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Identification of the Specific Mechanism by which the CO_2 System in Building TRA-648 Accidentally Discharged

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ABSTRACT

This report provides information obtained since the Type A Accident Investigation Board Report of the July 28, 1998, *Fatality and Multiple Injuries Resulting from Release of Carbon Dioxide at Building 648, Test Reactor Area Idaho National Engineering and Environmental Laboratory* (EH2PUB/09-98/01AI) was issued. This report responds to the judgment of need in the Investigation Report that directed Lockheed Martin Idaho Technologies Company to identify the specific mechanism by which the CO_2 system in Test Reactor Area Building 648 discharged on July 28, 1998. It also describes the testing and analysis of Notifier AFP-200 Analog Fire Panels, including the panel installed in Test Reactor Area Building 648, that was performed by independent laboratories and Lockheed Martin Idaho Technologies Company to determine the specific mechanism that caused the CO_2 system to discharge without warning.

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EXECUTIVE SUMMARY

On September 18, 1998, the Department of Energy (DOE) issued the *Type A Accident Investigation Board Report of the July 28, 1998, Fatality and Multiple Injuries Resulting from Release of Carbon Dioxide at Building 648, Test Reactor Area Idaho National Engineering and Environmental Laboratory* (Investigation Report). One of the judgments of need directed Lockheed Martin Idaho Technologies Company (LMITCO) to determine the specific mechanism by which the CO_2 system in Test Reactor Area Building (TRA-648) discharged. This report summarizes results of testing done by two independent laboratories and LMITCO to determine the mechanism that caused the CO_2 system to discharge.

The specific mechanism that caused the CO_2 system to discharge without warning was a design defect in the Notifier AFP-200 Analog Fire Panel. The design defect caused the activation of the output circuits to the CO_2 releasing solenoids, bypassing the predischarge warning alarm, immediately following interruption of 120 volt AC power to the Notifier AFP-200 Analog Fire Panel. The Notifier AFP-200 Analog Fire Panel has a design defect that under specific circumstances may cause random activation of the output circuits. The design defect is largely masked when the Notifier AFP-200 Analog Fire Panel is employed with the internal battery charger. If the AFP-200 panel is configured to use the internal charger, actuation of the solenoids can occur on loss of AC power if the DC backup batteries are not connected or are defective. However, if the AFP-200 panel is configured for an external charger, actuation of the solenoids can occur with any condition that causes interruption of 120 volt AC power. The frequency of activation increases with elevated ambient alarm panel temperatures.

As testing and analysis has revealed the precise nature of the design defect in the AFP-200 Analog Fire Panel, LMITCO has shared this information with the Department of Energy complex and the fire protection community. LMITCO issued a letter of notification of safety issues associated with the Notifier AFP-200 Analog Fire Panel to Notifier November 10, 1998, and a Red Lessons Learned to the Department of Energy community on November 20, 1998. On January 13, 1999, LMITCO sent letters summarizing the testing results to OSHA, UL, FM, and other organizations that had listed or approved the AFP-200 Analog Fire Panel.

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FIGURES

ACRONYMS

AC	alternating current
CLK	clock pin
CO_2	carbon dioxide
DC	direct current
DOE	U.S. Department of Energy
DOE-ID	Department of Energy Idaho Operations Office
FM	Factory Mutual
INEEL	Idaho National Engineering and Environmental Laboratory
JON	judgment of need
LMITCO	Lockheed Martin Idaho Technologies Company
NFPA	National Fire Protection Association
OSHA	Occupational Safety and Health Administration
TRA	Test Reactor Area
UL	Underwriters Laboratory
VDC	volts of direct current
VR	voltage regulator

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NOMENCLATURE

Bell circuit	One of four output circuits connected to terminal block 2 of the Notifier AFP-200 Analog Fire Panel. These circuits are used (1) to control notification appliances (audible or visual alarms, bells, strobes), or (2) to control releasing devices which discharge fire extinguishing agents, or (3) to control preaction/deluge systems.
Dranetz meter	An instrument that measures and records waveforms, amplitude, and frequency of electronic signals.
High pressure CO_2	Carbon dioxide gas stored at ambient temperature in steel cylinders (approximately 850 psi at 70°F).
Kidde control head	An electrical/mechanical assembly attached to the CO_2 cylinder valve assembly that opens the valve, thus discharging the CO_2 from the storage cylinders.
Listed	Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets identified standards or has been tested and found suitable for a specified purpose.
Oscilloscope	An electronic laboratory instrument that produces an instantaneous trace on the screen of a cathode-ray tube corresponding to voltage waveforms. It may be used to measure voltages within the fire alarm control panel.
Pulse	A change in a signal typically characterized by a rise and a decay of finite duration.
Release solenoid	(See Solenoid)
Signal	An electrical waveform that conveys information or instructions.
Solenoid	An electrical/mechanical assembly that operates when supplied electrical energy. A solenoid is part of the Kidde control head attached to the CO_2 storage cylinders that discharges the CO_2 system.
Spurious pulse	An unwanted (false) change in an electrical waveform which may convey false information or false instructions (see spurious signal).
Spurious signal	A unwanted signal conveying false information or unwanted instructions.
Terminal block	Connection point for incoming and outgoing conductors.

Identification of the Specific Mechanism by which the CO_2 System in Building TRA-648 Accidentally Discharged

1. INTRODUCTION

1.1 Background

On July 28, 1998, thirteen workers, including foremen, operators, electricians, and fire protection personnel, were engaged in deenergizing electrical circuit breakers in preparation for a preventive maintenance activity on the electrical system in Building TRA-648 of the Engineering Test Reactor Facility at the Test Reactor Area (TRA) on the Idaho National Engineering and Environmental Laboratory (INEEL). As the last 4160 volt circuit breaker was opened, the carbon dioxide (CO_2) fire suppression system unexpectedly discharged without the annunciation of the evacuation warning alarm. Eight workers, including a fire protection engineer, were able to escape from the facility unassisted. Immediately after exiting the facility, at 6:15 p.m., the fire protection engineer radioed the alarm center in the INEEL Central Facilities Area and a fire truck and ambulance were dispatched, which arrived at 6:25 p.m. The workers who had escaped from TRA-648, security officers, and members of the Advanced Test Reactor Incident Response Team were able to rescue three of the remaining personnel from the building. The Fire Department and ambulance personnel removed the last two workers. The accident resulted in one fatality from exposure to the CO_2 atmosphere and injuries to three other workers who required hospitalization. The accident resulted from the unexpected activation of electric control heads that initiated the release of CO_2, without annunciation of the predischarge warning alarm.

On July 29, 1998, Peter N. Brush, Acting Assistant Secretary, Environment, Safety and Health of the U.S. Department of Energy (DOE) appointed a Type A Accident Investigation Board (Board) to investigate the accident in accordance with DOE Order 225.1A, "Accident Investigations." The Board began its investigation on July 29, 1998. The investigation concluded on August 28, 1998, and the findings were reported to the DOE Acting Assistant Secretary for Environment Safety and Health on August 31, 1998. The Board's report, *Type A Accident Investigation Board Report of the July 28, 1998, Fatality and Multiple Injuries Resulting from Release of Carbon Dioxide at Building 648, Test Reactor Area Idaho National Engineering and Environmental Laboratory*, EH2PUB/09-98/01AI,[1] (Investigation Report) was released on September 18, 1998. The Investigation Report identified 22 judgments of need (JON) to which the Department of Energy Idaho Operations Office (DOE-ID) and Lockheed Martin Idaho Technologies Company (LMITCO) were required to develop responses.

In response, DOE-ID and LMITCO issued the *Consolidated Response to the Type A Investigation of CO_2 Fatality at Test Reactor Area, Idaho National Engineering and Environmental Laboratory*, DOE/ID-10699, INEEL/EXT-98-01020,[2] (Consolidated Response), which describes the actions that DOE-ID and LMITCO are taking to answer the Board's judgments of need (JONs).

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1. U. S. Department of Energy, "Type A Accident Investigation Board Report of the July 28, 1998, Fatality and Multiple Injuries Resulting from Release of Carbon Dioxide at the Building 648, Test Reactor Area, Idaho National Engineering and Environmental Laboratory," EH2PUB/09-98/01A1, "Final Report," September 1998.

2. Lockheed Martin Idaho Technologies Company, "Consolidated Response to the Type A Investigation of CO_2 Fatality at Test Reactor Area, Idaho National Engineering and Environmental Laboratory," DOE/ID-10699, INEEL/EXT-98-01020, October 1998.

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1.2 Report Scope

This report addresses technical issues associated with the CO_2 accident, including the results of an investigation to determine the specific mechanism that caused the non-fire initiated discharge of the CO_2 fire suppression system in TRA-648, as specified in the JON in the Investigation Report (p. viii), which states:

> "LMITCO needs to determine the specific mechanism by which the CO_2 system in Building 648 discharged on July 28, 1998, and take actions as appropriate to avoid a recurrence in the future. Until this is done, the CO_2 system in Building 648 should remain out of service and compensatory fire protective measures implemented, as appropriate."

The LMITCO review effort included facilitation and technical support by qualified personnel from other Lockheed Martin companies, and independent laboratories and industry experts. In particular, LMITCO acquired the services of Guardian Services, Inc., a fire protection industry expert from Frankfort, Illinois to provide technical review and input to the LMITCO Technical Response Team. LMITCO also acquired the services of Tronamix, Inc., an independent electronic design and testing laboratory from Orland Park, Illinois; and MET Laboratories, Inc., an independent Nationally Recognized Testing Laboratory (NRTL) from Baltimore, Maryland, to conduct circuit analysis and testing of the AFP-200 Analog Fire Panel (also referred to as the AFP-200 panel, and AFP-200) to identify and verify the specific mechanism by which the CO_2 system in TRA-648 discharged. Summary reports from testing at the independent laboratories are in Appendices A and B of this report. The independent testing laboratories tested Notifier AFP-200 Analog Fire Panels and associated devices, and determined the failure mode. The results of the testing and analysis are presented in Section 2 of this report.

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2. THE SPECIFIC MECHANISM BY WHICH THE CO_2 SYSTEM IN BUILDING 648 DISCHARGED

One of the JONs in the DOE Investigation Report (pp. viii and 42) instructed LMITCO to

> "determine the specific mechanism by which the CO_2 system in Building 648 discharged on July 28, 1998, and take actions as appropriate to avoid a recurrence in the future."

This section of the report describes the specific mechanism by which the CO_2 system in TRA-648 discharged on July 28, 1998. It also describes the way that LMITCO identified the specific discharge mechanism.

2.1 Background and Direct Cause

A Notifier AFP-200 panel was installed in TRA-648 in 1997 to replace an older CO_2 discharge panel that was not compatible with the upgraded INEEL fire alarm system. Kidde electric control heads were connected to the AFP-200 panel output circuits on Terminal Block 2. These output circuits are referred to as "notification appliance" or "bell" circuits. The bell circuits may be used to operate notification appliances, such as bells, horns, or strobe lights; or releasing devices that discharge a fire extinguishing agent, such as CO_2. National Fire Protection Association (NFPA) standards require that devices connected to the bell circuits be listed or approved for compatibility. The Kidde electric control heads are listed and approved for compatibility with the AFP-200 bell circuits. The AFP-200 panel was installed with 55 ampere-hour (amp hour) batteries to meet the DOE-ID Architectural Engineering Standard[3] requirement for 60 hours of battery backup. An NR45-24 Remote Battery Charger (external charger) was installed as required by Notifier for systems using 20 amp hour or larger batteries.[4]

The Kidde heads were electrically activated on July 28, 1998, when alternating current (AC) power was disconnected from the Notifier AFP-200 panel. The activation of the control heads discharged the CO_2 fire extinguishing system into TRA-648. The CO_2 system predischarge alarm did not activate. The history of events that was maintained by the AFP-200 panel did not show that the bell circuits had activated.

To discover the specific mechanism that caused the CO_2 system to discharge without warning, LMITCO established a team of experts to investigate the fire alarm circuits in TRA-648 and the Notifier model AFP-200 panel. The results of the team's research are summarized below.

The specific mechanism that caused the CO_2 system to discharge without warning was a design defect in the AFP-200 panel. This design defect consists of the following:

1. A circuit design that permits the power (voltage) to the microprocessor to drop below the microprocessor operating range (5 volts ± 10%) immediately after AC power is disconnected, and before the standby battery is connected

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3. DOE-ID, "Architectural Engineering Standard," Section 1670-5.5.3, U.S. Department of Energy Idaho Operations Office.

4. Notifier AFP-200 Analog Fire Panel Instruction Manual, P/N 15511:D, Section 2.7, "The NR45-24 Remote Battery Charger," Revision D, September 14, 1994, page 45.

2. Use of a microprocessor that generates spurious signals, which sometimes mimic valid signals to actuate the circuits that release the CO_2, during the period when the power to the microprocessor is below its operating range

3. A circuit design that permits the driver chips that control the release of CO_2 (flip-flop logic chip U21 and Darlington Array U22) to react to these spurious signals

4. A circuit design that maintains sufficient power (voltage) on the bell circuits, that is the CO_2 discharge circuits (+24 VU bus), to fire the Kidde control heads when the power to the microprocessor has dropped below its operating range.

The discharge, on the evening of July 28, 1998, was initiated by disconnecting AC power to the AFP-200 panel. The design defect described above was the specific mechanism that caused the CO_2 system to discharge without warning.

The design of the power supply and internal battery charger are such that the design defect is masked when the AFP-200 internal battery charger is used and the standby batteries are functioning properly. Under these circumstances a power back-flow (from the standby batteries through the voltage regulator (VR) VR3 in the battery charger) keeps the power (voltage) to the microprocessor within its operating range during transition from AC power to the standby batteries. When an external charger is connected to AFP-200 panel in accordance with the installation instructions in the AFP-200 Analog Fire Panel Instruction Manual,[5] the back-flow circuit is broken. Then the microprocessor power (voltage) is not maintained within its operating range during transition from AC power to the standby batteries and the AFP-200 panel may fire the CO_2 solenoids when the AC power is disconnected.

The spurious pulses generated by microprocessor do not always mimic valid signals to actuate the circuits that release the CO_2 during the period when the power to the microprocessor is reduced below its operating range. Thus, the CO_2 releasing solenoids do not always fire when the AC power is disconnected. Over 1,000 tests were performed in which AC power was disconnected from an AFP-200 panel where either the internal battery charger had been used with the standby batteries disconnected, or NR45 external battery charger had been installed. During this testing one or more of the CO_2 Kidde electric control heads fired on more than 30 occasions.

Despite the Factory Mutual (FM) approval and Underwriter's Laboratory (UL) listing, the design defect in the Notifier AFP-200 panel makes it non-compliant with NFPA 12 (1993) and NFPA 72 (1993). The specifics of the NFPA Code non-compliance are discussed in Subsection 3.1. When the control panel bell circuits are used in an approved configuration to release a CO_2 system, the design defect described above can have serious consequences—this was the case on July 28, 1998, at TRA-648.

The remainder of this section describes the investigation that identified the design defect and provides a more detailed description of this design defect. Subsection 2.2 describes the testing and circuit analysis that was performed to identify the specific mechanism that caused the accidental CO_2 discharge, and provides details about those portions of the design of the AFP-200 panel that are related to the accidental discharge mechanism. The testing described in Subsection 2.2 was performed on AFP-200 panel mockups configured like the AFP-200 panel in TRA-648. Subsection 2.3 presents the results of confirmatory testing and measurements conducted on the CO_2 fire suppression system in TRA-648. Subsection 2.4 summarizes the findings of independent experts regarding the mechanism that caused the accident. Subsection 2.5 provides additional detail about the requirements for the use of the NR45-24

5. *Ibid.*

external battery charger and its installation. Finally, Subsection 2.6 describes the testing performed to determine whether other factors suggested in the DOE Investigation Report, such as externally generated transients or externally generated electrical noise played a role in the accidental CO_2 discharge.

2.2 Testing and Analysis of AFP-200 Panel Mockups

This subsection presents the consolidated results of testing and analysis, performed primarily on Notifier AFP-200 panels configured as mock-ups of the panel in TRA-648, to determine the specific mechanism by which the CO_2 system in TRA-648 discharged. This testing and analysis was performed at LMITCO and at independent laboratories. Appendices A and B contain summary reports from the independent laboratories.

2.2.1 Circuit Analysis and Testing

A team of technical experts investigated the Notifier model AFP-200 panel and fire alarm circuits in TRA-648 to determine the specific mechanism by which the CO_2 system accidentally discharged. Two Notifier AFP-200 panels were set up at independent laboratories, and configured as mock-ups of the panel in TRA-648. The team performed tests on the mock-up panels, attempting to recreate the events of the accident and determine its cause. Testing was also performed on the incident panel at TRA-648. The team also corresponded with the panel manufacturer to uncover any panel vulnerabilities that the manufacturer would disclose. Notifier's correspondence to LMITCO (August 21, 1998) stated that:

> "Notifier's testing has shown that the AFP-200, when used with the separate NR45 charger, can be perturbed momentarily by an AC power loss or an AC voltage transient. When this perturbation occurs, it is possible that the output circuits could momentarily activate."[6]

Notifier's response only tells part of the story. It does not identify the specific mechanism that causes the output circuits to activate momentarily. Undesired operation of the output circuits revealed in the Notifier correspondence is a deficiency with potentially serious consequences. Moreover, it does not state, as determined in this investigation, that unwanted, undesired, and dangerous activation of the AFP-200 output circuits can occur immediately following interruption of AC power, even when there is no NR45 charger installed.

The response team discovered the specific mechanism by which the AFP-200 panel activates the output circuits upon AC power loss. The mechanism reflects serious deficiencies in the design of the AFP-200 panel. To understand the mechanism, two areas of the panel circuitry must be considered:

1. Output (bell) circuits
2. Internal power supply.

2.2.1.1 Output (bell) Circuit Analysis. The Kidde control heads for the CO_2 system at TRA-648 were connected to Bell Circuit 2 and Bell Circuit 3. Each of these bell circuits is functionally identical (see Figure 2-1). During the remainder of the circuit analysis, Bell Circuit 2 will be referenced.

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6. D. D. Anderson, Notifier, Senior Vice President, Engineering, Letter to Bruce Stewart, INEEL, dated August 21, 1998.

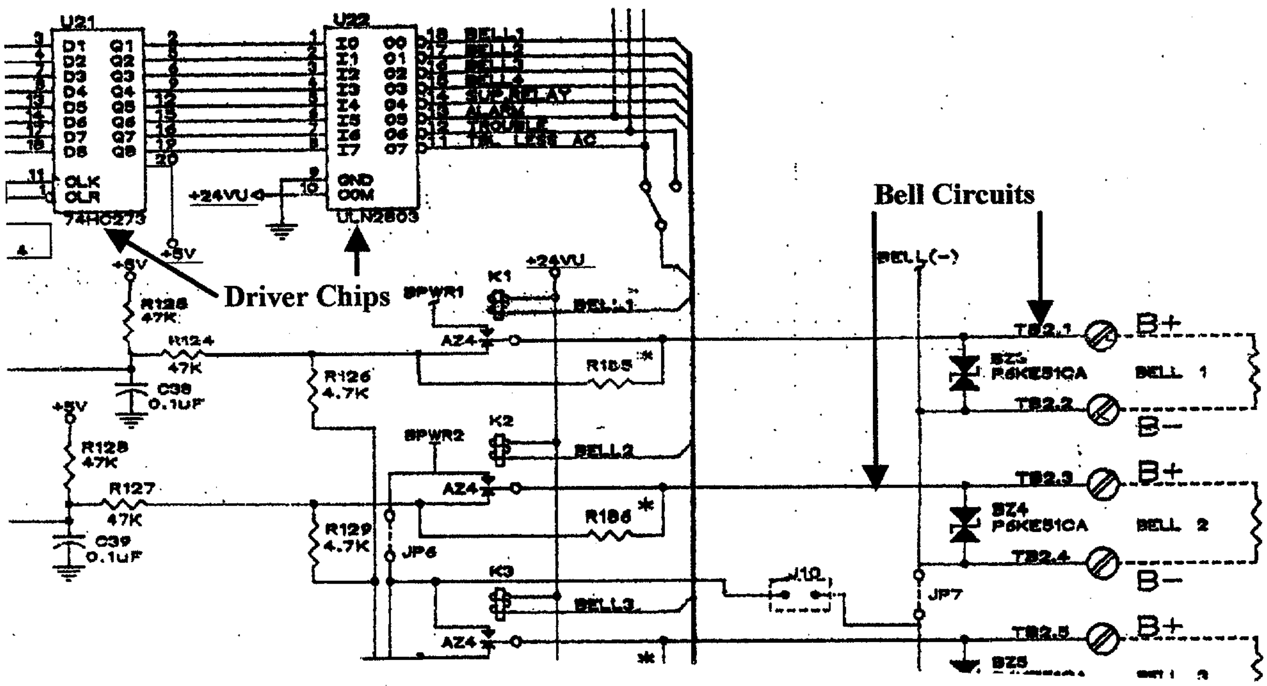

Figure 2-1. Bell circuit and driver chips.

Under normal conditions (120 volts AC power supplied to the panel, no alarm condition), a small supervisory current flows from the terminals on the output circuits to the device (Kidde control heads for the CO_2 at TRA-648) connected to the output circuit terminals. Figure 2-2 shows that relay K2 is deenergized and contact AZ4 is connected to a source of supervisory voltage (~ -2 V). The fire panel monitors the continuity of the wiring connection between the terminals and the CO_2 system actuator by this current flow. An open circuit between the terminals and the actuator will prevent flow of the supervisory current and cause a "trouble" or "supervisory" alarm at the control panel.

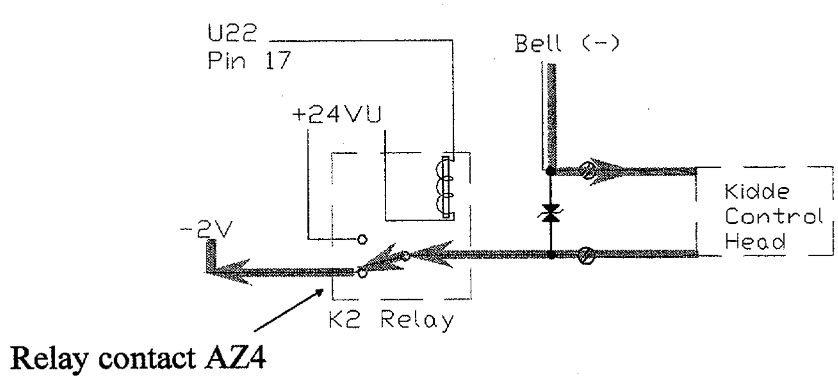

Figure 2-2. Bell Circuit 2 in normal supervisory condition—no alarm. Relay K2 is deenergized.

The operation of relay K2 is controlled by semiconductor chips labeled U21 and U22. Chip U21 is a 74HC273 Octal D flip-flop with common clock and reset, high performance silicon-gate CMOS logic chip. Operation of a flip-flop circuit in U21 is depicted in Figure 2-3.[7]

The data input leads D1 through D8 receive signals from the microprocessor circuitry. The clock pin (CLK) (Pin 11) receives a positive high-going signal every 250 milliseconds when the panel is operating normally. The signals needed to generate the clock pulse originate in the microprocessor circuitry.

To activate a bell circuit, a high signal must exist on an input data pin of U21, simultaneously with a high signal on Pin 1 of U21, and simultaneously with a high-going pulse on Pin 11 of U21. With these three high pulses present, the voltage on the related output pin of U21 will go high and stay high until chip U21 is reset. In other words, the circuit latches. The high output signal from U21 is applied to the connected input pin of U22 causing the related transistor in U22 to operate. Key points of the U21 flip-flop chip include:

- Specified operating voltage +2 to +6 volts direct current (DC)
- High output signal occurs when (1) high signal on reset pin, (2) high signal on data pin (3) high-going signal on clock pin occur simultaneously
- High output signal latches until chip is reset.

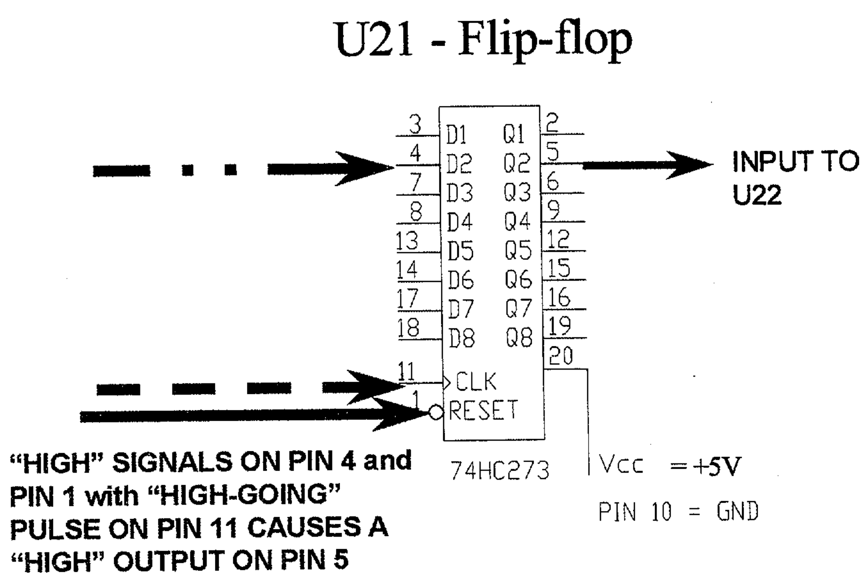

Figure 2-3. Operation of U21 flip-flop circuit

Semi-conductor chip U22 is a ULN2803 Octal High Voltage, High Current Darlington Transistor array. A relatively small input voltage on any input lead will operate the related transistor in the array.

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7. Motorola Semiconductor Technical Data, Revision 7, 1997.

The input leads of U22 are connected to output leads on U21. As used in the AFP-200 circuit under consideration, a small input voltage on an input lead of U22 will cause the associated output lead to go to DC ground.

Figure 2-4 shows U21 and U22 activating Bell Circuit 2. High signals at U21 provide the input signal to U22. The U22 output lead is connected to ground. Current flows through the relay coil and the relay operates.

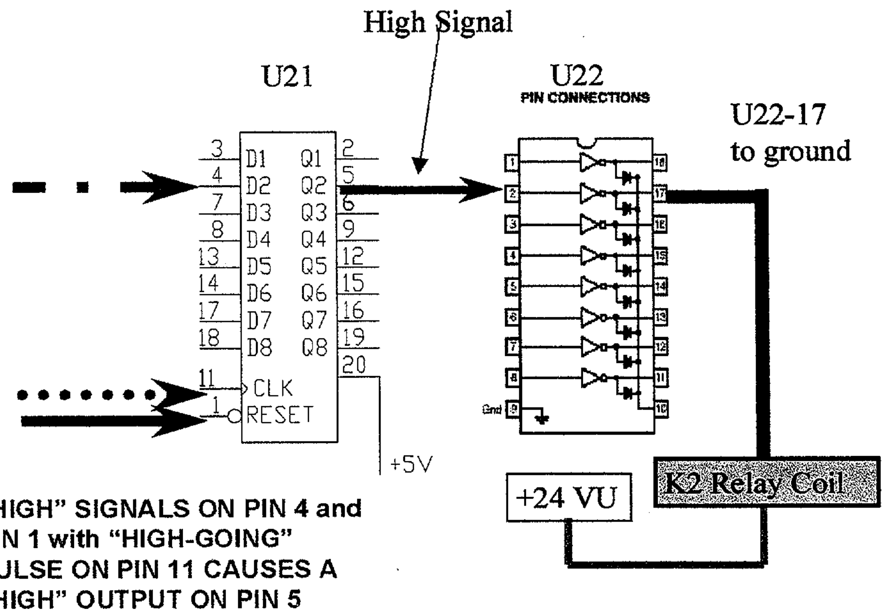

Figure 2-4. U21 and U22 activate Bell Circuit 2.

Figures 2-5 shows Bell Circuit 2 activated. When the Darlington transistor in U22 operates, Pin 17 pulls one side of the K2 relay coil to ground while the other side of the relay coil is connected to +24 volts (+24 VU). The coil is energized and the AZ4 relay contact is transferred. Terminal TB2.3 is now connected to +24 VU and the solenoid coil in the Kidde control head on Bell Circuit 2 is energized.

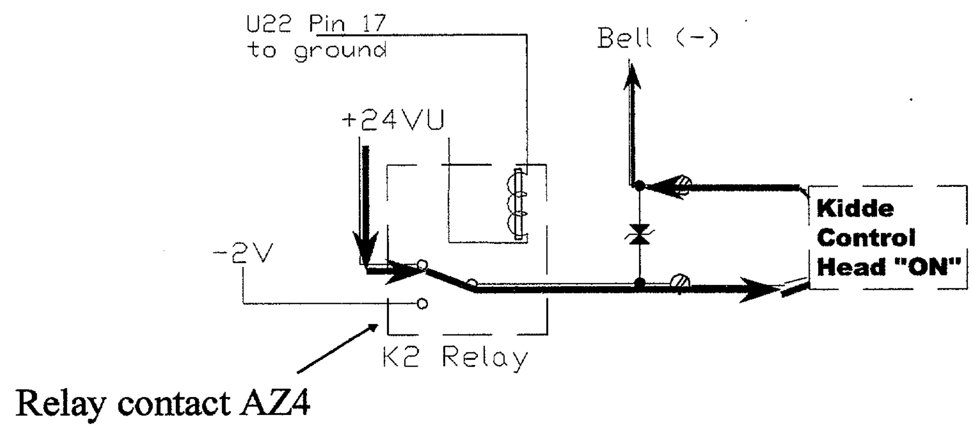

Figure 2-5. Relay K2 is energized activating Bell Circuit 2.

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Key points with respect to the operation of the AFP-200 bell circuits are:

- Bell circuits are activated when the associated relay (K1, K2, K3, K4) is energized
- Operation of a transistor in U22 causes the associated bell circuit relay to energize
- A high signal on a U21 output pin will cause the associated transistor in U22 to operate
- Two simultaneous high signals and a high-going signal on appropriate pins of U21 are required to cause a high signal on a U21 output pin.

With understanding of the operation of the bell circuits, data taken during testing of the AFP-200 panel can be examined.

2.2.2 Output (bell) Circuit Data

2.2.2.1 Normal Standby Operation. Figure 2-6 is a recording of pulses from the clock pin (Pin 11) of U21 and a data pin (Pin 4) of U21. These pulses are typical of those recorded when the AFP-200 panel is in normal, standby operation with no alarm. The high-going clock pulses occur every 250 milliseconds but do not occur simultaneously with the data pulses.[8]

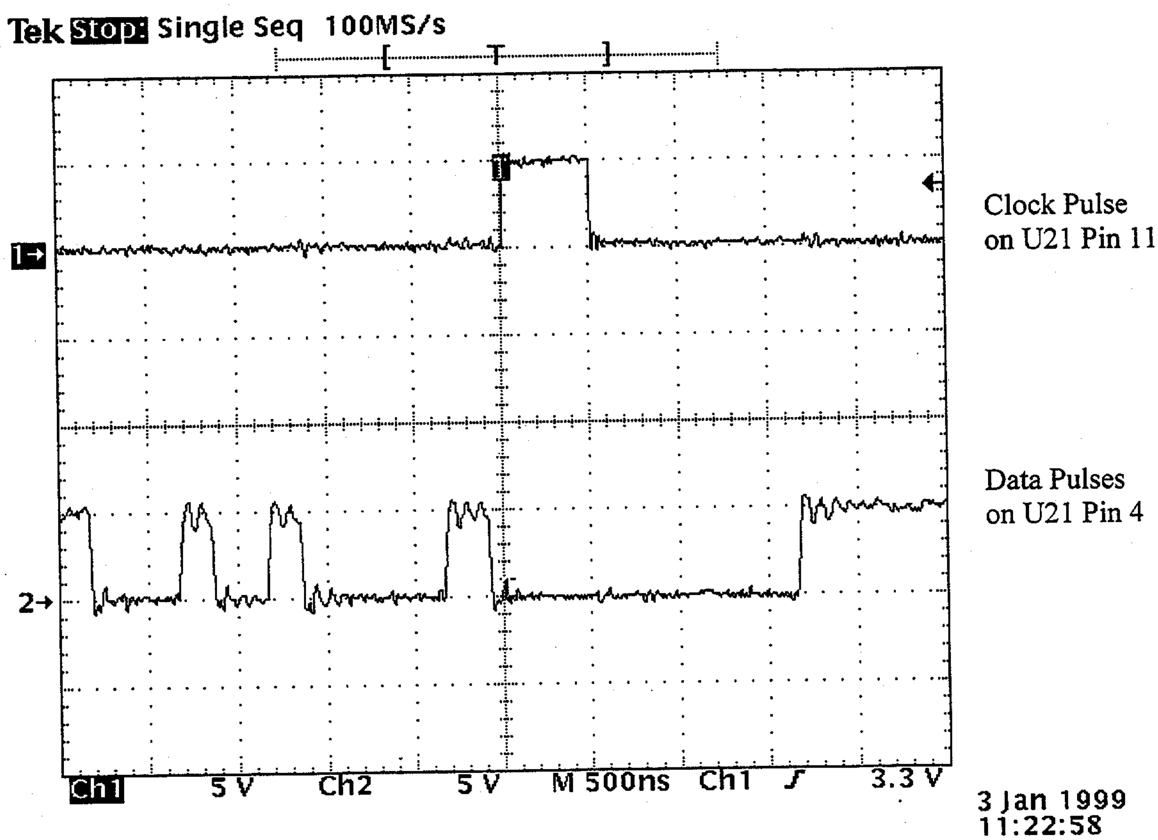

Figure 2-6. Oscilloscope recording of typical pulses in a normal (no alarm) condition.

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8. Data recorded at Tronamix.

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2.2.2.2 *Normal Activation of Bell Circuits by Manual Station.* The oscilloscope traces in Figures 2-6 and 2-7 are typical of normal, expected operation of the AFP-200 bell circuits.

Figure 2-7 is a recording of pulses on the clock pin (Pin 11) of U21 (lower trace) and a data pin (Pin 4) of U21 (upper trace). These pulses are typical of those recorded as a manual station or detection device activates a bell circuit. Note that the high-going clock pulse occurs simultaneously with a data pulse. Also note that the peak voltage on the pulses is approximately 5 volts. The reset pin of U21 (Pin 1) is also high and a high signal on the associated output, Pin 5, of U21 results. The transistor connected to Pin 17 of U22 operates, energizing Relay K2 to energize Bell Circuit 2. These pulses were recorded when the bell circuit was activated by operation of a manual station connected to the TRA-648 fire alarm control panel.

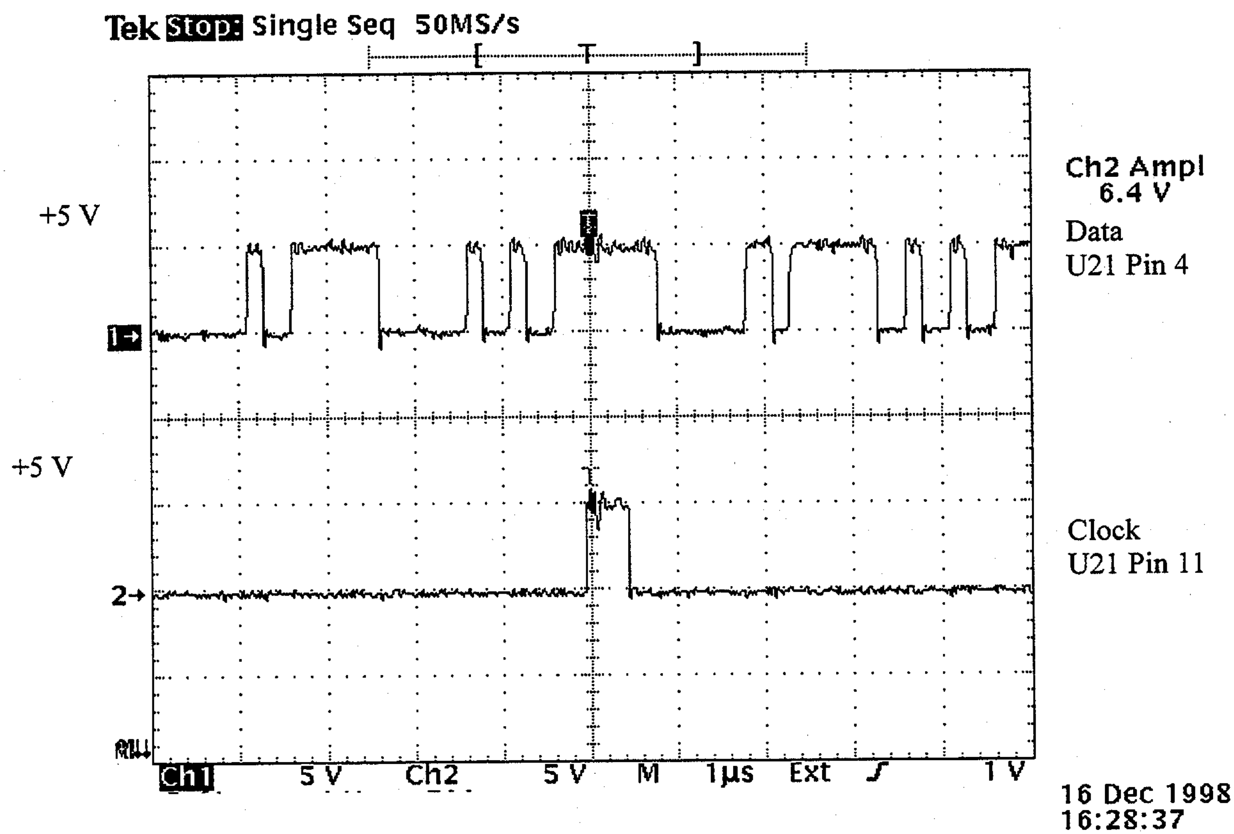

Figure 2-7. Oscilloscope recording of pulses during activation of Kidde electric release heads initiated by operation of a manual station.

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2.2.2.3 *Unexpected, Undesired, Dangerous Operation of Bell Circuit Initiated by AC Power Loss.*

Figures 2-8 and 2-9 were taken at Tronamix, Inc. laboratory during unexpected, unwanted operations of Bell Circuit 2 that activated the Kidde electric control head 24 VDC (part number 890181) installed on Bell Circuit 2. In each case:

- The undesirable operation was initiated when AC power was disconnected from an AFP-200 panel
- Simultaneous high signal on a data pin of U21 coincided with a high-going signal on the clock pin of U21
- No detectors or manual stations were in alarm
- Solenoid circuits were software disabled
- Standby batteries were connected to a NR45 external battery charger installed with the AFP-200 panel per Notifier instructions[9]
- Peak signals were 3 volts or less (corresponding to the voltage on the +5 volt power bus at the time of activation).

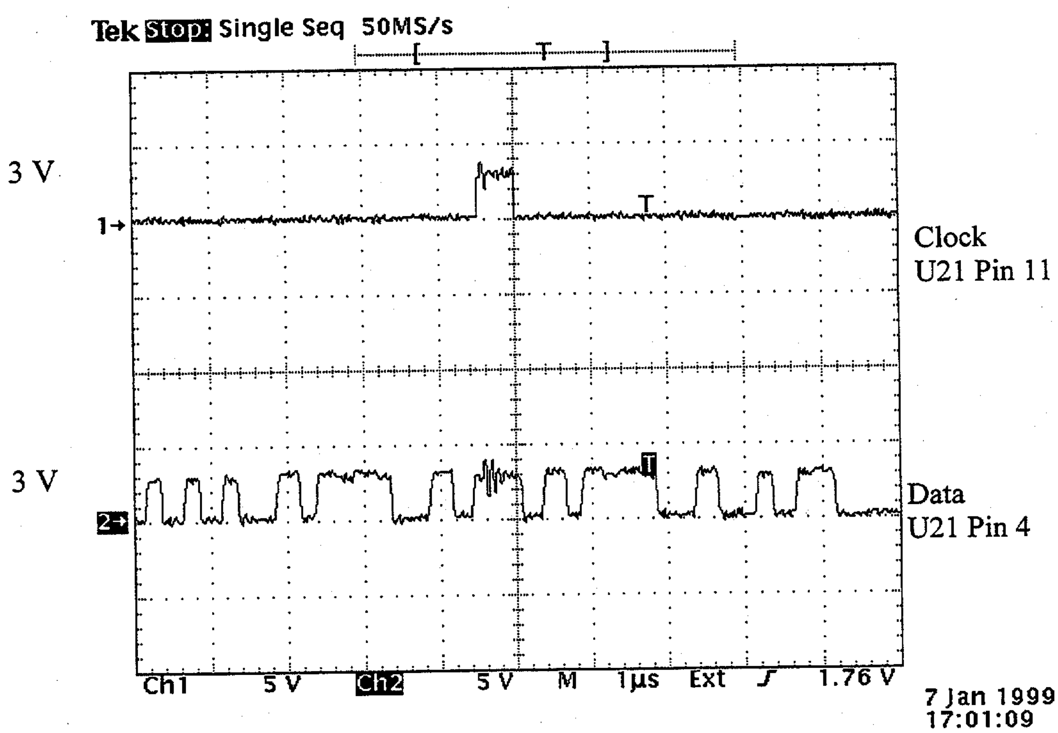

Figure 2-8. Oscilloscope traces when Bell Circuit 2 activated after AC power was disconnected.

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9. Notifier, *op. cit.*

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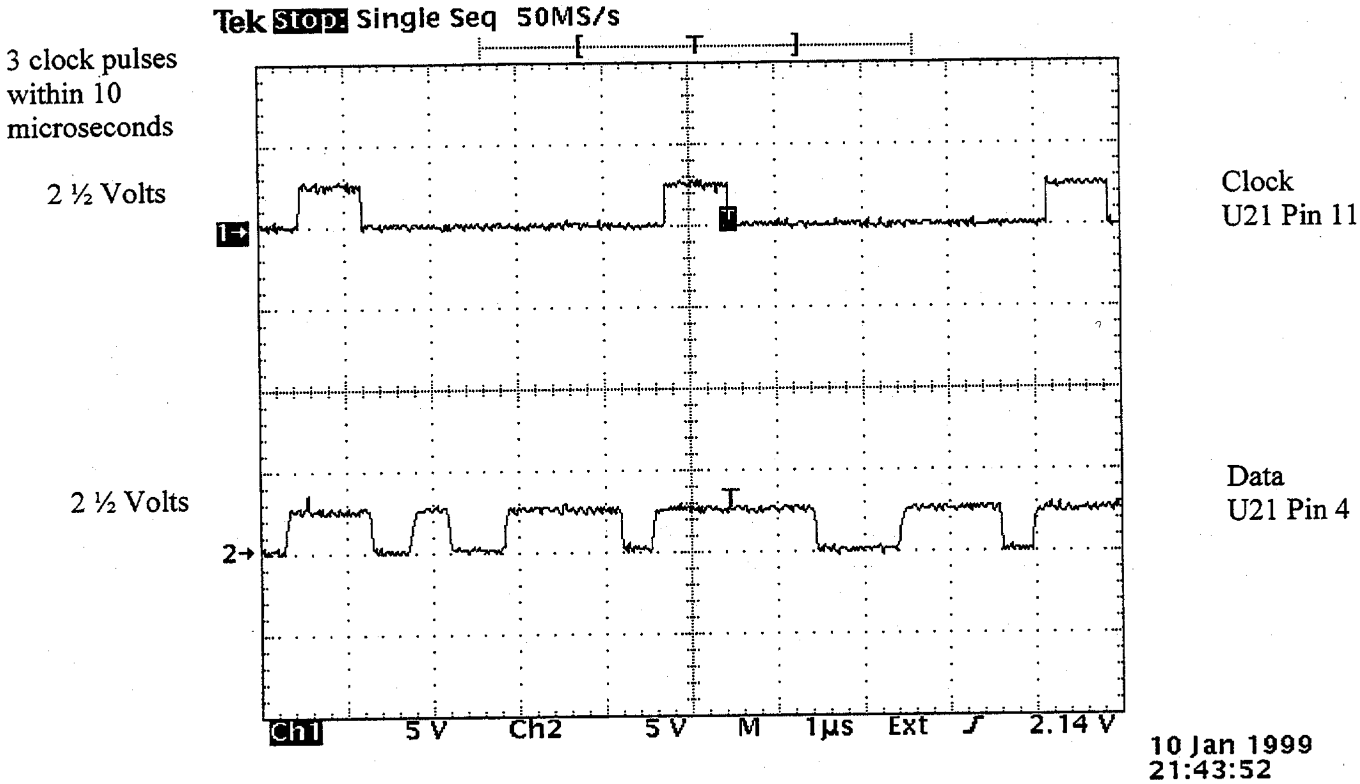

Figure 2-9. Oscilloscope traces show three clock pulses within 10 microseconds.

In Figure 2-9, spurious signals occur on the clock pin—three high clock signals are noted within 10 microseconds. Normal clock pulse spacing was measured on the subject AFP-200 panel as 250 milliseconds. The lower trace is the data bus to Pin 4 of chip U21; the upper trace is the signal on Pin 11 (clock pin) of chip U21. The spurious signals followed removal of AC power from the AFP-200 panel and caused operation of the Kidde electric release connected to Bell Circuit 2.

Figures 2-8 and 2-9 are examples of the many recordings taken during research into the operation of the AFP-200 panel.

2.2.2.4 Conditions for Bell Circuit Activation Upon Loss of AC Power. A variety of spurious pulses were recorded on the clock pin (Pin 11) and the data pins of chip U21, following loss of AC power to the AFP-200 panel. The data were recorded at two independent laboratories (Tronamix at Orland Park, Illinois and at MET Laboratories at Baltimore, Maryland), and at the LMITCO laboratory at the INEEL, as well as on the AFP-200 panel in TRA-648.

LMITCO observed the phenomenon of activation of the circuits upon loss of AC power as described above. The activation is caused when spurious pulses are introduced on a data pin and the clock pin of U21 simultaneously. These spurious pulses are generated by the internal panel circuitry. They are not the result of external noise entering the panel circuits.

The spurious signals that cause activation of the bell circuits upon loss of AC power to the AFP-200 panel typically were observed as voltage on the panel's 5 volt DC bus dropped below approximately 3 volts.

The signals appear to be random in sequence, amplitude, duration, and frequency of occurrence. The random signals account for the random activation of the bell circuits following a loss of AC power to the panel.

2.2.2.4.1 Panel Configurations Tested—During the tests, the AFP-200 panels were configured

1. With the NR45 charger and AVPS-24[10] (like the panel at TRA-648)
2. With the NR45 charger, but no AVPS-24
3. With neither the NR45 nor AVPS-24
4. With standby batteries connected
5. Without standby batteries connected
6. With solenoids software enabled
7. With solenoids software disabled.

The phenomenon that causes undesired operation of the bell circuits upon loss of AC power to the AFP-200 panel was found to be configuration sensitive. In other words, the phenomenon was observed only when certain configurations of the AFP-200 panel and auxiliary equipment were existent. Specifically the phenomenon was recorded when AC power to the panel was disconnected (1) after the standby batteries were first disconnected, or (2) when the AFP-200 is configured for an external battery charger in accordance with the instructions in the Notifier AFP-200 Analog Fire Panel Instruction Manual, Revision D.[11]

Over 1,000 tests were done with the AFP-200 panel installed in one of the above configurations. Over 30 operations of one or more bell circuits, initiated by disconnecting AC power to the control panel, were recorded.

Operation of the bell circuits initiated by AC power loss was never recorded if the AFP-200 panel was configured with the panel's internal battery charger connected to a well-charged set of standby storage batteries. Over 600 tests were done in this configuration when AC power to the test panel was disconnected; no operations of the bell circuits were recorded during these tests.

The presence or absence of an AVPS-24 auxiliary power supply had no effect on the phenomenon. Software settings of solenoid (bell circuit) enabled or solenoid (bell circuit) disabled had no discernable effect on the phenomenon.

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10. The AVPS-24 is an auxiliary power supply that increases the power available to the AFP-200 bell circuits by three amperes. See AFP-200 Analog Fire Panel Instruction Manual, P/N 15511:D, Appendix J, "AVPS-24 Power Expansion," Revision D, September 14, 1994, pages 111 and 112. The additional power was required to provide the power (electric current) level specified for the Kidde electric control heads (the CO_2 release solenoids).

11. Notifier, *op. cit.*

2.2.2.4.2 Location of Testing—Regardless of the location of the testing (i.e., Tronamix, MET Labs, LMITCO laboratory, or TRA-648), the spurious signals and activation of release heads occurred on an apparently random basis after loss of AC power. This shows that the phenomenon is not specific to the AFP-200 panel installation at TRA-648.

2.2.2.4.3 DC Voltage Decay—Undesired circuit activation was typically observed to occur as the voltage on the +5-volt bus decayed below 3 volts. The decay of the +5 V voltage just after loss of AC power was observed when AC power to the panel was disconnected with the NR45 external battery charger installed in accordance with the instructions in Notifier's AFP-200 Analog Fire Panel Instruction Manual, Revision D.[12]

The control panel microprocessor circuitry is specified to operate at +5 volts ± 10 % DC.[13] Operation of the processor circuitry at lower voltages (i.e., below its operating range) is unspecified. Testing has shown that spurious signals result when the +5-volt DC bus supplying the microprocessor drops to approximately 3 volts DC. With sufficient energy available on the panel's internal +24 VU bus, devices connected to the output circuits can operate. Details of this mechanism are discussed in Subsection 2.2.3.

12. Notifier, *op. cit.*

13. Siemens Data Book 01.97, "Microcontrollers," SAF 80C537, p. 188.

2.2.3 Internal Power Supply

2.2.3.1 Recording of DC Voltages After Loss of AC Power. Figure 2-10 shows a Dranetz meter recording taken from the AFP-200 panel at TRA-648 configured with standby batteries connected to an external battery charger. The 120 volts AC power to the panel was disconnected and drops to zero volts at approximately 11 hours 25 minutes 45.55 seconds. In less than one-half second after AC voltage to the panel is zero, Bell Circuits 2 and 3 activated. The Kidde control heads connected to Bell Circuits 2 and 3 operated.

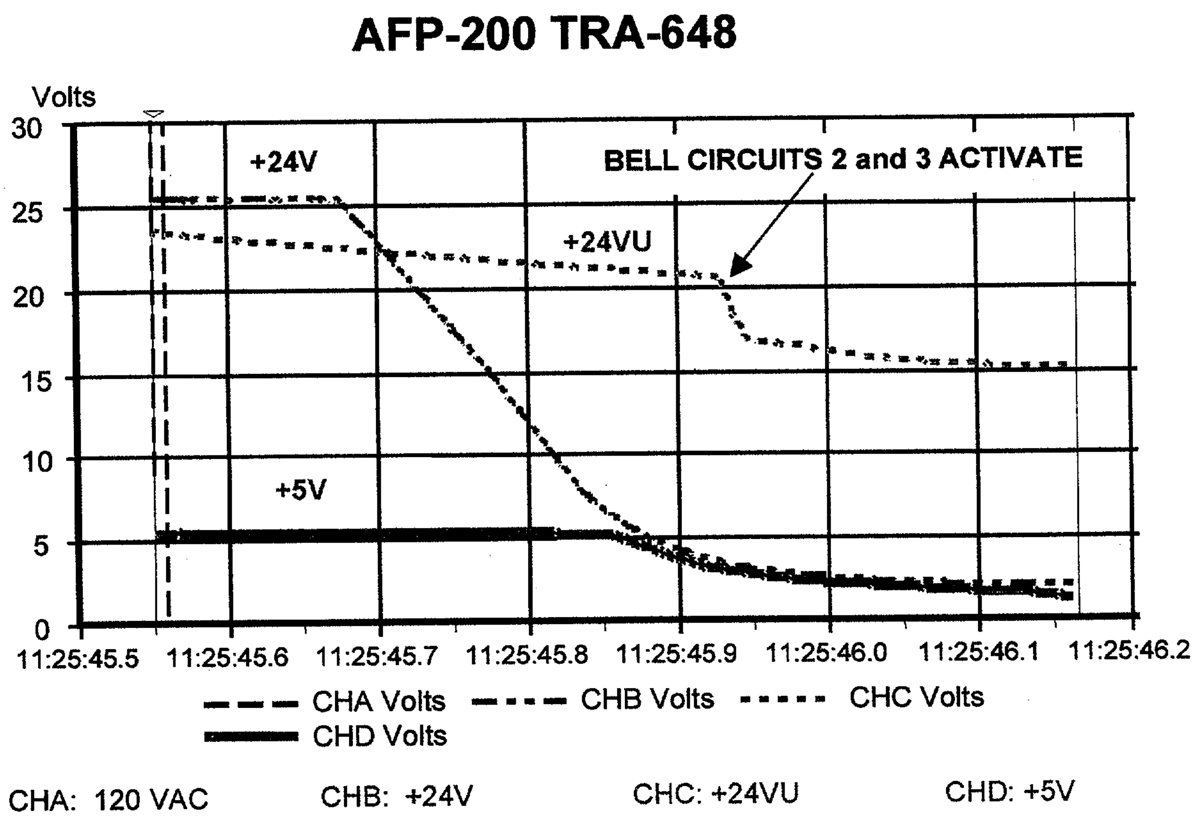

Figure 2-10. Dranetz recording shows decay of DC voltages after AC power loss with external charger installed. Bell circuits activate.

The bell circuit activation was initiated solely by disconnecting AC power to the AFP-200 system. No detectors, manual stations, or other initating devices in the system were in alarm.

Note that voltage on the +24 V bus decayed to about 4 volts at the time of the bell circuit activation. The +5 V bus had decreased to approximately 3 volts at the time the Kidde control heads operated. Note also that the voltage on the +24 VU bus was over 20 volts at the time of the activation.

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The decay of the DC voltages in the AFP-200 panel after disconnecting AC power is typical of the measurements on all AFP-200 panels tested by LMITCO's team for the following configurations:

- AFP-200 panel with external battery charger installed, storage batteries connected to system
- AFP-200 panel; no external charger; storage battery disconnected prior to disconnecting AC power.

A Dranetz meter recording of the DC voltages within the AFP-200 panel with a good charged standby battery connected to the internal charger is shown in Figure 2-11.

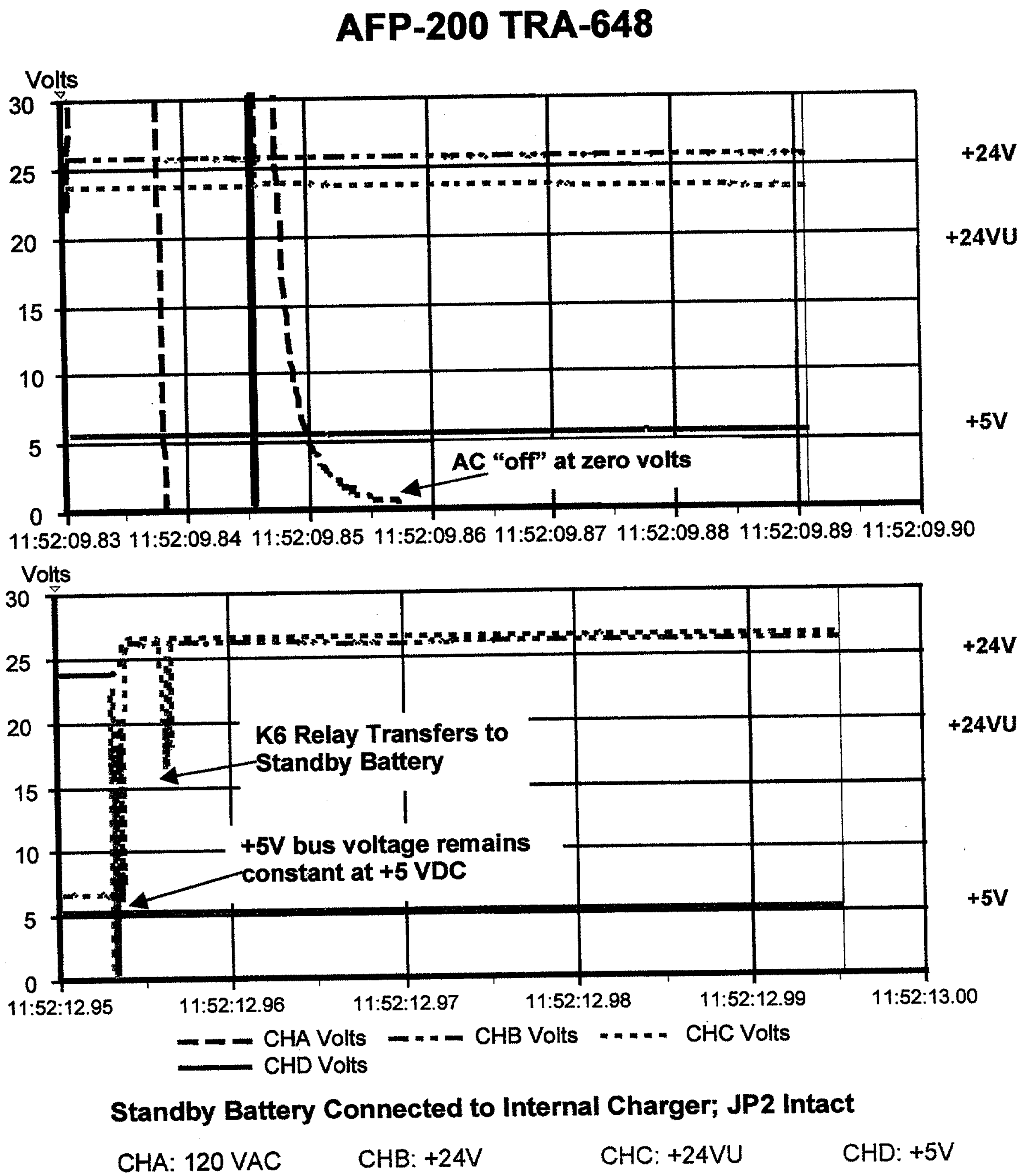

Figure 2-11. Dranetz recording shows DC Voltage after AC power loss in AFP-200 panel with standby battery connected to internal charger.

If a good, charged standby battery is connected directly to the internal battery charger in the AFP-200 panel (no external battery charger installed), a slight decay in the +24 V voltage was observed but no decay in the +5 V voltage was measured. Since the +5 V voltage remains normal, the microprocessor is not subjected to lower than specified operating voltages. Random activation of the bell circuits was not observed in this panel configuration.

To understand the relationship between the loss of AC power and the low DC voltages on the panel voltage buses that cause the microprocessor to produce spurious signals, the AFP-200 power supply circuits must be studied.

2.2.3.2 *AFP-200 Power Supply Circuit.* If the required capacity of the standby batteries for the AFP-200 fire alarm system does not exceed 20 amp hours, the internal battery charger in the AFP-200 panel may be used. This arrangement is depicted in Figure 2-12. The components essential to the current discussion are included.[14] This figure shows the power supply condition with 120 volts AC power connected to the AFP-200 panel.

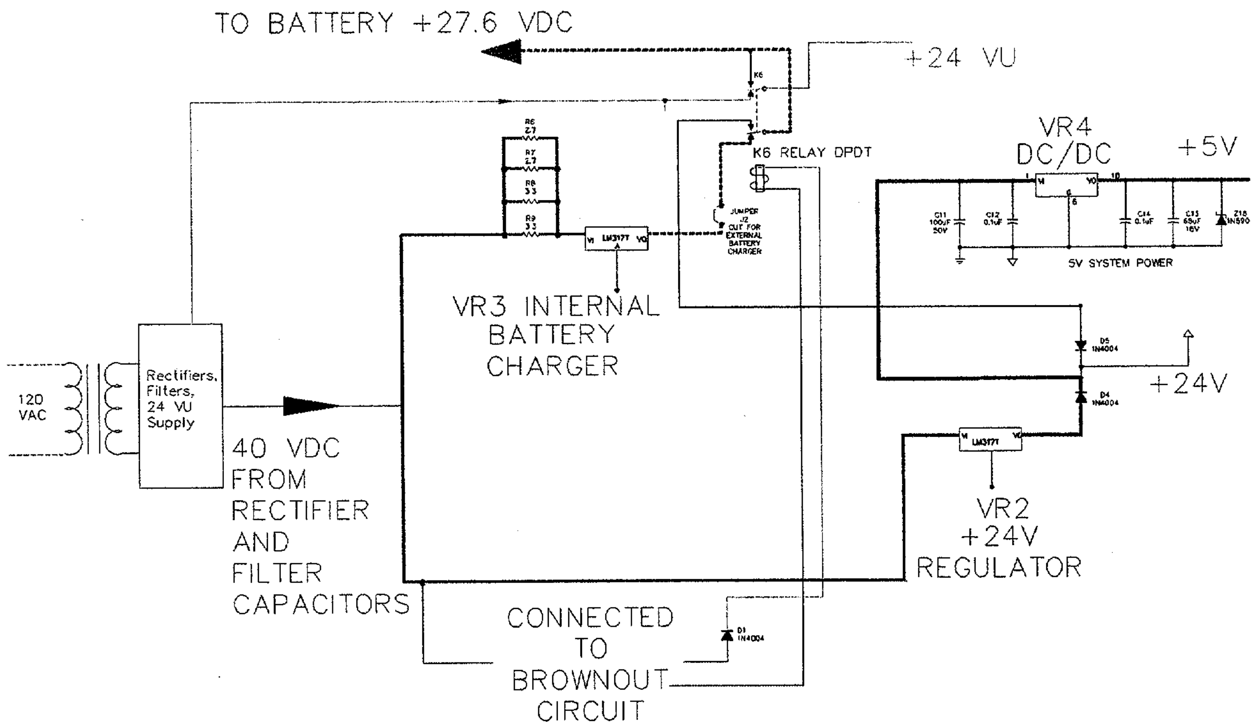

Figure 2-12. Simplified diagram of internal power supply section of AFP-200 panel.

A power transformer reduces the 120 volts AC voltage, and sets of rectifiers convert the low voltage AC to DC. Some of the DC is filtered and supplied to the input side of voltage regulators VR2 and VR3. In Figure 2-12, this voltage is labeled "40 VDC FROM RECTIFIER AND FILTER CAPACITORS."

Voltage Regulator VR2 regulates the 40 volts DC to approximately 24 volts. This 24 volt DC bus supplies power to signaling line circuits and various other components of the system. It supplies power to the input of VR4.

VR4 converts 24 volts DC from VR2 into 5 volt DC power. This 5 volts DC powers the microprocessor circuitry as well as most of the discrete semiconductor circuits in the AFP-200 panel. Note that the +5 volts developed by VR4 remains near +5 volts as long as the voltage on +24 V is above 7 volts (see Figure 2-10).

14. Extracted from Notifier Document Number 70577 Revision B, dated April 5, 1995.

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Voltage Regulator VR3 regulates the nominal 40 volts DC to approximately 27.6 volts DC and provides charging current to the standby batteries. This charging current is depicted by the line labeled "TO BATTERY" in Figures 2-12 and 2-13.

A portion of the DC from the rectifier is supplied as nominal 24 volts DC to an internal voltage bus labeled +24 VU. The +24 VU bus drives the output circuit (bell circuit) control relays, supplies power to the output circuits, and powers the Octal Darlington array chip U22.

Figure 2-13 is an enlarged view of the internal battery charger circuit showing the battery transfer relay K6 in an energized condition (sufficient AC power connected).

Internal Battery Charger with 120 VAC "ON"

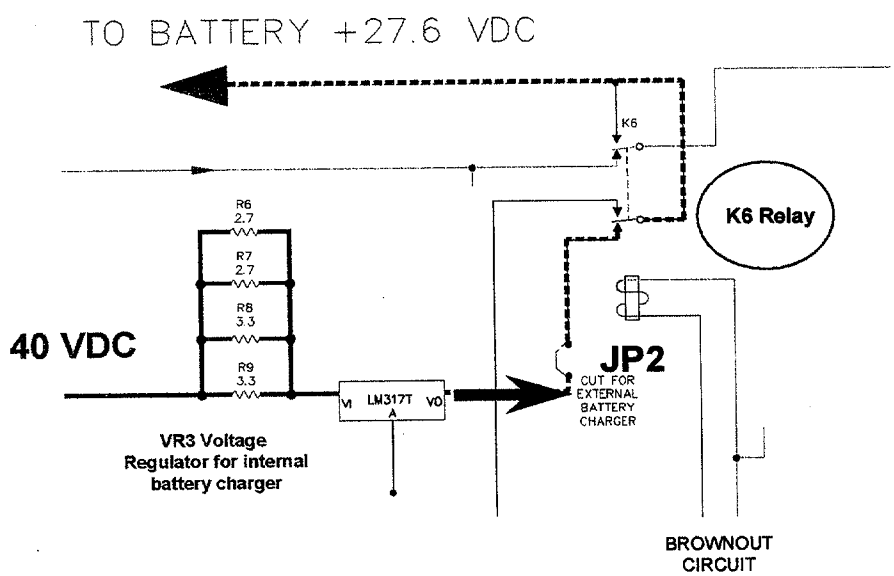

Figure 2-13. Enlarged view of the internal battery charger circuit.

2.2.3.3 ***Brownout Circuit.*** When nominal 120 volts AC is supplied to the control panel, the brownout circuit keeps relay K6 energized. This condition is shown in Figure 2-13. If AC line voltage falls to an unacceptably low level (approximately 100 volts or 85% of the nominal rated voltage), a brownout circuit acts to de-energize relay K6 and permit its contacts to transfer. When K6 is deenergized, the relay contacts connect the standby battery to the internal power supply circuits in the AFP-200 panel.

Data taken from the AFP-200 panels during testing show a delay of 1 to 3 seconds between loss of AC power (0 AC voltage) and transfer of the K6 relay contacts. For example, Figures 2-11 shows a delay of approximately 3 seconds from loss of AC power to K6 relay contact transfer.

When the panel is configured with an external charger or if the standby battery is disconnected, the DC voltages decay during this time interval. The low voltage that occurs on the +5 V bus puts the microprocessor circuitry into an unspecified operational range. When the microprocessor is in this unspecified operational range, the microprocessor circuitry generates spurious signals. These signals sometimes cause the output circuits to operate without a valid initiating signal to the AFP-200 panel.

When the AFP-200 internal battery charger is connected to an adequate standby battery, the delay in transfer of the K6 relay contacts is still present. In this configuration, however, no decay of the voltage on the +5 V bus was observed (see Figure 2-11).

2.2.3.4 *Back-Flow Through VR3 Maintains Voltage.* Review of the AFP-200 power supply circuit drawing does not show a traditional electrical path by which the voltage on the +24 V bus is maintained during the time between loss of AC voltage and transfer of the K6 relay contacts. The apparent mechanism to maintain this voltage bus is shown in Figure 2-14. The back-flow path through VR3 supplies nominal 24 volts to VR2 after AC power is lost, before relay K6 transfers.

With nominal 120 volts AC supplying the AFP-200 panel, approximately 40 volts DC is supplied by the power supply rectifier/filter circuits to the input leads on voltage regulators VR2 and VR3. When AC power is disconnected, the input voltage to these regulators decreases. As the voltage from the rectifier circuits decrease, with the panel configured as shown in Figure 2-14, current from the standby batteries back-flows through VR3 and thence to the input lead on VR2, the 24 volt supply regulator. This back-flow maintains the input voltage to VR2 at or above a nominal 24 volts—VR2 is able to maintain a nominal 24 volt level on the input pin of VR4. VR4 is able to maintain 5 volts to the microprocessor circuitry and other semiconductor components. No spurious signals were observed under these conditions.

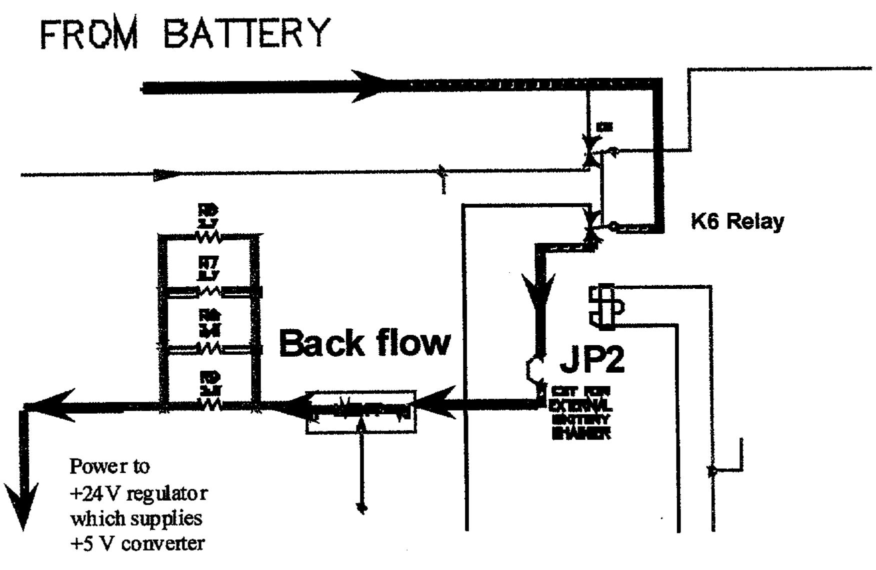

Figure 2-14. Internal battery charger—AC disconnected—K6 has not yet transferred its contacts.

The use of the LM317T voltage regulator in the back-flow mode is not a standard configuration. The LMITCO technical team contacted manufacturers of the LM317T for specifications on this device in the back-flow mode. The manufacturers of the LM317T were unable to supply specifications for the device used in this manner. Such usage is unspecified.

After an AC power loss and before relay K6 transfers, the microprocessor functions normally if its supply voltage is maintained at a nominal +5 volts. In certain panel configurations, the backflow through VR3 provides sufficient electrical energy to maintain the critical +5 V bus voltage.

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2.2.3.5 *Standby Battery Disconnected or External Charger Installed—Backflow is Disabled.* If the standby battery is disconnected from the AFP-200 panel prior to disconnecting AC power, the back-flow cannot occur. This was confirmed by testing at the independent laboratories. The voltage on the input to VR2 drops, the +24 V bus decays, the +5 V bus decays, and spurious signals are observed on the data and clock leads of chip U21. Undesired activation of the bell circuits was observed under this condition.

If an external battery charger is installed as part of the AFP-200 system, the Jumper JP2 is to be cut. The Notifier AFP-200 Analog Fire Panel Instruction Manual, Release 2, Revision D and Revision E instructs the installer to cut JP2 when installing an NR45 external charger.[15] Notifier Document 70577, Revision B, dated April 5, 1995, also had a note stating "JP2 JUMPER CUT FOR EXTERNAL BATTERY CHARGER."[16]

The AFP-200 panel printed-circuit board has "CUT FOR EXT. CHG" imprinted next to Jumper JP2 (see Figure 2-19).

With JP2 cut, the back-flow path from standby battery to the input of VR2 is broken (see Figure 2-15). The voltage decay described above occurs after AC power is lost before relay K6 transfers. The spurious signals described above are generated. Undesired activation of the bell circuits occurs on a random basis. The occurrence of activation is random because the signal generation by the microprocessor circuits under low voltage conditions becomes erratic.

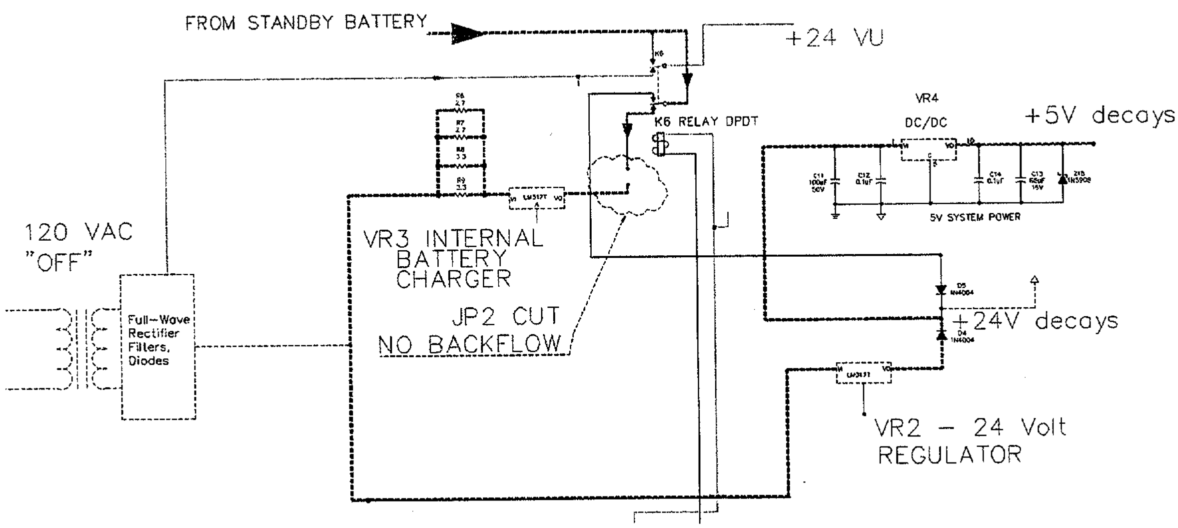

Figure 2-15. With JP2 cut, the back-flow path from standby battery to the input of VR2, the 24 volt DC regulator, is eliminated.

15. Notifier 1994, *op. cit.*

16. Notifier Document 70577, Revision B, dated April 5, 1995.

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2.3 Confirmatory Testing of TRA-648 AFP-200 Panel

On February 10, 1999, the AFP-200 panel at TRA-648 was instrumented with two Dranetz meters and a recording oscilloscope. This testing was done to verify that the same design defect and discharge mechanism observed in AFP-200 panels used in the mockups were present in TRA-648 CO_2 fire suppression system. Data were recorded that document the mechanism of discharge of the CO_2 system that resulted in the July 28, 1998, fatal accident. Prior to starting data acquisition, the surroundings were heated to approximately 100°F and Bell Circuits 3 and 4 were software disabled, to approximate the conditions present at the time of the accident.

Power to the AFP-200 panel and its external battery charger was disconnected simultaneously by means of a single switch located adjacent to the control panel. The panel and external battery charger were the only loads controlled by the disconnect switch.

The data that follow (Figures 2-16, 2-17, and 2-18) were taken as both Bell Circuit 2 and Bell Circuit 3 activated and operated the connected Kidde electric release heads. The activation was initiated by disconnecting AC power to the AFP-200 panel.

Figures 2-16, 2-17 and 2-18 show the result of AC voltage being disconnected from the AFP-200 panel. Approximately 0.36 seconds after AC voltage drops to zero, the output Pin 5 of U21 goes high, causing Pin 17 of U22 to go low. This energizes Relay K2, which operates Bell Circuit 2. Three separate recording instruments were used to record the data shown in Figures 2-16, 2-17, and 2-18. The slight variation in time markings is due to the technical difficulty in synchronizing the three instruments. The loss of AC power is a common event that was used as the reference point to coordinate the Dranetz recordings.

Figure 2-16 shows that within a fraction of a second (0.15 sec) after AC power goes to zero volts, decay of the voltage on the +24 V bus is evident. As the +24 V bus drops below about 7 volts, decay of the voltage on the +5 V bus is evident. As +5 V decays to approximately 3 volts, spurious signals are observed on U21 pins (see Figure 2-17). The +24 VU decays slowly until the bell circuits are activated—the change in slope of the +24 VU decay curve indicates flow of electrical energy to the Kidde electric discharge heads.

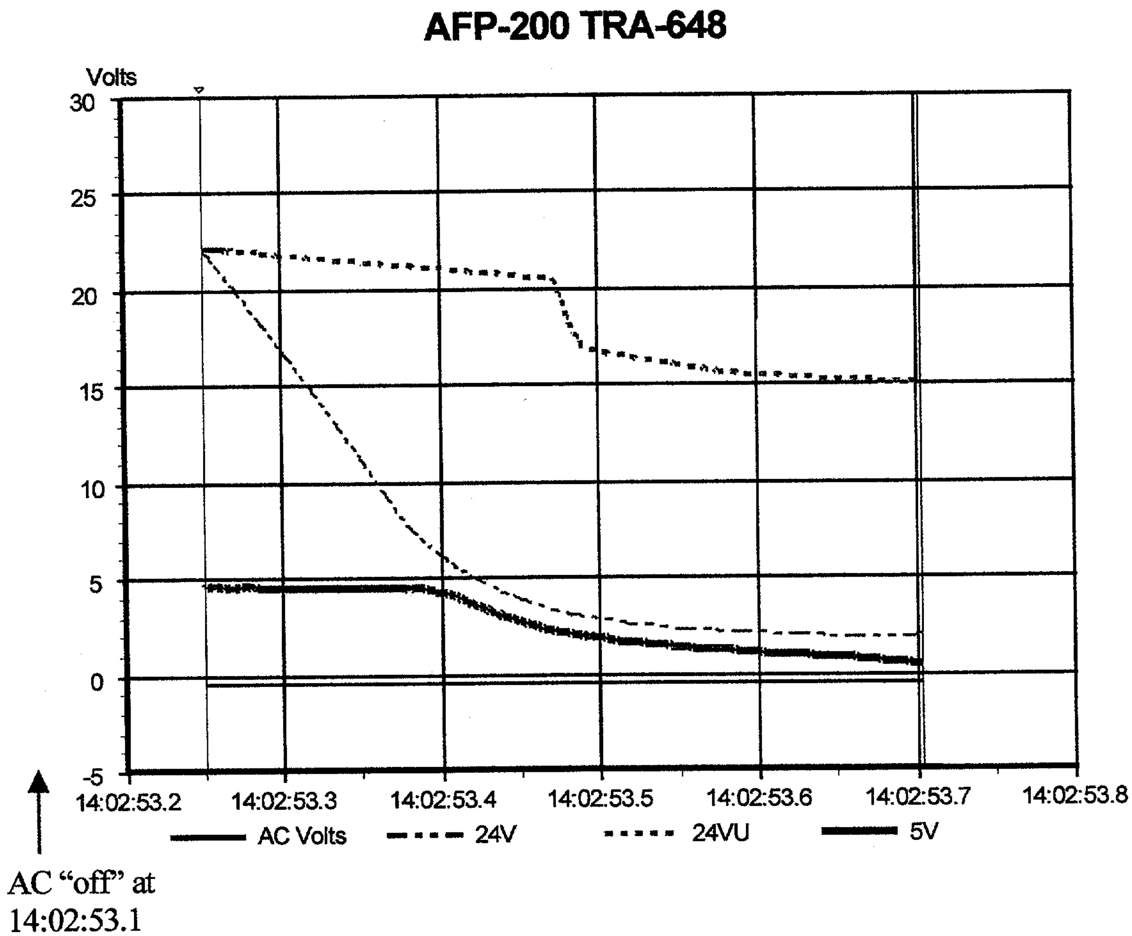

Figure 2-16. Dranetz recording shows voltage decays.

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Figure 2-17 shows a high pulse on U21 Pin 4 coincident with a high-going pulse on U21 Pin 11. These pulses activate the associated flip-flop circuit in U21 causing U21 Pin 5 to go high. The high output on U21 Pin 5 is input to U22 Pin 2. The high signal on U22 Pin 2 causes U22 Pin 17 to pull one side of the K2 relay coil toward DC ground. This energizes relay K2.

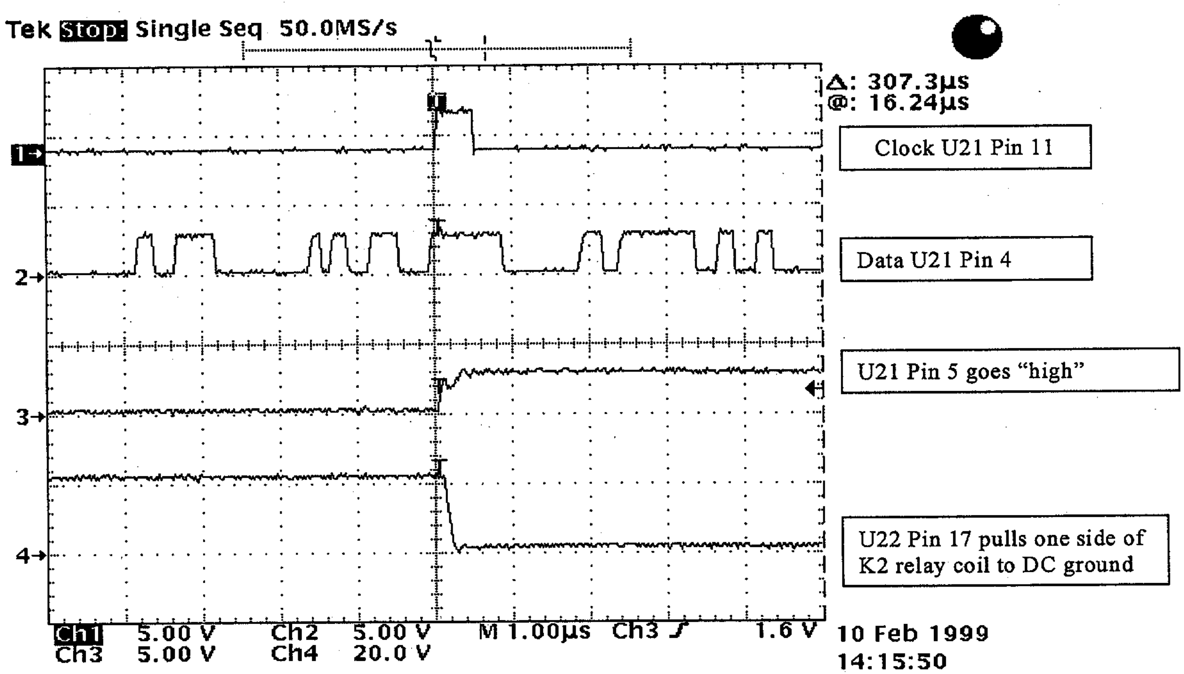

Figure 2-17. Oscilloscope traces from AFP-200 panel in TRA-648.

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Figure 2-18 also records the high signal on U22 Pin 2 and the resulting signal on U22 Pin 17. The resulting activation of Bell Circuit 2 is likewise recorded. U21 Pin 5 output goes high causing U22 Pin 17 to pull one side of the K2 relay coil to DC ground. Voltage on Bell Circuit 2 reverses from approximately –2 volts supervisory status to +24 volts activated status. The high voltage pulse on Bell Circuit 2 lasts approximately one-eighth second. The strength and duration of the pulse is sufficient to activate the Kidde electric control head connected to Bell Circuit 2. The Kidde control head discharges the CO_2 system.

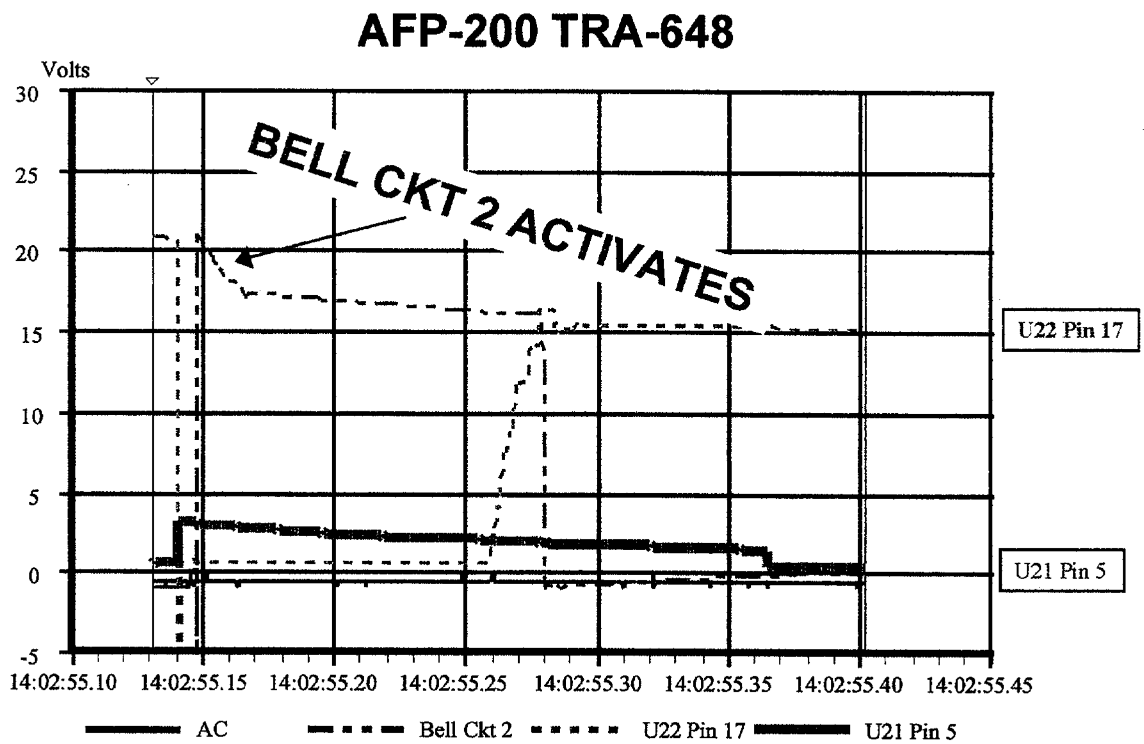

Figure 2-18. Dranetz recording shows Bell Circuit 2 activates.

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2.4 Specific Mechanism that Caused the CO_2 System to Discharge Without Warning as Determined by Independent Experts

The specific mechanism that caused the CO_2 system to discharge without warning was the identified design defect in the AFP-200 panel circuitry, which:

1. Permits essential DC voltages to decay immediately after AC power is disconnected and before standby battery is connected

2. Permits spurious signals to be generated on loss of AC power that sometimes mimic valid signals to activate the bell circuits

3. Permits the logic chip U21 to react to spurious data and clock pulses by activating one or more bell circuits upon loss of AC power

4. Permits the Darlington array U22 to operate when the microprocessor is emitting spurious signals

5. Provides sufficient energy on +24 VU bus to operate releasing devices when microprocessor is emitting spurious signals.

This design defect is evident from the behavior of the AFP-200 panel when installed in certain configurations. The use of the AFP-200 panel in these configurations is specified as acceptable, and required, in the Notifier installation instructions for the AFP-200 panel, Document 15511, Revision E and prior revisions. These prior revisions include Revision D, dated September 14, 1994, which was the basis for the design and installation of the TRA-648 CO_2 fire suppression system.

Notifier states[17] that the AFP-200 Analog Fire Panel complies with the numerous NFPA standards including NFPA 12. The design defect in the AFP-200 panel contradicts this declared compliance. Code compliance of the AFP-200 panel is discussed further in Subsection 3.1.

Moreover, good engineering requires that systems operate safely under all reasonably foreseeable conditions or, where design or equipment limitations may result in unsafe operation under such reasonably foreseeable conditions, the engineer must provide warnings or procedures to mitigate the danger.

The AFP-200 panel should have operated safely under the following conditions:

1. AC power loss (planned or unplanned) is expected

2. Standby power is provided by DC batteries for continued operation

3. Transfer of AC power to DC standby power should not discharge the CO_2 system.

17. Notifier AFP-200 Analog Fire Panel Instruction Manual, P/N 15511:D, Revision D, September 14, 1994, page 4.

Operation of the bell circuits in a fire panel during the switchover from AC line voltage to DC standby power is a violation of good engineering, NFPA Standards, and common sense. When the bell circuits in question are approved to control releasing devices for gaseous fire extinguishing agent systems, the design defect can produce deadly consequences—this was the case on July 28, 1998, at TRA-648.

2.5 External Battery Charger and Installation

The specific mechanism that caused the CO_2 system to discharge without warning was the design defect in the AFP-200 panel circuitry. The panel configuration at TRA-648 was one in which the design defects inherent in the AFP-200 panels manifest themselves. An external battery charger was installed by a Notifier factory trained installer as part of the AFP-200 system in TRA-648. As the Notifier AFP-200 Analog Fire Panel Instruction Manual Revision D, September 14, 1994, states:

> "The NR45-24 Remote Battery Charger is capable of charging 20 to 55 amp-hour batteries. This unit is required in a control panel system using 20-amp-hour or larger batteries." [18]

2.5.1 Standby Battery Requirement

The DOE-ID Architectural Engineering Standard, Section 1670-5.5.3, dated December 1994, requires 60 hours of backup battery supply for the fire alarm initiating panel.[19]

2.5.2 Battery Calculations

The total ampere hour requirement for the AFP-200 panel with field devices in TRA-648 was calculated to be 25.3 amp hours.[20] For the panel to remain powered for the required 60 hours with an adequate safety factor, two 12 volt, 55 amp-hour batteries are furnished in series for a 24 volt backup power supply. An external Notifier NR45 battery charger was installed per Notifier instructions to accommodate these standby batteries.

2.5.3 Installation of an External Charger and Batteries

The Notifier factory trained installer of the AFP-200 panel cut Jumper JP2 to accommodate higher capacity batteries, in accordance with the Notifier instructions. The requirement to cut Jumper JP2 can be found in

1. Notifier, AFP-200 Analog Fire Panel Instruction Manual, P/N 15511:D, Section 2.7, "The NR45-24 Remote Battery Charger," Revision D, September 14, 1994, page 45
2. AFP-200 circuit diagram, Notifier document 70577 Revision B, April 5, 1995
3. AFP-200 printed circuit board, as shown in Figure 2-19.

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18. Notifier AFP-200 Analog Fire Panel Instruction Manual, P/N 15511:D, Section 2.7, "The NR45-24 Remote Battery Charger," Revision D, September 14, 1994, page 45.

19. DOE-ID, "Architectural Engineering Standard," Section 1670-5.5.3, U.S. Department of Energy Idaho Operations Office.

20. LMITCO, *Engineering Design File*, EDF-768, "Building TRA-648 Fire Alarm Panel Battery Calculations," 1999.

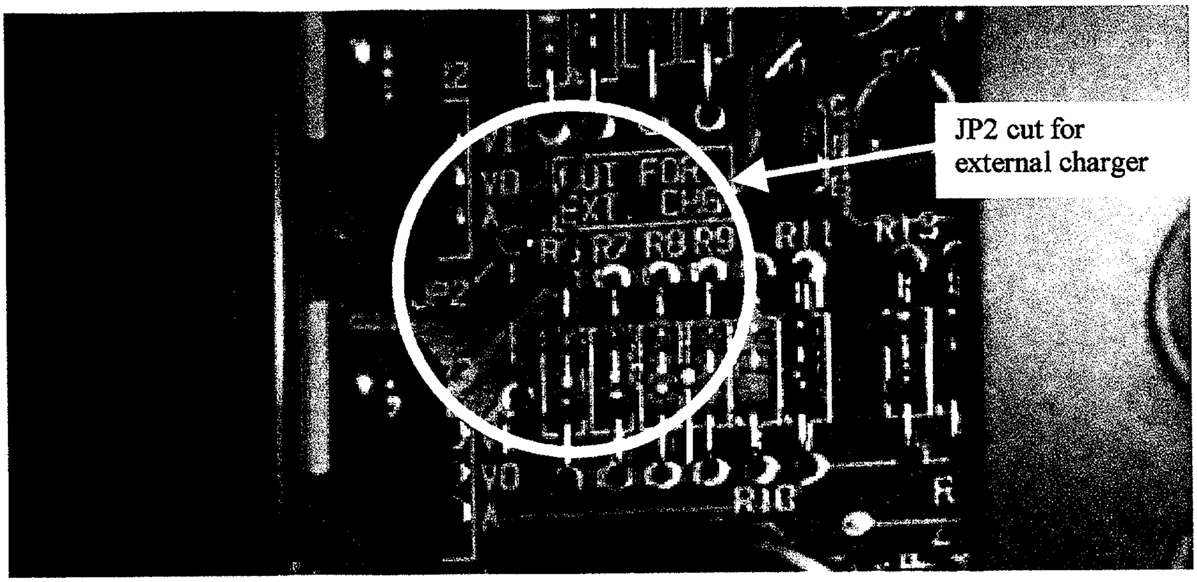

Figure 2-19. The AFP-200 printed circuit board instructions to cut JP2.

2.6 Other Factors Suggested in the DOE Investigation Report

The portion of the DOE Investigation Report entitled "Mechanism of Discharge" (pp. 40 and 41) suggests two issues that may be related to the specific mechanism that caused the CO_2 system to discharge without warning. These two issues were diligently pursued in the LMITCO and independent testing laboratory efforts to identify the specific mechanism that caused the CO_2 system to discharge without warning. This Subsection describes the testing and analysis that provide the bases for determining that these issues were not related to the specific mechanism that caused the accidental CO_2 discharge.

2.6.1 Investigation Report Statement—Installation Errors

The Investigation Report (p. 40) stated:

> "The CO_2 discharge probably was a consequence of external voltage induced or imposed on the releasing circuits or other panel inputs (i.e., via the neutral or ground of the AC power connection, or via improperly shielding signaling line circuits)."

The Investigation Report (p. 34) stated that the following installation errors were present in the TRA-648 AFP-200 system:

1. "Only part of the signaling line circuit is shielded. This circuit branches directly from the control panel terminals; one branch is shielded and the other is not."

2. "In addition, the shield drain conductor on the shielded branch is connected to the wrong terminal on the fire alarm panel main board."

3. "One of the two releasing circuits is powered by an unregulated, unfiltered auxiliary power supply, which the panel installation manual indicates is only to be used to power notification appliances (i.e., fire alarm bells or horns)."

The Investigation Report (pp. 34 and 37) stated:

> "It is not clear at this time whether these installation deviations were significant with respect to the accidental CO_2 discharge. The auxiliary power supply is suspect because opening Breaker No. 13 appears to have been the cause of the CO_2 discharge, presumably as a consequence of a voltage surge or spike. The fact that this power supply is unregulated and unfiltered may make it easier for a transient input to that supply to get through to the panel and trip the releasing circuits. The shielding on the addressable circuits is suspect because it is intended to dissipate transient signals before they can affect system operations."

Because the activation of the bell circuits caused by loss of AC power to the panel is due to spurious signals generated inside the panel circuitry, the signaling line circuit shielding had no effect on the phenomenon.

The design defect in the Notifier AFP-200 panel was observed both with and without the AVPS-24 auxiliary power supply installed. Use of the AVPS-24 had no discernible effect on the occurrence of bell circuit activation initiated by disconnecting AC power.

Thus, the three the installation practices cited as errors in the Investigation Report were unrelated to the cause of the accident.

2.6.2 Externally Generated Transients

Notifier stated:

> "There are many possible scenarios that could cause a transient to activate panel circuits without logging the event in history. We believe one prominent possible cause relates to the fact that the AFP-200 is microprocessor-based. Any microprocessor, if sufficiently disturbed by power transients or nearby electromagnetic fields can possibly change its program execution. It is possible that the erroneous instructions could include instructions to activate output circuits, including the AFP-200 releasing circuits."[21]

The Investigation Report (p. 38) stated:

> "Test results suggest that the design of the AFP-200 control panel allows power supply transients (such as those resulting from opening 4160 volt breakers or 110 volts AC contacts) to bypass the system program/logic and energize the releasing circuits."

Neither of these statements is supported by the test results obtained by LMITCO and the independent laboratories. The activation of the output circuits caused by disconnecting AC power is not the result of externally generated power supply transients energizing the release circuits. Subsection 2.6.2.1 below and Appendices A and B of this report contain the results of testing done to examine the effect of power supply transients on the panel. This testing demonstrated that power supply transients that bypassed the AFP-200 system program logic to energize the releasing circuits were not the mechanism by which the CO_2 system in TRA-648 discharged on July 28, 1998.

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21. D. D. Anderson, Notifier, Senior Vice President, Engineering, Letter to Bruce Stewart, INEEL, dated August 21, 1998.

Testing and evaluation concluded that externally generated electrical transients bypassing the programmed logic in the control panel was not the release mechanism that caused the accident.

2.6.2.1 Testing the Effects Electrical Noise—Tronamix, Inc. (Orland Park, Illinois) performed initial tests to determine if externally generated noises, including externally generated electrical transients, would cause false operation of the Kidde control heads (release solenoids) on Bell Circuits 2 and 3. An AFP-200 panel with fully charged batteries was tested. The AFP-200 panel was subjected to conducted and radiated noise of high intensity to test its susceptibility to externally generated noise.

Devices known as noise producers, such as solenoids, transformers, and electric motors, were used for these tests. These devices and the AFP-200 panel were connected to the AC line at the same point and the noise producing devices were switched on and off to generate conducted line noise (electrical transients). The AFP-200 panel was also tested with the noise devices in close proximity to the panel circuitry for testing radiated noise susceptibility. Tests were made at line voltages from 99.4 to 130.2 volts.

Over 12,000 on/off AC power cycles accompanied by transient noises were applied to the test panel to test its susceptibility to externally generated noises. No recorded incident of false operation of the Kidde control heads due to external noise was observed during these tests.

3. CONCLUSIONS

After the TRA-648 CO_2 discharge accident, two independent laboratories and LMITCO staff began a significant testing and analysis effort to identify the specific mechanism that caused the TRA-648 CO_2 discharge accident. This effort and the results have been summarized in this report.

3.1 Discovery of the Specific Mechanism that Caused the CO_2 System to Discharge Without Warning

The independent testing laboratory and LMITCO analyzed the mechanisms that were suggested in the Investigation Report as possible causes of the accident. Testing and evaluation concluded that externally generated electrical transients bypassing the programmed logic in the control panel was not the release mechanism that caused the accident. This testing and evaluation also concluded that the installation practices cited as errors in the Investigation Report had no relationship to the cause of the accident.

The specific mechanism that caused the CO_2 system to discharge without warning was the design defect in the UL-listed FM-approved Notifier AFP-200 panel, which activated the output circuits immediately following interruption of 120 volt AC power. The Notifier AFP-200 panel has a design defect that sometimes causes random activation of the output circuits to the CO_2 releasing solenoids, bypassing all warning alarms. The design defect is largely masked when the AFP-200 panel is employed with the internal battery charger. However, if the panel is configured for an external charger, such as at TRA-648, actuation of the solenoids can occur with any condition that causes interruption of 120 volt AC power.

3.2 Communication of Test and Analysis Results

As testing and analysis revealed the precise nature of the design defect in the AFP-200 panel, LMITCO shared this information with the DOE complex and the fire protection community. LMITCO issued a letter of notification of safety issues associated with the Notifier AFP-200 Analog Fire Panel to Notifier November 10, 1998, and a Red Lessons Learned to the DOE community on November 20, 1998. On January 13, 1999, LMITCO sent letters summarizing the testing results to OSHA, UL, FM, and other organizations that had listed or approved the AFP-200 panel. In April 1999, these agencies were provided with a more complete description of the direct cause and the test results.

Appendix A

Testing at MET Laboratories, Inc.

Appendix A

Testing at MET Laboratories, Inc.

A-1. INTRODUCTION

The purpose of the MET Laboratories tests was to determine the conditions that caused the unintentional activation of the solenoids attached to the Notifier AFP-200 fire alarm panel. This appendix summarizes MET Report EMI113, "Test Report for a Notifier Fire Alarm Panel Model: AFP-200," prepared by Tom Bennington, Test Engineer, and Chris Harvey, Project Manager at Met Laboratories in Baltimore, Maryland.

The test system components were similar to the components in TRA-648. The test system components included a Notifier AFP-200 Fire Control Panel and a Notifier NR45 external charger to supply charging power to the backup batteries. Table A-1 shows the equipment tested.

Table A-1. Equipment tested at MET Labs.

Equipment	Ports	Cable Type	Length	Shielded	Termination
Notifier AFP-200 Fire Alarm Panel	AC Power	Single phase AC	~ 1 m	No	Power distribution
	DC Power	Twin lead	~ 1 m	No	Battery and charger
	Solenoid #1 out	Twin lead	~ 1 m	No	Solenoid
	Solenoid #2 out	Twin lead	~ 1 m	No	Solenoid
	Alarm out	Twin lead	~ 1 m	No	Alarm
Notifier NR45-battery charger					
2-Dynasty UPS12-170 12 volt batteries					
Power distribution Panel					
Kidde Fennal Model 890181 Solenoid #1					
Kidde Fennal Model 890181 Solenoid #2					
2-Wheelock Model P82464 Alarm/Horns					

A-1.1 Test System Configuration

The Notifier AFP-200 Analog Fire Panel Instruction Manual, Rev. D, dated September 14, 1994, was used for the test-system configuration (identical to the system installation in TRA-648). Figure A-1 shows the diagram of the test-system configuration.

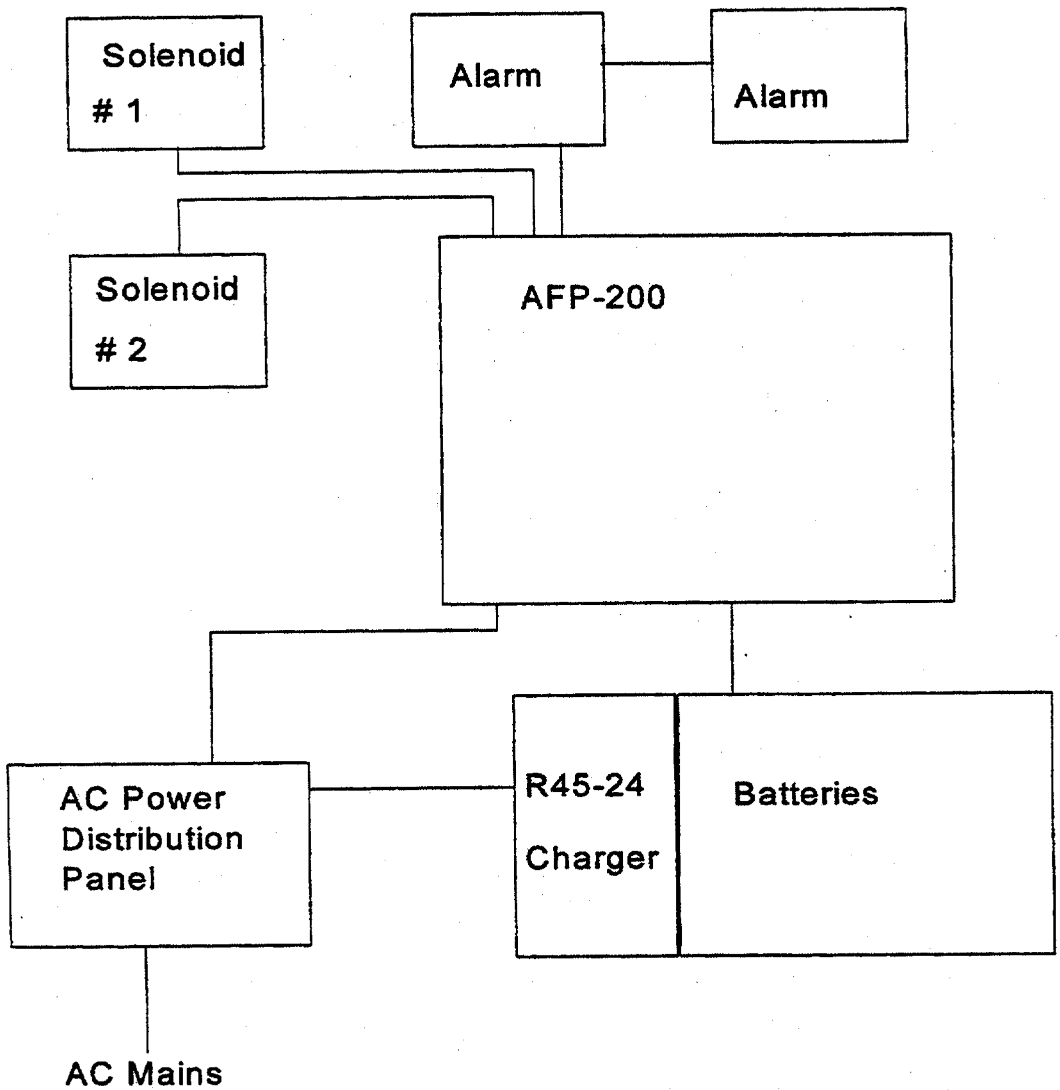

Figure A-1. Test system configuration, functional block diagram.

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A-2. ABNORMAL WAVEFORM HYPOTHESIS

The hypothesis tested was: The unwanted activation of the solenoids was caused by an abnormal AC waveform observed during the activation of the solenoids.

A-2.1 Methods

The AFP-200 fire alarm panel was configured in accordance with the manufacturer's instructions, and power was switched on and off throughout the test. The controller display and solenoids were visually monitored for signs of failure or activation, and the alarms were audibly monitored to determine activation. A multi-line analyzer was used to record the performance of the panel during each test. The test equipment included a programmable power supply and oscilloscope.

Based on preliminary information in the Investigation Report, the unintentional solenoid activations were thought to be caused by AC power transients. The hypothesis was tested by reproducing the power waveform recorded during the first successful reenactment. Figure A-2 shows the waveform recorded during the first successful reenactment of the activation.

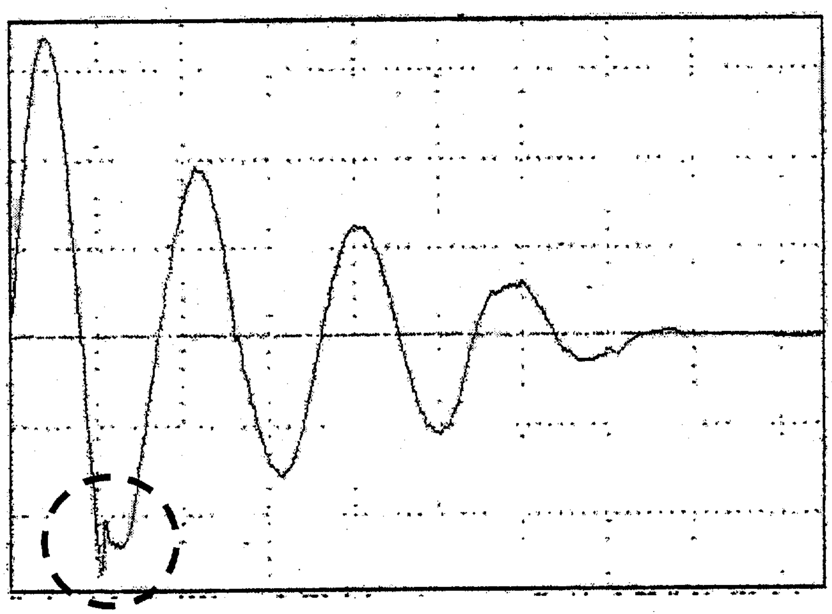

Figure A-2. Waveform during activation.

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The fire alarm control panel was repeatedly powered-down by the programmed injected waveform shown in Figure A-3, and variations of this waveform involving:

1. The position in phase at which the dropout occurs
2. The level and number of cycles that occur during the power-down
3. The presence of 500-volt spikes or surges on the waveform.

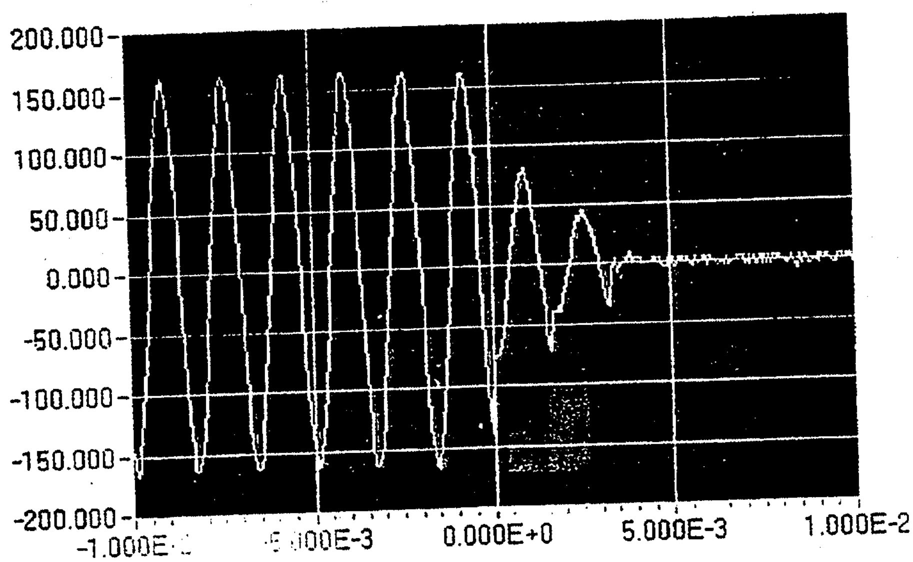

Figure A-3. Injected waveform.

A-2.2 Abnormal Waveform Test Results

During the waveform tests there were three activations. The observed activations were either a random event or due to other conditions that were not waveform related. After each activation, the test conditions were duplicated to attempt to verify repeatability. However, the tests did not create two successive activations. Approximately 300 attempts showed little or no correlation to waveform or injected interference.

A-3. TEMPERATURE HYPOTHESIS

The hypothesis tested was: The unwanted activation of the solenoids was caused by elevated temperature during AC power removal.

Note: The ambient temperature on July 28, 1998, was estimated to be near 100°F. Elevated temperatures can cause instability in electronic devices.

A-3.1 Methods

The AFP-200 fire alarm panel was configured in accordance with the manufacturer's instructions, and power was switched on and off throughout the test. To test the temperature hypothesis, the temperature of the AFP-200 circuit was raised and AC power was repeatedly applied and removed. A multi-line analyzer was used to record the performance of the panel during each test. The test equipment included a programmable power supply, oscilloscope, and thermal chamber. The hypothesis was tested by reproducing the power waveform recorded during the first successful reenactment (see Figure A-2). The power waveform was applied to the fire alarm panel with the electronics portion of the panel in a thermal chamber at temperatures ranging from 70 to 125°F. The panel was placed in the thermal chamber and the temperature was defined and stabilized. The panel was powered down 10 times at each defined temperature while observing the solenoids and alarms for activations.

A-3.2 Configuration

Figure A-4 shows the temperature test configuration.

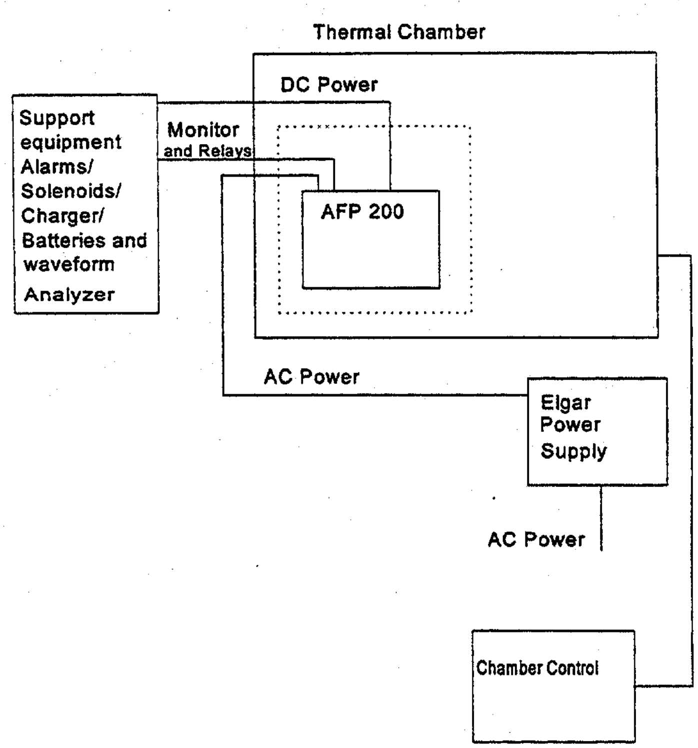

Figure A-4. Temperature test configuration.

A-3.3 Temperature Test Results

The panel as configured will activate on a random basis, with the probability increasing as the temperature is increased. Table A-2 shows the data of the temperature tests, detailing the solenoid and alarm activations.

Table A-2. Thermal chamber test results.

Temperature °F	Solenoid #1 Activations	Solenoid #2 Activations	Alarm Activations	Total Number of Attempts	Total Number of Attempts with Activations
70	0	0	0	10	0
90	0	0	0	10	0
100	0	0	0	10	0
110	0	0	0	10	0
115	0	0	0	10	0
120	2	4	2	10	4
125	4	3	1	10	4

A-4. SUMMARY OF MET LABORATORIES TESTS

The tests conducted at MET Laboratories concluded that activation of the CO_2 releasing mechanism was not the result of electrical waveform variations; but that upon interruption of AC power, the panel will activate on a random basis more frequently as temperature is increased.

Appendix B

Testing at Tronamix, Inc.

Appendix B

Testing at Tronamix, Inc.

B-1. INTRODUCTION

The technical response team (including the independent laboratories) identified a mechanism by which the AFP-200 control panel can activate the control panel output coincident with interruption of AC power supplying the panel. The output circuits affected are those connected to Terminal Block 2. In the case of the AFP-200 controlling the TRA-648 CO_2 system, these circuits included the solenoid release mechanisms for the CO_2 system cylinders.

Testing indicates that activation of the output circuits without a valid fire signal coincident with interruption of AC power to the control panel sometimes occurs with Jumper JP2 is cut. Jumper JP2 is intended to connect the on-board battery charger to the standby batteries. The onboard battery charger is capable of maintaining standby batteries with a capacity not exceeding 20 AH. The jumper is to be cut if an external battery charger, such as the Notifier NR45, is required to accommodate higher capacity batteries. JP2 is cut to disconnect the internal battery charger from the standby batteries while permitting the external charger to maintain the batteries. Testing also indicates that activation of the output circuits upon interruption of AC power to the control panel sometimes occurs with Jumper JP2 is intact (not cut) but the standby batteries are not connected to the control panel.

Jumper JP2 was cut in the control panel at Building 648 in accordance with the instructions provided by the AFP-200 manufacturer. An NR45 charger was used in the system to charge batteries with capacity greater than 20 AH.

B-1.1 Circuit Analysis

Figure B-1 shows the schematic diagram to facilitate the narrative that follows on circuit analysis.

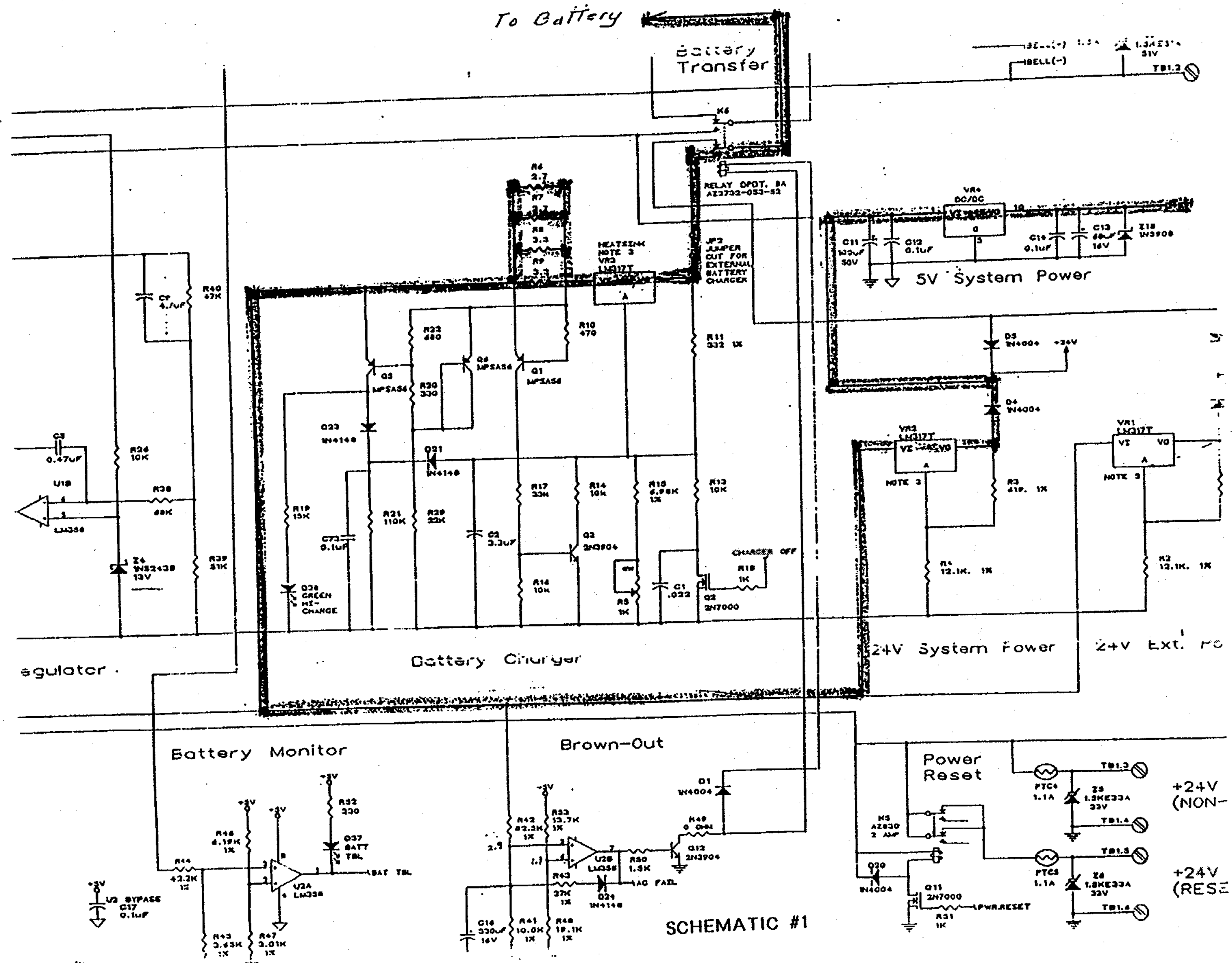

Figure B-1. Circuit analysis schematic.

B-1.1.1 Configuration Jumper JP2 Cut

With Jumper JP2 cut, the fire control system can falsely actuate the release solenoids.

When AC power is removed, the AFP-200 panel switches to battery power. This process of switching takes approximately one second or more because of time delays built into the *brownout circuit.* The panel uses energy stored in capacitors for power from the time the AC power is removed until the time the batteries are switched in. Under these conditions of power down, the +24VDC bus voltage decreases to zero volts as the energy in the capacitors is dissipated. This DC bus is also used to provide +5 volts to the microprocessor and other circuits. When the +24 V bus reaches approximately +7 volts, the +5 V bus voltage also drops. When +5 V bus drops to approximately +3 volts, the microprocessor begins to send out spurious signals to the circuits that are connected to it. These circuits may respond to these spurious signals and ultimately trigger the release solenoids. CO_2 is then released. Once the batteries are switched in, they provide continuous power to the panel until the batteries become depleted or AC power is restored.

Three power buses need to be tracked to see how the false actuation of release solenoids occurs: +24 V, +24 VU, and +5 V.

> **Note:** It is important to understand that the +5 V supply is derived from the +24 V supply by a 5-volt DC/DC chip attached to the output of +24 V regulator.

The +24 V is also used for power for some of the internal control circuits. The +24 VU is also used to power some of the internal control circuits but is used mainly used to power the external components connected to the system. The +5 V is used to power some of the internal circuits including the microprocessor.

When AC power is removed, the AFP-200 panel switches to battery power. This process of switching takes a second or more because of the time delay built into the brownout circuit. The time delay is determined by Capacitor C16 and the connected resistors and is approximately one second in duration. This time delay appears to vary considerably depending on conditions and the oscillatory action of the relay driver. The panel uses energy stored in capacitors for power from the time the AC power is removed until the batteries are switched in (Relay K6 drops out). The battery transfer relay is normally energized when AC power is present and drops out upon loss of AC power. When Relay K6 drops out, the batteries provide power to the panel until they are depleted or AC power is restored. During the time AC power is not present and the battery transfer Relay K6 is still energized, +24 VU bus drops about 2 volts exponentially. At this voltage the energy stored on the capacitors is adequate to actuate the release solenoids. During the first few hundred milliseconds after AC power removal, the +24 V bus decreases toward zero volts as the energy in the capacitors is dissipated. This +24 V bus provides the source for +5 V bus. When the +24 V bus reaches approximately 7 volts, the +5 V bus voltage drops also. When +5 V bus voltage drops to approximately +3 volts, noise appears on the microprocessor data bus and spurious select signals are generated by the microprocessor. Sometimes this combination of improper signals is picked up by one of the D flip-flops in U21 connected to the output of the microprocessor. The D flip-flop processes the signal as a legitimate fire signal and provides an output to the connected darlington transistor in U22. The darlington transistor activates one of the K-series relays, which in turn connects power to the connected release solenoid. This is possible because the energy stored on the capacitors on the +24 VU bus is adequate to operate the solenoids and their drivers at this time.

The +5 V bus powers the microprocessor U5 and the associated chips including the D flip-flops U21. The outputs of the D flip-flops drive the high current darlington transistors U22. The U22 chip is powered by the +24 VU bus. The outputs from U22 drive the K-series Relays (K1, K2, K3, and K4), which in turn connect power to the release solenoids. The K-series relays are powered by the +24 VU bus. Refer to Figure B-2.

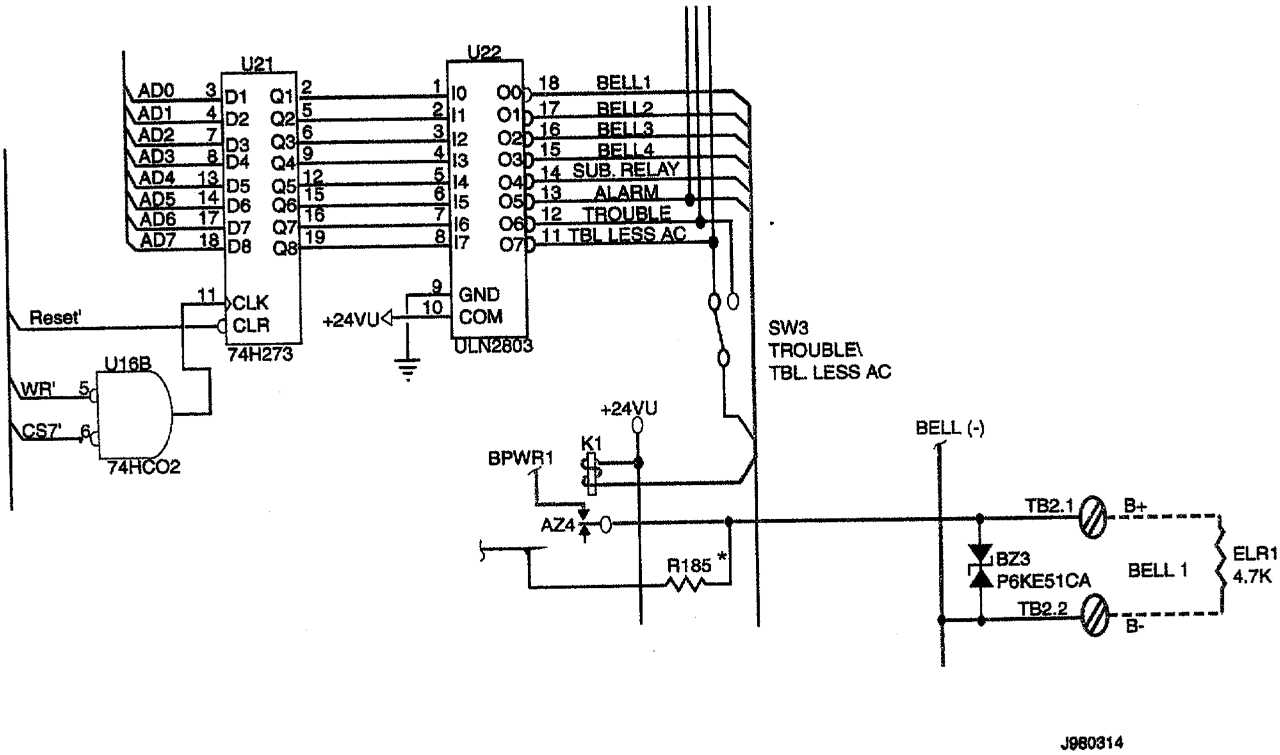

Figure B-2. The energy stored on the capacitors on the +24 VU bus is adequate to operate the solenoids.

B-1.1.2 Configuration Jumper JP2 Intact

With any configuration with Jumper JP2 intact in the AFP-200 panel and properly charged batteries connected, the fire control system does not falsely actuate the release solenoids.

The switching operations are similar to the above with the exception that the +24 V bus voltage does not drop significantly. With the Jumper JP2 intact and the power transfer relay energized, a circuit path exists from the battery through relay contacts and the Jumper JP2 and a back flow condition of Voltage Regulator VR3 and several shunt resistors to the source for the +24 V bus. This path from the battery to +24 V source prevents the +24 V bus from dropping significantly. Since the +24 V bus is relatively steady, the +5 V bus also remains constant at +5 volts; therefore, the microprocessor does not produce spurious output signals and no false actuations of the release solenoids occur. No CO_2 is released.

Figure B-1 schematic diagram shows the path from the battery to the DC/DC chip to power the +24 V and the +5 V buses during AC power interruptions that prevents false actuation of the release solenoids.

The battery is connected to one of the swinger contacts on Relay K6. RelayK6 remains energized after power interruption until battery transfer occurs. After AC power loss but before relay K6 is deenergized, a current path exists from the battery to the power source for +24V. Since the Jumper JP2 is intact, current flows through JP2 to the Vo pin of Voltage Regulator VR3. Back-flow occurs through the Voltage Regulator VR3. The use of this device in this manner may be unspecified, and the device may not perform reliably. Current then flows through the shunt resistor combination R6, R7, R8, and R9 to Voltage Regulators VR1 and VR2. Voltage regulator VR2 provides power to Voltage Regulator VR4, the DC/DC chip that makes +5V. This circuit path replaces the rectified output voltage on the bus (cathodes of Rectifiers D11 and D12) that was lost with the AC power interruption so that the +24 V and the +5 V buses remain constant.

B-1.1.3 Back-flow Tests on the LM317T Voltage Regulator

The back-flow characteristics of LM317T are necessary to make the panel work properly with the Jumper JP2 cut. The Motorola published specification sheets do not address the back-flow characteristics of the LM317T, and the device may not be specified for this application. Conversations with the Motorola engineering department have been initiated to determine if this device will perform satisfactorily in this mode.

An LM317T voltage regulator was obtained and was setup as shown in Figure B-3 to test the back-flow mode of this chip. The findings were that this device does exhibit back-flow characteristics, and the voltage drop across the device is approximately 0.4 volts. Tests show that when +26.2 volts is applied to V-out, V-in becomes 25.8 volts. It appears that under these conditions the voltage drop across the LM317T is approximately 0.4 volts.

B-1.1.4 Voltage Traces on Important Leads

A Tektronix 2221A digital storage oscilloscope was used to record the voltages at various important points in the circuitry. The configuration included an NR45 charger connected to the AFP-200 panel with Jumper JP2 cut. Figure B-4 shows five traces on one sheet with a common start point and sweep speed for reference purposes. Individual traces shown are with an AC power reference for the +24 V bus voltage, the +5 V bus voltage, the +24 VU bus voltage, and the battery transfer relay voltage. The drop-out characteristics of the battery transfer relay is oscillatory and could affect the timing for relay drop-out.

Another important set of recorded voltage traces displayed on Figure B-4 shows spurious *select pulses*. These traces were recorded on a digital storage oscilloscope at MET Labs in Baltimore, MD while the AFP-200 panel was at 115°F. The AFP-200 panel was equipped with a NR45 charger and an AVPS24 power supply. The top trace shows the declining +5 V bus after loss of AC power. The bottom trace shows the *select pulses*. The first and second *select pulses* appear at the observed regular 250-millisecond rate; however, the second *select pulses* is lower in amplitude. *Select pulses* labeled 3 and 4 appear at reduced amplitudes at approximately 28 and 36 milliseconds after the second *select pulse*. These *select pulses* occurring out of the normal timing sequence could produce a false “fire” signal to start the chain of events leading to false operation of the release solenoids.

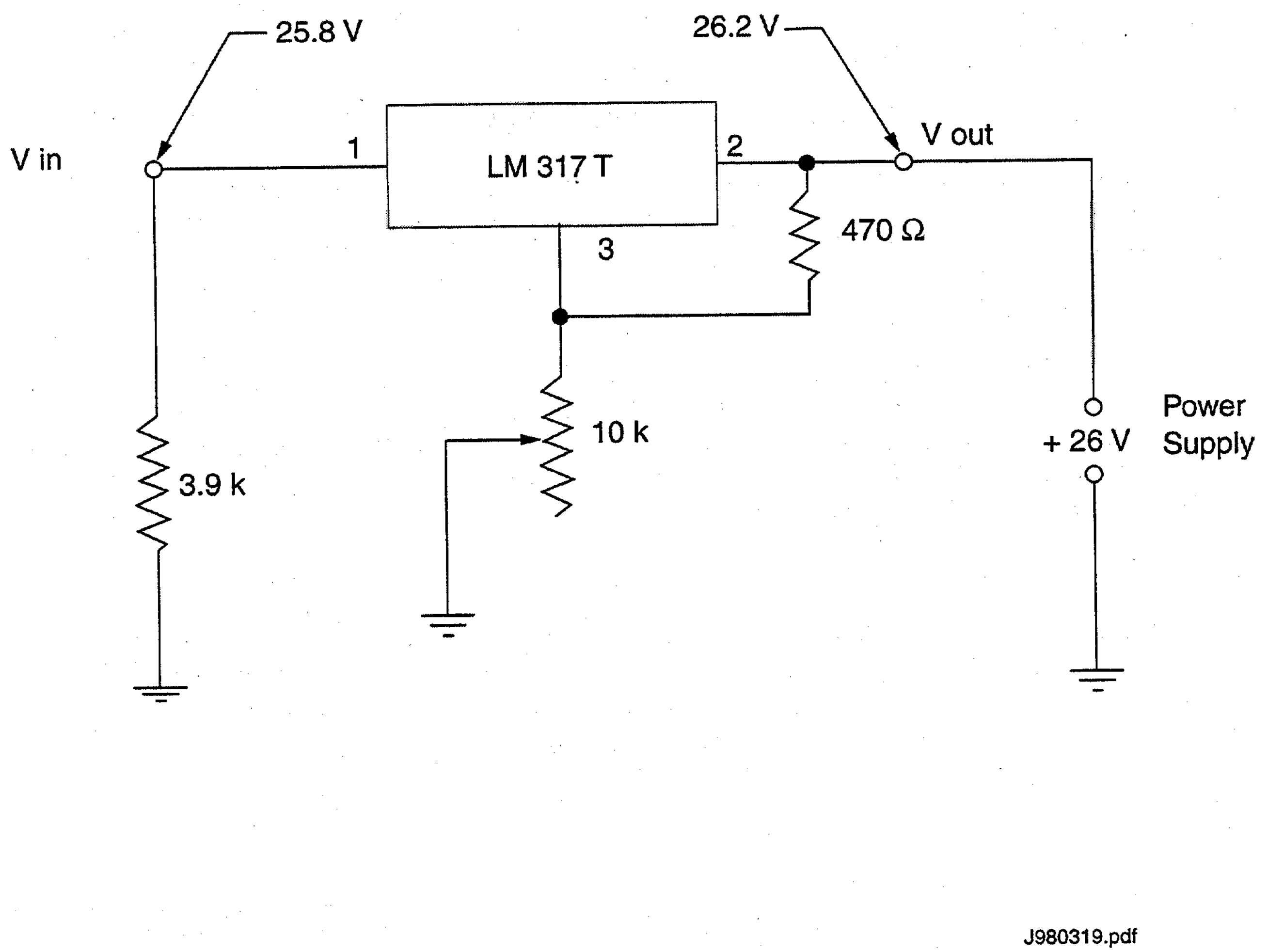

Figure B-3. Select pulses following loss of AC power.

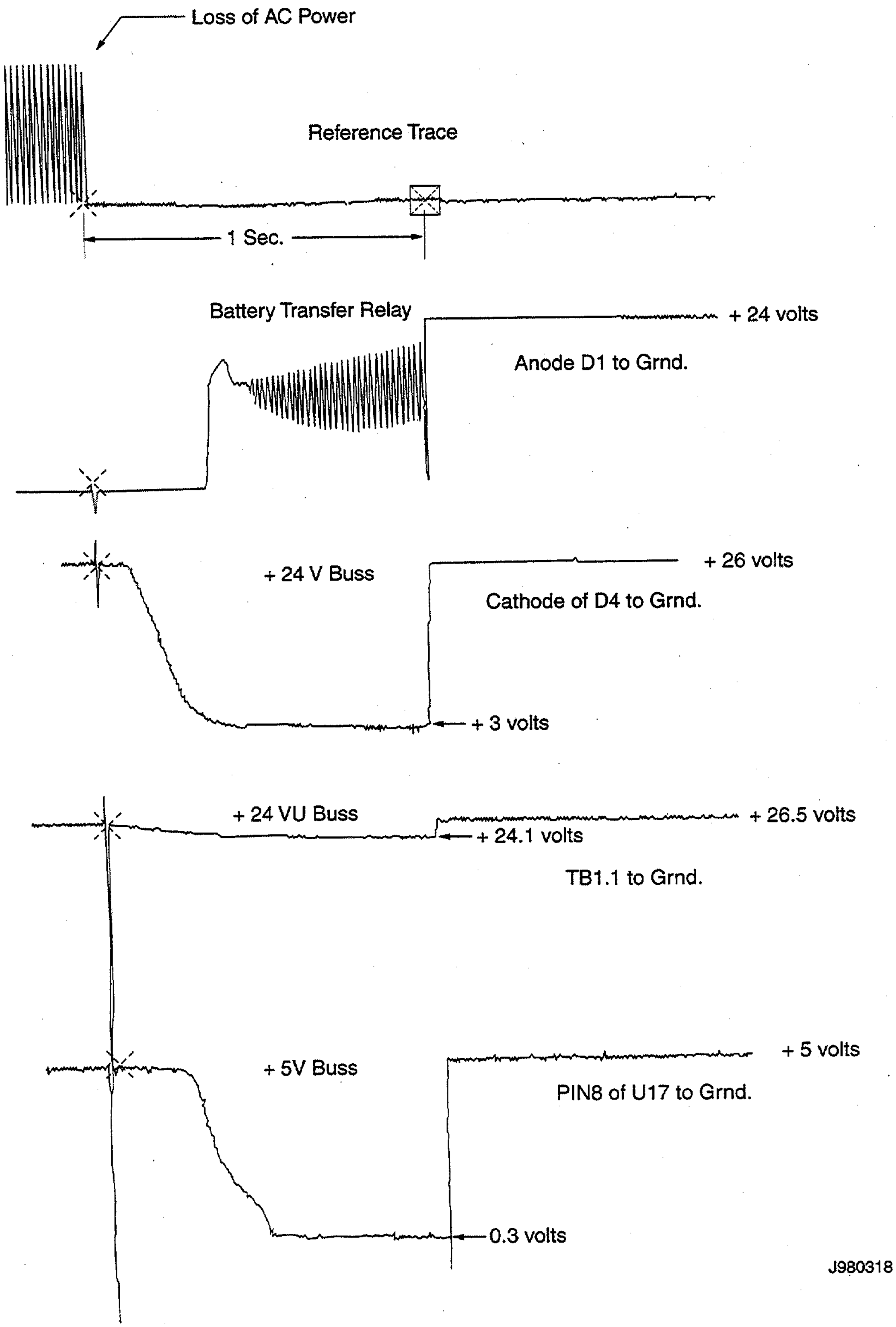

Figure B-4. Voltage traces on important leads.

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B-1.1.5 Reconciliation of Observations

While testing the panel, actuation of release solenoids without a valid fire signal occurred several times while the battery was disconnected and AC power was interrupted. A battery that is disconnected has the same effect on the panel as cutting the Jumper JP2. When AC power is disconnected and the K6 battery transfer relay is still energized and the battery is disconnected, no voltage is available to power the +5 V via the discussed path through Voltage Regulator VR3. With no source voltage to power the +5 V bus, the +5 V bus voltage will drop, passing through the 3-volt range; making the system subject to actuations of release solenoids without a valid fire signal.

B-1.1.6 Test Data Summary

Sufficient data has been taken to date to establish that actuation of the output circuits occurs without a valid fire signal, and the mechanism that makes it happen has been discovered. Table B-1 shows the results of tests conducted to examine how the panel is affected by variations in temperature, and different combinations of battery, jumper, and charger connections. All tests at 74°F were made using an automatic test fixture that cycled the panel on/off at a 30 second-per-cycle rate; tests at 120°F were made by manually switching the AC power. Line voltage was at 118 ± 4 volts. A standard set of relay contacts was used to switch the panel on and off.

Table B-1. Test results.

Panel Configuration	Jumper JP2	Temperature	Number of AC power interruptions	Number of Actuations of Output Circuits
AFP-200, "good" battery connected, 74°F	Intact	74°F	360	0
AFP-200 with AVPS24, "good" battery connected, 74°F	Intact	74°F	256	0
AFP-200, "good" battery connected, 120°F±5°	Intact	120°F	10	0
AFP-200 with NR45, AVPS24, battery connected, 74°F±3°	Cut	74°F	364	4
AFP-200 with NR45, battery connected, 74°F±3°	Cut	74°F	240	5
AFP-200	Cut	74°F	240	2
AFP-200 with NR45 and AVPS24	Cut	120°F	10	4

With JP2 intact: Total power interruptions = 626. Total output circuit actuations = 0.
With JP2 cut: Total power interruptions = 854. Total output circuit actuations = 15.

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B-1.1.7 Mechanism

Team members observed activation of the control panel output circuits during the course of testing. During the testing done at INEEL and MET Labs, instrumentation displayed the immediate cause of the output circuit activation.

Relays K1, K2, K3, and K4 control the output circuits that are being studied. These relays are activated by a transistor array chip U22. The transistor array chip circuits are activated by outputs from flip-flop circuits contained in chip U21. The flip-flop circuits are activated by outputs from the control panel microprocessor array.

Figures B-5 through B-8 depict the essential circuitry and connections. All figures depict the system with no fire detectors, manual stations, or other initiating devices in "alarm." All figures depict the system with an acceptably charged backup battery connected to the control panel.

Figure B-5 shows the circuits with AC power to the panel ON.

B-1.1.8 AC Power Interruption With Jumper JP2 Intact and Standby Battery Connected (Figure B-6)

During testing, when AC power was disconnected from the panel with Jumper JP2 intact and a suitably charged standby battery connected to the panel, the 24 volt DC supplying chip VR4 remains essentially at 24 volts. Chip VR4 is a DC/DC chip which makes the 5 volt DC supply. The +5 volt DC bus remains at 5 volts DC and the microprocessor circuitry remains "normal"— in other words, no spurious signals are emitted from the microprocessor. No output circuit activation was observed under these conditions.

B-1.1.9 AC Power Interruption With Jumper JP2 Cut (Figure B-7)

With JP2 cut, the 24 volt DC power from chip VR2 falls to nearly zero. As this +24 volt bus drops below 7 volts, VR4 is unable to produce 5 volts DC. The voltage on the +5 volt DC bus decays. As the +5 bus voltage dropped to approximately 3 volts, "random" or "spurious" signals were observed on the outputs from the control panel microprocessor into the flip-flop circuits. At times the particular combination of spurious signals caused one or more flip-flop circuits to operate. Operation of a flip-flop circuit caused the connected transistor on chip U22 to operate, in turn, causing the connected output circuit relay to operate.

B-1.1.10 AC Power Interruption With Jumper JP2 Intact and Standby Battery Disconnected (Figure B-8)

Tests were done with JP2 intact and the standby battery disconnected from the panel. Under this condition, the 24 volt DC supplying chip VR4 drops to zero volts when AC power is disconnected. Before the 24 VDC voltage goes to zero, the voltage on the +5 VDC bus decays. As the +5 bus voltage drops below approximately 3 volts, "random" or "spurious" signals were observed on the outputs from the control panel microprocessor into the flip-flop circuits. At times the particular combination of spurious signals caused one or more flip-flop circuits to operate. Operation of a flip-flop circuit caused the connected transistor on chip U22 to operate, in turn, causing the connected output circuit relay to operate.

FIGURE B-5. Simplified diagram of AFP-200 control panel circuit that operates output circuits on terminal block 2

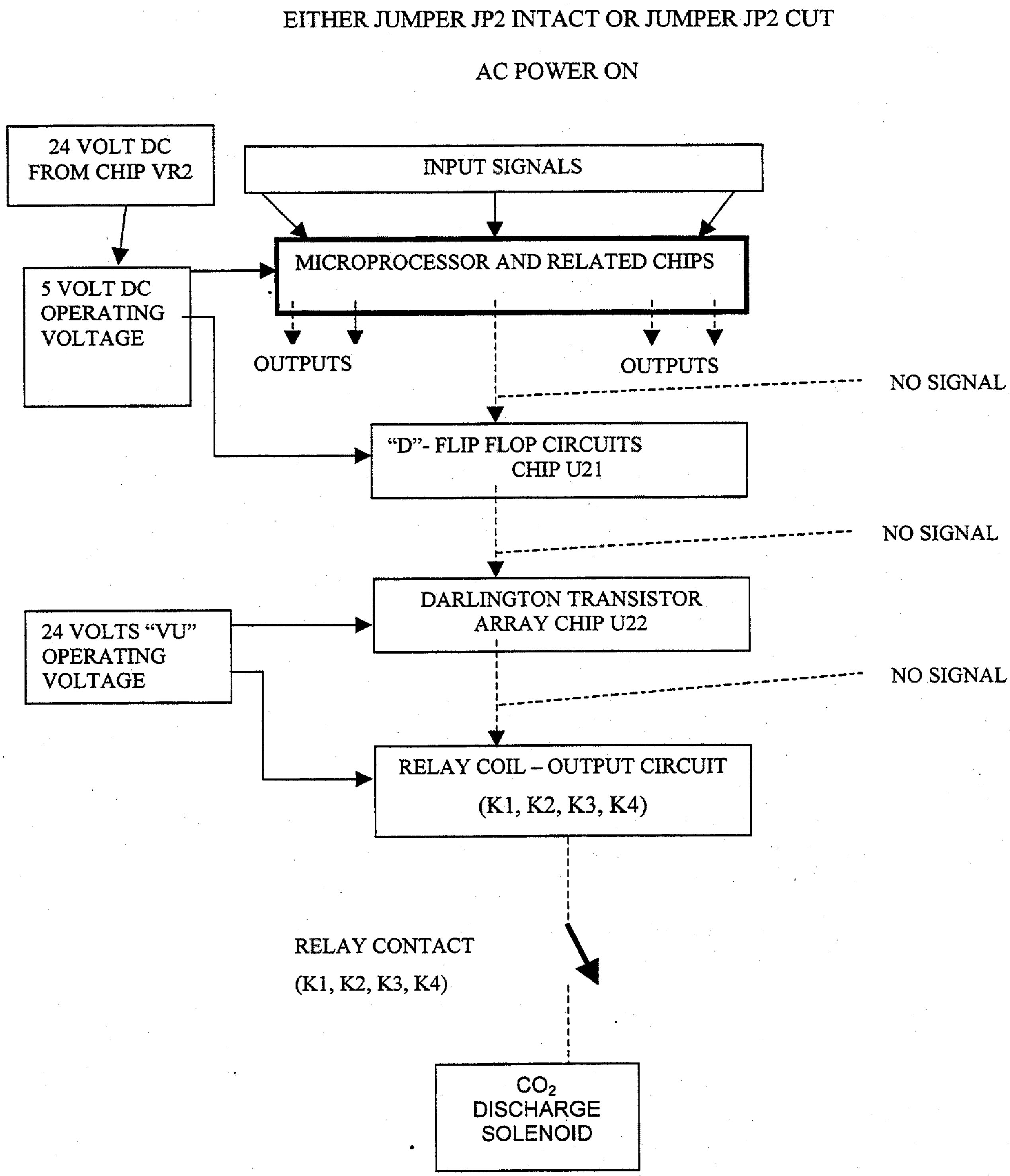

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Figure B-6. Simplified diagram of AFP-200 control panel circuit that operates output circuits on terminal block 2

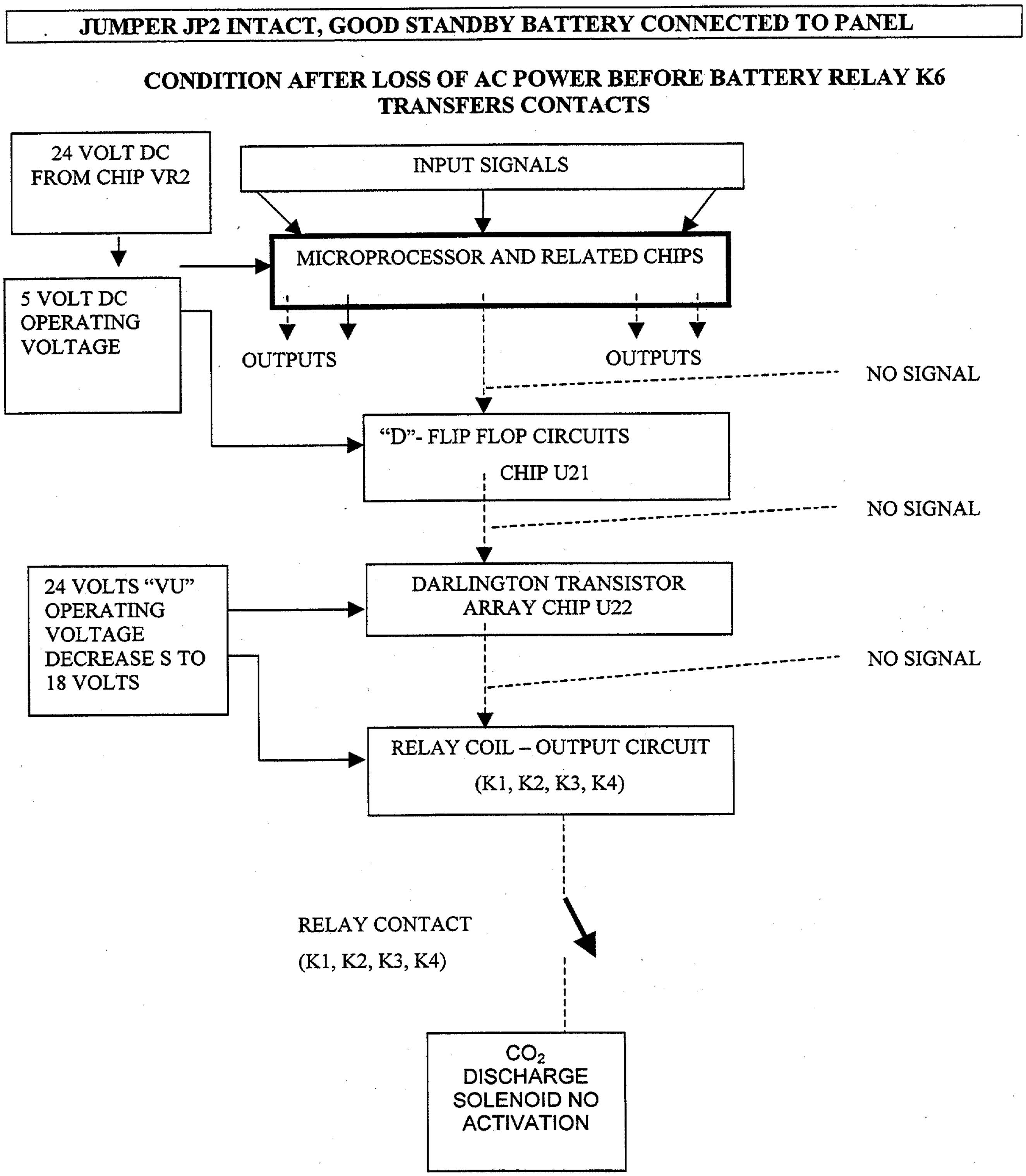

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Figure B-7. Simplified diagram of AFP-200 control panel circuit that operates output circuits on terminal block 6

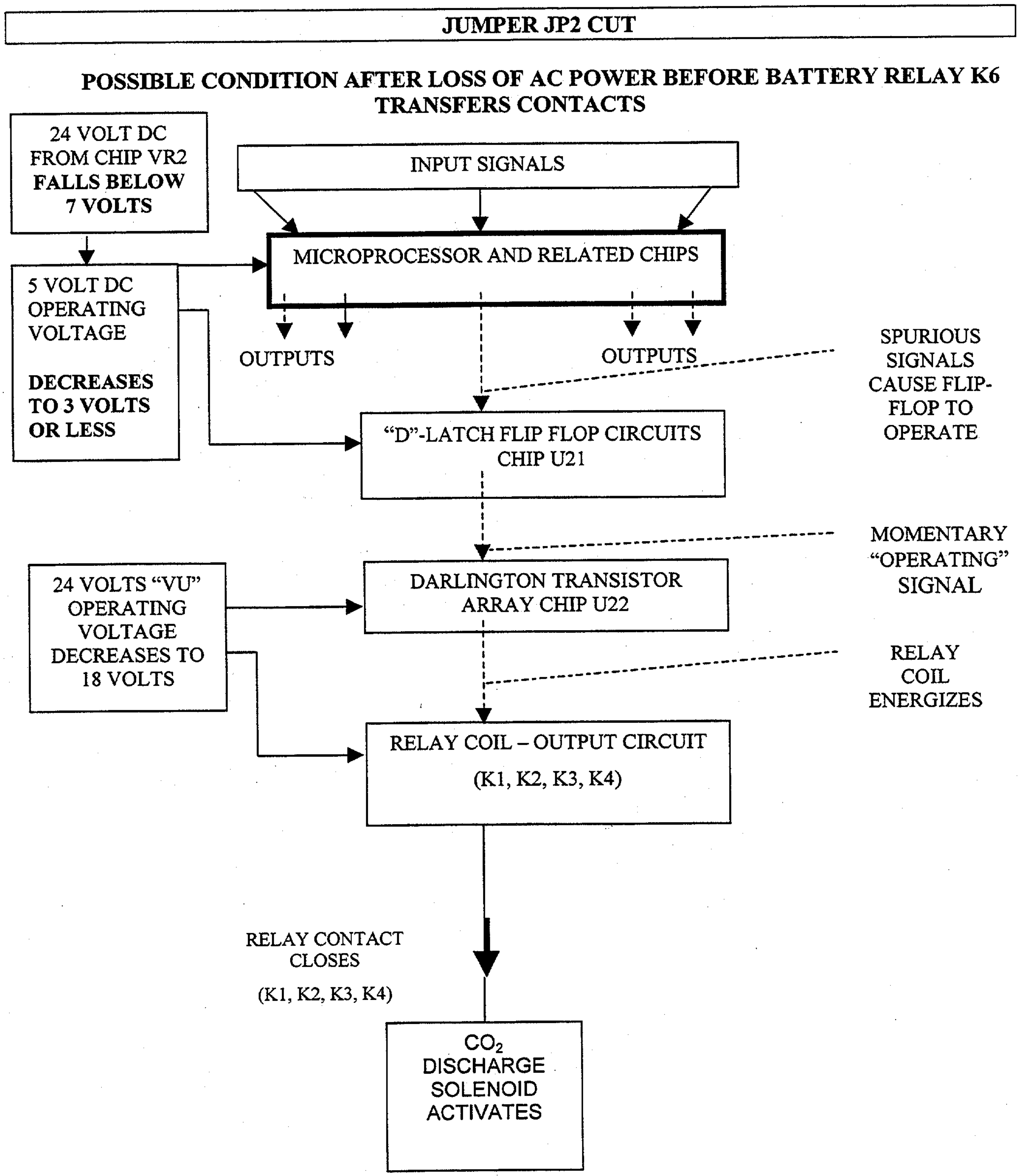

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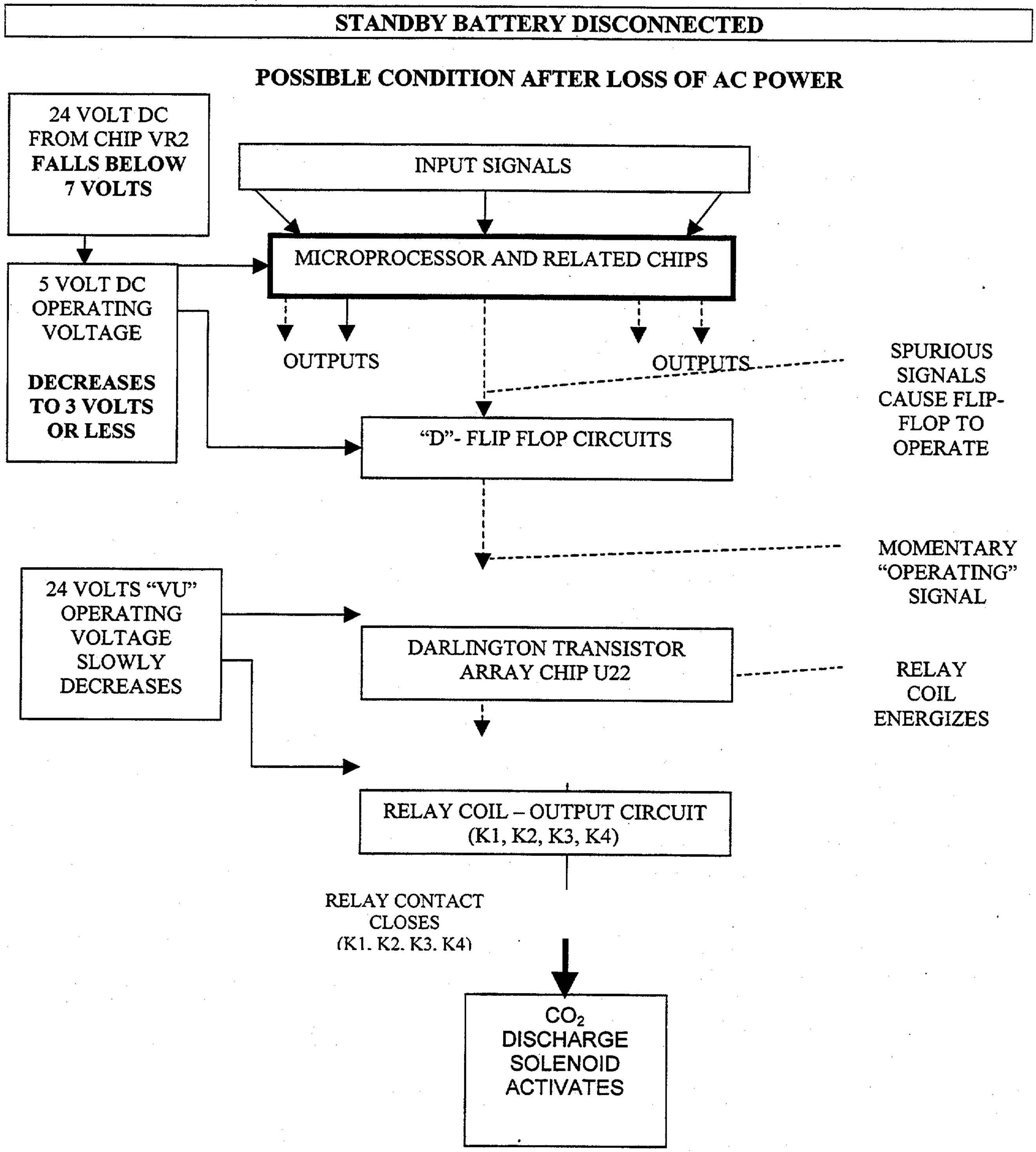
Figure B-8. Simplified diagram of AFP-200 control panel circuit that operates output circuits on terminal block 2



B-1.1.11 Mechanism of 5 Volt Decay

The cause of the decay of the panel's 5 volt DC power was investigated by reviewing the AFP-200 power supply circuitry. A possible mechanism for decay of the voltage on the 5 volt DC bus was identified. The mechanism was verified by laboratory testing.

Notifier Document Number 70577, Rev. B, April 5, 1995, shows the internal battery charger and power supply circuitry for the AFP-200 panel.

When AC power is interrupted, a brown out circuit in the panel senses the AC power loss and causes Relay K6 in the panel to transfer the AFP-200 operating circuits to run from the standby DC batteries. Measurements taken during testing showed that approximately two seconds elapsed after AC power was disconnected before the relay contacts on K6 transferred. Thus there was a lag on the order of one or more seconds after AC power failed before the relay transferred the control panel operating circuits to the standby batteries. During this lag time, the voltage conditions in the panel differed depending on whether Jumper JP2 was intact or cut.

With the Jumper JP2 intact and a suitably charged standby battery connected to the panel, the +5 volt bus voltage remains steady during the lag time before Relay K6 transfers. With adequate AC power supplied to the panel, the battery is connected to the output terminal on Voltage Regulator VR3 through the K6 relay contact and Jumper JP2. Between the time AC power is interrupted and Relay K6 transfers, current from the battery "back flows" through Jumper JP2 into the output terminal on Voltage Regulator VR3, and out the input terminal on VR3. During this time, the battery supplies voltage to VR2 enabling it to supply voltage to VR4 — the DC/DC chip which makes the 5 volt DC for the +5 VDC bus. During the lag time, the +24 VDC from VR3 remains well above 20 volts DC.

With the jumper cut, the +5 volt bus voltage drops below 3 volts before the Relay K6 transfers the panel to the standby battery. Since the standby battery is disconnected from the control panel operating circuits before the AC power occurs, during the lag time the only sizeable electric power available to power the control panel operating circuits comes from the filter capacitors in the on-board power supply. The power bleeds rapidly from these capacitors; the 24 volt source supplying the 5 volt DC/DC chip drops to near zero, and the 5 VDC voltage falls below that required for reliable operation of the microprocessor circuitry. This occurs because Jumper JP2 is cut. Hence, there is no possibility of back flow into the on-board voltage regulators from the standby batteries until Relay K6 transfers its contacts.

Back flow from the standby battery through the Relay K6 contact and Jumper JP2, and then through Voltage Regulator chip 3, prevents the microprocessor from emitting spurious signals due to low voltage when the standby battery is charged from the onboard charging circuit. When an external charger is used and JP2 is cut, there is no adequate source of electric power available to power the microprocessor during the lag time between AC interruption and transfer of Relay K6 contacts to battery power.

B-1.2 Summary

Given the verification of the reasons why the 5 VDC stays essentially at 5 VDC with Jumper JP2 intact—and conversely explaining why the 5 VDC decays with Jumper JP2 cut—the team discovered how the output circuits momentarily activate at times when AC power to the control panel is interrupted.

Activation of the output circuits coincident with AC power interruption occurred in every panel configuration tested as long as JP2 was cut..

Activation of the output circuits was also observed with JP2 connected if the standby batteries were disconnected from the control panel prior to interruption of AC power.

Circuit analysis results indicate that if the standby batteries are "weak" or faulty, activation of the output circuits upon interruption of AC power may occur. This condition has not been tested.

With Jumper JP2 intact and a suitably charged standby battery connected to the panel, no activation of the output circuits was observed during 626 AC power interruptions.

Notifier's August 21, 1998, correspondence to LMITCO stated that Notifier's testing "has shown that the AFP-200, when used with the separate NR45 charger, can be perturbed momentarily by an AC power loss or an AC voltage transient. When this perturbation occurs, it is possible that the output circuits could momentarily activate."

Testing by the technical response team indicates that the output circuits can momentarily activate coincident with AC power loss with Jumper JP2 cut. Activation was observed with and without the NR45 charger connected. In other words, the NR45 charger does not cause the observed effects. Jumper JP2 being cut permits the observed effects to occur. Use of any equipment with the AFP-200 panel that requires JP2 to be cut would appear to result in the same potential for operation of the output circuits coincident with interruption of AC power. Also if the standby batteries are disconnected from the control panel, interruption of AC power to the panel can cause activation of the output circuits.

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