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Abuse Tests on Sealed Lead-Acid Batteries

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ABUSE TESTS ON SEALED LEAD-ACID BATTERIES

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ABSTRACT

Abuse tests were conducted on the lead-acid batteries used to power electrical testers used at the Department of Energy's Pantex Plant. Batteries were subjected to short circuits, crushes, penetrations, and drops. None of the observed responses would be a threat to nuclear explosive safety in a bay or cell at Pantex. Temperatures, currents, and damage were measured and recorded during the tests.

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SUMMARY

Sealed lead-acid batteries are used at the Pantex Plant. Some of the batteries are used to power electrical testers that are listed on the Master Tester List (MTL). Such testers connect to the electrical circuitry in nuclear explosives. Because such testers are used in close proximity to nuclear explosives, it is important they have safe responses[a] to all credible normal and abnormal environments. Lead-acid batteries used in MTL testers must be evaluated.

Prior to the work described here, sealed lead-acid batteries had been used in MTL testers for at least 15 years. There was neither a record nor a report of any unsafe response from this type of battery. Also, when asked, battery engineers at Sandia National Laboratories and sales engineers at Panasonic, the manufacturer of the batteries, stated that the types of sealed lead-acid batteries used in MTL testers would have safe responses to short circuits and other abuses.

Tests were conducted to obtain data on the responses of batteries to short-circuit conditions, to crush, to penetration, and to drop. The tests were conducted on 12 V batteries rated at 2.3 ampere-hours (Ahr), 4 Ahr, and 5 Ahr. No response that would challenge nuclear explosive safety was observed. In some short-circuit tests, battery temperatures approached 130°C; that is, they became hot enough to cause minor burns. (Technicians should be made aware of this hazard.) Leakage of acid was observed after tests in which battery cases were broken. Breakage occurred in crush tests and penetration tests. Breakage did not occur after drops from a height of four feet onto a concrete floor.

The test data support the continued use of sealed lead-acid batteries in MTL testers.

[a] Safe responses are those that do not release energy or material that could challenge the safety of operations, require evacuation of the work area, or require actions from emergency response teams. A temperature rise that did not lead to burning or excessive electrical output would be a safe response. The release of acid gel into a tester cabinet would be undesirable, but by itself would be safe. Burning and explosion are examples of unsafe responses.

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INTRODUCTION

Sealed lead-acid batteries are used to power Master Tester List (MTL) testers at the Department of Energy's Pantex Plant. An MTL tester is a tester that connects to the electrical circuitry in nuclear explosives, thus extreme care is exercised in the design of such testers. Many MTL testers are powered by batteries, rather than from ac power, to isolate nuclear explosives from high voltage transients and other electrical disturbances that could occur on the plant electric service.

Sealed lead-acid batteries have many advantages as a source of electric power for testers. They are available with suitable voltage ratings and ampere-hour ratings. They have acceptable energy per unit volume and energy per unit weight, they are rechargeable, and they have good service life. They are affordable and used extensively by the general public to power electronic devices such as camcorders.

It is important that batteries used in MTL testers have safe responses[a] to credible abnormal environments. The use of these batteries in consumer electronics suggested that the batteries would remain safe when exposed to the expected abnormal conditions for consumer electronics. Applications specialists at Panasonic[b] and battery specialists at Sandia assured tester engineers that sealed lead-acid type batteries would remain safe when exposed to the abuses just mentioned. This type of battery has been used for many years at Pantex without incident. Before the test program described in this report, there were no data from abuse tests to confirm the assurance of safe response received from specialists and inferred from experience. A series of tests was performed to obtain data on the response of batteries to short circuits, crushes, penetrations, and drops.

The test program is described in the next section. Test results are provided, a discussion of the tests and of the results is given, and final comments are presented.

TEST PROGRAM AND TEST RESULTS

Batteries used in MTL testers or planned for use in these testers were evaluated. Panasonic batteries with ratings of 2.4 ampere-hours (Ahrs), 4 Ahrs, and 5 Ahrs at 12 V were tested. Model numbers and other details are shown in Table 1, and photographs of the batteries are shown in Figure 1. The photographs in Figure 1 also define the top, front, and side faces of the batteries.

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[a] Safe responses are those that do not release energy or material that could challenge the safety of operations, require evacuation of the work area, or require actions from emergency response teams. A temperature rise that did not lead to burning or excessive electrical output would be a safe response. The release of acid gel into a tester cabinet would be undesirable, but by itself would be safe. Burning and explosion are examples of unsafe responses.
[b] The batteries that were tested were manufactured by Panasonic, Inc.

Table 1. Battery specifications.

	Model Number		
Characteristic	LC-SA122R3CU	LCR-12V4BP	LC-R125P
Amp-hr rating	2.3	4	5
Height (mm)	23.9	102	102
Width (mm)	61	90	90
Length (mm)	182	70	70
Weight (kg)	0.63	1.7	1.9

The batteries were fully charged in accordance with manufacturer's instructions before they were tested. All tests were conducted in a battery test cell that could safely contain the outcome of any violent response from the batteries.

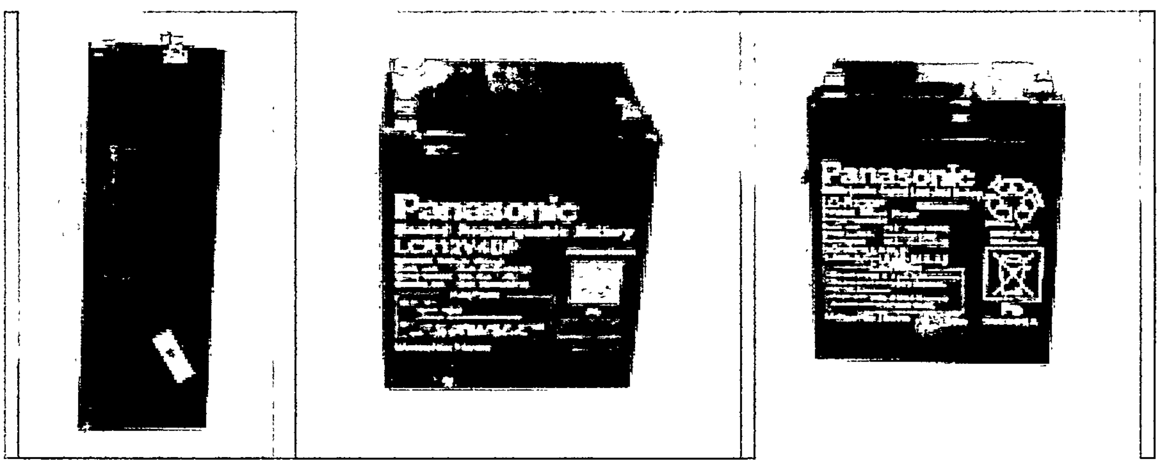

Figure 1. Photographs of the batteries. A 2.3-Ahr battery is shown on the left, a 4-Ahr battery is shown in the center, and a 5-Ahr battery is shown on the right.

Short-Circuit Tests

Two units of each model were tested. One unit was tested in a circuit shown in Figure 2. It contained a shorting switch, a 60 milliohm load resistor and a 10 milliohm current viewing resistor (CVR). The resistance of the connectors and switch was less than 2 milliohms. The second unit was tested in the circuit shown in Figure 3. It contained only a shorting switch and the battery.

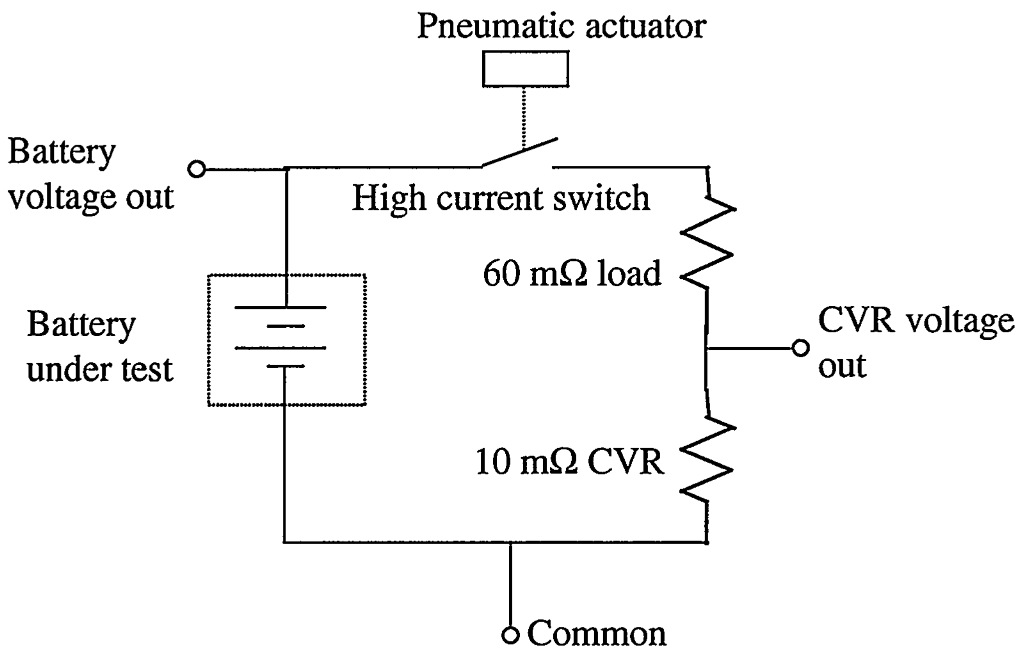

Figure 2. Battery test circuit with 60-millohm load and 10-millohm CVR. This circuit is referred to as Circuit 1 in the text.

The pneumatic actuator was operated remotely from a laboratory that was separated from the test cell by thick concrete walls. Measurement equipment was in the same laboratory as the remote controls. A video link between the test cell and the laboratory allowed viewing the batteries during tests.

The temperatures recorded when 2.3 Ahr battery SN790 was tested in Circuit 1 are shown in Figure 4. The temperatures were measured with thermocouples attached to the front face and to the top face of the battery. The current recorded in the same test is shown in Figure 5.

It is seen in Figure 4 that both temperatures peaked at about 55°C. It is seen in Figure 5 that the highest current during the short-circuit test was approximately 72 amperes.

Figure 6 shows the temperatures measured when a second battery of the same type was tested in Circuit 2. It is seen that the temperatures measured at the top of the battery were similar to those measured on battery SN790. However, it is seen in Figure 6 that the temperatures measured on the face of the battery were lower. It is not known why the face temperatures measured in the two tests were different.

The results obtained when 4 Ahr batteries were subjected to short-circuit tests are shown in Figures 7 through 9.

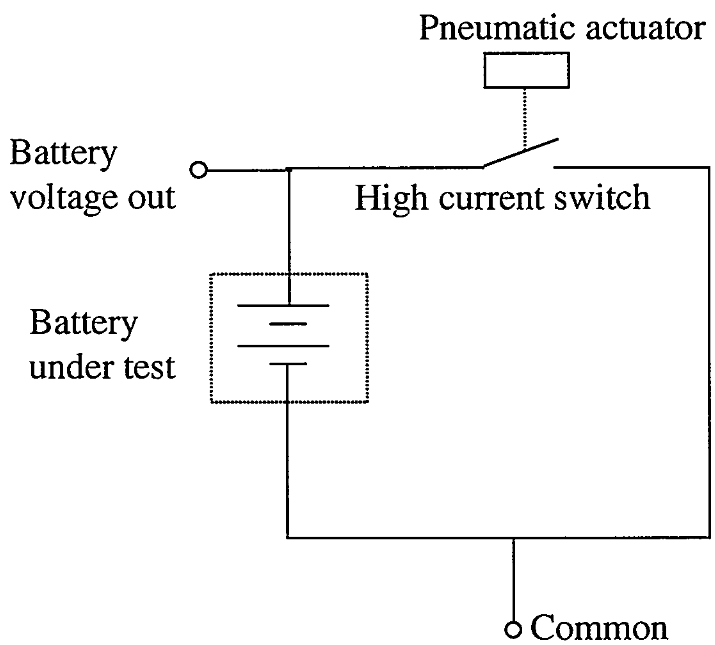

Figure 3. Battery test circuit without load and without CVR. This circuit is referred to as Circuit 2 in the text.

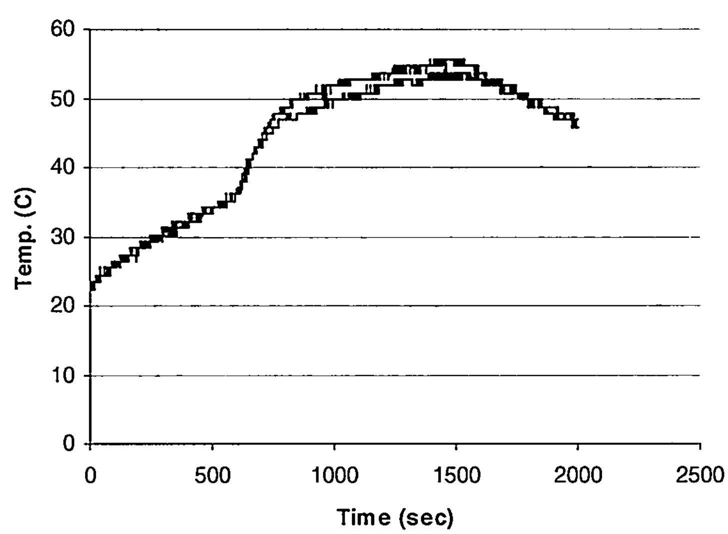

Figure 4. The temperatures recorded on the front face (upper line) and on the top face (lower line) when 2.3 Ahr SN790 was tested in Circuit 1.

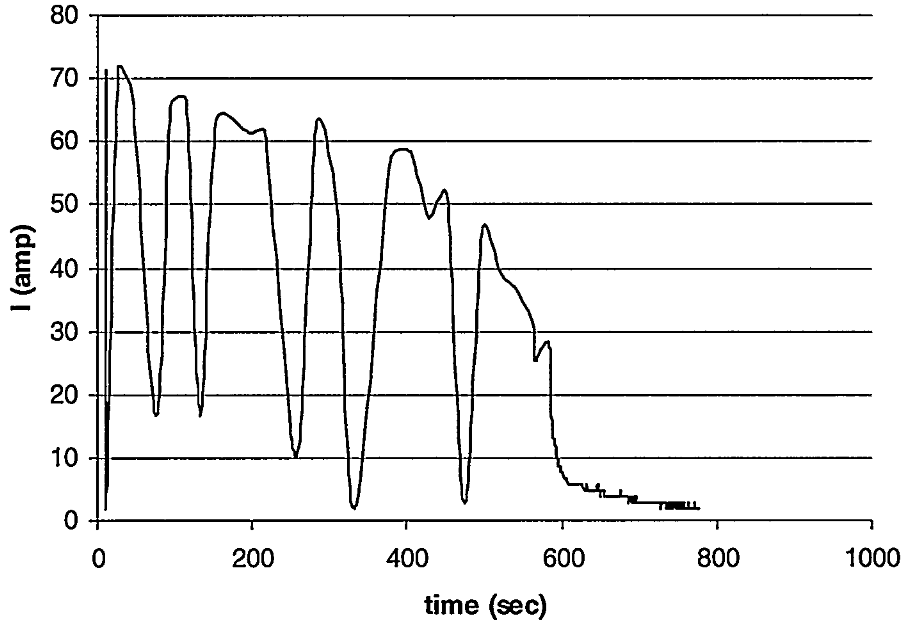

Figure 5. The current recorded when the 2.3-Ahr battery SN790 was tested in Circuit 1. The oscillatory waveform occurred because the battery contained a positive temperature coefficient safety device. This device operated to reduce the output current when the battery became hot.

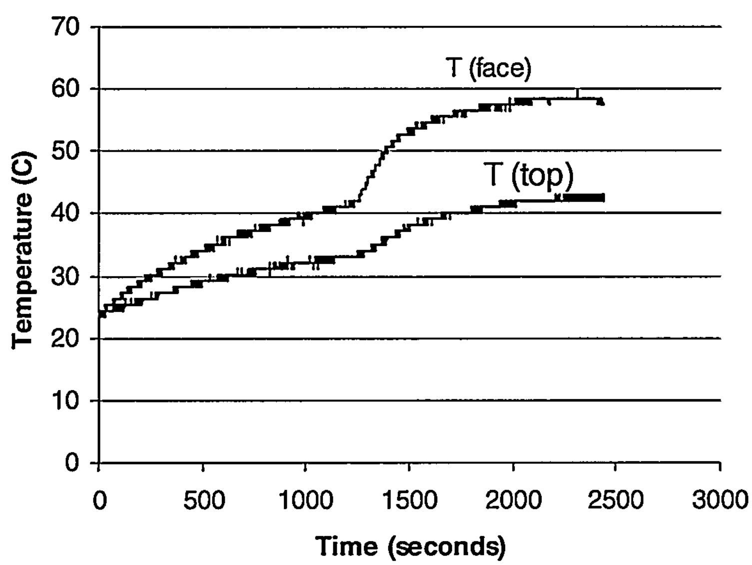

Figure 6. The temperatures measured when the 2.3-Ahr battery SN791 was tested in Circuit 2.

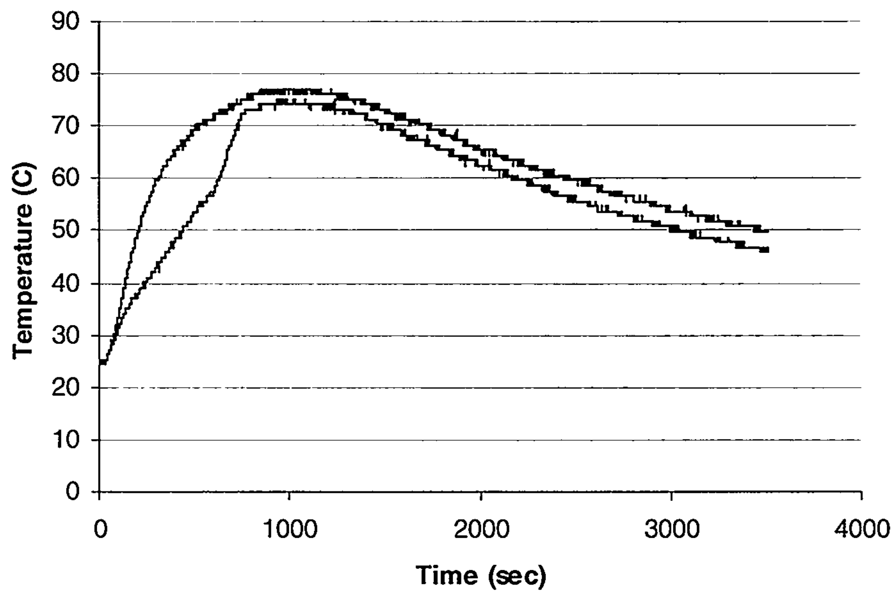

Figure 7. The temperatures measured when the 4-Ahr battery SN786 was tested in Circuit 1. The upper line shows temperatures measured on the face, and the lower line shows temperatures measured on the top.

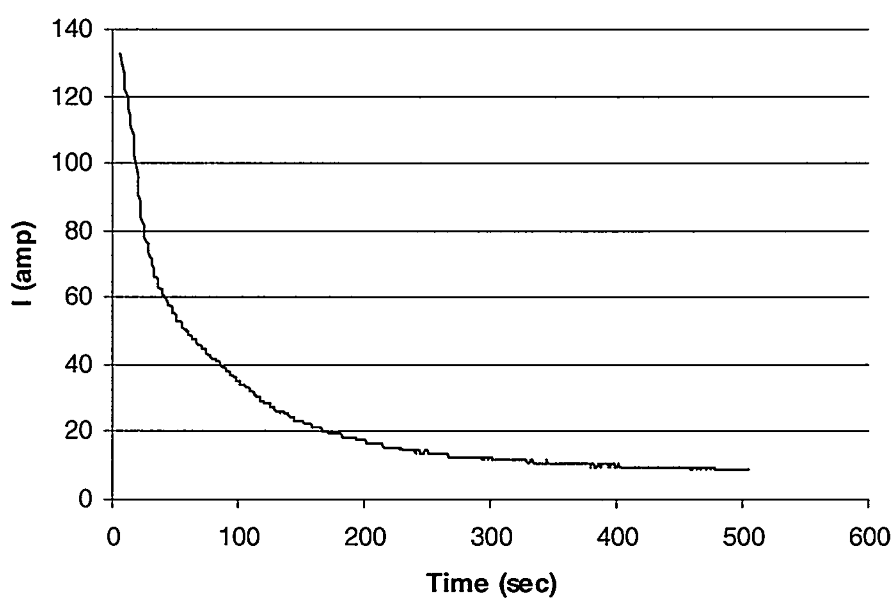

Figure 8. The current measured when the 4-Ahr battery SN786 was tested in Circuit 1.

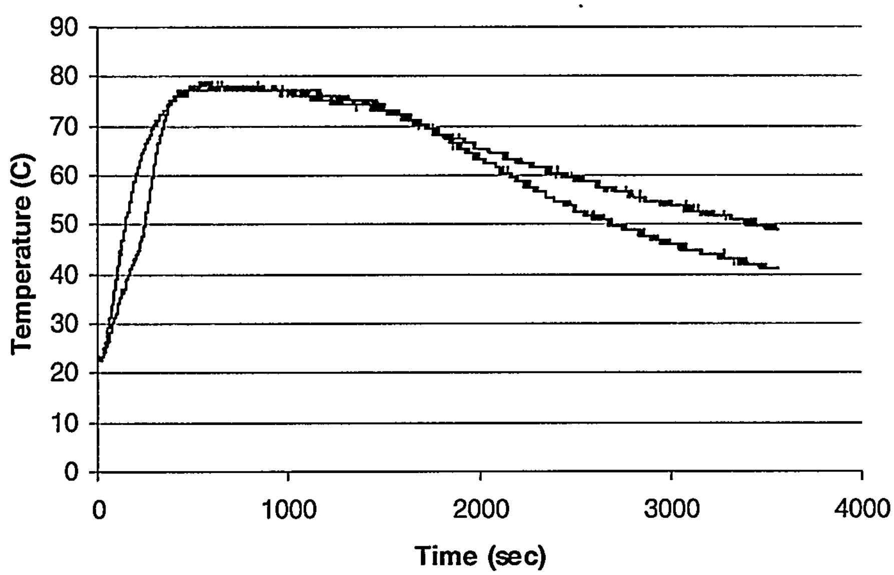

Figure 9. The temperatures measured on the face (top line) and the top (bottom line) when the 4-Ahr battery SN787 was tested in Circuit 2.

Temperatures and currents measured when 5 Ahr batteries were tested are shown in Figures 10 through 12.

As is shown in Figure 12, higher temperatures were measured at the top of the battery than at the face of the battery. The data show that the measurement equipment did not record the highest temperatures. This occurred because amplifiers in the data acquisition system saturated. It is estimated that the peak temperature was approximately 130°C. No venting or seepage of electrolyte was observed. In the other five short-circuit tests, the highest temperatures were measured at the face of the battery. It is not known why different results were obtained for battery SN789.

No violent response was observed in any of the tests. Furthermore, neither venting of steam nor acid, nor deformation of any battery case was observed. The highest temperatures observed are hundreds of degrees below the ignition temperature of tester components.

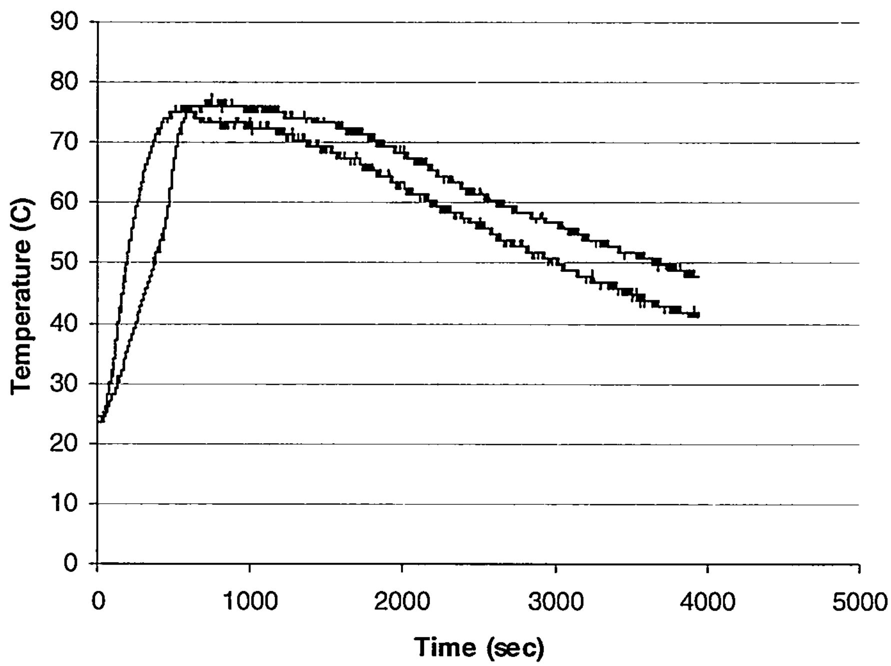

Figure 10. The temperatures measured when the 5-Ahr battery SN788 was tested in Circuit 1. The upper line shows the temperatures measured on the face of the battery.

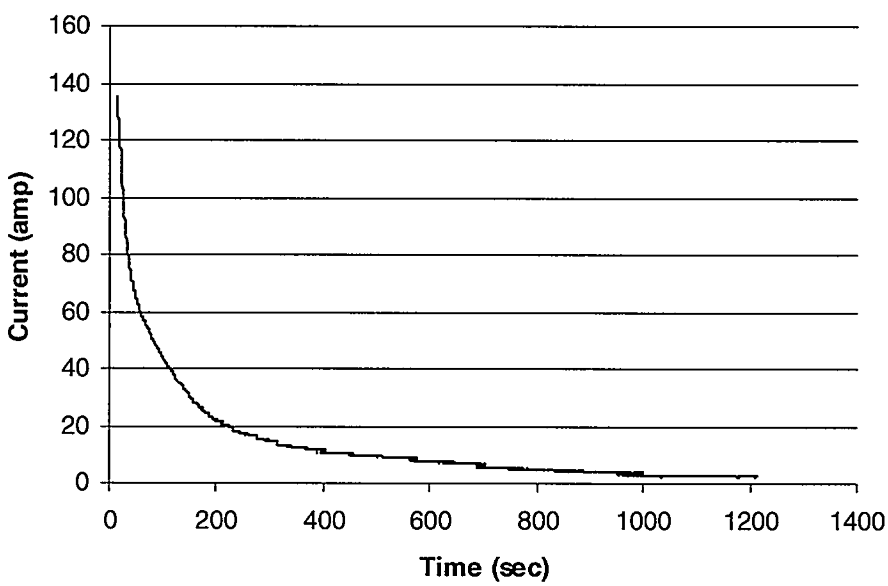

Figure 11. The current measured when the 5-Ahr battery SN788 was tested in Circuit 1.

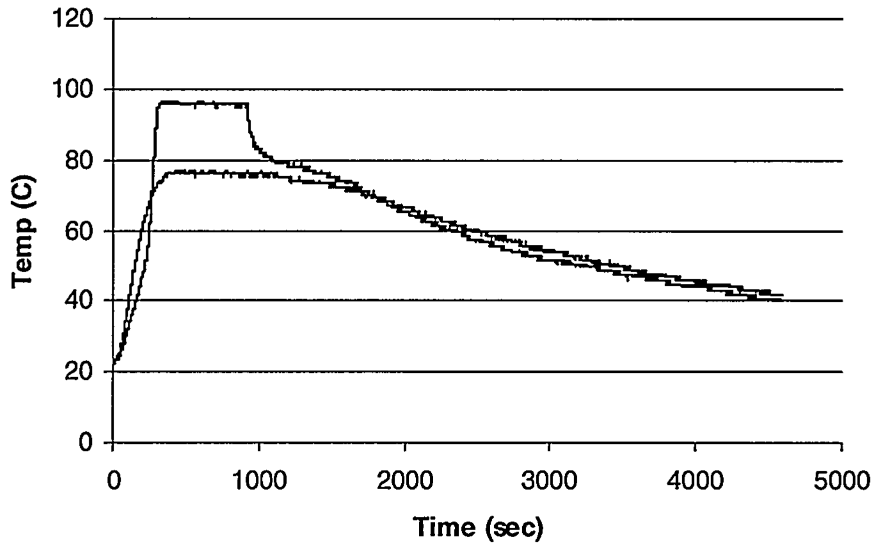

Figure 12. The temperatures measured on the face and on the top (the line that has a plateau at about 95 °C) when the 5-Ahr battery SN789 was tested in Circuit 2.

Crush and Penetration Tests

The test setup used for uni-axial crush and for penetration is shown in Figure 13. To simulate crush of 2.3-Ahr batteries, an aluminum bar 4 in. long with a 1-in. x 1-in.- (25 mm by 25 mm) square cross section was pressed into a battery. The rate of travel of the bar was approximately 1 in. per second. The results are shown in Figure 14. To simulate crush of the larger batteries, a 7-in. long hexagonal bolt head was pressed through the battery under test. Results are shown in Figures 15 and 16. The distance between opposite faces on the hexagonal bolt head was 1 ½ in. (38 mm).

Battery voltages and temperatures (at three locations) were recorded during the crush tests. The records for the 2.3 Ahr battery did not indicate any drop in cell voltage or any significant increase in battery temperature. These results suggest that, although the battery was significantly deformed, short-circuiting of cells did not occur. The records for the 4-Ahr and 5-Ahr batteries show definite voltage drops and increases in battery temperature. Data on temperature increases are given in Table 2 (shown after Figure 16).

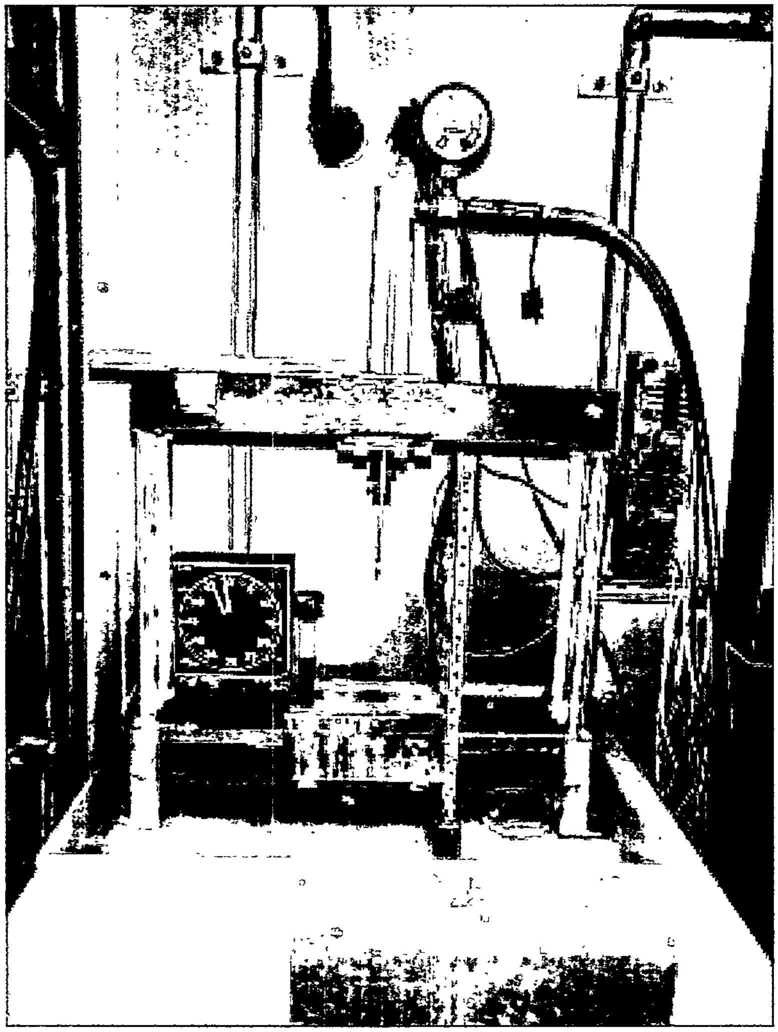

Figure 13. The photograph shows the test setup used for crush and penetration tests and a brass penetration rod mounted in the hydraulic ram.

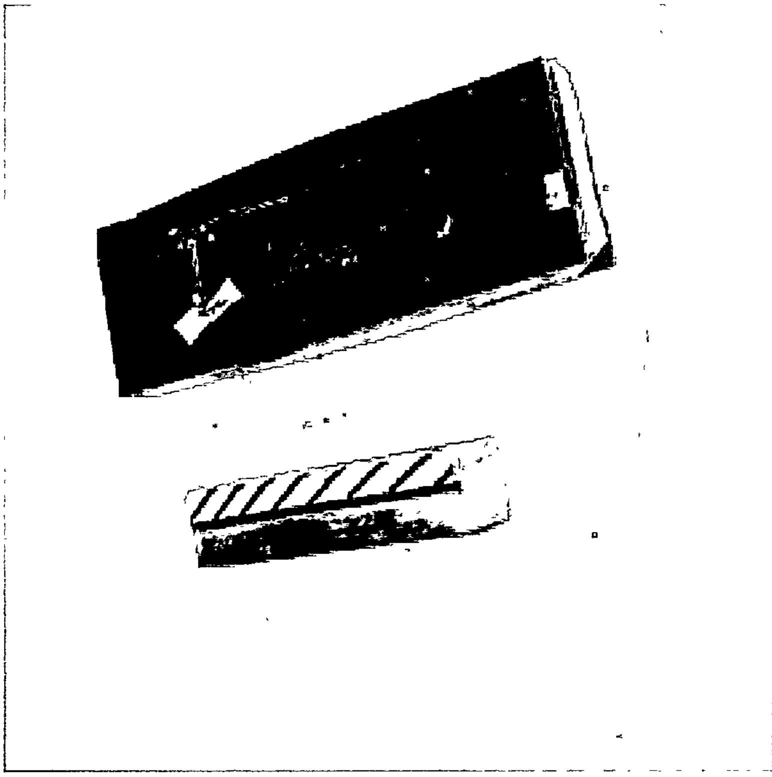

Figure 14. The photograph shows a 2.3-Ahr battery after the aluminum block shown in the lower part of the picture was pressed into it.

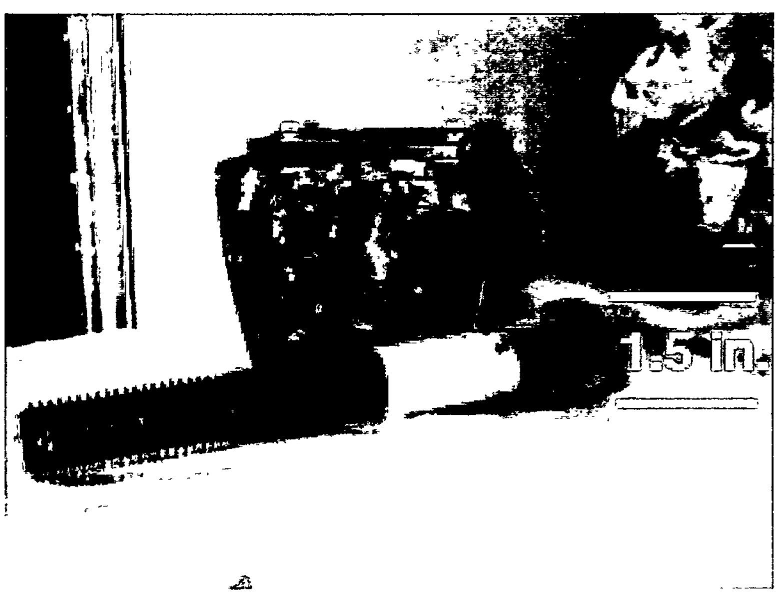

Figure 15. The photograph shows a 4-Ahr battery after the hexagonal head of a bolt was pressed through it.

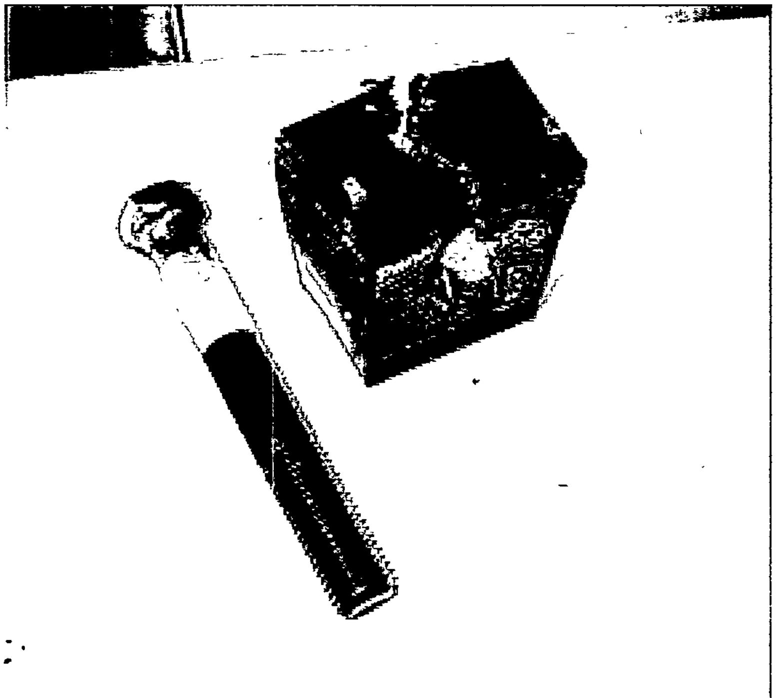

Figure 16. The photograph shows a 5-Ahr battery after the hexagonal head of a bolt was pressed through it.

Figures 17 through 19 show photographs of batteries that had been penetrated by a 3/16-in.- (4.8 mm) diameter brass rod. One test was conducted on a 2.3-Ahr battery, and two tests were conducted on 5 Ahr batteries. No penetration tests were conducted on 4 Ahr batteries because it was thought that the most extreme responses would be recorded for 5 Ahr batteries.

Table 2. The maximum temperatures recorded on the external surfaces of the batteries during the various tests.

Test	Battery		
	2.3 Ahr	4 Ahr	5 Ahr
Short Circuit	59°C	79°C	≈ 130°C
Crush	31°C*	87°C	50°C
Penetration	64°C	82°C	85°C

* Records indicate that no internal shorting occurred

Figure 17. The photograph shows a 2.3-Ahr battery that has been penetrated by a 3/16-in.-diameter brass rod. The top of the battery was crushed by the chuck that held the rod.

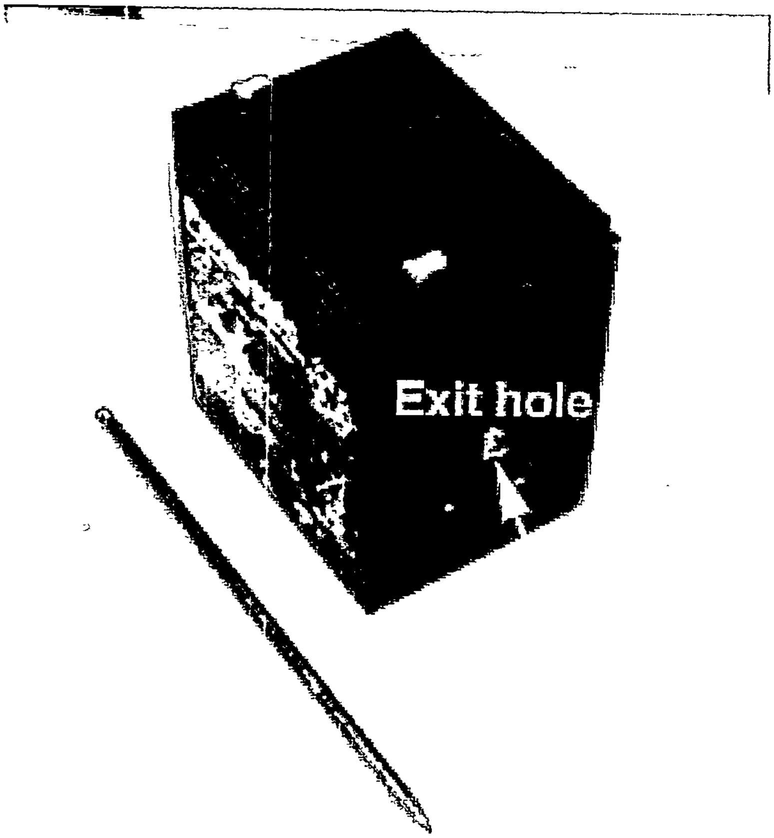

Figure 18. The photograph shows a 5-Ahr battery that has been penetrated from side –to side by a 3/16-in.-diameter brass rod.

Figure 19. The photograph shows a 5-Ahr battery that had been penetrated from front face –to back face by 3/16-in.-diameter brass rod. The entrance hole is shown.

Drop Tests

One battery of each type was dropped from a height of 4 feet (1.2 m) onto a concrete floor. The test setup is shown in Figure 20. The battery under test was pushed off the ladder step, fell to the concrete flour, and bounced until it came to rest. The wires shown on the floor in Figure 20 were not present during the drop tests. Open circuit voltage was recorded during each test. The test records show that all open circuit voltages stayed constant throughout the drops, falls, and bounces.

After the tests, there was no visible damage to the 2.3-Ahr battery nor to the 5-Ahr battery. There was slight visible damage to one corner of the 4 Ahr battery. There was so little damage to the batteries that the post-drop-test photographs of the batteries were used to show the original shape and condition of the batteries used for the study. The post-test photographs are those shown in Figure 1. The slight damage to the 4-Ahr battery is at the upper right front corner.

Figure 20. The setup used for drop tests is shown. The drop height was 4 feet (1.2 m).

DISCUSSION

Samples of three sealed lead-acid batteries used in MTL testers at the Pantex Plant were subjected to short circuits, to crush, to penetration by a metal rod, and to impact after a four foot drop. A total of 15 batteries were tested as follows: two of each type were short-circuited, one of each type was crushed, one 2.3-Ahr and two 5-Ahr batteries were penetrated with a brass rod, and one of each type was dropped. No violent or dangerous reactions were observed. Some acid did leak out after battery cases were broken by crush or penetration.

The temperatures recorded during short-circuit tests were hundreds of degrees Celsius below the ignition temperatures of tester components. However, technicians who might touch a battery that is at the highest temperature observed might be burned. Such contact is extremely unlikely in weapon assembly areas because all batteries are internal to testers. Short-circuiting and subsequent contact with a hot battery might occur during calibration or maintenance. This sequence would not pose a challenge to nuclear explosive safety because calibration and maintenance are done in special areas in which there is no work on nuclear explosives. However, instrument technicians should be made aware of the possibility of a burn from a short-circuited battery.

There was little or no visible damage to the batteries after they were dropped 4 feet onto a concrete floor. The open-circuit voltage from the batteries was the same before, during, and after each drop test. The principle dangerous response was the leakage of some acid after crush and penetration tests. Leakage was expected because the outer battery case was damaged in these tests.

The tests confirmed expert opinion that tested batteries would have safe responses to the various abuses. The tests did not show that a sealed lead-acid battery would never have an unsafe response to an abnormal environment. This could not be shown by the limited number of tests that were conducted.

CONCLUSIONS

Sealed lead-acid batteries are used extensively at the Pantex Plant to power MTL testers. Prior to the test program described in this report, application engineers at Panasonic and battery engineers at Sandia had stated that the batteries would have safe responses to abuses such as short circuit, crush, penetration, and drop. However, there were no test data to support their opinions. The results obtained in the test program confirm the expert opinion. However, technicians should be alerted to the possibility of a burn from a short-circuited battery and the possibility of contact with acid gel.

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