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

1.0 INTRODUCTION

1.1 BACKGROUND

On July 28, 1998, thirteen workers were engaged in de-energizing electrical circuit breakers while preparing for preventive maintenance activity on the electrical system in Building 648 (Electrical Building) of the Engineering Test Reactor (ETR) Facility in the Test Reactor Area (TRA) of Idaho National Engineering and Environmental Laboratory (INEEL). At approximately 6:11 p.m., as the last 4160 volt circuit breaker was opened, the carbon dioxide (CO_2) fire suppression system discharged unexpectedly and without warning, instantaneously creating a lethal atmosphere with near zero visibility. The accident resulted in fatal injuries to a contractor electrician, injuries to 12 workers, and potential injuries to two others.

On July 28, 1998, one worker died and 14 others were injured or exposed to carbon dioxide when a fire suppression system discharged unexpectedly.

On July 29, 1998, Peter N. Brush, Acting Assistant Secretary for Environment, Safety and Health, U.S. Department of Energy (DOE), appointed a Type A Accident Investigation Board (referred to as "the Board") to investigate the accident in accordance with DOE Order 225.1A, *Accident Investigations* (see Appendix A).

1.2 FACILITY DESCRIPTION

INEEL is located on 890 square miles of desert in a rural, sparsely populated area of southeastern Idaho. INEEL is a multi-program laboratory whose mission is to integrate engineering and applied science to solve problems relating to environmental management, waste disposition, nuclear technology and application, and national security.

The accident occurred in Building 648 of the Engineering Test Reactor Facility in the Test Reactor Area at Idaho National Engineering and Environmental Laboratory.

The TRA (see Exhibit 1-1) contains an operating test reactor, four inactive research reactors, reactor fuel storage areas, laboratories, and area and site support systems. The ETR Facility consists of a

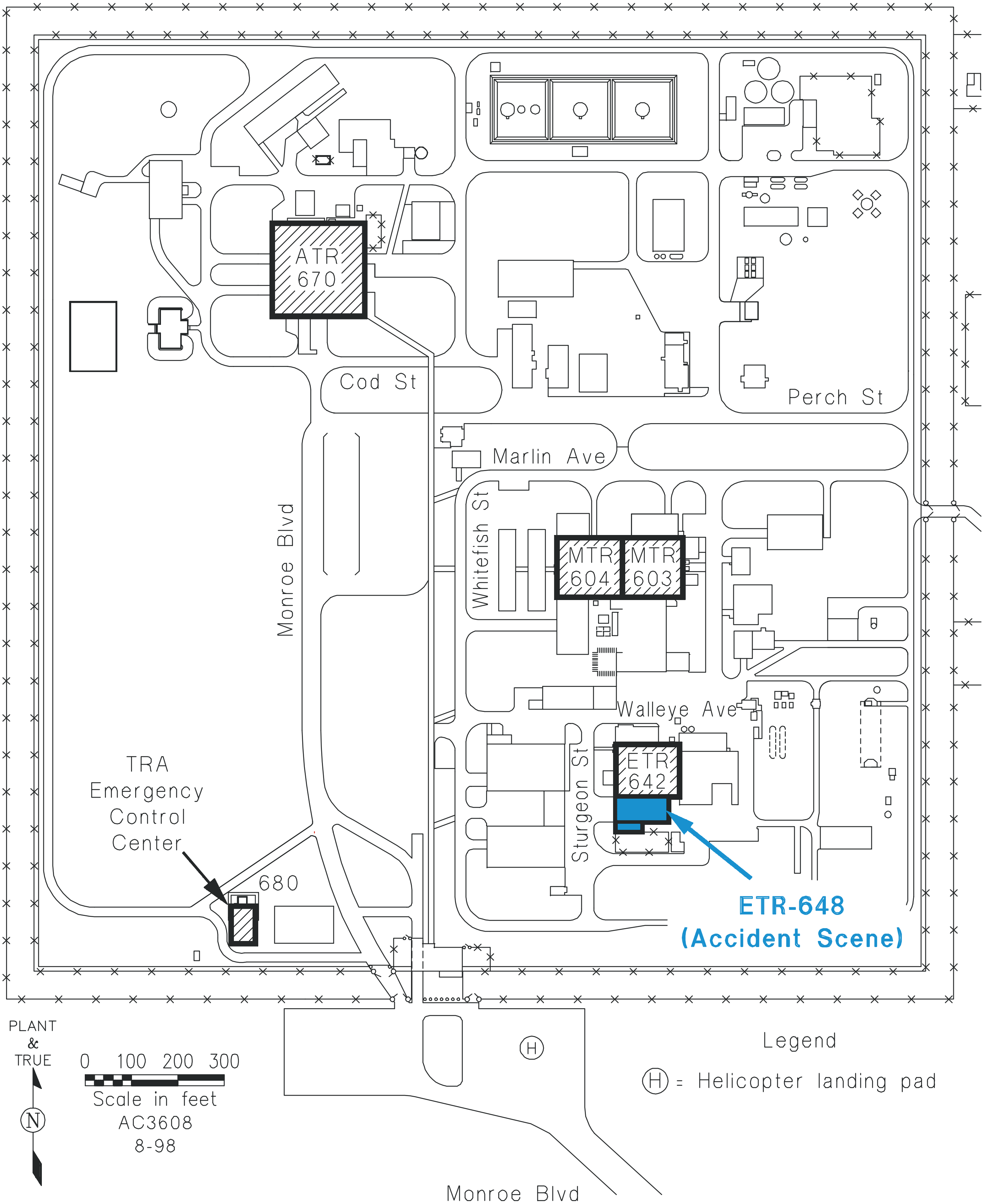

Exhibit 1-1. Site Plan for Test Reactor Area

number of separate buildings that, until it was inactivated in 1982, directly supported the ETR reactor and experimental operations. Building 648 houses electrical equipment for the TRA complex and ETR Facility. It is a two-level structure consisting of the ground-level floor and a basement level that contains electrical cable trays. The accident occurred on the ground level of the building, which contains switchgear, control panels, and power systems.

The electrical components are protected from fire by a CO_2 fire suppression system. When the system is activated, CO_2 is discharged from numerous nozzles in the ceiling of the ground-level floor. The release of CO_2 is controlled by two electronic control heads located in a storage building adjacent to Building 648. Fifty-five 100-pound bottles of CO_2 are also located in the storage building.

The fire suppression system was installed to protect the electrical components housed in Building 648.

Contractor activities at INEEL are managed by the DOE Idaho Operations Office (ID). The facility in which the accident occurred is under the cognizance of the Office of Nuclear Energy, Science and Technology (NE). Lockheed Martin Idaho Technologies Company (LMITCO) is the management and operating contractor for INEEL and for the TRA Facility.

1.3 SCOPE, PURPOSE, AND METHODOLOGY

The Board began its investigation on July 29, 1998, completed the investigation on August 28, 1998, and submitted its report to the Acting Assistant Secretary for Environment, Safety and Health on August 31, 1998.

The Type A accident investigation began on July 29, 1998.

The **scope** of the Board's investigation was to review and analyze the circumstances of the accident to determine its causes. The Board also evaluated the adequacy of safety management systems and work control practices of ID and LMITCO, as they relate to the accident.

The **purposes** of this investigation were to determine the causes of the accident, and to assist DOE in understanding lessons learned to improve safety and reduce the potential for similar accidents at INEEL and across the complex.

The investigation determined the causes of the accident and developed judgments of need to prevent recurrence.

The Board conducted its investigation using the following **methodology:**

Inspecting and photographing the accident scene

- Gathering facts through interviews, document and evidence reviews, and performance testing. The Investigation Board requested and participated in several performance tests:

    - Reenacting the electrical preventive maintenance steps that preceded the CO_2 system discharge, particularly the opening of the eight 4160 volt breakers. The objective was to determine the source of the activation signal to the CO_2 solenoid valves (with the CO_2 system physically disconnected).
    - Examining the manual operation of the chain opener for the Emergency Control Center, where electrical power was not available to open the door and procure the Incident Response Team van and self-contained breathing apparatus.
    - Recommending additional performance testing to further isolate facts regarding CO_2 system activation:

        - The removal of the 25-second mechanical delay from the CO_2 system header and bench testing to verify the length of the time delay. This test is pending.
        - Forensic testing of the CO_2 activation system (equipment and installation). This testing is still in progress.
- Reviewing the emergency and medical response.
- Analyzing facts and identifying causal factors[2] through events and causal factors charting and analysis,[3] barrier analysis,[4] and

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[2] A causal factor is an event or condition in the accident sequence that contributes to the unwanted result. There are three types of causal factors: **direct cause,** which is the immediate event(s) or condition(s) that caused the accident; **root cause(s),** which is (are) the causal factor(s) that, if corrected, would prevent recurrence of the accident; and **contributing cause(s)**, which are causal factors that collectively with other causes increase the likelihood of an accident, but that individually did not cause the accident.

[3] Events and Causal Factors Analysis includes charting, which depicts the logical sequence of events and conditions (causal factors) that allowed the event to occur and the use of deductive reasoning to determine events or conditions that contributed to the accident.

[4] Barrier analysis reviews hazards, the targets (people or objects) of the hazards, and the controls or barriers that management systems put in place to separate the hazards from the targets. Barriers may be administrative, physical, or supervisory/management.

change analysis[5] to correlate and analyze facts and identify the accident's causes.

- Developing judgments of need for corrective actions to prevent recurrence, based on analysis of the information gathered.

2.0 THE ACCIDENT

2.1 RISKS ASSOCIATED WITH CARBON DIOXIDE

The percentage of CO_2 in the building 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. At 50 percent CO_2, the oxygen levels within the building would be approximately 10.5 percent, well below that needed to sustain life. This atmosphere can result in symptoms of nausea; vomiting; near-complete impairment; unconsciousness followed by death and spasmodic breathing; convulsive movements; and death in

The fire suppression system discharged a significant amount of carbon dioxide for fire protection, reducing the amount of oxygen to a life-threatening level.

Facts about Risks Associated with Using Carbon Dioxide as an Extinguishing Agent

- The use of CO_2 is limited primarily by the factors influencing method of application and its intrinsic health hazards.
- At the minimum design concentration (30 percent) for its use as a total flooding fire suppressant, CO_2 is lethal.
- The risk involved with the use of CO_2 systems is based on the fact that the level of CO_2 needed to extinguish fires is many times greater than the lethal concentration.
- Because consequences of exposure happen quickly and without warning, there is little margin for error.
- Although the risk associated with the use of CO_2 for fire protection may be fairly well understood by regulators, standard-setting bodies, and insurers, the risk of CO_2 may not be well understood by maintenance workers who perform maintenance on or around CO_2 systems.
- Since 1975, there have been a total of 63 deaths and 89 injuries resulting from accidents involving the discharge of CO_2 fire extinguishing systems.
- The purpose of a pre-discharge alarm prescribed by the National Fire Protection Association and the Occupational Safety and Health Administration is to allow occupants time to evacuate from an area into which CO_2 will be discharged.
- Evacuation is particularly difficult once discharge begins, because of reduced visibility, the loud noise of discharge, and the disorientation resulting from physiological effects.

Source: *Carbon Dioxide as a Fire Suppressant: Examining the Risks* (Draft)
U.S. Environmental Protection Agency
August 1998

[5] Change analysis is a systematic approach that examines failures in barriers and controls that result from planned or unplanned changes in a system.

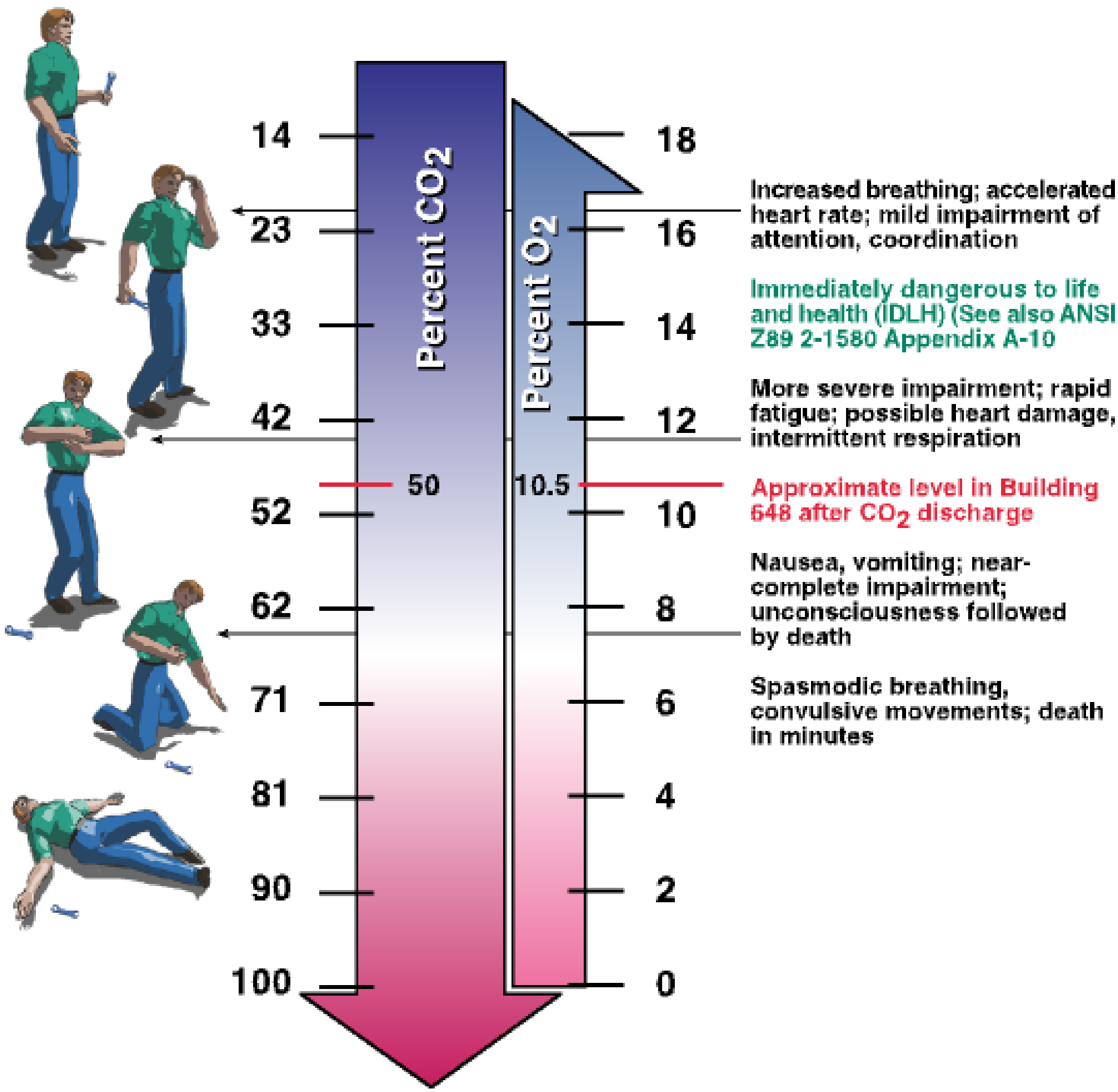


Figure 2-1. Physiological Effects of CO_2 Exposure

minutes. The personnel in the building during the accident experienced vomiting, impairment of actions, spasmodic breathing seizures, and unconsciousness, and their attempts to escape were hindered by the disorienting physiological effects of CO_2.

2.2 ACCIDENT DESCRIPTION AND CHRONOLOGY

Overview. The accident occurred at approximately 6:11 p.m. on Tuesday July 28, 1998, in Building 648 (Electrical Building) of the ETR Facility in the TRA at INEEL. The layout of the building in which the accident occurred, including a schematic of the area depicting the location of injured workers is depicted in Exhibit 2-1. The designations for the workers indicated on the Exhibit (e.g., E-1) correspond to similar citations in the text that follows. At the time of the accident, 13 contractor workers (foremen, operators, electricians, and a fire protection engineer) were in the building.

The accident occurred at 6:11 p.m. on Tuesday, July 28, 1998.

Background. On the afternoon of Tuesday, July 28, 1998, individuals at the TRA were engaged in preparations for a preventive maintenance activity on the Building 648 electrical switchgear. This activity included removal of 4160 volt electrical circuit breakers, vacuuming out breaker cubicles, inspecting ground straps, lubricating racking mechanisms, and basic inspections of the switchgear. This preventive maintenance, which had been changed from a two-year to a four-year frequency, was last conducted in 1994.

Two noteworthy changes had occurred in Building 648 since circuit breaker preventive maintenance was last conducted. A new fire panel was installed as an upgrade to the TRA fire protection system. This new panel controlled the Building 648 high-pressure CO_2 fire suppression system as well as the dry pipe water sprinkler system. In the past, preventive maintenance on these breakers was performed without de-energizing all sections of the 13.8 kV and 4160 volt buses, but rather by de-energizing only sections of the buses as they were being worked on. The decision to de-energize all buses at once for the preventive maintenance in progress at the time of the accident was based on electrical safety considerations.

In support of preventive maintenance being performed on electrical switchgear, the decision was made to de-energize all electrical buses, including the power supply to the fire panel.

Work Planning and Preparation. Building 648 is no longer considered a reactor or process building. In the months prior to the accident, landlord and maintenance responsibility for this facility had been transitioned from Reactor Programs to Site Support Services. On the afternoon of July 28, 1998, the group

The work package and power outage request had been approved the previous day.

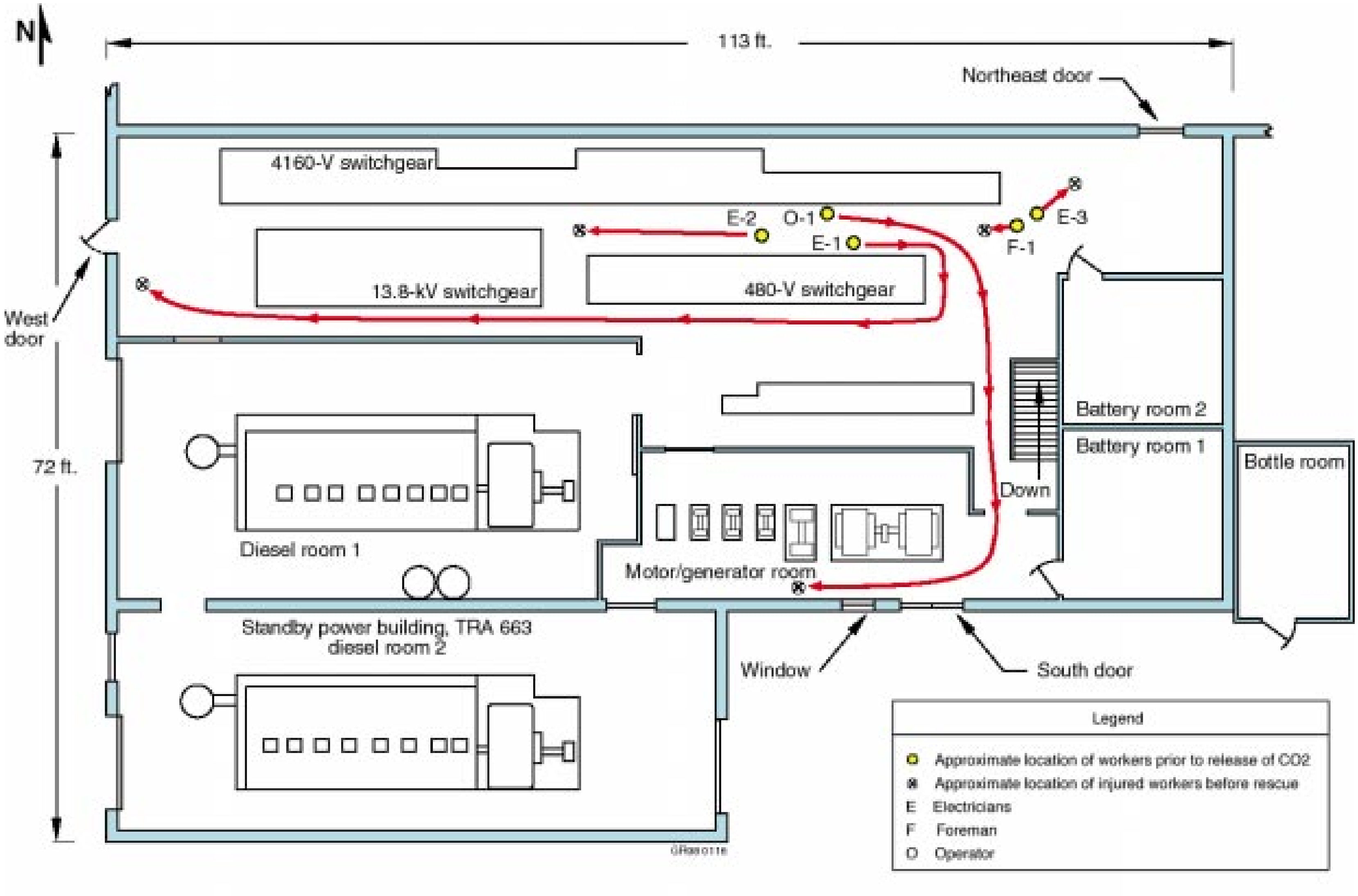


Exhibit 2-1. Building 648 Layout with Escape Routes of Five Injured Workers

designated to be involved in the work activity included a Site Support Services foreman, a TRA foreman, seven electricians from both TRA Operations and Site Support Services, two operators, a utilities operations supervisor, and a fire protection engineer. The work was scheduled after normal working hours to minimize disruptions caused by the loss of power that would occur in conjunction with this work. The power outage impacted several TRA buildings, including the TRA Emergency Control Center. The work package and outage request had been processed and approved on Monday, July 27, 1998.

At the pre-job briefing, a decision was made to disable the fire suppression system electronically, rather than by physical lockout.

At approximately 4:30 p.m., on July 28, 1998, everyone involved in the work met in Building 653 for a pre-job briefing. The scope and approach for the maintenance activity were discussed. The need to complete all work before midnight, due to the need to return the TRA deep well pumps to service, was also discussed. Three teams of two workers each were to be established to accomplish the work within the prescribed schedule. The CO_2 fire suppression system was discussed. It was decided to electronically impair the fire panel signal as a "safety barrier." Impairment, as defined in LMITCO procedures, means any planned or unplanned action that removes automatic protection systems or equipment from service. In this case, it meant disabling the system electronically at the control panel for the system, rather than physically locking out the system. Impairment is a maintenance mechanism for isolating a system; it is not related to personnel protection.

Safety Questions Are Raised. At the pre-job briefing, an operator questioned whether there was a need to remove the electric control heads from the CO_2 bottles to achieve physical isolation and lockout. He was assured that impairment of the alarm panel would preclude the CO_2 system from discharging for any reason during the maintenance activity. The crew broke for lunch at about 4:50 p.m. and agreed to reassemble at about 6:00 p.m. During the intervening period, the remaining requirements of the outage request were completed, and the CO_2 system was impaired.

The Work Begins. At 6:00 p.m. the crew went to Building 648 to begin work preparation. One group of electricians donned high voltage gloves to test the operability of the voltmeter that would be used later for zero voltage checks. This meter had to be tested on an energized position. In the first test attempt, a spare 4160 volt breaker was rolled out into the aisleway, but the meter configuration could not reach energized elements. The group moved to the east end of the 4160 volt bus, where they were able to verify meter operability at the TRA deep well pump breaker position.

About this time, the operators began to open 4160 volt breakers beginning at the west end of the bus and working east. Eight breakers were opened with approximately ten-second pauses between each opening. The total sequence took about one and one-half minutes. The two 13.8 kV breakers were to be opened and locked out next, which would remove all AC electrical power within the building.

The Accident Occurs. At approximately 6:10 p.m., the last breaker in the 4160 volt sequence was opened. The opening of the 4160 volt breakers had gradually eliminated normal building lighting. Lighting was now available from three portable light stands powered by portable generators. At this point, there were a total of 13 workers in Building 648, and a number of them were assembled at the east end of the 4160 volt switchgear.

The last circuit breaker was opened at approximately 6:10 p.m., eliminating normal building power; portable light stands provided lighting.

Within seconds after the opening of the last 4160 volt breaker, the CO_2 fire suppression system unexpectedly discharged and without warning created a lethal atmosphere deprived of oxygen with near zero visibility. Witnesses described hearing a hissing sound and then a “woosh,” followed by “total whiteout” conditions within seconds, in which they could not see anything at all. Most individuals instinctively ran toward the west door by which they entered and which was still open (because cables to the lights were run through it), allowing daylight to shine into the area. Transcribed interviews revealed that escape necessitated groping along switchgear and running into and around obstacles (see Exhibit 2-2). One individual (E-2) describes running into something (perhaps the rolled out 4160 volt breaker), falling down, and then passing out as he took a breath of CO_2.

Within seconds, the fire suppression system discharged, creating a lethal atmosphere and near-zero visibility.

One other individual (O-1) headed in a different direction, through the pump and motor generator room toward an exit door on the south side of the building (Exhibit 2-3). Unable to find the door in the whiteout conditions, he reached a window just past the door. In desperation, he put his hand through the thick glass window embedded with wire, sustaining severe arm lacerations and blood loss before losing consciousness (see Exhibit 2-4). Another individual (E-1) groped along switchgear, only to become entangled in an instrument cart and cable wires en route to the west door (Exhibit 2-5). He tripped, rolled, hit his head, and passed out inside the building.

In the next few minutes, eight workers escaped by groping along the switchgear and dodging obstacles. Five remained in the building.

By this time, eight individuals had escaped the potentially lethal CO_2 fog, and five unconscious individuals were still in the building. One was just south of the west door (E-1), one midway down the 4160 volt aisle (E-2), two at the east end of the 4160 volt bus (F-1 and E-3), and one in the pump and motor generator room on the south side of the building (O-1). (See Exhibit 2-1.)

Consequences of the Accident. A total of 15 personnel received medical treatment or evaluation as a result of the accident. One electrician was fatally injured, and several other workers sustained life-threatening injuries and CO_2 inhalation levels. Sections 2.3.3 and 2.3.4 provide details of the injuries sustained.

One worker died, and several others sustained life-threatening injuries and carbon dioxide inhalation levels.

DIRECT CAUSE

The direct cause of the accident was the inadvertent activation of electric control heads (possibly caused by an electrical transient) that initiated the unexpected release of CO_2 in an occupied space without a pre-discharge warning alarm.

Figure 2-2 summarizes the chronology of significant events leading up to and after the accident.

2.3 EMERGENCY RESPONSE AND MEDICAL EVALUATION

2.3.1 The Initial Emergency Response

Initial emergency response and rescue attempts were conducted by a combination of individuals who had escaped from the building, security police officers, and members of the ATR Incident Response Team. At 6:15 p.m., the Fire Protection Engineer from the work area radioed the alarm center in the INEEL Central Facilities Area approximately 4.6 miles from the TRA, and a fire truck and ambulance were dispatched.

An engineer from the work area called the alarm center at 6:15 p.m., and a fire truck and ambulance were dispatched.

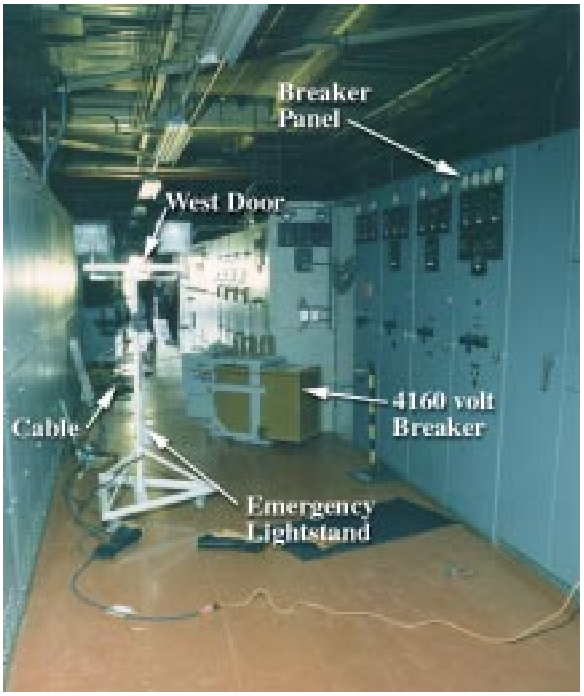


Exhibit 2-2. Switchgear Looking West Toward Exit Door

Exhibit 2-3. Motor Generator Room Near South Door

Exhibit 2-4. Broken Window, South Side

Exhibit 2-5. West Door

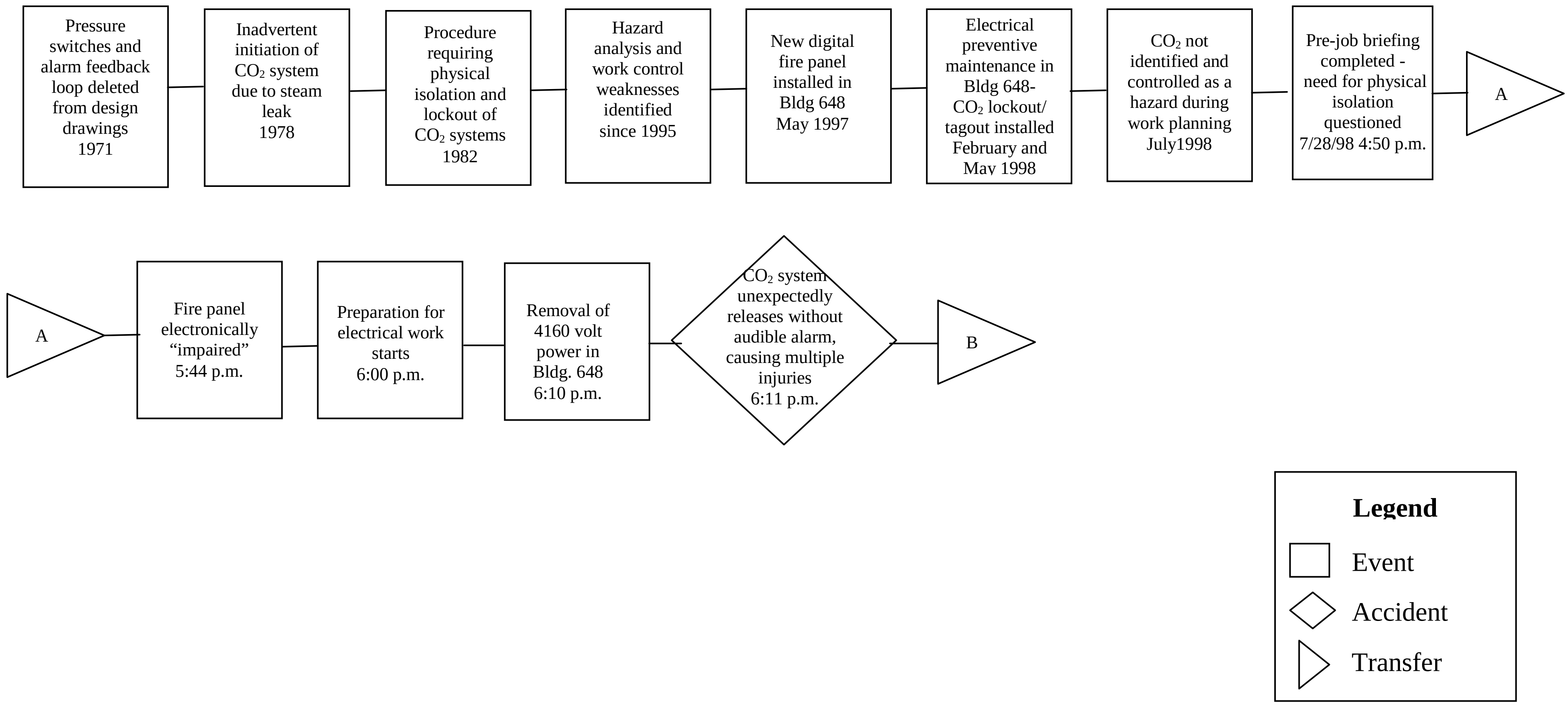
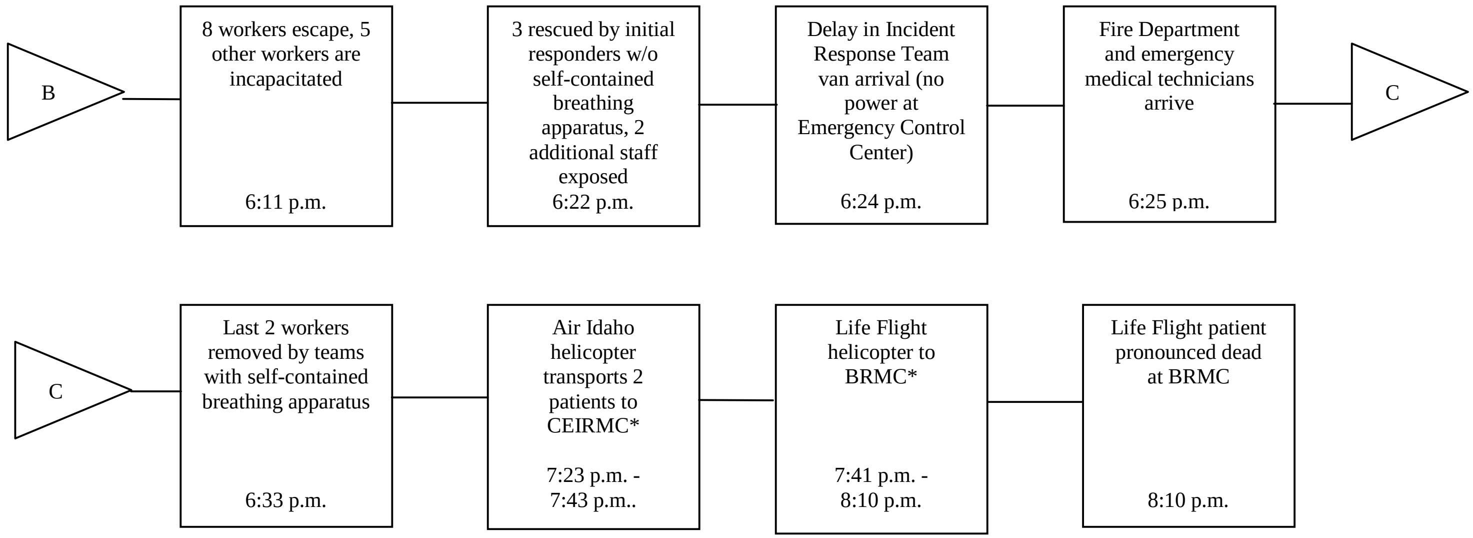


Figure 2-2. Summary Events Chart and Accident Chronology



*CEIRMC - Columbia Eastern Idaho Regional Medical Center (Idaho Falls)
BRMC - Bannock Regional Medical Center (Pocatello)

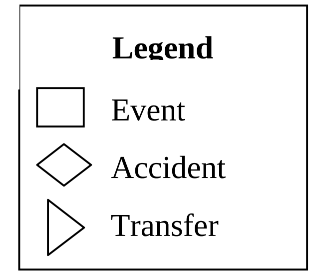


Figure 2-2. Summary Events Chart and Accident Chronology (Continued)

Between the call to Central Facilities Area and arrival of the Fire Department, initial responders proceeded to make repeated attempts to locate and rescue co-workers still trapped in the building. As rescuers gathered at the west door, the hand of an individual appeared out of the fog and rescuers pulled him to safety, as he collapsed in their arms. Rescuers searched for self-contained breathing apparatus[6] to facilitate safe search and rescue, but none were staged or available in the area. An operator was dispatched to the TRA Emergency Control Center to obtain the Incident Response Team van, which contained self-contained breathing apparatus. The power to the Emergency Control Center, however, had been shut off due to the preventive maintenance outage, and the diesel generator was disabled from automatic start. Thus, the garage door could not be opened electrically, and its manual chain opener was inoperable (see Exhibit 2-6). The diesel generator was started after approximately five minutes and the door opened electrically, but this caused a delay in getting self-contained breathing apparatus to the accident scene. Ultimately, the van arrived at Building 648 at 6:24 p.m. Additionally, eleven self-contained breathing apparatus in the Center's break room were not brought to the accident scene. The room used to store the apparatus was dark because of the power outage.

Self-contained breathing apparatus was not readily accessible to the initial responders.

Meanwhile, at the accident scene, two rescuers took a deep breath and went about 15 feet into the building to rescue an injured worker (E-2) who was purple and not breathing, and who went into seizures after rescue. Several attempts were necessary, without the benefit of self-contained breathing apparatus, to rescue another injured party (E-1) tangled up in an instrument cart, cables, and other materials near the west door (see Exhibit 2-5). Rescuers described the effects of the CO_2 as including dizziness, tunnel vision, and disorientation, as they attempted to pull injured parties out while trying to exit for air after short forays into the building.

Rescuers reached several of the unconscious workers, at a risk to their own lives.

[6] Self-contained breathing apparatus is any forced air breathing system that has its own air supply.

Exhibit 2-6. Emergency Control Center Door

Final rescue attempts reached the last two unconscious workers. One worker died en route to the hospital.

Attempting to ventilate the building, two individuals went to the south entrance and were able to jerk open the normally locked doors since the lock was broken. This attempt resulted in rescuing an additional worker lying under the window west of the doors (O-1); during an earlier attempt, he had been obscured by the dense CO_2 fog. Since he was not breathing, cardiopulmonary resuscitation (CPR) was initiated immediately. This was the same worker who had tried to escape by breaking though a glass window, and his severe arm injuries also required immediate medical attention. One individual also went through the ETR Building to reach the exit door in the northeast corner of the switchgear room and chained this door open for ventilation. Two other injured workers in this general area were probably not observed because of the fog and the absence of any temporary or emergency lighting in this corner. One was later rescued and revived (F-1), and the other died en route to the hospital (E-3).

2.3.2 Emergency Response

The text box summarizes the key events involved in emergency response to the accident. Emergency response was activated at 6:15 p.m. on July 28, 1998.

RESPONSE CHRONOLOGY

- **6:25 p.m. - Fire department and ambulance arrive and enter to extricate the last two workers in the building. This occurred within five minutes of arrival.**
- **One of the last two workers rescued (F-1) is successfully triaged with high flow oxygen.**
- **The second of the last two workers (E-3) retrieved is cyanotic (blue) and in full cardiac arrest:**

  - **Difficulty experienced in clearing airway (aspiration)**
  - **Some delay in administering oxygen, due to limited supply**
  - **CPR administered**
  - **Electrical defibrillation at 6:40 p.m. unsuccessful**
  - **Successful intubation is accomplished approximately 28 minutes after the initial CO_2 discharge.**

- **Alert classified at 7:05 p.m.**
- **7:01 p.m and 7:13 p.m. - Air Idaho Rescue and Life Flight helicopters arrive with emergency medical technicians (support also was provided from the INEEL on-call occupational medicine nurse).**
- **7:23 p.m. - 7:43 p.m. - Air Idaho helicopter transfers two patients (O-1 and F-1) to the Columbia Eastern Idaho Regional Medical Center in Idaho Falls.**
- **7:41 p.m. - 8:10 p.m. - Life Flight helicopter transports mortally injured worker (E-3) to the Brannock Regional Medical Center in Pocatello.**

  - **Pacemaker applied and CPR continued in flight**
  - **Pronounced dead at 8:10 p.m.**

- **9:41 p.m.- Eight workers with milder symptoms arrive by van at Columbia Eastern Idaho Regional Medical Center; examined and released.**
- **Two security police officers exposed to CO_2 drive themselves to Columbia Eastern Idaho Regional Medical Center.**
- **Emergency terminated at 12:37 a.m., July 29, 1998.**

2.3.3 Medical Treatment and Prognosis

A total of 15 personnel received medical treatment or evaluation. This includes three employees transported by helicopter, four employees transported by ambulance, six employees transported by van, and two security police officers who drove themselves to Columbia Eastern Idaho Regional Medical Center.

Thirteen workers and two security police officers received medical treatment or evaluation.

Of the 14 surviving employees, 11 were evaluated and treated in the Columbia Eastern Idaho Regional Medical Center Emergency Department and released. The three others were admitted. The operator (O-1) was comatose when admitted, and his respiration had to be supported by a ventilator. He had numerous deep lacerations on his right forearm and hand. A number of muscles and tendons, the radial artery, and the median nerve had been partially severed and were repaired surgically. By July 29, 1998, he was breathing on his own and was removed from the ventilator.

Within the next few days, he came out of the coma and gradually became more alert and oriented. He was able to carry on a conversation, but had a deficit of recent memory. This problem gradually improved. He was able to walk unsteadily, and his speech was somewhat slurred. He was discharged from the hospital on August 5, 1998, and was scheduled for outpatient therapy, including physical therapy, occupational therapy, and speech therapy.

Another injured party (E-2) was not breathing on arrival at the Emergency Department and had to be intubated and his breathing assisted mechanically. He had suffered lacerations his tongue, which he had apparently bitten during a seizure shortly after he was pulled from the building. By the next day, he was breathing on his own and alert. He was discharged on July 31, 1998, and returned to work on August 3, 1998.

The final surviving worker (E-1) who was hospitalized had hit the floor when he fell unconscious, bruising the left side of his head. In the Emergency Department, he was alert and breathing on his own, but was suffering from nausea and vomiting. He was given medication and experienced some sedation and a drop in blood pressure. For this reason, he was transferred to the Intensive Care Unit, but fully recovered by the next day. He was discharged on July 30, 1998, and returned to work on August 3, 1998.

2.3.4 Autopsy Findings and Cause of Death

An autopsy and toxicology screen of the fatally injured worker (E-3) were performed at the Bannock Regional Medical Center and reported by the Bannock County Coroner. The autopsy report was not provided to the Board. However, indications are that the cause of death was asphyxiation complicated by aspiration (inhalation of vomitus).

The injured worker died of asphyxiation.

2.3.5 Analysis

No evacuation warning alarm occurred prior to the unexpected CO_2 discharge. Escape from the area was significantly impeded by various pathway obstacles, low visibility, the disorienting effects of CO_2, the failure to designate emergency exit pathways, and inadequate exit path lighting, particularly in the northeast corner and in the pump and motor generator set rooms.

There was no warning alarm before the fire suppression system discharged, and workers' escape paths were impeded by obstacles, carbon dioxide fog, and poor visibility.

The initial rescue efforts by TRA site personnel—which were crucial, given the concentration and toxicity of the CO_2 atmosphere resulting from the discharge—were impeded by absence of readily available self-contained breathing apparatus. The unavailability of self-contained breathing apparatus resulted in multiple rescue attempts at significant personnel risk, placed the initial responders in the untenable position of having to decide to violate OSHA and LMITCO prohibitions against entry without self-contained breathing apparatus or delay search and rescue until the Fire Department arrived. These individuals elected to risk their own life and safety to rescue fellow workers. Their determination and heroic efforts contributed to three rescues and probably saved the lives of three workers. Had they not been successful, the loss of life might have been much greater and could have included rescuers. These same initial responders also contributed to life-saving activities, including CPR, first aid, and assistance to Fire Department and medical personnel.

The inaccessibility of self-contained breathing apparatus significantly increased the risk of initial rescue attempts.

LMITCO did not establish adequate means for immediate response to lethal levels of CO_2 exposures from an automatic or accidental discharge. and had not adequately considered the need to be prepared for escape from an accidental discharge or to accomplish immediate search and rescue. Prior to the discharge, planning was flawed, preparation inadequate, and equipment was not available to assure safe emergency egress, facilitate immediate search and rescue, or protect workers and initial responders. The decision to not provide electrical power to the TRA Emergency Control Center during the preventive maintenance outage delayed departure of the Incident Response Team van and arrival of the self-contained breathing apparatus at the accident scene. There was also a shortage of oxygen bottles causing delays in administering oxygen to at least one critically injured worker. Although it cannot be concluded that early administration of oxygen could have altered the outcome, its limited availability could have contributed to further fatalities or more serious injuries.

Flawed planning contributed to inadequate immediate search and rescue, workers' difficulty in escaping, and high risk initial rescue efforts.

Barriers designed to and means to facilitate immediate search and rescue were not in place or failed. These included the absence of physical barriers (evacuation warning alarm, personal protective equipment, clear entry/exit pathways, and evacuation lighting) and management barriers (effective immediate rescue and response planning and implementation). Injuries to the workers and immediate response rescuers directly resulted from the unavailability of self-contained breathing apparatus. The barrier failures that created or exacerbated the inability of workers to

Failure of physical and administrative barriers prolonged workers' exposure to the hazard.

escape, or of rescuers to rapidly enter/leave the area, contributed to the severity of the injuries received by the workers, because it prolonged their exposure to the hazard. While proper immediate response and evacuation planning would not have prevented the accidental release of CO_2, it would have mitigated the adverse impacts on workers.

RELATED CAUSAL FACTORS

Failure to identify, institutionalize, and implement requirements for immediate emergency rescue and response to planned and unplanned CO_2 discharges, was a contributing cause to insufficient immediate response and accident mitigation.

There were other contributing causes that impacted accident mitigation (i.e., failure to install a warning alarm and failure to adequately evaluate the impact of infrastructure reductions on worker safety). These causal factors are discussed in Sections 3.2 and 3.5 of the report, where more facts regarding them are presented. Section 4.0 discusses how they relate to the root causes of the accident, and Figure 4-2 depicts this relationship. See these sections for further discussion.

JUDGMENTS OF NEED

LMITCO needs to assure the ability to accomplish immediate rescue and response to planned and unplanned CO_2 discharges, including the capability to deal with mass casualties having insufficient oxygen.