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SNAP-27 CAPSULE BURIAL TESTS

F. L. Baker, 9312

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ABSTRACT

This report presents the data generated by three soil burial tests of full-scale, simulated SNAP-27 fuel capsules. These tests were performed by Sandia Laboratory as part of the SNAP-27 Safety Test Program.

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SUMMARY

Three burial tests of electrically heated SNAP-27 capsules were performed. Each capsule was buried at a depth of 33 inches and energized to a power level of 1500 watts. Instrumentation was the same for each test.

The first capsule, which was buried in bentonite (a low thermal conductivity soil), experienced considerable interior melting of the Haynes-25 case material. Melt-through occurred near the center of the case, and the molten Haynes-25 escaped and ran down the exterior surface. The heater operated for 48.58 hours before it failed. Bentonite near the heater was vitrified; a soil mass was formed around the capsule, with a void area being formed between the capsule and the soil.

The second capsule, which was buried in Ottawa sand (a high thermal conductivity material), showed no exterior evidence of melting, but some oxidation of the case material was evident. The heater operated for 77.5 hours before it failed. Ottawa sand near the heater formed a vitrified and/or near-vitrified mass around the heater; the mass varied from 1/8 to 1/2 inch in thickness.

The third capsule, which was buried in a mixture consisting of equal parts of bentonite, Ottawa sand, and feldspar (a low melt-point material), experienced some melting of the Haynes-25 in a thin section at the top. This heater operated for 210.6 hours before it failed. A soil mass of vitrified and near-vitrified soil 8- to 10-inches in diameter and shaped like an over-sized football was formed around the heater. A void area was formed between the heater and the soil mass.

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CHAPTER I
INTRODUCTION

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CHAPTER I

Introduction

The burial test of the electrically heated SNAP-27 capsules were performed by Sandia Laboratory in cooperation with the Missile and Space Division of the General Electric Valley Forge Space Technology as part of the SNAP-27 Safety Test Program. This report presents the data generated, accompanied by photographs and other pertinent information.

Objective

The primary purpose of the tests was to determine the temperatures attained when a SNAP-27 capsule is buried in representative soils. This information is needed to:

1. Determine the temperature at which loss of capsule integrity due to melting will expose fuel to soil and the temperature of possible fuel-soil-clad reactions; and
2. Verify the validity of analytical techniques for predicting the maximum capsule temperatures from known soil thermal properties and/or scale model testing.

Another purpose was to observe any gross soil reactions, such as melting, flowing, or other physical changes.

General Test Information

The three burial tests were performed with full scale, electrically heated SNAP-27 capsules furnished by General Electric. The capsules had a Haynes Alloy-25 shell with an iron titanate emissive coating and a platinum-40 percent rhodium, 0.030-inch diameter wire core resistance heater. Each capsule was instrumented with eight platinum, platinum-10 percent rhodium alumina-sheathed thermocouples. See Figure 1 for capsule thermocouple locations. Certification for the capsule thermocouples is given in Appendix A.

All soil thermocouples were chromel-alumel. Stainless steel sheathed thermocouples were used for the buried TC's located one inch from the capsule surface.

The soils for the burial tests were selected to represent the extreme conditions that could be experienced by the capsule when subjected to actual burial conditions. The soils selected were:

1. bentonite - for low thermal conductivity,
2. Ottawa sand - for high thermal conductivity, and
3. mixture (1/3 bentonite, 1/3 Ottawa sand, and 1/3 crushed feldspar by volume) - for low melt point.

Figure 1. Location of thermocouples for monitoring capsule temperature

Test Procedure

Each of the three selected soil types was emplaced in an excavation that was a 5-foot cube. During the fill operation, a soil sample was taken to determine the physical properties, i.e., density, particle size distribution, etc. Attempts to compact the soil proved unsuccessful, so the density measurement was loose unit fill.

Prior to capsule burial, each of the capsule thermocouples was checked for continuity; where possible or practical, inoperative TC's were repaired or replaced. The soil thermocouples and capsules were installed as the soils were emplaced. The capsules were installed vertically because this is the most probable attitude for penetration and burial. Another small excavation was made and filled with the test soil at a distance of approximately 8 feet from the fill area. Two thermocouples were installed on the surface of this fill as reference TC's to record the normal surface temperature changes. Both areas were covered in a manner that allowed air circulation (Figure 2).

All thermocouples were monitored and recorded continuously throughout each test. Data were tabulated for each hourly reading. The power input was recorded continuously on a recording wattmeter. It was planned to terminate each test either when the capsule temperature stabilized over a 24-hour period or when the heater failed. Each test was terminated due to heater failure.

At the completion of each test, the capsule and the affected adjacent soil were recovered. X-rays were made of each of the units in the affected soil mass. The soil mass was then removed from the capsule, and photographs were taken to show the effects of temperature on the soil and the capsule. The capsules and the affected soil for each were shipped to General Electric for further evaluation.

Figure 2. Test site cover
(C67-2784)

Representative Test Results

Figures 3 and 4 show capsule surface temperature versus time for thermocouples 1 and 5 for the three capsule burial tests; Figures 5 and 6 show soil temperature versus time at 1 (TC 13) and 3 (TC 14) inches from the capsule surface for the three tests. These are representative test results.

Figure 3.
Capsule surface temperature
vs time for thermocouple #1,
Tests 1, 2, and 3

Figure 4.
Capsule surface temperature
vs time for thermocouple #5,
Tests 1, 2, 3

Figure 5. Soil temperature at 25-inch burial depth, 1 inch from capsule surface for thermocouple #13, Tests 1, 2, and 3

Figure 6. Soil temperature at 25-inch burial depth 3 inches from capsule surface for thermocouple #14, Tests 1, 2, and 3

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CHAPTER II

CAPSULE BURIAL TEST NO. 1

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CHAPTER II

Capsule Burial Test No. 1

General Information

The electrically heated capsule (Serial No. 1) was buried in bentonite (Figure 7). A representative chemical and physical analysis of the bentonite is as follows:

Silica	64.72%
Alumina	20.82%
Iron Oxide	3.44%
Titanium Oxide	0.14%
Lime	0.49%
Magnesia	2.38%
Alkalies	2.92%
Ignition Loss	4.84%
Fusion Point	2440°F

Table I gives the results of bentonite density and gradation tests; Table II and Figure 8 give the results of particle size determination of the bentonite by hydrometer analysis. These tests and the analysis were performed by the Albuquerque Testing Laboratory.

Figure 7. Capsule emplacement operation (D67-5074)

GRADATION

HYDROMETER

PROJECT	G.E. Capsule Burial Tests
LOCATION	Sample of Bentonite Fill
STATION	Material obtained from
OFFSET	Jobsite on 3/23/67

Figure 8. Hydrometer analysis of bentonite

TABLE I

Density and Gradation Tests of
Bentonite Fill Material

Loose unit weight - 76.0 lbs/cu ft*

Gradation Test: (Cumulative % Passing)

<u>Screen Size</u>	<u>Dry Screen Analysis</u>
No. 4	100.0
No. 10	81.4
No. 30	19.4
No. 60	8.4
No. 100	4.8
No. 200	1.6
No. 270	1.1

*Note: The bentonite fill material was "too dry and loose" to make in-place field density tests. In-place densities could probably be best made in this type of material through the use of calibrated containers such as 1/2 or 1 cubic foot boxes placed in the fill area and removed and weighed during fill placement.

Prior to burial, a check of the capsule thermocouples revealed that those identified as 1, 2, and 3 on Figure 1, had been damaged during shipping beyond repair. The damaged thermocouples were replaced with stainless steel sheathed platinum, platinum-10 percent rhodium thermocouples insulated with Al₂O₃.

After burial of the capsule and installation of the soil thermocouples (Figures 9 and 10), the heater was energized slowly over a period of 24 hours to the operating power level of 1500 watts (Figure 11). Some difficulty was encountered with the recording equipment early in the test. As noted in Table III, an auxiliary recorder was employed approximately 17 hours after initiation of the test. Figures 12 and 13 show temperature versus time for Test No. 1. Figure 14 shows the location of the soil thermocouples.

The heater operated for 48.58 hours. Figure 15 shows the capsule recovery operation. An X-ray of the recovered capsule in the affected soil mass revealed considerable melting of the Haynes-25 case (Figure 16). Also evident in the X-ray was an opening in the case material (melt through) where the molten Haynes had escaped and run down the exterior surface, apparently filling the void area that had formed between the capsule and the soil. Figure 17 shows the capsule with the affected soil mass attached. When the affected soil mass was removed from the capsule, the melt through opening and the once-melted Haynes-25 on the lower exterior capsule surface was obvious (Figure 18 and 19). The void area that was formed between the capsule and the soil is visible in Figure 18.

TABLE II

Hydrometer Analysis of Bentonite

Sample No. <u>Bentonite Fill Material</u>	Wet Weight <u>32.491</u>
Date of Test <u>3/24/67 thru 3/30/67</u>	Dry Weight <u>30.457</u>
Wet Wt. of Dispersed Sample <u>32.398</u>	Hygroscopic Moisture Content <u>6.68</u>
Dry Wt. of Dispersed Sample <u>30.369</u>	Hydrometer Type <u>152 H</u>
Specific Gravity <u>2.70 (Assumed)</u>	Hydrometer No. <u>CO 3556</u>

Time	Elapsed Time (min)	Hydrometer Reading	Temp °F	Composite Correction	Corrected Hydrometer Reading	Specific Gravity Constant (a)
9:00 A.M.	0					
9:02 A.M.	2	42.5	72	12.75	29.7	0.99
9:05 A.M.	5	42.2	72	12.75	29.4	0.99
9:15 A.M.	15	42.0	72	12.75	29.2	0.99
9:30 A.M.	30	41.9	72	12.75	29.1	0.99
10:00 A.M.	60	41.7	72	12.75	28.9	0.99
1:10 P.M.	250	41.0	74	12.60	28.4	0.99
5:20 P.M.	500	41.0	75	12.52	28.5	0.99
9:00 A.M.	1440	40.7	72	12.75	27.9	0.99
9:00 A.M.	2880	40.0	71	12.80	27.2	0.99
Sieve Size	Cumulative Weight Retained (grams)	Cumulative % Retained	Cumulative % Passing			
No. 10						
No. 30						
No. 60						
No. 100	0.044	0.14	99.86			
No. 200	0.317	1.04	98.96			
No. 270	0.467	1.54	98.46			
Elapsed Time (min)	P Percent in Solution	L Effective Length	L/T	$\sqrt{L/T}$	K Tabular Value	Diameter of Particles (mm) $d = K\sqrt{L/T}$
2	96.8	9.3	4.6500	2.156	0.01309	0.0282
5	95.8	9.36	1.8700	1.367	0.01309	0.0179
15	95.2	9.4	0.6267	0.7918	0.01309	0.0104
30	94.9	9.42	0.3140	0.5604	0.01309	0.0073
60	94.2	9.46	0.1577	0.3975	0.01309	0.0052
250	92.6	9.6	0.0384	0.19596	0.01292	0.0025
500	92.9	9.6	0.01920	0.1386	0.01284	0.0018
1440	91.0	9.63	0.00669	0.08179	0.01309	0.0011
2880	88.7	9.7	0.00337	0.05805	0.01317	0.0008

TABLE III

Thermocouple Data From Burial Test No. 1

	Capsule Thermocouple Temperatures (°F)								Buried Soil Thermocouple Temperatures (°F)								Surface Soil Thermocouple Temperatures (°F)									
Test Time (Hours)	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 13	TC 14	TC 15	TC 16	TC 17	TC 18	TC 27**	TC 19	TC 20	TC 21	TC 22	TC 23	TC 24	TC 25†	TC 26†			
0	60	60	60	60	60	60	60	60	60	60	60	60	60	54	60	60	60	58	60	60	60	60	60			
1	105	117	105	----	----	----	----	128	81	60	60	60	61	56	60	60	64	58	63	64	64	60	61			
2	150	231	171	----	----	----	----	278	137	60	60	60	63	56	60	60	62	64	62	66	68	63	63			
3	211	328	250	----	----	----	----	358	184	82	62	64	62	56	63	69	68	62	69	70	71	64	69			
4	296	435	367	----	----	----	----	485	-----	----	----	----	----	----	----	----	----	----	----	----	----	----	----			
5	----	----	----	----	----	----	----	----	265	----	----	----	----	----	----	----	----	----	----	----	----	----	----			
6	----	----	----	----	----	----	----	----	297	158	----	----	----	----	----	----	----	----	----	----	----	----	----			
7	460	596	501	485	620	533	635	772	345	172	80	61	58	52	81	63	61	62	61	64	63	62	61			
8	493	628	541	517	658	565	682	780	386	187	90	60	57	52	91	62	62	60	60	61	60	60	59			
9	604	727	612	596	750	651	772	----	427	196	102	59	57	52	101	60	60	60	59	60	59	58	58			
10	704	810	682	674	832	727	869	----	483	206	113	60	55	51	113	57	58	57	57	57	56	55	55			
11	817	914	765	757	935	825	972	----	548	220	128	61	56	51	130	57	57	55	55	54	54	53	52			
12	892	1001	840	832	1015	892	1051	----	612	237	143	62	55	49	142	54	54	54	54	53	51	49	49			
13	979	1087	935	921	1122	994	1150	----	682	261	157	64	54	49	154	54	52	53	52	52	51	50	49			
14	1143	1185	1037	-----	-----	1094	1295	----	755	294	170	65	56	51	167	52	52	50	51	49	48	46	46			
15	1017	1261	-----	1079	-----	-----	-----	----	827	336	182	67	55	49	176	49	50	51	49	48	48	46	46			
16	-----	-----	-----	-----	-----	-----	-----	----	899	383	194	71	57	51	187	51	49	48	48	47	45	44	44			
17 *	1161	1401	1260	1222	1454	1296	1484	1579	990	437	200	73	56	51	195	48	47	49	48	45	44	43	43			
18	1248	1501	1350	1313	1556	1389	1582	1684	1060	494	210	78	56	51	199	49	49	47	47	47	46	44	45			
19	1343	1598	1447	1404	1661	1484	1695	1793	1150	554	215	82	57	53	205	49	49	47	45	45	44	43	43			
20	1451	1708	1554	1509	1779	1595	1813	1917	1240	617	219	88	57	52	210	50	48	47	47	46	44	43	42			
21	1558	1805	1663	1613	1888	1708	1922	2022	1350	682	226	96	57	52	214	49	49	47	46	46	44	44	45			
22	1666	1905	1771	1717	-----	1815	2033	2119	1490	757	236	105	57	52	223	52	51	49	49	49	50	48	48			
23	1765	1992	1868	1810	-----	1914	2136	2226	1620	834	252	114	56	53	243	55	54	53	53	54	56	54	54			
24	1872	2101	1969	1914	-----	2025	2251	2326	1750	930	277	127	57	53	273	58	57	57	57	55	57	56	56			
25	1945	2182	2142	1988	2300	2119	2344	2396	1830	1010	316	140	57	53	314	62	61	60	60	60	62	63	62			
26	1983	2215	2155	2033	2354	2152	2395	2446	1860	1100	365	154	60	53	364	66	64	64	64	64	65	66	66			
27	2010	2223	2128	2083	2384	2112	2416	2476	1870	1170	417	169	58	52	420	68	64	65	64	64	65	66	66			
28	2036	2215	2025	2097	2402	2142	2456	2497	1870	1230	472	180	59	52	476	68	66	66	64	64	65	66	66			
29	2051	2194	2229	2124	2422	2205	2479	2511	1860	1290	526	191	61	53	530	68	66	65	64	64	65	66	66			
30	2066	2166	2236	2140	2434	2187	2492	2533	1850	1330	577	199	60	53	580	68	66	65	64	64	66	66	64			
31	2080	2139	2256	2158	2437	-----	2501	2542	1830	1380	626	205	60	52	626	70	68	67	66	65	66	68	67			
32	2091	2096	2354	2176	2450	-----	2512	2546	1840	1420	670	213	61	52	670	72	70	69	64	64	64	64	64			
33	2096	2072	2423	2179	2459	-----	2516	2548	1820	1460	709	218	62	53	710	74	71	66	64	62	61	63	62			
34	2104	2054	2425	2185	2464	-----	2521	2551	1800	1500	746	222	62	53	748	75	72	67	62	60	60	61	60			
35	2113	2042	2166	2191	2444	-----	2525	2558	1800	1530	778	225	61	53	782	76	72	70	62	60	60	59	59			
36	2122	2025	2134	2199	2446	-----	2531	2559	1800	1560	810	227	62	52	813	76	73	71	63	60	60	60	59			
37	2113	2006	2130	2193	2432	-----	2528	2546	1790	1580	839	228	63	54	842	78	76	71	60	56	55	55	54			
38	2113	1994	2066	2199	2429	-----	2530	2546	1780	1600	863	229	64	54	868	80	77	71	61	56	55	56	54			
39	2113	1988	2048	2203	2428	-----	2534	2551	1770	1620	887	230	65	54	892	81	78	72	61	54	54	52	52			
40	2115	1980	2033	2212	2422	-----	2539	2543	1760	1630	899	230	67	53	899	83	81	74	61	55	53	52	52			
41	2115	1974	2021	2217	2426	-----	2545	2545	1680	1650	-----	231	68	53	-----	85	82	76	59	52	51	49	49			
42	2121	1971	2025	2217	2423	-----	2551	2546	1690	1660	-----	232	69	53	-----	87	84	77	62	53	52	51	50			
43	2119	1962	2009	2212	2423	-----	2554	2548	1660	1670	-----	234	70	54	-----	89	87	79	62	51	52	50	49			
44	2115	1957	2004	2212	2414	-----	2575	2576	1280	1680	-----	239	72	53	-----	90	89	82	63	50	50	48	47			
45	2118	1949	1994	2214	2414	-----	2576	2574	1700	1700	-----	242	73	54	-----	92	90	82	63	49	49	47	47			
46	2115	1943	1986	2212	2413	-----	2575	2570	1740	1710	1020	253	77	54	1010	94	93	85	64	52	51	50	49			
47	2118	1945	1978	2217	2411	-----	2576	2573	1840	1720	1040	260	79	54	1020	93	94	89	69	57	57	59	59			
48	2115	1940	1965	2215	2410	-----	2593	2572	1820	1720	1050	268	82	54	1040	98	99	92	73	62	61	62	62			
48.58	2112	1936	1975	2214	2405	-----	2595	2501	1790	1730	1060	274	83	54	1050	100	100	93	75	62	61	63	63			

*Auxiliary recorder employed; new confidence in data.

**TC 27 was located at the same distance from the capsule as TC 15 but 180° from it.

†Reference soil surface TC's located approximately 8 feet from test site.

Figure 9. Buried thermocouple installation and location at 25 in. depth (D67-5076)

Figure 10. Soil surface thermocouple location (D67-5072)

Figure 11.
Power input vs time
for Test No. 1.

Figure 12.
Temperature vs time for
Test No. 1

Figure 13
Temperature vs time for
Test No. 1

Figure 14. Soil thermocouple location

Figure 15
Capsule recovery
operation
(C67-2247)

Figure 16
X-ray of recovered capsule
(D67-5133)

Figure 17. Recovered capsule in affected soil mass
(D67-5083)

Figure 18. Recovered capsule with affected soil mass partially removed. (C67-2332)

Figure 19. Recovered capsule with affected soil mass removed. (C67-2329)

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CHAPTER III

CAPSULE BURIAL TEST NO. 2

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CHAPTER III

Capsule Burial Test No. 2

General Information

The electrically heated capsule (Serial No. 3) was buried in 20-30 graded Ottawa sand, conforming to ASTM C-190 (Figure 20). This sand is essentially pure SiO_2 . Table IV gives the results of Ottawa sand density and gradation tests; these tests were performed by the Albuquerque Testing Laboratory.

Prior to burial, each capsule thermocouple was checked. It was found that TC's #7 and #8 were inoperative. As indicated in Figure 1, these TC's were inside the capsule and could not be repaired or replaced.

After burial of the capsule and installation of the soil thermocouples (Figures 21 and 22), the heater was energized slowly over a period of 20 hours to the operating power level of 1500 watts (Figure 23). As can be seen from Figure 23, toward the end of the test it was impossible to maintain the full power level of 1500 watts. Apparently this was due to heater deterioration. Figure 24 shows temperature versus time for Test No. 2; Figure 25 shows the location of the soil thermocouples. Table V lists the thermocouple data from Test No. 2.

TABLE IV

Density and Gradation Tests of Standard Ottawa Sand Fill Material

Loose Unit Weight - $97\frac{1}{2}$ lbs/cu ft

Gradation Test: (Cumulative % Passing)

Screen Size

No. 10	100.0
No. 40	0.5
No. 60	-

The heater operated for 77.5 hours. Figure 26 shows the capsule recovery operation. An X-ray and visual inspection of the capsule revealed no melting of the capsule (Figure 27 and 28). When the affected soil was removed, considerable oxidation of the Haynes-25 was visible (Figure 29 and 30). There was also evidence of cobalt migration from the Haynes-25 to the alumina thermocouple sheathing, i.e., the white alumina was now a dark blue. The cobalt had acted as an eutectic; this lowered the melt point of the alumina, and the sheathing had melted in some areas. A vitrified or near-vitrified layer of sand, varying from 1/8 to 1/2 inch in thickness, was formed around this capsule.

TABLE V

Thermocouple Data From Burial Test No. 2

Test Time (Hours)	Capsule Thermocouple Temperatures (°F)								Buried Soil Thermocouple Temperatures (°F)								Surface Soil Thermocouple Temperatures (°F)									
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 13	TC 14	TC 15	TC 16	TC 17	TC 18	TC 27*	TC 28*	TC 19	TC 20	TC 21	TC 22	TC 23	TC 24	TC 25**	TC 26**		
0	65	65	65	65	65	65	NO DATA	NO DATA	68	68	68	67	65	61	68	68	55	54	54	54	54	55	58	57		
1	106	128	94	106	128	94			94	69	68	67	65	61	92	69	59	58	58	58	58	58	59	61	60	
2	221	269	191	221	269	201			153	79	69	68	66	61	151	78	63	62	62	61	62	63	64	64	64	
3	341	384	296	341	384	296			221	99	69	67	65	61	219	96	65	63	64	65	65	66	68	67	67	
4	418	476	401	418	476	358			286	126	72	68	65	61	284	121	67	66	66	67	67	67	69	68	68	
5	501	573	427	476	573	435			343	154	78	68	65	61	343	148	68	67	68	68	68	69	69	70	69	
6	573	643	501	549	643	501			397	184	85	68	65	61	398	178	69	68	69	69	69	69	70	71	70	
7	658	742	589	635	742	589			455	214	94	68	65	61	455	207	69	68	68	68	68	69	70	69	69	
8	765	862	682	742	855	682			532	249	104	69	66	62	531	240	68	67	67	67	67	67	67	67	67	
9	855	965	765	832	965	765			607	290	115	70	66	61	606	280	66	66	65	65	65	66	66	65	64	
10	943	1058	847	914	1051	847			677	331	128	71	65	61	679	321	65	64	64	64	64	64	64	63	63	
11	1022	1150	928	1001	1148	921			745	373	144	72	66	61	749	363	64	64	63	62	62	62	63	62	62	
12	1108	1247	1015	1072	1233	1008			814	416	160	73	66	61	821	406	65	63	62	62	62	62	63	62	62	
13	1199	1330	1108	1157	1316	1087			885	460	178	76	66	61	893	451	64	62	62	62	62	62	62	61	61	
14	1316	1451	1220	1275	1424	1192			980	508	197	77	66	62	970	498	63	63	62	61	61	61	61	60	60	
15	1410	1556	1295	1363	1543	1289			1070	562	218	80	66	62	1070	553	64	62	61	60	60	60	60	58	59	
16	1484	1647	1384	1451	1627	1363			1160	620	241	82	65	61	1160	610	63	62	60	60	60	60	60	58	59	
17	1589	1755	1477	1549	1742	1457			1270	685	268	86	67	62	1260	673	63	61	60	60	60	59	59	58	58	
18	1692	1868	1576	1647	1843	1549			1360	755	297	90	66	62	1360	743	63	62	60	59	58	59	57	58		
19	1787	1966	1660	1755	1942	1647			1460	829	328	95	66	62	1460	817	62	61	58	58	57	57	56	56		
20	1868	2063	1742	1849	2045	1723			1560	899	360	100	66	62	1560	891	62	60	58	57	57	57	55	55		
21	1948	2154	1818	1929	2130	1799			1650	990	399	106	66	62	1650	980	63	61	58	58	57	57	55	56		
22	1990	2202	1868	1972	2184	1837			1710	1070	438	112	67	62	1720	1060	64	61	59	58	58	58	57	57		
23	2027	2238	1892	2009	2232	1874			1760	1140	480	120	66	62	1770	1130	66	63	61	60	60	60	61	60		
24	2051	2262	1917	2033	2256	1892			1810	1200	520	128	67	62	1820	1190	68	66	64	62	62	62	63	64		
25	2069	2291	1935	2051	2274	1911			1840	1250	561	136	67	63	1850	1230	70	67	66	64	64	64	65	65		
26	2087	2303	1960	2069	2297	1929			1870	1290	600	144	67	62	1870	1280	72	69	67	65	65	65	66	66		
27	2112	2327	1984	2093	2321	1948			1900	1320	636	154	68	62	1900	1320	73	70	68	66	66	66	66	66		
28	2124	2339	----	2112	2327	1960			1920	1360	672	166	69	62	1920	1350	75	72	70	68	67	67	69	68		
29	2142	2351	----	2124	2339	1972			1940	1390	705	175	69	62	1940	1380	78	75	72	69	69	69	71	71		
30	2154	2363	----	2142	2351	1978			1950	1410	735	188	69	62	1950	1410	80	76	72	70	70	70	71	70		
31	2172	2381	----	2154	2351	1997			1970	1440	770	201	70	63	1970	1430	80	76	72	70	69	69	68	69		
32	2184	2399	----	2154	2232	1960			1990	1460	800	212	70	62	1990	1450	77	75	71	68	66	66	65	65		
33	2190	2411	----	2184	2184	1948			2000	1480	820	224	71	62	2000	1480	76	73	68	64	63	63	61	61		
34	2195	2411	----	2190	2232	----			2000	1500	850	237	71	62	2010	1490	74	72	67	63	61	60	60	60		
35	2202	2417	----	2190	2303	----			2010	1510	870	250	72	63	2020	1500	74	72	66	62	61	59	59	59		
36	2202	2429	----	2196	2296	----			2020	1530	890	263	73	63	2030	1520	74	72	65	61	59	59	58	58		
37	2202	2435	----	2190	2268	----			2020	1540	900	275	73	62	2030	1530	75	72	65	60	57	57	56	57		
38	2202	2435	----	2184	2363	----	2030	1550	920	288	73	63	2030	1540	75	72	64	59	56	56	55	56				

*Reference TC's directly opposite TC's 13 and 14 at 1" and 3" from the capsule surface.

**Reference soil surface thermocouples to indicate normal ground surface temperatures.

TABLE V (Continued)

	Capsule Thermocouple Temperatures (°F)								Buried Soil Thermocouple Temperatures (°F)								Surface Soil Thermocouple Temperatures (°F)							
Test Time (Hours)	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 13	TC 14	TC 15	TC 16	TC 17	TC 18	TC 27	TC 28	TC 19	TC 20	TC 21	TC 22	TC 23	TC 24	TC 25	TC 26
39	2202	2435		2184	2381				2030	1560	940	299	74	63	2030	1550	75	72	67	58	56	56	54	55
40	2208	2435		2190	2441				2040	1560	950	311	75	62	2040	1560	76	73	66	58	55	54	53	54
41	2208	2429		2196	2561				2050	1570	960	322	76	62	2050	1570	75	73	64	57	54	53	52	53
42	2214	2405		2196	2501				2050	1580	980	332	77	62	2050	1580	76	73	64	57	53	53	52	53
43	2214	2381		2202	2507				2050	1590	990	344	78	63	2060	1580	77	74	65	57	52	52	51	52
44	2220	2333		2202	2574				2060	1600	1000	356	80	62	2060	1590	77	75	66	56	52	51	51	51
45	2214	2344		2202	2604				2060	1610	1020	365	81	63	2060	1600	78	75	65	57	52	52	53	52
46	2214	2344		2202	2628				2080	1620	1040	383	83	63	2080	1610	81	79	70	61	57	57	56	56
47	2232	2345		2226	2543				2100	1630	1050	393	84	63	2100	1630	84	82	72	65	59	58	59	59
48	2244	2363		2232	2549				2110	1640	1060	402	86	63	2100	1640	86	85	75	66	60	60	60	60
49	2233	2214		2232	2573				2120	1650	1070	410	88	63	2110	1650	79	77	67	58	52	52	50	51
50	2262	2274		2236	2712				2120	1660	1080	420	90	63	2110	1660	79	77	67	56	49	48	47	47
51	2262	2250		2262	2730				2130	1670	1090	428	91	63	2120	1660	84	81	69	56	47	46	47	47
52	2268	2196		2262	3084				2130	1670	1100	436	92	63	2120	1670	84	80	68	55	44	43	45	45
53	2268	2184		2268	2853				2130	1680	1110	443	94	63	2120	1680	84	82	71	56	46	44	46	44
54	2268	2190		2262	2791				2140	1690	1120	452	96	63	2070	1680	87	83	70	56	45	44	45	45
55	2274	2160		2262	2736				2140	1690	1130	461	98	63	2060	1690	88	84	73	58	45	43	45	44
56	2274	2172		2262	2767				2140	1700	1140	469	99	64	2040	1690	91	87	75	60	46	44	44	43
57	2268	2172		2262	2712				2140	1700	1150	476	101	64	2010	1700	91	87	74	59	46	43	43	42
58	2268	2142		2262	2827				2140	1700	1150	484	103	63	2010	1700	90	87	74	58	44	41	41	40
59	2262	2166		2262	2791				2140	1710	1160	491	104	63	2000	1700	90	87	73	58	43	40	40	39
60	2262	2142		2250	2791				2140	1700	1170	498	106	64	2000	1700	89	86	72	56	41	39	39	37
61	2262	2142		2256	2797				2150	1710	1170	505	110	64	2000	1700	90	86	71	56	40	38	37	35
62	2262	2124		2262	2815				2150	1710	1180	512	111	64	2010	1710	90	88	73	57	41	38	38	37
63	2256	2100		2250	2797				2160	1720	1180	520	113	63	2010	1710	93	90	75	58	41	38	38	37
64	2262	2112		2244	2755				2150	1720	1190	525	115	64	2010	1710	94	91	76	60	41	37	38	36
65	2256	----		2256	2743				2150	1720	1190	532	117	64	2000	1720	90	88	72	56	39	36	37	36
66	2262	----		2250	2743				2150	1720	1200	537	119	64	2010	1720	90	87	73	56	39	34	37	35
67	2244	----		2238	2664				2150	1720	1200	544	121	64	2000	1720	91	90	74	57	38	34	35	33
68	2256	----		2236	2682				2150	1720	1200	549	124	64	2000	1720	90	89	72	56	38	34	35	34
69	2244	----		2244	2682				2160	1730	1210	555	125	64	2000	1720	88	88	72	56	40	37	38	37
70	2268	----		2244	2670				2170	1730	1210	561	128	64	2000	1730	92	90	75	57	41	38	40	38
71	2262	----		2262	2682				2170	1740	1210	565	130	64	2000	1730	94	92	76	59	42	40	41	40
72	2262	----		2268	2682				2170	1740	1220	572	133	64	2000	1740	98	96	81	62	44	41	42	42
73	2262	----		2274	2658				2180	1740	1230	578	135	64	2010	1740	102	100	85	66	47	44	44	43
74	2286	----		2262	2664				2180	1750	1230	581	137	64	2010	1740	107	105	90	70	48	45	45	45
75	2268	----		2262	2682				2180	1750	1230	588	139	64	2010	1750	107	105	89	71	51	47	48	47
76	2262	----		2262	2652				2180	1750	1240	592	141	66	2000	1750	107	106	91	72	54	51	51	51
77	2291	----		2262	2622				2190	1760	1240	593	143	64	2010	1750	106	105	90	73	55	52	53	52
77.5*	2324	----		2262	2628				2060	1750	1250	597	144	65	1930	1740	108	107	92	74	56	53	53	53
78	2021	----		2021	2166																			

*Breakdown

Figure 20. Capsule emplacement operation
(D67-2528)

Figure 21. Buried thermocouple installation and location at 25-inch depth

Figure 22. Soil surface thermocouple location (C67-2591)

Figure 23. Power input vs time for Test No. 2

Figure 24. Temperature vs time for Test No. 2

TC 13 and 19, 1 INCH FROM HEATER
 TC 14 and 20, 3 INCHES FROM HEATER
 TC 15 and 21, 6 INCHES FROM HEATER
 TC 16 and 22, 12 INCHES FROM HEATER
 TC 17 and 23, 24 INCHES FROM HEATER
 TC 18 and 24, 40 INCHES FROM HEATER
 TC 27, 1 INCH FROM HEATER
 TC 28, 3 INCHES FROM HEATER
 TC 25 and 26, TOP OF TEST SOIL OF REFERENCE HOLE

Figure 25.
 Soil thermocouple location

Figure 26.
 Capsule recovery
 operation
 (C67-2795)

Figure 27.
X-ray of recovered capsule
Test No. 2

Figure 28.
Recovered capsule in affected
soil mass

Figure 29.
Recovered capsule with soil
mass partially removed
(C67-2793)

Figure 30. Capsule with soil mass removed (C67-2792)

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CHAPTER IV
CAPSULE BURIAL TEST NO. 3

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CHAPTER IV

Capsule Burial Test No. 3

General Information

A mixture of 1/3 bentonite, 1/3 Ottawa sand, and 1/3 crushed feldspar by volume was prepared (Figure 31), and the electrically heated capsule (Serial No. 2) was buried in it (Figure 32). A representative chemical and physical analysis of each of these is as follows.

Bentonite:

Silica	64.72%
Alumina	20.82%
Iron Oxide	3.44%
Titanium Oxide	0.14%
Lime	0.49%
Magnesia	2.38%
Alkalies	2.92%
Ignition Loss	4.84%
Fusion Point	2440°F

Ottawa Sand - SiO₂

Graded 20 - 30 conforming to ASTM 190

Feldspar:

Silica	64.5%
Alumina	19.3%
Iron Oxide	0.02%
Calcium Oxide	0.1%
Magnesium Oxide	Trace
Sodium Oxide	3.1%
Potassium Oxide	12.5%
Ignition Loss	0.4%

Table VI gives the results of density and gradation tests of the mixture. These tests were performed by the Albuquerque Testing Laboratory. Lump feldspar was crushed so that 100 percent of it would pass through a 3/16-inch mesh screen, i.e., it ranged in size from less than 3/16 inch to dust.

Prior to burial, each of the capsule thermocouples was checked. It was found that TC's 2 and 3 (Figure 1) were damaged beyond repair, but since TC's 5 and 6 were located directly opposite TC's 2 and 3, it was decided not to attempt to replace these TC's due to the possibility of damaging others.

After burial of the capsule and installation of the soil thermocouples (Figures 33 and 34), the heater was energized slowly over a period of 22 hours to the operating power level of 1500 watts (Figure 35). Some improvements were made to the power supply equipment which enabled a much steadier power level to be held than was possible on the

previous tests. Figure 36 shows temperature versus time for Test No. 3; Figure 37 shows the location of the soil thermocouples. Table VII lists the thermocouple data for Test No. 3.

This heater operated for approximately 211 hours. Figure 38 shows the capsule recovery operation. An X-ray of the unit revealed no melting of the Haynes-25 (Figure 39); however, visual inspection after removal of the soil mass revealed some melting of the Haynes-25 in the thin section of the top. The top plate, which was stainless steel, was badly oxidized.

This unit created a vitrified and sintered soil mass shaped like a large football, approximately 8 inches in diameter at the center and about 18 inches in length (Figure 40). Upon removal of the soil mass, it was found that melting of the soil had occurred. A void area had been formed between the soil and the heater (Figures 41 and 42). Migration of the cobalt from the Haynes-25 to alumina thermocouple sheath material and to the soil near the heater was evidenced by the dark blue coloring. As a result of the eutectic action of the cobalt, the alumina sheathing again melted.

As is indicated in Table VII, all capsule thermocouples and one buried soil thermocouple were lost prior to the end of the test. TC #27 was a back-up buried soil thermocouple for TC #13 which was lost.

TABLE VI

Density and Gradation Tests of
Composite Fill Material

1/3 Standard Ottawa Sand
1/3 Bentonite
1/3 Feldspar

Loose Unit Weight 85.4 lbs/cu ft

Gradation Tests: (Cumulative % Passing)

<u>Screen size</u>	<u>Dry analysis</u>	<u>Wet analysis</u>
No. 4	100	100
No. 10	88.8	93.2
No. 30	12.6	31.7
No. 60	5.5	26.2
No. 100	2.2	23.8
No. 200	1.0	21.8
No. 270	0.4	21.6
Wash Test	---	21.4

TABLE VII (Part 1)

Thermocouple Data From Burial Test No. 3

	Capsule Thermocouple Temperatures (°F)								Buried Soil Thermocouple Temperatures (°F)								Surface Soil Thermocouple Temperatures (°F)							
Test Time (Hours)	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 13	TC 14	TC 15	TC 16	TC 17	TC 18	TC 27*	TC 28*	TC 19	TC 20	TC 21	TC 22	TC 23	TC 24	TC 25**	TC 26**
0	70			71	70	71	71	71	69	68	68	68	66	61	76	69	46	46	46	46	46	47	46	46
1	105			117	128	105	150	160	92	70	68	69	66	61	93	70	48	47	47	47	47	49	47	47
2	201			221	259	211	278	306	143	78	69	68	66	61	144	80	51	51	51	51	51	52	51	49
3	296			314	358	305	384	427	196	98	70	69	66	61	198	101	55	53	53	53	53	54	53	51
4	384			401	468	384	501	549	255	123	73	69	66	61	258	130	58	57	56	56	56	57	56	54
5	468			485	557	468	589	651	315	149	79	69	65	62	319	156	59	59	58	57	57	58	59	56
6	557			573	662	557	704	780	380	173	88	69	66	61	384	180	61	59	58	58	57	58	58	56
7	643			658	757	651	795	892	448	198	99	70	66	61	452	207	60	59	58	58	58	58	58	57
8	727			742	855	742	899	1008	521	227	116	70	66	60	525	239	60	58	57	57	57	56	57	56
9	817			832	965	825	1008	1115	595	263	127	71	66	60	606	277	56	57	56	55	55	54	52	53
10	892			906	1044	906	1087	1213	661	302	142	72	66	60	669	320	55	53	53	52	52	52	50	52
11	979			994	1143	1008	1199	1316	733	345	156	74	66	61	743	361	54	52	50	49	49	49	47	49
12	1079			1101	1261	1101	1302	1451	817	391	170	76	66	61	831	410	52	49	47	46	47	46	43	46
13	1178			1185	1357	1192	1417	1576	900	442	183	78	66	61	910	462	51	47	44	44	44	44	39	43
14	1275			1282	1464	1295	1517	1660	990	498	196	82	66	60	990	520	48	44	42	42	42	42	38	41
15	1350			1363	1536	1384	1614	1762	1060	555	211	85	65	60	1070	577	47	43	41	40	40	40	37	39
16	1417			1431	1634	1451	1685	1855	1140	610	230	90	66	61	1140	633	46	42	40	39	39	40	36	38
17	1490			1503	1711	1523	1774	1960	1210	665	253	96	66	60	1220	690	46	42	40	39	39	39	34	38
18	1563			1569	1787	1595	1849	2063	1290	721	280	103	66	61	1300	747	46	41	39	38	38	37	33	37
19	1653			1672	1892	1698	1960	2178	1370	781	310	110	66	60	1380	806	45	40	38	36	36	36	32	35
20	1742			1755	1997	1787	2057	2256	1460	844	342	119	66	60	1470	872	46	40	37	36	36	36	32	35
21	1849			1849	2100	1868	2160	2333	1560	910	377	129	67	61	1570	950	46	40	36	34	34	34	35	35
22	1929			1935	2202	1948	2238	2411	1660	980	415	139	67	60	1660	1010	49	42	39	38	38	39	35	37
23	1990			2021	2232	2003	2280	2417	1740	1050	455	148	67	61	1740	1090	53	46	43	42	41	53	42	41
24	2051			2081	2286	2057	2327	2327	1790	1120	497	156	67	61	1790	1150	56	51	47	45	44	46	45	44
25	2051			2069	2303	2093	2345	2465	1840	1170	540	166	68	60	1840	1210	60	55	52	49	49	51	52	49
26	2063			2081	2309	2112	2351	2453	1880	1220	582	174	69	60	1880	1250	62	57	55	52	52	53	53	51
27	2081			2093	2321	2142	2357	2411	1900	1260	620	183	69	61	1910	1300	66	61	57	55	53	56	57	54
28	2087			2112	2321	2148	2363	2351	1920	1300	656	190	69	61	1950	1330	69	63	60	57	56	57	61	56
29	2100			2118	2321	2154	2363	2321	1930	1330	690	194	70	61	1980	1370	71	66	62	59	57	58	60	58
30	2112			2124	2327	2172	2369	2321	1930	1370	724	200	70	61	2000	1400	72	67	62	60	59	60	61	60
31	2118			2130	2321	2172	2369	2327	1930	1400	754	206	71	61	2010	1430	75	68	63	60	59	60	62	60
32	2124			2142	2309	2178	2363	2339	1920	1420	782	212	72	61	2020	1450	75	69	64	60	58	59	61	59
33	2130			2148	2309	2196	2375	2357	1910	1440	806	222	72	61	2040	1480	78	70	64	59	57	57	57	57
34	2142			2160	2309	2208	2369	2351	1910	1460	830	229	73	61	2050	1500	76	69	63	59	57	57	56	56
35	2142			2166	2309	2220	2375	2339	1900	1480	851	241	74	61	2050	1520	76	68	62	56	55	53	52	53
36	2154			2172	2321	2184	2381	2339	1900	1500	872	251	76	60	2060	1530	76	67	60	55	52	51	49	51
37	2160			2184	2333	2190	2381	2333	1880	1510	890	264	77	61	2070	1550	76	66	59	52	49	49	46	49
38	2172			2184	2321	2202	2381	2327	1870	1530	---	277	77	61	2080	1560	77	65	57	51	47	46	42	46
39	2178			2202	2321	2208	2387	2321	1870	1540	---	289	79	60	2080	1570	76	65	56	49	45	43	40	43
40	2184			2202	2321	2202	2387	2321	1860	1550	---	301	80	60	2090	1590	75	65	56	48	44	42	38	42
41	2190			2202	2327	2208	2387	2327	1860	1570	---	317	82	61	2090	1600	76	65	56	47	42	41	37	40
42	2190			2208	2333	2208	2393	2309	1850	1580	---	327	84	60	2100	1610	76	64	56	47	42	40	35	39

*Reference TC's directly opposite TC's 13 and 14 at 1" and 3" from the capsule surface.

**Reference soil surface TC's to indicate normal ground surface temperatures.

TABLE VII (Part 2)

Capsule Thermocouple Temperatures (°F)								Buried Soil Thermocouple Temperatures (°F)								Surface Soil Thermocouple Temperatures (°F)									
Test Time (Hours)	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 13	TC 14	TC 15	TC 16	TC 17	TC 18	TC 27	TC 28	TC 19	TC 20	TC 21	TC 22	TC 23	TC 24	TC 25	TC 26	
43	2202	NO DATA	NO DATA	2214	2333	2202	2393	2303	1850	1590	----	340	86	60	2100	1620	76	64	55	46	40	39	34	38	
44	2202			2214	2333	2297	2393	2303	1840	1600	----	352	88	60	2110	1630	76	64	55	45	39	38	32	37	
45	2202			2220	2333	2232	2393	2291	1830	1610	----	364	90	60	2100	1650	79	67	56	46	39	38	34	36	
46	2208			2214	2327	2232	2387	2262	1830	1610	----	376	92	61	2110	1650	82	71	60	49	42	42	38	39	
47	2208			2232	2339	2208	2399	2262	1830	1620	1040	388	94	60	2120	1660	86	74	65	53	45	45	43	42	
48	2214			2232	2339	2214	2405	2274	1830	1640	1050	399	97	61	2120	1680	90	80	71	58	49	49	48	46	
49	2208			2232	2339	2196	2399	2250	1820	1650	1060	410	100	60	2120	1690	93	84	76	63	54	54	53	50	
50	2214			2232	2333	2220	2387	2262	1820	1650	1070	420	102	61	2120	1690	95	87	78	66	57	58	58	55	
51	2214			2226	2327	2208	2387	2256	1820	1660	1080	430	105	61	2120	1700	99	90	82	70	61	60	60	57	
52	2214			2232	2333	2214	2393	2270	1850	1670	1090	440	107	61	2130	1710	100	92	84	73	63	63	64	60	
53	2214			2226	2327	2202	2381	2238	1830	1680	1100	448	110	61	2130	1710	99	93	85	75	65	64	64	61	
54	2214			2226	2333	2202	2381	2232	1810	1690	1110	458	113	62	2130	1720	102	96	87	76	65	64	65	62	
55	2220			2232	2333	2202	2381	2238	1800	1700	1130	466	115	61	2130	1730	104	97	88	77	66	65	65	62	
56	2220			2232	2333	2196	2381	2238	1790	1700	1130	475	118	62	2130	1730	101	95	88	77	67	64	65	63	
57	2226			2232	2333	2190	2381	2202	1770	1710	1140	483	121	62	2150	1740	100	95	86	77	66	63	62	61	
58	2232			2232	2339	2202	2381	2214	1770	1710	1150	493	124	61	2130	1740	103	96	88	76	64	61	59	59	
59	2232			2238	2345	2202	2381	2202	1750	1720	1150	501	124	62	2140	1740	105	95	86	74	61	57	54	55	
60	2244			2238	2345	2202	2381	2208	1730	1720	1160	510	128	61	2140	1750	107	96	85	72	58	53	50	52	
61	2250			2244	2351	2208	2387	2220	1740	1730	1170	516	130	62	2150	1750	105	96	85	72	57	51	47	49	
62	2250			2250	2351	2321	2393	2232	1750	1730	1180	524	132	62	2150	1750	104	93	82	70	55	49	44	47	
63	2262			2262	2357	2207	2399	2190	1750	1740	1180	530	134	62	2150	1750	104	92	82	69	53	48	43	45	
64	2262			2262	2357	2214	2405	2202	1740	1750	1190	537	136	62	2160	1760	99	90	80	68	51	46	42	44	
65	2262			2262	2351	2214	2411	2184	1740	1750	1200	545	139	62	2160	1760	103	92	82	68	52	47	42	44	
66	2268			2262	2363	2220	2411	2202	1730	1750	1200	551	141	62	2160	1760	104	92	82	68	51	44	40	43	
67	2268			2262	2363	2226	2411	2172	1730	1760	1200	560	142	62	2170	1760	102	91	81	67	50	43	38	41	
68	2274			2262	2369	2232	2417	2166	1720	1770	1210	565	145	62	2170	1760	102	92	81	67	50	43	38	40	
69	2280	2262	2375	2232	2417	2172	1720	1770	1220	570	148	62	2170	1770	102	91	81	68	50	44	41	41			
70	2274	2262	2369	2196	2417	2172	1700	1770	1220	578	149	63	2170	1770	106	95	85	71	52	47	42	43			
71	2280	2274	2375	2220	2423	2190	1680	1780	1230	583	153	63	2170	1770	109	97	89	75	56	51	47	46			
72	2286	2268	2375	2232	2423	2208	1690	1780	1240	588	155	63	2180	1780	109	99	91	80	60	55	53	51			
73	2280	2268	2369	2226	2423	2262	1660	1790	1240	596	158	64	2180	1780	114	104	95	83	63	58	56	54			
74	2291	2274	2381	2232	2423	----	1660	1790	1250	601	158	64	2180	1780	116	106	97	87	67	63	61	58			
75	2291	2268	2381	2232	2417	----	1670	1800	1250	606	160	64	2180	1780	115	107	100	89	70	65	65	61			
76	2291	2268	2369	2232	2417	----	1680	1800	1260	612	162	64	2180	1780	118	109	101	92	72	68	68	65			
77	2291	2268	2375	2250	2411	----	1760	1810	1260	616	164	64	2180	1780	119	110	102	93	74	69	70	66			
78	2291	2262	2369	2244	2411	----	1800	1810	1270	622	166	65	2180	1780	118	109	102	94	76	71	73	69			
79	2274	2262	2363	2232	2399	----	1760	1820	1270	628	168	65	2180	1780	118	109	101	94	76	72	73	70			
80	2274	2256	2357	2238	2387	----	1780	1820	1280	632	170	65	2180	1780	116	107	101	92	76	70	72	69			
81	2274	2250	2357	2250	2387	----	1810	1820	1280	638	171	66	2190	1780	110	102	95	91	75	69	69	67			
82	2268	2250	2357	2208	2387	----	1760	1830	1280	641	172	66	2190	1780	110	102	96	90	72	67	65	64			
83	2268	2250	2357	2202	2381	----	1740	1830	1290	647	173	65	2180	1780	114	104	96	89	70	64	62	62			
84	2268	2244	2357	2208	2381	----	1770	1830	1290	651	175	66	2180	1780	115	106	98	90	70	62	58	59			

TABLE VII (Part 3)

Test Time (Hours)	Capsule Thermocouple Temperatures (°F)								Buried Soil Thermocouple Temperatures (°F)								Surface Soil Thermocouple Temperatures (°F)									
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 13	TC 14	TC 15	TC 16	TC 17	TC 18	TC 27	TC 28	TC 19	TC 20	TC 21	TC 22	TC 23	TC 24	TC 25	TC 26		
85	2268			2244	2357	2208	2381		1790	1830	1300	656	176	67	2190	1780	117	105	96	87	68	58	54	56		
86	2268			2244	2357	2208	2375		1890	1840	1300	660	177	66	2180	1780	117	104	96	86	66	56	52	53		
87	2268			2244	2357	2208	2375		1960	1840	1300	665	178	66	2190	1780	114	102	93	84	64	54	49	51		
88	2262			2244	2351	2208	2363		2010	1840	1310	668	180	67	2190	1780	116	103	93	84	63	52	48	50		
89	2262			2238	2351	2214	----		2050	1850	1310	673	180	67	2190	1780	115	103	93	83	63	51	47	48		
90	2262			2244	2351	2208	----		2130	1850	1310	677	182	68	2190	1770	115	102	92	83	62	51	47	48		
91	2262			2232	2351	2214	2363		2190	1850	1320	682	184	68	2190	1770	116	102	92	82	62	51	46	48		
92	2262			2232	2357	----	2357		2190	1850	1320	685	185	68	2190	1770	118	104	94	83	62	50	45	47		
93	2262			2232	2351	----	2351		2240	1850	1320	690	187	69	2190	1770	121	106	95	84	63	49	46	47		
94	2262			2232	2345	----	----		2250	1860	1330	694	188	69	2200	1770	126	109	98	87	64	52	47	48		
95	2262			2232	2345	----	----		2290	1860	1330	697	188	70	2200	1770	130	112	100	90	68	54	50	49		
96	2256			2238	2333	----	----		2330	1860	1330	700	190	69	2200	1770	128	115	104	94	72	59	56	53		
97	2250			2220	2333	----	----		2350	1860	1340	705	191	70	2200	1770	131	116	105	96	74	62	60	57		
98	2244			2214	2333	----	----		2400	1860	1340	708	192	70	2200	1760	130	117	106	98	76	66	65	61		
99	2244			2214	2327	----	----		2370	1860	1350	710	194	72	2200	1760	129	115	104	98	78	68	70	64		
100	2238			2214	2327	----	----		2370	1860	1340	715	194	72	2200	1760	128	116	105	99	80	71	72	68		
101	2244			2220	2327	----	----		2440	1860	1350	720	197	71	2200	1760	129	117	106	100	81	72	73	69		
102	2244			2190	2327	----	----		2390	1870	1350	720	200	72	2200	1760	127	116	106	100	82	73	75	71		
103	2244			2184	2327	----	----		2360	1860	1350	730	201	72	2200	1760	126	116	106	100	82	73	75	72		
104	2244			2184	2321	----	----		2290	1860	1360	730	202	73	2200	1750	116	106	98	95	80	72	73	70		
105	2244			2184	2321	----	----		2330	1860	1360	730	204	73	2200	1750	120	110	100	95	79	70	71	68		
106	2244			2202	2321	----	----		2270	1860	1370	740	204	74	2200	1750	119	109	98	94	77	68	66	66		
107	2250			2309	2321	----	----		2250	1860	1370	740	206	74	2200	1750	118	108	99	94	77	66	62	63		
108	2250			----	2321	----	----		2190	1860	1370	740	206	73	2200	1750	119	107	98	92	76	64	59	60		
109	2250			----	2321	----	----		2160	1860	1370	750	210	74	2200	1740	129	115	102	94	76	61	56	57		
110	----			----	2321	----	----		2230	1860	1370	750	210	74	2200	1740	129	115	103	95	75	60	53	55		
111	----			----	2321	----	----		2280	1860	1370	750	212	75	2200	1740	124	111	100	92	74	60	52	54		
112	----			----	2321	----	----		2280	1860	1380	750	214	75	2200	1740	122	111	100	92	73	60	52	53		
113	----			----	2315	----	----		2350	1860	1380	750	215	76	2200	1740	131	115	102	91	72	56	48	51		
114	----			----	2321	----	----		2360	1850	1380	760	217	76	2200	1730	130	114	101	89	70	52	46	48		
115	----			----	2321	----	----		2360	1850	1380	760	217	77	2200	1730	130	114	100	88	69	51	44	46		
116	----			----	2327	----	----		2360	1850	1390	760	220	77	2210	1730	131	114	100	88	68	49	42	44		
117	----			----	2321	----	----		2360	1850	1390	760	222	77	2210	1730	130	114	100	88	67	49	42	44		
118	----			----	2321	----	----		2380	1850	1390	770	222	77	2210	1730	134	117	102	90	70	53	46	46		
119	----			----	2315	----	----		2380	1850	1390	770	225	78	2210	1730	137	121	106	94	73	57	50	49		
120	----			----	2309	----	----		2430	1850	1400	770	226	78	2210	1730	132	119	107	96	77	62	56	53		
121	----			----	2309	----	----		2450	1850	1400	780	228	79	2210	1730	133	120	108	98	80	65	59	56		
122	----			----	2309	----	----		2410	1850	1400	780	230	80	2210	1730	132	121	110	100	82	68	62	60		
123	----			----	2303	----	----		2450	1850	1400	780	231	80	2210	1730	134	123	111	102	84	71	65	62		
124	----			----	2303	----	----		2490	1840	1410	790	233	80	2220	1730	136	124	113	104	86	72	68	64		
125	----			----	2309	----	----		2470	1840	1410	790	235	80	2220	1730	135	124	113	104	88	74	71	67		
126	----			----	2303	----	----		2420	1840	1410	790	236	81	2220	1720	135	124	114	105	88	75	71	67		

TABLE VII (Part 4)

	Capsule Thermocouple Temperatures (°F)								Buried Soil Thermocouple Temperatures (°F)								Surface Soil Thermocouple Temperatures (°F)									
st Time Hours)	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 13	TC 14	TC 15	TC 16	TC 17	TC 18	TC 27	TC 28	TC 19	TC 20	TC 21	TC 22	TC 23	TC 24	TC 25	TC 26		
127					2303				2460	1840	1410	790	237	81	2210	1720	136	126	114	106	89	75	71	68		
128					2303				2490	1840	1420	800	240	81	2210	1720	136	125	114	104	88	73	69	67		
129					2309				2490	1840	1410	800	241	82	2210	1720	133	123	112	102	85	71	65	64		
130					2315				2490	1840	1420	800	241	82	2210	1710	134	122	111	101	84	70	62	63		
131					2321				2490	1840	1420	800	244	82	2210	1710	140	128	115	101	83	66	60	60		
132					2321				2490	1830	1420	800	245	82	2220	1710	146	131	115	101	83	63	56	56		
133					2321				2490	1830	1420	810	247	82	2220	1710	147	130	115	100	81	62	52	54		
134					2321				2490	1830	1420	810	247	84	2220	1710	147	130	115	100	80	59	49	51		
135					2321				-----	1840	1430	810	251	84	2210	1710	146	131	115	100	81	59	50	51		
136					2321				-----	1840	1430	810	252	85	2220	1710	141	129	114	99	80	59	49	50		
137					2321				-----	1830	1430	810	255	84	2210	1710	140	127	112	97	78	57	46	49		
138					2333				-----	1830	1430	820	256	84	2220	1820	146	130	113	97	78	55	46	48		
139					2339				-----	1830	1430	820	256	85	2220	1830	144	128	112	95	75	53	43	46		
140					2321				-----	1820	1440	820	260	86	2220	1840	143	126	111	94	74	51	42	44		
141					2321				-----	1830	1440	830	261	87	2220	1850	149	128	111	95	75	52	43	44		
142					2339				-----	1830	1440	830	261	86	2220	1850	140	126	111	95	75	56	48	48		
143					2357				-----	1820	1440	830	264	87	2220	1860	140	128	114	97	78	60	52	52		
144					-----				-----	1820	1440	830	265	87	2220	1860	142	130	116	102	82	65	58	55		
145					-----				-----	1820	1450	830	266	86	2220	1850	131	121	111	100	84	69	64	60		
146					-----				-----	1820	1450	840	269	88	2220	1860	135	126	115	104	86	72	67	62		
147					-----				-----	1810	1450	840	270	89	2220	1860	136	126	116	106	90	76	71	66		
148					-----				-----	1810	1450	840	272	88	2220	1860	139	130	119	108	92	77	73	68		
149					-----				-----	1810	1450	840	273	89	2220	1870	140	131	121	110	94	80	75	70		
150					-----				-----	1810	1450	850	275	90	2220	1860	142	131	121	112	95	80	76	71		
151					-----				-----	1810	1450	850	276	90	2220	1860	141	131	121	111	95	80	76	71		
152					-----				-----	1810	1450	850	278	91	2220	1860	142	132	122	111	96	80	74	71		
153					-----				-----	1810	1450	850	280	90	2220	1860	141	131	121	111	94	77	71	69		
154					-----				-----	1810	1460	850	280	90	2220	1850	144	134	122	110	93	75	67	66		
155					-----				-----	1810	1460	850	281	91	2220	1850	135	141	126	111	92	71	62	63		
156					-----				-----	1810	1460	850	283	92	2220	1850	138	141	126	110	91	68	58	59		
157					-----				-----	1800	1460	850	284	91	2230	1850	157	142	125	108	90	66	55	56		
158					-----				-----	1800	1460	850	285	92	2210	1850	152	138	122	106	87	65	55	56		
159					-----				-----	1800	1460	860	287	91	2220	1860	155	139	122	106	86	63	52	54		
160					-----				-----	1800	1460	860	287	91	2220	1860	147	136	121	104	84	63	54	55		
161					-----				-----	1810	1460	860	290	94	2220	1860	156	141	123	106	85	62	51	53		
162					-----				-----	1810	1470	860	291	93	2220	1860	157	140	123	105	84	60	47	50		
163					-----				-----	1810	1470	860	293	93	2220	1860	156	138	122	104	82	57	46	48		
164					-----				-----	1820	1470	860	294	94	2230	1860	155	139	121	104	82	57	46	48		
165					-----				-----	1860	1470	860	294	94	2230	1860	154	138	122	104	82	59	48	48		
166					-----				-----	1850	1470	870	297	94	2220	1850	162	144	126	108	86	62	51	51		
167					-----				-----	1850	1480	870	298	95	2220	1840	160	145	130	111	89	66	56	54		
168					-----				-----	1890	1480	870	300	96	2230	1840	160	146	132	113	91	71	61	58		

TABLE VII (Part 5)

Test Time (Hours)	Capsule Thermocouple Temperatures (°F)								Buried Soil Thermocouple Temperatures (°F)								Surface Soil Thermocouple Temperatures (°F)									
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 13	TC 14	TC 15	TC 16	TC 17	TC 18	TC 27	TC 28	TC 19	TC 20	TC 21	TC 22	TC 23	TC 24	TC 25	TC 26		
169										1830	1480	870	301	97	2230	1830	160	147	134	115	94	75	65	62		
170										1830	1480	870	303	96	2230	1830	160	148	136	119	97	78	70	65		
171										1830	1480	880	304	97	2220	1830	163	151	138	121	99	80	72	68		
172										1830	1480	880	305	98	2220	1830	167	154	141	123	101	82	76	71		
173										1830	1480	880	305	97	2220	1830	166	154	140	124	103	84	78	73		
174										1840	1480	880	308	98	2220	1850	169	155	141	124	102	82	75	73		
175										1860	1490	880	310	99	2220	1850	170	156	140	124	103	83	77	72		
176										1860	1490	880	310	99	2220	1850	172	160	146	127	105	84	77	73		
177										1860	1490	880	312	99	2220	1850	177	161	144	126	104	81	73	72		
178										1860	1490	890	312	99	2270	1850	174	158	142	123	102	79	71	69		
179										1860	1490	890	314	99	2220	1850	178	160	144	124	102	78	68	67		
180										1850	1490	890	315	99	2210	1900	172	156	140	121	99	75	66	64		
181										1850	1490	890	316	99	2210	1900	166	151	136	117	96	71	61	62		
182										1840	1490	890	317	99	2220	1900	161	147	131	114	92	69	60	60		
183										1830	1490	890	317	100	2220	1900	163	148	132	114	91	68	57	58		
184										1920	1500	900	319	100	2220	1890	158	142	128	111	89	65	55	56		
185										1940	1500	890	320	100	2220	1880	160	144	128	110	87	64	54	55		
186										1950	1500	900	321	101	2220	1880	160	144	128	110	87	64	53	54		
187										1960	1500	900	323	102	2220	1870	160	144	128	110	86	62	52	53		
188										1990	1500	900	323	101	2220	1880	163	146	130	110	86	61	50	52		
189										2020	1500	900	325	101	2220	1900	154	140	124	107	83	62	52	52		
190										2020	1500	900	327	102	2220	1900	158	143	129	111	86	65	56	55		
191	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA	2010	1500	900	327	104	2220	1900	166	149	134	116	91	70	62	58		
192										2070	1510	900	328	104	2220	1910	162	149	135	118	93	74	67	62		
193										2050	1500	900	330	104	2210	1940	167	153	139	121	96	77	69	65		
194										2050	1510	910	331	104	2210	1940	170	156	141	124	99	80	74	69		
195										2050	1510	910	332	105	2210	1940	172	158	144	127	102	83	76	72		
196										2020	1510	910	333	104	2210	1940	172	160	145	128	103	85	78	74		
197										2020	1510	910	334	104	2210	1940	167	155	141	127	103	86	81	75		
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201										2000	1510	910	337	107	2210	1970	167	156	144	130	106	86	77	75		
202										2000	1510	910	339	107	2210	1970	177	162	148	131	107	84	72	72		
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206										2150	1520	920	342	108	2220	1990	164	152	138	124	97	78	69	68		
207										2130	1520	920	344	108	2210	1990	168	155	142	125	99	80	68	68		
208										2160	1520	920	344	108	2210	1990	172	160	144	127	100	78	66	66		
209										2150	1520	920	345	108	2210	1990	169	157	143	126	99	77	65	65		
210										2170	1520	920	346	109	2210	2000	165	153	139	123	96	75	64	64		
211										2080	1520	920	347	109	1990	1890	162	152	139	123	95	76	64	64

Figure 31. Excavation fill operation -
mixing Ottawa sand, bentonite,
and feldspar (C67-2790)

Figure 32. Capsule emplacement operation
(C67-2789)

Figure 33. Buried thermocouple installation and location at 25 inch-depth (C67-2785)

Figure 34. Soil surface thermocouple installation (C67-2786)

Figure 35. Power input vs time for Test No. 3

Figure 36. Temperature vs time for Test No. 3

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TC 13 and 19, 1 INCH FROM HEATER
 TC 14 and 20, 3 INCHES FROM HEATER
 TC 15 and 21, 6 INCHES FROM HEATER
 TC 16 and 22, 12 INCHES FROM HEATER
 TC 17 and 23, 24 INCHES FROM HEATER
 TC 18 and 24, 40 INCHES FROM HEATER
 TC 27, 1 INCH FROM HEATER
 TC 28, 3 INCHES FROM HEATER
 TC 25 and 26, TOP OF TEST SOIL OF REFERENCE HOLE

Figure 37.
 Soil thermocouple location

Figure 38.
 Capsule recovery
 operation (D67-9421)

Figure 39.
X-ray of recovered capsule
Test No. 3

Figure 40. Recovered capsule in affected soil mass

Figure 41a. Capsule with soil mass partially removed (C67-4540)

Figure 41b. Capsule with soil mass partially removed (C67-4541)

Figure 41c. Capsule with soil mass partially removed (C67-4544)

Figure 42. Capsule wall close-up showing scaling (C67-4542)

APPENDIX A

Certification and Instructions for Handling Burial Capsules

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Copy

January 12, 1967

Thermo Physics Corp.
639 Massachusetts Avenue
Cambridge, Mass. 02139

Subject: Your Request for Material Certification

Gentlemen:

The items shipped on your Order Number E354, our
Order No. F196, listed below are composed of the
McDaniel material AP 35

40 AR2T164116 18"

24 ARST332316 20"

6 ARPT716 5"

Thank you for the privilege of serving you.

Very truly yours,

MCDANEL REFRACTORY PORCELAIN COMPANY

s/s David Murray

for Melvin W. McDanel, Vice President
& Treasurer

Copy

January 30, 1967

Thermo-Physics Corp.
639 Massachusetts Ave.
Cambridge, Mass. 02139

Subject: Your Request for Material Certification

Gentlemen:

The items shipped on your Order Number E334, our
Order No. E12615, listed below are composed of
the McDanel material AP 35

5 AP 35 heater cores per dwg GEM-3-1

Thank you for the privilege of serving you.

Very truly yours,

MCDANEL REFRACTORY PORCELAIN COMPANY

s/s Melvin W. McDanel

Melvin W. McDanel, Vice President
& Treasurer

Copy

C E R T I F I C A T E O F C O M P L I A N C E

Date: February 16, 1967

Thermo-Physics Corporation
639 Massachusetts Ave.
Cambridge, Massachusetts

ATTENTION:

REFERENCE: #E-331

Gentlemen:

We hereby certify that the

288 ft - 0.030" dia Platinum 40% Rhodium Heater Wire,
annealed

shipped against the above order complies in all respects
with the specifications of said order.

Very truly yours,

ENGELHARD INDUSTRIES, INC.

s/s
BY: Joseph Condon
Joseph Condon

s/s Patricia Hughes
Witness

/pjh

Copy

CERTIFICATE

(90) (10)

C. P. Platinum vs Platinum - Rhodium Thermocouple
(Reference Grade Thermocouple .010" Diameter)

Customer: Thermo-Physics Corporation

P.O. No.: E331

Electromotive Force vs Temperature of Measuring
Junction (Reference Junction 0°C)

The standard thermocouple used for this calibration is
traceable to the National Bureau of Standards by Test
No.: 183699A-3.

Millivolts	Degrees C.	Millivolts	Degrees C.
3.252	400	9.575	1000
4.223	500	10.742	1100
5.227	600	11.931	1200
6.264	700	13.127	1300
7.333	800	14.318	1400
8.437	900		

The thermocouple was annealed electrically in air for one
hour at about 1450°C (2642°F) before testing.

The calibration of thermocouple may change during use.
The magnitude of the change depends upon the temperature,
the length of time, and the conditions under which it is
used. Thermocouples of the type covered by this certi-
ficate are reliable within about 1/4% up to 1300°C (2372°F)
if used in a clean oxidizing atmosphere and not used for
extended periods above 1300°C (2372°F).

Test No.: 0062 S.P.

S.O. No.: 116790

C.P. Pt (175100-2)

Pt 10% Rh (57560)

s/s R. Wroblewski
R. Wroblewski
PYROMETRY LABORATORY
1/3/66

Copy

March 13, 1967

GENERAL ELECTRIC COMPANY
Missile and Space Division
Valley Forge Space Technology Center
P. O. Box 8555
Philadelphia, Pennsylvania

Received
Mar 14, 1967
J. T. Smith

Attn: J. T. Smith, Administrator
Room 2450M-VFSTC

Ref: Subcontract 214-VH0202

Subject: Handling of Burial Capsules

Gentlemen:

In handling the Burial Capsule delivered as part of the referenced contract, we would like to indicate several important points. It is recommended that these instructions be read before handling the capsule and the procedures described as follows:

1. The capsule is shipped in a wooden crate. The crate should be handled and stored with the end up as indicated. It should be handled carefully and shocks from dropping or rough handling should be avoided. Ceramic parts are used in the construction of this capsule and these parts are shock sensitive.
2. The cover of the crate may be removed by removing all of the screws in the cover.
3. After removal of the cover, the tissue paper may be removed which is packed around the capsule power and thermocouple leads. Care should be taken not to bend the leads.
4. Observe the six thermocouples which lie along the capsule wall. These are extremely fragile and held in place only by the spot welded junction.
5. Remove the four screws in the side of the crate which secure the two wooden pieces clamping the capsule in place. These pieces are now removed.
6. The capsule may be gently removed from the crate. Two people should handle it, one to lift the capsule and one to handle the leads. It is very important that the section of leads taped is not bent. This contains ceramic thermocouple insulators which if broken might break the fine platinum thermocouple wires.
7. In laying the capsule flat it is suggested that same support be placed under the taped section of leads. This will avoid strain and possible breakage of the ceramic insulators mentioned in (6) above.

Copy

Thermo-Physics Corporation

Page 2

8. To straighten the leads which have been folded for shipment, grasp the lead bundle at the end of the tape section and bend each lead gently until it is straight.
9. For shipment the capsule should be repackaged following the reverse of the above instructions.
10. In placing the capsule in the ground for test, place soil around the capsule gently to avoid damaging the thermocouples and leads. Note the leads from the side thermocouples which extend through the capsule cover and bend to join the other leads. This bend section is fragile and could be broken throwing soil in on top of the capsule.
11. In operation the two power leads, covered with asbestos, are connected to the electrical power supply. The thermocouple extension wires are for the platinum-platinum 10% rhodium thermocouples. The red lead is negative and joined to the platinum. The black lead is positive and connects to the alloy.
12. In applying power to the capsule, it is suggested that power be increased at a rate not in excess of 200 watts per hour or that the capsule temperature be increased at a rate not in excess of 100°F/hour. In cooling the capsule the reverse of this is true. The capsule contains ceramics subject to thermal shock and materials of different coefficients of expansion. A slow heating and cooling rate is advised.

The above instructions cover the handling and testing of the capsule. The high temperature materials required for this capsule are fragile. The capsule must be handled with care especially in regard to the thermocouples and leads.

Should you have any questions concerning these instructions or any other question concerning the capsule, do not hesitate to contact us.

Very truly yours,
THERMO-PHYSICS CORPORATION
s/s James K. Sparrell

James K. Sparrell
President

JKS:lm

Figure A-1. Burial capsule

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