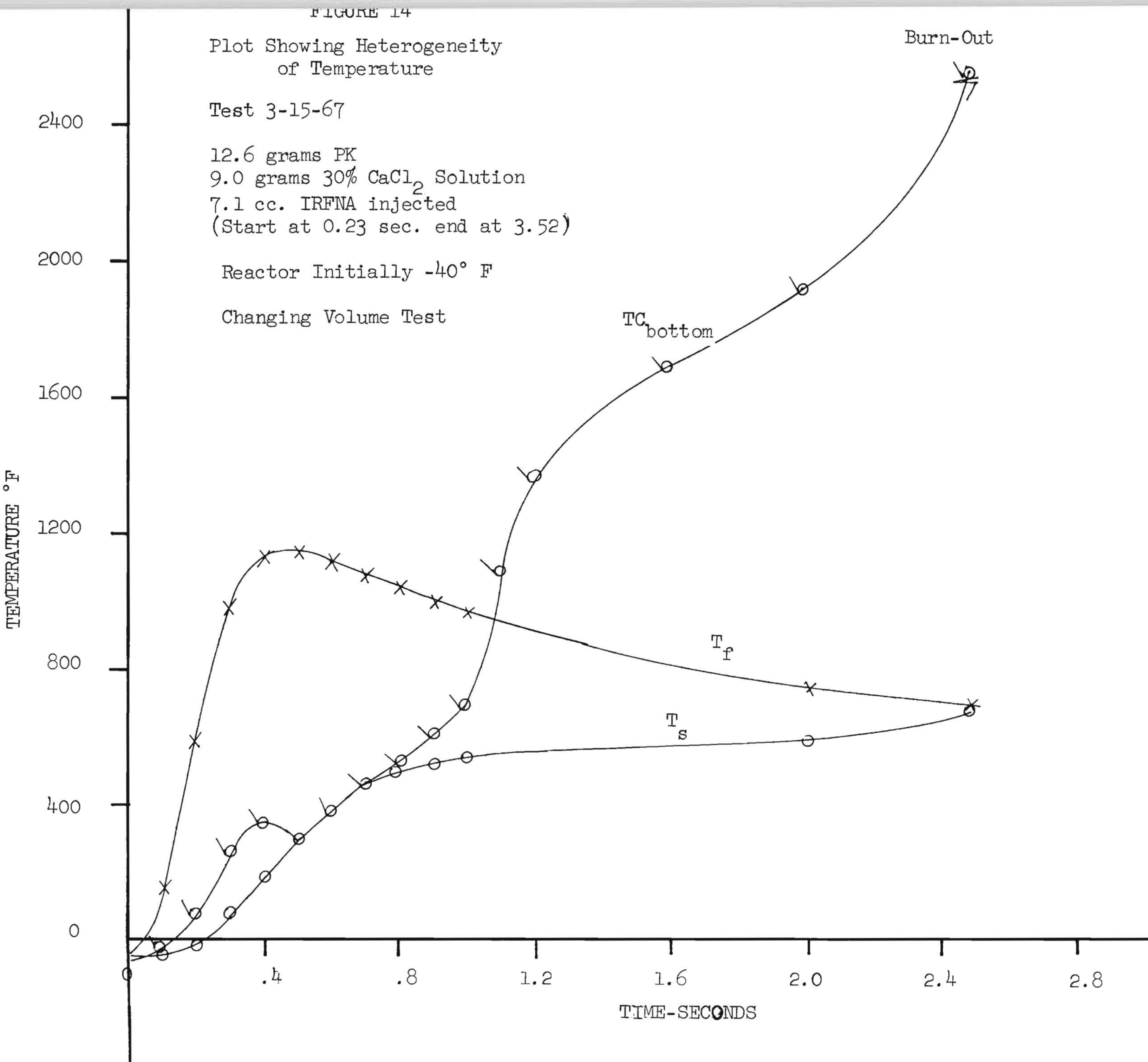


FIGURE 14
Plot Showing Heterogeneity of Temperature
Test 3-15-67
12.6 grams PK
9.0 grams 30% $CaCl_2$ Solution
7.1 cc. IRFNA injected
(Start at 0.23 sec. end at 3.52)
Reactor Initially -40° F
Changing Volume Test
Burn-Out
TC_{bottom}
T_f
T_s
TEMPERATURE °F
2400
2000
1600
1200
800
400
0
0
.4
.8
1.2
1.6
2.0
2.4
2.8
TIME-SECONDS

seconds after initiation of the hot gas into the reaction chamber, produced some severe reactions, even though appropriate quantities of "Purple K" were utilized. At -40° F and using the changing volume reactor, significant reactions were obtained with normal quantities of "Purple K" carried in with the hot fuel gases. The addition of oxygen to the system further complicated the neutralization problem and particularly with the constant volume reactor, the "Purple K" was ineffective in handling the quantities of oxygen that were used in the tests. In these cases, again, early injection was utilized and little neutralization was obtained regularly. These tests are summarized in Table II for the constant volume and changing volume reactors.

2. Tests with "Purple K" and 30% $CaCl_2$ Solution

Earlier work had indicated that a potassium bicarbonate-water slurry had worked well under certain conditions. Since the water would freeze at the lower temperature of operation to which the LANCE might be exposed, a 30% solution of calcium chloride was substituted for the water and tests conducted utilizing separate packages of "Purple K" and 30% $CaCl_2$ solution. The initial tests, conducted at ambient temperature and for late injection of the IRFNA appeared to produce some neutralization. However, the incorporation of early injection with a -40° F reactor temperature introduced occasional reactions, which were uncontrolled. The initial studies using the constant volume reactor with IRFNA and oxygen suggested near control with 10 times the quantity of neutralizer previously used.

Early injection in the changing volume reactor again produced some uncontrolled reactions, more frequent than occasional; on dropping the reactor temperature down to -40° F, again reactions of an uncontrolled nature, more frequent than occasional were obtained, using a normal quantity of neutralizer.

C. Materials Studies

1. Seal Studies

A number of tests were conducted for the purpose of studying not only hot gases but IRFNA passing the seal under load similar to that in the LANCE system under the temperature, pressure and oxidizer conditions similar to those occurring in the LANCE system. These studies are summarized in Table V.

Photographs of the different degrees of burning of the seal material are shown in Figure 15.

Some of the latter tests incorporated a glass-wool insultation between a piece of aluminum foil (in contact with the needle) and the heavy stainless steel bracket. Foil having little overall heat capacity (0.015" thickness) indicated melting of the aluminum foil.

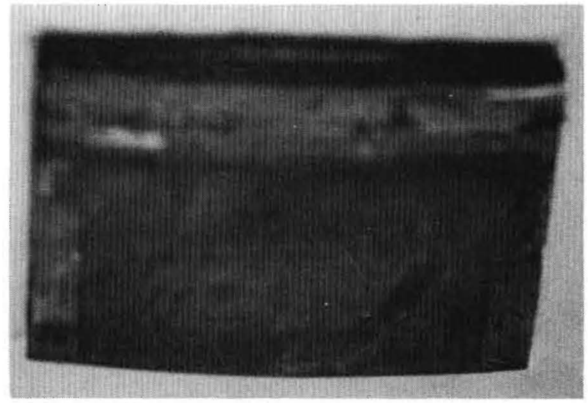
2. Tests with TR-69 Ablative Material

Twenty-three (23) tests were conducted with the TR-69 ablative material in the reactor with various time intervals. These tests were conducted during the months of April and May, 1967 and are summarized in Appendix A.

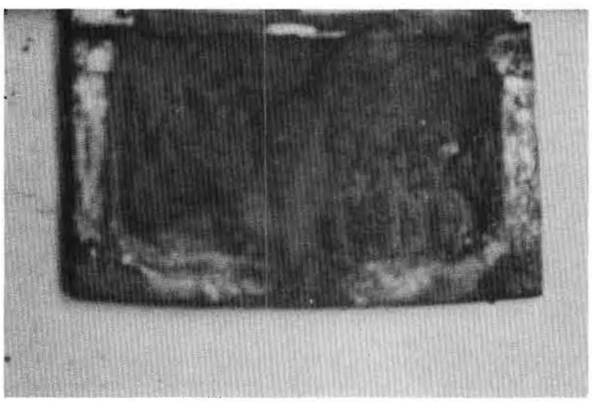
In general, when the ablative material was stacked or piled in the bottom of the reactor and quantities of IRFNA were injected at 16 cc.'s or less per minute, (generally approximately 5 cc.'s per second) significant reactions were obtained. In several cases the burst diaphragm was ruptured. In many cases, the pressure went up from 15 psi to 400 or more psi and the temperature, measured within approximately an inch of the pile of TR-69, went up to 1500° Fahrenheit or more.

The ablative material was formed on an aluminum surface in part of the tests, either the reaction chamber wall (5/8" thick) or aluminum foil varying in thickness down to 0.001 inches. It appears that the heat sink capacity of

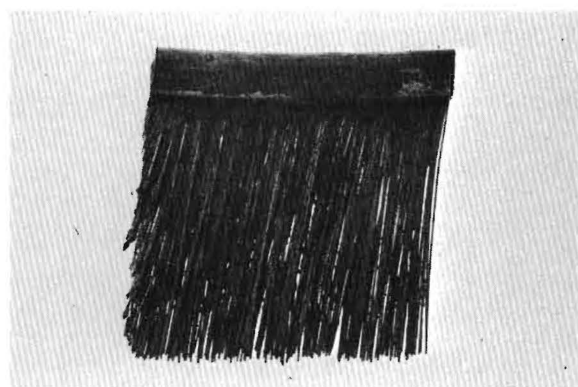
NO - No Burning



B - Burned



S - Severe Damage



SB - Severe Burning
(Wire Showing)

Figure 15. Photograph Showing Degrees of Burning of the Seal Material

the aluminum could be sufficient to absorb enough heat to prevent the runaway reaction (significant temperature or pressure increases).

Tests were also conducted at 150° F reactor temperature. With the aluminum and TR-69 at 150°F, and the IRFNA at ambient temperature at the time of injection, the thickness of the aluminum, required to prevent temperature and pressure increases, fell between .040 and .016 inches. In no case did thicknesses greater than 0.040 inches produce a significant reaction and in no cases did thicknesses of aluminum foil equal to or less than 0.016 inches fail to produce a significant reaction.

The tests at 150° F also indicated a regular increase in the delay associated with the time to reaction (using a 2 cc. per minute injection rate over one hour period). This increase is a function of the thickness of the aluminum upon which the TR-69 was formed and is presented in Figure 16. Unfortunately, the 68 minute end point corresponded to the established end point of the observation period so that it cannot be specifically stated that the 0.040 inch aluminum prevented any reaction. However, the break-down time of the equipment subsequent to the last observation, suggests that no reaction in 90 minutes is a likely extrapalation. Furthermore, no tests were conducted at 150° F without aluminum backing on the TR-69, therefore, a no zero-aluminum-induction time has been established.

In summary, it appears that at 70° F, 0.03 pounds aluminum per pound of TR-69 is sufficient to quench the reaction; at 150° F, 0.5 pounds of aluminum per pound of TR-69 is apparently required to quench the reaction.

D. Tests with Residual IRFNA and Oxygen

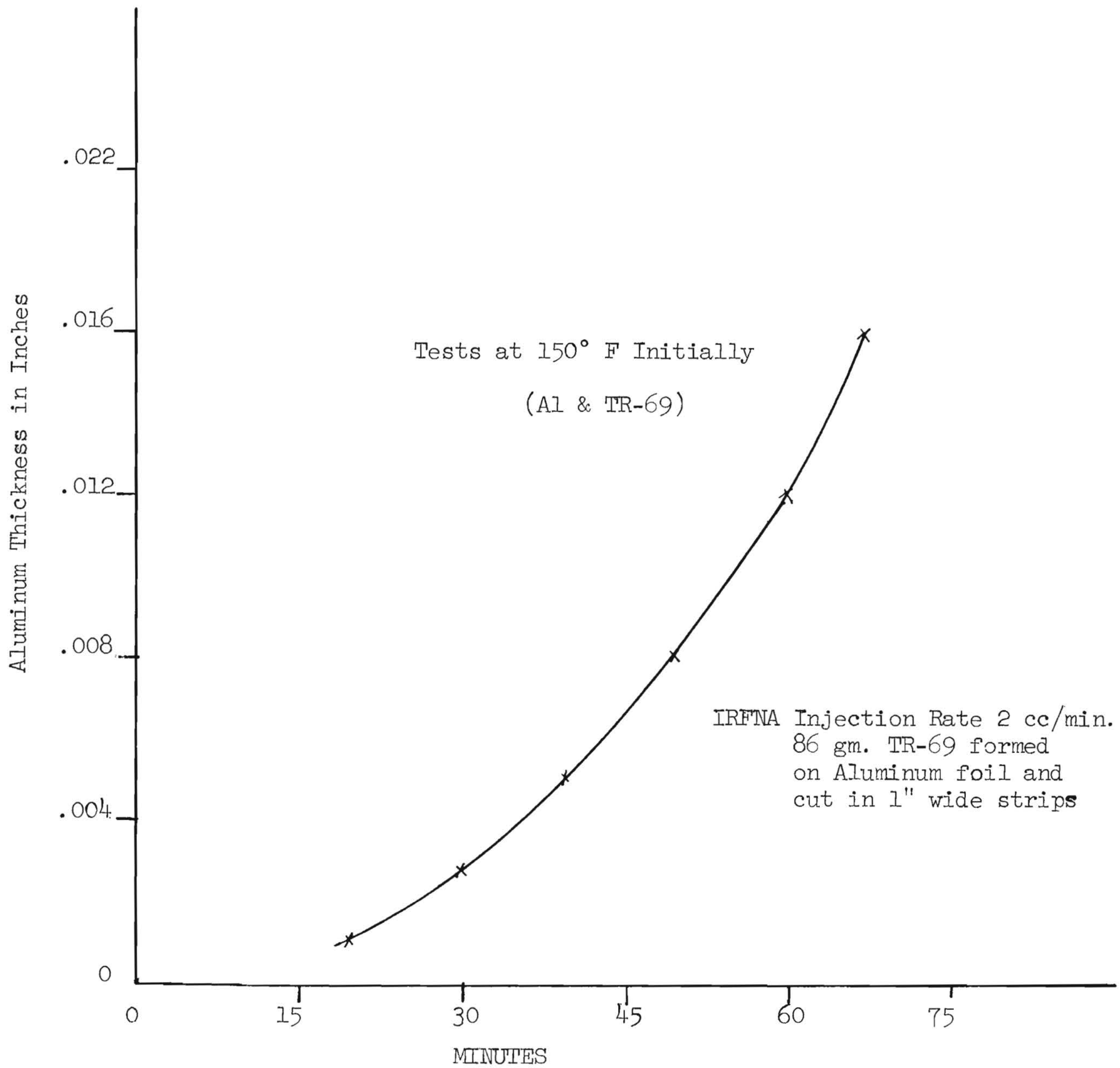
Temperature cycling of IRFNA undergoes a non-reversible decomposition with the result that the gases in the ullage space above the IRFNA contain

FIGURE 16

Time Delay

vs.

Aluminum Foil Thickness



approximately 70% oxygen. This ullage gas creates an additional hazard (additional oxidizer) in the LANCE system. Tests utilizing residual IRFNA and oxygen injected through the injection system revealed frequent uncontrolled reaction using both the dual neutralizer, "Purple K" with $CaCl_2$ solution, or singularly, the "Purple K", alone. Even with quantities of the order of 10 times the neutralizer previously considered satisfactory, reactions that have to be classified as uncontrolled from the standpoint of the LANCE operation, were obtained.

It appears that oxygen addition to the system places considerable additional load on the neutralizing effect of a "Purple K"-$CaCl_2$ type neutralizer. Essentially all of the tests were conducted with commercial "Purple K" material which has nominal 100 mesh particles. Much of the "Purple K" weight is larger than 100 mesh. The effect of smaller particles with the resultant large increase in surface area exposed to the hot gases has not been determined at this time. Further testing in this area is necessary.

E. Miscellaneous Tests

The miscellaneous tests consisted of using water only, or water and "Purple K" as the neutralizer, as well as tests with trichloroethylene (TCE) and unsymmetrical dimethyl hydrazine (UDMH), both with and without IRFNA.

Only a few tests were conducted, but reactivity of the TCE or the UDMH with the hot synthetic AGJ gases was not apparent. The reaction of the IRFNA-UDMH was to be expected, with or without the synthetic AGJ atmosphere.

VI. CONCLUSIONS

It is concluded that:

1. The addition of oxygen in significant quantities to the hot AGJ gas-IRFNA system complicates the neutralization problem -- providing an additional oxidant which was present previously only in small quantites.

2. The "Purple K" material has limited usefulness as a neutralizer with AGJ-type gases if significant quantites of gaseous oxygen are present in the AGJ-IRFNA system.

3. The combination of "Purple K" with 30 percent calcium chloride solution may provide improved neutralization in the AGJ gas-IRFNA system over "Purple K" alone. This improvement, if present, does not appear to be sufficient to provide neutralization under all conditions pertinent to LANCE operation if significant quantities of gaseous oxygen are present in the AGJ-IRFNA system.

4. "Purple K" requires some finite time in the hot gas atmosphere to become effective.

5. The liquid in the combination neutralizer ("Purple K" with $CaCl_2$ solution) appears to help during the early phase because of the fine (spray) dispersal of the liquid, presenting a larger surface area for heat transfer.

6. The effect of very large surface area (fine particle size) has not been determined to date for this sytem (with either liquid or solid-type neutralizers).

7. The mechanism of neutralization of the IRFNA, or the IRFNA-O_2, AGJ fuel gas system is not understood to date.

RECOMMENDATIONS

It is recommended that:

1. Effort be continued on the neutralization study to provide some criteria for suppression of the unwanted reaction in the event of IRFNA leakage past the seal in the LANCE system.

2. Additional work be initiated to further the understanding of neutralization of HNO_3, NO_2, NO, O_2 reactions with H_2, CO, and CH_4.

3. The effect of surface area be determined both in regards to liquids and solids, since if the effect is the same, the primary effect may be that of a heat sink.

4. The use of other neutralizing agents be investigated further, particularly the oxalates and alums with particular reference to the use of heavier metals (cesium and rubidium in the place of potassium) in the salts.

5. Faster responding thermocouples be surveyed which will stand-up under the hot, acid, oxidizing as well as reducing atmospheres.

Respectively submitted,

J. F. Kinney
Project Director

REFERENCES

1. Kinney, J. F., and Harrison, C. M., Hot Gas-IRFNA Compatibility, (1964) Final Report, Project A-738, Engineering Experiment Station, Georgia Tech, under Contract No. DA-01-009-AMC-86(Z) with Headquarters, U. S. Army Missile Command, LANCE Project Office.

2. Kinney, J. F., and Harrison, C. M., Neutralizer for Hot Gas-IRFNA Reaction, (1966), Technical Report, Project A-849, Engineering Experiment Station, Georgia Tech, under Contract No. DA-01-021-AMC-11885(Z) with Headquarters, U. S. Army Missile Command, LANCE Project Office.

3. Kinney, J. F., and Harrison, C. M., Neutralizer for Hot Gas-IRFNA System, (1966) Final Report, Project A-849, Engineering Experiment Station, Georgia Tech, under Contract No. DA-01-021-AMC-11885(Z) with U. S. Army Missile Command, LANCE Project Office.

APPENDICES

APPENDIX A

Summary of Tests Conducted

TABLE VIII

SUMMARY OF DATA

Run No. 1966	Mix Tank		Htr. Temp.	$T_{gas_{in}}$	Neutralizer	IRFNA Residual	IRFNA Inj. Rate	IRFNA Dip	Inject Time Start	Inject Time End	Time Stroke End	$P_{g_{max}}$ psi	$\theta_{P_{max}}$ sec	P_{H_2O} max	Fast TC °F	Fast TC θ	Slow TC °F	Slow TC θ	Rate of Rise Initial	Rate of Rise Due to Inj.	Remarks
8-1	1300	710	2320		14 gms basket, 4.67 W, Poly on piston		3.1	(10.0)	1.1	4.22	-4.81	970/1292	0.4/4.39	970	1179	4.9	1031	6.0	4100	1600	Piston bottomed prior to injection. Barksdale valve open at start.
8-2	1300	600	2360	1995	14 gms basket, 4.67 W, Poly on piston		2.1	(10.9)	1.09	4.83	5.82	1086	0.33	1043	947	2.85	585	1.5	5820		
8-3	1300	975	2100	1805	14 gms basket, 4.67 W, Poly on piston		2.3	(5.8)	1.12	4.30	5.22	1195	3.22	1161	1201	4.82	1307	5.17	5900	1450	
	970	610	2080	1735			2.3	(8.2)	1.09	4.27	6.65	787	0.31	761	755	0.35	541	1.5	5820		
8-4	1300	920	2220	1880	14 gms basket, 4.67W, Poly on piston	2	2.1	(8.2)	1.07	4.26	5.81	1079	0.75	1039	837	0.75	572	1.75	6520		
	930	690	2210	1860		2	2.3	(5.9)	1.09	4.22	5.14	745/861	0.37/2.73	719/831	1416	3.67	1503	4.62	5440	465	
8-5	1300	925	2150	1825	14 gms basket, 4.67 W, Poly on piston	2	2.0	(8.1)	1.05	4.23	5.26	1086	0.45	1043	757	0.55	572	1.4	6600		
	1000	975	2190	1830			2.2	(8.1)	1.05	4.25	6.59	826	0.4	790	658	3.35	489	1.35	6140		
8-8	1280	950	2160	1830	14 gms PK + 2.3 cc H_2O Polyethylene	2	2.3	24.0(8.7)	1.86	5.02	5.85	1086/1172	0.55/8.75	1043	791	9.15	808	9.5	6220		
	1020	650	2190			2	2.3	(8.4)	1.09	4.27		838	0.35	800	693	4.75	497	2.0	5440		
8-9	1300	920	2140	1810		2	2.2	10.6(8.6)	1.10	4.27	5.34	1075	0.55	1034	735	0.5	563	1.35	5980		
	950	665	2140	1790		2	2.3	0.0(10)	1.10	4.27	6.16	776	0.3	766	799	0.4	585	1.5	5440		
8-10	1300	940	2220	1885		2	2.1	8.0(8.2)	1.05	4.23	5.31	1086	0.5	1053	968	0.45	735	1.10	6000		
	1000	750	2210	1860		2	2.2	24.0(9.0)	1.09	4.27	5.95	842	0.35	808	1485	3.2	1772	4.40	5280		
8-11	1300	1000	2290	1949		2	2.1	10.6(7.1)	1.10	4.27	5.55	1079	0.51	1058	1091	2.85	1934	3.75	6220		
	1080	730	2290	1925		2	2.2	21.2(10.8)	1.11	4.29	6.21	889	0.3	855	1011	0.35	884	0.55	6820		
9-12	1300	985	2265	1940	14 gms PK + 2.3 cc H_2O in chamber void	2	2.1	15.9(8.2)	1.02	4.20	5.26	1086/1300	0.5/5.85	1062/1250	1158	5.85	1286	5.85	6040		
	1070	665	2170	1840		2	2.2	10.6(5.5)	1.06	4.24	5.91	892/1070	0.3/3.26	860/1043	1116	3.91	1330	3.95	6980	1420	Barksdale Valve open at start of
8-16	1300	930	2240	1915	14 gms PK	2	2.4	(8.8)	1.12	4.27	5.40	10[illegible]0/1474	0.69/6.04	1001/1419	1424	7.54	1659	6.89			test ($\frac{dP}{d\theta}$ - 1240 @ bottom. Fast
	1050	710	2170	1825		2	2.3		1.08	4.19	5.95	850	0.5	827			385	2.5	3480		TC out
8-17	1300	1000	2260	1920	2.3 gms H_2O above piston	2	2.1	15.9(7.1)	1.02	4.17	5.26	1075	0.7	1043	998	0.62	1556	4.62	5000		
	1080	685	2180	1840	2.3 gms H_2O above piston	2		MT* tank on at start		4.22	5.83	931	0.45	907	2257	1.33	1394	3.07	5820		IRFNA valve open @ start of run
8-18	1300	940	2150		14 gms PK							1071	0.55	1034	757	0.6	431	3.1	3690		
	1060	730	2150	1805							5.85	869	0.35	851	658	0.6	386	5.85	3000		
8-19	1300	950	2180	1850	14 gms PK, 2.3 cc H_2O (above piston - Polyethylene)						5.36		0.45	1034	820	0.45	400	5.36	3880		
	1010	690	2180	1830							6.08	823	0.35	808	650	0.35	350	6.08	4100		
8-22	1300	920	2240		14 gms PK						Const. Vol.	962	0.76		1116	0.38	565	3.0	3480		Ablative Test - Constant Volume
	970	670	2140									695	0.45		1074	0.32	563	3.0	2960		
8-24	1250	860	2270		14 gms PK		2.1	8.0(6.7)	1.07	4.23	Const. Vol.	920	0.6		1137	0.32	735	0.65	3660		Ablative Material - Constant Volume
	885	615	2210				1.9	10.6(6.3)	1.05	4.2		632	0.32		1074	0.25	563	0.81	3440		
8-25	1300	800	2210								Const. Vol.	951	0.4		1154	0.3	735	0.66	3800		Ablative Material - Constant Volume
	1010	671	2190									745	0.4		1116	0.8	714	0.60	3500		

*Empty

(continued)

TABLE VIII (Continued)

SUMMARY OF DATA

Run No. 1966	Mix	Tank	Htr. Temp.	$T_{gas_{in}}$	Neutralizer	IRFNA Residual	IRFNA Inj. Rate	IRFNA Dip	Inject Time Start	Inject Time End	Time Stroke End	$P_{g_{max}}$ psi	$\theta_{P_{max}}$ sec	$P_{H_2O\,max}$	Fast TC °F	Fast TC θ	Slow TC °F	Slow TC θ	Rate of Rise Initial	Rate of Rise Due to Inj.	Remarks
8-26	1300	900	2150				2.2	0.0(7.2)	1.12	4.29	Const. Vol.	962	0.5		1137	0.31	727	0.76	4640		Ablative Test--Constant Volume.
	930	650	2175				2.0	? (6.3)	1.1	4.26		679	0.37		1137	0.32	791	2.23	2960		
8-29	1300	910	2220				2.2	2.1(7.1)	1.12	4.27	Const. Vol.	962	0.45		1235	0.37	714	0.75	4120		Ablative Test--Constant Volume.
	930		2205				1.5	? (4.9)	1.08	4.24		648	0.4		1137	0.37	863	5.0	3120		
8-30	1300	910	2140				1.8	2.1(6.1)	1.07	4.24	Const. Vol.	873	0.5		1167	0.3	752	0.93	4440		Ablative Mat'l. Test--Const. Vol.
	1050		2140				2.3	? (7.1)	1.12		Const. Vol.	585	0.4		1137	0.3	563/1053	0.75/4.75	3100		Ablative Mat'l. Test--Const. Vol.
8-31	1300		2210		14 gms PK; 2.3 cc 30% $CaCl_2$			(10.8)		4.26		884		1034	726	4.5	363	2.0	6220		
9-1	1300	930	2220		14 gms PK; 3.4 cc 30% $CaCl_2$	2	2.0					958		1062	744	5.25	363	5.25	6440		Doubtful injection.
9-2	1300	830	2285		14 gms PK; 4.3 cc 30% $CaCl_2$	2		(7.3)						1039	748	5.0					Chanber pressure gage polarity reversed.
	960		2260			2		(7.6)				780		757	484	5.0	300	2.0	6200		
9-6	1300	920	2230		14 gm PK; 4.3 cc 30% $CaCl_2$	2	2.2	34.0(8.2)	1.08	4.24		1083	0.5	1043	497	6.0	297	6.02	6200		
	970	660	2210			2	2.2	(7.8)	1.08	4.26		815	0.4	790	386		497		5960		
9-7	1300	830	2220	1930	14 gms PK; 4.3 cc 30% $CaCl_2$	4	2.4	31.0(8.5)	1.05	4.23	6.52	1044	0.47		310	3.5	296	1.57	7000		
	910	600	2200	1835		4	2.2	0.0(7.4)	1.07	4.24	7.59	776	0.28		383	7.59	287	3.25	6360		
9-8	1300	890	2240	1890	14 gms. PK; 4.3 cc 30% $CaCl_2$	4	2.3	10.6(8.4)	1.05	4.25	6.29	1086	0.4		1099	5.1	290	2.72	6980		
	860	400	2300	1910		4	2.2	10.6(7.8)	1.12	4.30	7.75	714	0.27		663	4.5	260	1.66	5820		
9-9	1300	890	2200	1860	14 gms PK; 4.3 cc 30% $CaCl_2$	6	2.9		1.1	4.30	6.0	1086	0.57		799	3.75	296	2.77	6140	Neg	Injection questionable.
	960	560	2210	1835		6		5.3(9.7)	1.12	4.29	7.84	737	0.3		639	7.0	274	7.84	5740		
9-12	1300	920	2260	1900	14 gms PK; 4.3 cc $CaCl_2$	6	2.5	0.0(8.6)	2.46	5.66	6.27	1044	1.22		938	5.8	431	3.15			Barksdale valve cracked open at start of test.
9-13	1300	900	2280	1930	14 gms PK; 4.3 30% $CaCl_2$	6		0 ?			6.03	1110	0.58	1072	701	5.0	400	5.0	6980		Barksdale valve cracked open at at start of test. Doubtful injection.
9-14	1300	940	2320	1960	14 gms PK; 4.3 cc 30% $CaCl_2$	6		5.3 ?	2.57	4.30	6.07	1105	0.45	1048	735	4.25	458	0.75			Ch. press. pen did not write
9-15	1300	890	2340	1980	14 gms PK; 4.3 cc 30% $CaCl_2$	6		5.3			6.20	1125	0.4	1072	735	3.5	466	2.5			Mkr ckt not operating properly, P_{ch} pen not inking.
	920	640	2240	1860		6		5.3(8.9)	1.25	4.25	7.63	768	0.4	729	628	4.64	386	1.0			P_{ch} pen not inking.
9-19	1300	890	2260	1910	14 gms PK; 4.3 cc 30% $CaCl_2$	6	2.8	10.6(9.6)	1.11	4.25	5.94	1086	0.4	1058	761	4.5	386	6.0			Slight lk @ gas inlet of RC, P_{ch} pen not inking.
	940	630	2215	1860		6	2.6	0.0(9.0)	1.08	4.23	6.13	776	0.4	752	563	5.35	386	1.2			Slight lk @ spark plug, P_{ch} pen not inking
9-20	1300	830	2325	1975	14 gms PK; 4.3 cc 30% $CaCl_2$	6	2.6	15.9(9.6)	0.42	3.63	5.43	1086	0.4	1048	812	0.4	431	1.0	6980		
	1020	630	2190	1830		6	2.5	5.3(9.4)	0.38	3.58	6.84	854	0.4	832	537	4.0	475	1.0	6980		Slight leak @ spark plug.
9-22	1300	990	2265	1925	14 gms PK; 4.3 cc 30% $CaCl_2$	6	0.9	0.0(3.9)	0.37	3.58	5.77	1156	1.25	1105	out	out	2675	2.0	7680		
			2220	1870		6	1.7	0.0(4.8)	0.40	3.61	6.32	954	1.75	917	out	out	2144	3.61	6740		
9-23	1300	930	2265	1925	14 gms PK; 4.3 30% $CaCl_2$	6	1.9	16.6(2.5)	0.40	3.61	5.94	1086/1214	1.15/1.35	1048/1175	1667	3.51	1957	2.7	7060	640	
	1040		2235	1870		6	2.0	29.0(8.0)	0.35	3.56	7.01	854	0.4	827	654	5.18	409	7.01	6280		

(continued)

TABLE VIII (Continued)

SUMMARY OF DATA

Run No.	Mix	Tank	Htr. Temp.	$T_{gas_{in}}$	Neutralizer	IRFNA Residual	IRFNA Inj. Rate	IRFNA Dip	Inject Time Start	Inject Time End	Time Stroke End	$P_{g_{max}}$	$\theta_{P_{max}}$	$P_{H_2O_{max}}$	Fast TC °F	Fast TC θ	Slow TC °F	Slow TC θ	Rate of Rise Initial	Rate of Rise Due to Inj.	Remarks
1966																					
9-26	1300	940	2280	1930	14 gms PK	6	2.0	10.6(4.0)	0.65	3.56	6.2	1078/1249	0.65/2.11	1048/1208	1550	3.55	1627	3.4	6280	1780	
	1000	700	2200	1850		6	2.0	10.6(3.0)	0.37	3.59	6.7	815/989	0.35/1.92	799/945	1762	3.15	no print		5660	1460	TC_2 indicated ΔT, did not ink
9-27	1300	940	2330	1900	12.6 gms PK, 7 cc 30% $CaCl_2$	6	2.0	5.3(4.4)	0.37	3.57	5.76	1079/1257	0.37/2.02	1048/1222	1460	3.7	1685	2.8	6140	1330	
	1030	710	2220	1860		6					6.7	881	0.27	846	528	6.7	377	2.5			Mkr ckt not operating
9-28	1300	900	2330	1875	12.6 gms PK, 7 cc 30% $CaCl_2$	6		5.3			6.02	1079	0.5	1034	662	5.02	475	1.25			Mkr ckt not operating
	950	680	2240	1880		6	1.8	21.2(3.5)	0.38	3.6	6.63	778/958	0.38/2.17	663/926	1503	3.9	981	4.5	5880		
9-29	1300	970	2240	1870	12.2 gms PK, 7 cc 30% $CaCl_2$	4	2.0	5.3(4.4)	0.36	3.64	5.23	1078/1207	0.4/1.65	1039/1152	1685	3.52	1158	5.23	6620	600	
	1000	720	2230	1890		4	1.3	5.3(2.8)	0.37	3.62	6.79	854/1203	0.37/2.30	827/1161	1350	3.9	1636	4.15	7100	5450	
9-30	1180	930	2210	1890	12.6 gms PK, 7 cc 30% $CaCl_2$ solution	2	2.3	(1.8)	0.35	1.12	5.76	954/1389	0.36/2.80	940/1344	1305	3.8	no print		3840	2400	
10-4	1300	935	2210	1860	12.6 gms PK, 7 cc 30% $CaCl_2$	2	2.0	5.3	0.33	3.53	8.11	1136	0.4	1105	650	4.0	453	3.0			
	1000	660	2220	1840		2		8.0	0.37	3.6	9.57	838	0.4	813	554	7.0	363	0.75			
10-7	1120		2220		12.6 gms PK, 7 cc 30% $CaCl_2$ sol'n.		2.0		0.3	3.62		1017	0.45	959	968	3.98	926	4.55			
10-10	1240	945			12.6 gms PK, 7 cc 30% $CaCl_2$		2.0	2.7	0.32	3.62	7.98	1121	0.55	1081	1286	3.35	1695	3.85			
	930	695						2.7	0.33	3.63	9.28	811	0.32	780	2014	3.69	2081	3.80			
10-11	1300	1050			12.6 gms PK (only)		2.0	15.9	0.29	3.59	5.37	1125	0.34	1081	1503	2.37	1717	3.07			
	1050	790						10.6	0.34	3.65	8.82	923	0.34	879	2062	3.45	2144	3.25			
10-12	1300	960			14 gms PK (only)		2.0	15.9	0.31	3.61	8.09	1125	0.31	1081	1569	3.5	1658	3.5	1658	3.66	(1) Approximately 6 gms PK remaining in basket
	1000	660						15.9	0.31	3.62	9.77	861	0.31	832	692	7.5	497	1.0			
10-13	1300	920			14 gms PK + 7.6 gms in and behind basket		2.9	10.6	0.33	3.63	8.08	1106/1211	0.55/2.15	1062	1925	3.50	1864	3.7			6.4 gms PK left behind finger (1)
	920	630						8.9	0.31	3.62	(bottom)	683/1141	0.32/2.32	649	1459	3.0	1372	3.34			Piston inadvertantly at bottom at start

(continued)

TABLE VIII (Continued)

SUMMARY OF DATA

Run No.	Mix Tank		Htr. Temp.	$T_{gas_{in}}$	Neutralizer	IRFNA Residual	IRFNA Inj. Rate	IRFNA Dip	Inject Time Start	Inject Time End	Time Stroke End	$P_{g_{max}}$	$\theta_{P_{max}}$	$P_{H_2O\ max}$	Fast TC		Slow TC		Rate of Rise Initial	Rate of Rise Due to Inj.	Remarks
1966												psi			°F	θ	°F	θ			
10-14	1300	940	2350		14 PK + 7.6 PK in bag behind basket		2.5					1227	1.75		1864	3.70	1725	3.70	6980		Plastic bag w/7.6 gms PK
	1060	745	2345				2.3					1163	3.12		1481	4.42	1459	6.20	6980		did not break on Run 1
10-17	1300	1000	2300		No Neutralizer							1148	0.44		777	0.45	714	0.55	7760		Cleaned intake pipe prior
	930	695	2375		No Neutralizer							939	3.64		1795	1.57	2452	3.64	6980		to Run No. 1
10-18*	1300	1000	2350		No Neutralizer							1132	0.50		757	0.48	715	0.55	7760		New inj. N_2 gauge
	910	620	2340		No Neutralizer							896	1.4		632	0.57	541	0.55	5810		
10-20*	1300	955	2340		No Neutralizer		1.6					1280	2.8		921	1.80			8540		Changed mix tank pressure
	1000	710	2355		No Neutralizer		2.0					970	1.10		1521	4.15	1158	3.5	6590		prior to run
10-21*	1280	895	2310		No Neutralizer							1171	1.01		888	0.32	536	0.70	8540		
	920	630	2375		No Neutralizer		1.9					833	1.0		641	5.00	386	0.30	6210		
10-24*	1300	887	2300		No Neutralizer							1163	0.70		854	1.07			6600		TC did not print--1st run
	890	620	2325		No Neutralizer		2.2					977	0.38		563	2.50			6990		with new IRFNA
10-25*	1300	933	2320		No Neutralizer		2.1					1094	0.64		1006	0.45	563	3.70	6990		
	970	620	2485		No Neutralizer		1.7					822	0.30		829	0.40	735	1.90	6990		
10-26*	897	2355	2355		No Neutralizer	2	2.3					703	1.50		1804	4.95	1257	5.87	1166		Leak at head gasket
10-28	1300	905	2344		No Neutralizer		2.0					1064	0.6		1014	0.4	1014	4.75			Cold Box
10-30	1275	805	2350		No Neutralizer		1.8								888	0.9	735	4.65			Cold box, marker ckt inop.
11-1	1255	842	2355		No Neutralizer		1.89	3/16"				1088	0.85		905	0.50	880	3.10	5580		
11-2	1210	845	2310		No Neutralizer		0.95	1/16"				1041	0.37		981	0.45	675	4.45	6547		
11-3	1310	897	2320		No Neutralizer		1.62	1/16"				1116	0.65		Did not print		777	5.05	8923		
11-28	1300	880	2365		No Neutralizer	1	1.52	1/16"				1101	0.28		1929	2.30	1269	2.85	7440		
	925	600	2345		No Neutralizer	1						-			519	0.30	278	0.30			Gas press. did not print
11-29	825	600	2375		No Neutralizer	1		3/8"				-			1892	3.00	1312	4.75			Gas press. did not print
11-30	1225	845	2280		No Neutralizer	1	1.059					1052	0.58		879	3.60	1065	3.78	8930		
11-4	1280	905	2355		No Neutralizer	2	1.18	1/4"				1104	0.33		998	0.45	1040	1.27	9660		
11-7	1310	905	2300		No Neutralizer	4	1.38	1/4"				1112	0.45		1048	0.57	2237	1.37	8560		
11-8	1285	900	2325		No Neutralizer	4	2.16	1/16"				1072	0.51		989	0.50	820	1.40	8930		Leak at O-rings
	895	595	2345		No Neutralizer	4	2.04	1/8"				741	0.33		1591	2.15	1503	1.25	6330		Pressure leak

*IRFNA injection of questionable reliability

(continued)

TABLE VIII (Continued)

SUMMARY OF DATA

Run No.	Mix Tank		Htr. Temp.	$T_{gas_{in}}$	Neutralizer	IRFNA			Inject Time		Time Stroke End	$P_{g_{max}}$	$\theta_{P_{max}}$	$P_{H_2O_{max}}$	Fast TC		Slow TC		Rate of Rise		Remarks
1966						Residual	Inj. Rate	Dip	Start	End		psi			°F	θ	°F	θ	Initial	Due to Inj.	
11-9	1255	945	2365		14 gms PK	4	2.86	3/16"				1986	0.75		2042	1.02	1326	4.81	7076		Lead at O-rings
	965	610	2327		14 gms PK	4	2.00	1/16"				792	0.50		623	3.82	216	3.16	5580		-31° F Ambient on Run No. 2
11-10	1275	895	2366		14 gms PK	4	1.44	1/8"				1049	0.49		1600	1.96	2052	2.36	7070		
11-11	1300	960	2370		14 gms PK	2	0.88	3/16"				1131	0.45		1006	1.56	1808	1.77	6700		
	1000	655	2366		14 gms PK	2	2.42					788	0.30		684	3.47	386	0.93	5580		
11-14	1275	895	2366		14 gms PK		1.50	1/8"				1082	0.47		Burned out		1808	1.98	7070		
11-15	1295	1095	2390		14 gms PK		1.10	1/8"				1113	0.42		837	1.60	1708	2.38	7070		
	1095	695	2331		14 gms PK		1.89	3/16"				863	0.35		666	4.88	368	0.82	5580		
11-16	1300	755	2333		12.6 gms PK + 7 cc $CaCl_2$ solution		1.62	1/4"				1101	0.33		597	5.05	378	6.40	7070		
	770	500	2350		12.6 gms PK + 7cc $CaCl_2$ solution		1.81	1/4"				632	0.32		448	4.00	199	3.30	5960		
11-17	1300	895	2332		12.6 gms PK + 7 cc $CaCl_2$ solution	2	1.90	3/16"				1039	0.53		649	6.88	413	8.62	7070		
11-18	1300	890	2390		12.6 gms PK + 7 cc $CaCl_2$ solution	4	1.20	1/4"				1116	0.50		2338	3.97	519	7.10	9660		
	815	550	2375		12.6 gms PK + 7 cc $CaCl_2$ solution	4	1.49	1/16"				684	0.29		493	5.10	350	5.90	6700		
11-21	1200		2340		14 gms PK	1															Gasket blew out at Neut. Flanges
11-22	1275	850	2380		14 gms PK	1	0.71	3/16"				1072	0.48		2217	1.60	2109	2.08	7440		
11-23	1285	885	2360		12.6 gms PK + 7 cc $CaCl_2$ solution	1	1.53					1088	0.30		2379	3.58	1260	4.70	8930		
12-2	1300	605	2380		14 gms PK w/o pressure tubes	2															Blew cylinder
12-6	1300	906	2345		14 gms PK w/o pressure tubes	2	2.39					848	0.54		1175	3.32	1863	3.53	6330		
12-8	1245	815	2360		14 gms PK w/o pressure tubes	1	2.21					996	0.80		1149	1.42	1485	3.23	>440		
12-9	1300	978	2300		12.6 gms PK + 7 cc 30% $CaCl_2$	2															Recorder paper slipping & ambient not -40°
12-12	1275	885			12.6 gms PK + 7 cc 30% $CaCl_2$	2	Injected all IRFNA in reservoir														Without pressure tubes
12-15	1300	915	2270		12.6 gms PK + 7 cc 30% $CaCl_2$	2	1.29	1/16"				1101	0.42		649	0.70	769	4.50	6660		Without pressure tubes
12-16	1300	885	2250		14 gms PK w/o pressure tubes							1109	0.35		632	4.60	359	1.88	6330		
12-19	1300	900	2257		12.6 gms PK + 7 cc 30% $CaCl_2$							1082	0.56		482	5.50	359	5.45			With pressure tubes
12-29	1200	800			No Neutralizer							1030	0.55		829	0.55	422	0.55	7440		Inlet TC in off position during run
12-20	1215	825					1.38					1032	0.50				998	3.93	5960		Inlet TC in off position during run

(continued)

TABLE VIII (Continued)

SUMMARY OF DATA

Run No. 1967	Mix Tank		Htr. Temp.	$T_{gas_{in}}$	Neutralizer	IRFNA Residual	IRFNA Inj. Rate	IRFNA Dip	Inject Time Start	Inject Time End	Time Stroke End	$P_{g_{max}}$ psi	$\theta_{P\,max}$	P_{H_2O} max	Fast TC °F	Fast TC θ	Slow TC °F	Slow TC θ	Rate of Rise Initial	Rate of Rise Due to Inj.	Remarks
1-10																					Blew gasket in reaction chamber
1-11	1300	765	2350		No neutralizer	4									1158	0.	921	0.50			Polarity reversed
1-12	1300	880	2300		No neutralizer	4						977	0.40		1106	0.25	580	0.85	4070		
	885		2340		No neutralizer	4						629	0.35		1244	0.20	632	1.00	3330		
1-16	1300	800	2250		No neutralizer		3.21	5/16"				969	0.40		1032	0.30	457	0.60	3700		
1-17	1300	750	2400		No neutralizer							958	0.42		1082	0.32	457	0.92	3700		Micro-injection did not occur
1-18	1300	790	2375		12.6 gms PK + 7 cc 30% $CaCl_2$ solution							955	0.47		1048	0.27	536	1.07	3700		
1-19	1200	590			No neutralizer																Incorrect scale used on TC's
1-20	1300		2280		No neutralizer							918	0.47		989	0.32	377	1.22	3552		
1-23	1225	825	2150		No Neutralizer	2	4.04	1/16"				999	1.57		1346	2.97	905	5.43	3478		
1-24	1300		2200		12.6 gms PK + 7 cc 30% $CaCl_2$ solution	2	4.50	3/16"				866	0.60		649	0.55	404	1.05	2960		
1-26	1265	850	2369		12.6 gms PK + 7 cc 30% $CaCl_2$ solution	2	4.37	1/16"				1006	1.35		1699	3.25	989	4.80	3700		
1-27	1300		2380		12.6 gms PK + 7 cc 30% $CaCl_2$ solution		4.22	1/16"				1088	2.00		1433	2.65	896	4.30	3552		
1-30	1300		2390		12.6 gms PK + 7 cc 30% $CaCl_2$ solution							969	0.45		1158	0.30	510	2.15	3700		
1-31	1300		2300		12.6 gms PK + 7 cc 30% $CaCl_2$ solution							962	0.40		1158	0.35	475	1.60	3700		
2-1	1300		2390		No neutralizer	1	1.31					1017	2.00		1441	2.30	718	5.50			14 ga needle -- SB
2-2	1300		2340		12.6 gms PK + 7 cc 30% $CaCl_2$ solution							962	0.50		1090	0.35	475	1.10			Bottom piston injection only -- NO
2-3	1310		2350		12.6 gms PK + 7cc 30% $CaCl_2$ solution							932	0.50		1116	0.35	475	1.15			Bottom piston injection only -- NO
2-8	1300		2360		No neutralizer		4.46	37				1102	1.50		1808	2.77	1398	4.90			#14 needle* -- SB
2-9	1254		2400		No neutralizer							921	0.55		not operating		457	3.00			IRFNA froze, 18 ga needle* -- NO
2-10	1285		2360		No neutralizer		4.21	15				913	0.75		1116	0.30	404	1.35			#18 needle*, inj. not indicated -- NO
2-13	1300		2360		No neutralizer		3.33	6				954	0.50		1150	0.35	386	2.45			14 ga needle* -- SB
2-14	1270		2380				1.91					1032	2.40		1235	3.30	650	5.25			14 ga needle* -- S
2-16	1300		2380		No neutralizer		1.93	5				969	0.45		1158	0.30	475	2.75			Pressure injection from bottom
2-20	1200		2020		12.6 gms PK + 7 cc 30% $CaCl_2$ solution		12.7	15				869	0.60		1158	3.00	692	4.85			Began before gas entered RC --S
2-22	1220		2400		12.6 gms PK + 7 cc 30% $CaCl_2$ solution		4.91	10				925	0.50		1158	0.35	422	2.10			Pressure injection from bottom
2-24	1300		2130		12.6 gms PK + 7 cc 30% $CaCl_2$ solution		9.9	10				844	0.6		1137	0.4	533	2.4			Pressure injection from bottom

SB -- Wire slow
S -- Subst.
B -- Burn indicated
NO -- No burn indicated

(continued)

*Pressure from bottom

TABLE VIII (Continued)

SUMMARY OF DATA

Run No. 1967	Mix Tank		Htr. Temp.	$T_{gas_{in}}$	Neutralizer	IRFNA Residual	IRFNA Inj. Rate	IRFNA Dip	Start	End	Time Stroke End	$P_{g_{max}}$ psi	$\theta_{P_{max}}$	$P_{H_2O_{max}}$	Fast TC °F	Fast TC θ	Slow TC °F	Slow TC θ	Initial	Due to Inj.	Remarks
3-1	1243	872			12.6 PK + 7 cc 30% $CaCl_2$ solution							984	0.38		1244	0.32 (smpl)	550 1061	0.5 1.08			Bottom injection, 14 gage needle--NO
3-2	1290		2255 2030		1/32" IRFNA in box with seal material							937	0.95		1222	0.5 (smpl)	541	1.85			S
3-8	1250	900	2210		12.6 PK + 7 cc 30% $CaCl_2$ solution (146)		8.3	2.76				890	0.55		1157	0.45 (820 @ 4.25)	528	1.45			TC over sample--S
3-9	1280				12.6 PK + 7 cc 30% $CaCl_2$ solution							1020	0.25		2150	1.65 (1887 @ .04 sec. ?)	1795	0.53			TC under sample--SB
3-10	1280	790	2090		12.6 PK + 7 cc 30% $CaCl_2$ solution							875	0.55		1158	0.35	542	2.3			14 gage needle, box--S
															TC	scale gain	miss-set				TC under sample, 14 gage needle--SB
3-14	1260				12.6 PK + 7 cc 30% $CaCl_2$ solution		5.2	5.52													
3-15	1300	950	2220		12.6 PK + 7 cc 30% $CaCl_2$ solution		9.98	11.0				930	0.26		1158	0.45 (2550 @ 2.48)	820	3.52			14 gage needle, TC under sample--SB
3-16	1280	949	2270		12.6 PK + 7 cc 30% $CaCl_2$ solution	(2014 al)	10.2	5.5				940	0.5		1158	0.44 (2477 @ 3.25)	520	2.45			14 gage needle, TC under sample--S
3-17	1300		2250		12.6 PK + 7 cc 30% $CaCl_2$ solution	(2014 al) .030	6.5					930	0.45		1050	0.28 (1350 @ 2.15)	520	2.0			14 gage needle, TC under sample--SB
3-20	1300	850	2210		12.6 PK + 7 cc 30% $CaCl_2$ solution							915	0.4		1137	0.35 (820 @ 1.20)	470	2.45			14 gage needle, TC under sample with al/gl, no injection--SB
3-21	1750		2250		12.6 PK + 7 cc 30% $CaCl_2$ solution	.015	4.0	5.3				877	0.36		1185	0.33 (1704 @ 3.31)	490	3.0			14 gage needle, TC under sample with al/gl, aluminum melted--SB
3-22	1300		2270		12.6 PK + 7 cc 30% $CaCl_2$ solution							950	0.43		1158	0.41 (981 @ 0.95)	572	2.7			Box parted--S
3-28	1220				12.6 PK + 7 cc 30% $CaCl_2$ solution	Late (1.0)	9.0	58.4				1804	3.45		1770	5.0 (burn-out @ 3.58 sec.)	795	6.4			Barksdale valve oper. @ 2.2 sec., inj. prior gas, al sand. with insulation -- SB
3-30	1275		2270		12.6 PK + 7 cc 30% $CaCl_2$ solution	Late (1.0)	11.3	3.19				1440	1.95		burn-out	1.6	2148 2148	 2.48			Al sand. with insulation -- S
3-31	1210		2270									818	0.8		1074	0.69 (563 @ 1.8)	409	2.74			Seal sand., no injection -- NO
4-7					16 cc IRFNA @ 10 min. intervals-- 3 injections 100 cc IRFNA @ 30 min. intervals (burst diaphragm out 17 min. later)																Inj. orif. 0.018 86 gm TR - 69 ∇P = 400

SB -- Wire slow
S -- Subst.
B -- Burn indicated
NO -- No burn indicated

(continued)

TABLE VIII (Continued)

SUMMARY OF DATA

Run No. 1967	Mix Tank	Htr. Temp.	$T_{gas_{in}}$	Neutralizer	IRFNA Residual	IRFNA Inj. Rate	IRFNA Dip	Inject Time Start	Inject Time End	Time Stroke End	$P_{g_{max}}$ psi	$\theta_{P_{max}}$	$P_{H_2O_{max}}$	Fast TC °F	Fast TC θ	Slow TC °F	Slow TC θ	Rate of Rise Initial	Rate of Rise Due to Inj.	Remarks
4-13				16 cc IRFNA 2 min. 40 sec. after 1st inj.																86 gm TR $\Delta P = 50$
4-14				3 x 16 cc IRFNA @ 10 min. int. 100 cc IRFNA after 30 min. 45 sec. after ist inj.							(350)			1457		799				$\Delta P = 400$
4-17				3 x 16 cc IRFNA @ 10 min. int. 100 cc after 30 min. 50 sec. after 1st inj.							220			1011		1459				$\Delta P = 400$ Butyl Seal w/silicone strip
4-18				3 x 16 cc IRFNA @ 10 min. int., 100 cc after 30 min. (no apparent reaction)																(10" sector) $\Delta P = 400$
4-19				3 16 cc IRFNA @ 10 min. int., 100 cc after 30 min. (No apparent reaction)																TR 69 coated 180° RC top to bottom $\Delta P = 400$
4-20				3 x 16 cc IRFNA @ 10 min. int., 3 x 100 cc @ 30 min. int., 8 min. 10 sec. after 1st 100 cc inj.							60			burn out						TR 69 strips TR 69 strips -- $\Delta P = 400$ 0.1875" D orif in blow down
4-21				3 x 16 cc IRFNA @ 10 min. int. 3 x 100 cc @ 30 min. int. (No apparent reaction.)																15-4X1X3/16 Al w/TR 69 (90 gms)
4-24				IRFNA (no apparent reaction)																
4-25 (1)				IRFNA (no apparent reaction)																TR 69 strips 9" 3 in one
4-25 (2)				IRFNA (no apparent reaction)																4-1/2 ^{3} TR 69 strips
4-26				IRFNA, 3 min. after 1st inj. 2 min. 13 sec. after total of 73 cc IRFNA inj'd.							10 off scale									2-1/4 ^{3} TR 69 strips 1-1/8 in ^{3} TR 69 strips
4-27				500 cc IRFNA @ start (no other)							5	end								86 gm cured in bottom sides - 5/8 " strip up
4-28				4 cc IRFNA @ 1 min. interval $\Sigma = 30$ inj. $\Delta P = 400$							>350	45 sec. aft 9th inj.		2525 @ reaction		1840 @ reaction				4 cc @ 1 min intervals 86 gms TR 69 strips
5-1				16 cc IRFNA @ 5 min. int., DP 4 cc, $\Delta P = 415$ (total of 10 inj.)							5	end								86 gms on 60 in. of 1/32 Aluminum
5-2				28 injs. - 2 cc IRFNA @ 1 min int. $\Delta P = 415$							300	25 sec aft. 28th inj.		7250		burn out at reaction				86 gms TR-69 strips (our mix) (Blew out rupture disc)
5-8				1cc @ 1 min. Δ P inj. = 415.										62 mv	42.5	TC_B(BO)	42.5			86 gms TR-69
5-9				2 cc @ 1 min. Δ P inj. = 415. Ran out of N_2 inj. gas after 42 injections.																TR-69 on 3/16" Aluminum

(continued)

TABLE VIII (Continued)

SUMMARY OF DATA

Run No. 1967	Mix Tank Start	Mix Tank End	Htr. Temp.	Test Notes	Inject Time Start	Inject Time End	Time Stroke End	$P_{g_{max}}$ psi	$\theta_{P_{max}}$	P_{H_2O} max	Fast TC °F	Fast TC θ	Slow TC °F	Slow TC θ	Rate of Rise Initial	Rate of Rise Due to Inj.	Remarks
5-16(1)				2 cc @ 1 min Δ P inj. = 400													84 gms TR-69 on 60 in.^{2} 1 mil. al.
(2)				2 cc @ 1 min Δ P inj. = 400 NO_2 release, no sig. reaction													84 gms TR-69 on 60 in.^{2} 3/16" al.
5-17				2 cc @ 1 min. Δ P inj. = 400 NO_2 release, no sig. reaction													86.0 gms TR-69 on 60 in.^{2} 1 mil. al. x1" strips
5-18	Reactor @ 150° F			2 cc @ 1 min. Δ P inj. = 400					20' 55"			20'55"	TC_B	22'55"			86 gms TR-69, al. foil, 15.4"x1" strips
5-22	Reactor @ 150° F			2 cc @ 1 min. Δ P inj. = 400 No release									TC_B acid failure				86 gms. TR-69, 60 in.^{2} on 3/16 al.
5-23	Reactor @ 150° F			2 cc @ 1 min. Δ P inj. = 400					50'				TC_B	50'			86 gms. TR-69, 60 in.^{2} .008 al.
5-24	Reactor @ 150° F			2 cc @ 1 min. Δ P inj. = 400 NO_2 release													86 gms. TR-69, 60 in.^{2} .040 al.
5-25	Reactor @ 150° F			2 cc @ 1 min. Δ P inj. = 400					63' 47"								86 gms. TR-69, .016 al.
6-9	1200	880	2320	8 cc, 18 gage needle				974	3.8		1416	4.8	1459	4.75			12.6 PK + 7.0 PK inj., 1.0 → 3.7 sec. -40°
6-15	1155	630	2250	Bottom injection, 0.2 → 2.85 injection, 18 gage needle				669	0.32								12.6 PK + 7.0 PK inj. @ 0.2 → 2.85 inj. before pressure rise -40° F

Run No. 1967	Mix Tank Start	Mix Tank End	Htr. Temp.	Injection	Dip	Inject Time Start	Inject Time End	Time Stroke End	$P_{g_{max}}$ psi	$\theta_{P_{max}}$	P_{H_2O} max	Fast TC °F	Fast TC θ	Slow TC °F	Slow TC θ	Rate of Rise Initial	Rate of Rise Due to Inj.	Remarks
7-3	1160	720	2200	1.2 → 3.85 second injection	6.9				669	0.32		1074	0.17	778 650	1.85 1.6			12.6 + 7 PK Protected sample
7-5	1245	900	2200	1.2 → 3.8 second injection	10.6				811	3.7				990 BO	4.4 4.7			12.6 + 7 PK Protected sample
7-6	1270	900	2200	1.22 → 3.82 second injection	8.0				691	1.0		990	0.25	606 585	1.0 1.0			12.6 + 7 PK Protected sample
7-7	1200	830	2300	TCE (10 cc) (top injection)	45.0				696	0.6		947	0.3	563 650	1.6 1.5			12.6 + 7 cc Solution Tri Chlor Ethylene
7-10	1240	870	2200	10 cc TCE, changing volume	40.0				844	0.17		714	3.77	341	1.5			12.6 + 7 cc Solution TCE
7-11	1240		2100	Changing volume (.21 → 3.77 sec)	32.0				912	3.77		1957	4.96	1887	4.66			12.6 + 7.49 PK

(continued)

TABLE VIII (Continued)

SUMMARY OF DATA

Run No. 1967	Mix Tank Start	Mix Tank End	Htr. Temp.	Injection	Dip	Inject Time Start	Inject Time End	Time Stroke End	$P_{g_{max}}$ psi	$\theta_{g_{max}}$	P_{H_2O} max	Fast TC °F	Fast TC θ	Slow TC °F	Slow TC θ	Rate of Rise Initial	Rate of Rise Due to Inj.	Remarks
7-12	1200	950	2300	Changing volume, 0.17 - 3.84 seconds 4.92 11.4	127				1230	0.71		1592	3.00	1690	3.39			12.6 + 16.7 PK
7-13		925	2200	Constant volume, O_2 injection					931	0.2		1730	0.67	1630 1887	1.26 0.95			NO_2 - O_2 Gas Injection
7-14 (1)	1285	939	2220	O_2 - NO_2 injection					1049	0.53		1780	1.18	1550 2150	1.72 0.93			NO_2 - O_2 Injection NN
7-14 (2)	935	~ 0	2180	O_2 - NO_2 injection					1240	0.39		1772	0.54	1750 2425	0.73 0.66			NO_2 - O_2 Injection NN Head out of place -- blew
7-18	1145		2200	Changing Volume, (top inj.) (.15 → .63 sec)	5.3				874	0.63		585	0.99	230	2.25			12.6 PK (Large TC) (Lg. TC on Slow)
7-19	1210	860	2200	Changing Volume, (top inj.) (.14 → 1.2 sec)	10.6				1042	1.2		1053	1.8	990	2.65			12.6 + 7 cc Sol'n. (Lge TC)
7-20	1300	950	2200	Constant Volume (.11 → 1.09 sec)	5.3				923	1.09		1614	1.11	1115	2.70			12.6 + 7 cc Sol'n.
7-21	1300	950	2200	Constant Volume (.11 → 0.57 sec.)	2.8				937	0.65		1355	0.65	820	2.55			12.6 + 7 cc Sol'n.
7-24	1240	920	2200	Changing Volume (.12 → .58 sec.)								BO	0.8	2197	3.55			No Neutralizer O_2 - NO_2 gas
7-26	1175	885	2200	Changing Volume (.11 → .57 sec)					960	0.165		2510	0.43	1821	0.23			No Neutralizer NO_2 - O_2
7-27	1245	850	2200	Changing Volume (.105 → .575 sec.)					1040	0.41		2033	0.51	1929	0.96			12.6 + 7 cc Sol'n. NO_2 - O_2
									990	0.3								

Run No. 1967	Mix Tank Start	Mix Tank End	Htr. Temp.	IRFNA	Dip	Inject Time Start	Inject Time End	Time Stroke End	$P_{g_{max}}$ psi	$\theta_{g_{max}}$	P_{H_2O} max	Fast TC °F	Fast TC θ	Slow TC °F	Slow TC θ	TC Bottom °F	TC Bottom θ	Remarks
8-2	1450	450	2200						990	0.3		1053	0.3	786	0.7			Const. Vol. 10 cc UDMH residual
8-3	1317 700	670 430	2190 2190						714 346	0.5 0.5		1035 900	0.3 0.4	296 208	2.0 2.0			Const. Vol. 100 cc UDMH residual
8-4	1275	820							878	0.35		888	0.35	585	1.5			Const Vol. 10 cc UDMH (after bath) 5 cc UDMH (basket)
8-7	990 670	610	2200 2200						577 409	0.35 0.4		734 593	0.35 0.5	563 364	1.28 2.0			Blank - leak @ burst diaphragm " " " " "
8-9									740	0.4		900	0.3	658	1.5			Const. Vol., no neut. RC flushed with dry air

(continued)

TABLE VIII (Continued)

SUMMARY OF DATA

Run No. 1967	Mix Tank Start	Mix Tank End	Htr. Temp.	IRFNA	Dip	Inject Time Start	Inject Time End	Time Stroke End	$P_{g_{max}}$ psi	$\theta_{g_{max}}$	P_{H_2O} max	Fast TC °F	Fast TC θ	Slow TC °F	Slow TC θ	TC Bottom °F	TC Bottom θ	Remarks
8-10	1280	975		28.7 cc (boat)					993	0.225		918	0.525	1890	2.5	Burn out	0.4	$NO_2 - O_2$ gas injected, aluminum boat melted
8-11	1300	1010		28.7 cc (boat)					967	0.275		2430	0.375	2540	3.75	2408	1.05	$NO_2 - O_2$ gas/12.6 gms* PK
	600	400		28.7 cc (boat)					818	0.185		2370	0.5	BO	0.285	1890	0.425	$NO_2 - O_2$ gas/12.6 gms* PK
8-14	1300	830							766	0.3		1076	0.2	1256	2.3	855	1.0	12.6 gms PK/dry air
8-15	1300	900	2200						818	0.35		1044	0.25	801	1.0	1161	1.0	
									578	0.3		1032	0.25	650	1.5	905	0.5	
8-16	1200	930	2200						837	0.25		1733	0.25	1733	0.45	1800	1.25	4.4 cc UDMH residual
8-17	1300	970	2200		(5.3)				911	0.25		1643	0.4	1418	1.3	BO	0.5	8.8 cc UDMH residual, 12.7 + 7 cc solution**
8-18	1300		2200						893	0.25		1683	0.45	1534	1.0	2500	0.75	No neutrilizer--4.4 cc UDMH residual
8-21	1300		2200	Direct IRFNA expulsion					919	1.3		2367	1.67	2228	3.6			
8-22	1300		2200	Direct IRFNA expulsion					915	1.0		>2500	1.5	1525	1.5			
9-8	1300	400	1800	30 cc injection 0.08 → 0.18 sec. Blew - disjointed blow-down riser					1098	0.2		1329	0.22	BO	0.2			120 gms PK
9-11	1300		1800	30 cc injection 0.12 → 0.2 sec					810	1.0		1547	0.5	252	0.5			120 PK - 95 gms $CaCl_2$ Sol'n. O_2 injection -Barksdale valve leaked
9-18	1300		1800	30 cc injection 0.12 → 0.2 sec					864	0.5			0.28		0.38			(same as Run 9-17)
9-19	1300	900	2000	30 cc injection 0.11 → 0.18 sec					900	0.7		778	0.3	628	1.25			120 gms PK - 95 gms $CaCl_2$ Sol'n.
9-22 (1)	1300		2000						841	0.4		778	0.3	296	0.5			Blank
9-22 (2)	1300	0	2000	30 cc injection 0.12 → 0.19 sec					880	1.0		820	0.4	341	1.0			120 gms PK - 95 gms $CaCl_2$ Sol'n.
9-25	1190		2000	30 cc injection 0.15 → 0.21 sec					731	0.3		819	0.3	333	0.37			120 gms PK - 95 gms $CaCl_2$ Sol'n.

*Aluminum boat partially melted.

**12.6 grams of PK plus 7 cc 30% $CaCl_2$ solution in neutralizer package.

(continued)

TABLE VIII

SUMMARY OF DATA

Run No. 1967	Mix Tank Start	Mix Tank End	Htr. Temp.	IRFNA	Dip	Inject Time Start	Inject Time End	Time Stroke End	$P_{g_{max}}$ psi	$\theta_{g_{max}}$	$P_{H_2O\,max}$	Fast TC °F	Fast TC θ	Slow TC °F	Slow TC θ	Remarks
10-2	1460		1830	3.0 residual, 0.035" dia. orifice, O_2 1500-950 psi, chang. vol., 16 gms PK + 8 gms sol'n in bag @ ch. inlet.					1113	0.33		828	1.25	675	2.0	Injection at -0.75 sec.. end injection @ 0.23 sec (Δ = 1.0 sec.)
10-3	945		2050	3.0 residual, O_2 1500 →, 16 gms. PK + 8 gms sol'n. @ ch. inlet. Changing volume.					813 rupt.	0.5 120 sec		519 BO	4.0 120.0	386 BO	6.5 120.0	Injection at 0.12 → 0.23. Timer over-ran Inj. O_2 @ end
10-9	1130	665		O_2 1500 → 1350 Const. Vol.					1818			1818	0.4			Heater out after test
10-16	1195	800		6 cc residual, 90 gms sol'n and 105 gms PK, (in bags @ ch. open) O_2 → 1100, Const. Vol.					929	0.5						
10-17	1230	810		6 cc residual, 11 gms $CaCl_2$ Sol'n + 12.7 PK (bags 2 in inlet) O_2 1500 - 1360, Const. Vol.					1295	0.4		1283	0.8	1305	1.5	
10-18	1170	785		6 cc residual 8 gms Sol'n (bskt) + 12.7 PK (after bskt) 1500 - 100, Piston 1/8" orifice.					1469	1.7		2048	5.65	BO	2.15	Pre-injection of O_2 (heater out after test)
10-26	1360	850	1950	6 cc residual, 8 gms sol'n (bskt) 12.7 gms PK in after basket, Piston					1121	0.25		720	0.4			O_2 injection, 1465-1370
10-27	1350	920	1900	3 cc residual, 12.7 gms PK in after bskt, Piston 1-1/4 down.					1121	1.0		612	3.0	405	1.0	O_2 injection, 1410-1330
10-30	1290	870	1930	3 cc residual, 12.7 gms PK in after bskt. Piston 1-1/4 down.					1137	0.25		675	0.5	441	1.0	O_2 Injection, 1390-1310
10-31	1250	860	1640	3 cc residual, 12.7 gms PK in after bskt. Piston 1-1/4 down.					1104	0.6		486	1.0	405	1.0	O_2 Injection, 1350-1275

APPENDIX B

Summary of Gas Analyses

DATE	H_2	H_2O	CH_4	CO	N_2	CO_2
8- 2-66	.294	.059	.017	.503	.087	.056
8- 3-66	357	.059	.012	.450	.088	.046
8- 4-66	.293	.059	.015	.486	.089	.056
8- 5-66	.240	.059	.037	.390	.099	.126
8- 6-66	.360	.059	.013	.471	.111	.044
8- 9-66	.264	.059	.016	.525	.099	.056
8-10-66	.284	.059	.173	.512	.094	.054
8-11-66	.287	.059	.024	.499	.093	.052
8-12-66	.303	.059	.017	.471	.092	.070
8-16-66	.294	.059	.017	.471	.092	.070
8-17-66	.2692	.0649	.0341	.3938	.1633	.0704
8-18-66	.284	.059	.016	.480	.091	.067
8-19-66	.268	.059	.016	.484	.108	.060
8-22-66	.291	.059	.018	.462	.099	.071
8-24-66	.2500	.0649	.0305	.4370	.1497	.0710
8-26-66	.296	.059	.073	.529	.091	.032
8-29-66	.322	.059	.016	.460	.083	.063
8-31-66	.3091	.0649	.0190	.4087	.1274	.0724

DATE	H_2	H_2O	CH_4	CO	N_2	CO_2
9- 1-66	.3098		.0212	.4303	.1054	.0708
9- 2-66	.3073	.0649	.0214	.4230	.1279	.0676
9- 6-66	.2641	.0649	.01849	.4942	.1090	.0543
9- 7-66	.3662	.0649	.0180	.3529	.0892	.1032
9- 8-66	.2768	.0649	.0579	.3779	.1038	.1179
9- 9-66	.2653	.0649	.0308	.4256	.0953	.1172
9-13-66	.2737	.0649	.0195	.4637	.1155	.0556
9-14-66	.2834	.0649	.0146	.4647	.1195	.0521
9-15-66	.2715	.0649	.0115	.3751	.2296	.0462
9-16-66	.2675	.0649	.0230	.4388	.0965	.1149
9-19-66	.3087	.0649	.0200	.4043	.0960	.1051
9-20-66	.3007	.0649	.0280	.3794	.0944	.1303
9-22-66	.3026	.0649	.0268	.4015	.0944	.1088
9-23-66	.1880	.0649	.0260	.5099	.1597	.0543
9-26-66	.2891	.0649	.0406	.3574	.0976	.1335
9-27-66	.2303	.0649	.0210	.5244	.0956	.0751
9-28-66	.5446	.0649	.0224	.3324	.0885	.1085
9-29-66	.2956	.0649	.0310	.3679	.0945	.1227
9-30-66	.3156	.0649	.0310	.3679	.0945	.1227
10-4-66	.3073	.0649	.0409	.3434	.0910	.1505
10-6-66	.3537	.0649	.0194	.3400	.1095	.1073
10-7-66	.2874	.0649	.0210	.4038	.1045	.1108
10-10-66	.5039	.0649	.0124	.3050	.0678	.0432
10-11-66	.5200	.0649	.0126	.2846	.0761	.0398
10-12-66	.2913	.0649	.0266	.3934	.1368	.0842
10-13-66	.3066	.0649	.0256	.3907	.1237	.0864
10-14-66	.2224	.0649	.0245	.4668	.1941	.0252
10-17-66	.3804	.0649	.0266	.3831	.1063	.0253
10-18-66	.3716	.0649	.0163	.4042	.0516	.0774
10-20-66	.3356	.0649	.0185	.3458	.1303	.0882
10-21-66	.3356	.0649	.0176	.3424	.1457	.0896
10-24-66	.2979	.0649	.0156	.4219	.1583	.0442
10-25-66	.3070	.0649	.0180	.3518	.1653	.0885
10-26-66	.3628	.0649	.0177	.3461	.1149	.0889
10-28-66	.3544	.0649	.0181	.3470	.1192	.0905

DATE	H_2	H_2O	CH_4	CO	N_2	CO_2
11-1-66	.3348	.0649	.0132	.4519	.0969	.0418
11-2-66	.3705	.0649	.0132	.3870	.1040	.0576
11-3-66	.3443	.0649	.0220	.3494	.0990	.1175
11-7-66	.2885	.0649	.0157	.3956	.1986	.0520
11-8-66	.3121	.0649	.0177	.4238	.1155	.0608
11-9-66	.3094	.0649	.0173	.4281	.1141	.0602
11-10-66	.2682	.0649	.0188	.4331	.1328	.0765
11-11-66	.3406	.0649	.0200	.4302	.1044	.0395
11-14-66	.2908	.0649	.0338	.3600	.1880	.0653
11-15-66	.3007	.0649	.0226	.3459	.1767	.0842
11-16-66	.2925	.0649	.0236	.3653	.1622	.0878
11-17-66	.2704	.0649	.0210	.4782	.1023	.0642
11-18-66	.3046	.0649	.0262	.4681	.0908	.0517
11-21-66	.2792	.0649	.0274	.4510	.1405	.0453
11-22-66	.2693	.0649	.0255	.4747	.1108	.0600
11-23-66	.2695	.0649	.0226	.4867	.1141	.0526
11-28-66	.3902	.0649	.0244	.3172	.1138	.0775
11-29-66	.3889	.0649	.0242	.3076	.1249	.0758
11-30-66	.3496	.0649	.0239	.1996	.2560	.0891
12-2-66	.3165	.0649	.0128	.4845	.0863	.0410
12-6-66	.3093	.0649	.0184	.4526	.1030	.0551
12-8-66	.3177	.0649	.0161	.4496	.1053	.0514
12-9-66	.3096	.0649	.0163	.4571	.1068	.0490
12-12-66	.3430	.0649	.0161	.4955	.0252	.0482
12-15-66	.2933	.0649	.0172	.4515	.1266	.0527
12-16-66	.2914	.0649	.0173	.4714	.1017	.0589
12-19-66	.3088	.0649	.0169	.4586	.0994	.0578
12-23-66	.3109	.0649	.0236	.4442	.1496	.0708
12-29-66	.2916	.0649	.0160	.4313	.1564	.1432
12-30-66	.3425	.0694	.0206	.3568	.1253	.0834
1-11-67	.2688	.0649	.0090	.4566	.1279	.0793
1-12-67	.4287	.0649	.0157	.1348	.2432	.0910
1-16-67	.3133	.0649	.0109	.4376	.1061	.0751
1-17-67	.2944	.0649	.0109	.4491	.1120	.0742
1-18-67	.2952	.0649	.0108	.4571	.1212	.0554
1-19-67	.2778	.0649	.0113	.4530	.1299	.0721
1-20-67	.2757	.0649	.00974	.4351	.1498	.0691
1-23-67	.4040	.0649	.0140	.3855	.0567	.0567
1-24-67	.2759	.0649	.0140	.4963	.0981	.0568
1-26-67	.2950	.0649	.01717	.4661	.1049	.0575
1-27-67	.2987	.0649	.0177	.4637	.0890	.0727
1-30-67	.3064	.0649	.0173	.4614	.0905	.06567

DATE	H_2	H_2O	CH_4	CO	N_2	CO_2
2-1-67	.4284	.0649	.0203	.3082	.1167	.0420
2-2-67	.3433	.0649	.0189	.3990	.1158	.0565
2-3-67	.3419	.0649	.0192	.4076	.1019	.0612
2-8-67	.3425	.0649	.0194	.4105	.0942	.0633
2-9-67	.3001	.0649	.0159	.4803	.1089	.0564
2-10-67	.2930	.0649	.0174	.4320	.1492	.03337
2-13-67	.2973	.0649	.0177	.4320	.1330	.0493
2-14-67	.3067	.0649	.0170	.4554	.1073	.0508
2-16-67	.3012	.0649	.0178	.4243	.1248	.0538
2-20-67	.3151	.0649	.0169	.4311	.1120	.0583
2-22-67	.2852	.0649	.0150	.5018	.0945	.0475
2-24-67	.2992	.0649	.0157	.4812	.0962	.0494
3-1-67	.2712	.0649	.0099	.4538	.1613	.0426
3-2-67	.2606	.0649	.0081	.5420	.0877	.0452
3-8-67	.3660	.0649	.0223	.3795	.1016	.0648
3-9-67	.3082	.0649	.0112	.4681	.0957	.0484
3-10-67	.3246	.0649	.0089	.4363	.1164	.0396
3-14-67	.3190	.0649	.0107	.4707	.0942	.0440
3-15-67	.3204	.0649	.0105	.4524	.1421	.0345
3-16-67	.2808	.0649	.0101	.5464	.0567	.0429
3-17-67	.2893	.0649	.0096	.4662	.1108	.0641
3-20-67	.3013	.0649	.0106	.5125	.0904	.0468
3-21-67	.2707	.0649	.0085	.4717	.1625	.0294
3-22-67	.2974	.0649	.1038	.5115	.0867	.0460
3-28-67	.2654	.0649	.00902	.4673	.1720	.0292
3-30-67	.2988	.0649	.0107	.5019	.0851	.0455
3-31-67	.2919	.0649	.0111	.5019	.0931	.0450
4-3-67	.2948	.0649	.0109	.5173	.0861	.0469
4-4-67	.2821	.0649	.0092	.5006	.1093	.0385
4-6-67	.3053	.0649	.0094	.4999	.0811	.0441
8-30-67	.2936	.0649	.0183	.4211	.1307	.0748

APPENDIX C

Estimate of IRFNA-TR-69 Reaction Temperature

ESTIMATE OF COMBUSTION OF TR-69

TR-69 Composition is made up of equal parts by weight of Part A and Part B.

Part A	Part B
57.1 % filler (Versamid 125)	43.4 % filler (Epon 828)
3.4 % Ti	44.0 % Ti
6.7 % B	5.9 % B
1.7 % Al	2.3 % Al
0.57% Fe	1.3 % Si
0.55% Si	0.73% Mg
0.07% Pb	0.46% Fe
0.03% Ca	0.045% Ca

It is assumed that the metallic constituents enter the reaction by virtue of their heat capacity only, and that the general formula for each filler may be represented as follows:

Versamid 125	Epon 828
$(C_4H_{11}O_2N)_2$ M=(105)x	$(C_6H_7O)n$ M=(95)n

For 1 lb. TR-69

0.5(.571) = 0.285 lb.	0.5(.434) = 0.217
$\frac{0.285}{(105)} = 0.0027$	$\frac{0.217}{(95)} = 0.0023$
$0.0108\ C + 0.0108\ O_2 \rightarrow 0.0108\ CO_2$	$0.0137\ C + 0.0137\ O_2 \rightarrow 0.0137\ CO_2$
$0.0149\ H_2 + 0.0074\ O_2 \rightarrow 0.0149\ H_2O$	$0.008\ H_2 + 0.004\ O_2 \rightarrow 0.008\ H_2O$
or 0.00136 #moles N_2 0.0128 #moles O_2 Reg'd.	or 0.0131 #moles O_2 Reg'd.

The following reactions are assumed to prevail:

$$C + O_2 \rightarrow CO_2 + 167{,}000 \text{ Btu}$$

$$C + 2NO_2 \rightarrow CO_2 + 2NO + 119{,}000 \text{ Btu}$$

$$H_2 + NO_2 \rightarrow H_2O + NO + 79{,}000 \text{ Btu}$$

$$H_2 + \tfrac{1}{2}O_2 \rightarrow H_2O + 121{,}800 \text{ Btu}$$

$$NO_2 \rightarrow \tfrac{1}{2}N_2 + O_2 - 12{,}600 \text{ Btu}$$

The O_2 and NO_2 from heating and decomposition of 1cc IRFNA is:

0.0052 gmol O_2 0.0254 gmol NO_2

Calculation Assuming NO Product

For the "A" Part

$$0.00372\ C + .01488\ O_2 \rightarrow 0.003718\ CO_2$$

$$0.00708\ C + .0149\ NO_2 \rightarrow .00708\ CO_2 + .01416\ NO$$

$$.0149\ H_2 + .0149\ NO_2 \rightarrow .0149\ H_2O + .0149\ NO$$

For the "B" Part

$$.0038\ C + .0038\ O_2 \rightarrow .0038\ CO_2$$

$$.0099\ C + .0198\ NO_2 \rightarrow .0099\ CO_2 + .0198\ NO$$

$$.008\ H_2 + .008\ NO_2 \rightarrow .008\ H_2O + .008\ NO$$

NO_2 Req'd. = 0.0569 # moles (.0275 # moles H_2O, .01165 # moles O_2)

or $$0.0569 \times \frac{454}{.0254} = 1016 \text{ cc IRFNA}$$

$$\frac{1016 \times 1.57}{454} = 3.5 \text{ \# IRFNA/\# TR-69}$$

Products: All metallic components lumped and treated as Ti (inert)

0.0504	lb. moles	H_2O	10.3	.0075 x 167K =	
0.0245		CO_2	8.75	.0170 x 119K =	
0.0569		NO	7.1	.022 x 79K =	
0.0103		Ti	9.2		5013 Btu
.00136		HF	7.1		
0.1435	lb. moles		1.24 Btu/°F		

Heat required in vaporizing and decomposing IRFNA

$$740 \frac{\text{cal}}{\text{cc}} \times 1016 \text{ cc} \times \frac{\text{Btu}}{252 \text{ cal.}} = 2983 \text{ Btu}$$

Heat for heating products = 2031 Btu

$$\frac{2031}{1.24} = 1638 \text{ °F rise in temperature}$$

Thus, even with the low energy oxidation involving NO products, the temperature rise due to reaction can become significant.

Calculation Assuming N_2 Product

For overall:

$$.0245 \text{ C} + .0245 \text{ O}_2 \rightarrow 0.0245 \text{ CO}_2$$

$$0.0229 \text{ H}_2 + 0.0115 \text{ O}_2 \rightarrow 0.0229 \text{ H}_2$$

$$0.09 \text{ NO}_2{}^* \rightarrow .009 \text{ O}_2 + 0.0045 \text{ N}_2$$

O_2 required $= 0.036$ # moles x $\frac{1.57}{.0306}$ = 1.847 lb. IRFNA/# TR-69

NO_2 figured as providing O_2 only, 83% of O_2 from this source.

Products:

0.0103 lb. moles Ti	9.2
0.0068 lb. moles N_2	7.1
0.0245 lb. moles CO_2	8.75
0.0229 lb. moles H_2O	10.3
0.0014 lb. moles HF	7.1
.0659 lb. moles	0.602 Btu/°F

Heat Released:

0.0245 x 167K

\+ 0.0229 x 121.8K

\- 0.09 x 12.6K

\- 1.874 x 0.847K

Heat for Heating Products 4,158 Btu

$$\frac{4{,}158 \text{ Btu}}{0.602 \frac{\text{Btu}}{°\text{F}}} = 6907\ °\text{F rise in temperature}$$

The data suggest that 0.031 lbs.Al/lb.TR-69 is sufficient to quench the reaction at 70 °F ambient temperature, and that 0.5 lbs.Al/lb.TR-69 is required to suppress the uncontrolled reaction at a 150 °F ambient temperature. Pertinent values for these amounts of aluminum are:

Wt. of aluminum, lbs.	0.031	0.5
Heat capacity, Btu/°F	0.234	3.9
Equilibrium temperature for NO product, °F	1390	397
Equilibrium temperature for N_2 product, °F	5034	926

It does not appear that the heat sink is the overall effect, although heat absorbing capability in the early phase of a reaction could readily slow or prevent a specific run-away scheme.