



INEEL/EXT-99-00282

April 1999

**Supplemental  
Response to 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**

**Supplemental Response to 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**

**Published April 1999**

**Idaho National Engineering and Environmental Laboratory**

**Lockheed Martin Idaho Technologies Company  
Idaho Falls, Idaho 83415**

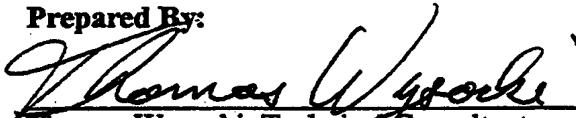
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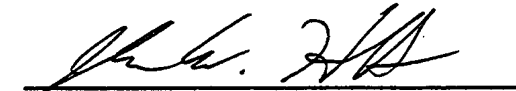
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**LMITCO Supplemental Response  
to the DOE Type A Investigation Report  
of the TRA-648 CO<sub>2</sub> Accident**

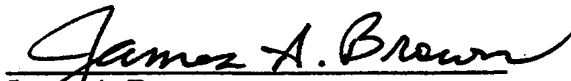
**Prepared By:**

  
Thomas Wysocki, Technical Consultant  
Guardian Services, Inc.

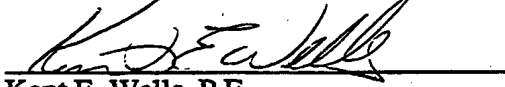
  
John Hockert, Ph. D., Vice President  
X E Corporation

  
Pete T. Scobby, Team Leader  
Safety Engineer

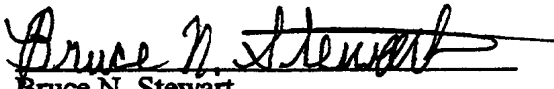
  
Lannie D. Workman  
Project/Construction Management

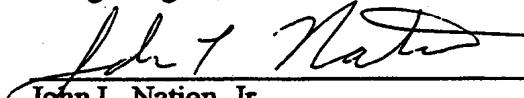
  
James A. Brown  
Supervisor, Fire Protection Engineer

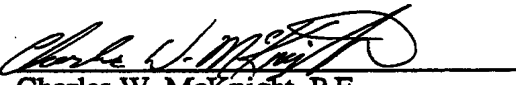
  
Walter B. Carnes, CSP  
Industrial Safety Engineer

  
Kent E. Wells, P.E.  
Design Engineer

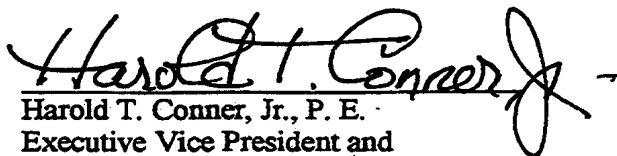
  
Terry L. Julius  
Design Engineer


  
Bruce N. Stewart  
Life Safety Systems Engineer


  
John L. Nation, Jr.  
Design Engineer

  
Charles W. McKnight, P.E.  
Design Engineer

**Reviewed By:**

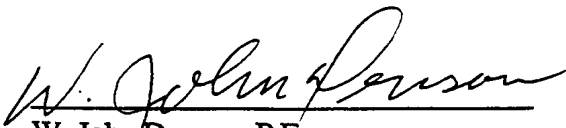
  
Harold T. Conner, Jr., P. E.  
Executive Vice President and  
Chief Operations Officer

  
James A. Van Vliet, Vice President and  
General Manager, ESH&QA

  
W. D. Altman, Ph.D.  
Deputy General Manager, ESH&QA

  
Willis Walker  
Vice President and General Counsel

**Approved By:**

  
W. John Denson, P.E.  
President

**LMITCO Supplemental Response  
to the DOE Type A Investigation Report  
of the TRA-648 CO<sub>2</sub> Accident**

**Independent Peer Review By:**

Thomas J. Wysocki  
Technical Consultant, Guardian Services, Inc.  
Chairman, NFPA 12A Technical Committee  
Member, NFPA CO<sub>2</sub> Committee  
Editor of NFPA *Fire Protection Handbook* Chapter on CO<sub>2</sub> Systems

Frank S. Kasper  
Technical Consultant and Independent Testing Laboratory  
President, Tronamix, Inc.

John D. Jensen, P.E.  
Fire Protection Consultants, Inc.  
Member, NFPA Technical Committee on Centrifugal Fire Pumps  
Member, NFPA Technical Committee on Water Tanks  
Member (former), NFPA Advisory Council  
Director and Vice President (former), Society of Fire Protection Engineers

Calvin C. Murphy  
District Manager, (former) for the Division of Enforcement of Occupational Safety and Health for the state of Nevada  
DOSII Compliance Officer (former), Department of Industrial Relations, state of Nevada  
OSHA Consultant (former), Department of Industrial Relations, state of Ohio  
Industrial Safety Inspector (former), Division of Safety and Hygiene, state of Ohio

## ABSTRACT

This Supplemental Response 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 Supplemental Response 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<sub>2</sub> 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<sub>2</sub> system to discharge without warning.

This Supplemental Response also documents results of the review of Lockheed Martin Idaho Technologies Company compliance with applicable Occupational Safety and Health Administration regulations and National Fire Protection Association codes and standards, performed by independent experts and Lockheed Martin Idaho Technologies Company to support the development of the corrective actions in the *Consolidated Response to Type A Investigation of CO<sub>2</sub> Fatality at Test Reactor Area, Idaho National Engineering and Environmental Laboratory* (DOE/ID-10699, INEEL/EXT-98-01020). It also documents results of the review of design and installation practices employed for the 1997 upgrade of the Test Reactor Area Building 648 CO<sub>2</sub> fire suppression system and the work practices employed at the time of the accident. This Supplemental Response includes a brief description of the health and safety enhancements and achievements at the Idaho National Engineering and Environmental Laboratory over the past 4-1/2 years. This discussion provides a safety context for the events leading to the accident and the results of the reviews discussed above. Finally, the conclusions of the testing, analysis, and reviews are briefly summarized.

This Supplemental Response does not affect the Lockheed Martin Idaho Technologies Company commitment to implement the corrective actions in the *Consolidated Response to Type A Investigation of CO<sub>2</sub> Fatality at Test Reactor Area, Idaho National Engineering and Environmental Laboratory*, as modified by the subsequent *INEEL CO<sub>2</sub> Corrective Action Implementation Plan* (DOE/ID-10671, INEEL/EXT-98-01172). The information in Section 5 of this Supplemental Response demonstrates that Lockheed Martin Idaho Technologies Company has been and remains deeply committed to improving safety and health protection at the Idaho National Engineering and Environmental Laboratory.



## EXECUTIVE SUMMARY

On September 18, 1998, the Department of Energy 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<sub>2</sub> system in Test Reactor Area Building (TRA-648) discharged. This Supplemental Response to the Investigation Report summarizes results of testing done by two independent laboratories and LMITCO to determine the mechanism that caused the CO<sub>2</sub> system to discharge.

The specific mechanism that caused the CO<sub>2</sub> 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<sub>2</sub> 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.

In conjunction with this testing, to determine the specific mechanism that caused the CO<sub>2</sub> system to discharge without warning, a team of safety professionals knowledgeable in the applicable codes, standards, and requirements reviewed the design and installation of the TRA-648 CO<sub>2</sub> fire suppression system. This team of safety professionals also reviewed the design and installation process for the TRA-648 CO<sub>2</sub> fire suppression system and the planning, management, and execution of the electrical maintenance being performed the evening of the accident. These reviews demonstrated that:

- The TRA-648 CO<sub>2</sub> fire suppression system employed a microprocessor-based fire panel, the AFP-200, which was Underwriters Laboratory (UL)-listed and Factory Mutual (FM)-approved as being compliant with the National Fire Protection Association (NFPA) *Standard on Carbon Dioxide Extinguishing Systems* (NFPA 12) and the *National Fire Alarm Code* (NFPA 72). Despite the NFPA 12 and NFPA 72 requirements that fire panels controlling CO<sub>2</sub> systems be designed to preclude accidental discharge of CO<sub>2</sub> upon transition from AC power to battery backup, the AFP-200 had a design defect that caused such accidental discharges to occur randomly and without any warning alarm.
- Neither Occupational Safety and Health Administration (OSHA) regulations nor NFPA codes and standards required lockout/tagout of the CO<sub>2</sub> fire suppression system for the maintenance work in progress at the time of the accident. There was no requirement for lockout/tagout because the CO<sub>2</sub> system was not being worked on and because personnel performing the work were familiar with the operation of the CO<sub>2</sub> system.
- The design of the TRA-648 CO<sub>2</sub> fire suppression system employed provisions for lockout of the CO<sub>2</sub> discharge that were acceptable under OSHA regulations and NFPA requirements.
- The TRA-648 emergency egress pathways and emergency lighting met the applicable OSHA regulations and the NFPA Life Safety Code (NFPA 101) requirements.



- The design of the TRA-648 CO<sub>2</sub> fire suppression system met applicable NFPA 72 requirements without use of a pressure switch and feedback circuit to trigger the predischage warning alarm.
- Personnel who designed the CO<sub>2</sub> system upgrades and installed the Notifier AFP-200 Analog Fire Panel followed applicable requirements, which included operational acceptance tests and quality assurance inspections. These personnel met or exceeded applicable qualification requirements.
- Personnel who planned, managed, and performed the maintenance work the evening of the accident followed applicable LMITCO procedures and met or exceeded applicable qualification requirements.

The CO<sub>2</sub> discharge accident was caused by a design defect in the Notifier AFP-200 Analog Fire Panel. The UL listing and FM approval of the AFP-200 panel implies that this specific defect was not detected during testing for listing and approval. This specific design defect did not manifest itself in the acceptance tests performed by the installation subcontractor and the System Operations (SO) tests performed by LMITCO, nor did it show up under operating conditions prior to the accident. Furthermore, the TRA-648 CO<sub>2</sub> system had been disconnected from AC power 10 times within the previous 16 months before the evening of the accident without incident. The personnel who designed and installed the CO<sub>2</sub> system upgrades and who planned, managed, and performed the electrical maintenance work the evening of the accident made reasonable decisions and exercised appropriate professional judgment based on the information available to them at the time. They did not knowingly endanger, or fail to take appropriate steps to protect, themselves and their fellow workers.

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. This Supplemental Response is one more step in sharing information about, and the lessons learned from, the CO<sub>2</sub> discharge accident.

Throughout its tenure as the management and operations contractor for the Idaho National Engineering and Environmental Laboratory, LMITCO has been committed to ensuring protection of the environment, the workforce, and the public, and to improving safety and health programs. The CO<sub>2</sub> discharge accident has reinforced this commitment. Nothing in this Supplemental Response affects the LMITCO commitment to implement the corrective actions in the *Consolidated Response to the Type A Investigation of CO<sub>2</sub> Fatality at Test Reactor Area, Idaho National Engineering and Environmental Laboratory* (Consolidated Response) as modified by the subsequent *INEEL CO<sub>2</sub> Corrective Action Implementation Plan* (DOE/ID-10671, INEEL/EXT-98-01172), including accelerating the implementation of Integrated Safety Management.

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## ACRONYMS

AC	alternating current
AHJ	Authority Having Jurisdiction
CFA	Central Facilities Area
CLK	clock pin
CO <sub>2</sub>	carbon dioxide
DC	direct current
DOE	U.S. Department of Energy
DOE-ID	Department of Energy Idaho Operations Office
EMI	electromagnetic interference
EPA	Environmental Protection Agency
ETR	Engineering Test Reactor
EWP	Enhanced Work Planning
FM	Factory Mutual
IDLH	Immediately Dangerous to Life and Health
INEL	Idaho National Engineering Laboratory
INEEL	Idaho National Engineering and Environmental Laboratory (formerly INEL)
ISM	Integrated Safety Management
JON	judgment of need
LITCO	Lockheed Idaho Technologies Company
LMITCO	Lockheed Martin Idaho Technologies Company (formerly LITCO)
MSDS	material safety data sheets
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
NRC	Nuclear Regulatory Commission
NSPE	National Society of Professional Engineers
NICET	National Institute for Certification in Engineering Technologies
NRTL	Nationally Recognized Testing Laboratory

OSHA	Occupational Safety and Health Administration
PBF	Power Burst Facility
RFI	radio frequency interference
RWMC	Radioactive Waste Management Complex
SO	System Operations
SOLAS	Safety of Life at Sea
TAN	Test Area North
TRA	Test Reactor Area
UL	Underwriters Laboratory
VAC	volts of alternating current
VDC	volts of direct current
VPP	Voluntary Protection Program
VR	voltage regulator

## 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.
Halon	Halogenated hydrocarbon compounds used in fire suppression system applications such as Halon 1301 (bromotrifluoromethane).
High pressure CO <sub>2</sub>	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 <sub>2</sub> cylinder valve assembly that opens the valve, thus discharging the CO <sub>2</sub> 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.
Monitor module	An addressable module that monitors conventional alarm initiating devices.
National consensus standard	Any occupational safety and health standard promulgated by a nationally recognized standards-producing organization. Persons interested and affected by the scope or provisions of the standard reach substantial agreement on its adoption, and the standard is formulated in a manner which affords an opportunity for diverse views to be considered.
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 <sub>2</sub> storage cylinders that discharges the CO <sub>2</sub> 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.

# **Supplemental Response to 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**

## **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<sub>2</sub>) 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<sub>2</sub> 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<sub>2</sub>, without annunciation of the predischage 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,<sup>1</sup> (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<sub>2</sub> Fatality at Test Reactor Area, Idaho National Engineering and Environmental Laboratory*,

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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.

DOE/ID-10699, INEEL/EXT-98-01020,<sup>2</sup> (Consolidated Response), which describes the actions that DOE-ID and LMITCO are taking to answer the Board's judgments of need (JONs).

## **1.2 Supplemental Response Scope**

This Supplemental Response addresses technical issues associated with the CO<sub>2</sub> accident, including the results of an investigation to determine the specific mechanism that caused the non-fire initiated discharge of the CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> system in Building 648 should remain out of service and compensatory fire protective measures implemented, as appropriate.”

As a part of the effort to determine the specific discharge mechanism, a team of LMITCO safety professionals and independent experts knowledgeable in the applicable codes, standards, and requirements reviewed the design and installation of the TRA-648 CO<sub>2</sub> fire suppression system. The LMITCO review effort included facilitation and technical support by qualified personnel from other Lockheed Martin companies, and independent laboratories and industry experts.

### **1.2.1 Supplemental Response Team Membership and Qualifications**

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<sub>2</sub> system in TRA-648 discharged. Summary reports from testing at the independent laboratories are in Appendices A and B of this Supplemental Response; qualifications and certifications of the response team are shown in Appendix C. 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 Supplemental Response.

### **1.2.2 Supplemental Response Report Scope**

As part of the effort to develop the Consolidated Response, this team also reviewed the design and installation process for the TRA-648 CO<sub>2</sub> fire suppression system and the planning, management, and execution of the electrical maintenance being performed the evening of the accident. These reviews produced information related to LMITCO compliance with regulatory requirements and applicable codes and standards; the design and installation process for the 1997 upgrade of the TRA-648 CO<sub>2</sub> fire protection system; and the planning, management, and performance of the electrical maintenance work performed the evening of the accident. This Supplemental Response summarizes the information discovered during these reviews and provides a brief description of the health and safety enhancements

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

and achievements at the INEEL over the past five years. This discussion provides a safety context for the events leading to the accident and the results of the reviews discussed above.

## 2. THE SPECIFIC MECHANISM BY WHICH THE CO<sub>2</sub> 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<sub>2</sub> 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 Supplemental Response describes the specific mechanism by which the CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub>. 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<sup>3</sup> 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.<sup>4</sup>

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<sub>2</sub> fire extinguishing system into TRA-648. The CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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  $\pm$  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<sub>2</sub>, 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<sub>2</sub> (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<sub>2</sub> 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<sub>2</sub> 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,<sup>5</sup> 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<sub>2</sub> 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<sub>2</sub> during the period when the power to the microprocessor is reduced below its operating range. Thus, the CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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

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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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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.”<sup>6</sup>

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.

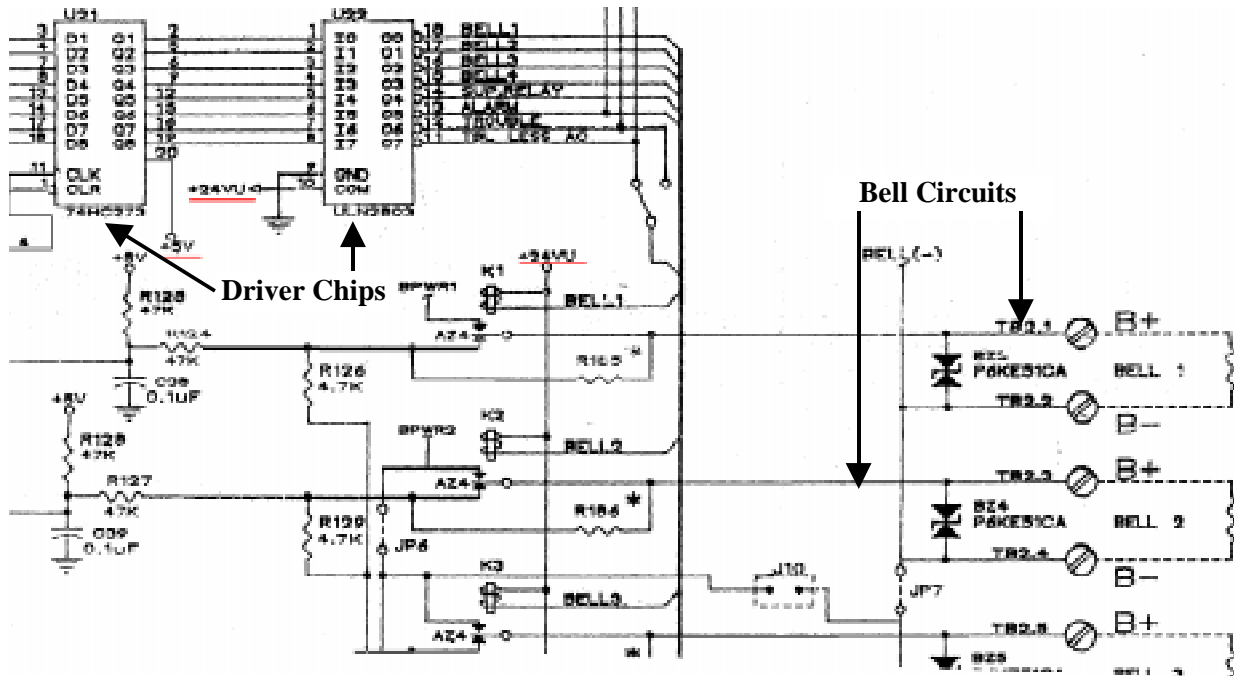
The response team discovered the specific mechanism by which the AFP-200 panel activates the output circuits upon AC power loss. The mechanism reflects serious deficiencies in the design of the AFP-200 panel. To understand the mechanism, two areas of the panel circuitry must be considered:

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

**2.2.1.1 Output (bell) Circuit Analysis.** The Kidde control heads for the CO<sub>2</sub> 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.

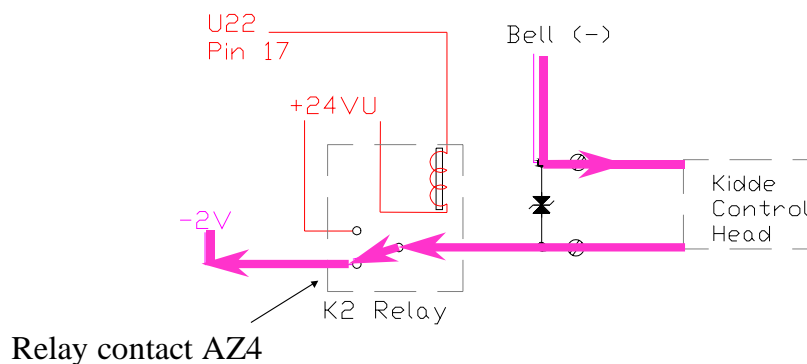
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6. D. D. Anderson, Notifier, Senior Vice President, Engineering, Letter to Bruce Stewart, INEEL, dated August 21, 1998.



**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<sub>2</sub> 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<sub>2</sub> 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.

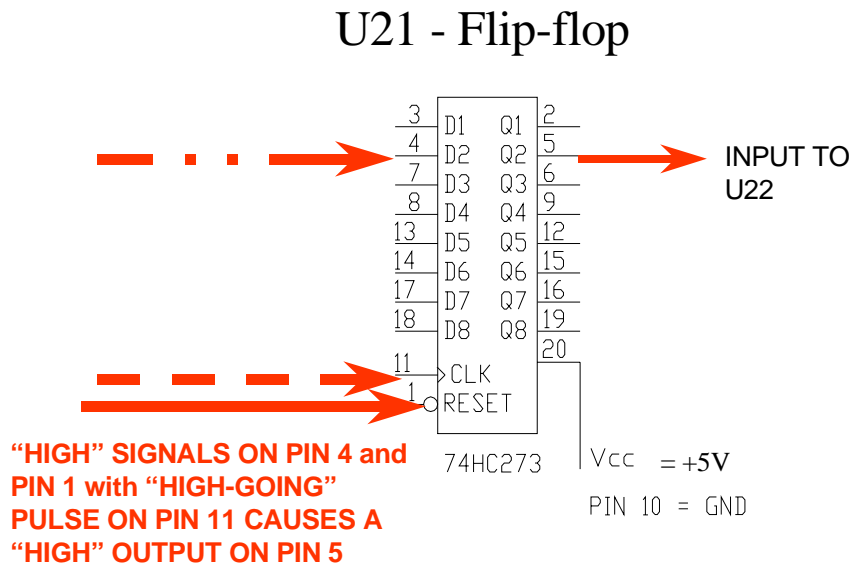


The operation of relay K2 is controlled by semiconductor chips labeled U21 and U22. Chip U21 is a 74HC273 Octal D flip-flop with common clock and reset, high performance silicon-gate CMOS logic chip. Operation of a flip-flop circuit in U21 is depicted in Figure 2-3.<sup>7</sup>

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 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.



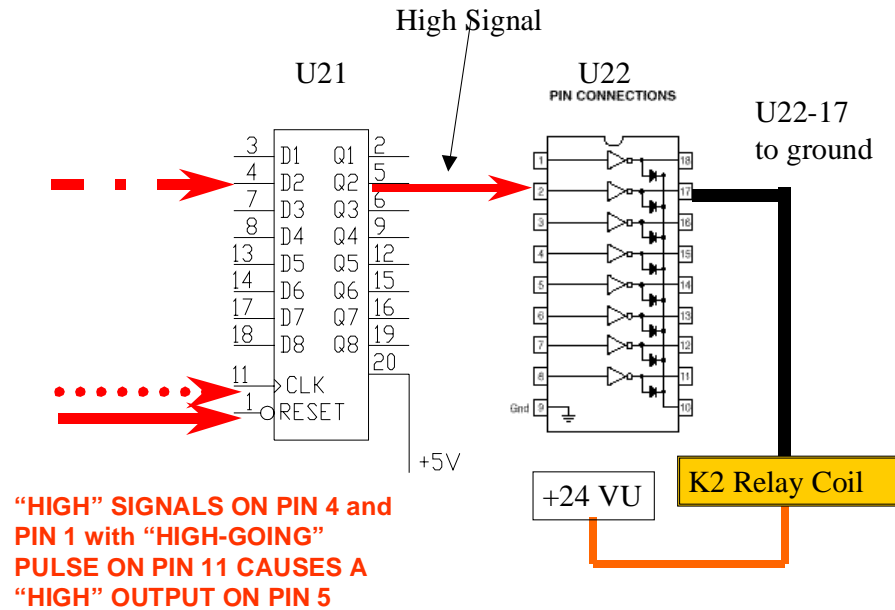
**Figure 2-3.** Operation of U21 flip-flop circuit

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.

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

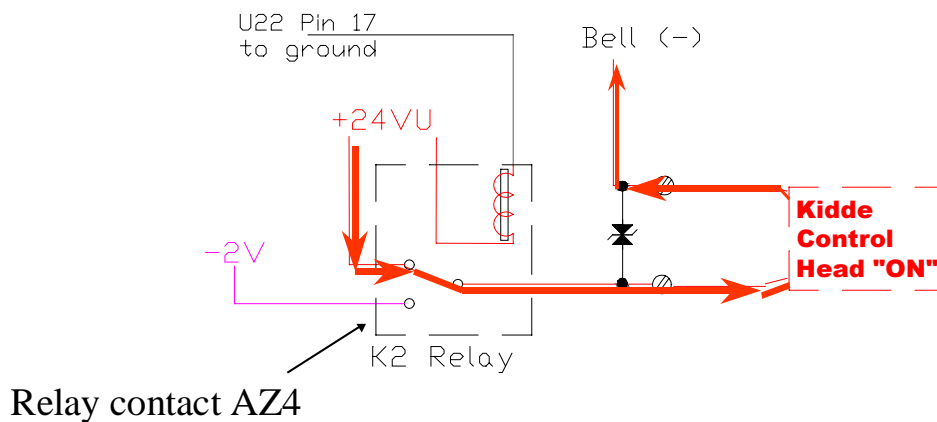
The input leads of U22 are connected to output leads on U21. As used in the AFP-200 circuit under consideration, a small input voltage on an input lead of U22 will cause the associated output lead to go to DC ground.

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.

Figure 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.

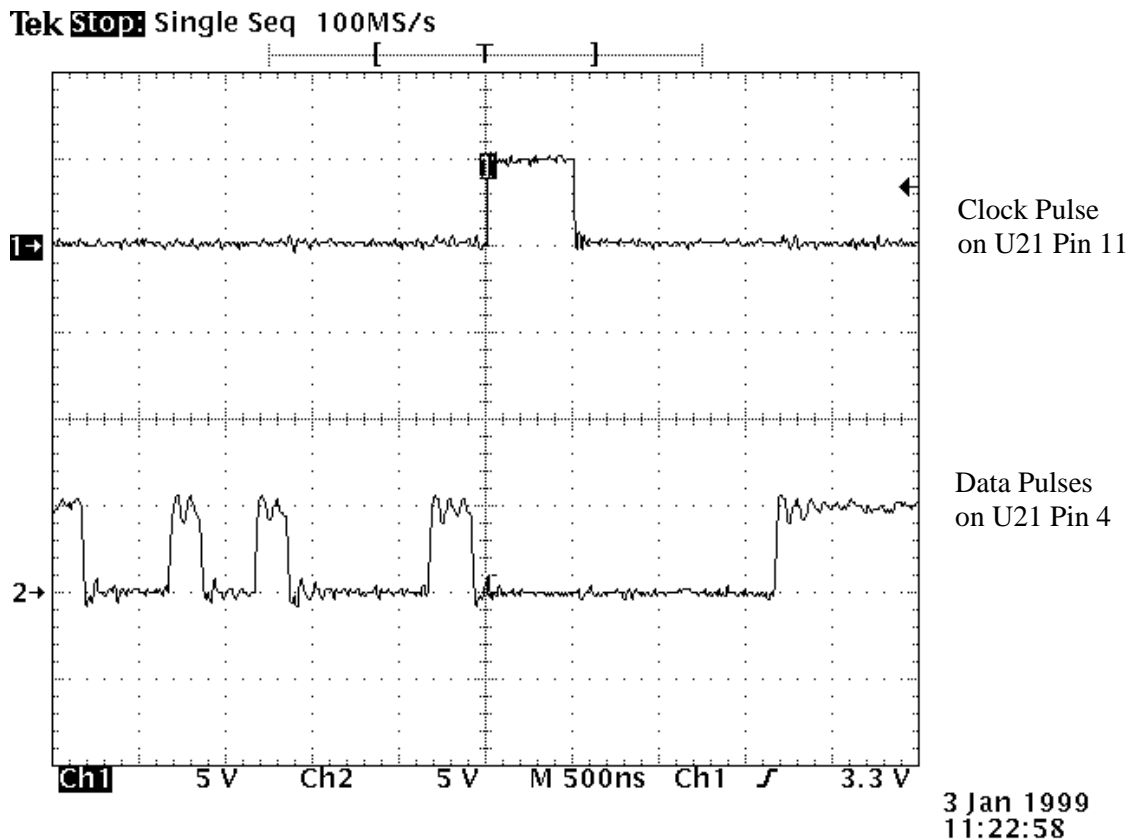
Key points with respect to the operation of the AFP-200 bell circuits are:

- 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.<sup>8</sup>

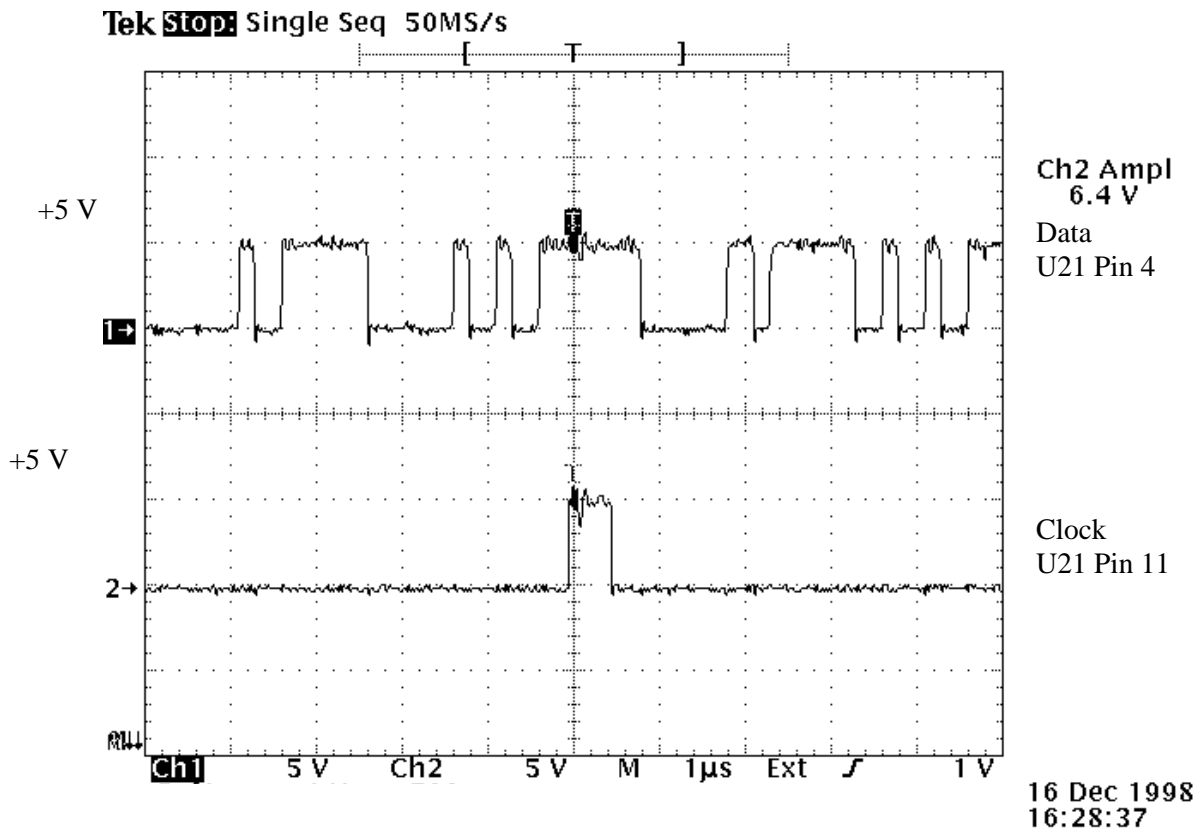


**Figure 2-6.** Oscilloscope recording of typical pulses in a normal (no alarm) condition.

8. Data recorded at Tronamix.

**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.

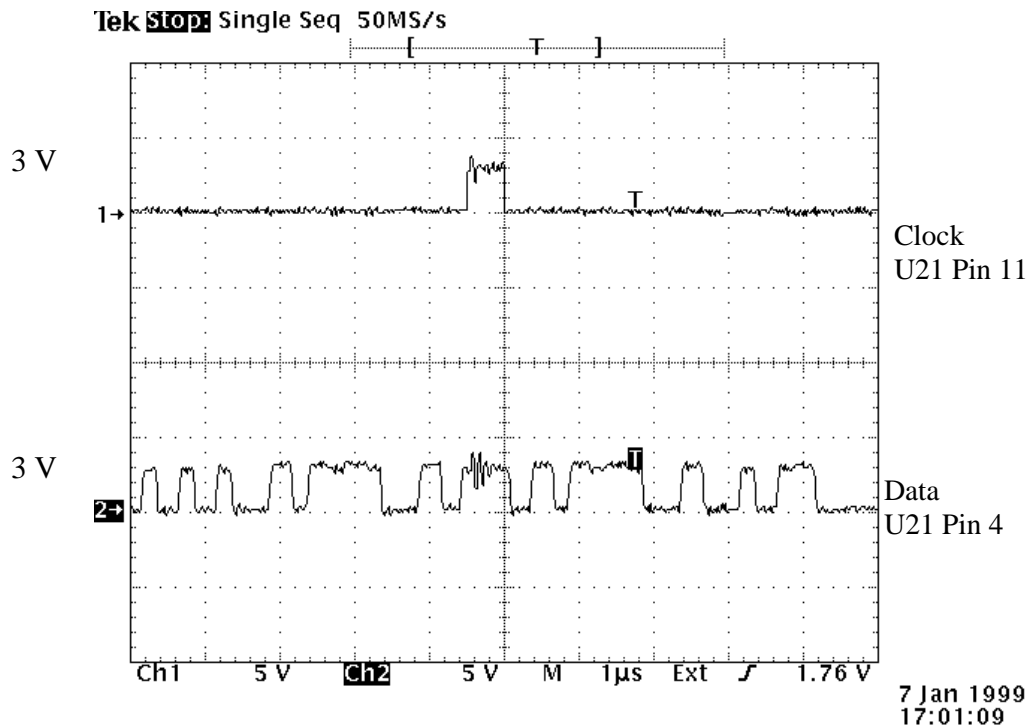
Figure 2-7 is a recording of pulses on the clock pin (Pin 11) of U21 (lower trace) and a data pin (Pin 4) of U21 (upper trace). These pulses are typical of those recorded as a manual station or detection device activates a bell circuit. Note that the high-going clock pulse occurs simultaneously with 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.

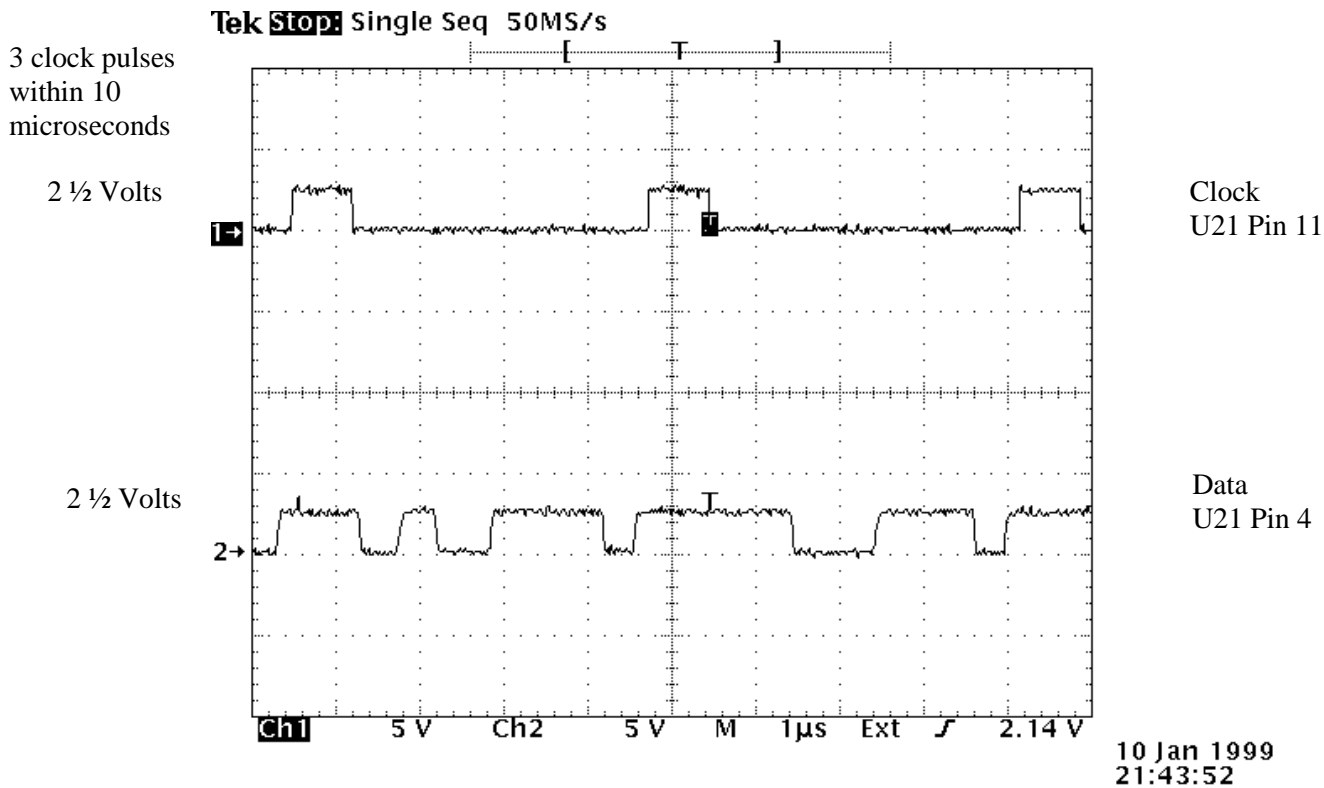
**2.2.2.3 Unexpected, Undesired, Dangerous Operation of Bell Circuit Initiated by AC Power Loss.** Figures 2-8 and 2-9 were taken at Tronamix, Inc. laboratory during unexpected, unwanted operations of Bell Circuit 2 that activated the Kidde electric control head 24 VDC (part number 890181) installed 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<sup>9</sup>
- 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.

9. Notifier, *op. cit.*



**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<sup>10</sup> (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.<sup>11</sup>

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<sub>2</sub> 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.<sup>12</sup>

The control panel microprocessor circuitry is specified to operate at +5 volts  $\pm$  10 % DC.<sup>13</sup> 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.

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12. Notifier, *op. cit.*

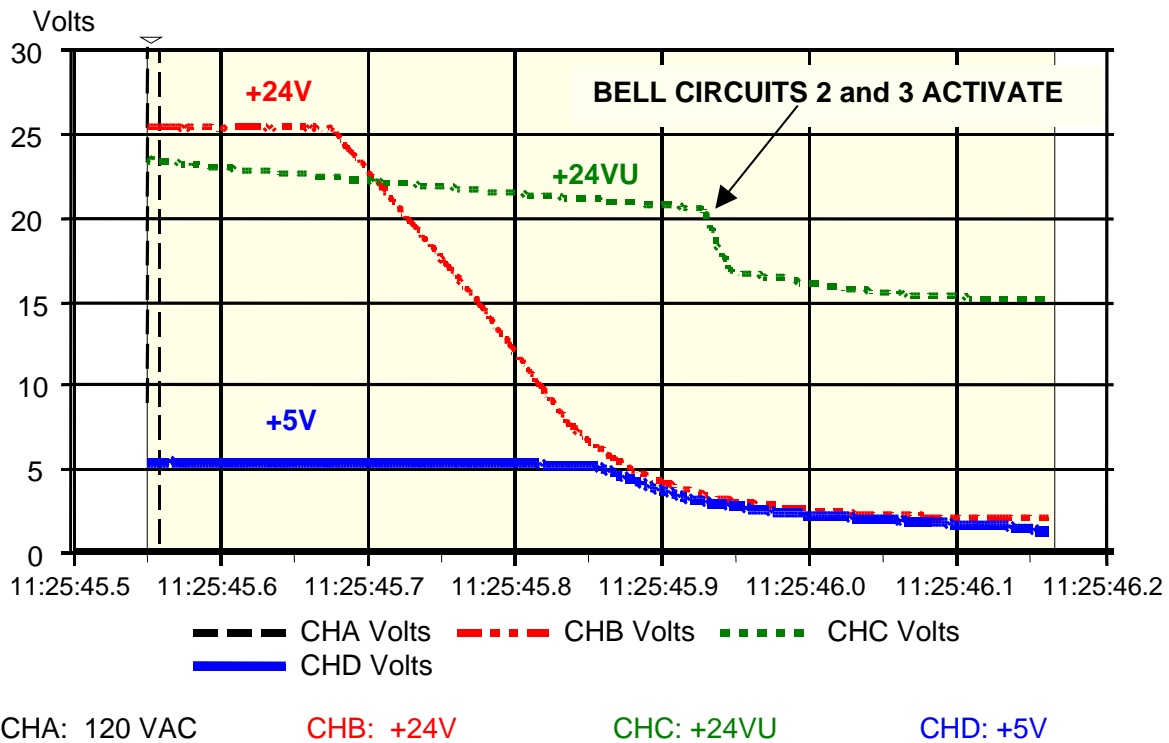
13. Siemens Data Book 01.97, “Microcontrollers,” SAF 80C537, p. 188.



## 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.

### AFP-200 TRA-648



**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 initiating devices in the system were in alarm.

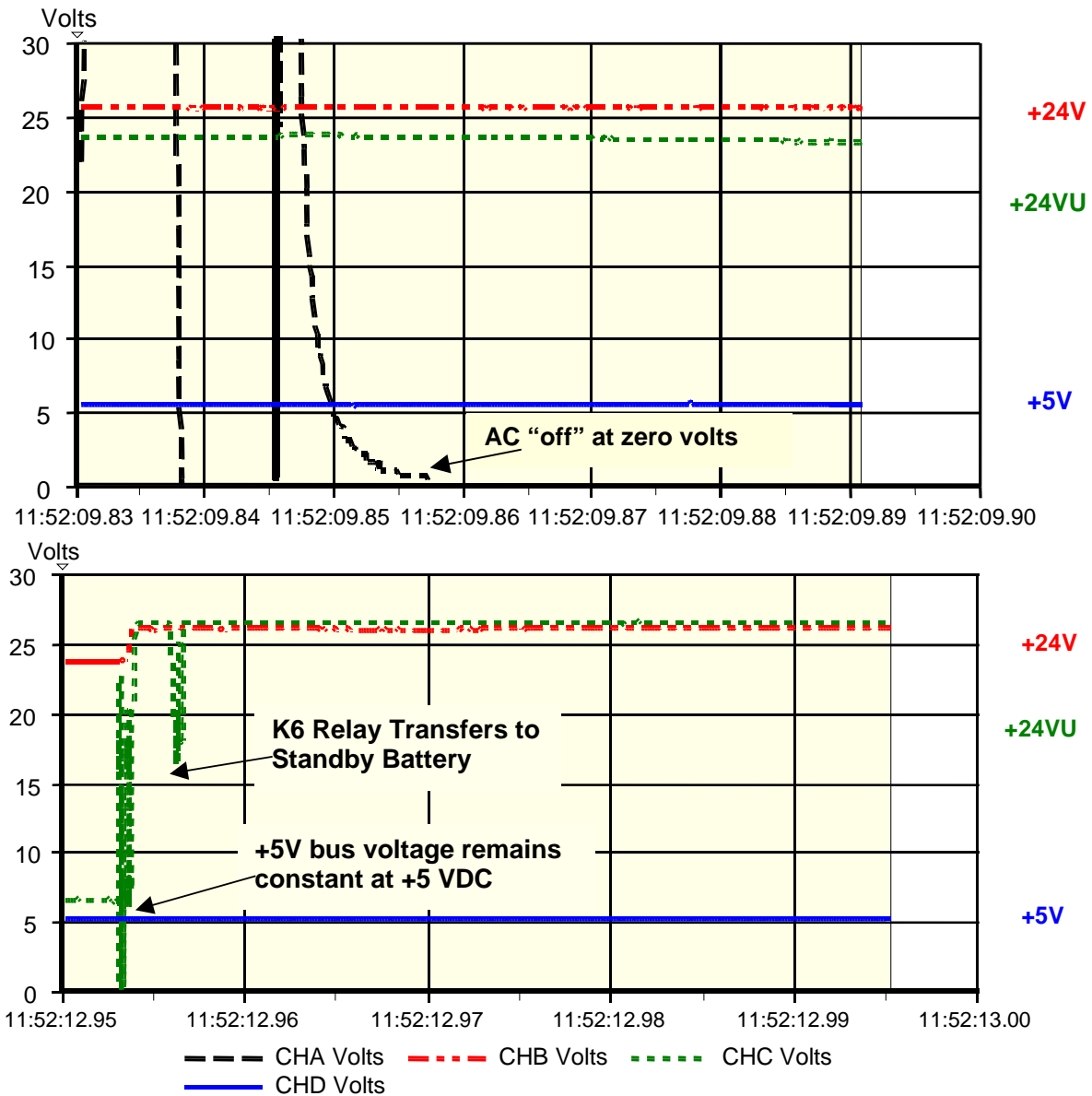
Note that voltage on the +24 V bus decayed to about 4 volts at the time of the bell circuit activation. The +5 V bus had decreased to approximately 3 volts at the time the Kidde control heads operated. Note also that the voltage on the +24 VU bus was over 20 volts at the time of the activation.

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.

## AFP-200 TRA-648



### Standby Battery Connected to Internal Charger; JP2 Intact

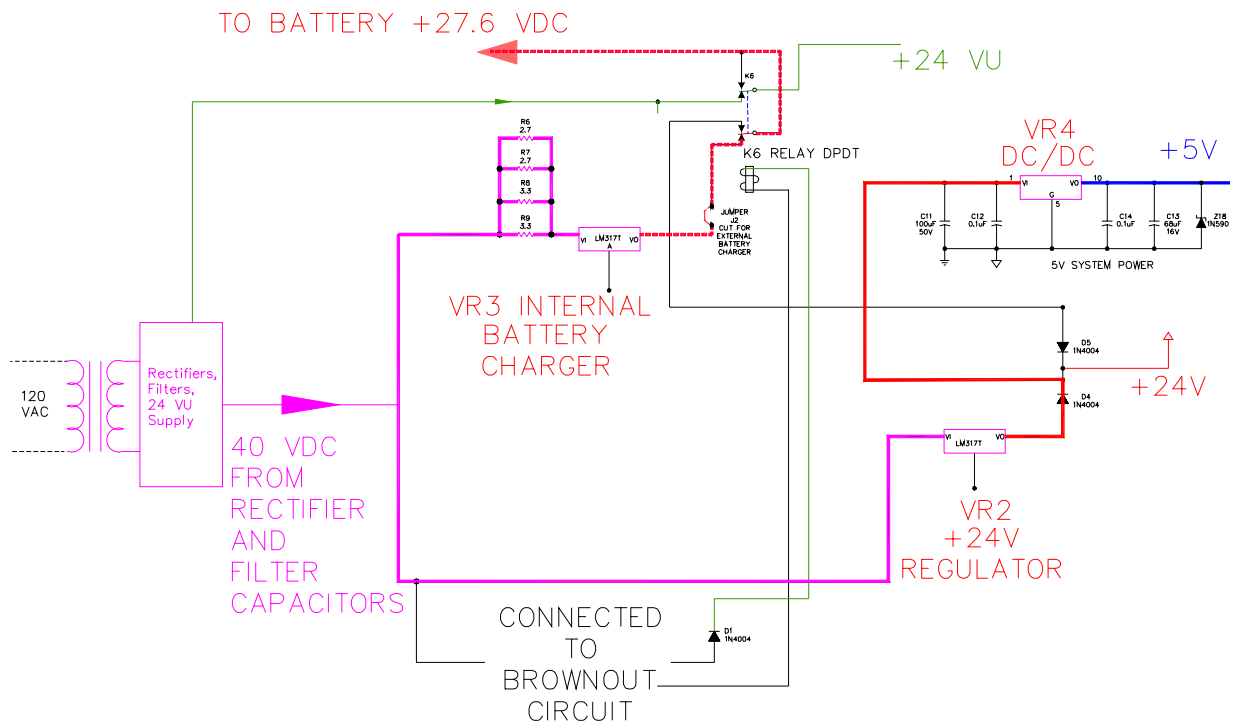
CHA: 120 VAC      CHB: +24V      CHC: +24VU      CHD: +5V

**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.<sup>14</sup> 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).

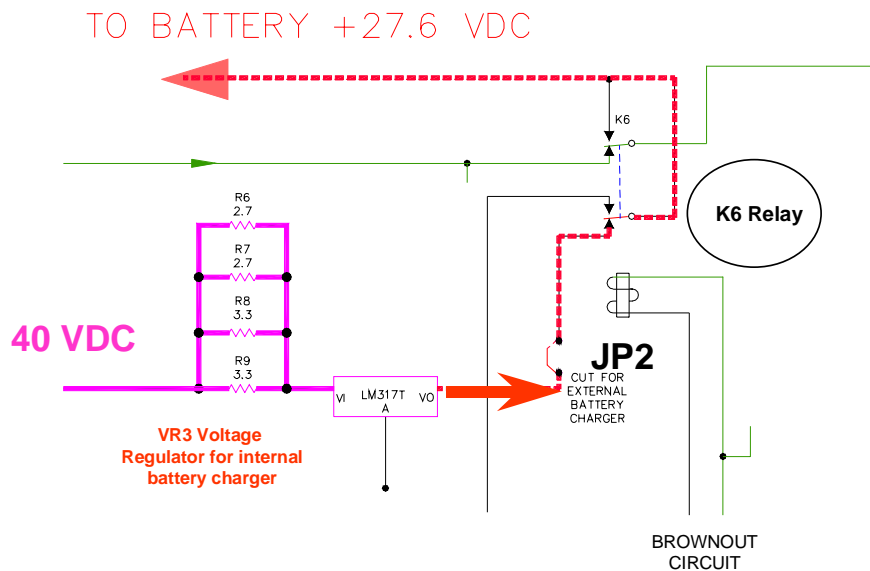
14. Extracted from Notifier Document Number 70577 Revision B, dated April 5, 1995.

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.

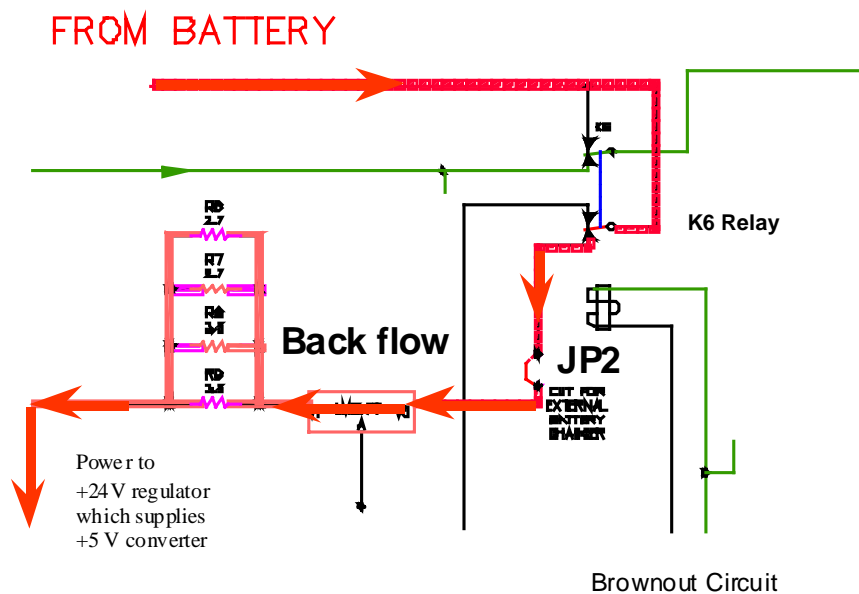
Data taken from the AFP-200 panels during testing show a delay of 1 to 3 seconds between loss of AC power (0 AC voltage) and transfer of the K6 relay contacts. For example, Figures 2-11 shows a delay of approximately 3 seconds from loss of AC power to K6 relay contact transfer.

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.

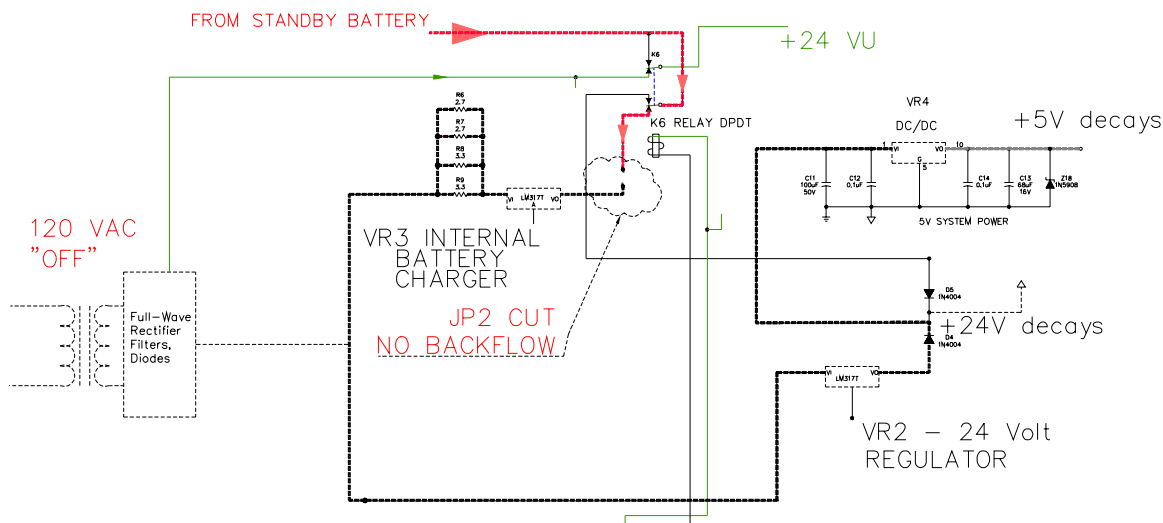
After an AC power loss and before relay K6 transfers, the microprocessor functions normally if its supply voltage is maintained at a nominal +5 volts. In certain panel configurations, the backflow through VR3 provides sufficient electrical energy to maintain the critical +5 V bus voltage.

**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.<sup>15</sup> Notifier Document 70577, Revision B, dated April 5, 1995, also had a note stating “JP2 JUMPER CUT FOR EXTERNAL BATTERY CHARGER.”<sup>16</sup>

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.

## 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<sub>2</sub> fire suppression system. Data were recorded that document the mechanism of discharge of the CO<sub>2</sub> 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.

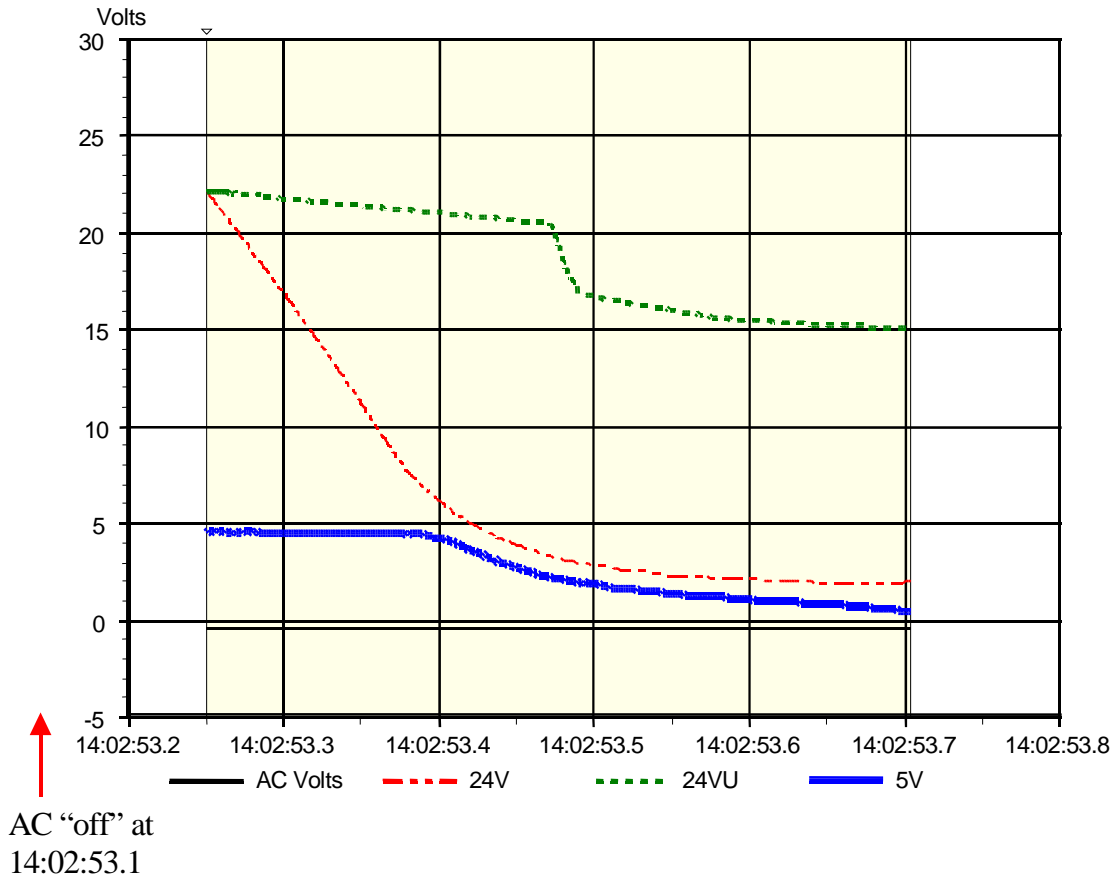
The data that follow (Figures 2-16, 2-17, and 2-18) were taken as both Bell Circuit 2 and Bell Circuit 3 activated and operated the connected Kidde electric release heads. The activation was initiated by disconnecting AC power to the AFP-200 panel.

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.



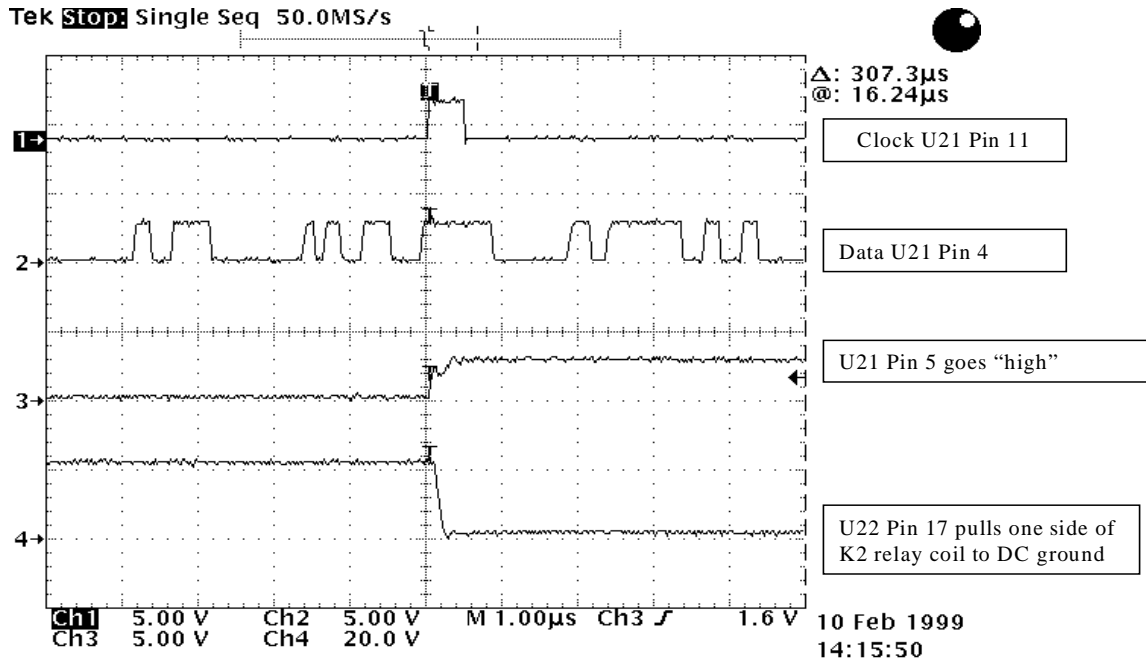
Figure 2-16 shows that within a fraction of a second (0.15 sec) after AC power goes to zero volts, decay of the voltage on the +24 V bus is evident. As the +24 V bus drops below about 7 volts, decay of the voltage on the +5 V bus is evident. As +5 V decays to approximately 3 volts, spurious signals are 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.

### AFP-200 TRA-648



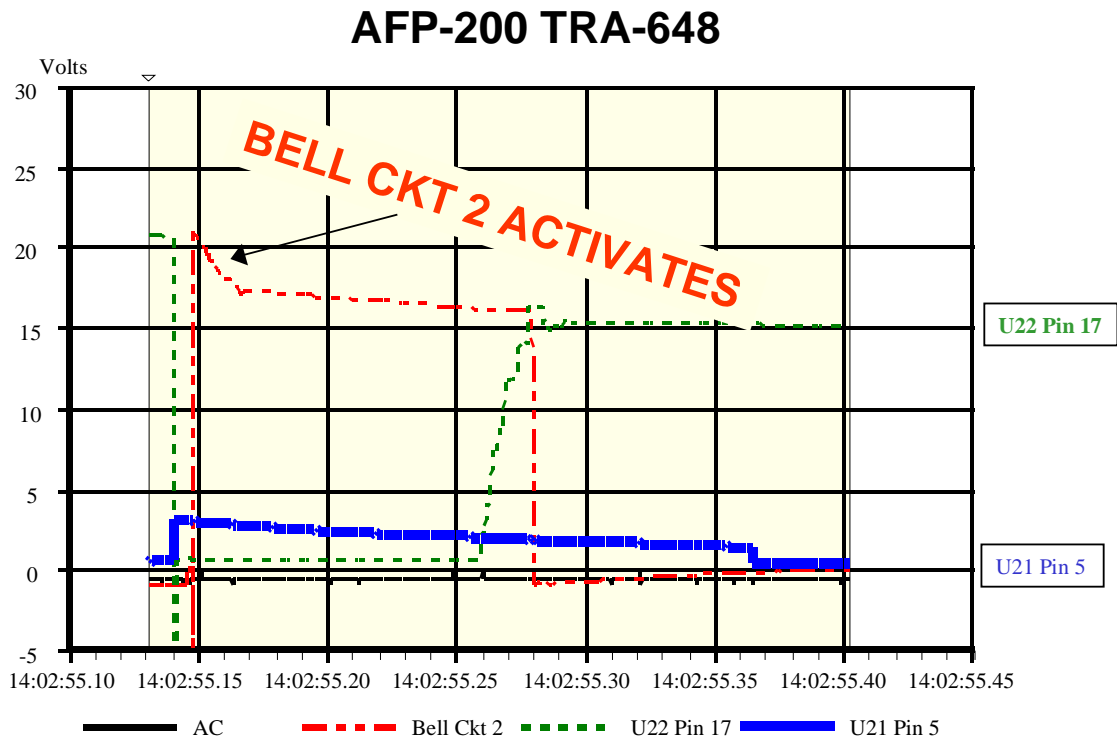
**Figure 2-16.** Dranetz recording shows voltage decays.

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.

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<sub>2</sub> system.



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

## 2.4 Specific Mechanism that Caused the CO<sub>2</sub> System to Discharge Without Warning as Determined by Independent Experts

The specific mechanism that caused the CO<sub>2</sub> 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<sub>2</sub> fire suppression system.

Notifier states<sup>17</sup> 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<sub>2</sub> system.

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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<sub>2</sub> 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.”<sup>18</sup>

### 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.<sup>19</sup>

### 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.<sup>20</sup> 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

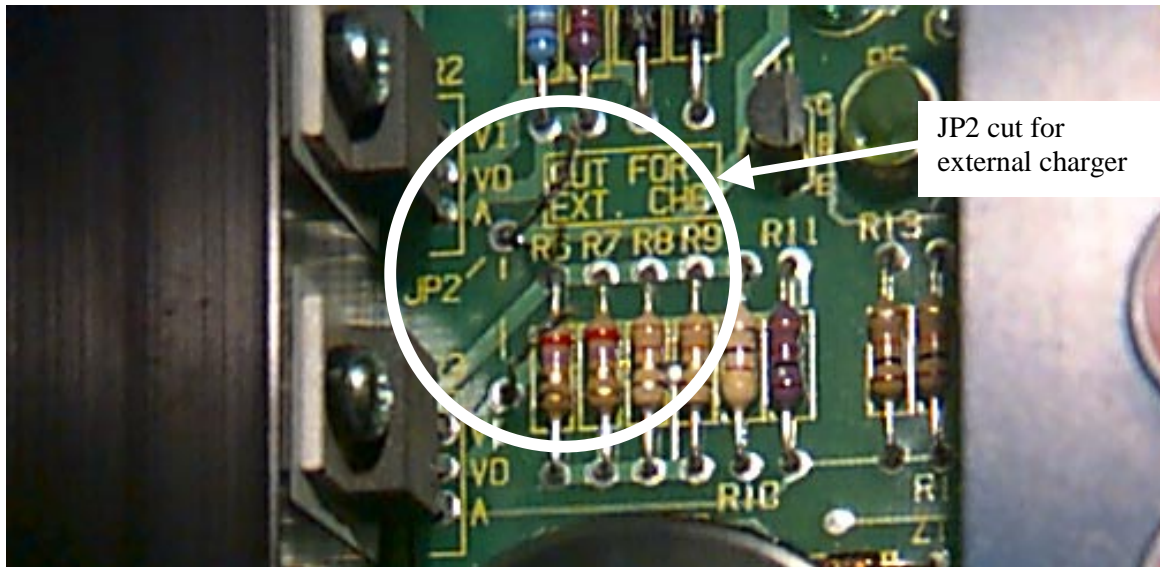
1. Notifier, AFP-200 Analog Fire Panel Instruction Manual, P/N 15511:D, Section 2.7, “The NR45-24 Remote Battery Charger,” Revision D, September 14, 1994, page 45
2. AFP-200 circuit diagram, Notifier document 70577 Revision B, April 5, 1995
3. AFP-200 printed circuit board, as shown in Figure 2-19.

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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) suggest two issues that may be related to the specific mechanism that caused the CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> discharge.

### 2.6.1 Investigation Report Statement—Installation Errors

The Investigation Report (p. 40) stated:

“The CO<sub>2</sub> 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<sub>2</sub> discharge. The auxiliary power supply is suspect because opening Breaker No. 13 appears to have been the cause of the CO<sub>2</sub> 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.”

Independent verification confirmed that the signaling line circuits were shielded in accordance with the manufacturer’s requirements for the AFP-200 panel. Termination of the shield drain conductor was in accordance with requirements for the AFP-200 panel.

Furthermore, since 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, two of the installation practices cited as errors in the Investigation Report, the partial shielding and the shield drain connector termination, were in accordance with the manufacturer’s requirements. The third installation practice cited as an error, the use of the unregulated AVPS-24 power supply, was unrelated to the cause of the accident. These installation topics are discussed more fully in Section 4 of this report.

## **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.”<sup>21</sup>

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.”

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

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 Supplemental Response 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<sub>2</sub> system in TRA-648 discharged on July 28, 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. REVIEW OF CODE COMPLIANCE**

The Investigation Report contained the following judgment of need:

“DOE needs to actively campaign to improve consensus standards and in the interim should consider strengthening Orders and policies related to fire protection and worker safety to clearly define lockout, to limit occupancy in CO<sub>2</sub> flood areas, and to prevent use of fire system impairments as a means of personal protection.” (Investigation Report, p. viii and p. 27)

To address this judgment of need, it is necessary to have a clear understanding of what is required by the current consensus code standards. The LMITCO review of the design and installation of the TRA-648 CO<sub>2</sub> fire suppression system and the activities associated with the accident included an extensive review of the applicable codes and standards. In six specific areas, the results of this review differed from the summary material presented, and the conclusions drawn, in the Investigation Report. These areas were (1) listed fire panel (AFP-200), (2) application of lockout/tagout, (3) requirements for locking devices, (4) emergency egress, (5) lighting, and (6) pressure switch and discharge monitoring. This section of the Supplemental Response discusses each of these six areas of difference to assist DOE in its effort to improve the current consensus standards.

#### **3.1 Listed Fire Panel (AFP-200)**

This subsection of the Supplemental Response discusses the use of the AFP-200 panel, including its certification and testing and performance prior to the TRA-648 accident; addresses issues related to code compliance of the AFP-200 panel; summarizes actions taken by LMITCO to alert the DOE community and industry to the results of the testing described in Section 2 of this report; and provides recommendations about possible improvements to codes and standards for DOE consideration.

##### **3.1.1 AFP-200 System Performance Prior to the Accident**

The design of the TRA-648 CO<sub>2</sub> fire suppression system used Factory Mutual (FM)-approved and Underwriters Laboratory (UL)-listed fire alarm panels. The design and installation process for the TRA-648 CO<sub>2</sub> fire suppression system is discussed in more detail in Subsections 4.2 and 4.3 of this report. The Notifier AFP-200 panel is listed for use as a special (e.g., CO<sub>2</sub> or Halon) fire suppression system releasing panel. The installation incorporated a listed external battery charger and backup DC batteries. The panel should have been designed by the manufacturer to transfer from primary AC power to backup DC power without discharging the fire suppression agent (i.e., firing the TRA-648 CO<sub>2</sub> Kidde electric discharge heads).

The system installed in TRA-648 functioned properly until the Notifier alarm panel design defect caused the CO<sub>2</sub> discharge on the evening of the accident. In the 16 months prior to the accident, the TRA-648 CO<sub>2</sub> fire suppression system had been transferred from AC power to battery backup, without incident, for:

- Three power outages associated with chip replacements/upgrades in the AFP-200 panel
- Two acceptance tests performed by the installer
- One acceptance (Systems Operations) test performed by LMITCO

- Four power outages for other work in the area not related to the Fire Suppression System.<sup>22</sup>

This operating history is described in more detail in Appendix E of this Supplemental Response.

The Technical Committee responsible for NFPA 72 considered the possibility of power failure or circuit fault in fire panels causing inadvertent release of an extinguishing agent. A proposal to modify the 1996 edition of NFPA 72 to require additional prohibitions against inadvertent release of extinguishing agents upon loss of power was submitted by Argonne National Laboratory-East. In its response, the Technical Committee stated its opinion that there were adequate provisions in NFPA 72 to ensure that control units would not cause inadvertent release of an extinguishing agent upon loss of AC power.<sup>23</sup> The opinion that code compliance provided adequate protection against inadvertent release of CO<sub>2</sub> on loss of AC power was consistent with LMITCO operating experience prior to the accident.

### 3.1.2 Code Compliance of the AFP-200 Panel

As discussed in Section 2 of this report, testing demonstrated that the AFP-200 panel contains a design defect that renders it susceptible to accidental (i.e., spurious) operation upon loss of AC (primary) power. This design defect makes the panel noncompliant with NFPA 12 when used as an operating device for a CO<sub>2</sub> fire suppression system.

In particular, Section 1-7.3.2 of NFPA 12 (1993) states:

“All devices shall be designed for the service that they will encounter and shall not be readily rendered inoperable or susceptible to accidental operation.”

Section 1-8.3 of NFPA 12 (1993) further states:

“Operating devices include carbon dioxide releasing devices or valves, discharge controls, and equipment shutdown devices, all of which are necessary for successful performance of the system.”

The Notifier AFP-200 panel is listed to activate the discharge of CO<sub>2</sub>. Therefore, it is an operating device within the definition of NFPA 12 (1993). Section 1-7.6 of NFPA 12 (1993) states:

“When failure of the primary power source of energy will jeopardize protection provided for the hazard, the life safety, or both, an independent secondary (standby) power supply shall supply energy to the system in the event of total failure or low voltage (less than 85% of the nameplate voltages) of the primary (main) power supply.”

Loss of primary power is clearly a part of the service that the AFP-200 panel would be expected to encounter. Therefore, NFPA 12 requires that the AFP-200 panel be designed for loss of primary power and that it not be readily rendered susceptible to accidental operation under this circumstance. Thus,

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22. The Environmental Protection Agency draft report, *Carbon Dioxide as a Fire Suppressant: Examining the Risks*, includes, in Appendix A, an extensive list of accidents involving CO<sub>2</sub> systems. With the exception of the TRA-648 accident, no CO<sub>2</sub> discharges were identified as being caused by loss of AC power to a CO<sub>2</sub> fire suppression system. See Subsection 4.1 of this report.

23. NFPA72-A96 Record of Change, Change Request 72-182-(3-10.7).

because of the identified design defect, the Notifier AFP-200 panel does not meet the requirements of Section 1-7.3.2 of NFPA 12 (1993).

NFPA 72 is not as explicit as NFPA 12 with regard to the required performance of a system control unit, such as the Notifier AFP-200 panel, under loss of power. However, in its rejection of the proposal from Argonne National Laboratory-East to prohibit the use of a releasing configuration that is failsafe upon loss of AC power, the NFPA 72 technical standard committee stated:

“The Committee recognizes that the Submitter has made an attempt to revise text of his original proposal 72-W3 (Log #252) in order to ensure that the power failure or circuit fault of the system control unit does not result in the inadvertent release of the extinguishing agent into a space where such a release may pose a threat to persons occupying that space...Adequate provisions exist elsewhere in this Code [NFPA 72 (1993)] (1-5.5.2.2, 1-5.5.3, 1-5.5.4, and 1-5.8.2) and in the test standards of the nationally-recognized laboratories to assure that the system control unit does not cause inadvertent release of an extinguishing agent [upon power failure].”<sup>24</sup>

This statement establishes the clear intent of the NFPA 72 technical standard committee that Sections 1-5.5.2.2, 1-5.5.3, 1-5.5.4, and 1-5.8.2 of NFPA 72 (1993) require that the fire suppression system control unit for a potentially hazardous extinguishing agent, such as CO<sub>2</sub>, not inadvertently release that agent upon loss of AC power. Thus, because of the identified design defect, the Notifier AFP-200 panel does not meet the requirements of one or more of Sections 1-5.5.2.2, 1-5.5.3, 1-5.5.4, and 1-5.8.2 of NFPA 72 (1993).

Despite the FM approval and UL listing, the Notifier AFP-200 panel had a design defect that kept it from being compliant with NFPA 12 (1993) and NFPA 72 (1993).

### **3.1.3 Notifier Requirements Related to Use of External Battery Chargers With AFP-200 Panel**

The Investigation Report (pg. 41) noted that:

“The vendor [Notifier] was aware of the potential for an inadvertent output signal from the fire panel on an AC power transient such as the shutdown of the 4160 volt bus, and a resulting activation of the carbon dioxide system solenoids and system discharge. This information, however, was apparently not communicated to INEEL during the panel installation in 1997 or through a vendor notice or bulletin.”

Our post-accident review of the design and installation of the TRA-648 CO<sub>2</sub> fire suppression system identified additional information from Notifier regarding the use of external battery chargers with the AFP-200 panel. This information includes:

- A revision to the Notifier AFP-200 Analog Fire Panel Instruction Manual (Document 15511 Revision F, dated August 26, 1997), published after the TRA-648 CO<sub>2</sub> fire suppression system was installed, that eliminated the provisions for use of an external battery charger.<sup>25</sup>

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24. NFPA72-A96 Record of Change, Change Request 72-182-(3-10.7)

25. Notifier AFP-200 Analog Fire Panel Instruction Manual, Document 15511 Revision F, dated August 26, 1997, page 18.

As discussed in Section 2.5.3, prior revisions of the AFP-200 Analog Fire Panel Instruction Manual (Revisions D and E) required installation of an external charger (the NR-45 Battery Charger) if batteries of 20 ampere hours or larger were used.<sup>26</sup>

- The CHG-120 Charger Instruction Manual (Document 50641 Revision A, dated June 24, 1997), published after the TRA-648 CO<sub>2</sub> fire suppression system was installed stated, “For example, do not use the [CHG-120 external battery] charger with an AFP-200, because you cannot disable the FACP [Fire Alarm Control Panel] battery charger.”<sup>27</sup>

As the Investigation Report indicated, LMITCO was never notified of Notifier’s changed position regarding the use of an external battery charger with the AFP-200 panel. Indeed, even after the accident, in a letter responding to a LMITCO question regarding AC power transients, Notifier recommended the removal of the NR45 battery charger as a means for “eliminating another input path for AC power transients.”<sup>28</sup> However, this letter from Notifier failed to inform LMITCO that the current Notifier product instruction manuals for both the AFP-200 panel and the CHG-120 Charger, which replaced the NR45-24, did not permit the use of an external battery charger with the AFP-200 panel.

A contributing cause of the TRA-648 CO<sub>2</sub> accident was the failure of the AFP-200 panel manufacturer, Notifier, to inform LMITCO or DOE, in June 1997 or later, that it was no longer permissible to disable the AFP-200 panel internal battery charger.

### **3.1.4 Lessons Learned and Recommendations for Revision of Standards**

LMITCO communicated the problems it discovered during post accident testing with the AFP-200 panel to Notifier November 10, 1998, and to the DOE complex by a Red Lessons Learned notice on November 20, 1998. On January 13, 1999, as additional test results became available, LMITCO notified the Occupational Safety and Health Administration (OSHA), Underwriters Laboratory (UL), Factory Mutual (FM) Research Corporation, and other organizations that had listed or approved the AFP-200 panel of the results of the post-accident testing of the AFP-200. The notification letters are included as Appendix D of this Supplemental Response. The application of this information should prevent a similar accident involving a fire alarm panel that controls a fire suppression system.

In its campaign to improve consensus standards, DOE may wish to recommend provisions that specifically require manufacturers to inform purchasers of products and listing organizations and approving organizations, such as UL, and FM, of defects that render their products non-compliant with codes and standards. DOE may also wish to pursue the possibility of obtaining statutory authority, similar to that afforded to the Nuclear Regulatory Commission under Section 5846 of Title 42 of the United States Code (42 USC 5846) to require reporting of defects.

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26. Notifier AFP-200 Analog Fire Panel Instruction Manual, Document 15511 Revision D, dated September 14, 1994, page 45.

27. “CHG-120 Battery Charger Instruction Manual,” Document 50641, Revision A, Notifier, Northford CT, June 1997, page 1.

28. D. D. Anderson, Notifier, Senior Vice President Engineering, Letter to Manuel B. Sifuentes, LMITCO, dated September 25, 1998.

## 3.2 Application of Lockout/Tagout

The DOE Investigation Report (p. 26) stated that Occupational Safety and Health Administration (OSHA) regulations and NFPA standards required the CO<sub>2</sub> fire suppression system be locked out prior to the electrical maintenance activity that was performed in TRA-648 on July 28, 1998. The paraphrased summaries of 29 CFR 1910 Subparts J and L and NFPA 12 Sections 1 through 5 in Table 3-1 of the Investigation Report are used in an attempt to support this statement. However, these paraphrased summaries do not include certain detailed provisions that are relevant to a determination of whether or not the regulatory requirements were met.

### 3.2.1 OSHA Lockout/Tagout Requirements

In the case of 29 CFR 1910 Subpart J (29 CFR 1910.147 *et seq.*), these provisions relate to the scope and applicability of the regulation.

In particular, 29 CFR 1910.147(a)(1)(i), “Scope,” states:

“This standard covers the servicing and maintenance of machines and equipment in which the ‘unexpected’ energization or startup of the machines or equipment, or release of stored energy could cause injury to employees...”<sup>29</sup>

Likewise, 29 CFR 1910.147 (a)(2)(i), “Application,” states:

“This standard applies to the control of energy during servicing and/or maintenance of machines and equipment.”<sup>30</sup>

The background information provided in the Federal Register (55 FR 38677) Final Rule Corrections and Technical Amendments states:

“The final standard for the control of hazardous energy (Lockout/Tagout), which was promulgated on September 1, 1989 (54 FR 36644), requires employers to develop an energy control program consisting of the adoption and utilization of written procedures for shutting off and disabling machines and equipment whenever maintenance or servicing are performed on those machines and equipment, the instruction in use of the procedure to employees and the periodic inspection of the use of the procedure.”<sup>31</sup>

The provisions of 29 CFR 1910 Subpart J and the background information in the Federal Register make it clear that the lockout/tagout requirements in the regulation are applicable to the machines and equipment being serviced or maintained, not other nearby equipment that is not undergoing servicing or maintenance. This view is supported by the OSHA Standard Interpretation and Compliance Letter, dated January 16, 1996, addressing the lockout/tagout standard, which states:

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29. 29 CFR 1910.147, *Code of Federal Regulations*, Office of the Federal Register.

30. *Ibid.*

31. 55 FR 38677, “Final Rule Corrections and Technical Amendments,” *Code of Federal Regulations*, Office of the Federal Register.

“The Lockout/Tagout Standard covers the servicing and maintenance of equipment in which the unexpected energization of machines being serviced or maintained could cause injuries to employees.”<sup>32</sup>

Because the electrical maintenance activity that was performed in TRA-648 on July 28, 1998, did not include maintenance of the CO<sub>2</sub> fire suppression system, the lockout/tagout requirements of 29 CFR 1910 Subpart J did not require the lockout/tagout of the CO<sub>2</sub> fire suppression system.

### **3.2.2 NFPA 12 Lockout Requirements**

NFPA 12 (1993) provisions related to equipment lockout are found in Section 1-5.1.7, which states:

“To prevent accidental or deliberate discharge, a “lock-out” shall be provided when persons not familiar with the systems and their operation are present in a protected space.”<sup>33</sup>

The workers performing maintenance in TRA-648 were familiar with the CO<sub>2</sub> hazards present. This awareness was demonstrated by:

- Discussion of the CO<sub>2</sub> system during the pre-job briefing<sup>34</sup>
- The immediate response to the discharge by the workers inside the building
- Information signs posted on the entrance and basement doors.

Thus the lockout requirements in NFPA 12 (1993) were not applicable in this case.

### **3.2.3 Conclusions**

The provisions of 29 CFR 1910, Subpart J did not require lockout/tagout of the TRA-648 CO<sub>2</sub> fire suppression system for the electrical maintenance being performed on July 28, 1998, because no maintenance activities were being performed on the CO<sub>2</sub> fire suppression system. Furthermore, NFPA 12 (1993) did not require lockout because the people in the protected area were familiar with the system and its operation.

## **3.3 Requirements for Locking Devices**

The Investigation Report (p. 23) stated:

“Servicing, maintenance, and design modification activities were performed on the CO<sub>2</sub> fire suppression system in Building 648 since the revision of the OSHA regulations on January 2, 1990. These regulations require installation of an energy isolation device, or other systems and equipment, capable of accepting a

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32. OSHA Standard Interpretation and Compliance Letter, dated January 16, 1996.

33. NFPA Standard 12, “Carbon Dioxide Extinguishing Systems,” National Fire Protection Association.

34. Workers were told to respond (evacuate) to all alarms at the pre-job briefing. See page 53 of the Investigation Report.

lockout device, whenever major modification of equipment is performed. Modifications to the system piping in 1997 fall into this category and within the purview of the regulations. Design drawings for the Building 648 CO<sub>2</sub> fire suppression system did not include energy isolation devices (such as a manual valve), and no energy isolation device that meets the requirements of 29 CFR 1910.147, Subpart J, was installed in the CO<sub>2</sub> system in Building 648.”

### 3.3.1 OSHA Requirements for Lockout Devices

The OSHA regulation the Investigation Report appears to be referring to is 29 CFR 1910.147(c)(2)(iii), which states:

“After January 2, 1990, whenever replacement or major repair, renovation or modification of a machine or equipment is performed, and whenever new machines or equipment are installed, energy isolating devices for such machine or equipment shall be designed to accept a lockout device.”

This requirement is clarified in the Federal Register (58 FR 16618) Final Rule; Supplemental Statement of Reasons, Section II, “The Lockout Preference Issue,” which states:

“By requiring that lockable equipment replace unlockable equipment in the ordinary course of industrial modernization, this provision will result in a future increase in the use of lockout instead of tagout. The provision imposes no cost on employers because lockable energy isolating devices are readily available and are not more expensive than unlockable ones.”<sup>35</sup>

Additional clarification is provided in the Federal Register (54 FR 36669) Final Rule, Summary and Explanation of the Final Standard, which states:

“Accordingly, paragraph (c)(2)(iii) of the Final Rule requires that new equipment ordered or purchased after the effective date of this standard, and existing equipment which [is] otherwise undergoing extensive repair, renovation or modifications must be provided with the capability of being locked out if such design is feasible.”<sup>36</sup>

In this discussion, providing equipment being modified with the capability of being locked, refers to the following definition in 29 CFR 1910.147(b):

“‘Capable of being locked out.’ An energy isolating device is capable of being locked out if it has a hasp or other means of attachment to which, or through which, a lock can be affixed, or it has a locking mechanism built into it. Other energy isolating devices are capable of being locked out, if lockout can be

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35. 58 FR 16618, “Final Rule, Supplemental Statement of Reasons,” Section II, “The Lockout Preference Issue,” *Code of Federal Regulations*, Office of the Federal Register.

36. 54 FR 36669, “Final Rule, Summary and Explanation of the Final Standard,” *Code of Federal Regulations*, Office of the Federal Register.

achieved without the need to dismantle, rebuild, or replace the energy isolating device or permanently alter its energy control capability.”<sup>37</sup>

Thus, this regulation does not require that *additional* energy isolating devices be added to the design of modified or new equipment. Rather it requires that equipment used as an energy isolation device have a mechanism that can accept a “lock” as opposed to a “tag.”

The TRA-648 CO<sub>2</sub> fire suppression system was designed without an energy isolating device, as defined in 29 CFR 1910.147 for isolating the high pressure CO<sub>2</sub> supply. Therefore, there was no unlockable energy isolating device to replace with a lockable energy isolating device pursuant to 29 CFR 1910 Subpart J (29 CFR 1910.147(c)(2)(iii)). Thus, the TRA-648 CO<sub>2</sub> fire suppression system design was compliant with 29 CFR 1910 Subpart J.

### **3.3.2 NFPA Requirements Related to Lockout Devices**

As discussed previously, Section 1-5.1.7 of NFPA 12 (1993) states:

“To prevent accidental or deliberate discharge, a “lock-out” shall be provided when persons not familiar with the systems and their operation are present in a protected space.”<sup>38</sup>

This creates an implicit requirement for some method for lockout of the CO<sub>2</sub> system discharge, if persons not familiar with the systems and their operation are permitted to enter the protected space. NFPA 12 (1993) does not specify a required lockout device or method and there have been no formal NFPA interpretations in this area. Thus the type of lockout is left to the judgment of the authority having jurisdiction. The TRA-648 CO<sub>2</sub> fire suppression system has several mechanisms for preventing CO<sub>2</sub> discharge, including disconnection of the control and slave heads from each of the cylinders. These isolation methods provide a level of protection that meets the lockout requirements of NFPA 12 (1993).

### **3.3.3 Conclusion**

The TRA-648 CO<sub>2</sub> fire suppression system design met both the explicit requirements of 29 CFR 1910 Subpart J and the implicit requirements of NFPA 12 (1993) with regard to the provision of lockout devices.

### **3.3.4 Lessons Learned and Recommendations for Revision of Standards**

As discussed above, NFPA 12 does not define an acceptable lockout device for a CO<sub>2</sub> fire suppression system. In its campaign to improve consensus standards, DOE may wish to request that the Technical Committee responsible for NFPA 12 modify the standard to define an acceptable lockout device for a CO<sub>2</sub> fire suppression system.

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37. 29 CFR 1910.147, *Code of Federal Regulations*, Office of the Federal Register.

38. NFPA Standard 12, “Carbon Dioxide Extinguishing Systems,” National Fire Protection Association.



## 3.4 Emergency Egress Pathways

The DOE Investigation Report (p. 73) stated:

“Prompt discovery and rescue of injured workers were hindered by failure to understand and follow DOE, OSHA and NFPA requirements for...clear exit paths.”

There are no specific DOE requirements relating to clear exit paths. Rather DOE invokes the OSHA requirements in this area through DOE Orders 5480.4, “Environmental Protection, Safety, and Health Protection Standards,” and 5483.1A, “Occupational Safety and Health Program for DOE Contractor Employees at Government-owned Contractor-operated Facilities.” The NFPA requirements are invoked through DOE Order 5480.4. Compliance with both DOE order 5480.4 and 5483.1A is required by the LMITCO contract with DOE.

### 3.4.1 OSHA Emergency Egress Pathway Requirements

The OSHA emergency egress requirements are found in 29 CFR 1910 Subpart E—Means of Egress (29 CFR 1910.35 – 1910.38). The specific requirements regarding clear exit paths are found at 29 CFR 1910.37(f)(6), and 29 CFR 1910.37(k)(2), which state, respectively:

“The minimum width of any way of exit access shall in no case be less than 28 inches.” (29 CFR 1910.37(f)(6))<sup>39</sup>

“Means of egress shall be continuously maintained free of all obstructions or impediments to full instant use in the case of fire or other emergency.” (29 CFR 1910.37(k)(2))<sup>40</sup>

The TRA aisle that serves as an exit path also serves the “minimum depth of clear working space in front of electrical equipment.” This minimum workspace requirement for the area in front of 4160-Volt equipment like that in TRA-648 is established as 6 feet in Table S-2 of 29 CFR 1910.303(h)(3)(i) “Working space.” The TRA-648 aisle is 10 feet wide at the east end and 8 feet wide near the west door, which clearly meets the 6 foot width requirement. This regulatory requirement for clear work space is specifically designed for electricians to service and maintain electrical equipment, including space to rack out and position electrical breakers. Positioning portable lights, tools, and testing equipment is also an acceptable use of the space. After the accident, the width of the TRA-648 aisle that was used as an exit path was measured under conditions virtually identical to those the evening of the accident. The aisle width between the switchgear and a breaker racked out for work, as on the evening of the accident, is 44-¼ inches. The aisle width between the switchgear and the light stands that were placed in the work area on the evening of the accident is between 47-½ and 55-½ inches.

In 1976, OSHA issued an interpretation letter related to 29 CFR 1910.37(f)(6) and 29 CFR 1910.37(k)(2), which stated:

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39. 29 CFR 1910.27, “Means of Egress,” *Code of Federal Regulation*, Office of Federal Register.

40. *Ibid.*

“In our telephone conversation, you indicated that all passages were more than 44 inches unimpeded width and that vending machines, coat racks, and similar items are only permitted where the hallways, passages, and aisles, exceeded the 44 inch width. It appears that compliance with OSHA part 1910.37(k)(2) and 1910.37(f)(6) has been achieved by maintaining unobstructed egress in excess of 44 inches.”<sup>41</sup>

The configuration of the TRA-648 aisle provided an unobstructed egress in excess of 44 inches. Thus, although breakers were racked out and light stands were installed in the aisle at the time of the accident, as permitted by 29 CFR 1910.303, the clear aisle space met the requirements of 29 CFR 1910 Subpart E that the means of egress be maintained clear of all obstruction. Figure 3-1 is a photograph taken after the accident in TRA-648 showing the clear egress path available in a configuration virtually identical to that the evening of the accident.

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41. Alfred Barden, OSHA Regional Administrator, Letter to John M. Reynolds, Manager Occupational Safety and Health. General Electric Corporate Research and Development Center, dated February 17, 1976.



**Figure 3-1.** Clear egress path around electrical work equipment.

Looking at Exhibit 2-5 in the Investigation Report, a reader might infer that the egress path to the west door was blocked. Such an inference would be incorrect for two reasons. First, the equipment carts, papers, and cables shown in the Investigation Report Exhibit were dragged to the area south of the west door when the fire engineer and a security guard rescued a worker.<sup>42</sup> This equipment was positioned out of the egress pathway when the work was being performed. Second, even after the equipment had been dragged to the area south of the west door, the main aisle still provided a clear egress path. Figure 3-2, taken at about the same time as Exhibit 2-5 in the Investigation Report, looking in from the west door, shows the clear egress path down the main aisle. As is evident from Figure 3-2, the egress path to the west door met the requirements of 29 CFR 1910 Subpart E.



**Figure 3-2.** Clear egress path to west door remains even after equipment was moved during the rescue.

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42. See the discussion in Section 2.2 (bottom of p. 10) and 2.3.1 (bottom of p. 16) of the Investigation Report regarding the rescue of the individual, referred to as E-1, who became entangled in the equipment staged near the south wall enroute to the west door.

### 3.4.2 NFPA Egress Pathway Requirements

The NFPA requirements relating to the egress pathways are found in NFPA-101, “Life Safety Code.” Section 5-3.4.1 of NFPA 101 (1991) provides the following general requirements regarding the minimum width of exit pathways:

“The minimum width of any exit access shall be as specified for individual occupancies by Chapters 8 through 30, but in no case shall such width be less than 36 in. (91 cm)...

Exception No. 2: In existing buildings, the minimum width shall not be less than 28 in. (71 cm).”<sup>43</sup>

TRA-648 meets the NFPA 101(1991) definition of an industrial occupancy. Thus, Chapter 28 of NFPA 101 (1991) contains the specific requirements applicable to TRA-648. Section 28-2.3.1 of NFPA 101(1991) states:

“The capacity of means of egress shall be in accordance with Section 5-3.”<sup>44</sup>

Thus, the NFPA 101 (1991) requirements for egress pathways are the same as the OSHA regulations. The LMITCO compliance with the OSHA requirements for egress pathways discussed in Subsection 3.4.1 also ensures compliance with the NFPA-101 requirements.

NFPA recommendations relating to egress pathways are discussed in Section A-1-5, Safety Requirements, of non-mandatory Appendix A of NFPA 12 (1993), which states:

“The steps and safeguards necessary to prevent injury or death to personnel in areas whose atmospheres will be made hazardous by the discharge of carbon dioxide may include the following:

(a) Provision of adequate aiseways and routes of exit and keeping them clear at all times.”<sup>45</sup>

As described in Subsection 3.4.1, the layout of TRA-648 provided adequate aiseways and routes of exit. The positioning of work equipment (e.g., light stands and racked out breakers) on the evening of the accident was such that the egress paths were clear. Thus, LMITCO was in compliance with the NFPA requirements regarding egress pathways.

### 3.4.3 Emergency Egress Doors

The Investigation Report (p. 26) stated:

“Obstacles and pathway obstructions hindered both escape from and entry into the area during the accident. Entry doors to Building 648 are normally locked. A broken door latch facilitated locating and rescuing one worker. Unblocking

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43. NFPA Standard 101, “Life Safety Code,” National Fire Protection Association.

44. *Ibid.*

45. NFPA 12, “Carbon Dioxide Extinguishing Systems,” Appendix A, National Fire Protection Association.

and propping these doors open during the preventive maintenance would have significantly aided in both emergency egress and search and rescue.”

The OSHA requirements relating to locking of emergency exit doors are found at 29 CFR 1910.36(b)(4), which states:

“In every building or structure exits shall be so arranged and maintained as to provide free and unobstructed egress from all parts of the building or structure at all times when it is occupied. No lock or fastening to prevent free escape from the inside of any building shall be installed...”<sup>46</sup>

The emergency exits from TRA-648 were equipped with “panic hardware” to permit exit from the inside, as required by 29 CFR 1910.36(b)(4). Figure 3-3 shows the type of panic hardware installed on the emergency exits. These emergency exit doors, with the exception of the west door, which was under the observation of the personnel performing the work,<sup>47</sup> were locked from the outside to prevent entry by individuals who may not have been familiar with the TRA-648 CO<sub>2</sub> fire suppression system and its operation [see NFPA 12 (1993), Section 1-5.1.7]. However, the doors were not blocked.

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46. 29 CFR 1910.36, *Code of Federal Regulations*, Office of Federal Register.

47. The personnel performing the work were qualified personnel as defined in 29 CFR 1910.332(b))



**Figure 3-3.** “Panic hardware” installed on TRA-648 emergency exits.

#### **3.4.4 Conclusion**

The layout of TRA-648 and the manner in which work equipment (e.g., light stands and racked out breakers) was positioned on the evening of the accident met the DOE, OSHA, and NFPA requirements regarding maintenance of adequate and clear egress pathways. Furthermore, the emergency exit doors met the applicable OSHA and NFPA requirements.

### **3.5 Lighting**

The DOE Investigation Report (p. 19) stated:

“Escape from the area was significantly impeded by ... inadequate exit path lighting...”

This statement might lead a reader to infer that the exit lighting provided in TRA-648 did not meet applicable OSHA regulatory requirements and NFPA standards. Such an inference would be incorrect. The OSHA requirements related to exit lighting are found at 29 CFR 1910.37(q)(6) which states:

“Every exit sign shall be suitably illuminated by a reliable light source giving a value of not less than 5 foot-candles on the illuminated surface.”<sup>48</sup>

In addition, the NFPA exit lighting requirements in Sections 5-8.1.3 and 5-9.2.1 of NFPA 101, Life Safety Code, mandate an illumination level of at least 1 foot-candle at the exit and 0.1 foot-candles along the exit pathway, measured at the floor. After the accident, the light levels in TRA-648 were measured under circumstances that were as nearly identical to those the evening of the accident as LMITCO could establish. The normal lights turned off, portable lights were staged where the light stands were placed on the evening of the accident and the emergency lighting was on. The light level at the west door exit sign measured 18 foot-candles. The intensity of the floor level lighting in the exit path corridor between the rows of switchgear varied between 1 and 16 foot-candles depending upon location. The intensity of the floor level lighting at the west door measured 10 foot-candles with the door closed.<sup>49</sup> The measured illumination at the exit sign exceeds the OSHA requirement by more than a factor of 3. The intensity of the floor level lighting along the exit path, at the darkest point measured, exceeded the NFPA 101 requirements by a factor of 10. The light level at the west door, with the door closed, also exceeded the NFPA 101 requirements by a factor of 10. The lighting conditions in TRA-648 when the measurements were made may have differed somewhat from the actual conditions on the evening of the accident. However, the measured light levels exceeded the applicable OSHA and NFPA 101 requirements by such a substantial margin that it is apparent that the OSHA and NFPA requirements for emergency lighting were met on the evening of the accident. In addition, the combination of temporary lighting and ambient daylight provided on the evening of the accident in the switchgear room met the requirements of 29 CFR 1910.303(h)(3)(ii) and 303(g)(1)(v) for adequate work area lighting.<sup>50</sup>

It should be noted that these emergency lighting requirements are not intended to provide adequate visibility in the white out conditions that result from a CO<sub>2</sub> discharge. CO<sub>2</sub> is a cold gas that chills the air, causing the water vapor in the air to condense into small droplets, creating a dense water fog when it discharges into the atmosphere. This water fog makes the atmosphere virtually opaque. Under these conditions additional lighting may not increase visibility. A similar situation arises when driving an automobile in heavy fog. Increasing the illumination by turning on headlight high beams usually does not improve visibility.

### 3.5.1 Conclusion

The emergency lighting provided in TRA-648 met the OSHA and NFPA requirements for exit pathway lighting. The combination of temporary lighting and ambient daylight provided in the switchgear room at the time of the accident met the requirements of 29 CFR 1910.303(h)(3)(ii) and 303(g)(1)(v) for adequate work area lighting.

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48. 29 CFR 1910.37, “Means of Egress,” *Code of Federal Regulations*,” Office of Federal Register.

49. With the door open, as it was on the evening of the accident, the illumination at 3 feet above the ground measured 200 foot-candles.

50. 29 CFR 1910.37, “Working Space,” *Code of Federal Regulations*,” Office of Federal Register.



### 3.6 Pressure Switch and Discharge Monitoring

The DOE Investigation Report (p. 34) stated:

“The as-installed CO<sub>2</sub> releasing system does not monitor discharge of the suppression system it controls, as required by Sections 3-8.8.1 and 5-7 of NFPA 72, National Fire Alarm Code, 1996 edition.”

Section 3-8.8.1 of NFPA 72 (1996) states:

“The operation of an automatic fire suppression system installed within the protected premises shall cause an alarm signal at the protected premises fire alarm control unit.”<sup>51</sup>

Section 5-7 of NFPA 72 (1996) states:

“The operation of other fire extinguishing system(s) or suppression system(s) shall initiate an alarm signal by means appropriate to the system, such as agent flow or agent pressure, by alarm-initiating devices installed in accordance with their individual listings.”<sup>52</sup>

NFPA 72 (1996) Section A-5-7 of Appendix A, “Explanatory Material,” gives examples of some appropriate means in Section 5-7, as follows:

“Appropriate means may involve

- (a) Foam systems (flow of water)
- (b) Pump activation
- (c) Differential pressure detectors
- (d) Halon (pressure detector)
- (e) CO<sub>2</sub> (pressure detector).

In any case, an alarm that activates the fire extinguishing system may be permitted to be initiated from the detection system.”<sup>53</sup>

The TRA-648 CO<sub>2</sub> fire suppression system provides notification locally via horns, and provides notification to the Central Facilities Area fire department through an electronically supervised communication loop (EIA-485 Loop). The TRA-648 AFP-200 also sends a signal to the AM2020 fire alarm panel to alert the rest of the building complex of the fire alarm or CO<sub>2</sub> discharge via speakers distributed throughout the facility. Because this alarm actuates from the detection system, it is an appropriate means as identified in Section A-5-8 of NFPA 72 (1993) (see the final paragraph quoted from Section A-5-7). Thus, the TRA-648 fire suppression system complies with Sections 3-8.8.1 and 5-7 of

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51. NFPA Standard 72, “National Fire Alarm Code,” National Fire Protection Association.

52. *Ibid.*

53. *Ibid.*

NFPA 72 (1996), *National Fire Alarm Code*. This review also demonstrates that the TRA-648 CO<sub>2</sub> fire suppression system complied with Sections 3-8.9.1 and 5-8.1, which are the corresponding sections of NFPA 72 (1993), which is the code of record under which the system was designed.

In the discussion of compliance with Sections 3-8.8.1 and 5-7 of NFPA 72 (1996), the DOE Investigation Report (p. 34) stated:

“The as-installed CO<sub>2</sub> releasing system does not monitor discharge of the suppression system it controls, as required by Sections 3-8.8.1 and 5-7 of NFPA 72, National Fire Alarm Code, 1996 edition.

The failure to install a carbon dioxide system discharge monitoring circuit prevented a 25-second predischarge warning alarm and safe escape.”

This might lead a reader to infer that the purpose of the cited NFPA 72 requirements was to ensure the reliability of the predischarge warning alarm. Based on the previous discussion, such an inference would be incorrect. Sections 3-8.8.1 and 5-7 of NFPA 72 (1996) address the way local panels report to the main fire alarm panel, not predischarge alarm requirements.

### **3.6.1 Feedback Loop in the Original Design Documents**

The Investigation Report (p. 34) described the design evolution of the TRA-648 CO<sub>2</sub> fire suppression system as follows:

“These [1971] design documents called for installation of pressure switches to the CO<sub>2</sub> manifold with a feedback loop to the fire alarm panel, but the switches and feedback loop were deleted and never installed (see Figure 3-1). LMITCO also failed to install this monitoring circuit during the 1997 modifications and fire alarm panel upgrade. It is not clear that designers understood the significance of having pressure operated backup alarm features in the CO<sub>2</sub> system or the impact of their original removal in 1971.”

The preliminary 1971 design included pressure switches. These pressure switches were to be wired directly to an electric alarm gong. This design also incorporated a pneumatic (mechanical) time delay on the release so that the electric alarm gong would provide the predischarge warning required by NFPA 12. There was no control panel in this design and, therefore, no feedback loop. This design was a standard Walter Kidde Company design for electrically controlled CO<sub>2</sub> systems of that era. DWG #1230-MTR-642-P-17 E-13 dated July 1971, was provided by Fire Engineering Company of Salt Lake City, Utah. The proposed system used Kidde components.

Drawing 1230-MTR-642-C-4 issued February 13, 1971, showed a different control arrangement. This design used relay logic: (1) to cause an alarm bell and beacon to operate; (2) to cause a fire alarm signal to be transmitted to a central monitoring point; and (3) to energize the CO<sub>2</sub> system Kidde 120 volt AC actuating heads after a time delay (electrically timed by using a relay with adjustable 10 to 30 second delay relay contacts). The pressure switches that were originally intended to operate the alarm bell were rendered unnecessary by use of the relay logic and were removed from the design. The pneumatic time delay remained in the design and was installed. The purpose of the mechanical time delay is not documented in the as-built drawings or the sequence of operation found on DWG 1230-MTR-642-C-1.

During the mid-1980s (1985 drawings), the fire alarm panels at TRA were upgraded to multiplex type panels. It is presently unclear whether any change was made to the relay based control unit for the CO<sub>2</sub> system in TRA-648.

During the 1997 upgrades, the CO<sub>2</sub> system serving the cable vault in TRA-648 was removed, the 120 Volt AC actuating heads were replaced with 24 Volt DC actuating heads, and the selector valves serving the TRA-648 first floor switchgear area and basement area were removed. This design used the AFP-200 panel microprocessor logic: (1) to cause an alarm bell and strobe to operate; (2) to cause a fire alarm signal to be transmitted to the building fire alarm panel and thence to a central monitoring point and; (3) to energize the CO<sub>2</sub> system Kidde electric discharge heads after a time delay (programmable up to 60 seconds). Once again the pneumatic time delay was left in the manifold.

### **3.6.2 Conclusion**

The TRA-648 CO<sub>2</sub> fire suppression system design meets Sections 3-8.9.1 and 5-8.1 of NFPA 72 (1993) and the corresponding sections of NFPA 72 (1996) as installed without pressure switches. The elimination of the pressure switches in the designs after the 1971 preliminary design was simply a design evolution within standard requirements. The pneumatic time delay is not required by standard, nor is it required for operation of the system controls as installed in 1971 and 1997. Its presence does not violate a standard.

### **3.6.3 Lessons Learned and Recommendations for Revision of Standards**

The movement from mechanical relay logic control systems to microprocessor control systems within the fire protection community has largely reduced maintenance costs and increased system reliability. However, the centralization of functions in the microprocessor has increased the risk of common cause failures. These are situations in which failure or malfunction of the microprocessor causes the system to fail to perform several functions as intended. As discussed in Chapter 2, the design defect in the AFP-200 panel caused the microprocessor: (1) to send spurious signals that caused the solenoids to fire the CO<sub>2</sub> system; (2) to fail to signal the CO<sub>2</sub> pre-discharge alarm to annunciate; (3) to fail to inform the Central Facilities Area that the TRA-648 CO<sub>2</sub> system had discharged, and (4) to fail to send an alarm signal to TRA-647 Building Complex to evacuate due to a fire alarm. Although the TRA-648 CO<sub>2</sub> discharge accident involved a fire suppression system, microprocessor control systems are being used for control of processes involving hazardous materials and for other applications where malfunctions can have significant impact on safety. Therefore, DOE may wish to develop design guidance for its contractors that describes appropriate measures to reduce the risks associated with common cause failures in microprocessor-based control systems. Once this guidance has been developed and proven in DOE-contractor facilities, DOE, in its campaign to improve consensus standards, may wish to request that OSHA modify 29 CFR 1910.119, "Process Safety Management of Highly Hazardous Chemicals," to incorporate this guidance.

## 4. REVIEW OF SIGNIFICANT INVESTIGATION REPORT ISSUES

This section contains additional analysis of significant Investigation Report issues that do not directly relate to compliance with codes and standards.

### 4.1 Hazards and Risks Associated with Carbon Dioxide

This subsection provides clarification of the material related to the risks of CO<sub>2</sub> that are presented in Section 2.1 of the Investigation Report. The Investigation Report includes information that may convey an incorrect perception of the hazards of CO<sub>2</sub> and the risks associated with its use as a fire suppression agent.

#### 4.1.1 Carbon Dioxide Hazards

The severity of the physiological effects of exposure to various concentrations of CO<sub>2</sub> indicated in the Investigation Report differs from information provided by other authoritative sources. For example, the physiological effect shown on Figure 2-1 of the Investigation Report for a 20% concentration of CO<sub>2</sub> is:

“increased breathing; accelerated heart rate; mild impairment of attention, coordination.”

OSHA Hazard Information Bulletin 19960605 states that:

“Gaseous carbon dioxide is an asphyxiant. Concentrations of 10% (100,000 ppm) or more can produce unconsciousness or death.”<sup>54</sup>

Thus, OSHA stated that the hazard associated with exposure to a 10% CO<sub>2</sub> concentration is significantly more severe than Figure 2-1 of the Investigation Report indicates. Similarly, the CO<sub>2</sub> concentration level shown on Figure 2-1 of the Investigation Report as Immediately Dangerous to Life and Health (IDLH) is approximately 33%. However, the National Institute for Occupational Safety and Health (NIOSH) states that the IDLH concentration for CO<sub>2</sub> is 4% (40,000 ppm).<sup>55</sup> Thus, both OSHA and NIOSH state that the hazards of exposure to CO<sub>2</sub> are more severe than the data indicated in Figure 2-1 of the Investigation Report. Therefore, it would not be prudent to use the information in Figure 2-1 of the Investigation Report to assess the hazards associated with exposure to various concentrations of CO<sub>2</sub>.

The first paragraph of Section 2.1 of the Investigation Report stated:

“The percentage CO<sub>2</sub> in the building [TRA-648 Electrical Equipment Room] following the accidental initiation of the fire suppression system was estimated at approximately 50 percent. This is well above the 30 percent minimum concentration necessary for fire protection and is lethal to occupants or individuals, as shown in Figure 2-1.”

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54. OSHA Hazard Information Bulletin 19960605, “Potential Carbon Dioxide (CO(2)) Asphyxiation Hazard When Filling Stationary Low Pressure CO(2) Supply Systems,” Occupational Safety & Health Administration, U.S. Department of Labor, June 5, 1995.

55. National Institute of Occupational Safety and Health (NIOSH) Documentation for Immediately Dangerous to Life and Health: Carbon Dioxide at <http://www.cdc.gov/niosh/idlh/124389.html>.

Readers might infer from these statements and from the Investigation Report Figure 2-1, which shows a 30% CO<sub>2</sub> concentration as less than the IDLH level, that the TRA-648 CO<sub>2</sub> fire suppression system could have been designed in such a manner that the system discharge without a pre-discharge warning would not have posed a lethal hazard to occupants or individuals. Such an inference would be incorrect for two reasons. First, as discussed above, a 30% CO<sub>2</sub> concentration exceeds the 10% concentration that OSHA and NIOSH state can produce unconsciousness or death. Second, Section 2-4.2.1 of NFPA 12 requires a 50% design CO<sub>2</sub> concentration for CO<sub>2</sub> fire suppression systems covering dry electrical hazards, like those in TRA-648.<sup>56</sup>

#### 4.1.2 Risk Associated With Use of CO<sub>2</sub> in Fire Suppression Systems

Section 2.1 of the Investigation Report stated:

“Since 1975, there have been a total of 63 deaths and 89 injuries resulting from accidents involving the discharge of CO<sub>2</sub> fire extinguishing systems.”

To obtain a clear perspective on the risks associated with CO<sub>2</sub> fire suppression systems, it is necessary to review the incidents described in the Environmental Protection Agency (EPA) draft report, *Carbon Dioxide as a Fire Suppressant: Examining the Risks*, that is cited as the basis for these statistics. Only 22 of these 63 deaths occurred in the United States and Canada. The remaining 41 deaths occurred in foreign countries where the standards for CO<sub>2</sub> fire suppression design differ significantly from those in the United States and Canada.<sup>57</sup> Because of these differences in governing standards, the frequency of fatalities in countries other than the United States and Canada is not directly relevant to the risks associated with CO<sub>2</sub> fire suppression systems in the United States.

Sixteen of the 22 deaths within the United States and Canada that are cited in the EPA draft report involved marine applications of CO<sub>2</sub> fire suppression systems. The regulations applicable to marine applications of CO<sub>2</sub> fire suppression systems vary depending upon whether the vessels navigate domestic or international waters. The U.S. Coast Guard (46 CFR 76.15) regulates ships in domestic waters and the International Maritime Organization, Safety of Life at Sea (SOLAS) requirements cover internationally registered vessels. “Maritime regulations (46 CFR 76.15 and SOLAS) do not provide detailed requirements to ensure safety of personnel.”<sup>58</sup> In addition, shipboard areas protected by CO<sub>2</sub> systems frequently have longer exit paths than would be permissible under the OSHA regulations applicable to general industry (see Subsection 3.4 of this Supplemental Response). Thus, the frequency of fatalities associated with maritime applications of CO<sub>2</sub> fire suppression systems is not directly relevant to the risks associated with CO<sub>2</sub> fire suppression systems in the United States.

The EPA draft report cites six deaths, since 1975, within the United States and Canada as being associated with non-maritime applications of CO<sub>2</sub> fire suppression systems. Four of these fatalities are

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56. NFPA 12, “Standard on Carbon Dioxide Extinguishing Systems,” National Fire Protection Association, 1993 Edition. It should also be noted that Section 2.3.2 of NFPA 12 mandates a minimum CO<sub>2</sub> concentration of 34 percent for any application, rather than the 30 percent cited in the Investigation Report.

57. *Carbon Dioxide as a Fire Suppressant: Examining the Risks*, page 19.

58. *Ibid.*, page 20.

associated with an incident at the Surry Nuclear Power Station in December 1986.<sup>59</sup> A Nuclear Regulatory Commission (NRC) information notice describes this incident as follows:

“On Tuesday, December 9, 1986, at 2:20 p.m., both units at the Surry Power Station were operating at full power when the 18-inch suction line to the main feedwater pump A for Unit 2 failed catastrophically. [The feedwater in the line was at a temperature of approximately 370°F, under a pressure of approximately 450 pounds per square inch gauge, and flowing at a rate of about 5 million pounds per hour]. Eight workers who were replacing thermal insulation on a nearby line were burned by flashing feedwater [i.e., feedwater that flashed to steam when the pressure was released]. All were transported to area hospitals. Two workers were treated and released. Four other workers subsequently died.”<sup>60</sup>

The NRC information notice also notes that:

“Steam flashing from the break and condensing in control cabinets and in open conduit piping apparently caused the fire suppression system to actuate, resulting in release of Halon and carbon dioxide in the emergency switchgear room and in various cable tunnels and vaults and in the cable spreading room.”<sup>61</sup>

This fire suppression system actuation, resulting in the discharge of Halon and CO<sub>2</sub> to locations other than where the workers were killed, appears to be the reason that the Surry incident is included in the data in the EPA draft report. This incident is clearly irrelevant to the risk associated with use of CO<sub>2</sub> fire protection systems. Eliminating these four fatalities leaves two deaths since 1975 that were associated with the use of CO<sub>2</sub> fire suppression systems in non-maritime applications in the United States and Canada. One of these fatalities happened in the TRA-648 accident.

Thus, aside from the TRA-648 accident, the EPA draft report identified only one death since 1975 that was associated with the use of CO<sub>2</sub> fire suppression systems in non-maritime applications in the United States and Canada. In this incident an “employee of Carolina Fire Protection was checking out a carbon dioxide system in a bus garage when the system accidentally discharged.”<sup>62</sup> Thus, the data in the EPA draft report indicates that the likelihood of a fatal accident related to the discharge of a CO<sub>2</sub> fire suppression system is quite small (two events over a 24-year period in the United States and Canada where thousands of CO<sub>2</sub> fire suppression systems are in use).

It is also interesting to note that, with the exception of the TRA-648 accident, the EPA draft report records no incidents, foreign or domestic, maritime or non-maritime, from 1948 to the present, in which death or injury resulted from spurious actuation of a CO<sub>2</sub> fire suppression system that was caused by the loss of AC power.<sup>63</sup>

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59. *Ibid.*, Appendix A

60. IE Information Notice No. 86-106: Feedwater Line Break, page 1.

61. *Ibid.*, page 2.

62. EPA *op. cit.*, Appendix A, page 3.

63. *Ibid.*

## 4.2 Design of the 1997 Upgrade

The Investigation Report was critical of the design process employed for the 1997 upgrade of the TRA-648 CO<sub>2</sub> fire suppression system. The design process criticism in the Investigation Report was generally presented as an inference from the failure of the LMITCO design of the CO<sub>2</sub> fire suppression system to comply with the Investigation Board's interpretations of OSHA regulations and NFPA Standards discussed in Subsections 3.3 and 3.6 of this Supplemental Response. The Investigation Report did not identify specific deficiencies in the implementation of design procedures or other design process requirements. For example, the Investigation Report (pp. 39 and 40) stated:

“If requirements for the system and the design and approval process had been known, understood, documented, and implemented, the deficiencies could have been identified and rectified either in 1971 or in 1997. Thus, it is concluded that a failure to understand or implement applicable procedural requirements for system design and installation, including engineering oversight and quality assurance, contributed to the accident.”

In developing its initial response to the Investigation Report, LMITCO conducted a thorough review of the design process for the 1997 modification of the TRA-648 CO<sub>2</sub> fire suppression system. This review included the examination of information from sources that the DOE Investigation Board may not have had time to pursue during the limited time available for their investigation. The information in this section is drawn from interviews with project personnel, site investigations, and a review of the complete project file. Personnel interviewed included the responsible design engineer, project manager, and quality inspector.

This review established that applicable requirements and procedures were followed throughout the design process in the areas of work scope determination, design review, procurement, quality assurance, and documentation.

### 4.2.1 Work Scope Determination

The fire protection upgrades at TRA were a result of multiple fire protection audits performed by DOE, DOE Tiger Team, EG&G Idaho Co., Factory Mutual, and outside consultants. These audits were consolidated in a deficiency list in 1991 for all areas of the INEL, documenting items that needed correction.

Project proposals for several line item construction projects were developed to correct the deficiencies on these lists. Two of these projects dealt with the deficiencies at TRA, the *INEL Fire and Life Safety Improvements, FY-92* and the *TRA Fire and Life Safety Improvements, FY-95*, which included TRA-specific upgrades.

The deficiencies on the 1991 deficiency list were assigned priorities and dispositioned based on safety risk, available funding, and planned use of the buildings. Where appropriate, equivalent protection evaluations were performed to resolve deficiencies. The prioritization and the proposed resolutions of (or corrective actions for) the deficiencies at TRA were reviewed by the EG&G Idaho Facility Fire Protection Engineer, EG&G Management, Advanced Test Reactor Operations, TRA Landlord, TRA Systems Engineering, and EG&G Architectural Engineering, and were presented to DOE-ID Fire Protection Authority Having Jurisdiction (AHJ) and other affected organizations. The *INEEL Fire and Life Safety Improvements, FY-92* included the TRA-648 fire alarm upgrades. A letter from the Project Manager, dated June 8, 1996, documented final concurrence by all parties.

A key decision during this period was whether to retain the CO<sub>2</sub> fire suppression system for TRA-648. The following factors were considered in making this decision. The Engineering Test Reactor (ETR) adjacent to TRA-648 had been shut down and the TRA-648 electrical systems were no longer critical to its operation. However, the switchgear that controls two deep water wells supporting safety systems for the Advanced Test Reactor is located in TRA-648. Furthermore, the maximum possible fire loss for TRA-648 and its contents was over \$7.6 million. DOE Order 5480.7A, "Fire Protection," requires that automatic fire suppression systems be installed for property protection in all facilities with a maximum possible fire loss in excess of \$1 million.<sup>64</sup> Worker safety was the primary consideration in determining the best approach to meet this requirement. Installation of a water fire suppression system was considered. However, the electrical maintenance organization was concerned about safety risks from inadvertent actuation of such a system during maintenance work. The use of a Halon system was excluded from consideration because of DOE Headquarters memo, dated September 27, 1990, that prohibited installation of new Halon systems. After considering the options, the design team determined that the best decision for both worker safety and property protection was to retain the CO<sub>2</sub> fire suppression system and to upgrade the associated fire detection system and control panel. The use of CO<sub>2</sub> fire suppression systems for high voltage switchgear is a standard industry practice.

At the time that the upgrade was being designed, the TRA-648 basement cable vault was protected by both a water fire suppression system and a CO<sub>2</sub> fire suppression system. During the design of the upgrade, the exit pathways from the cable vault were reviewed. The exit pathways from the basement cable vault are significantly longer than exit pathways from the switchgear area. This caused concern about the ability of workers to exit the basement cable vault safely in response to the CO<sub>2</sub> fire suppression system predischarge warning alarm. With the ETR out of service there was also no reason for concern about the possible effects that discharging water on a cable fire would have on the safe operation of the ETR. Therefore, the CO<sub>2</sub> system was removed from the basement cable vault and the water fire suppression system was relied upon for the automatic fire suppression required by DOE Order 5480.7A.

Once these key design decisions had been made, the detailed design of the project followed the path defined in the applicable INEL procedures including defining the work scope and documenting the design requirements in a Task Baseline Agreement with the design team. Monthly and bi-monthly design progress meetings, design reviews, comment tracking, and verification were conducted. Meeting minutes documenting decisions were sent to affected groups.

#### **4.2.2 Design Review**

The design review requirements applicable to the project were established in DOE Order 4700.1, "Project Management System," which was the governing DOE order at the time of the project.<sup>65</sup> These requirements were incorporated into company procedures. The TRA-648 design was reviewed in accordance with EG&G Idaho Company Procedure 2.16, "Design Verification," which was in force at that time. An independent review was required. A company-certified independent design review chairman, who was not a member of the project design team, conducted the TRA Fire and Life Safety Improvements project review. Independent individuals from affected organizations, as shown in Table 4-1, formally reviewed the project design.

All design review comments were documented, answered, and incorporated as required.

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64. DOE Order 5480.7A, "Fire Protection," February 17, 1993, Paragraph 9.b(3).

65. DOE Order 4700.1, "Project Management System," Change 1, June 2, 1992; Chapter III, Part D, Paragraph 2.c; Attachment III Paragraph 2.a(2); Chapter V, Part A, Paragraph 2.o(1)(d); and Chapter V, Part C, Paragraph 1.g.



**Table 4-1.** Organizations represented in the project design review.

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TRA Facility Fire Protection Engineer	TRA Maintenance Operations
Site Cognizant Professional for Fire Protection	Site Landlord Environmental Support
Advanced Test Reactor Operations Management	Site Life Safety Systems
TRA Landlord Management	Project/Construction Management
TRA Systems Engineering	Project/Construction Management Quality Engineering
TRA Industrial Safety	Project/Construction Management Safety
TRA Quality Engineering	Project/Construction Quality Inspection
TRA Radiological Control	Site Construction Cost Estimating
TRA Industrial Hygiene	Architectural Engineering Design
TRA Construction Management	DOE-ID TRA Facility Manager
TRA Physical Security	DOE-ID Project Management
TRA Environmental Support	DOE-ID Authority Having Jurisdiction for Fire Protection
TRA Waste Minimization	

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### 4.2.3 Procurement

After design review, the project was formally bid. Competitive bids were received from four prequalified construction companies. These companies used equipment and prices from two preapproved fire alarm manufacturers.<sup>66</sup> The selected electrical subcontractor supplied Notifier products, which met the contract specifications.

### 4.2.4 Project Quality Assurance

The quality assurance requirements for the TRA-648 CO<sub>2</sub> fire suppression system upgrade project were established in DOE 4700.1<sup>67</sup> and implemented by company procedures and the approved company Quality Program Plan for construction projects. These documents required the Quality Engineer to write a Project Inspection Plan based on the quality requirements and the contract specifications. This plan was written on September 18, 1995, reviewed and received final approval on November 28, 1995. The Project Inspection Plan established the basis for quality inspections performed during construction. A Quality Inspector for each discipline was assigned to the project. The Quality Inspection and Quality Engineering organizations were independent of the engineering design organization, the construction subcontractor, and the Construction and Project Management organizations.

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66. DOE approved the addition of Notifier equipment to the list of acceptable fire alarm equipment approved for use at the INEEL in a letter from Patrick Smith, Fire Protection Engineer, DOE Idaho Operations Office, to W. R. George, Manager LITCO Life Safety Systems, dated January 9, 1995.

67. DOE 4700.1, *op cit.*, Chapter III, Part D.

During construction of this installation, the inspection plan was followed, verified, documented, and signed-off at completion. The Quality Inspection Plan, along with the subcontractor acceptance test and the LMITCO System Operations (SO) test procedure, required the Quality Inspector, the Facility Fire Protection Engineer, and the LMITCO Life Safety Systems Organization to verify installations and witness all testing. The Quality Inspector documented inspections of the testing of the AFP-200 panel in TRA-648 on Daily Inspection Reports. The report dated April 30, 1997, documented that the panel testing was successful.

The overall design networked 27 Notifier fire panels. Each panel protected specific buildings. Panels were organized into eight groups. All panels were installed and networked together. The function and networking of the panels was tested by the subcontractor's test documents previously submitted by the subcontractor for approval by the Quality Engineer and the Design Engineer. This system test was witnessed by the Quality Inspector, the LMITCO Life Safety Systems representative, and the Facility Fire Protection Engineer.

After the TRA-648 fire alarm panel communication system was tested by the subcontractor and verified to be properly functioning, the SO test was performed by LMITCO Life Safety Systems organization, witnessed by the Quality Inspector, and by the Facility Fire Protection Engineer. The SO test, including successfully switching from primary AC power to DC backup power, was documented on July 17, 1997. This test also included 60 hours of operation on backup batteries. At the end of 60 hours, alarm and reporting systems were tested using the backup power. LMITCO Life Safety Systems took control of the maintenance of the system.

#### **4.2.5 System Documentation**

The configuration management requirements at the time of the TRA-648 CO<sub>2</sub> fire suppression system upgrade project were established in DOE 4700.1.<sup>68</sup> This DOE order required that configuration controlled documents be defined by the project and the facility. These requirements were rolled down into LMITCO company-wide Performance Requirement Documents, Management Control Procedures, and the TRA Standard Procedures that governed configuration management.

Items under configuration control must meet certain operational or mission needs, including consideration of their anticipated role throughout the expected life cycle of the facility. *Master facility* drawings and *key* drawings are updated, per TRA Standard Procedure SP 10.2.4.1. Standard Procedure 10.2.2.8, "Facility Change Form," documented the *master facility* drawings and *key* drawings affected by each project or activity. For the Fire and Life Safety Upgrade Project, a detailed control process, involving a Facility Change Form, was followed throughout the construction and closeout process. Interim drawings were created for plant use during construction. As construction work was done, all *master facility* drawings and *key* drawings were updated, including all fire alarm drawings. The CO<sub>2</sub> piping drawing was the only drawing that was not updated, because it was not on the list for *master facility* drawings and *key* drawings. Since the accident investigation, this drawing has been updated. All required operational and maintenance procedures were current at the time of the accident.

### **4.3 Installation of the TRA-648 AFP-200 Analog Fire Panel**

In developing its initial response to the Investigation Report, LMITCO conducted a thorough review of the installation process for the 1997 modification of the TRA-648 CO<sub>2</sub> fire suppression system.

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68. DOE 4700.1, *op. cit.*, Chapter III, Part C.

This review included the examination of information from sources that the DOE Investigation Board may not have had time to pursue during the limited time available for their investigation. The information in this section is drawn from interviews with project personnel, extensive site investigations, and a detailed review of the complete project file. Personnel interviewed include the responsible design engineer, project manager, construction coordinator, quality inspector, and installation subcontractor. In addition, external and internal fire alarm experts performed a detailed inspection of the system installation.

#### **4.3.1 Original Installation of the TRA-648 AFP-200 Analog Fire Panel**

Qualified, licensed electricians, with over 14 years experience in fire alarm system installation, installed the AFP-200 panel and associated equipment managing the CO<sub>2</sub> system. The installation subcontractor employed a factory trained and certified installer for the TRA-648 installation, who was qualified National Institute for Certification in Engineering Technologies (NICET) Level II in fire alarms and had over 20 years experience installing fire alarm systems.<sup>69</sup>

LMITCO Construction and Quality personnel monitored installation of the equipment. Wire labels were approved, installed and witnessed, and documented during the continuity and megger testing. After the AFP-200 panel and all field devices were installed and inspected, the Notifier factory trained representative installed the electronic modules into the AFP-200 panel enclosure, under the observation of LMITCO Quality and Life Safety Systems personnel. The factory trained representative completed programming of the AFP-200 panel and the subcontractor and LMITCO personnel tested the system for operation. LMITCO Engineering Design File 752 lists construction reports, inspection reports, and daily logs specific to the TRA-648 installation.

The AFP-200 panel in TRA-648 was put on line April 30, 1997, and LMITCO Life Safety Systems took over maintenance control and operation of the panel at that time. Periodic maintenance had been successfully performed in May 1998. No abnormal operations or panel defects were noted during the subcontractor test, SO tests, battery tests, loss of AC power tests, or maintenance tests.

#### **4.3.2 Original Installation Quality Control**

LMITCO Design Engineering, TRA Facility Systems Engineering, Quality, Fire Protection, Life Safety Systems, Construction Management, and Project Management were involved in the review and the installation of the Notifier AFP-200 panel in accordance with the project inspection and testing requirements. The LMITCO Design Engineer was a NICET Level IV with nine years experience in fire alarm systems design. A Notifier factory-trained NICET Level II installer with 20 years experience in fire alarm installation reviewed the design and installation. The design was also reviewed by his manager who has 20 years of fire alarm experience, NICET Level II certification, Journeyman Electrician license,

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69. NICET is a not-for-profit division of the National Society of Professional Engineers (NSPE). NICET is an independent, internationally-recognized evaluator of knowledge and experience for engineering technicians and technologists. NICET provides certification programs for individuals in multiple fields. The NICET certified individuals involved in the installation and testing of the TRA-648 fire alarm panel were certified specifically in fire alarm planning, design, installation, acceptance, operation, and maintenance. Engineering technicians can be certified at four levels, level four being the senior level. NICET certified engineering technologists have met experience requirements and passed certification tests, thus demonstrating a thorough knowledge of the equipment, applications, and established state-of-the-art design and implementation methods in a particular engineering area. To become NICET certified, candidates must: (a) meet minimum work experience requirements (up to ten years), (b) pass written examinations, (c) obtain supervisor's affirmation of correct performance of tasks and application of knowledge under a variety of on-the-job conditions, and (d) obtain a personal recommendation from a qualified professional who is familiar with the technical capabilities, background, quantity, and quality of the candidate's work.

and an associates degree in electronics. These three individuals are NICET certified specifically for fire alarm systems, including design and installation.

### 4.3.3 Post-Accident Review of System Installation

After the accident, LMITCO investigated and verified the panel installation using qualified LMITCO personnel and consultants from independent laboratories. As discussed in Section 2, this investigation was performed as a part of the LMITCO effort to identify the specific mechanism by which the CO<sub>2</sub> system in TRA-648 discharged. The following three installation errors cited in the Type A Investigation Report were examined:

1. *“Use of unfiltered auxiliary power supply for a releasing application”*

The manufacturer’s instructions with regard to the auxiliary power supply (AVPS-24) are open to differing interpretations.

Appendix J of Revision D of the Notifier Instruction Manual (p. 111) states:

“The notification appliance power available from the system can be increased by three amperes when an AVPS-24 is added to the system...Since the AVPS-24 supplies special purpose (unfiltered, unregulated) power, only compatible notification appliances listed in Device Compatibility Document can be connected to Bell Circuits 3 and 4.”<sup>70</sup>

Appendix D of Revision D of the Notifier Instruction Manual (p. 91) states:

“This control panel may be used as a control panel for agent release or preaction/deluge control applications. When used with compatible, listed actuating and initiating devices, the system meets the requirements of the following standards: NFPA 12 CO<sub>2</sub> EXTINGUISHING SYSTEMS (HIGH PRESSURE ONLY)...”<sup>71</sup>

The list of devices is found in the Notifier Device Compatibility Document. The Kidde Electric Control Heads are listed on page 1 of the Notifier Document #15378, “Notifier Device Compatibility Document,” Revision Q, dated February 20, 1998. The listing agency and the manufacturer approve use of Kidde Electric Control Heads with the AFP-200 panel.

The Notifier Instruction Manual does not specifically exempt, nor does it include any specific warnings addressing the use of the AVPS-24 power supply. As demonstrated in Section 2 of this Supplemental Response, the auxiliary power supply was not a factor in the specific mechanism that caused the release of the CO<sub>2</sub>, and is not a factor in the design defect found in the Notifier panel.

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70. Notifier, *op. cit.*, p. 111.

71. Notifier, *op. cit.*, p. 91.

2. *“On the signaling line circuits, one branch is shielded and the other is not.”*

The signaling line circuits do not require shielded conductors. The Notifier Instruction Manual, Revision D, Appendix F, (p. 99) states:

“Operates up to 1,000 ft with untwisted, unshielded wire and maximum of 10,000 ft with twisted, shielded pair wire.”<sup>72</sup>

The unshielded branch circuit referred to in the Investigation Report is a Class B, Type 4 signaling line circuit. The unshielded branch of this circuit extends to a supervisory monitor module used for AVAS control. This monitor module is located within 3 feet of the AFP-200 panel and, as indicated in the manufacturer’s manual, is not required to be shielded or twisted. The other branch of the circuit extends to various parts of the building and is shielded. The shield conductor is properly terminated within the AFP-200 panel.

As detailed in Subsection 2.6.2 of this Supplemental Response, subsequent laboratory testing has shown that the shielding of branch circuits was not a factor in the CO<sub>2</sub> discharge. The activation of the CO<sub>2</sub> releasing solenoids was not from externally induced transient voltage, but was a spurious signal internally generated by AFP-200 panel electronic components.

3. *“The shield drain conductor on the shielded branch is connected to the wrong terminal on the fire alarm panel main board.”*

The AFP-200 Analog Fire Panel Instruction Manual, Revision D, Release 2, Document 15511, dated September 14, 1994,<sup>73</sup> does not show how to terminate the shield at the panel (TB6). The direction is found on Notifier AFP-200 drawing No. 70577 furnished to LMITCO.<sup>74</sup> An independent review of this drawing and the installation verified that the drain wire is terminated correctly.

As detailed in Subsection 2.6.2 of this Supplemental Response, subsequent laboratory testing has shown that the shield drain conductor was not a factor in the CO<sub>2</sub> discharge. The activation of the CO<sub>2</sub> releasing solenoids was not from externally induced transient voltage, but was a spurious signal internally generated by AFP-200 panel electronic components.

## **4.4 Personnel Qualifications**

This subsection of the Supplemental Report provides additional information about the qualifications of the individuals who designed and installed the CO<sub>2</sub> fire suppression system upgrade for TRA-648 and the individuals who planned, managed, and performed the electrical maintenance work being conducted in TRA-648 the evening of the accident.

### **4.4.1 Design and Installation Personnel Qualifications**

The Investigation Report is critical of the qualifications of the personnel responsible for the design, the design reviews, and the installation of the 1997 upgrade of the TRA-648 CO<sub>2</sub> fire suppression system.

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72. Notifier, *op. cit.*, p. 99.

73. Notifier, *op. cit.*

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

The criticism of the qualifications of these personnel is generally presented as an inference from the failure of LMITCO to design the CO<sub>2</sub> fire suppression system in compliance with the Investigation Board's interpretations of OSHA regulations and NFPA Standards discussed in Subsections 3.3, "Requirements for Locking Devices," and 3.6, "Pressure Switch and Discharge Monitoring," of this Supplemental Response. The Investigation Report does not identify specific deficiencies in the qualifications of the personnel responsible for the design, the design reviews, and the installation of the 1997 upgrade of the TRA-648 CO<sub>2</sub> fire suppression system. For example, the Investigation Report (p. 46) stated:

"From the design and installation through the implementation of the work, there was insufficient knowledge or competence at all levels to prevent the accident from occurring. LMITCO engineering staff involved in the design, installation, and approval of the design and installation changes did not understand the significance of these changes on controlling the hazard and on worker safety organizational levels."

The design changes that the Investigation Report is referring to are those discussed in Subsection 3.6.1, "Feedback Loop in the Original Design Documents," of this Supplemental Response (i.e., the removal of the pressure sensors when the design changed from using a mechanical predischARGE alarm to employing an electrical discharge alarm).

The LMITCO designer assigned to the project had the NICET Level IV certification in fire alarm design with approximately nine years of experience in design and installation practices. The design used a FM-approved UL-listed fire alarm releasing panel. The NICET Level IV designer did component and wiring layouts inside the control panel and to all field devices. The Facility Fire Protection Engineer and a factory trained NICET Level II fire alarm installer conducted a review of the panel layout. The installation was performed by the factory trained NICET Level II certified technician and witnessed by the LMITCO quality inspector, Facility Fire Protection Engineer, and the NICET certified Life Safety Systems engineers and technicians. Multiple-disciplined professional engineers and NICET certified personnel reviewed the design.

The installing contractor exceeded the experience required by LMITCO contracting guidelines. The installing contractor employed a factory trained technician with 20 years experience in installing fire alarm systems. The factory trained technician also provided classroom and hands-on training to the electrical construction personnel for shielding and device termination. He also trained the TRA Facility Fire Protection Engineer on system operation and programming. The LMITCO Life Safety systems technicians and engineers were factory trained and certified on the Notifier fire alarm equipment.

The credentials of the inspector assigned to the project included: (a) State of Idaho Electrical License, (b) International Conference of Building Officials Certified Electrical Inspector, (c) International Association of Electrical Inspectors Certified Electrical Inspector, and (d) INEEL Certified Quality Electrical Inspector.

The qualifications of personnel involved with the design of the TRA-648 CO<sub>2</sub> fire suppression system upgrade and installation of the Notifier AFP-200 system in TRA-648 are detailed in Appendix C of this Supplemental Response.

#### **4.4.2 Qualifications of Personnel Planning, Managing, and Performing Work**

The Investigation Report is critical of the qualifications of the personnel responsible for planning, managing, and performing the electrical maintenance work being conducted in TRA-648 the evening of the accident. The criticism of the qualifications of these personnel is generally presented as an inference

from the failure of LMITCO to comply with the Investigation Board's interpretations of OSHA regulations and NFPA Standards discussed in Subsection 3.2, "Application of Lockout/Tagout," of this Supplemental Response. For example, the Investigation Report stated:

"Workers, planners, and line managers were not cognizant of personnel protection measures contained in 29 CFR 1910, Subpart L and NFPA Standard 12, which would have alerted them to hazards associated with CO<sub>2</sub> fixed fire suppression systems and mitigation measures that could have been employed in the event of an accidental release of CO<sub>2</sub> from the fire suppression system." (p. 44)

"Personnel involved in the work planning process had LMITCO lockout/tagout training but failed to recognize that the Building 648 CO<sub>2</sub> fire suppression system needed to be physically isolated, not electronically impaired." (p. 45)

"Line managers, planners, engineers, supervisors, and workers associated with the work did not understand the hazards associated with CO<sub>2</sub>, nor did they have sufficient knowledge of the requirements for dealing with the hazards." (p. 46)

The work planner for the TRA-648 electrical maintenance package had over 25 years experience as an electrician and 5 years experience in work planning and control at TRA.

The TRA Facility Fire Protection Engineer, who provided fire protection oversight during the electrical maintenance activities the evening of the accident, held a BS degree in Fire Protection and Safety Engineering and had 10 years fire protection engineering experience.

The qualifications and competence of the personnel managing, and performing the electrical maintenance work being conducted in TRA-648 the evening of the accident is further demonstrated by a subsequent review of the job that demonstrated that they complied with the applicable maintenance control procedures.<sup>75</sup> These included a formal written work order, outage form, and pre-job briefing that were completed before work began.

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75. The Investigation Report (p. 23) states that "a draft preventive maintenance procedure for the fire protection system was not used for this activity and CO<sub>2</sub> shutdown, because it was considered too restrictive." LMITCO does not permit use of unapproved, draft procedures because such use is not conducive to disciplined operations or maintenance. It should also be noted that the work being performed was not preventive maintenance on the fire protection system.

## 5. SAFETY MANAGEMENT INITIATIVES

Throughout its tenure as the management and operations contractor for the INEEL, LMITCO has been committed to ensuring protection of the workforce, the public, and the environment and to improving safety and health programs. This section presents an overview of the safety management initiatives undertaken by LMITCO at the INEEL since the contract began in October 1994.

Analysis of semiannual DOE-ID Performance Evaluation reports<sup>76</sup> and semiannual LMITCO Performance Assessments provides a substantial amount of evidence of:

- Significant Safety Accomplishments
- Management Involvement In Safety Programs
- Safety Management Program Improvements.

Table 5-1 shows a summary of significant safety accomplishments, LMITCO management involvement, safety programs, and safety management program improvements in semiannual reporting periods, which correspond to the Performance Evaluation periods, beginning in October 1994 through September 1998. The last column includes accomplishments documented in CO<sub>2</sub> Accident Corrective Action Project Reports.

From the beginning of the contract in October 1994, LMITCO emphasized safety programs and safety culture. Five INEL Safety and Health operations were organized into one cohesive unit and Total Safety Culture Training was started. The INEL hosted a Voluntary Protection Program (VPP) conference for the entire DOE complex. In 1995, a DOE-HQ evaluation acknowledged a strong safety culture and worker involvement, with exemplary performance in the Decontamination and Decommissioning Program.

A significant amount of LMITCO effort is acknowledged in the DOE-ID Performance Evaluation reports and noted in Table 5-1 in the four semiannual periods preceding the TRA-648 accident. In particular, an Enhanced Work Planning (EWP) pilot program was successfully implemented, including the Job Requirements Checklist system; VPP certification was incorporated into subcontractor requirements; the ICARE System was implemented; and Integrated Safety Management (ISM) clauses were incorporated into the LMITCO contract in February 1998. At the time of the TRA-648 accident LMITCO's implementation of ISM was being accomplished in accordance with the schedule identified by the DOE-ID Contracting Officer.<sup>77</sup> LMITCO formed a company-wide ISM Project Team in April 1998 and completed the following actions by August 1998:

- ISM System description
- Safety performance objective and performance measures for 1998 and 1999

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76. DOE-ID, "Performance Evaluation," Lockheed Martin Idaho Technologies Company, Contract No. DE-AC07-94ID13223.

77. J. M. Wilcynski, DOE-ID, Letter to W. John Denson, LMITCO, "Transmittal of Contracting Officer Guidance On Integrated Safety Management System Description Document Development and Implementation for Contract DE-AC07-94ID13223 (OPE-OS-98-041)," dated April 2, 1998.



- Confirmation of the existing requirements base
- ISM System gap analysis.

LMITCO was in compliance with the ISM implementation schedule to meet the Phase I (ISMSV-I), October 1998, milestone. LMITCO ISM System implementation was contractually directed for completion in August 1999, with DOE validation in September 1999.

In the four semiannual periods before the TRA-648 accident, three significant awards were received: (1) the EWP team received Vice President Gore's Hammer Award; (2) the Safety and Health Wellness Program was awarded the Health Promotion Business and Industry Award; and (3) the Occupational Medical Program was awarded the C. Everett Koop National Award. Noteworthy safety performance accomplishments were reached in construction safety and operational safety at TAN and TRA. The VPP Passport to Success Program marked 95% employee involvement and the results of the annual employee survey indicated high employee satisfaction and acceptance of safety and health programs.

LMITCO senior-level management has been consistently involved in leading and directing INEEL safety management programs. This involvement is noted in the safety performance emphasis stressed in the INEEL Long Range Plan, Site-wide Integrated Safety Action Plan, VPP infrastructure, and vertically integrated safety committees. LMITCO management established safety goals for each organization and included safety and health components in every employee performance appraisal. Leadership actions to promote employee involvement in safety programs and safety culture were recognized in Celebration of Safety Week activities. The Environmental Safety and Health, and Quality Assurance organizations were combined into one branch, with a Vice President reporting directly to the LMITCO President.

LMITCO improved the infrastructure supporting emergency response capabilities at the INEEL. Emergency response and preparedness was enhanced by:

- Constructing a new fire station located closer to the TRA and other operational sites to reduce the response time to emergencies
- Constructing a fire training facility to increase the proficiency of fire fighters and incident response teams that perform rescue
- Upgrading emergency response vehicles and equipment
- Providing rescue training and Advanced Emergency Medical Technician qualification for fire fighters
- Upgrading the fire protection features of INEEL operational facilities through multiple fire and life safety line item construction projects.

LMITCO evaluated changes to NFPA 600, "Standard on Industrial Fire Brigades,"<sup>78</sup> that required incident response teams to be trained to higher levels of qualification. LMITCO defined the scope of the local TRA Incident Response Team to ensure that workers potentially lacking proficiency and skill were not placed in hazardous rescue situations. LMITCO then increased the training and equipment for the

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78. NFPA, "Standard on Industrial Fire Brigades," National Fire Protection Association.

professional fire fighters. The INEEL Fire Department was designated as the LMITCO primary rescue service. The effectiveness of these actions and LMITCO's management was demonstrated by the emergency response to the TRA-648 accident. Three workers near the building doors were rescued by first aid and CPR-trained coworkers before the professional fire fighters arrived, and two workers inside the building were rescued by professional fire fighters. The five workers rescued from inside TRA-648 were given effective first aid and medical treatment at the scene and efficiently transported to a regional medical facility according to the INEEL Emergency Plan. The LMITCO emergency response mitigated the severity of this accident by prompt, effective rescue actions.



Table 5-1. Safety Management Initiatives.

Oct. 94 ← → Mar. 95	Apr. 95 ← → Sept. 95	Oct. 95 ← → Mar. 96	Apr. 96 ← → Sept. 96	Oct. 96 ← → Mar. 97	Apr. 97 ← → Sept. 97	Oct. 97 ← → Mar. 98	Apr. 98 ← → Sept. 98	Oct. 98 ← →
<ul style="list-style-type: none"> <li>Consolidated MEL Operations: 5 S&amp;H operations into one cohesive organization</li> <li>Excellent safety demonstrated in High Level Liquid Waste Tank Farm Project</li> </ul>	<ul style="list-style-type: none"> <li>Repackaged and transported hazardous waste containers safely to ALU-Well successfully with no safety deficiencies</li> <li>Performed 51 A&amp;H&amp;S maintenance activities with no safety and health issues</li> <li>DOE-HQ EH Safety Management Evaluation found pervasive safety culture and O&amp;M program safety performance exemplary</li> <li>DOE-HQ evaluation identified evidence of strong safety culture and worker involvement</li> <li>Significant improvement noted in TMA work control documents</li> <li>Completed 5 year ESMH management plan</li> <li>VPP positive influence noted safety performance improved substantially</li> </ul>	<ul style="list-style-type: none"> <li>Good progress on VPP and reduction in safety cost index</li> <li>Independent Safety Review Team Established</li> </ul>	<ul style="list-style-type: none"> <li>Included enhanced construction safety management programs and procedures</li> <li>Aggressive programs developed to include culture change in S&amp;H programs</li> <li>TMA achieved cost effective implementation plan of the Nuclear Safety DOE index</li> </ul>	<ul style="list-style-type: none"> <li>W&amp;CF achieves reduction of liquid waste amount of schedule and without safety incidents</li> <li>Significant progress in E&amp;H process noted at G&amp;P</li> <li>Completed National Institute of Occupational Safety and Health decontamination review</li> <li>Noted improved safety performance and a reduction in accidents and near misses</li> <li>Continued improvement in TMA maintenance organization and predictive maintenance efforts</li> <li>Operation of site wide high voltage system with good worker safety</li> <li>Significant progress made in the identification of safety issues</li> </ul>	<ul style="list-style-type: none"> <li>Aggressive approach in ensuring that workers at levels were aware of the hazards associated with the P&amp;M&amp;C job sites</li> <li>Safety committees comprised of management, labor, and non-represented employees established to provide safety facility advice</li> <li>New OPA Fire Training Facility online</li> </ul>	<ul style="list-style-type: none"> <li>Implemented organization goals for environmental safety and health performance</li> <li>Reviewed management attention to the integration of safety activities</li> <li>Second celebration of Safety Week</li> </ul>	<ul style="list-style-type: none"> <li>IS&amp;MS Project Team formed</li> <li>ES&amp;H&amp;QA organized into one division with a VP reporting directly to LMITCO President</li> <li>Third celebration of Safety Week</li> <li>Union Behavioral Based Safety Accountability Tool</li> <li>IM&amp;C, Risk Management Vision and Policy Issues</li> <li>Line management involvement and work control self-assessment process established</li> </ul>	<ul style="list-style-type: none"> <li>Walk down all facilities</li> <li>VPP independent assessment: 7 of 11 VPP Units ready for Star Status</li> <li>Construction achieved 2 years without lost time accident</li> <li>66 of 201 Corrective Actions from Consolidated Responses completed</li> <li>All LMITCO personnel name worn on Conduct of Operations Operational Excellence O&amp;M VPP-Vibe</li> <li>Training requirements and lesson plans approved for work planners</li> <li>Training for fire and security personnel to work with Lib Flight helicopter services completed</li> <li>Knowledge and skill requirements for each ES&amp;H&amp;QA discipline developed</li> </ul>
<ul style="list-style-type: none"> <li>Participated in MEL O&amp;H council</li> <li>Negotiated contract incentive for safety severity index and VPP modules</li> <li>LMITCO commitment to achieve VPP Star Status</li> </ul>	<ul style="list-style-type: none"> <li>Instituted process improvements to site issues management O&amp;M program</li> <li>Fostered good working relationship with line workers</li> <li>Healed VPP confidence for entire DOE complex</li> </ul>	<ul style="list-style-type: none"> <li>Strong commitment to safety management by "walk around" at W&amp;CF</li> </ul>	<ul style="list-style-type: none"> <li>IM&amp;C Long Range Plan addressed safety performance to attract new missions</li> <li>Integrated site wide Safety Action Plan</li> <li>Safety goals for each organization established</li> <li>Individual ESMH Performance goals included in employee performance appraisals</li> <li>First celebration of Safety Week No. 1 online</li> </ul>	<ul style="list-style-type: none"> <li>Aggressive approach in ensuring that workers at levels were aware of the hazards associated with the P&amp;M&amp;C job sites</li> <li>Safety committees comprised of management, labor, and non-represented employees established to provide safety facility advice</li> <li>New OPA Fire Training Facility online</li> </ul>	<ul style="list-style-type: none"> <li>Job Requirements Checklist system developed in pair of E&amp;H organization</li> <li>VPP certification incorporated into subcontractor requirements</li> <li>Incorporated Systems Engineering principles and practices in Program and Project Management</li> <li>Completed VPP supervisor and manager training (Part II)</li> </ul>	<ul style="list-style-type: none"> <li>News, Communication and Problem Environment (NCOPE) implemented as a control while system to process safety concerns and deficiencies</li> <li>ISM classes incorporated into contact</li> <li>Second Safety Level Knowledge competition</li> <li>Established and worked subcontractor VPP Implementation Plan</li> </ul>	<ul style="list-style-type: none"> <li>Safety Expo conducted with community involvement</li> <li>Complete VPP supervisor and manager training (Part IV)</li> </ul>	<ul style="list-style-type: none"> <li>3-Phase Safety and Health approach implemented</li> <li>Accoladed IS&amp;MS</li> <li>Facility Excellence Program</li> <li>Third Safety Level Knowledge competition</li> <li>ISM System Implementation on schedule</li> <li>Site Maintenance Manual on schedule</li> <li>Completed VPP supervisor and manager training (Part V)</li> </ul>
<ul style="list-style-type: none"> <li>ES&amp;H&amp;QA site wide data base established</li> <li>LMITCO Self Assessment Program began</li> </ul>	<ul style="list-style-type: none"> <li>VPP initiative program office developed</li> <li>Completed MEL work sites into 11 VPP units</li> </ul>	<ul style="list-style-type: none"> <li>Started site wide Total Safety Culture Training</li> <li>Started VPP Supervisor and Manager training (Part I)</li> </ul>	<ul style="list-style-type: none"> <li>Enhanced Work Planning (EWP) plan completed at G&amp;P</li> <li>Safety and Health Business Program awarded the Health Promotion Business and Industry Award</li> </ul>	<ul style="list-style-type: none"> <li>Integrated detailed site wide safety requirements for subcontractors and subcontractor work packages</li> <li>Occupational Medical Program reviewed - C. Everett Koop National Award</li> <li>First Safety Level Knowledge competition</li> <li>Completed VPP supervisor and Manager training (Part I)</li> </ul>	<ul style="list-style-type: none"> <li>Job Requirements Checklist system developed in pair of E&amp;H organization</li> <li>VPP certification incorporated into subcontractor requirements</li> <li>Incorporated Systems Engineering principles and practices in Program and Project Management</li> <li>Completed VPP supervisor and manager training (Part II)</li> </ul>	<ul style="list-style-type: none"> <li>News, Communication and Problem Environment (NCOPE) implemented as a control while system to process safety concerns and deficiencies</li> <li>ISM classes incorporated into contact</li> <li>Second Safety Level Knowledge competition</li> <li>Established and worked subcontractor VPP Implementation Plan</li> </ul>	<ul style="list-style-type: none"> <li>Safety Expo conducted with community involvement</li> <li>Complete VPP supervisor and manager training (Part IV)</li> </ul>	<ul style="list-style-type: none"> <li>3-Phase Safety and Health approach implemented</li> <li>Accoladed IS&amp;MS</li> <li>Facility Excellence Program</li> <li>Third Safety Level Knowledge competition</li> <li>ISM System Implementation on schedule</li> <li>Site Maintenance Manual on schedule</li> <li>Completed VPP supervisor and manager training (Part V)</li> </ul>

Figure 5-1. Safety Management Initiatives

 Significant Safety Accomplishments

 LMITCO Management Involvement

 Safety Management Programs



## 6. CONCLUSIONS

After the TRA-648 CO<sub>2</sub> 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<sub>2</sub> discharge accident. In conjunction with this testing, to determine the specific mechanism that caused the CO<sub>2</sub> system to discharge without warning, a team of safety professionals knowledgeable in the applicable codes, standards, and requirements reviewed the design and installation of the TRA-648 CO<sub>2</sub> fire suppression system. As part of the Consolidated Response to the Investigation Report, this team also reviewed the design and installation process for the TRA-648 CO<sub>2</sub> fire suppression system and the planning, management, and execution of the electrical maintenance being performed the evening of the accident. This testing, analysis, and review activity developed additional information that is material to the determination of the causes of the TRA-648 CO<sub>2</sub> discharge accident and any conclusions drawn about the circumstances under which it occurred.

### 6.1 Discovery of the Specific Mechanism that Caused the CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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.

### 6.2 Review of Regulatory and Code Compliance

Independent experts who contributed to this Supplemental Response provided the following professional interpretations with regard to compliance with OSHA regulations and NFPA codes and standards.

- Lockout/tagout of the CO<sub>2</sub> system to perform the electrical maintenance work in progress at the time of the accident was not required by DOE orders, NFPA standards, or OSHA regulations. The provisions of 29 CFR 1910, Subpart J did not require lockout/tagout of the TRA-648 CO<sub>2</sub> fire suppression system for the electrical maintenance being performed on July 28, 1998, because no maintenance activities were being performed on the CO<sub>2</sub> fire suppression system. Furthermore, NFPA 12 (1993) did not require lockout because the people in the protected area were familiar with the system and its operation.
- Emergency egress paths met the requirements of applicable codes and standards. The layout of TRA-648 provided adequate aisleways and routes of exit. The positioning of work equipment (e.g., light stands and racked out breakers) on the evening of the accident was

such that the egress paths were clear. Thus, LMITCO met the DOE, OSHA, and NFPA requirements regarding maintenance of adequate and clear egress pathways. Furthermore, the emergency exit doors met the applicable OSHA and NFPA requirements.

- The emergency lighting provided in TRA-648 met the OSHA and NFPA requirements for exit pathway lighting. The combination of temporary lighting and ambient daylight provided in the switchgear room on the evening of the accident met the requirements of 29 CFR 1910.303(h)(3)(ii) and 303(g)(1)(v) for adequate work area lighting, and had no impact on the occurrence or severity of the accident.
- The TRA-648 CO<sub>2</sub> fire suppression system was designed without an energy isolating device, as defined in 29 CFR 1910.147 for isolating the high pressure CO<sub>2</sub> supply. Therefore, there was no unlockable energy isolating device to replace with a lockable energy isolating device pursuant to 29 CFR 1910 Subpart J (29 CFR 1910.147(c)(2)(iii)) when the system was upgraded in 1997. Thus, the TRA-648 CO<sub>2</sub> fire suppression system design was compliant with 29 CFR 1910 Subpart J. The TRA-648 CO<sub>2</sub> fire suppression system design met both the explicit requirements of 29 CFR 1910 Subpart J and the implicit requirements of NFPA-12 (1993) with regard to the provision of lockout devices.
- Use of a pressure switch and feedback circuit in the system design was not required. The TRA-648 CO<sub>2</sub> fire suppression system design meets Sections 3-8.9.1 and 5-8.1 of NFPA 72 (1993) and the corresponding sections of NFPA 72 (1996) as installed without pressure switches. There was no control panel in the initial 1971 preliminary design and, therefore, no feedback loop from the pressure switch to the control panel. The elimination of the pressure switches in the designs after the 1971 preliminary design was simply a design evolution within standard requirements that resulted from the decision to employ a control panel in the 1971 design. The pneumatic time delay is not required by standard, nor is it required for operation of the system controls as installed in 1971 and 1997. Its presence is not a standard violation.
- Despite the FM approval and UL listing, the Notifier AFP-200 panel had a design defect that kept it from being compliant with NFPA 12 (1993) and NFPA 72 (1993). Neither LMITCO nor DOE-ID were aware of the design defect until it was identified through the analysis and testing performed after the CO<sub>2</sub> discharge accident.

### **6.3 Review of Investigation Report Statements and Issues**

The Investigation Report included information that could convey an incorrect perception of the hazards of CO<sub>2</sub> and the risks associated with its use as a fire suppression agent. Both OSHA and NIOSH documents state that the hazards of exposure to CO<sub>2</sub> are more severe than the data indicated in Figure 2-1 of the Investigation Report. The Investigation Report cited an EPA draft report as the basis for a statement that there have been a total of 63 deaths from accidents involving the discharge of CO<sub>2</sub> fire extinguishing systems since 1975. However, review of the data in the draft EPA report reveals that, aside from the TRA-648 accident, only one death occurred since 1975 that was associated with the use of CO<sub>2</sub> fire suppression systems in non-maritime applications in the United States and Canada. Furthermore, with the exception of the TRA-648 accident, the EPA report records no incidents from 1948 to the present, in which death or injury resulted from spurious actuation of a CO<sub>2</sub> fire suppression system that was caused by the loss of AC power.

The Investigation Report is critical of the design process employed for the 1997 upgrade of the TRA-648 CO<sub>2</sub> fire suppression system. The design process criticism in the Investigation Report is

generally presented as an inference from the failure of the LMITCO design of the CO<sub>2</sub> fire suppression system to comply with the Investigation Board's interpretations of OSHA regulations and NFPA standards regarding installation of lockout devices and a pressure switch and feedback circuit. As discussed previously, the review of code compliance by independent experts found that the LMITCO was compliant with OSHA requirements and NFPA 72 (1993) and acceptable under NFPA 12 (1993) with regard to installation of lockout devices and a pressure switch and feedback circuit. The review of the design process established that applicable requirements and procedures were followed throughout the design process in the areas of work scope determination, design review, procurement, quality assurance, and documentation.

The Investigation Report cited three practices employed to install the Notifier AFP-200 as installation errors. The review of the installation of the AFP-200 panel determined that two of these installation practices were in accordance with the manufacturer's document. The testing and analysis demonstrated that none of these design practices was related to the design defect that caused the CO<sub>2</sub> discharge accident. The review of the initial installation process for the Notifier AFP-200 revealed that the initial installation was performed by a factory trained and certified installer, who had NICET Level II qualification in fire alarms and over 20 years experience installing fire alarm systems. The design was also reviewed by his manager who has 20 years of fire alarm experience, NICET Level II certification, Journeyman Electrician license, and an associates degree in electronics. These individuals were NICET certified specifically for fire alarm systems, including design and installation.

The Investigation Report was critical of the qualifications of the personnel responsible for the design, the design reviews, and the installation of the 1997 upgrade of the TRA-648 CO<sub>2</sub> fire suppression system. The criticism of the qualifications of these personnel was generally presented as an inference from the failure of the LMITCO design of the CO<sub>2</sub> fire suppression system to comply with the Investigation Board's interpretations of OSHA regulations and NFPA standards regarding installation of lockout devices and a pressure switch and feedback circuit. As discussed previously, the review of code compliance by independent experts found that the LMITCO was compliant with OSHA requirements and NFPA 72 (1993) and acceptable under NFPA 12 (1993) with regard to installation of lockout devices and a pressure switch and feedback circuit. The review of the qualifications of the personnel responsible for the design, the design reviews, and the installation of the 1997 upgrade of the TRA-648 CO<sub>2</sub> fire suppression system found that they met or exceeded established qualification requirements.

The Investigation Report was also critical of the qualifications of the personnel responsible for planning, managing, and performing the electrical maintenance work being conducted in TRA-648 the evening of the accident. The criticism of the qualifications of these personnel is generally presented as an inference from the failure of LMITCO to comply with the Investigation Board's interpretations of OSHA regulations and NFPA Standards regarding lockout/tagout. As discussed previously, the review of code compliance by independent experts found that there were neither OSHA nor NFPA requirements to lockout the CO<sub>2</sub> fire suppression system for the electrical maintenance work being performed the evening of the accident. The review of the qualifications of the personnel responsible for planning, managing, and performing the electrical maintenance work found that they met or exceeded established qualification requirements. The review of the job demonstrated that they complied with the applicable maintenance control procedures. These included a formal written work order and outage form that were completed before work began.

## **6.4 Lessons Learned**

Testing and analysis revealed the precise nature of the design defect in the AFP-200 panel, and 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. This Supplemental Response is one more step in sharing information about, and the lessons learned from, the CO<sub>2</sub> discharge accident.

The lessons learned from the TRA-648 CO<sub>2</sub> discharge accident and the subsequent testing, analysis, and review suggest the following actions that DOE may wish to take to reduce the risk of similar accidents:

- Recommend provisions that specifically require manufacturers to inform purchasers of products and listing and approving organizations, such as UL and FM, of defects that render their products non-compliant with codes and standards.
- Pursue the possibility of obtaining statutory authority, similar to that afforded to the Nuclear Regulatory Commission under Section 5846 of Title 42 of the United States Code (42 USC 5846) to require reporting of defects.
- Develop design guidance for DOE contractors that describes appropriate measures to reduce the risks associated with common cause failures in microprocessor-based control systems.

## **6.5 Summary Conclusion**

The personnel who designed and installed the CO<sub>2</sub> system upgrades and who planned, managed, and performed the electrical maintenance work the evening of the accident made reasonable decisions and exercised appropriate professional judgment based on the information available to them at the time. They did not knowingly endanger, or fail to take appropriate steps to protect, themselves and their fellow workers.