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Thermal Test of Pershing II W86 Earth Penetrator (U)

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Wayne D. Sundberg

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Thermal Test of Pershing II W86 Earth Penetrator (U)

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Abstract ~~(C)(U)~~

Stockpile-to-Target Sequence thermal testing was conducted on a thermocouple-instrumented Pershing II W86 Earth Penetrator. The test penetrator (TA6-29) contained heat sources to simulate the internal heating which would occur in stockpile with a War Reserve penetrat–

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Summary

Thermal test (R782420) was performed on Pershing II W86 earth penetrator (EP) unit TA6-29 from April 21, 1981, through May 18, 1981. The EP is nominally 6 to 7 inches in diameter by 64 inches long, and is packaged inside an aluminum canister.

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Forty-two chromel-alumel (type K) thermocouples were used to instrument the unit. Thermal test conditions were based on the Pershing II W86 Stockpile-to-Target Sequence (STS) thermal environments.[1]

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Test Objectives

The purpose of the thermal test was twofold. One objective was to obtain data to help provide an understanding of the steady-state heat transfer and the transient response of the EP to varying thermal environments. The other objective was to provide temperatures for specific internal components during specific worst-case environments as defined in the STS thermal environments. The environments for the second objective are also the desired environments for the first objective. Some specific subobjectives of the first objective were to look for anomalies and unexpected results, to check the validity of some specific assumptions used in numerical thermal modeling, and to provide a data base to compare numerical thermal model results to experimental data.

Thermal Test of Pershing II W86 Earth Penetrator

Hardware and Test Configuration Descriptions

General Description

The TA6-29 test unit was built to duplicate as nearly as possible a War Reserve (WR) unit using hardware which was available for assembly at the time of the test. The test unit configuration is shown in Figure 1. Moving from the outside inward, the various pieces were the aluminum canister, the nominally 0.5 inch of 15 lb/ft^3 rigid foam, and then the steel EP case. Inside the EP case were the kennertium ballast forward, the component support structure (CSS) center, and the nuclear section mockup aft. The maraging steel CSS supports the various internal components included in the unit.

An interface unit was included as part of the test assembly. The assembly is shown in Figures 2, 3, and 4.

Internal Components

The internal components used in test unit TA6-29 were as close to WR component configuration as were available at that time for use in the test unit.

Interface Unit

The interface unit was a nonfunctional mass mockup designed to have the same thermal properties as a WR unit. The effect of the presence of the interface unit on the local temperatures on the canister was as important as internal temperatures in the interface unit itself.

Deviations from War Reserve Configuration

There were some differences between the TA6-29 test unit and a WR unit. A major difference is that the EP case on TA6-29 was of mild steel rather than of the 9-4-20 steel used for a WR unit. The mild steel has a higher conductivity, and therefore temperatures would be lowered slightly near heat-producing components and raised slightly elsewhere. These perturbations should be small compared to the temperature difference across the rigid foam.

In two places, flexible foam was substituted where desiccant would have been used in a WR unit. One place was between the front end of the nuclear section and the back of the last component on the CSS. The other place was between the EP case and the aluminum canister (radially out from the nuclear section) where flexible foam was substituted for an air gap and desiccant ring. In both instances, a low conductivity

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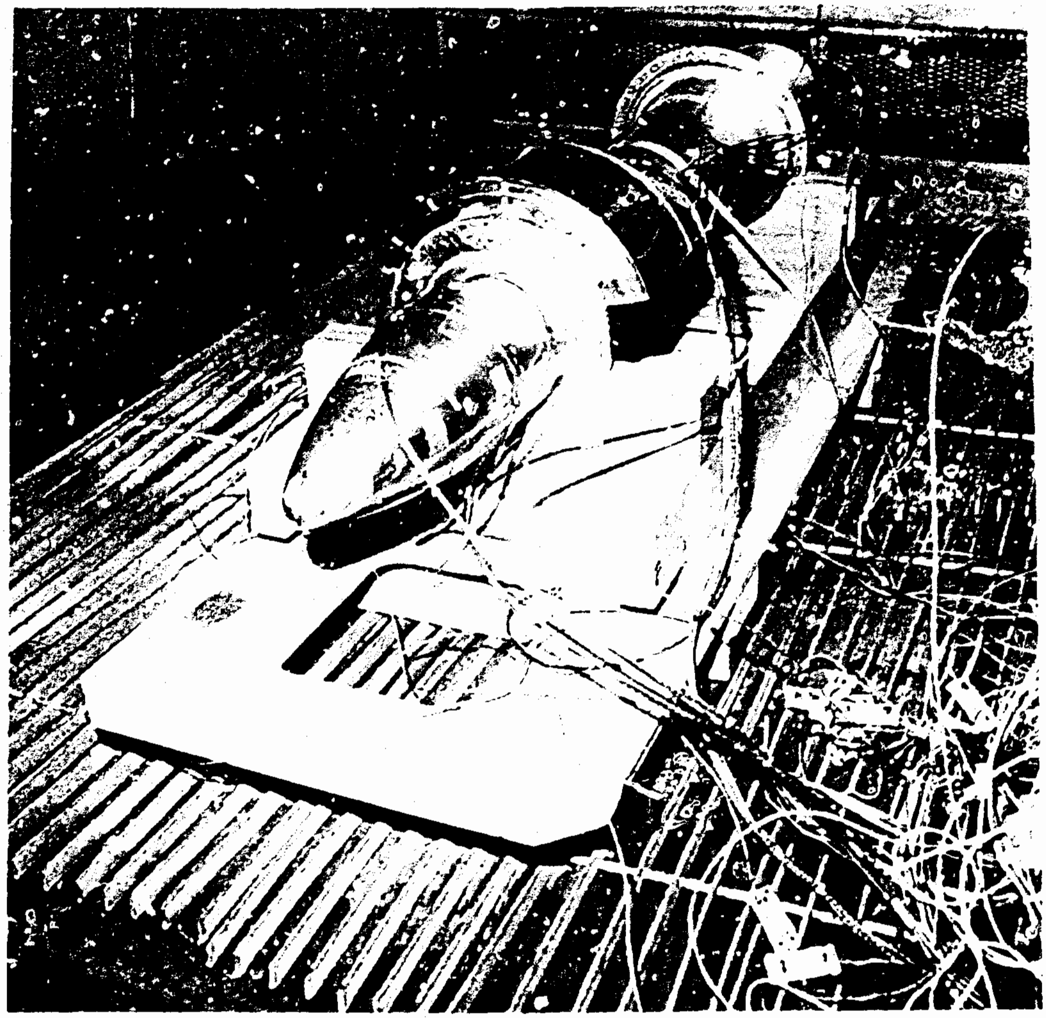

Figure 2. Front Left (South) Side View of TA6-29 Test Unit in Environmental Chamber EC-17

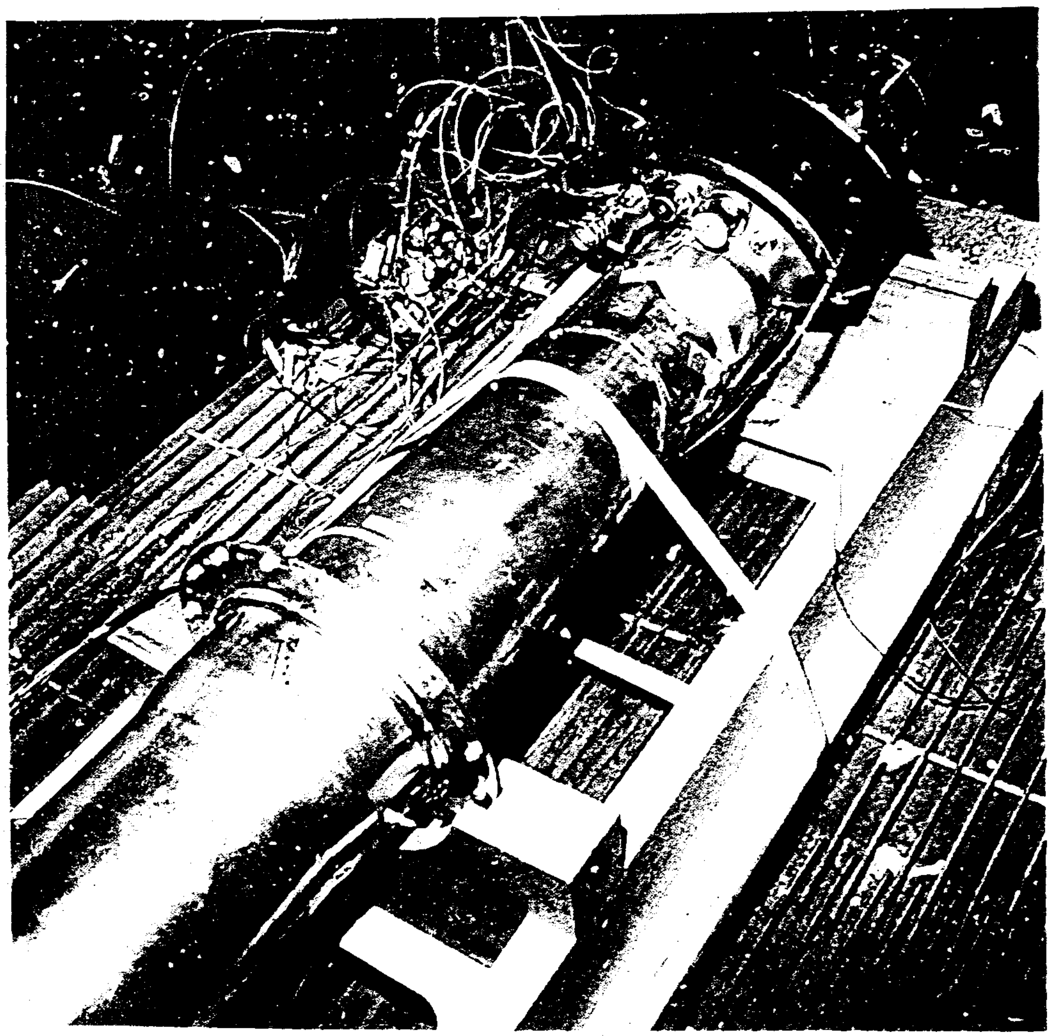

Figure 3. Top-Rear-Right Side View of TA6-29 Test Unit in Chamber EC-17

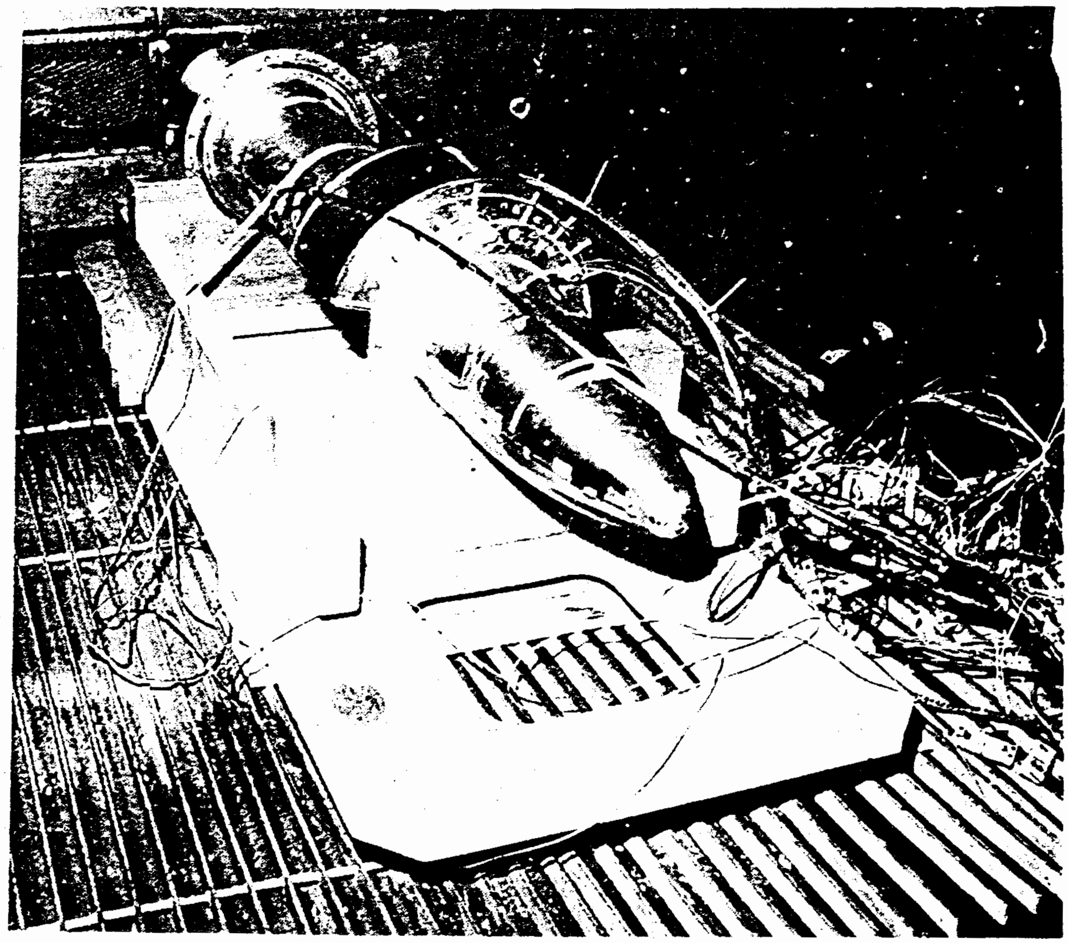

Figure 4. Front-Right (North) Side View of TA6-29 Test Unit in Chamber EC-17

material was substituted for another low conductivity material; this should cause little deviation in temperature values.

Other differences between the test unit and a WR unit were primarily due to the instrumentation (thermocouples) and the three access ports, through the EP case and foam, for the thermocouple leads.

Test Instrumentation

Rationale for Location of Thermocouples

The rationale for selecting the locations of the thermocouples more specifically defines the test objectives, and thus the rationale for the thermocouple locations is given in terms of meeting a specific objective.

One of the primary objectives was to measure the temperatures of internal components when the unit is subjected to the STS thermal environments to determine if the temperatures of the components are within the design range for the component or to define a temperature range for operation of that component.

Another primary objective was to understand the heat dissipation paths within the test unit. First, how well does the case distribute the thermal energy? To determine this required locating six thermocouples on the steel case from the nose of the test vehicle to the base. Secondly, are there significant axial variations in temperature on the outside surface of the aluminum canister due to distinct internal sources, or does the combination of internal conduction (in the steel case), conduction in the aluminum canister, and high surface heat transfer coefficient give a uniform temperature? To measure the aluminum canister surface temperature, thermocouples were placed at six axial stations from the nose to the base of the test unit. These thermocouples were located at the same axial positions as the thermocouples on the steel case to provide data to determine the temperature difference across the rigid foam, which was a major subobjective since the major thermal resistance was anticipated to be across the foam. To provide insight on thermal resistance between the CSS and the case, thermocouples were placed at forward, center, and aft positions on the CSS at the same axial stations as thermocouples on the case.

Another objective was to determine if there was significant circumferential variations of temperature, or if an axisymmetric assumption for modeling was sufficient. The primary instrumentation used to check for this was three thermocouples mounted on the top, side, and bottom of the aluminum canister and the axial midstation. To check the validity of an assumption of axial symmetry, a thermocouple was placed on the aluminum canister where it was "shadowed" by the interface unit; readings could be compared to another thermocouple on the canister at the same axial station which was not shadowed by the interface unit. The purpose was to determine if the interface unit provided any thermal protection to the canister.

One more subobjective was to determine if there was a significant temperature difference between the inner and outer layers of the aluminum canister in the region behind the point where the forward and center sections of the aluminum canister mate. Thermocouples were mounted on the inner and outer layers of the canister to measure the temperature of each.

Although the thermal-mockup interface unit, which was used in the test, already had thermocouple instrumentation installed in it, the rationale for the choice of the thermocouple locations was as follows. The primary objective was to determine the temperatures of electronic components in the interface unit. Therefore, four thermocouples were suspended in foam near various electronic components. One was suspended between the Trajectory Sensing Signal Generator (TSSG) printed circuit (PC) boards. Another thermocouple was attached to the heatsink for the Permissive Action Link (PAL) voltage regulator. As points of reference, thermocouples were attached to inside surfaces of the case on the inner and outer radii. These points of reference would provide boundary conditions for observing and understanding the internal time lag of thermal transients.

The nuclear section mockup was provided by Los Alamos National Laboratory and was instrumented with nine thermocouples. The particular positions of interest for specific temperature values were the same positions that are required for understanding the thermal energy dissipation. The maximum temperatures would occur in the (steel) pit, and thermocouples were located so as to determine the minimum and maximum temperatures within the pit. The maximum temperatures which would be seen by the mock HE are at the pit/HE interface, and thermocouples were provided to measure the minimum and maximum temperatures of this interface. A thermocouple also was located at the point in the region of highest heat flux from the pit heater. This point was also anticipated to have the highest temperature on the exterior of the nuclear section mockup. To determine other temperature boundaries which would be imposed by the heat generation in the nuclear section, thermocouples were placed externally on both ends of the nuclear section mockup.

All thermocouples were type K (Chromel-Alumel) thermocouples.

Location of Thermocouples

The sketch in Figure 1 shows radial and axial positions for most of the thermocouples. (Thermocouple positions within the interface unit are not necessarily in the correct radial position.) Table 1 indicates which thermocouples are on particular components and serves as a brief summary of Table 2. Table 2 gives the position of all the thermocouples and the component to which each thermocouple is attached. Appendix A details the location of the thermocouples.

In addition to the thermocouples mounted on the test unit, two thermocouples were mounted approximately nine inches to either side of the test unit and one thermocouple was mounted below the test unit to measure the surrounding air temperature. The thermocouple below the unit was positioned in the center of the cutout in the wooden stand which supported the unit during the test.

Table 1. Thermocouple Location by Components

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Component	Thermocouples
[redacted]	
Component Support Structure	TC11, TC22, TC27
Components Attached to CCS:	
[redacted]	
Earth Penetrator Case	TC8, TC10, TC21, TC28, TC30
Aft Cover	TC32
Aluminum Canister	TC9, TC13, TC14, TC15, TC18, TC19, TC20, TC29, TC31, TC33
Interface Unit	TC1A, TC2A, TC3A, TC4A, TC5A, TC6A, TC7A

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Test Description

Test Conditions

The test conditions included three environments (steady state, thermal shock, and diurnal cycling), and testing was done at/between three temperatures (cold, moderate, and hot). The testing under steady-state conditions was done primarily to understand the thermal energy dissipation and to identify the thermal resistance in the test unit without the complication of the presence of thermal transients. These data provide a necessary part of a data base for comparison with numerical, thermal modeling of the unit. In addition, the steady-state tests were run at the three different temperatures to determine if there were any detectable changes in energy dissipation paths at the different temperatures. Furthermore, steady-state testing at the three temperatures provides a data base for interpolation to other temperature conditions (in the absence of anomalies).

The thermal shock testing was done to verify our understanding of energy dissipation during transients, to look for anomalies during the transients, and to match a thermal shock requirement given in the STS thermal environment. The thermal-shock testing provides an ideal boundary condition for comparing numerical thermal transient modeling to actual experimental data. By contrast, using diurnal cycling as a boundary condition for comparison to thermal transient modeling would tend to mask the temperature decay because of the changing boundary condition. The moderate to late time data from thermal-shock testing also provides data for determining the time required to achieve a steady-state condition.

The third type of testing was diurnal cycling. This was done at the hot and cold temperature conditions to match the STS thermal environments for storage on a hot day and a cold day. Daily temperature cycling

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Table 2. Location of Thermocouples on TA6-29

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was also done at a moderate temperature to obtain data for more common conditions, rather than having to interpolate between the extremes. Also, the moderate temperature data provide a comparison point for determining if anomalies are occurring at either of the extremes.

Test Facilities

The thermal test was performed in Environmental Chamber EC-17 in Building 860 at Sandia National Laboratories. The desired temperature is attained in the chamber by the circulation of either heated or cooled air. Temperature setting was accomplished by a mechanical cam arrangement which was not rotating for steady chamber temperatures and rotated one revolution per day for diurnal cycling. The thermal response time of the chamber was not small enough to do thermal shocks directly; procedures to do the thermal shocks are discussed in the next sub- [redacted] DOE b(3)

power. The thermocouples were attached to a Kaye Instruments RAMP-128-SS remote analog multiplexing processor. A Hewlett-Packard Model HP-1000M series computer controlled data gathering, recorded the data, and provided data display during the test.

Test Procedures and Sequences

The thermal test lasted 28 days. The test began on April 21, 1981, at 1038 hrs and ended on May 18, 1981 at 0900 hrs. The thermal environment for the total test sequence is given in Figure 5. As shown in Figure 5, the sequence of events was as follows:

1. The heater was turned on and the unit was given three days to achieve a steady-state condition at the moderate temperature (25°C).
2. A thermal shock from moderate (+25°C) to cold (−30°C) was done, and the unit was given four days to achieve a steady-state at the cold temperature.
3. The STS cold daily cycle was done for two days, with the first day given to transition to the cyclic condition and the second day given to repeating the cyclic condition.
4. A steady cold condition (−31°C) was repeated for one day after the cycles to allow the unit to return to its steady-state.
5. A thermal shock from cold (−31°C) to moderate (+25°C) was done, and the unit was given four days to achieve a steady-state at the moderate temperature.
6. A moderate condition daily cycle was done for two days, with the first day given to transition to the cyclic condition and the second day given to repeating the cyclic condition.
7. A steady moderate condition (+22°C) was repeated for one day after the cycles to allow the unit to return to steady state. (The desired temperature setting was missed by a few degrees.)
8. A thermal shock from moderate (22°C) to hot (46°C) was done, and the unit was given four days to achieve a steady state at the hot temperature.
9. The STS hot daily cycle was done for two days, with the first day given to transition to the cyclic condition and the second day given to repeating the cyclic condition.
10. A steady hot condition (45°C) was repeated for one day after the cycles to allow the unit to return to steady state.
11. A thermal shock from hot (45°C) to moderate (25°C) was done and the unit was given three days to achieve a steady state at the moderate temperature.

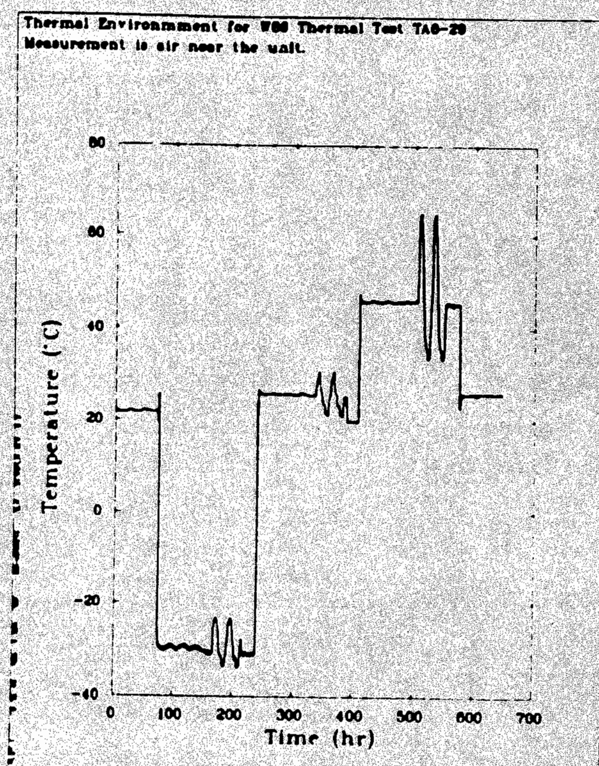

Figure 5. Complete Thermal Environment for W86 Thermal Test Unit TA6-29

To attain the thermal shock conditions on the unit, the unit was moved from the chamber to the laboratory (which was at a different temperature), or vice versa. For the moderate to cold thermal shock, the unit was first moved from the chamber (which was essentially at lab temperature) into the laboratory. The chamber was cooled to the desired temperature. The thermal shock occurred when the unit was moved from the moderate temperature lab into the cold chamber. Similarly, for the cold to moderate thermal shock, the thermal shock occured when the unit was moved from the cold chamber into the moderate temperature laboratory. The chamber was then brought to the moderate (controlled) temperature and the unit was placed in the chamber. The moderate-to-hot and hot-to-moderate thermal shocks were done in a similar manner. Figure 6 shows the unit outside the chamber while waiting for the chamber to establish a new temperature condition.

Test Results

Test Chamber Environments

As previously mentioned, the actual test chamber temperature history for the entire 28-day test is shown in Figure 5. More detailed plots of the daily cycle temperature histories are given in Figures 7, 8, and 9, for cold, moderate, and hot cycles, respectively. All cycles were begun between 0900 and 1000 hours. Shown in Figures 7, 8, and 9 are the temperature histories beginning at 0900 hours of the second day and also the desired (specified) temperature profiles. Table 3 tabulates the data shown in Figures 7, 8, and 9. The actual and desired (specified) temperatures for the thermal shock and transient portions of the test are given in Table 4.

The mechanical cam adjustment to control temperature in EC-17 did not provide accurate control of the temperature, but it was close enough to provide a good test. The one obviously missed setting was after the moderate daily cycles (Figure 5). An "after the fact" improved procedure to eliminate such discontinuities would be to set the constant chamber temperature by using the cycle cam positioned at the start/stop time of the cycle (and therefore at that temperature) but with the cam not rotating. Then cycles could be initiated by engaging the cam to turn at the proper time and similarly disengaging the cam to discontinue cycling. The cams were cut by hand and the sensitivity of the cams is approximately 0.017-in./°C, which makes accurate control very difficult.

Component Temperature Extremes

The components within a War Reserve (WR) unit must be designed to function under a range of temperatures. In this subsection, the extreme values of temperature of each component are presented. Table 5 gives the temperature extremes for the canister, foam, and the Earth-Penetrator case. The temperature values for the foam are inferred from thermocouples located adjacent to the foam. [redacted]

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components do not have thermocouples directly attached to them, but thermocouples are located on a surface adjacent to the component. Table 7 gives the temperature extremes in the nuclear assembly. Within the Interface Unit, the minimum temperature is essentially the same for all components, and the range in values for the minimum temperature is −33.566°C to −32.707°C, at a time of 210.3611 hours after the start of the test. Likewise, the maximum temperature in the Interface Unit was 63.864°C to 64.657°C, at a time of 509.3611 hours after the start of the test. Since there were no heat producing components in the unit, there is no reason to expect temperature differences within the unit in a slowly varying environment.

Spatial Temperature Distributions in Test Unit

Spatial temperature distributions are given for both steady-state environments and the diurnal cycles. The steady-state results are given in Figures 10, 11, and 12 for the moderate, cold, and hot environments, respectively. The temperatures are plotted versus axial position, and the difference in temperature between inside and outside locations allows the temperatures for all thermocouples to be displayed on one plot (except for the thermocouples in the interface unit). In Figure 10, the thermocouple identification for each temperature-position point is labeled. (Figure 10 should be used as a guide to correlate thermocouple identification and temperature-position points for subsequent plots since the shapes of the curves for other conditions are similar.) The particular times for the steady state plots in Figures 10, 11, and 12 are four days after a thermal shock and immediately before a daily cycle.

The daily cycle temperature results are given in Figures 13, 14, and 15 for cold, moderate, and hot cycles, respectively. Temperature values are shown

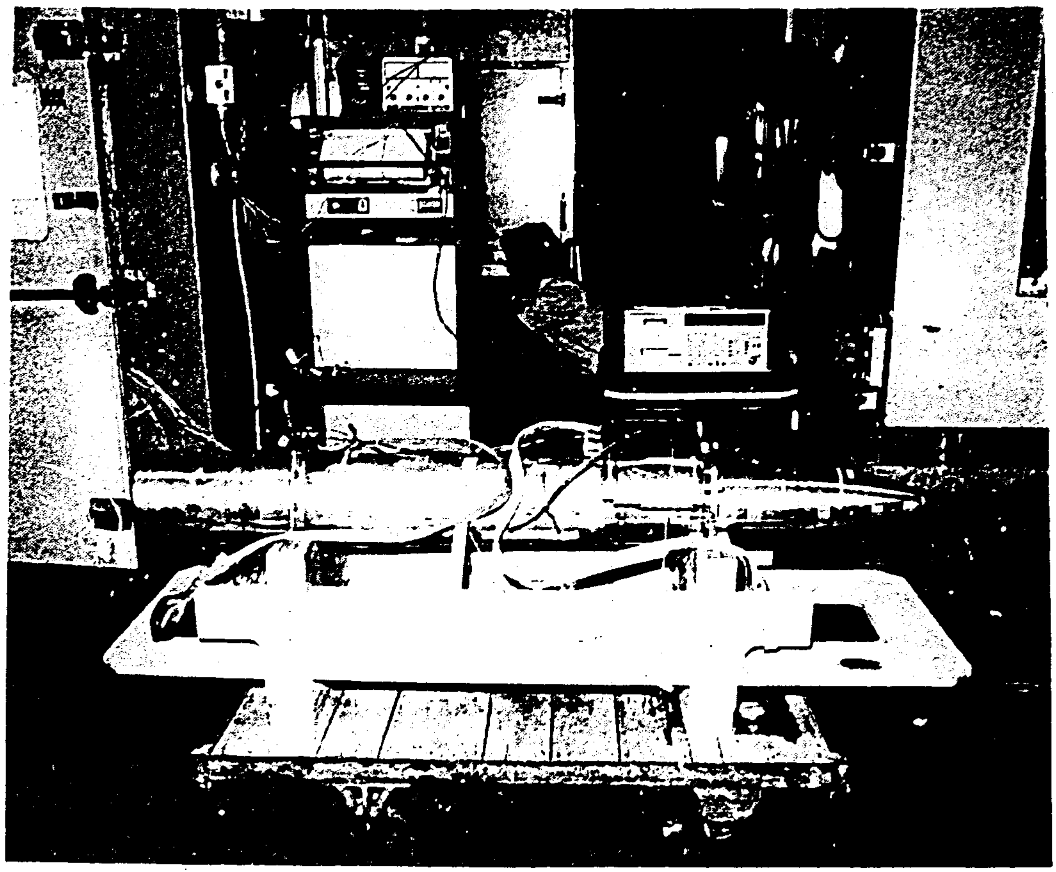

Figure 6. TA6-29 Test Unit Outside of Chamber During Thermal Shock

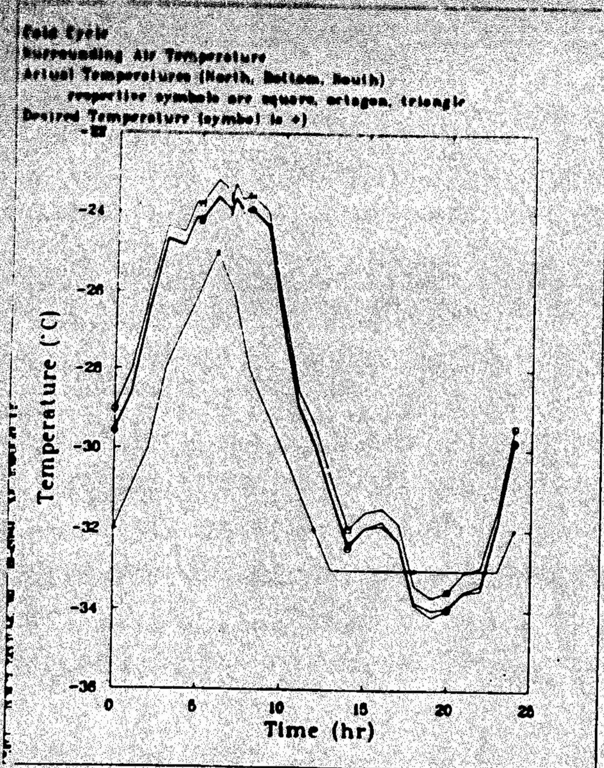

Figure 7. Cold Cycle Thermal Environment

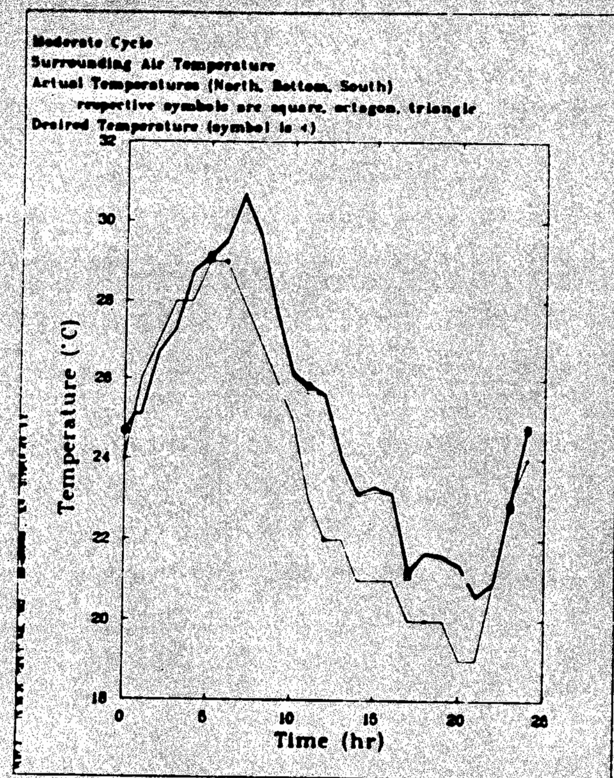

Figure 8. Moderate Cycle Thermal Environment

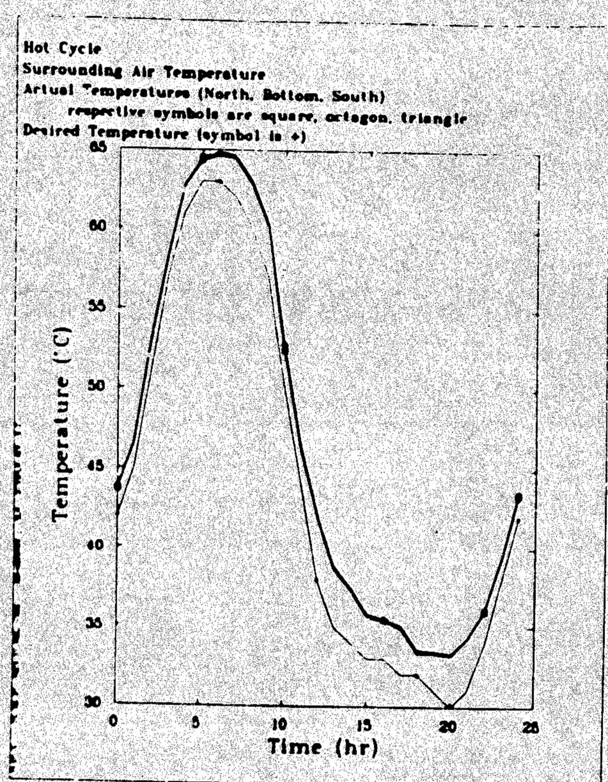

Figure 9. Hot Cycle Thermal Environment

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Table 3. Daily Temperature Variation for Cold, Moderate, and Hot Cycles

Time (hr)	Cold Desired (°C)	Cold Actual* (°C)	Moderate Desired (°C)	Moderate Actual* (°C)	Hot Desired (°C)	Hot Actual* (°C)
0100	−33	−31.7	21	23.2	33	35.5
0200	−33	−32.1	20	21.5	32	35.0
0300	−33	−33.7	20	21.7	32	33.5
0400	−33	−33.9	20	21.6	31	33.4
0500	−33	−33.8	19	21.4	30	33.3
0600	−33	−33.4	19	20.6	31	34.3
0700	−33	−33.3	21	21.0	34	36.0
0800	−33	−31.7	23	22.9	38	39.4
0900	−32	−29.5	24	24.7	42	43.6
1000	−31	−28.4	26	25.1	45	46.6
1100	−30	−26.3	27	26.7	51	53.1
1200	−28	−24.6	28	27.3	57	58.3
1300	−27	−24.7	28	28.8	61	62.8
1400	−26	−24.1	29	29.1	63	64.4
1500	−25	−23.5	29	29.5	63	64.8
1600	−26	−23.5	28	30.6	62	64.6
1700	−28	−23.8	27	29.6	60	62.9
1800	−29	−24.2	26	27.8	57	60.2
1900	−30	−26.7	25	26.1	50	52.7
2000	−31	−28.8	23	25.8	44	46.4
2100	−32	−29.7	22	25.6	38	42.1
2200	−33	−31.1	22	24.0	35	38.8
2300	−33	−32.3	21	23.1	34	37.4
2400	−33	−31.8	21	23.3	33	35.7
24 hr avg	−31	−29.0	24	25.0	44	46.4

*Average of 3 thermocouple readings

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Table 4. Chamber Temperature for Thermal Shock and Steady-State

Period	Temperature (°C) Actual	Desired
Initially achieve steady state at moderate temperature	25	24
Cold temperature for thermal shock and follow on steady state	−30 to −31	−31
Reestablish steady-state cold temperatures after cycles	−31	−31
Moderate temperature for thermal shock and follow on steady state	25	24
Reestablish steady state at moderate temperature after cycles	22	24
Hot temperature for thermal shock and follow on steady state	46	44
Reestablish steady state at hot temperature after cycles	45	44
Moderate temperature for thermal shock and follow on steady state	25	24

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Table 5. Temperature Extremes for Canister, Foam, and EP Case

Item	Temperature (°C) (min/max)	TC#	Time From Start of Test (hr)	Location
Aluminum canister (~outside of Foam)	−32.386 (min)	TC9	210.3611	Forward tip of nose
	64.369 (max)	TC33	509.3611	Aft surface
EP case (~inside of foam)	−24.090 (min)	TC8	213.3611	Forward tip of nose
	65.736 (max)	TC32	512.3611	Aft surface (inside)

Table 6. Temperature Extremes for Components Mounted on the Component Support Structure

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Table 7. Temperature Extremes at Locations on Nuclear Assembly

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every three hours during the cycle, beginning at 0900 hr on the second day of the cycle. The chamber temperatures during the cycles are plotted in Figures 7, 8, and 9 for the cold, moderate, and hot cycles, respectively. Maximum internal temperatures occur during the hot cycle.

mum temperature was 0800 to 0900 hr, which lags the minimum of the surrounding air temperature (−34°C at 0400 hr) by 4 to 5 hours. An additional form of the data, temperature versus time, for all components during the diurnal cycles is given in Appendix B.

Thermal Shock Transients for Selected Components

Temperature histories for the thermal shock conditions for selected thermocouples are given in Figures 16, 17, 18, and 19 for moderate-to-cold, cold-to-moderate, moderate-to-hot, and hot-to moderate thermal shocks, respectively.

The plots for each thermal shock condition are plotted on two time scales, 0 to 100 hr, which shows the relative response of the inner components, and 0 to 4 hr, which shows the response of the outer components. Because of the insulating affect of the foam and the large thermal mass (mass x specific heat) of the EP case, the internal components respond very slowly.

Time history plots for every thermocouple are given in Appendix B. Also given in Appendix B are temperature vs axial position plots for various times during the thermal shock transients. Time history plots of temperatures in the interface unit are given in Appendix B. The locations of the thermocouples in the interface unit are given in Appendix A.

Discussion of Test Data

Generally, the thermal test went well and most of the data appear to be good. This section, will discuss some of the anomalies and reasons for suspecting that thermocouples TC28 and TC30 gave erroneous readings. These thermocouples are located on the EP case.

First, consider the expected temperatures on the penetrator case as recorded by thermocouples TC8, TC10, TC21, TC28, TC30, and TC32. It would be expected that the temperature would rise near axial stations 20 in. and 50 to 60 in. due to internal heat-producing components. Considering that thermocouple TC32 was located on the inside of the aft case, and that the foam is thicker on the aft end, it seemed reasonable to expect TC32 to read higher; in fact TC32 more closely matched TC25 (which was on the other side of the nuclear section and mounted similarly with respect to the nuclear section) than other thermocouples on the penetrator case. The temperature of TC28 seemed to be depressed from what would be expected, especially for the cold steady-state (Figure 11) and the cold cycle (Figure 13). The temperature for TC30 seemed to be depressed from what would be expected, especially during moderate and hot steady-state (Figures 10 and 12) and moderate cycle (Figure 14). During the hot cycle (Figure 15), TC30 followed the aluminum canister temperature more closely than the other EP case thermocouples. TC30 was suspect during the test, and upon disassembly, it was discovered that a small amount of green flexible foam was between TC30 and the EP case. Time history plots in Appendix B show that TC28 and TC30 have different characteristics than the other thermocouples on the EP case.

The thermal shock testing involved moving the unit into or out of the environmental chamber, from or to the laboratory. In those cases where the thermal shock occurred by going out of the chamber into the laboratory, a definite change in the aluminum canister temperature was noted when the unit was placed back in the "room temperature" chamber. This is explained by the difference between natural convection from the canister while in the laboratory and forced convection when in the chamber. (Chamber temperature is controlled by circulating either heated or cooled air.)

Another anomaly is that in the high temperature environment, TC7, located in the nuclear section and radially outward from TC2 and TC2P, increased in temperature above the temperature of TC2 and TC2P.

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Three areas of interest in the instrumentation of the aluminum canister were

- Is there any angular position effect on the temperature on the aluminum canister (TC18, TC19, and TC20)?
- Is there a large temperature difference between the inner and outer parts of the cannister where they overlap (TC14 and TC15)?
- Does the interface unit thermally protect the area under it (TC13)?

The results of the test indicated that the answer is no to all three of these questions.

Conclusions

The conclusions from the test are

- The test was successful and a useful data base has been obtained to determine internal temperatures and for verification of numerical thermal models.
- There were no unexpected thermal phenomena occurring in the unit.
- Thermal transients internal to the unit are very small.
- Only two (TC28 and TC30) of the 42 thermocouples in the unit appeared to give questionable results.

References

[1]*Stockpile-to-Target Sequence (STS) for the W85 (AB/SB) Warhead, the W86 (EP) Warhead and the AB/SB Adaption Kit for Pershing II* (U) (Draft #6), SRD, RS4342/79/40, October 1979.

[2]CRD Memo, W. D. Sundberg, 5511, to W. J. Patterson, 4342, Subject: Thermal Analysis of Pershing II Earth Penetrator (W86) (U), August 25, 1980.

APPENDIX A

Thermocouple Locations

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APPENDIX B

Temperature Plots

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