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CHEMISTRY AND CHEMICAL ENGINEERING DIVISION
DEPARTMENT OF FIRE TECHNOLOGY
WWW.FIRE.SWRI.ORG
FAX (210) 522-3377

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COMPARATIVE ABUSE TESTING OF 36V AND 12V BATTERY DESIGNS IN GENERAL ACCORDANCE WITH SAE J2464

FINAL REPORT
Consisting of 45 Pages
SwRI® Project No. 01.06939.01.002
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Prepared for:

Motor Vehicle Fire Research Institute
1334 Pendleton Court
Charlottesville, VA 22901

Prepared by:

Nathan Weyandt

JH

Nathan Weyandt
Research Engineer
Engineering and Research Section

Approved by:

Janssens

Marc L. Janssens, Ph.D.
Director
Department of Fire Technology

ABSTRACT

Southwest Research Institute's (SwRI) Department of Fire Technology, located in San Antonio, Texas, performed comparative abuse testing of 36V and 12V battery designs on January 18 - April 5, 2005. Tests were performed in general accordance with the SAE J2464 standard, *Electrical Vehicle Battery Abuse Testing*, March 1999. Modifications were made to apply the test methods to typical-sized automotive batteries.

Four methods were chosen from the standard for this evaluation: Penetration Test, Crush Test, Radiant Heat Test, and Short Circuit Test. All tests included duplicate tests of new 36V batteries with a baseline test on a new 12V battery.

The penetration test involved the penetration of the batteries with a ⅛-in. conductive rod. High-speed video was taken, and the temperature of the battery was monitored with five combination thermocouple / heat flux transducers. The crush test involved the crushing of batteries in each of its three axes. IR video was taken, and the voltage of each battery was monitored throughout the tests. The radiant heat test involved the exposure of the batteries to the radiant heat of a heptane pool fire. IR video was taken, battery voltage was monitored, and the surface temperature of the batteries was monitored throughout the test. The short circuit tests involved the direct shorting of each battery. IR video was taken, and the temperature of the batteries were monitored with six combination thermocouple / heat flux transducers.

Both the 12V and 36V batteries showed minimal reactions to the tests. Slight heating occurred during the penetration, crush, and short circuit tests. Exterior temperature of the batteries remained below 200°F (93°C). The plastic exterior of both the 12V and 36V batteries ignited in less than 1 min during the radiant heat test.

There was no significant difference between the 12V and 36V batteries with respect to the abuse tests performed.

INTRODUCTION

The objective of this program was to investigate the possibility of a 36V battery (for a 42V charging system) igniting itself or providing otherwise hazardous conditions in an accident scenario. The objective was achieved by comparing the results of a 36V battery design to results of a similar 12V battery design when exposed to a series of abuse tests.

The results presented in this report apply only to the materials tested, in the manner tested, and not to any similar materials or material combinations.

TEST PROCEDURES

The four test methods for this project were chosen from the series of test methods outlined in the SAE J2464 standard, *Electrical Vehicle Battery Abuse Testing*, March 1999.

Penetration Test

The penetration test was performed in general accordance with the penetration test outlined in Section 4.2.3 of the test standard. One fully-charged 12V battery, and two fully charged 36V batteries were used for testing. Each battery was instrumented with five combination thermocouple / heat flux transducers. Each battery was penetrated with a 6-in. (15-cm) long, $^1/_8$-in. (3-mm) diameter mild steel rod in a direction perpendicular to its interior plates. The rod was propelled with a pressurized air gun at a velocity of approximately 1100 ft/s. The velocity was such that the rod would lodge itself within the battery in less than 0.005 sec. Documentation during the test included high-speed video at 1000 frames per second. Potential and resistance of the battery were measured before and after each test. The batteries were monitored for a minimum of one hour after each test.

Crush Test

The crush test was performed in general accordance with the crush test outlined in Section 4.2.6 of the test standard. Three fully-charged 12V batteries, and six fully charged 36V batteries were used for testing. Each battery was placed within a 25-ton H-frame press for testing. The press consisted of a 50,000 psig hydraulic jack utilizing a 2-in. diameter piston. A 6 × 6-in. crush plate was placed on the end of the ram. The hydraulic system was instrumented with a 10,000 psig pressure gauge, and the battery was instrumented to measure its voltage throughout the test. Each of the three 12V batteries was crushed on a different axis, and two 36V batteries were crushed on each of its three axes. Documentation included IR and standard video throughout the test period.

Radiant Heat Test

The radiant heat test was performed in general accordance with the radiant heat test outlined in Section 4.3.1 of the test standard. One fully-charged 12V battery, and two fully charged 36V batteries were used for testing. The standard specifies exposure to a *radiant heat source expected from a nominal 1630°F fuel source*. Each battery was placed on a brick surrounded by a heptane pool on three of its sides to provide an actual hydrocarbon fuel fire in the range of 1630°F. A thin screen shield was placed around the battery, approximately 2 in. away, in order to prevent direct flame impingement. The 12V battery and one of the 36V batteries were instrumented with five combination thermocouple / heat flux transducers. The final 36V battery was instrumented with only a single combination thermocouple / heat flux transducer. Each battery was instrumented for voltage measurement. For each test, the heptane pool was ignited, and the battery was observed for ignition or any other significant events. Documentation included IR and standard video throughout the test period.

Short Circuit Test

The short circuit test was performed in general accordance with the short circuit test outlined in Section 4.4.1 of the test standard. One fully-charged 12V battery, and two fully charged 36V batteries were used for testing. For each test, a hard short was applied across the positive and negative terminals, and the battery was observed for ignition or any other significant events. The hard short consisted of an 8-in. long steel plate with a current carrying area of $1^{1}/_{16} \times {}^{1}/_{4}$ in. (resistance of less than 0.001 Ohm). Each battery was instrumented with five combination thermocouple / heat flux transducers. Documentation included IR and standard video throughout the test period. Potential and resistance of the battery were made before and after each test. The batteries were monitored for a minimum of one hour after each test.

TEST SPECIMEN

Southwest Research Institute (SwRI) acquired seven 12V batteries (received November 3, 2004) and thirteen 36V batteries (received August 31, 2004) for testing. The 12V batteries measured $7 \times 3 \times 6^{1}/_{2}$ in. and the 36V batteries measured $10^{1}/_{8} \times 6^{5}/_{8} \times 6^{3}/_{4}$ in. The batteries were from the same manufacturer, and of similar design – sealed lead-acid batteries, typical of automotive applications.

FACILITY

All setup and testing was performed at SwRI in San Antonio, Texas. Penetration testing was performed at SwRI's Engineering Dynamics ballistic range, and short-circuit testing was performed in the Department of Fire Technology's indoor Engineering and Research Laboratory. Crush testing and radiant-heat testing were performed in the Department of Fire Technology's large-scale test laboratory.

INSTRUMENTATION

All data was obtained with calibrated test equipment. A PC-based data acquisition system logged the data for each test series. Documentation included digital photographs of each test along with the various forms of video documentation. Figure 1 depicts the numbering used for thermocouples and heat flux transducers.

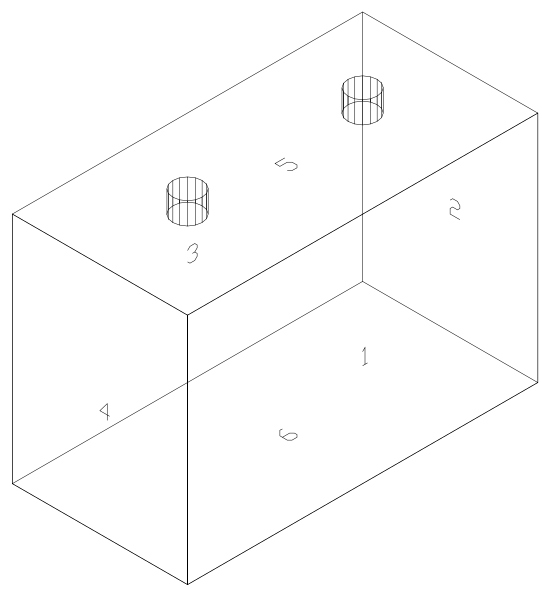

Figure 1. Thermocouple / Heat Flux Transducer Layout.

RESULTS

Tests were performed January 18 - April 5, 2005 at Southwest Research Institute's Department of Fire Technology.

Penetration Test

For each of the penetration tests, the ⅛-in. conductive rod successfully penetrated each battery's exterior and lodged within. The 12V battery showed a temperature increase in all thermocouple locations shortly after impact. The maximum temperature was at the impact face, approaching 130°F from an ambient temperature of 65°F at approximately 95 min. The heat flux sensor at the impact face was damaged at the beginning of testing. The highest heat flux reading was approaching 65 Btu/ft^{2}hr at approximately 95 min. The voltage of the 12V battery measured approximately 13.0 Volts prior to the test, and 12.6 Volts immediately following the test. The voltage slowly dropped to approximately 10.5 Volts after a period of 2 hours.

The first 36V battery showed only a slight temperature increase at one location: a rise of 6°F to approximately 71°F over a period of 30 min. The heat flux at this location showed an estimated time-averaged maximum of 15 Btu/ft^{2}hr. The voltage of the first 36V battery dropped from approximately 37.3 Volts to 36.7 Volts immediately following the test. The voltage did not have a significant change for an additional two hours following the test.

The second 36V battery showed no sign of temperature increase nor heat flux over a period in excess of 10 min. The voltage of the second 36V battery dropped from approximately 37.4 Volts to 37.0 Volts following the test, with no additional decrease for two hr following the test.

The higher temperature increase and heat flux shown by the 12V battery can be explained by the smaller mass (less thermal sink) of the smaller battery. The higher voltage drop following the 12V battery test can be explained by the fact that the same-sized penetrating rod was able to occupy (short circuit) a greater percentage of parallel plates within the 12V battery.

Graphical data depicting the test temperatures and heat fluxes can be found in Appendix A, A-1 through A-3. Photographs of the setup and results of the penetration tests can be found in Appendix B, Figures B-1 through B-8.

Crush Test

The axes for the batteries, along with a depiction of the plate orientation, are shown in Figure 2. Each of the batteries was successfully crushed to less than 75% of its length in the x-axis, and to less than 50% of its length in the y- and z-axes (separate tests). Each battery began leaking acid soon after crushing began. Acid vapors were emitted from cracks formed in the batteries. The rate of pressurization of the jack system varied greatly but averaged on the order of 100 psi/sec. Pressure was increased by hand in intervals, as observations were made. The pressure could be seen to drop slightly between intervals, as the plastic battery would slowly relax in its crushed state.

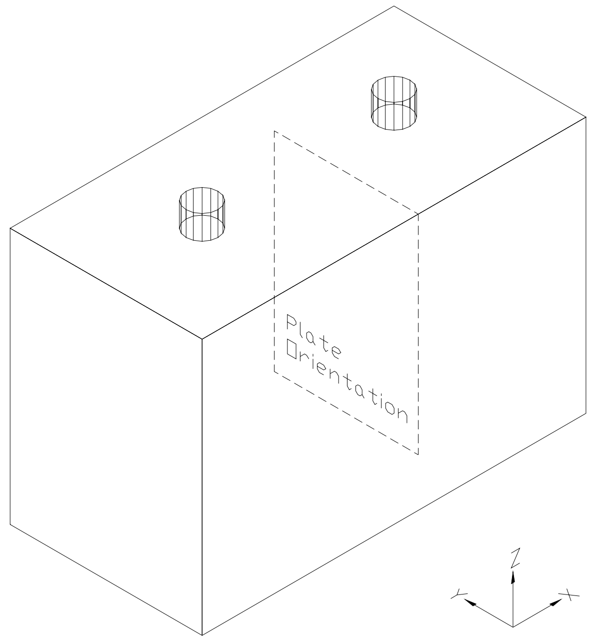

Figure 2. Battery Axis Definition.

Crushing in the x-axis (perpendicular to the plates) resulted in the quickest drop in battery voltage in all cases. Crushing in the y-axis (parallel to the plates, along their shorter dimension) resulted in the 12V battery dropping in voltage by approximately 50%. Under identical scenarios, one of the 36V batteries dropped in voltage by approximately 65%, and the other dropped in voltage by approximately 8%. Crushing in the z-axis (parallel to the plates, along their longer dimension) resulted in both 36V batteries dropping in voltage by approximately 8%. Voltage measurements were not made across the 12V battery during the z-axis crush test, due to the fact that the proximity of the poles caused them to be immediately grounded at the beginning of the test.

Surface temperature of the 12V batteries rose to a maximum on the order of 200°F during the crush tests as indicated by the thermal imaging camera. Surface temperature of the 36V batteries rose to a maximum on the order of 180°F during the crush tests. During the y-axis crush test of one of the 36V batteries, the surface temperature rose to approximately 180°F. Acid vapors were emitted from a hole formed in the battery for approximately 8 min, substantially longer than in any other test. This condition was not reproduced in the second y-axis crush test of a 36V battery.

Graphical data depicting the test temperatures and heat fluxes can be found in Appendix A, A-4 through A-9. Photographs of the crush tests can be found in Appendix B, Figures B-9 through B-18.

Radiant Heat Test

The heptane pool fire reached flame temperatures between 1600°F and 1700°F during the tests. One 36V battery was exposed to the heat source for a period of 5 min. Ignition of the battery material had occurred after 45 sec and the voltage dropped to 0 Volts after approximately 130 sec of exposure. The 12V battery and second 36V battery were exposed to the heat source for a period of 10 min. Ignition of both the 12V and 36V battery exteriors occurred after 40 sec of exposure. Voltage in the 12V battery began dropping after 400 sec of exposure, and voltage in the 36V battery began dropping after 280 sec of exposure.

Because of the high temperatures achieved around the battery, most thermocouple/heat flux sensors malfunctioned during testing. Surface temperatures and heat fluxes of the batteries varied widely throughout the tests, affected mostly by turbulent convection. Graphical data depicting battery voltage, flame temperature, and surface temperatures and heat fluxes at each location can be found in Appendix A, A-10 through A-16; data was truncated after sensor malfunction. Only one thermocouple/heat flux sensor was used in the final 36V battery test. The temperature and heat flux during this test showed good correlation (depicted on page A-16). Photographs of the radiant exposure tests can be found in Appendix B, Figures B-19 through B-26.

Short Circuit Test

Arcing occurred immediately upon the shorting of all three batteries, which stopped once a strong connection was made. Heat produced by the arcing and voltage discharge was sufficient to weld the conductive metal used to create the hard short. Thermal imaging showed a high rate of heating of the metal for a brief period of time; the metal would then show signs of cooling, signifying an internal short of the battery. For the 12V battery, the metal was removed at 150 sec, and the voltage was verified as 0 Volts. The metal short material could not be easily removed from either of the two 36V batteries, but Tests 1 and 2 showed signs of cooling at 10 and 5 min, respectively. Ambient temperature prior to testing was approximately 72°F. The maximum temperature and estimated maximum heat flux (time-weighted average) can be found in the following table:

Table 1. Short Circuit Test Summary.

	Max Temperature °F	Max Heat Flux Btu/ft^{2}hr
12V	80	15
36V Test No. 1	78	18
36V Test No. 2	76	17

Graphical data depicting temperatures and heat fluxes at each location can be found in Appendix A, A-17 through A-19. Photographs of the short circuit tests can be found in Appendix B, Figures B-27 through B-30.

CONCLUSIONS

Self-heating of the batteries was evident in all tests, with the exception of the radiant heat test in which the major heat source was external. However, self-heating in none of the tests reached a level sufficient to cause severe burns or ignite standard automotive fuels.

Results showed no significant increased risk of the 36V batteries over the 12V batteries with regard to the abuse testing performed.

APPENDIX A

GRAPHICAL DATA

(CONSISTING OF 19 PAGES)

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SwRI Project No. 01.06939.01.002
Test Date: January 18, 2005
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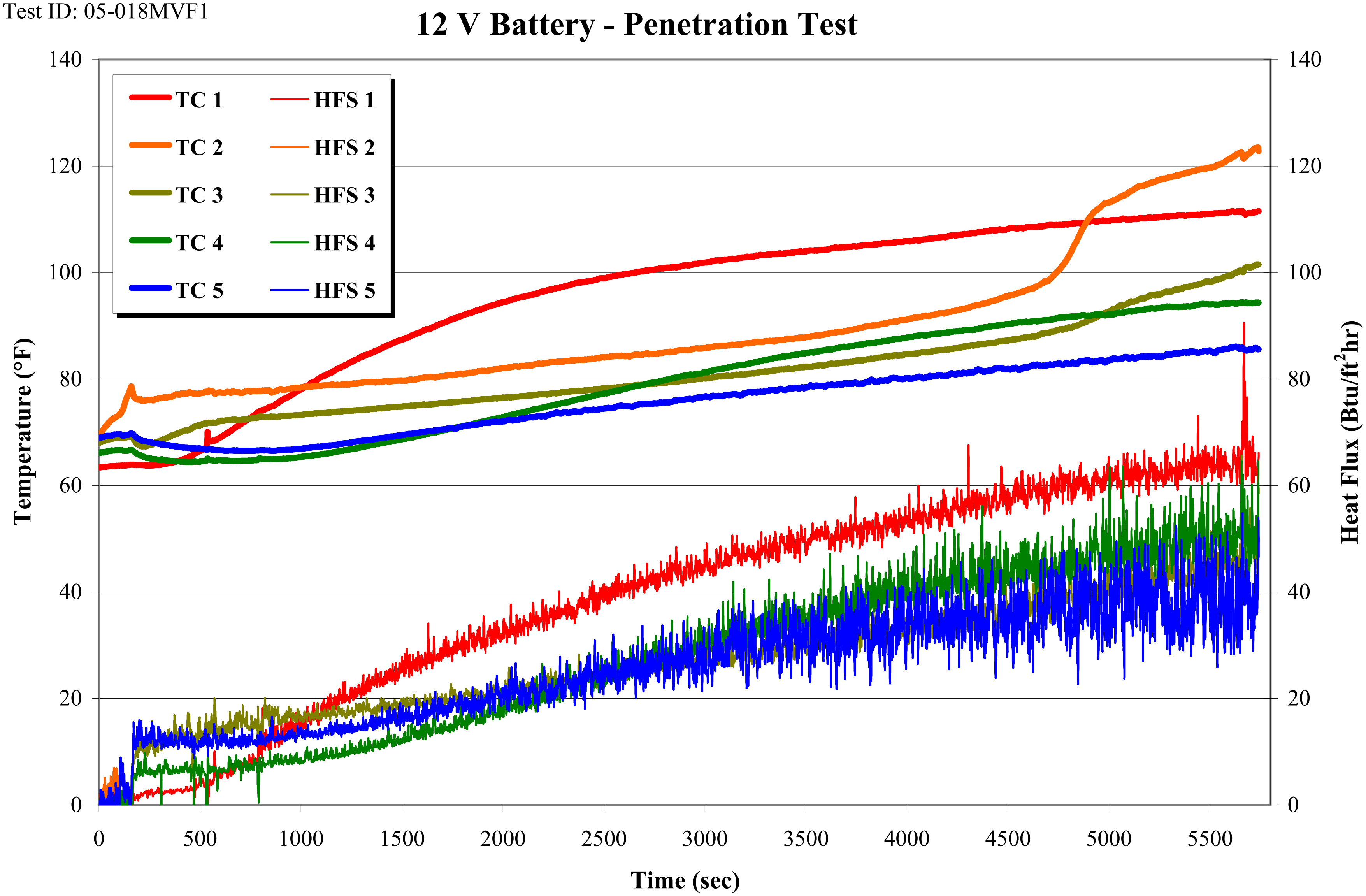

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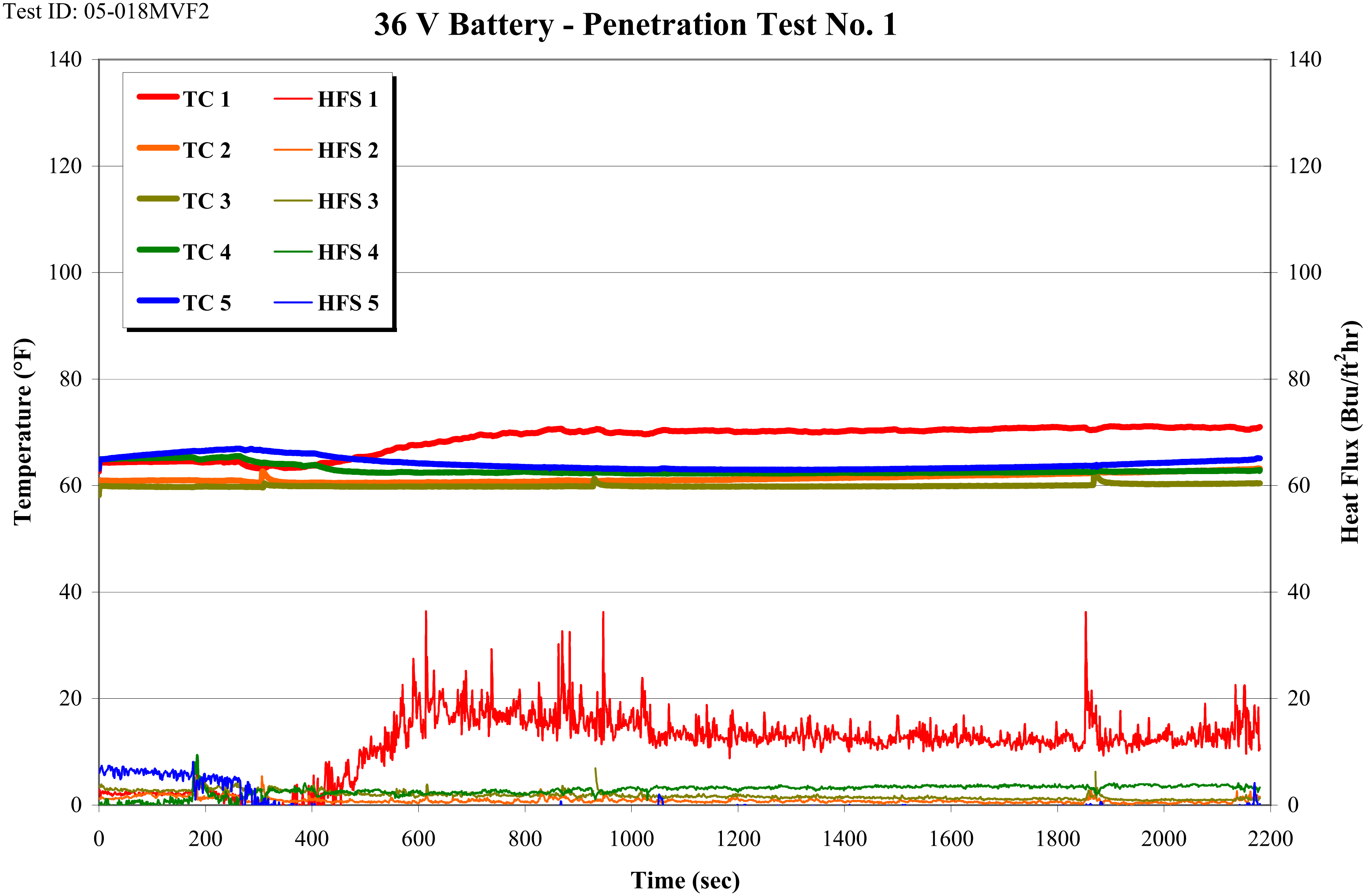

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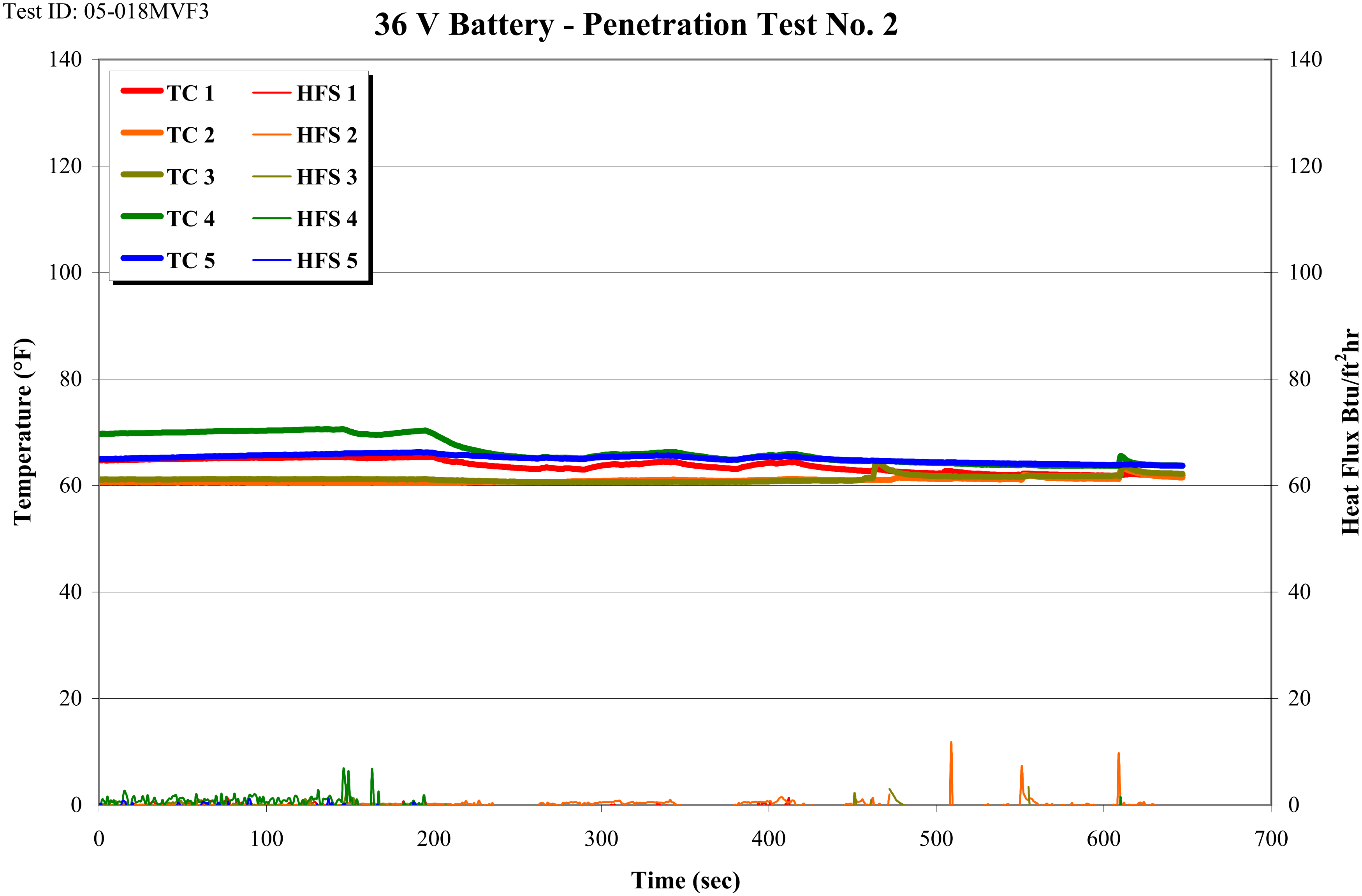

Motor Vehicle Fire Research Institute
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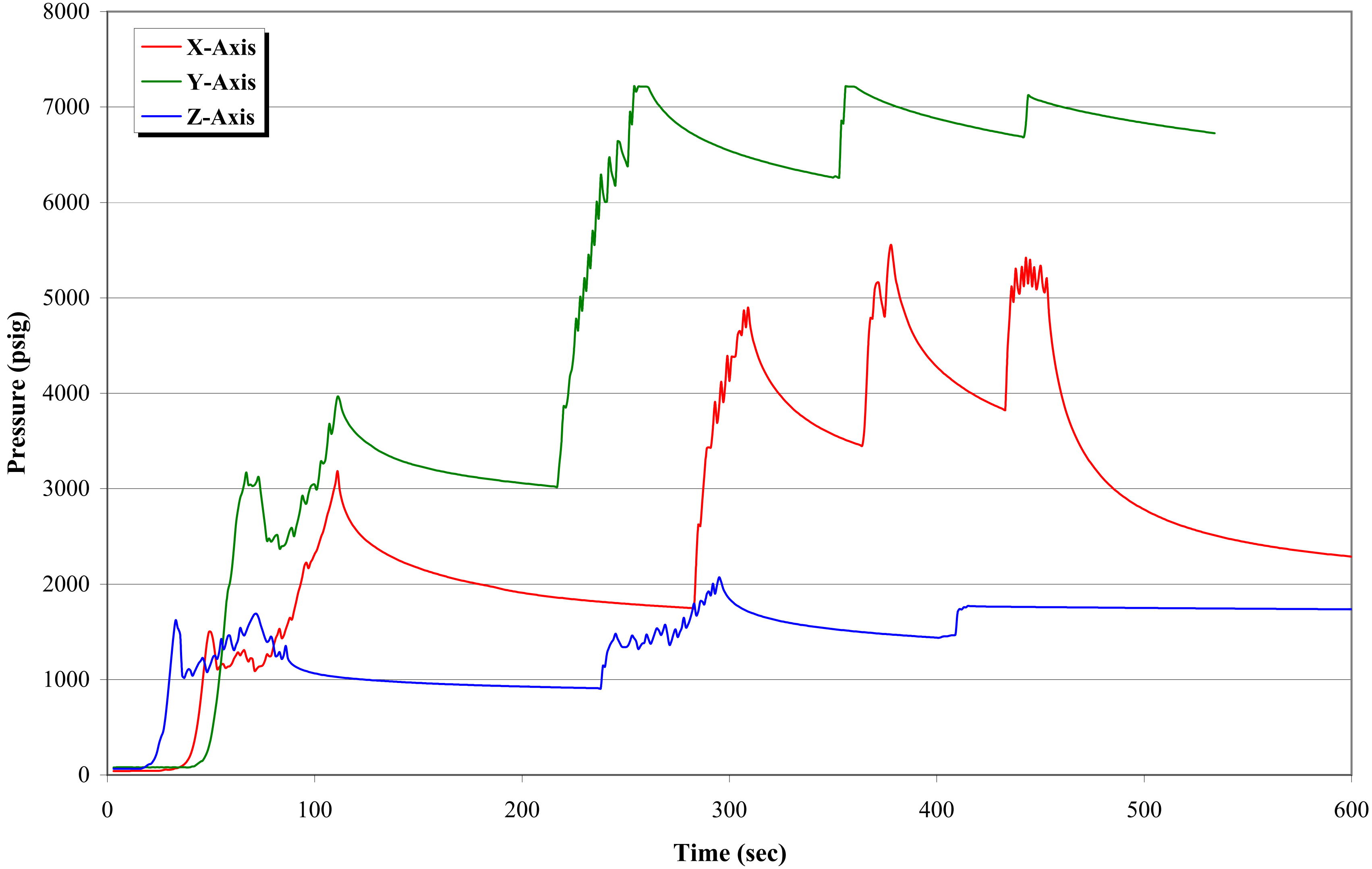
Test Date: April 5, 2005
Test ID: 05-095MVF1

12 V Battery - Crush Test Jack Pressures



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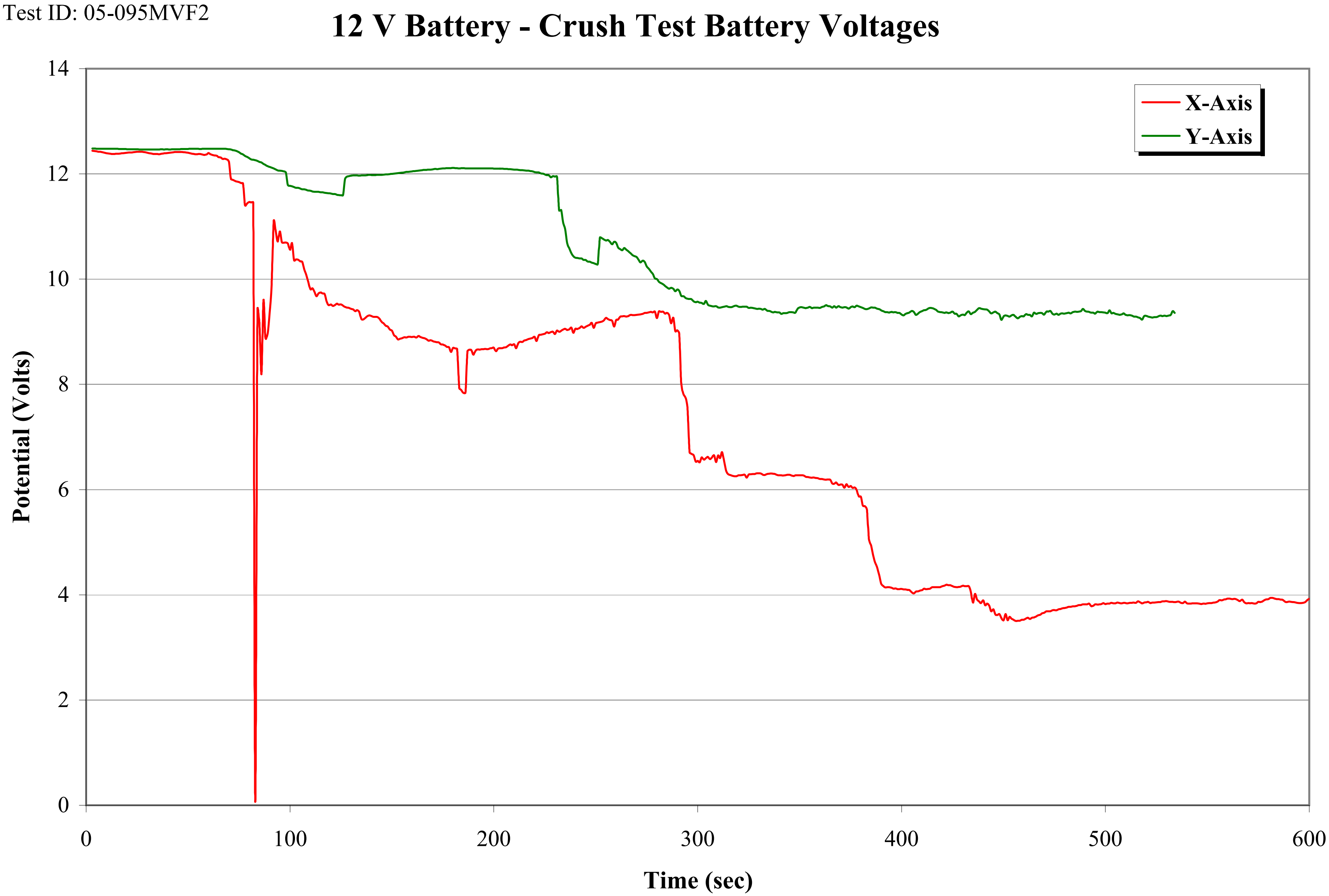

Motor Vehicle Fire Research Institute
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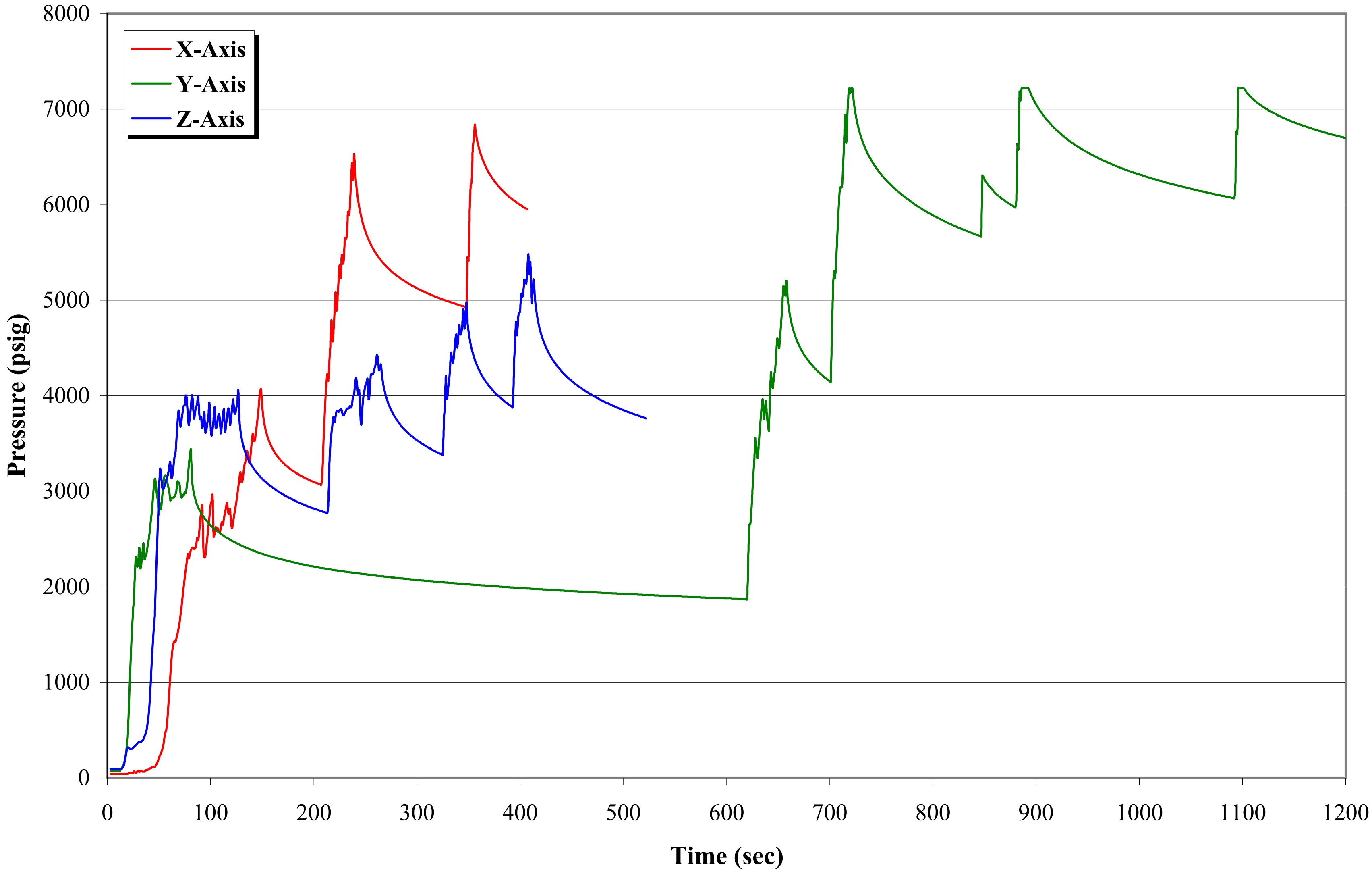
Test Date: April 5, 2005
Test ID: 05-095MVF3

36 V Battery - Crush Test No. 1 Jack Pressures



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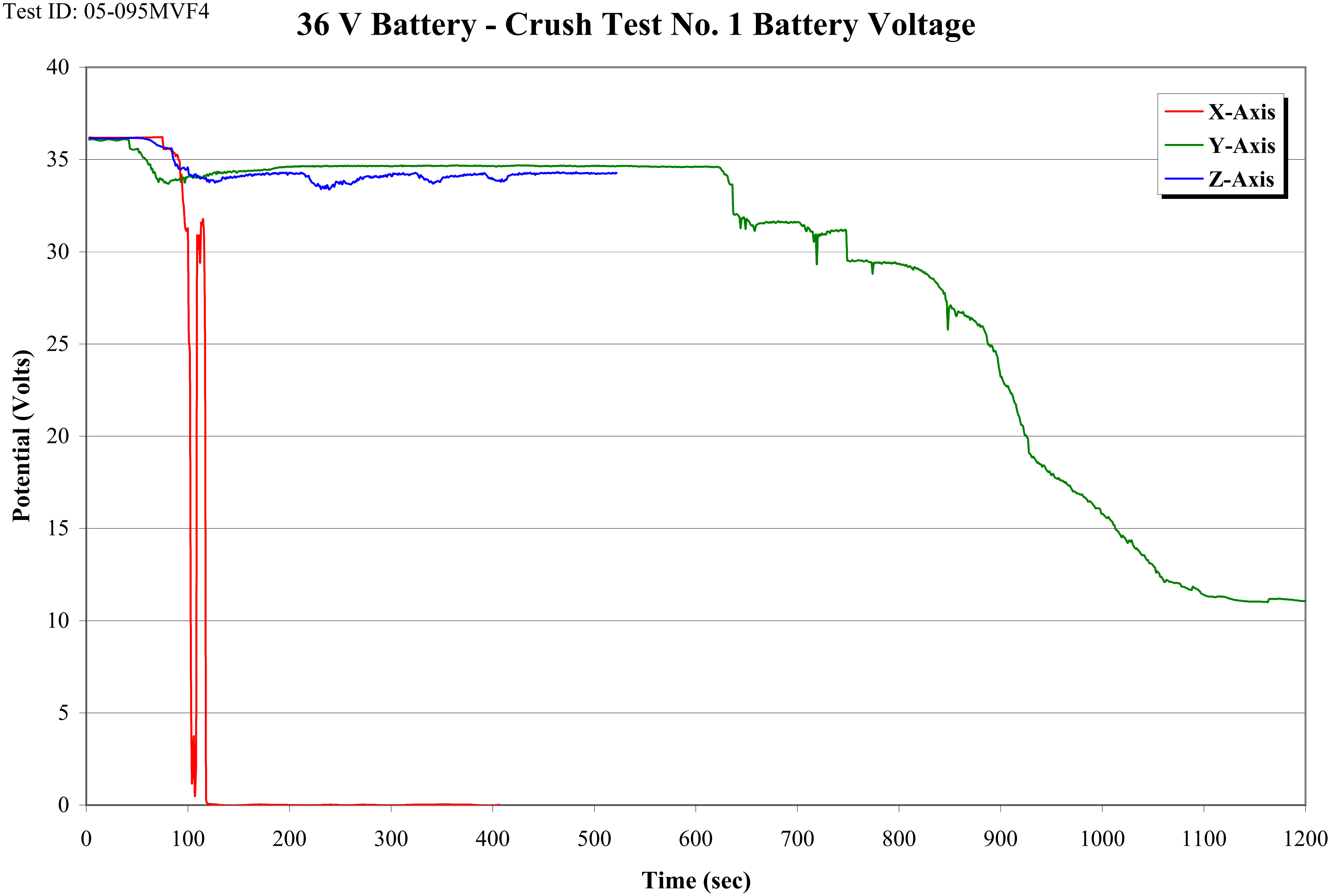

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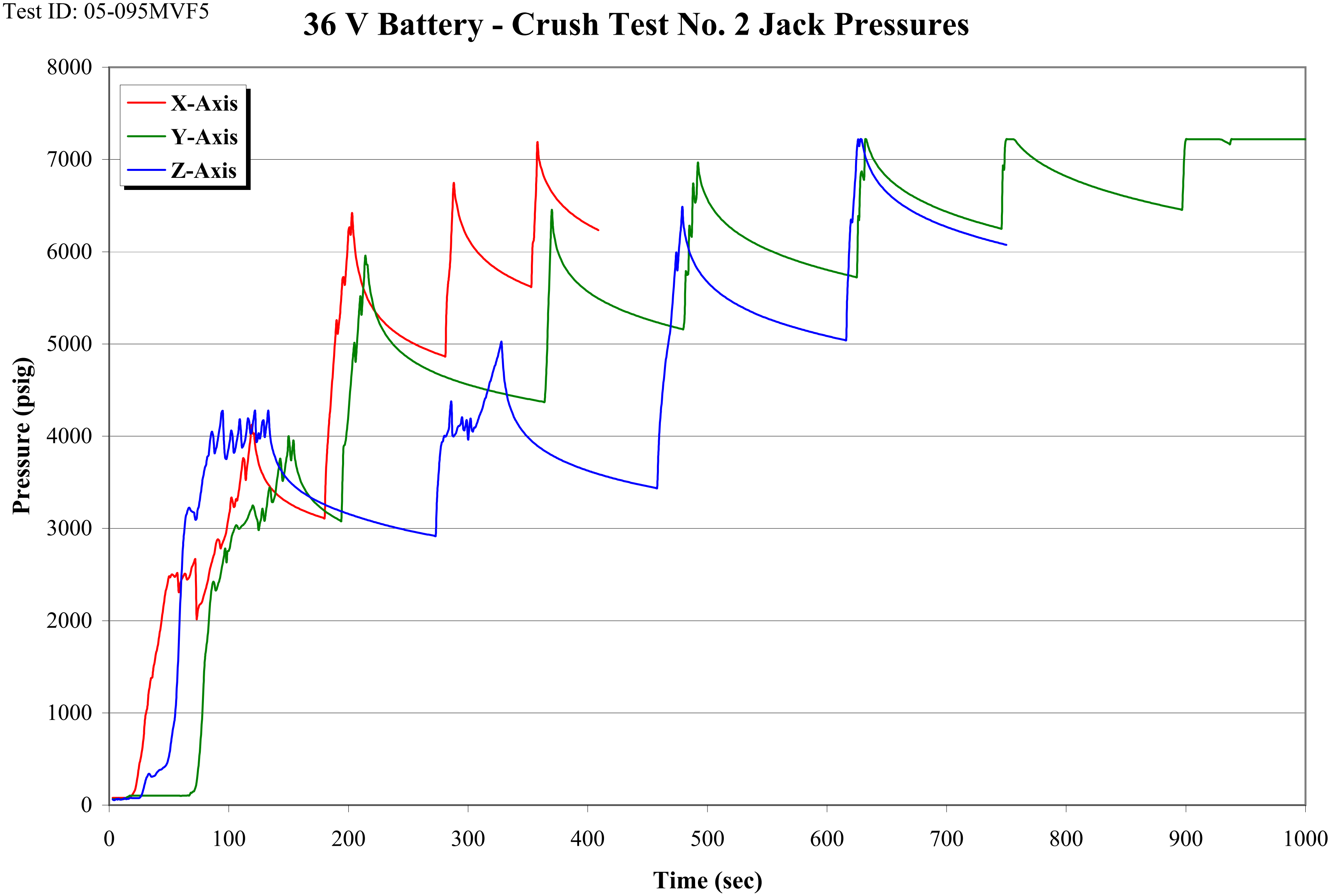

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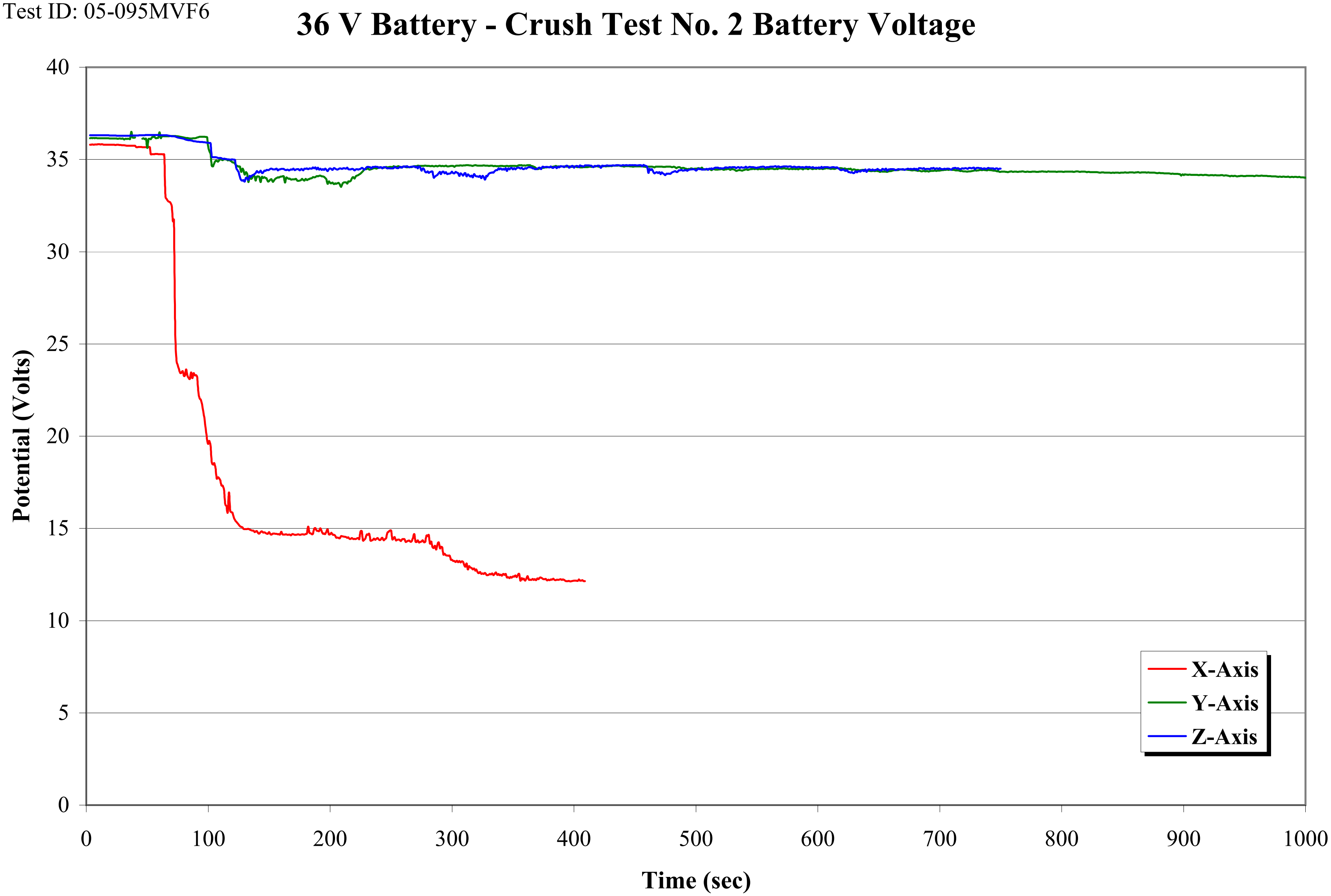

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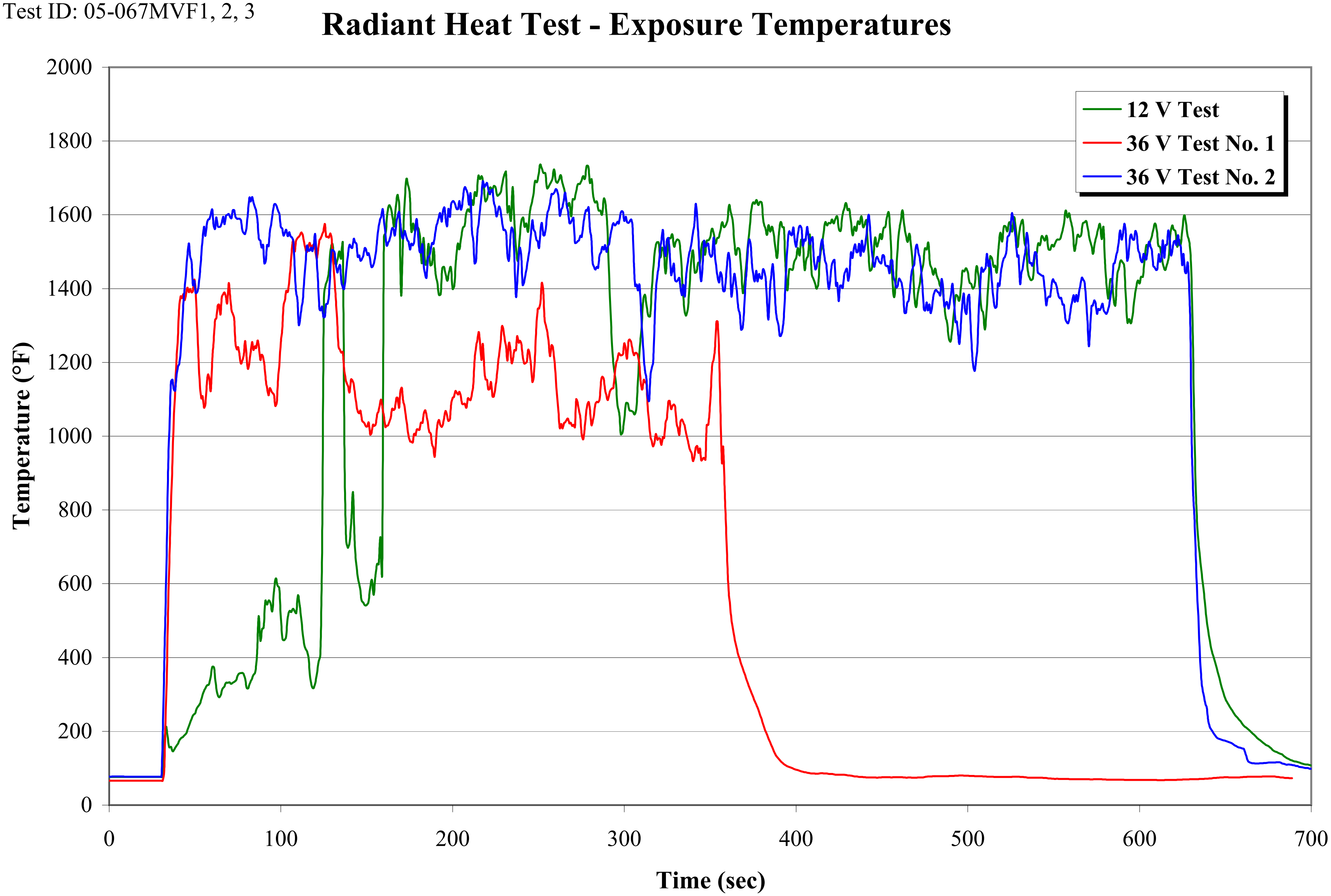

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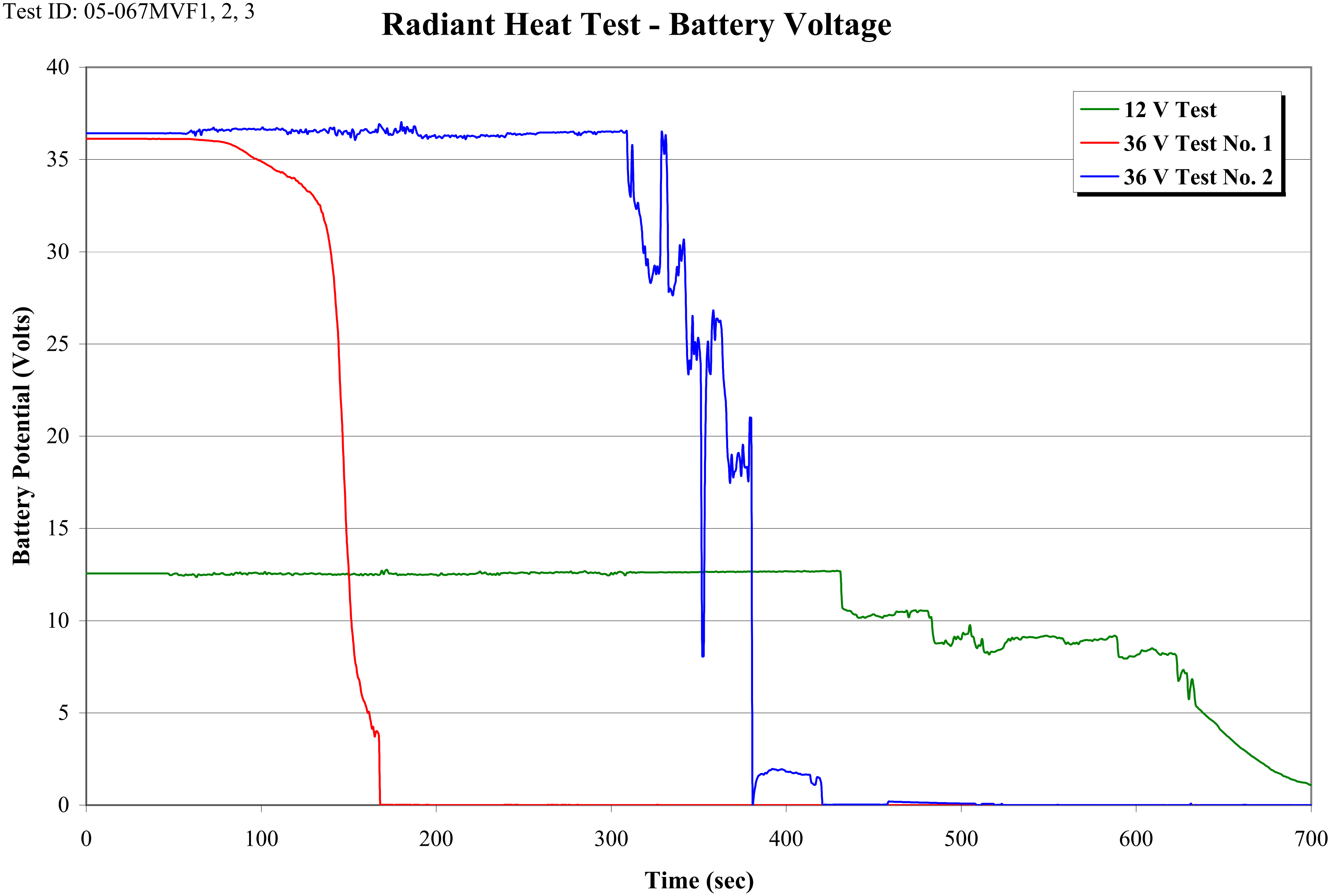

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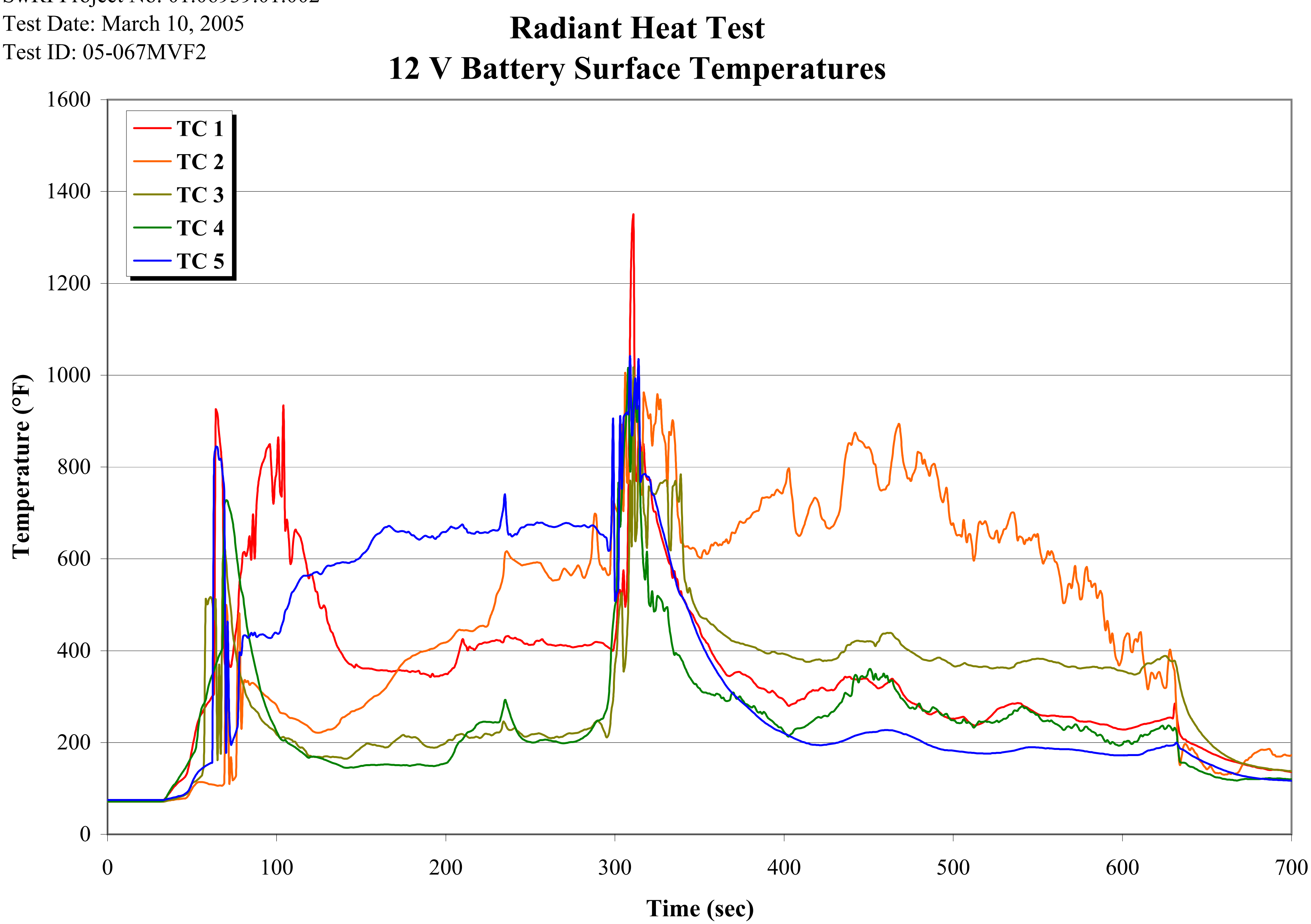

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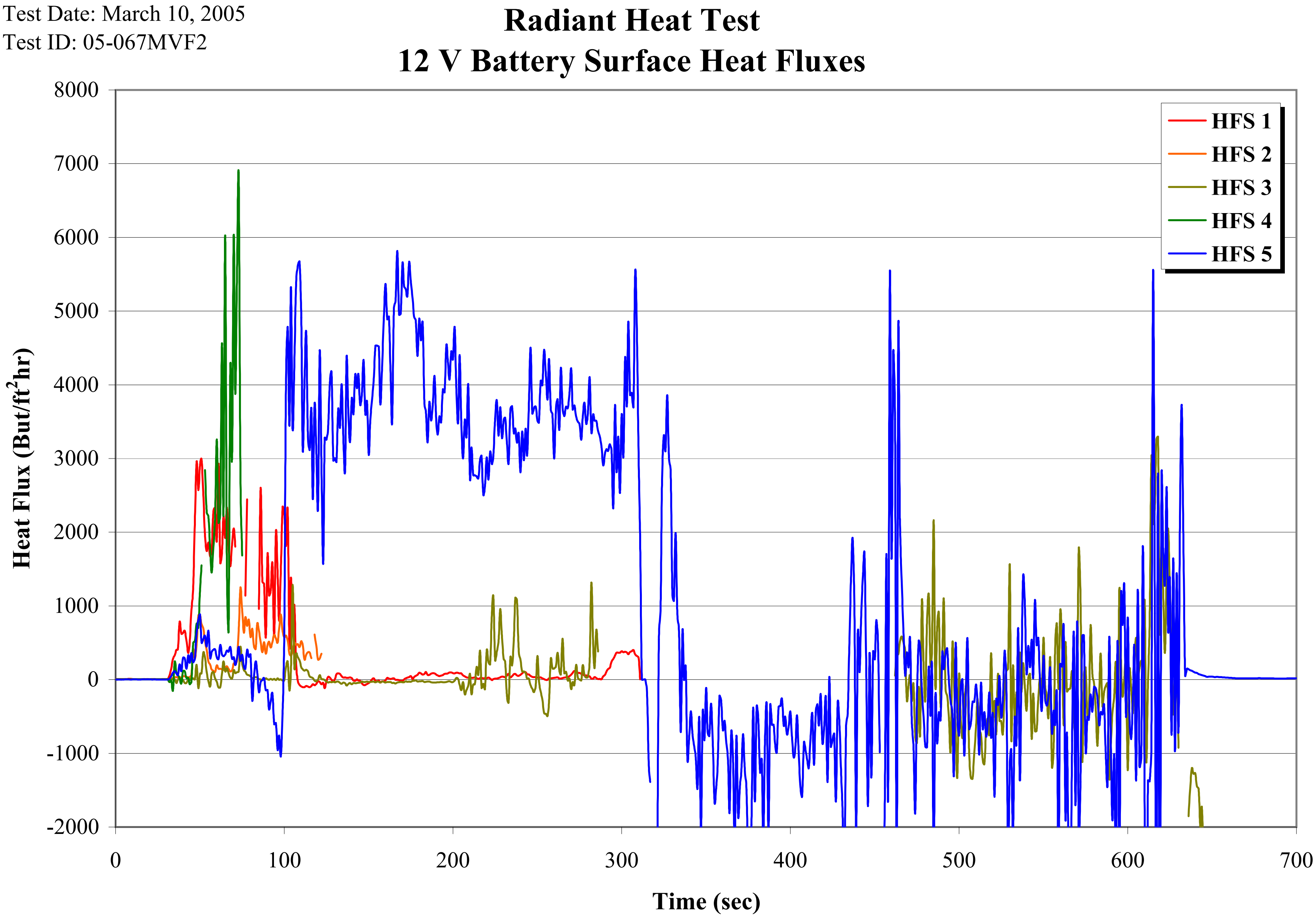

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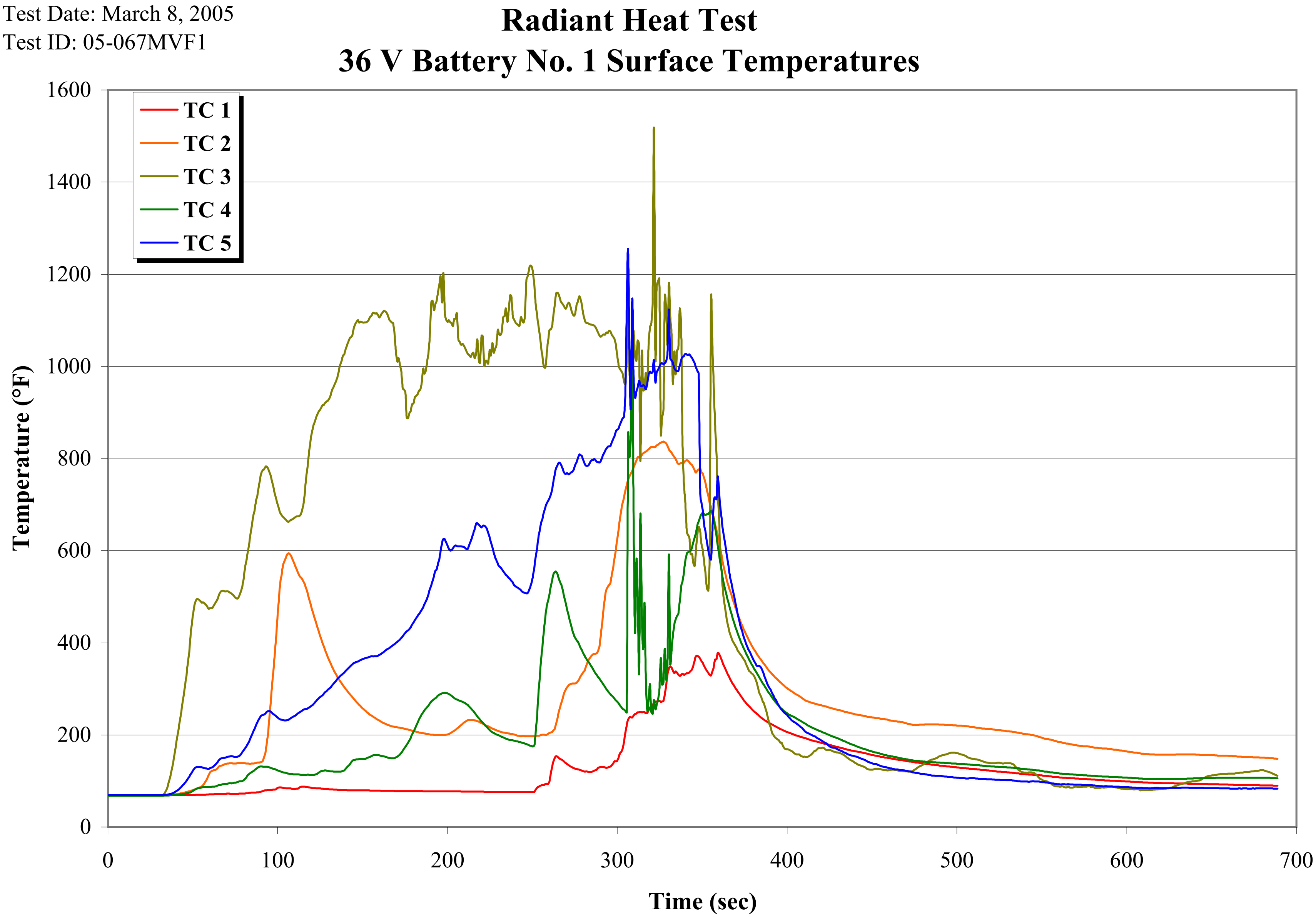

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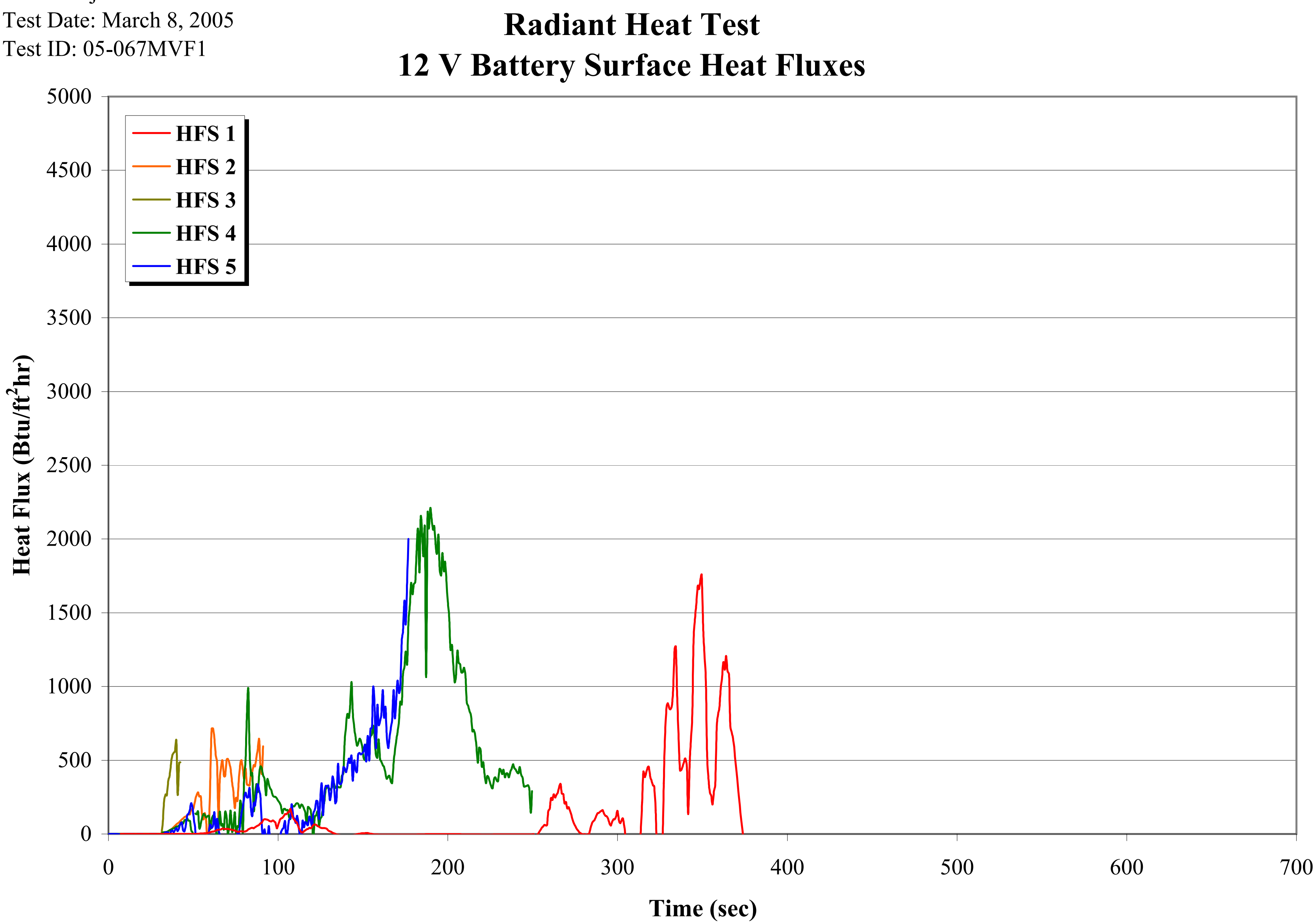

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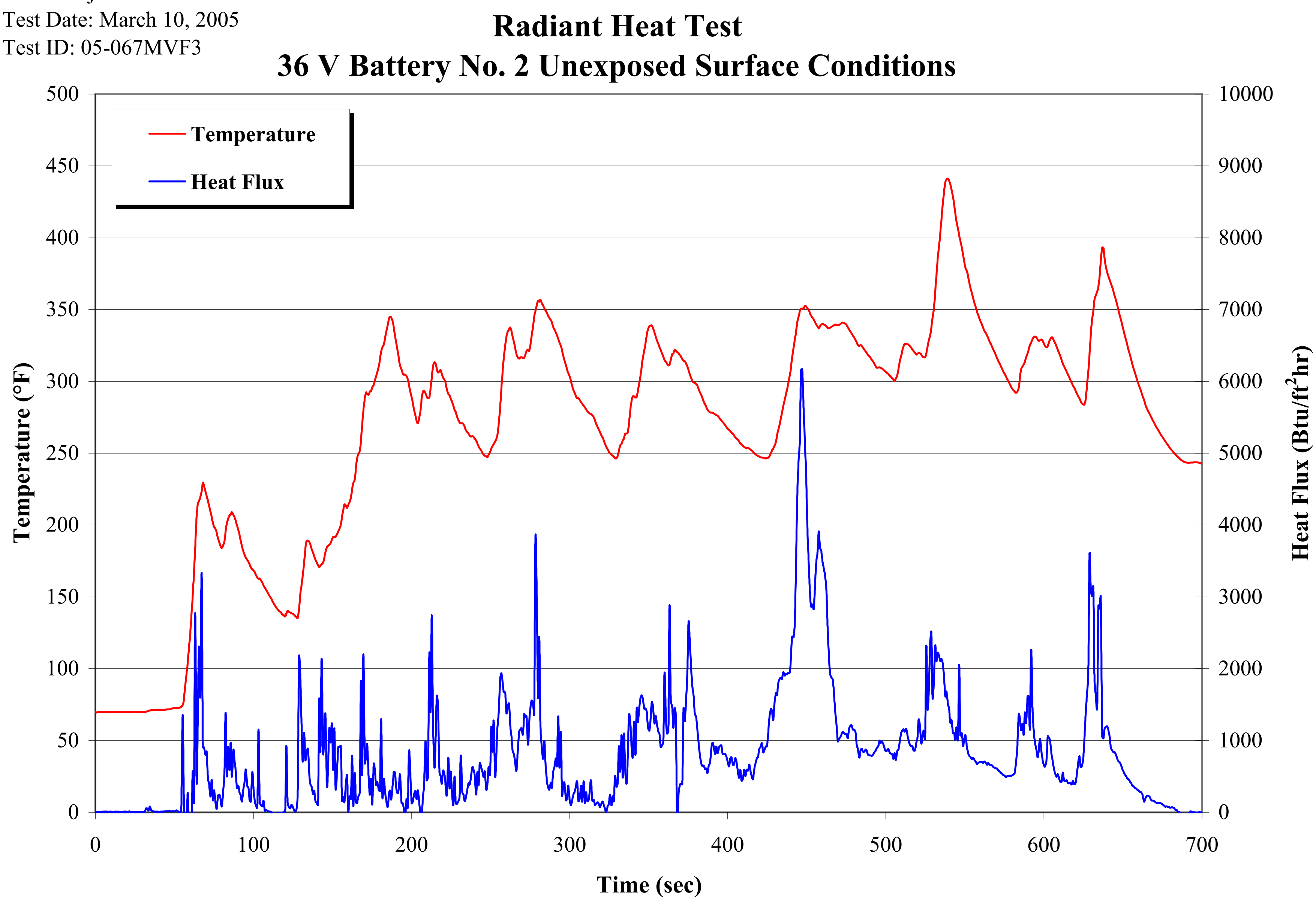

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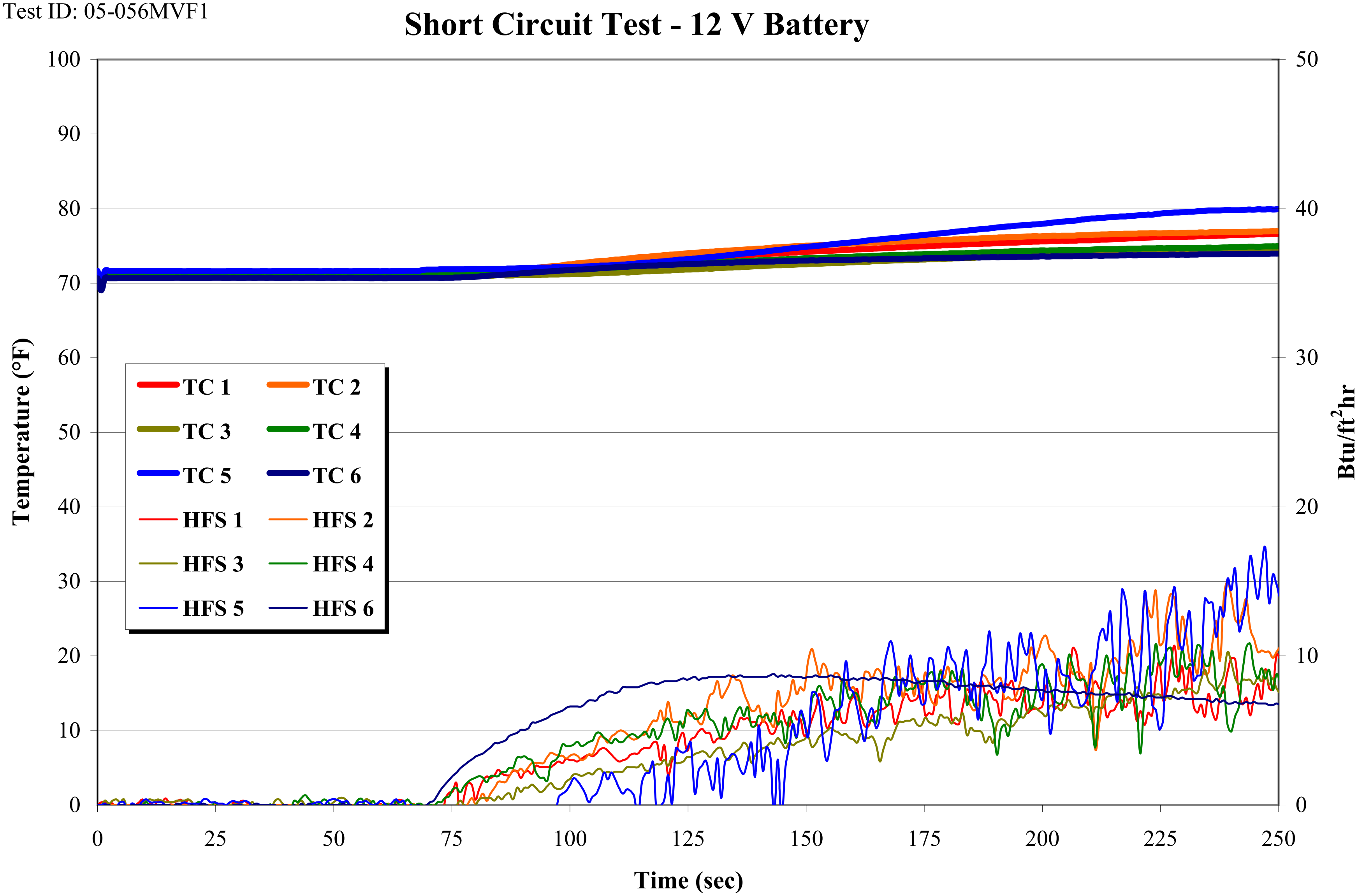

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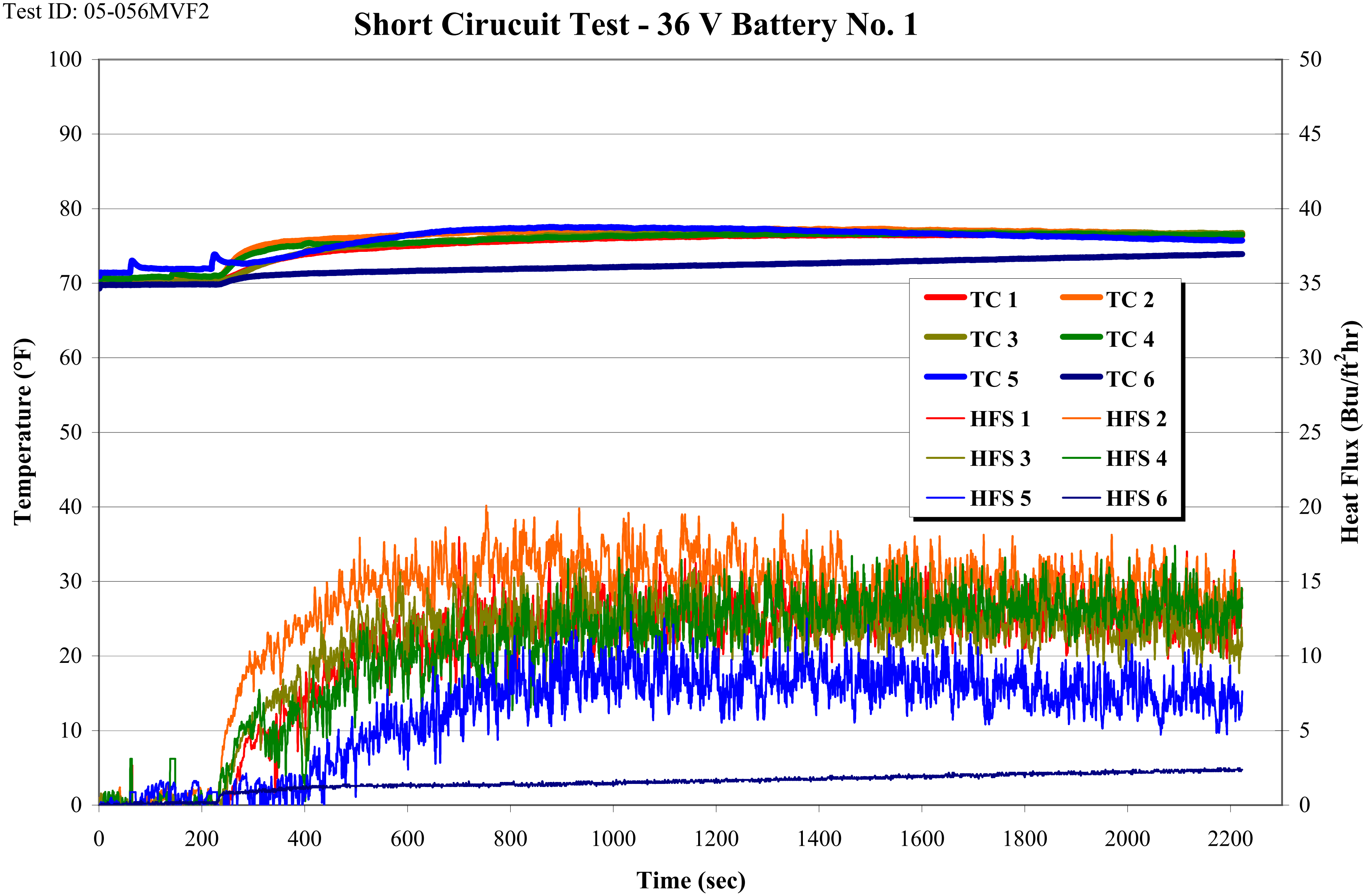

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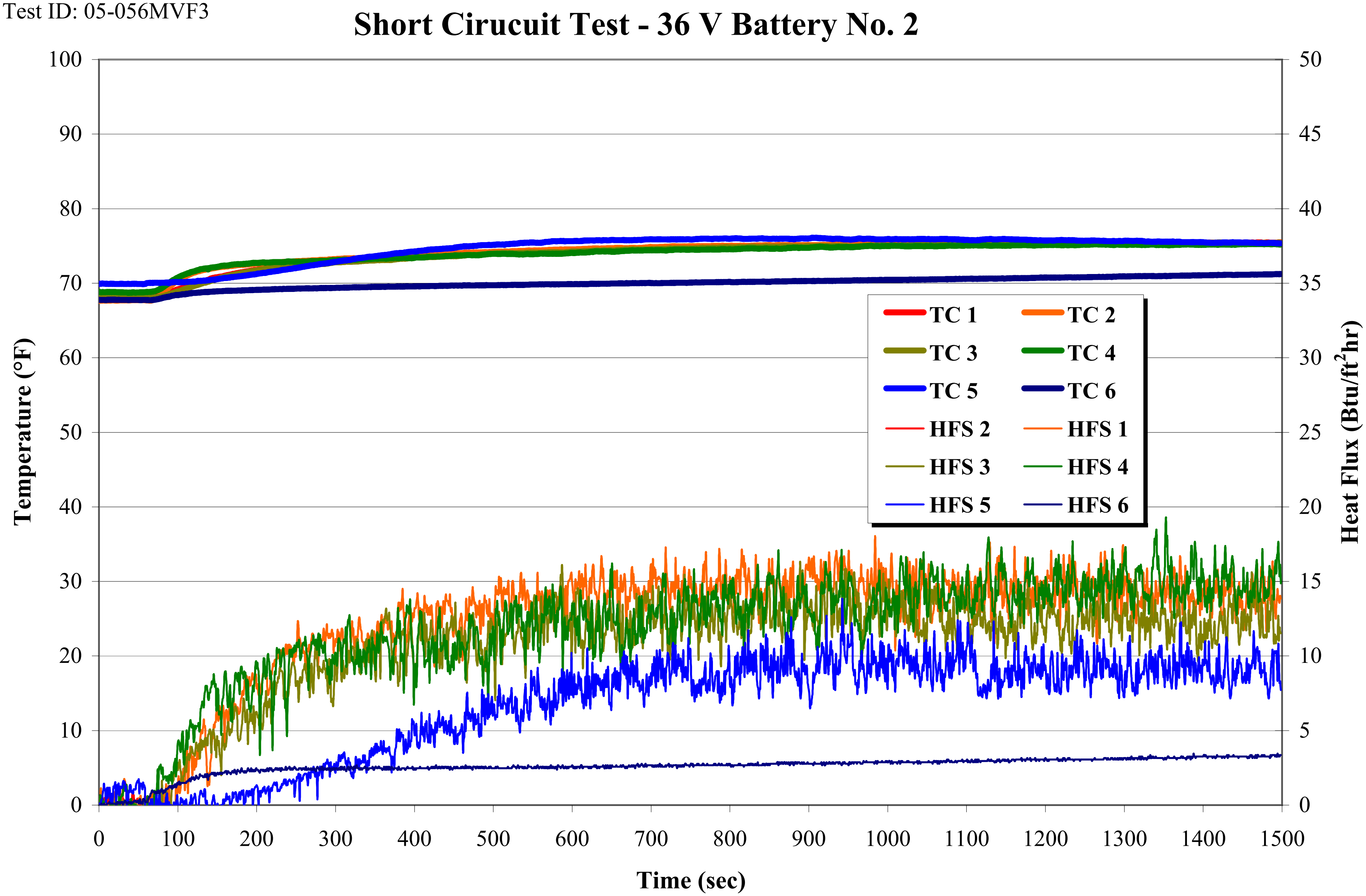

APPENDIX B

PHOTOGRAPHIC DOCUMENTATION

(CONSISTING OF 15 PAGES)

Figure B-1. Penetration Test Setup.

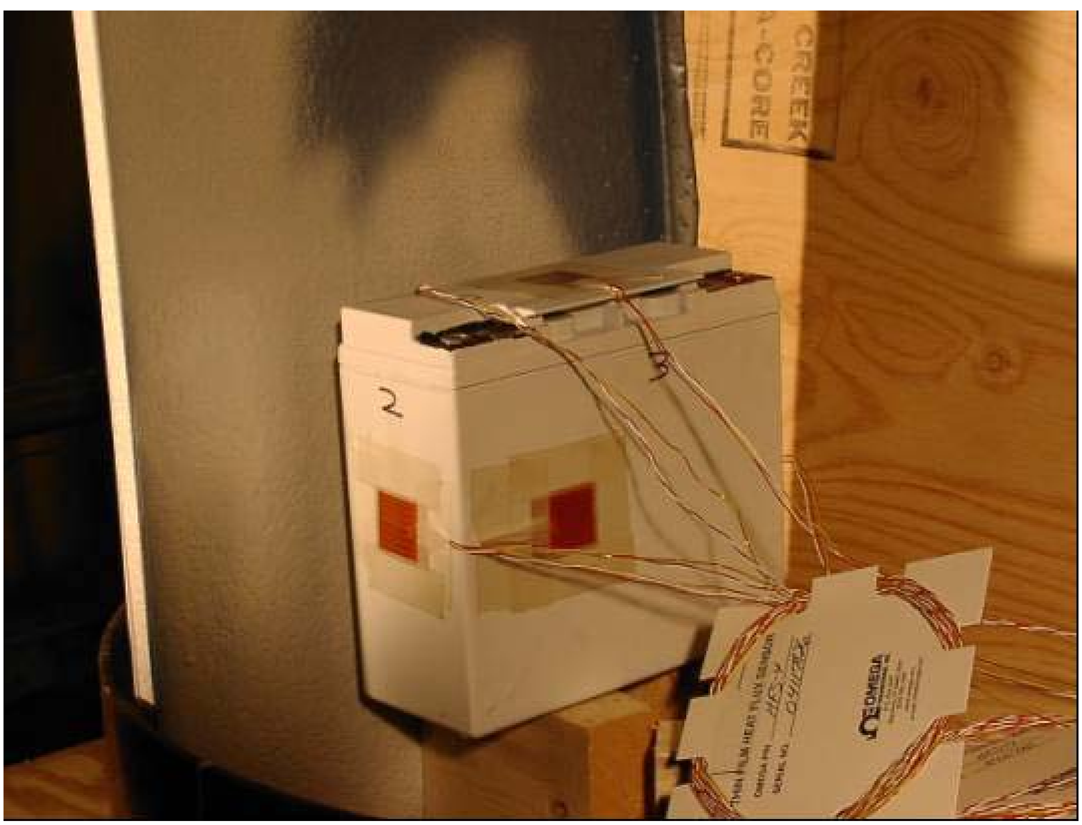

Figure B-2. 12V Battery prior to Penetration Test.

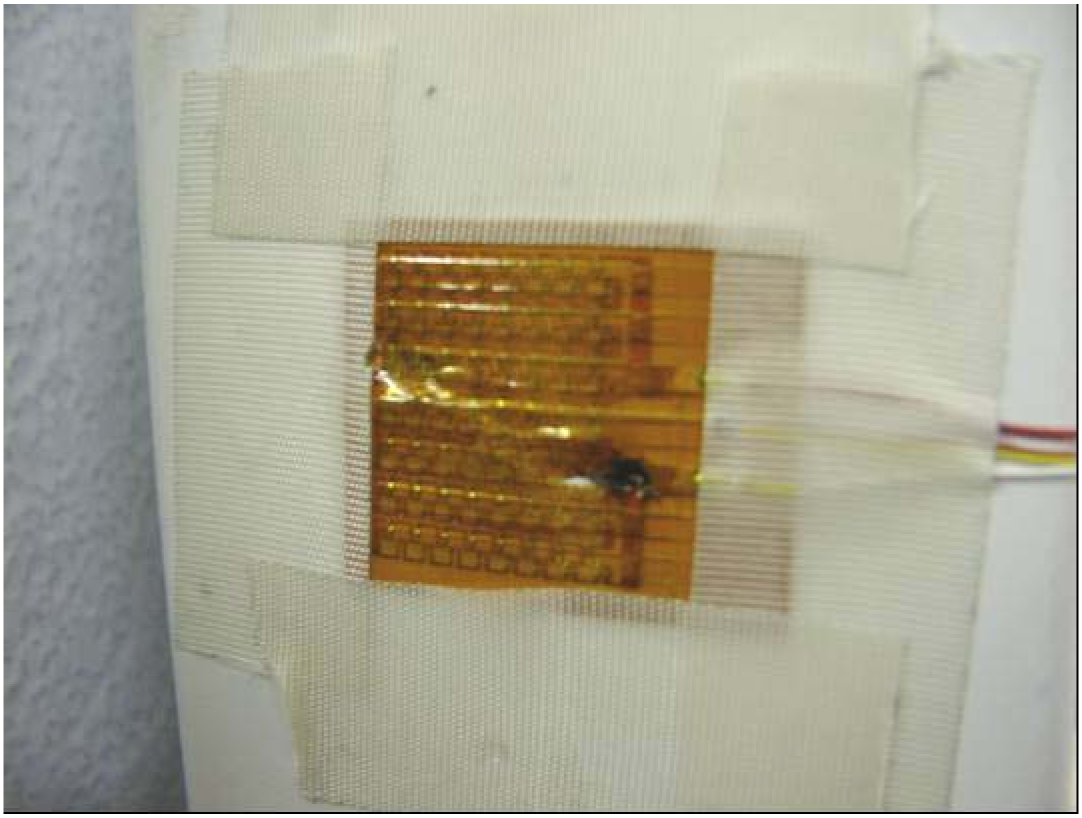

Figure B-3. Penetration Hole in 12V Battery (Through Heat Flux Sensor).

Figure B-4. Hot Spot Indicated on 12 V Battery Following Test.

Figure B-5. 36V Battery Prior To Test.

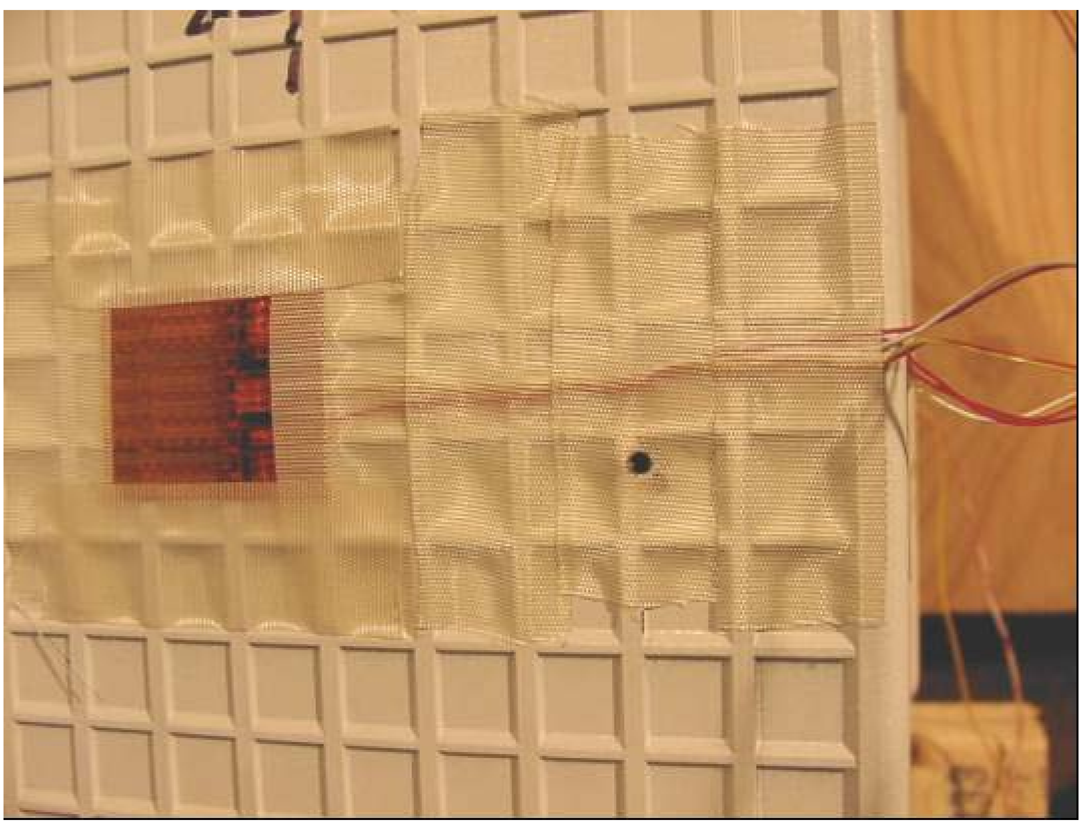

Figure B-6. Penetration Hole Through 36V Battery (Test No. 1).

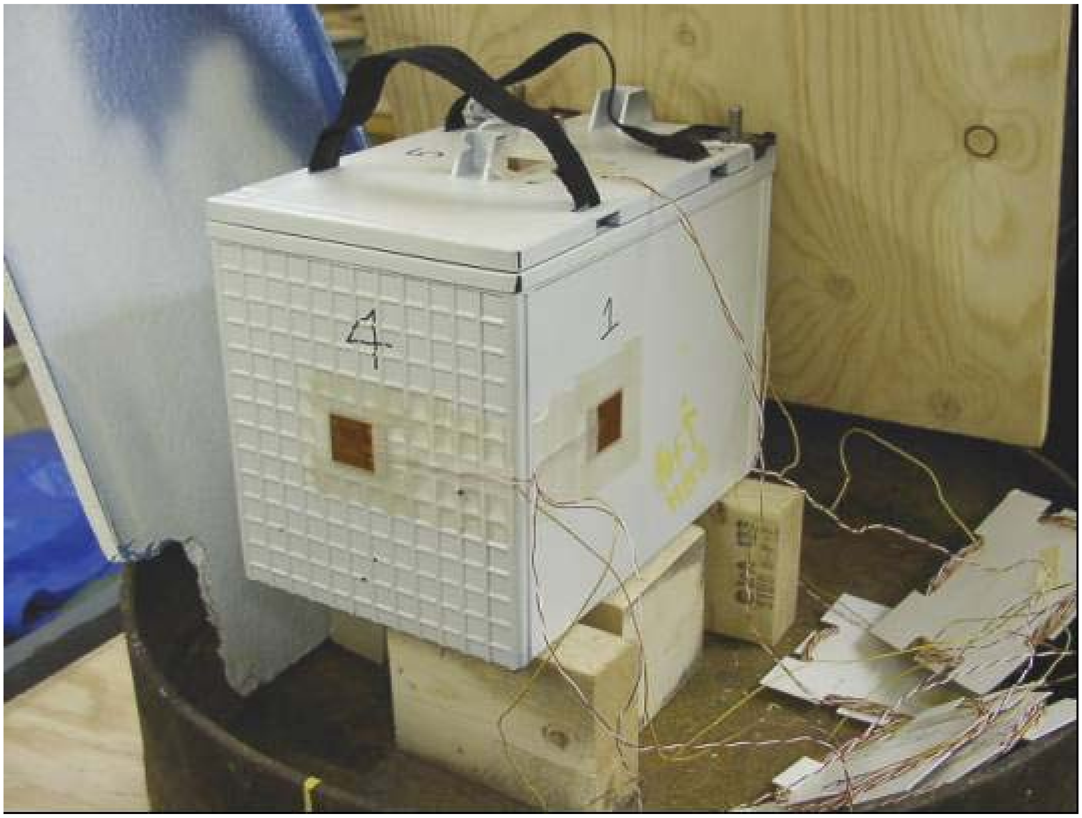

Figure B-7. Hot Spot Indicated on 36V Battery.

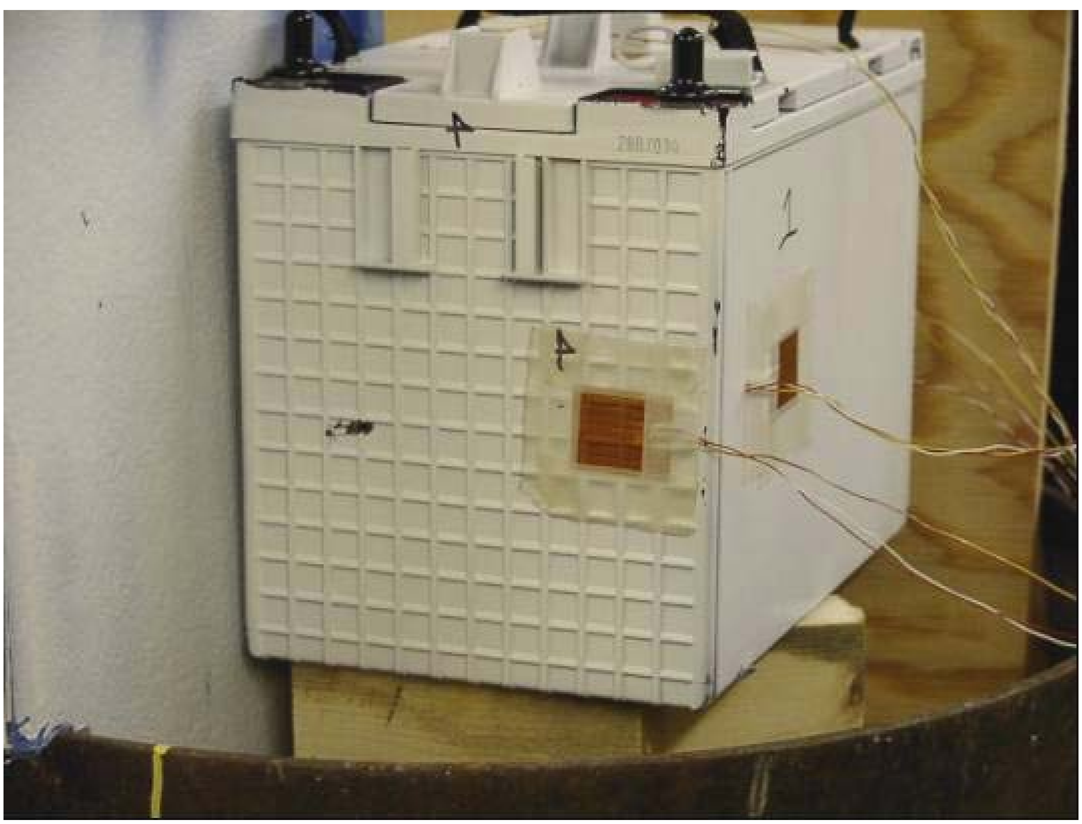

Figure B-8. Penetration Hole In 36V Battery (Test No. 2).

Figure B-9. X-Axis Crushing of 12V Battery.

Figure B-10. X-Axis Crushing of 12V Battery.

Figure B-11. 12V Battery Following Y-Axis Crushing.

Figure B-12. Z-Axis Crushing of 12V Battery.

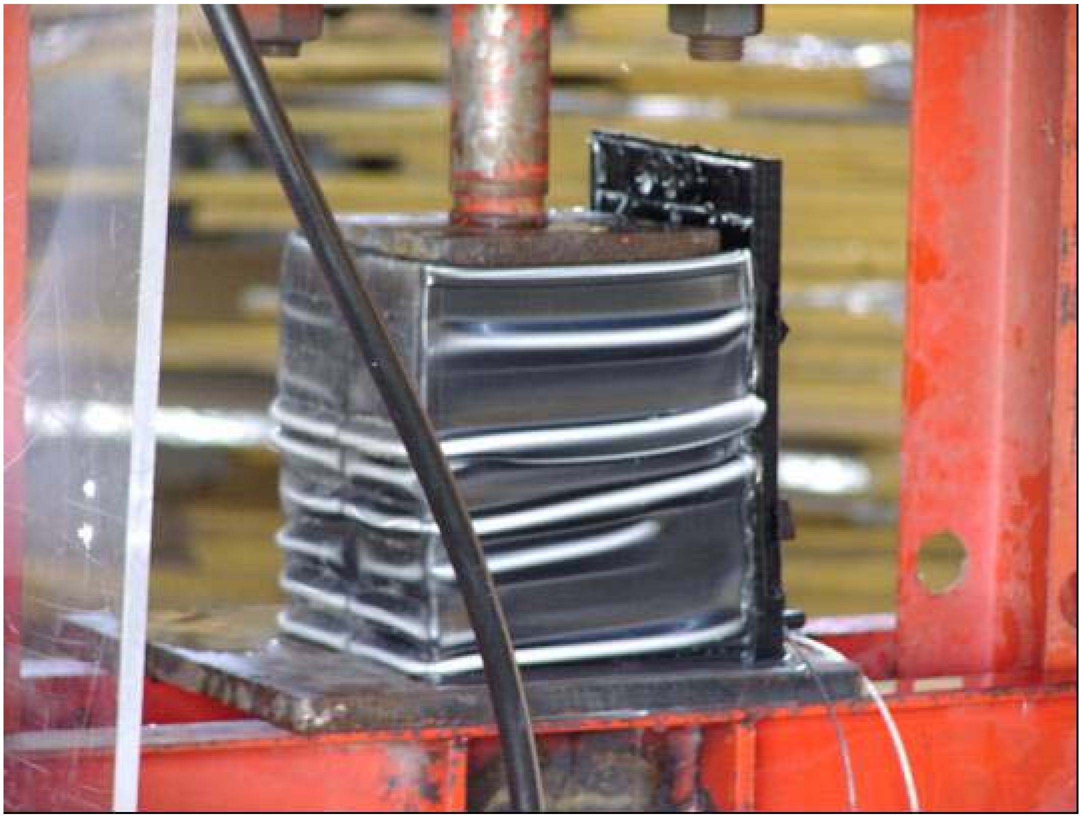
Figure B-13. Z-Axis Crushing of 36V Battery.


Figure B-14. Y-Axis Crushing of 36V Battery.

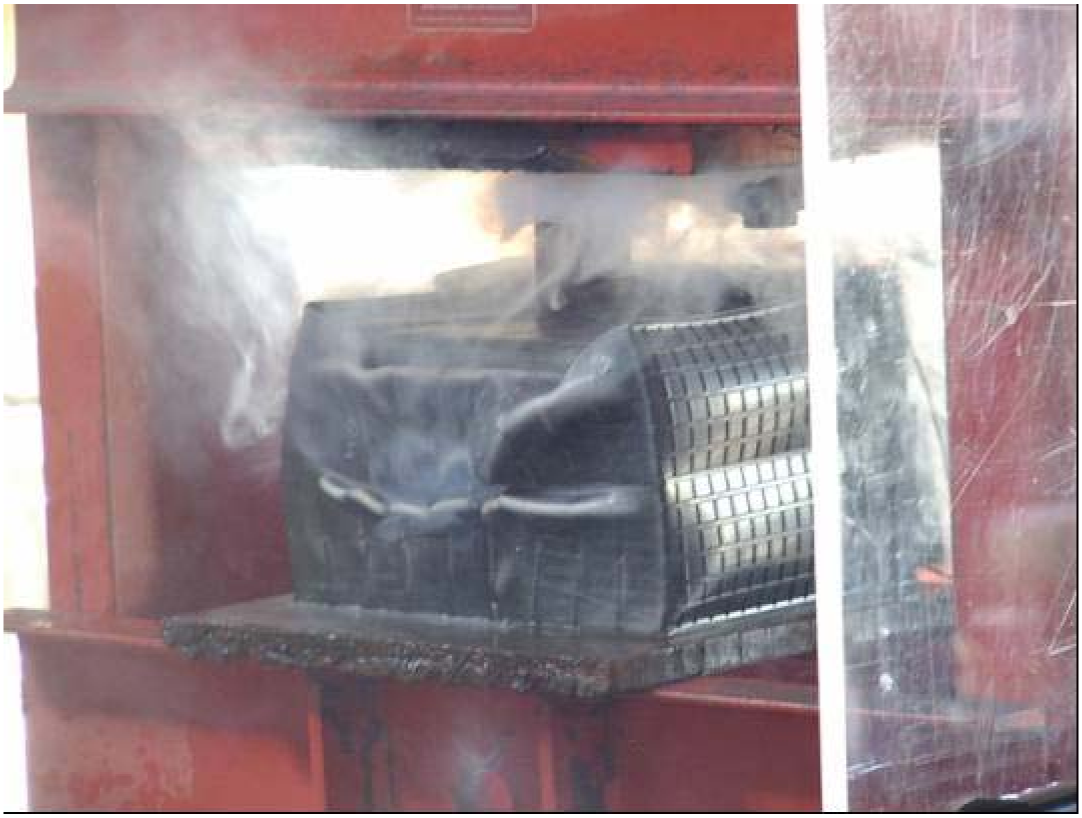

Figure B-15. Sulfuric Acid Vapors Emitting from 36V Battery During Y-Axis Crush Test No. 1.

Figure B-16. 36V Battery Following Crush Test.

Figure B-17. 36V Battery Prior to Z-Axis Crush Test.

Figure B-18. 36V Battery During Z-Axis Crush. Note Arcing to Crush Plate.

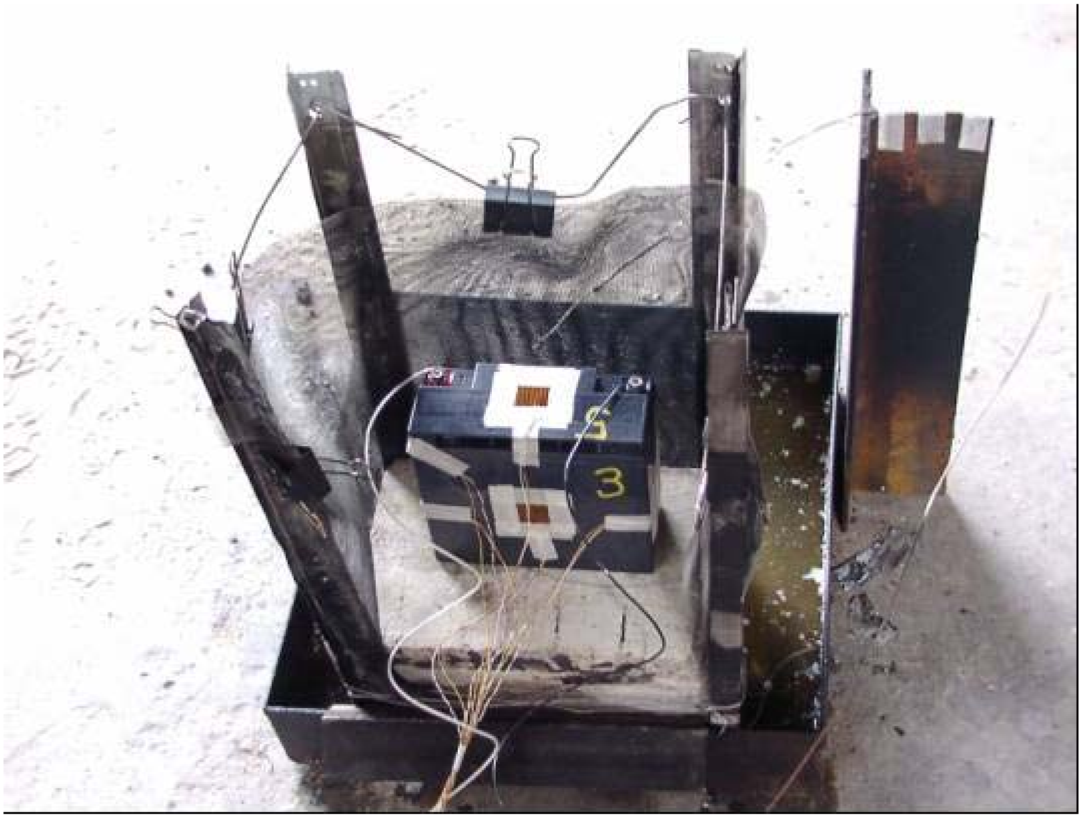

Figure B-19. 12V Battery Prior to Radiant Exposure Test.

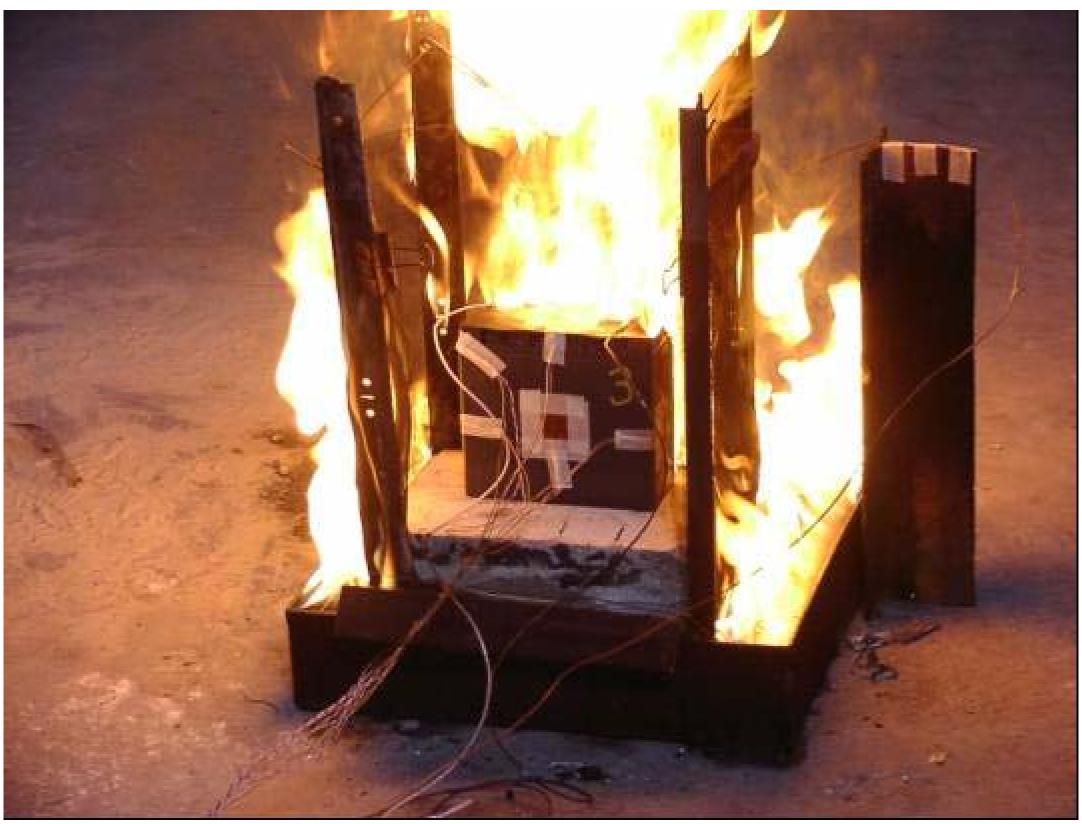

Figure B-20. 12V Battery Immediately after Ignition During Radiant Exposure Test.

Figure B-21. 12V Battery Following Radiant Exposure Test.

Figure B-22. 36V Battery prior to Radiant Exposure Test.

Figure B-23. 36V Battery at Beginning of Radiant Exposure Test.

Figure B-24. Ignition of 36V Battery During Radiant Exposure Test.

Figure B-25. 36V Battery Following Radiant Exposure Test No. 1.

Figure B-26. 36V Battery Following Radiant Exposure Test No. 2.

Figure B-27. 12V Battery prior to Short Circuit Test.

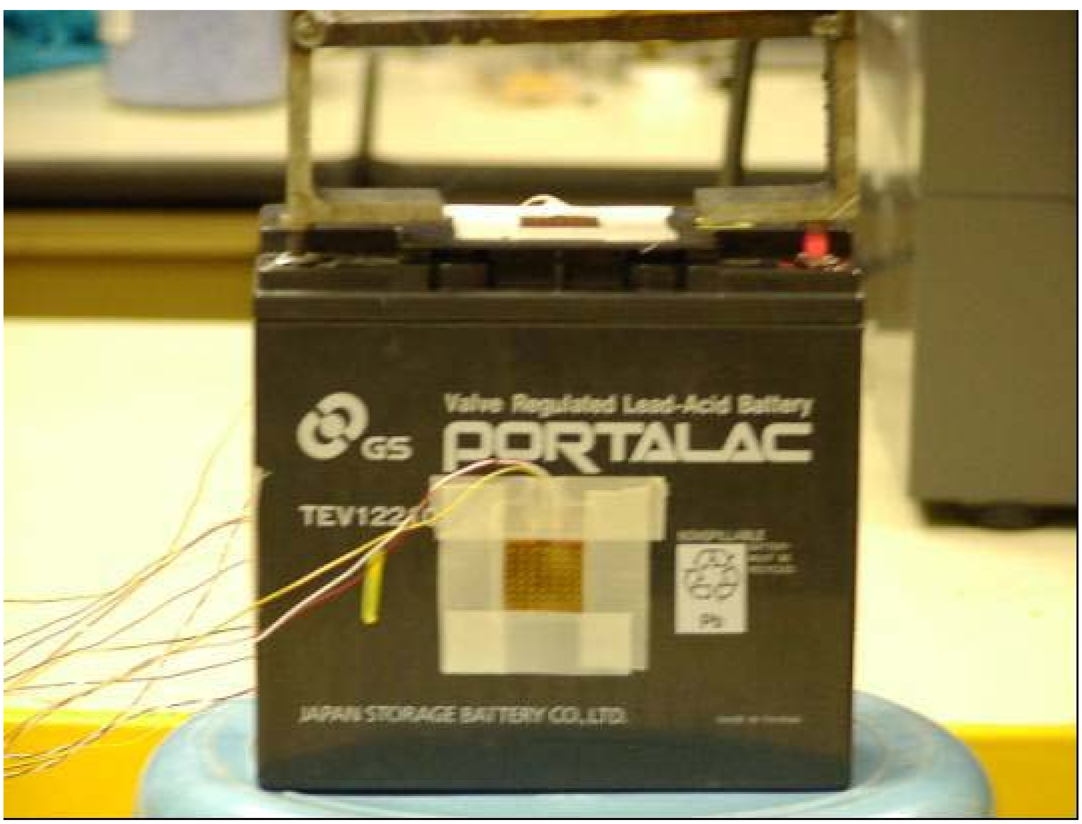

Figure B-28. 12V Battery after Application of Hard Short (Note Red-Hot Stem).

Figure B-29. Application of Hard Short to 36V Battery.

Figure B-30. Red-Hot Peg Shown after Application of Hard Short to 36V Battery.