Office of Environment, Safety and Health Oversight
Environment, Safety and Health

Type A Accident Investigation of the June 21, 2001

Drilling Rig Operator Injury at the Fermi National Accelerator Laboratory

August 2001

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OVERSIGHT

On June 25, 2000, I appointed a Type A Accident Investigation Board to investigate the June 21, 2001, Drilling Rig Operator injury at the FERMI National Accelerator Laboratory. The Board's responsibilities have been completed with respect to this investigation. The analysis, identification of contributing and root causes, and Judgments of Need reached during the investigation were performed in accordance with DOE Order 225.1A, *Accident Investigations.*

I accept the report of the Board and authorize release of this report for general distribution.

Steven V. Cary
Acting Assistant Secretary
Environment, Safety and Health

8/8/01
Date

This report is an independent product of the Type A Accident Investigation Board appointed by Steven V. Cary, Acting Assistant Secretary, Environment, Safety and Health, U.S. Department of Energy.

The Board was appointed to perform a Type A investigation of this accident and to prepare an investigation report in accordance with DOE Order 225.1A, *Accident Investigations.*

The discussion of facts, as determined by the Board, and the views expressed in the report do not assume and are not intended to establish the existence of any duty at law on the part of the U.S. Government, its employees or agents, contractors, their employees or agents, or subcontractors at any tier, or any other party.

This report neither determines nor implies liability.

Executive Summary

The Accident

On June 21, 2001, at approximately 9:40 A.M., a construction sub-tier contractor employee (the "Operator") at the Fermi National Accelerator Laboratory (Fermilab) received serious head injuries requiring hospitalization when he was struck by part of the drilling rig (a "tong") that he was operating. The equipment involved in the accident, known as a tong, was a 32-inch steel bar with a handle essentially used as a pipe wrench to connect and disconnect drill pipe. The accident occurred when a welded connection in the hydraulic system used to apply force to the tong failed, as the two-man crew was removing lower sections of the drill assembly. The drill rig Helper indicated that, at the time of weld failure, the Operator was standing with his head near the tong and operating the hydraulic cylinder to disconnect a drill section joint. Based on an analysis of the evidence, the Board concluded that the weld failure released tension on a wire rope sling attached to the tong; the tong recoiled toward the Operator and struck him in the head. Failure of the weld was determined to be the direct cause of the accident. The Operator remained hospitalized until July 9, 2001.

On June 25, 2001, the Acting Assistant Secretary for Environment, Safety and Health, U.S. Department of Energy (DOE), upon the recommendation of the DOE Chicago Operations Office, appointed a Type A Accident Investigation Board to analyze causal factors, identify root causes, and determine judgments of need to preclude similar accidents in the future. The Board arrived on site two days later and completed the investigation in July 2001.

Background

Fermilab is the nation's largest particle accelerator laboratory and lies 30 miles west of Chicago, Illinois. Fermilab operates under the programmatic direction of the DOE Headquarters' Office of Science. The DOE Fermi Area Office, under the DOE Chicago Operations Office, oversees site contractor activities. University Research Associates, Inc., a consortium of universities, manages and operates the site for DOE.

The injured Operator was an employee of the Layne-Western Company of Aurora, Illinois. The injury occurred at the Neutrinos at the Main Injector Project, whose construction includes tunnel boring and shaft drilling activities. Fermilab employed the S. A. Healy Company of Lombard, Illinois, to perform this underground construction work. S. A. Healy subcontracted with Layne-Western to drill six holes for air ventilation and survey risers. The Layne-Western crew was working on the fifth shaft at the time of the accident using a drilling rig that was manufactured in 1969.

On March 2, 1999, the drilling crew performed an "in-field" welding activity to repair a failure of the eyebolt-to-piston rod connection. The weld attached the eyebolt to the hydraulic cylinder piston rod that was used to apply force to the tong. Before the repair, the eyebolt apparently threaded directly into the end of the piston rod, and this threaded connection had evidently failed. At the time of the accident, one end of the wire rope sling was attached to the eyebolt by a shackle, and the other end was connected to the tong. The Board requested the record of this equipment modification, but Layne-Western could not produce it. The only documentation consisted of a brief entry in a daily drilling log, and the injured Operator, who had performed the weld repair in 1999, was the only person with first-hand knowledge of this work. The injured Operator declined to be interviewed by the Board.

Results and Analysis

The accident resulted from a number of deficiencies in the execution of specific activities and in the implementation of a series of management systems and related processes. These weaknesses involved all elements of the line organization, including the Office of Science, Chicago Operations Office, the Fermi Area Office, Fermilab, S.A. Healy, and Layne-Western.

In terms of weaknesses in executing specific activities, the injured Operator, who was not formally trained or qualified to make structural welds, performed a "field" weld repair to the eyebolt and piston rod connection in 1999. An independent engineering evaluation by an outside laboratory, performed at the request of the Board, indicated that the weld was of uncertain quality and likely failed due to either metal fatigue from repeated loading during equipment use or from unusually high stress at the time of failure. Evaluation also showed that three cracks in the end of the piston rod existed before the accident, and that makeshift weld repairs of these cracks had been attempted. These equipment modifications were not subject to an engineering review to determine whether the weld was equivalent in strength to the threaded connection it apparently replaced. In addition, the Operator stood with his head in close proximity to the tong while it was under tension from the hydraulic system. Widely available drilling industry guidance identifies this practice as unsafe. If a hazard analysis which addressed all job tasks and identified all controls had been performed, this unsafe work practice would have been recognized and the injury would have been prevented.

In terms of weaknesses in management systems and processes, the DOE Chicago Operations Office, the Fermi Area Office, and Fermilab did not effectively implement and ensure flowdown of the integrated safety management system framework to construction subcontractors and sub-tier contractors. These organizations did not use contracting, procurement, and project management mechanisms to consistently convey and enforce safety and health expectations to the construction subcontractor and sub-tier contractor. These weaknesses enabled key individuals to perform functions for which they were not qualified and allowed the construction workforce to perform activities without being held accountable for strict compliance with requirements.

Fermilab did not establish and implement processes to translate safety and health requirements into subcontractor procedures and did not tailor the existing systems for managing subcontractor construction safety to address sub-tier contractors. Controls were not established to assure that sub-tier contractors were adequately prepared to work safely before authorizing the start of work. These weaknesses enabled drilling to commence in September 2000 without formal authorization and resulted in neither Fermilab nor S.A. Healy enforcing contract requirements mandating development of a hazard analysis for drilling work.

The Fermi Area Office and Fermilab did not effectively communicate roles, responsibilities, and clear lines of authority to ensure the adequate protection of all workers, including construction subcontractors and sub-tier contractors. The Fermi Area Office conducted only two inspections at the drill site prior to the accident, focusing narrowly on environmental issues. Fermilab incorrectly believed that only S.A. Healy was required to review sub-tier contractor safety programs, and Fermilab neither conducted such reviews nor assured that S.A. Healy did. S.A. Healy did not require Layne-Western drilling personnel to conduct a hazard analysis and none was performed until June 2001.

The Fermi Area Office and Fermilab did not ensure that the construction subcontractor and sub-tier contractors had systems in place to train employees in hazard recognition and mitigation. Fermilab and S.A. Healy did not ensure that the Layne-Western personnel were adequately trained and qualified to perform work. Layne-Western personnel were not trained in the Fermilab hazard analysis process before starting work; did not participate in the June 9, 2001, safety stand-down training (which included hazards analysis training); and did not receive sitewide safety orientation.

The Fermilab hazard analysis system could not be effectively applied to task-specific hazards for construction subcontractors and sub-tier contractors. The Fermilab hazard analysis process did not provide clear guidance for evaluating task-specific hazards. The S.A. Healy hazards analysis process was not used; even if used, this process would not have resulted in an adequate hazards analysis because of its lack of specificity and rigor. Layne-Western did not provide a hazard analysis plan before commencing drilling operations, and the only hazards analysis that was conducted (June 2001) did not comprehensively address drilling hazards to which personnel were exposed. The Board identified this weakness (absence of task-specific hazards analysis) as the root cause of the accident and considered that an effective hazard analysis system would have identified and corrected the unsafe work practice concerning the Operator's location and could have drawn attention to the overall substandard condition of the drill rig and the related equipment.

During the investigation, the site provided construction injury rate data to the Board indicating that, for a 750-day period between August 1998 and September 2000, Fermilab experienced no lost-workday cases. However, the Board identified that a subcontractor pipe fitter dislocated his shoulder on November 11, 1998, which resulted in six lost workdays.

In addition, for six months during 1999, no fixed-price construction work was performed by subcontractors or sub-tier contractors, thus significantly lowering the possibility that lost workday cases would have been experienced.

Finally, the Fermi Area Office and Fermilab oversight programs did not identify fundamental weaknesses in construction subcontractor and sub-tier contractor safety and health programs. The Fermi Area Office and Fermilab did not adequately analyze prior construction occurrences to identify and correct root causes and systemic weaknesses underlying these events. Causal factors present in the two personnel injury events that led to project safety stand-downs in June 2001 were also contributors to the drilling rig accident, as were causal factors identified by two Type B accident investigations in 1997 and 1998. Recurring deficiencies from prior occurrence reports involving worker injuries at the construction site indicated that weaknesses persisted in work planning, hazard analysis, and work controls. Fermilab had not conducted a safety inspection of the Layne-Western equipment upon arrival at the Fermilab site. Work site safety inspections were not rigorous, formal, or documented. After the accident, the Board identified numerous safety deficiencies at the job site, including some potential imminent-danger situations, none of which had been identified by line management or oversight personnel.

Conclusions

The Accident Investigation Board concluded that this accident was preventable. The Board identified significant weaknesses in the site's implementation of integrated safety management policy as it related to the sub-tier contractor performing drilling activities. Weaknesses in translating safety and health requirements into operating procedures, implementing hazard analysis processes and associated controls, authorizing work, personnel training, and performing line oversight impacted the effectiveness of construction worker safety and health protection.

Fermilab did not ensure that the drilling sub-tier contractor met basic requirements imposed by the Department, the site, and the U.S. Occupational Safety and Health Administration. Although Fermilab experienced a series of construction safety events with similar systemic causes prior to the accident and instituted two safety stand-downs in the weeks before the event, a lack of rigorous causal analysis prevented identification of lessons learned and systemic weaknesses, and implementation of effective corrective actions. The hazard analysis program in place at the time of the accident had not evaluated specific hazards associated with the drilling operation, Fermilab had not enforced the requirement for preparing such a task-specific hazard analysis, and line oversight of the drilling operation had not identified the absence of such a hazard analysis.

The DOE Chicago Operations Office, the Fermi Area Office, and Fermilab need to intensify their efforts and commitment to ensure that all the elements associated with integrated safety management are promptly and effectively addressed for all construction subcontractors and sub-tier contractors to prevent additional accidents at the Neutrinos at the Main Injector Project and at other Fermilab construction sites.

Table ES-1. Causal Factors and Judgments of Need

Causal Factors	Judgments of Need
Fermilab failed to implement a hazard analysis process that was effectively applied to task-specific hazards for construction subcontractors and sub-tier contractors.	Fermilab needs to improve the existing hazards analysis process in Fermilab Environment, Safety and Health Manual 7010 by developing instructions and guidance to ensure that it applies to sub-tier construction contractors at the work activity level. Fermilab needs to implement a revised hazards analysis process such that: • Detailed procedures are established to formalize the process for conducting task-level job-specific hazard analyses (job hazard analyses). • Personnel are trained on the task-level hazard analysis processes to ensure implementation by all assigned persons. • The process is revised to ensure that all work operations at Fermilab are subjected to formal and effective hazard analyses. This would include all potentially hazardous operations planned for subcontractors and sub-tier contractors. • The process is revised to ensure that hazard analyses involve both the appropriate technical expertise and workers, and receive appropriate review and approval before work begins.
The Fermi Area Office and Fermilab failed to adequately analyze prior occurrences to identify and correct root causes and systemic weaknesses underlying these events.	Fermilab needs to ensure that root and contributing cause(s) from incidents and occurrences are thoroughly evaluated against integrated safety management core functions and guiding principles, and that resulting lessons learned are disseminated and communicated to all appropriate personnel. Additionally, Fermilab needs to conduct follow-up reviews to ensure that the information is used to improve the level of safety at the site. Fermilab needs to ensure that incidents and occurrences at Fermilab are reported through the appropriate DOE reporting systems (i.e., the Computerized Accident/Incident Reporting System and the Occurrence Reporting and Processing System), evaluated, analyzed, and trended to ensure that systemic weaknesses are identified and corrected in a timely manner. The Fermi Area Office needs to revise its process for validating closure and effectiveness of corrective actions. Additionally, FAO needs to conduct follow-up reviews to ensure that corrective actions are effectively implemented.

Table ES-1. Causal Factors and Judgments of Need (Continued)

Causal Factors	Judgments of Need
	The Chicago Operations Office Manager needs to develop and implement a process to provide assurance that effective corrective actions are implemented, and establish a method to obtain feedback on corrective actions taken.
Fermilab failed to establish and implement processes to translate safety and health requirements into subcontractor procedures. Fermilab did not establish controls to assure that sub-tier contractors were adequately prepared to work safely before authorizing the start of work. Fermilab failed to tailor the system for managing subcontractor construction safety to address sub-tier contractors.	Fermilab needs to establish and implement a process to ensure that all safety and health requirements flow down to subcontractors and sub-tier contractors such that: • Procedures are adopted by subcontractors and sub-tier contractors that are tailored for the specific roles and responsibilities for each contracting organization. • Specific procedures are validated to ensure that safety and health requirements are properly implemented. • Improved controls are established to assure that subcontractors and sub-tier contractors are adequately prepared to work safely before authorization to start work is issued. The FAO needs to ensure that Fermilab establishes and implements processes to verify and validate that safety and health requirements are translated into subcontractor and sub-tier contractor procedures. The Chicago Operations Office Manager needs to validate the processes and procedures used by FAO and Fermilab to verify that work controls are established and implemented before the start of work.
DOE and Fermilab oversight programs failed to identify fundamental weaknesses in construction subcontractor and sub-tier contractor safety and health programs.	Fermilab needs to ensure that a program is established and implemented for comprehensive environment, safety, and health oversight of all construction subcontractor and sub-tier contractor work operations. The FAO needs to ensure that oversight of Fermilab is effectively performed as specified in DOE Policy 450.5, *Line Environment, Safety and Health Oversight*. The Chicago Operations Office Manager needs to ensure that line management and independent oversight are being performed and are effective as specified by DOE Policy 450.5, *Line Environment, Safety and Health Oversight*, and DOE Order 414.1A, *Quality Assurance*. The Office of Science needs to ensure that formal corrective actions are developed and implemented for ES&H issues resulting from programmatic and technical reviews of the NuMI Project.

Table ES-1. Causal Factors and Judgments of Need (Continued)

Causal Factors	Judgments of Need
	The Office of Science needs to implement the requirements established in the Office of Science Functions, Responsibilities, and Authorities Manual for measuring line ES&H oversight effectiveness of the Chicago Operations Office.
Fermilab failed to effectively communicate roles, responsibilities, and clear lines of authority to ensure adequate protection of all workers, including construction subcontractors and sub-tier contractors.	Fermilab needs to establish and implement a formalized safety management system with clearly defined roles, responsibilities, and authorities when multiple organizations, subcontractors, and/or sub-tier contractors are involved in a construction project.
Fermilab failed to ensure that the construction subcontractor and sub-tier contractors had systems in place to train employees in recognition and mitigation of operational hazards.	Fermilab needs to strengthen the training and competence of all workers, managers, engineers, and safety professionals responsible for construction safety. Fermilab needs to establish processes to assure that hazard recognition and training are in compliance with applicable requirements (Occupational Safety and Health, DOE, and industry standards).
Chicago Operations Office and Fermilab failed to effectively utilize contracting, procurement, and project management mechanisms to consistently convey, oversee, and enforce safety and health expectations to the subcontractor and sub-tier contractors.	The Chicago Operations Office and Fermilab need to revise contracting, procurement, and project management processes to ensure that safety and health requirements associated with construction operations (by subcontractor and sub-tier contractors) are clearly conveyed.
Chicago Operations Office and Fermilab failed to properly implement and ensure the flowdown of the integrated safety management framework to subcontractors and sub-tier contractors.	Fermilab needs to strengthen implementation of the integrated safety management core functions to assure that all potentially hazardous work and operations are subjected to effective, formal, and documented hazard analysis. Fermilab needs to establish and implement a process to ensure that the framework of ISM flows down to all subcontractor and sub-tier contractors. The Chicago Operations Office Manager needs to ensure that the Fermilab process for flowdown of the ISM framework to subcontractors and sub-tier contractors is effective.

1.0 Introduction

1.1 Background

On June 21, 2001, at approximately 9:40 A.M., a construction subcontractor employee (referred to as the Operator) operating a drilling rig at the Fermi National Accelerator Laboratory (Fermilab) received serious head injuries that required hospitalization when he was struck by part of the drilling rig.

On June 25, 2001, the Acting Assistant Secretary for Environment, Safety and Health, U.S. Department of Energy (DOE), upon the recommendation of the DOE Chicago Operations Office, appointed a Type A Accident Investigation Board to investigate this accident in accordance with DOE Order 225.1A, *Accident Investigations.* A copy of the appointment memorandum appears in Appendix A.

1.2 Facility Description

Fermilab occupies approximately 6,800 acres of DOE property 30 miles west of Chicago, Illinois. Fermilab was established in 1968 by the U. S. Atomic Energy Commission. The site includes over 300 buildings, such as laboratories, shops, and assembly bays, along with particle accelerators and detector enclosures.

As the largest particle physics laboratory in the United States, Fermilab operates particle accelerators used in investigating the fundamental properties of matter, space, and time. Fermilab's other operations include superconducting magnet research, design, and development; detector development and operation; and high performance computing and networking. Some 2,500 physicists from around the world utilize Fermilab facilities for their research. Fermilab is open to the public and a typical day will find university students visiting the site.

Fermilab operates under the programmatic direction of the DOE Office of Science. The DOE Fermi Area Office (FAO) of the DOE Chicago Operations Office manages the site contractor operations. Universities Research Association, Inc., a consortium of universities, is the site contractor that manages and operates Fermilab for DOE. A Board of Trustees maintains fiduciary responsibility for the corporation.

Figure 1-1 displays the organizational relationships between Fermilab and the Neutrinos at the Main Injector (NuMI) construction project, where the accident occurred. (This organizational chart was provided to the Board by Fermilab during the in-briefing meeting on June 27, 2001.) The NuMI Project included excavating a series of tunnels and experimental halls beneath the Fermilab site, operations known as the NuMI Tunnels and Halls Project. The NuMI Project will support advanced physics experiments utilizing a neutrino beam that would enter a detector at Fermilab and pass through the earth to another detector located in northern Minnesota.

The lead subcontractor for the NuMI Tunnels and Halls Project was the S. A. Healy Company of Lombard, Illinois, a tunneling and heavy construction contractor. Layne-Western, a division of the Layne Christensen Company of Mission Woods, Kansas, a well drilling company and a S. A. Healy subcontractor, provided services for drilling exhaust air ventilation (EAV) and survey riser shafts from the surface to the underground tunnel. The injured Operator was a Layne-Western employee.

Early in the NuMI Project, Fermilab identified the need to augment its staff with persons having underground construction experience. In October 1999, Fermilab contracted with Harza Engineering to provide three individuals with underground construction experience to serve as construction coordinators. Under this contract, Harza employees would be supervised by Fermilab and would monitor, but not manage, S. A. Healy; nonetheless, they were assigned to direct certain aspects of the work. Fermilab subsequently increased the number of Harza construction coordinators to four. Harza also provided a safety consultant to conduct safety audits.

The NuMI Project Management Plan specified that construction work would be performed in compliance with standards contained in the Fermilab Environment, Safety, and Health (ES&H) Manual (FESHM) and all applicable ES&H standards in

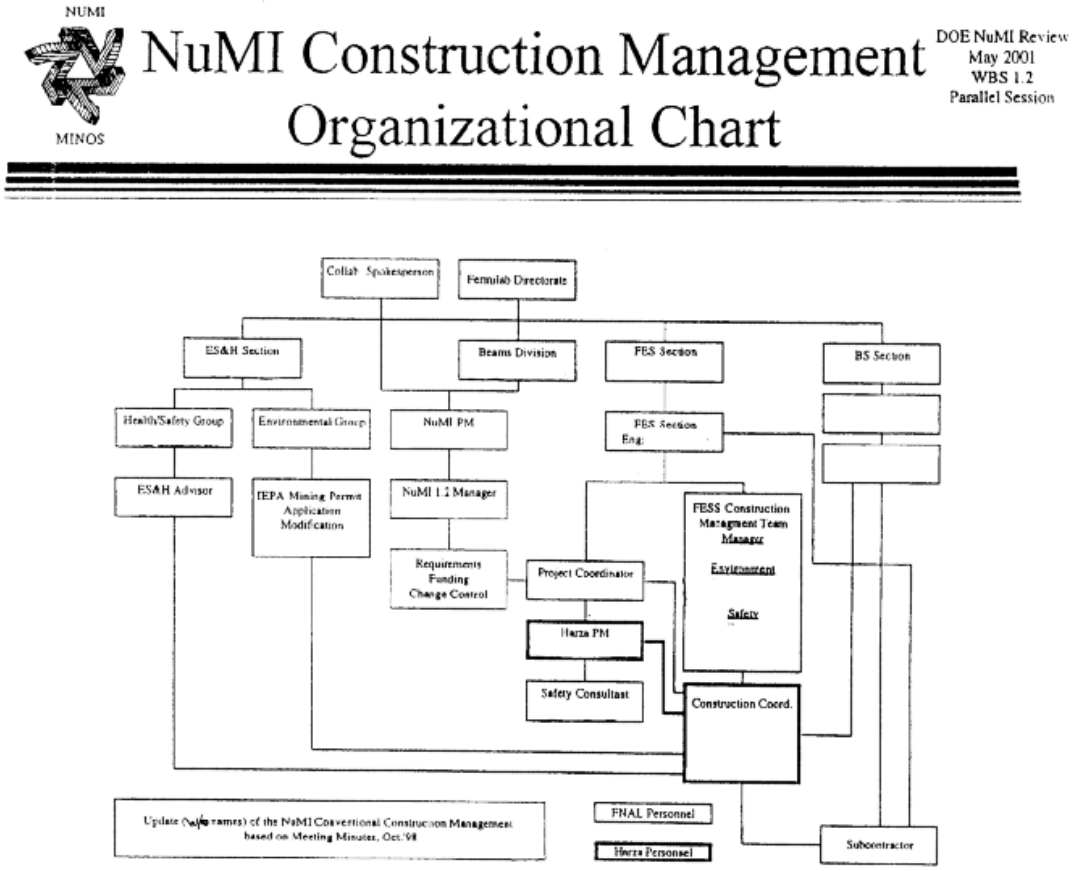


Figure 1-1. Organizational Chart Related to the NuMI Project

the laboratory's work smart standards. In addition, all related work was to be performed in compliance with applicable Federal, state, and local regulations. In October 1999, the DOE Chicago Operations Office verified that Fermilab had implemented the DOE integrated safety management (ISM) system, and that ISM policies were reflected in the site ES&H Manual.

1.3 Scope, Purpose, and Methodology

The Type A Accident Investigation Board began its onsite investigation on June 27, 2001; completed the onsite phase of its investigation on July 20, 2001; and submitted its report to the Assistant Secretary for Environment, Safety and Health. The scope of the Board's investigation was to review and analyze the circumstances of the accident to determine its causes in accordance with DOE Order 225.1A. The purposes of this investigation were to analyze causal factors, identify root causes and determine judgments of need to prevent recurrence of similar accidents at Fermilab and across the DOE complex.

The Board conducted its investigation using the following methodology:

- Inspecting and photographing the accident scene and individual items of evidence related to the accident
- Performing a limited engineering evaluation of the failed components
- Gathering facts through interviews, document and evidence reviews, and walk-downs of the area
- Reviewing emergency and medical response operations
- Analyzing facts and identifying causal factors through events and causal factors charting and analysis, barrier analysis, and change analysis
- Developing judgments of need for corrective actions to prevent recurrence based on analysis of the information gathered.

Accident Investigation Terminology

A **causal factor** is an event or condition in the accident sequence that produces or contributes to the occurrence of the accident. There are three types of causal factors:

(1) *Direct cause*, the immediate event(s) or condition(s) that caused the accident
(2) *Root cause(s)*, the causal factor(s) that, if corrected, would prevent recurrence of the same accident or similar accidents
(3) *Contributing causes*, factors that collectively with other causes increase the likelihood of an accident, but that individually did not cause the accident.

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.

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 physical, such as equipment design or protective clothing, or elements of management, such as training and supervision.

Change analysis is a systematic approach that examines planned or unplanned changes in a system that caused undesirable results related to the accident.

2.0 The Accident

2.1 Background and Accident Description

2.1.1 Accident Overview

On the morning of June 21, 2001, two Layne-Western employees, the drill rig Operator and a Helper, were conducting drilling operations at Fermilab. The accident occurred at approximately 9:40 A.M., as the drill crew was attempting to disconnect drill pipe sections. An equipment failure occurred during disconnecting (breaking) drill pipe sections as they were being removed from the shaft. A hydraulic system (hydraulic ram, piston rod, wire rope sling, shackle, and eyebolt) was being used to apply force to a tong, effectively a large pipe wrench, when the equipment failed. The threaded eyebolt, which served as the point of connection to the piston rod, disengaged, releasing the hydraulic force and resulting in an instantaneous release of energy stored within the drill pipe. The unrestrained tong and tong handle rotated, striking the Operator on the right side of his head, just below his hard hat. It was the Board's assessment that the tong, rather than the eyebolt and shackle assembly, struck the Operator; this conclusion differs form the Helper's verbal report immediately following the accident and is based upon the Board's engineering analysis, interview statements, and a subsequent job site walkdown.

Exhibit 2-1 shows the location of the drilling site. Exhibit 2-2 shows the drill rig operating station where the Operator was standing when the injury occurred. Figure 2-1 shows the eyebolt connection to the piston rod.

Exhibit 2-1. Drilling Site Where the Accident Occurred

2.1.2 Background

Fermilab pre-qualified construction contractors to bid on the NuMI Tunnels and Halls Project in July 1999. The pre-qualification process used the following "Safety and Health Program Criteria" to screen construction contractors to bid on the NuMI Project:

- The construction contractor's corporate safety philosophy
- Experience modification rates for the previous three years
- Occupational Safety and Health Administration (OSHA) 200 logs for the previous three years

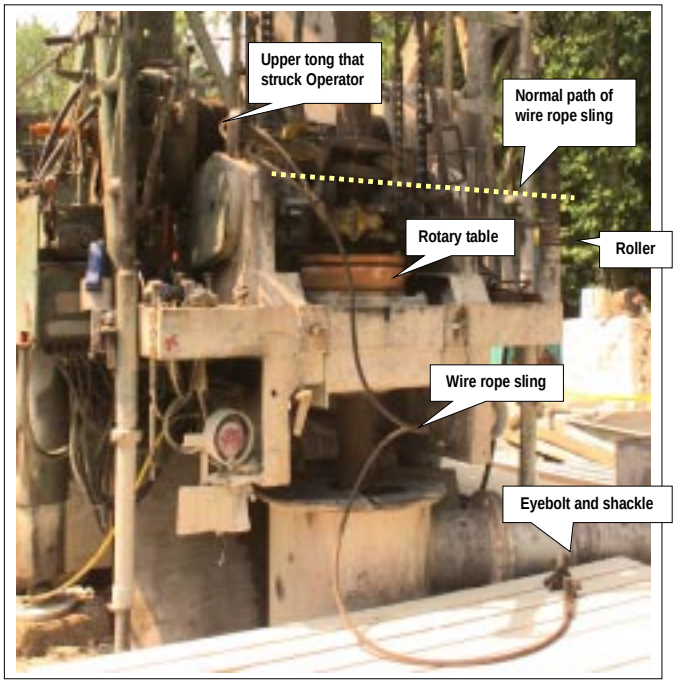


Exhibit 2-2. Drill Rig Where the Injury Occurred

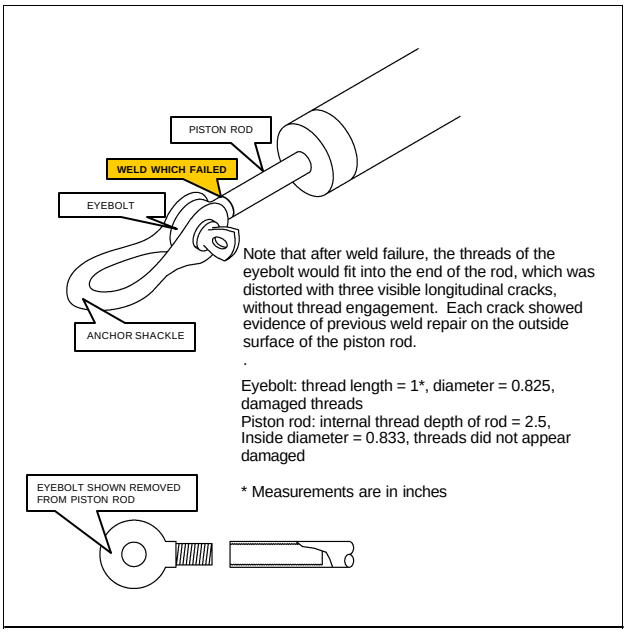


Figure 2-1. Piston Rod End Fixture

- Total number of hours worked by employees for each of the last three years

- Resumes of two to four safety professionals who are current employees of the company.

Fermilab evaluated the "Safety and Health Program Criteria" to ensure that each construction contractor had developed and implemented a corporate safety plan and that the contractor had achieved the following:

- Experience modification rate less than 1.0

- Recordable injury case rate less than or equal to 9.5

- Lost workday case rate less than or equal to 4.4.

Fermilab evaluated 13 construction contractors and qualified 10 to receive a Request For Proposal solicitation package. Criteria for evaluating each construction contractor's proposal were based on a weighted average considering 70 percent cost, 15 percent project schedule, 10 percent onsite personnel resources, and five percent onsite equipment resources. After this point, contractor safety and health programs and safety records were no longer considerations in the selection of the construction contractor for the NuMI Project.

Fermilab awarded the NuMI Tunnels and Halls contract to S. A. Healy, which had the lowest cost and the highest technical rating. When S. A. Healy began operations, a single full-time safety professional was on staff at the site. S. A. Healy supplemented the safety professional with a part-time consultant and later added two additional full-time safety personnel to their staff.

Fermilab issued a Notice to Proceed on March 6, 2000, and construction started shortly thereafter. On September 13, 2000, S. A. Healy subcontracted with Layne-Western to drill EAV and survey riser shafts for the NuMI Tunnels and Halls Project. A pre-qualifying process was not followed when S.A. Healy awarded the subcontract to Layne-Western. In addition, Fermilab did not review the past safety performance of Layne-Western before awarding the drilling contract.

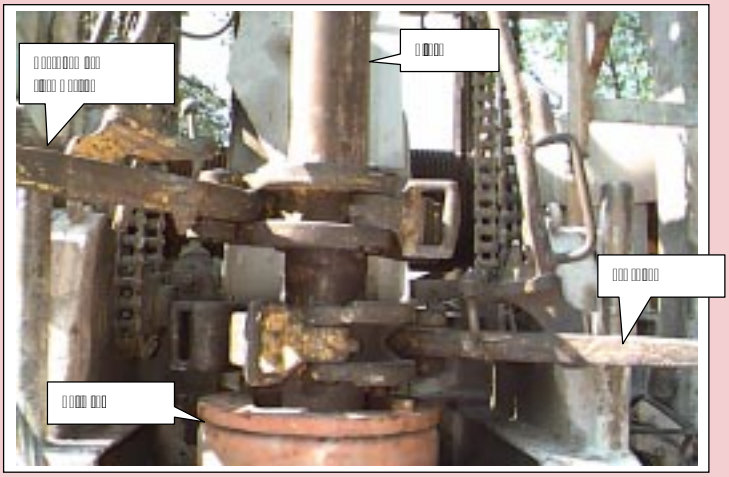
On September 25, 2000, Layne-Western began drilling the first of four EAV shafts and two survey riser shafts. These shafts ranged from 18 inches to 25 inches in rough diameter, with depths varying from approximately 100 feet to approximately 350 feet based on the tunnel's location. The accident occurred during drilling of EAV-2. This job site lies on the north side of Giese Road and west of, and adjacent to, Indian Creek, as shown in Exhibit 2-1.

The drilling rig involved in the accident was built by Gardner-Denver in 1969 and was mounted on a heavy truck bed for Layne-Western. Layne-Western had used the rig on various drilling projects since 1969.

The Board determined that at least two equipment modifications were made after the drill rig was built that are relevant to the accident. In the early 1970s, the hydraulic breaking mechanism was installed to replace a manual breakout wrench used to loosen and tighten the drill pipe section joints. In 1999, the eyebolt-piston rod connection involved in the accident failed. An entry in a Layne-Western Daily Drilling report dated March 2, 1999, stated "Broke eyebolt on end of hyd[raulic] ram for breaking but we [were] able to weld it up." The Daily Drilling report indicated that the drilling crew performed this repair in the field.

On April 20, 2001, representatives of the U. S. Department of Agriculture inspected the EAV-2/EAV-3 job site, acting on behalf of the U. S. Army Corps of Engineers in connection with the Fermilab wetlands permit, and requested that drilling operations be suspended until environmental improvements related to the work could be made. Layne-Western resumed work at the site on April 30, 2001, after S. A. Healy made necessary improvements, and after receiving verbal restart authorization from the U. S. Department of Agriculture. The Layne-Western crew began drilling EAV-2 on May 4, 2001.

The accident resulted from the failure of the weld connecting the wire rope to the hydraulic cylinder used in making and breaking threaded drill pipe section joints. Torsion is applied to the joints by mechanical tongs (in effect, pipe wrenches) that grip the outer diameter of the drill pipe section. One of the tongs is braced against a drill rig stop pin, while the other tong is operated (i.e., pulled) by a mechanical force supplied by the hydraulic cylinder. This force is transmitted through a wire rope sling connected with miscellaneous hardware.



On May 25, 2001, the Operator performed a safety inspection of the drilling rig, related equipment, and the EAV-2/EAV-3 job site. Although the inspection record completed by the Operator was incomplete, completed portions of the record did not identify safety deficiencies requiring corrective action. Between May 4, 2001, and June 21, 2001, a number of cognizant FAO, Fermilab, and S. A. Healy safety personnel visited the job site, but did not document any safety deficiencies.

On June 9, 2001, S. A. Healy instituted a safety stand-down on the NuMI Tunnels and Halls Project construction work following a rigging/material handling accident in which an S. A. Healy employee was struck by a suspended load. S. A. Healy used the stand-down to conduct pre-planned safety training. Work resumed on June 10, 2001.

On June 13, Fermilab and S. A. Healy jointly instituted another safety stand-down on the NuMI Tunnels and Halls Project construction work, following the injury of two S. A. Healy employees in another materials handling accident. This second accident occurred when rigging for a suspended load failed, causing the load to strike a man-lift in which the two employees were positioned. Work resumed on June 15. Although these safety stand-downs included training and orientation of the NuMI Tunnels and Halls Project workforce on safety policies and procedures, along with techniques of hazard analysis, the Layne-Western drilling crew was not asked to participate in the stand-downs, nor did they receive the related hazard analysis training.

On June 15, 2001, the Fermilab Director ordered an investigation into S. A. Healy's safety performance and safety management. The Fermilab investigation was under way when the drilling rig injury involving the Layne-Western employee occurred, and was completed on July 2, 2001.

On the morning of June 21, 2001, two NuMI construction coordinators visited the EAV-2/EAV-3 job site, but did not document any safety deficiencies.

When the accident occurred, the two-person crew, composed of the Operator and the Helper, was removing the second of six 20-foot drill collars from the EAV-2 shaft. A drill collar is a length of heavy pipe placed immediately above the drill bit to provide concentrated weight to enable the bit to drill properly, and to produce a vertical hole. Each collar was approximately six inches in diameter, and the entire drill assembly at maximum depth weighed approximately 15,000 pounds. A chronology of events related to the accident appears in Appendix B.

2.1.3 Accident Description

The accident occurred when the welded connection between the eyebolt and the hydraulic cylinder piston rod failed during operation. This event released tension on the wire rope sling connecting the eyebolt to the upper tong. The sling, with the shackle and eyebolt attached, sprang back toward the end of the drilling rig where the Operator and his Helper were standing.

The release of tension on the sling, coupled with the torsion on the drill collars, caused the tong to recoil toward the Operator. The tong, which was 32 inches long, made of forged steel, and weighed approximately 150 pounds, struck the Operator on the right side of his head, just below the rim of his hard hat.

After the accident, the Helper demonstrated the Operator's position to the Board, indicating that the Operator was leaning in towards the tong while operating the lever controlling pressure to the hydraulic cylinder with his left hand. This body position would have placed the Operator's head at the approximate elevation of the tong handle.

The Helper stated that he thought the shackle and eyebolt struck the Operator. However, the Board's engineering evaluation indicated that the tong most likely struck the Operator. The Operator declined to be interviewed by the Board. The Board concluded that a blow to the Operator's head by the recoiling tong handle was the most credible injury scenario.

On June 21, 2001, shortly following the accident, Fermilab issued a stop-work order for the NuMI Tunnels and Halls construction project, halting all drilling operations by Layne-Western and all S. A. Healy work. On June 28, 2001, Fermilab authorized a phased restart of work on the project.

2.1.4 Engineering Evaluation of the Failed Components

The Board conducted a limited engineering evaluation on the failed components using an independent offsite laboratory. Attorneys representing Layne-Western would not allow destructive tests to be performed.

The evaluation considered the condition of the eyebolt after the accident, and the condition of the end of the piston rod, as shown in Exhibit 2-3. It included detailed visual inspection, measurements, hardness testing, and engineering analyses. Visual inspection disclosed three longitudinal cracks in the threaded end of the piston rod, one of which is visible in Exhibit 2-3. The threaded portion of the eyebolt was considerably deformed, as can be seen in Exhibit 2-3.

Examination of the eyebolt and piston rod following the accident revealed that these components separated when a weld that held them together failed. The threaded portion of the eyebolt had been inserted into the threaded socket in the end of the piston rod, but there was apparently little or no thread engagement due to expansion of the socket diameter. This expansion was attributed to through-wall cracks in the socket and to possible distortion due to weld repairs of previous cracks. The load on the connection was apparently supported entirely by a circumferential weld that joined the shoulder of the eyebolt to the end of the piston rod. The weld failed either because of cracks that developed due to fatigue related to repetitive loading or because of unusually high stress at the time of failure.

2.2 Emergency Response and Medical Treatment

Emergency response to the accident consisted of (1) the initial emergency medical response operations at the scene, (2) the transport of the injured Operator to the hospital, and (3) the medical care provided at the hospital.

When the Operator was struck on the right side of his head, he fell onto the wooden platform that served as the operating deck. The Helper, who was also standing on the platform but to the right of and behind the Operator, provided immediate aid by laying him down on the wooden pallets to the left of and adjacent to the drill rig and then went to call for emergency assistance.

As the Helper was en route to obtain a cellular telephone available at the job site to call for assistance, he saw a Fermilab employee driving by the job site. The Helper flagged down the Fermilab employee, who

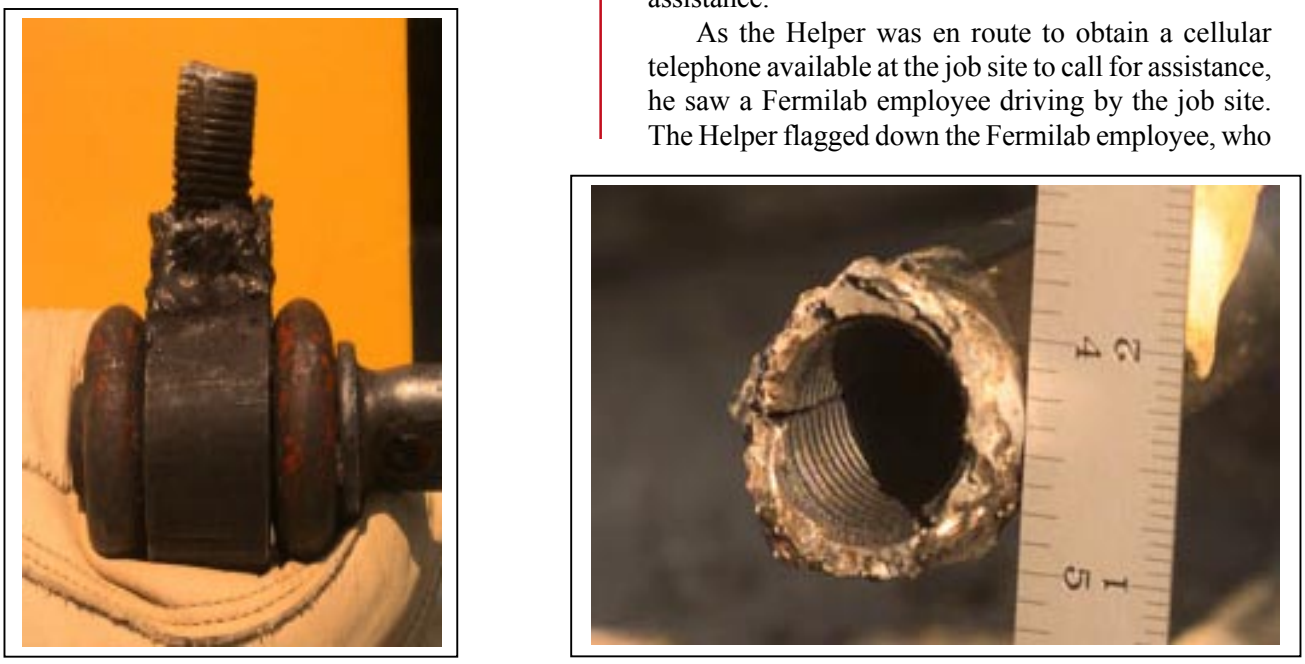


Exhibit 2-3. Eyebolt That Was Connected to the Piston Rod (Left) and the End of the Piston Rod After the Accident (Right)

Engineering Evaluation Supporting the Conclusion That the Operator Was Most Likely Struck by the Tong

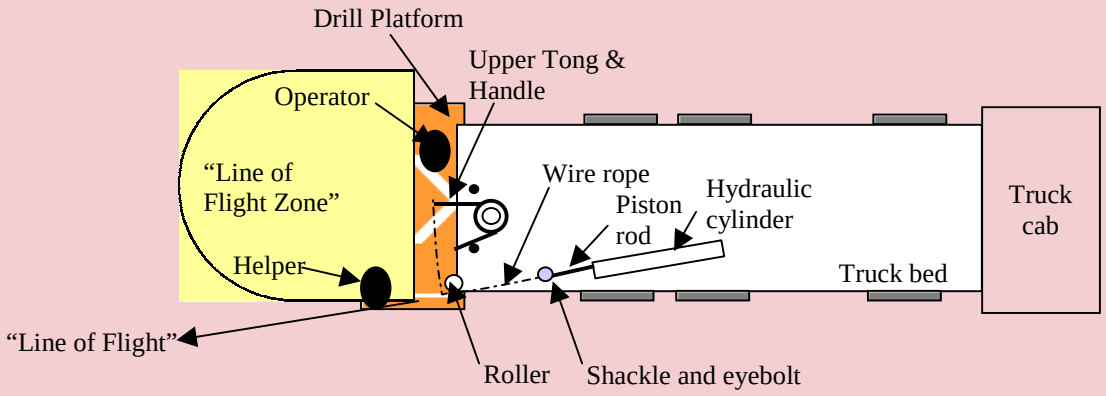
Although the Helper stated that he thought the Operator was struck by the shackle and eyebolt, it does not appear that there is a high probability that this happened. The motion of the wire rope would have been very rapid and ultimately could have resulted in the attached shackle and eyebolt being located near the injured Operator. However, the structural configuration of the rig and the fact that the Helper was not injured are principal reasons for not supporting this assertion.

- The assumed path of the broken shackle and eyebolt through the mast structure to the injured Operator was not a straight line. To reach the Operator, the shackle and eyebolt would need to "turn the corner" at the roller and somehow miss the Helper, who was reported to be standing on the corner of the drill platform. If the Operator had been hit by the shackle and eyebolt, the shackle, eyebolt and wire rope would also have struck, or wrapped around, the Helper. As shown in the accompanying sketch, the Helper would have had to be out of the "line of flight" of the wire rope.

- Instantaneous release of tension by the weld failure would have caused the shackle, eyebolt and wire rope to fly toward the roller – much like a rubber band. Its straight-line motion could have helped the shackle, eyebolt and 8 feet of wire rope pass through the mast structure and confining passages, so that the rope extended behind the drill platform. However, this initial rope movement should have resulted in injury to the Helper if he was standing in the "line of flight zone."

- Combined with the clockwise rotation of the tong handle, this tension release would have jerked the wire rope end (attached to the tong handle) toward the Operator's location while he was operating the hydraulic controls. This jerk (approximately 2 or 3 feet of tong handle movement) could have propelled the other rope end and shackle and eyebolt within the "line of flight zone" and toward the tong handle. Again, it is unclear how these assumed wire rope motions could have occurred without injuring the Helper.

In summary, based on the Helper's report of both his and the Operator's position, and the fact that the Helper was not injured, the wire rope and shackle/eyebolt end did not fly through the "line of flight zone" to strike the Operator. Therefore, the tong handle must have struck the Operator.



then called the site emergency telephone number using his cellular telephone. This call was placed at 9:44 A.M., approximately four minutes after the accident, and resulted in Fermilab emergency personnel arriving at the scene at 9:45 A.M. and the Fermilab ambulance arriving at 9:48 A.M.

Based on their initial assessment of the Operator's head injuries, the first Fermilab firefighters/emergency medical technicians (EMTs) arriving at the scene requested the aid of Tri-City Ambulance Service. (The laboratory had contracted with Tri-City Ambulance Service for advanced life support ambulance service.) Paramedics from the town of Geneva responded. The Fermilab fire department established incident command at 9:48 A.M., immediately outside the job site on Giese Road. The Geneva advanced life support ambulance arrived at the accident scene at 9:57 A.M. Initial reports indicated that the Operator's breathing was irregular, that he was not responsive, and that four EMTs were required to restrain and immobilize him as he regained consciousness.

At 10:15 A.M., the Geneva ambulance left the scene and transported the Operator to the Delnor Community Hospital for emergency care. A Fermilab firefighter/EMT drove the ambulance, enabling the two Geneva paramedics to continue rendering assistance to the Operator. He was transported to Delnor Community Hospital, where he was admitted and evaluated.

At the hospital, medical diagnosis determined that the Operator had sustained a frontal skull fracture with a mild to moderate brain injury consisting of a contusion of the right frontal lobe, with swelling. He also sustained a fracture of the right jawbone and dysfunction of the right third cranial nerve, which controls certain eye movements. These injuries are consistent with a blunt force type of trauma, such as being hit by the tong handle. After he regained consciousness, he exhibited some unsteadiness on his feet and mild difficulties with thinking and reasoning as a result of his injuries. He also had blurred vision and decreased vision in the right eye. The Operator did not require surgery, and improved sufficiently such that on July 2, 2001, he was transferred to a rehabilitation facility, where he received occupational, physical, and speech therapy.

The Board concluded that the initial emergency response and medical response were timely and well coordinated.

2.3 Investigative Readiness and Accident Scene Preservation

Shortly after the Geneva ambulance left the accident scene with the Operator, the Incident Commander turned custody of the scene over to a representative of the Fermilab Facility Engineering Services Section. Control of the accident scene was subsequently transferred to Fermilab ES&H Section. Arrangements were then made to clearly establish the accident scene perimeter with yellow tape, photograph the scene, and formally institute an access control point by posting a security guard at the entrance to the scene. The guard was given instructions to limit access to only authorized individuals. The guard maintained a record of those who entered the area, their duration at the scene, and the purpose of their visit.

On June 27, 2001, the Board assumed custody of the accident scene, relinquishing control back to the FAO on July 17, 2001. During this period, a security guard maintained continuous access control to the accident scene.

While the actions Fermilab took to preserve the accident scene were commendable, three areas of concern were noted by the Board:

(1) *Potential exposure to bloodborne pathogens.* Prior to establishing an access control point, Fermilab, S. A. Healy, and Layne-Western personnel were present at the accident scene for various purposes. In a typical accident involving contact between a human and equipment or machinery, it is not uncommon to have blood at the accident scene. Personnel visiting the accident scene could have come in contact with bloodborne pathogens, creating an unnecessary health risk to themselves and others they may come in contact with.

(2) *Alteration of evidence.* To obtain high-quality photographs of the failed components involved in the accident, personnel repositioned the components. Moreover, they degreased and cleaned the equipment in preparation for the photographer, thereby removing any other evidence, such as metal shavings, that might have been of use to the Board.

(3) *Removal of material.* The Operator's personal possessions were removed from the accident scene. Later, the Board was unable to validate certain specific testimonial information relative to his belongings (e.g., possession of the Operator's personal copy of his company's safety manual) because personnel from his organization removed them prematurely from the accident scene.

The Board concluded that an effective access control system was not instituted in a timely fashion to properly preserve the accident scene.

3.0 Accident Facts and Analysis

This section addresses the facts related to the accident, along with the results of the Board's analysis. The Board presents this information in terms of the ISM core functions and guiding principles, which comprise the fundamental DOE safety and health policies that should have been incorporated into the work planning and execution.

3.1 Physical Hazards, Controls, and Related Factors

3.1.1 Define the Scope of Work

Effective work execution begins with the preparation of a well-defined scope of work that translates the mission and requirements into terms that those who are to accomplish the work can clearly understand. The definition of work scope must provide sufficient detail to support hazard analysis and development and implementation of controls at the task level. To fulfill its responsibilities, line management must determine the work to be performed and be accountable for understanding it as completely as possible through every phase of the work cycle. This process applied to the NuMI Tunnels and Halls construction project and the associated Layne-Western shaft drilling operations. The scope of the construction project, including shaft drilling operations, was defined in a series of tiered documents. These documents, summarized below, included the Project Execution Plan, the NuMI Project Management Plan, the Fermilab-S. A. Healy contract, the S. A. Healy work plan, and Layne-Western "job letters."

The Project Execution Plan dated February 1999 described the mission needs and justification for the NuMI Project, its objectives and scope, the DOE project management structure, and the resource plan. DOE prepared the Project Execution Plan and the Director, Office of Energy Research, the predecessor organization to the Office of Science, approved the plan, which constituted Critical Decision number one in accordance with DOE Order 430.1A, *Life Cycle Asset Management*, and the Joint Program Office Direction on Project Management. Discussion of ES&H requirements in this plan was limited to references to the NuMI Environmental Assessment, excerpts from the subsequent Finding of No Significant Impact related to the Environmental Assessment, and a reference to the NuMI Preliminary Safety Assessment Document.

The Project Management Plan dated March 8, 1999, set forth the plans, organizations, and management systems to be used by Fermilab and DOE to manage the NuMI Project. The Fermilab NuMI Project Manager prepared the NuMI Project Management Plan, which complemented the Project Execution Plan and indicated that project management would be conducted in conformance with DOE Order 430.1A and the Joint Program Office Direction on Project Management. The Project Management Plan was prepared by Fermilab for approval by DOE. While it was approved by the FAO, the DOE Office of Science indicated "approved provisionally – pending peer review." At the time of the accident, this document remained provisionally approved by the Office of Science, and did not reflect the current site organizational structure or operations.

The Project Management Plan indicated that design, construction, operation, and decommissioning operations would be performed in compliance with the FESHM standards and all applicable ES&H standards in the work smart standards set. However, the document made minimal reference to construction safety.

The S. A. Healy contract with Fermilab for the NuMI Tunnels and Halls Project, dated February 11, 2000, described the scope of work associated with shaft excavation. The scope of work provided the general technical requirements and established the applicable American Society for Testing and Materials, the American Welding Society, the American Water Works Association, and OSHA standards—specifically the U. S. Code of Federal Regulations 29 CFR 1926, Subpart S (Underground Construction, Caissons, Cofferdam, and Compressed Air) and Subpart U (Blasting and Use of Explosives).

In August 2000, S. A. Healy submitted a "Work Plan for the Drilling of the Vent Shafts and Survey Risers (Submittal No. 42)" in accordance with its contract with Fermilab. The submittal identified Layne-Western as the subcontractor for the ventilation shafts and survey risers, and established the work progression for the task. It included a basic outline of the drilling methods and outlined the environmental precautions that would be taken at the EAV-2 and EAV-3 job site. The work plan referenced the need to de-energize overhead power lines at the EAV-1 and SR-2 job sites, and that the work would be completed in compliance with OSHA requirements. The work plan did not address the management of S. A. Healy subcontractors, nor was this required by the Fermilab-S. A. Healy contract.

On September 9, 2000, Fermilab reviewed the work plan and returned it with the notation "Approved as Noted: Resubmit," with comments concerning extending the gravel base at the EAV-2/EAV-3 job site due to environmental concerns. Fermilab approved the work plan on November 8, 2000.

Layne-Western signed a contract with S. A. Healy on September 13, 2000, to drill four EAV and two survey riser shafts for the NuMI Tunnels and Halls Project. However, the construction schedule called for drilling to commence on August 14, 2000, and finish on November 1, 2001. The contract required Layne-Western to provide a work plan to S. A. Healy 30 days before commencing work. Among the other Layne-Western contract requirements were:

- "Take all precautionary measures in protection of the environment and surrounding areas from impact due to their work."
- "Attend all required Safety Orientations (conducted by Fermilab and by the contractor) prior to commencement of work."
- "Provide a hazard analysis plan for work that they will be performing and all of their employees shall sign the plan to acknowledge that they have read and understand the plan."
- "State the name of the person that will be designated as their 'Competent Person' prior to commencement of the work. The Competent Person shall be at the work site whenever there is work in progress by the Subcontractor."

A Layne-Western job letter dated September 15, 2000, provided work instructions to the Operator and identified the Operator as the "Competent Person." The Fermilab-S. A. Healy contract, as referenced by the S. A. Healy-Layne-Western contract, defined a Competent Person as the onsite safety official, who must have completed the 30-hour OSHA construction safety course, or equivalent. The Layne-Western Operator had not met the Competent Person requirements. However, the Board noted that this determination applied only to the Operator's qualifications regarding safety, and not his competence in the drilling trade.

Layne-Western began mobilizing on September 18, 2000, and drilling the first of six shafts commenced on September 25, 2001. Layne-Western did not provide S. A. Healy with a formal work plan.

On March 12, 2001, Layne-Western began drilling the EAV-2 shaft. This work was also initiated without submitting a work plan to S. A. Healy, although the Layne-Western General Manager had issued a job letter on December 7, 2000, addressing the work at EAV-2, EAV-3, and EAV-4. The job letter had not specified worker safety and health requirements, had not referenced other documents that contained such requirements, and had not invoked OSHA requirements. The job letter also had not included a detailed breakdown of drilling tasks necessary to complete a comprehensive hazard analysis of every task.

Significant attention was paid to environmental aspects of the Layne-Western drilling operation. For example, the EAV-2/EAV-3 job site was requested to be shut down on April 20, 2001, after a U.S. Department of Agriculture inspection revealed non-compliance with the Fermilab wetlands permit. Layne-Western had penetrated the membrane placed under the gravel fill when it installed a settling basin. S. A. Healy took immediate action to correct the environmental non-compliances. However, minimal attention was focused on the safety and health aspects of the work.

The safety and health expectations associated with construction and shaft drilling operations were not fully conveyed as part of the array of "scope of work" documents, and project planning did not include provisions for managing S. A. Healy subcontractors. Neither Fermilab nor S. A. Healy enforced the contractual requirements for Layne-Western to provide a work plan 30 days before commencement of work. Layne-Western "job letters" had not provided sufficient breakdown of the work scope to support adequate task-specific hazard analysis.

The Board concluded that line management failed to adequately address safety as part of planning for Layne-Western drilling operations and failed to enforce compliance with existing safety requirements.

3.1.2 Hazard Analysis

The objective of hazard analysis is to develop an understanding of task-specific hazards that may affect the worker, the public, and the environment. Each level of hazard analysis is the foundation for a more detailed analysis; that is, a construction project hazard analysis is, in turn, used as the basis for an activity-level or task-level hazard analysis. Hazard identification and analysis must occur at any phase of the work cycle to which it applies, including construction. The procedures used to carry out hazard assessments at the project level are contained in the FESHM.

The FESHM established mandatory ES&H policies. FESHM 7010, *Subcontractor Safety Program*, described Fermilab's program, procedures, and safety requirements for construction work. According to FESHM 7010, "Work will not proceed on that activity until the hazard analysis has been accepted by the construction coordinator." Construction coordinators were defined as individuals specifically assigned to oversee the work of a fixed-priced subcontractor for conformance to the subcontract documents. Construction coordinators were primarily furnished by the Fermilab Engineering Services Section Engineering Group, which, at times, was supported by an outside Architectural Engineering Group.

The hazard analysis section in FESHM 7010 did not provide sufficient detail to communicate requirements to subcontractors specifying when and how a hazard analysis was to be completed for each task associated with the scope of work, nor did it indicate a need for worker involvement in the process. FESHM 7010 included ES&H Administrative Form #17, *Hazard Analysis Form*, but had not referenced or required completion of this form. Additionally, page one of the form stated: "This form is to be completed by the construction coordinator for acceptance prior to the Notice to Proceed," indicating that this was a one-time contract submittal before receiving authorization to initiate work.

The Fermilab contract with S. A. Healy did not directly invoke FESHM 7010; however, S. A. Healy essentially adopted the FESHM by referencing this document in the S. A. Healy Safety and Health Manual. The contract included various clauses for safe work operations. Two clauses important to this event were the "Project Specific Safety and Health" and the "ES&H Work Procedures" Exhibit A clauses. The hazard analysis requirement was contained in the Project Specific Safety and Health clause. Some of the more important requirements that affected hazard analysis were:

- Exhibit A, paragraph 13.6, of the S. A. Healy contract with Fermilab required hazard analyses for Healy operations and operations of its sub-tier contractors.
- Initial hazard analyses were required to be submitted and accepted by Fermilab before the Notice to Proceed.
- Sub-tier contractor operations were required to be included in the hazard analysis.
- An acceptable hazard analysis was required for all work.
- Fermilab would review all hazard analyses for completeness and conformance with OSHA and industry standards.
- The name of the Competent Person would be included on the hazard analysis and communicated to all workers.
- Job-specific safety orientation would be provided based on the hazard analysis.
- All contractual submissions would have to be met for Fermilab to issue a Notice to Proceed.

Section 16 of the S. A. Healy Safety and Health Manual outlined the hazard analysis process. This section included the Project Hazard Analysis Form from the June 1999 version of FESHM 7010. The general instructions in the S. A. Healy Safety and Health Manual, under Hazard Analysis and Site Inspections, required hazard analyses to be prepared as follows:

> "Before the start of each major work phase, a job safety analysis will be prepared. This will determine the safety and health hazards involved during this work phase. The name of Competent Persons shall be included on the Hazard Analysis [HA].
>
> "This is to isolate any anticipated hazard and to outline mitigating actions (including PPE [personal protective equipment]) in advance in order to control the hazards.
>
> "Prior to the start of actual work, a meeting will be held with the Contractor(s) representative and any affected

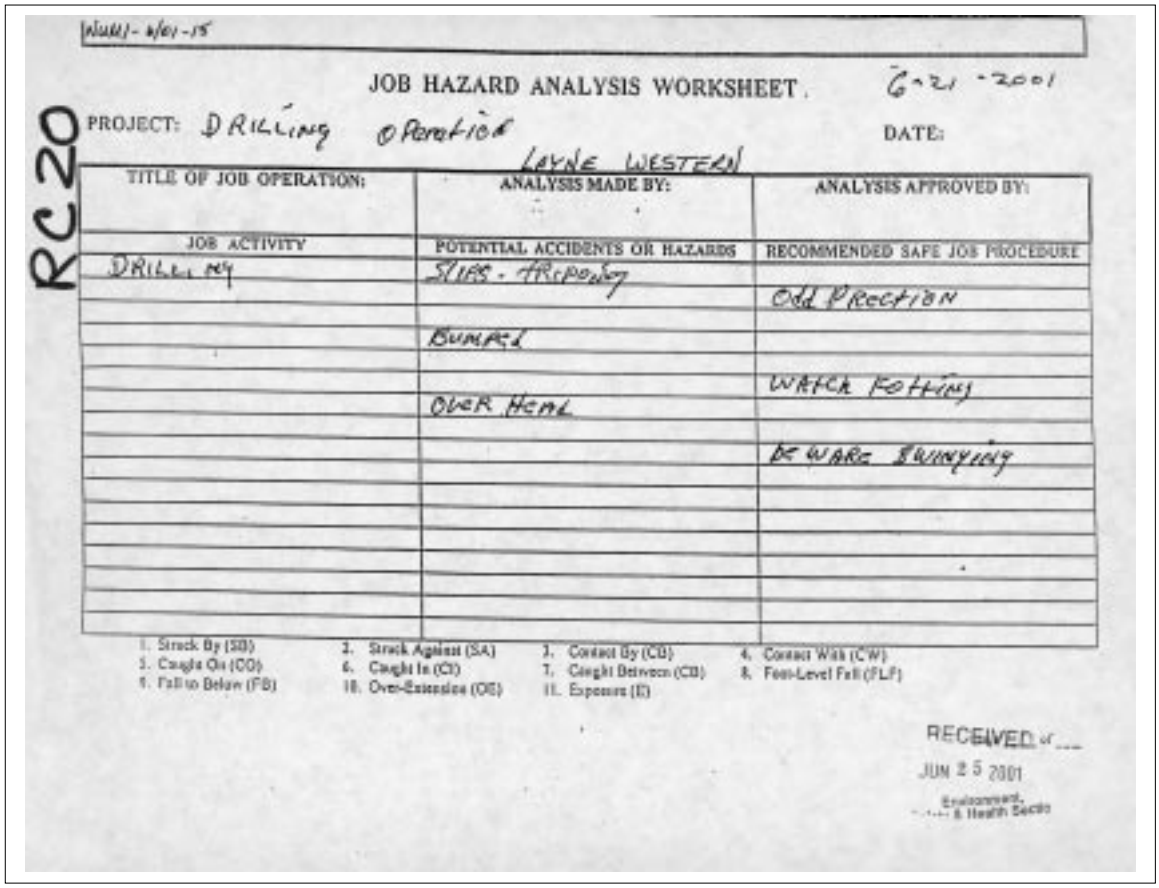
subcontractor to review the "Job Hazard Analysis" and be prepared for this work phase. A job-specific safety orientation to all Sub-contractor and Sub-Sub-contractor employees based upon each HA. Each employee will sign the HA to indicate having received the orientation. The signature list shall be available for review by the Construction Coordinator. As the HA is updated, the employees must be advised of the new information."

Section 16 of the S. A. Healy Safety and Health Manual did not reference FESHM 7010. It provided brief instructions for completing a hazard analysis, but they were not sufficient to prepare a proper hazard analysis at the task level.

The Layne-Western contract with S. A. Healy required development of a hazard analysis plan. It also required Layne-Western personnel to follow S. A. Healy contract requirements. However, these requirements were not met or enforced by Fermilab or S. A. Healy before drilling operations began.

Although Section 4 of the Layne Christensen Health and Safety Program was entitled "Hazard Analysis," it presented only some of the generic hazards that employees could encounter. An attached table, also entitled "Hazard Analysis," identified some of the hazards associated with drilling and very generic controls for the hazards. The table did not identify hazards specific to the drilling activity, nor did it identify specific controls to be implemented by the drilling crew. Additionally, Layne-Western did not have a documented procedure or process that provided instructions for employees to conduct a hazard analysis.

The S. A. Healy General Superintendent stated that he had asked the Layne-Western Operator to begin filling out the S. A. Healy hazard analysis forms approximately two weeks before the accident. After the accident, he asked the Layne-Western Helper for a copy of the hazard analysis for the job. The hazard analysis consisted of two pages dated June 21, 2001 (the date of the accident). The first page was similar to those provided by S. A. Healy for their work. A copy of the Layne-Western EAV-2/EAV-3 hazard analysis worksheet appears in Figure 3-1. No signatures appeared on the form. An approved hazard analysis could not be located for the Layne-Western work related to drilling the EAV-2 and EAV-3 shafts, nor were any hazard analyses performed for the work related to boring the previous shafts, which began in September 2000.



JOB HAZARD ANALYSIS WORKSHEET

6-21-2001

RC 20

PROJECT: DRILLING OPERATION

DATE:

LAYNE WESTERN

TITLE OF JOB OPERATION:	ANALYSIS MADE BY:	ANALYSIS APPROVED BY:
JOB ACTIVITY	POTENTIAL ACCIDENTS OR HAZARDS	RECOMMENDED SAFE JOB PROCEDURE
DRILLING	SLIPS - TRIPPING	ODD DIRECTION
	BURNS	WATCH FOOTING
	OVER HEAD	BE WARE SWINGING

1. Struck By (SB) 2. Struck Against (SA) 3. Contact By (CB) 4. Contact With (CW)
5. Caught On (CO) 6. Caught In (CI) 7. Caught Between (CB) 8. Fall-Level Fall (FLF)
9. Fall to Below (FB) 10. Over-Exertion (OE) 11. Exposure (E)

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Figure 3-1. Layne-Western Job Hazard Analysis Worksheet

Well drilling is a hazardous activity. It involves high-energy mechanical systems, hoisting and rigging capabilities, rotating machinery, highly-tensioned ropes, cables and chains, noise, chemicals, and structural issues. A hazard analysis addressing this activity would require the expertise of engineering personnel as well as craft workers. However, the inadequate hazard analysis prepared by the Operator focused solely on common occupational safety issues, such as slips and falls from walking and working surfaces, and contained no engineering or supervisory input.

The hazard analysis processes that were available to the Operator and the Helper for the drilling operation were the Layne Christensen Health and Safety Program, the S. A. Healy Safety and Health Manual, and FESHM 7010. The Layne Christensen Health and Safety Program (used by Layne-Western) did not specify a process that would allow the Operator and the Helper to identify and address task-specific hazards of the drilling operation (i.e., breaking down the operation into subtasks and associated hazards). The hazard analysis process identified in the S. A. Healy Safety and Health Manual also did not provide specific guidance for the development of task-specific hazard analyses. FESHM 7010 indicated that hazard analyses were required for all construction work, and ES&H Administrative Form #17 provided guidance that would be applicable to the drilling operation. However, FESHM 7010 did not require that the guidance in Form #17 be used in the development of a hazard analysis. Although the Layne-Western drill crew attempted to complete a form titled "Job Hazard Analysis Worksheet," neither the Fermilab, S. A. Healy, nor Layne-Western ES&H programs provided complete instructions for developing a hazard analysis at this level.

Regarding job site reviews, the FAO personnel, Fermilab personnel, NuMI Project construction coordinators, and S. A. Healy line managers visited the EAV-2/EAV-3 job site frequently to verify environmental compliance and to check on drilling progress. None of these personnel identified that the work was being performed without an approved hazard analysis, nor did they identify construction safety deficiencies at the job site.

The S. A. Healy General Superintendent, who was appointed three weeks before the accident, recognized that there was no hazard analysis for the work and initiated action to have one prepared; however, he took no action to curtail drilling operations until a hazard analysis was completed. The previous S. A. Healy General Superintendent took no action to assure that a hazard analysis was prepared. Various ES&H personnel who visited the Layne-Western job sites over a nine-month period did not identify the absence of a hazard analysis for the work.

The drilling operations were allowed to continue with numerous hazard analysis program deficiencies. As previously noted, a hazard analysis did not exist when drilling began and neither the General Superintendent nor the construction coordinator required completion of the hazard analysis. Consequently, no Competent Person was named on the hazard analysis as required. Documentation was unable to be produced which demonstrated that tool or equipment inspections were conducted by the construction coordinator.

The Board concluded the following:

- *The hazard analysis process outlined in the Layne Christensen Health and Safety Program was incomplete and did not adequately address this drilling operation.*

- *Fermilab and S. A. Healy procedures for requiring and performing hazard analyses of subcontractors and sub-tier contractors were ineffective.*

- *The hazard analysis program in place at the time of the accident did not evaluate task-specific hazards associated with the Layne-Western drilling operations for the NuMI Project.*

- *Fermilab and S. A. Healy did not enforce the requirement for preparing a hazard analysis, nor did Layne-Western implement the hazard analysis requirements for the drilling work.*

- *Safety and health oversight of the Layne-Western operations failed to identify the absence of a hazard analysis.*

3.1.3 Develop and Implement Controls

The objective of developing and implementing controls is to identify and provide the full range of controls (i.e., engineering, administrative, and personal protective equipment) consistent with the level and nature of the hazards to be encountered during task performance. The development and implementation of work controls assumes that the contractor has adequately and completely identified the hazards associated with the defined scope of work. The Board evaluated several aspects of this process, including

(1) requirements management and procedure development, (2) maintenance operations, and (3) general worker safety.

Throughout the Department, contractual requirements are used to establish the terms and conditions that define DOE safety expectations for its contractors. DOE Acquisition Regulation (DEAR) 970.5204-2 requires contractors to comply with the requirements of applicable Federal, state, and local laws and regulations in developing and implementing controls, unless the appropriate regulatory agency has granted a waiver in writing. DOE has identified safety requirements in rules and DOE orders and has developed a wide variety of associated technical standards, guides, and manuals, and encourages the use of national consensus technical standards. In addition to complying with applicable Federal, state, and local laws and regulations in developing and implementing controls, as required by DEAR 970.5204-2(a) (List A), the contractor must also comply with the requirements of applicable DOE directives appended to the contract (List B in DEAR 970.5204-2(b)).

Nonetheless, a number of weaknesses in the process of communicating safety and health requirements from Fermilab to S. A. Healy and from S. A. Healy to Layne-Western were identified. The weaknesses listed below contributed to a work environment where equipment use and equipment modifications were performed without a comprehensive set of formal procedures to guide these operations:

- Neither Fermilab nor S. A. Healy reviewed and accepted the Layne-Western ES&H Manual.

- The Fermilab contract with S. A. Healy required all subcontractors, including sub-tier contractors, to be managed in accordance with the S. A. Healy ES&H Manual, which invoked FESHM 7010. FESHM 7010 was not tailored to address S. A. Healy construction sub-tier contractors. Additionally, S. A. Healy had not established a method to implement the requirements of FESHM 7010.

- The S. A. Healy contract with Layne-Western for construction of vent and survey risers invoked requirements from the FESHM. Specifically, Appendix A of the Layne-Western contract stated that "All work shall be performed in full accordance with the Contract Documents for Fermi National Accelerator Laboratory's Project No. 6-7-4." This contract did not refer to specific requirements with which Layne-Western was expected to comply.

- Although no formalized work controls were established for the EAV-2/EAV-3 job site, personnel were expected to comply with requirements stipulated in the Layne Christensen Health and Safety Program. This document was not reviewed and accepted by S. A. Healy, nor was it located at the job site. Observations at the scene and personnel interviews indicated that full compliance with electrical safety, fall protection, and hoisting and rigging requirements was not ensured. As stated by Layne-Western personnel, many of the safe work procedures referenced in the hazard analysis section of the Layne Christensen ES&H Manual do not exist.

The Board evaluated maintenance operations and worker safety associated with the drilling work. An equipment maintenance program was not specifically identified as a contractual requirement between S. A. Healy and Layne-Western. Nonetheless, the nature of the work, the inherent hazards, and the type of equipment used would indicate the need for a rigorous, formalized maintenance program.

Layne-Western has a limited equipment maintenance program. Records indicated that the company expected the drilling rig crew to perform repairs in the field, including structural welding, for which they were not formally trained or qualified. When the crew welded the eyebolt to the hydraulic cylinder piston rod in 1999, no engineering evaluation was performed to determine whether the strength of the weld was equivalent to the threaded connection it apparently replaced.

A Layne-Western Field Superintendent and the Operator conducted a drill rig safety inspection at the EAV2/EAV-3 job site in September 2000, and the Operator conducted a similar inspection in May 2001, approximately one month before the incident. The Operator's safety inspection was incomplete; for example, it failed to cover all required inspection items or identify safety deficiencies and potential imminent-danger situations at the job site. The safety inspection deficiencies and safety conditions at the job site were indicative of a work environment that was not attentive to proper health and safety practices. Examples of safety deficiencies the Board discovered at the job site are listed in Table 3-1.

Management processes were not implemented to assure program compliance with applicable safety and

Table 3-1. Examples of Safety Deficiencies at the Drilling Site

Equipment	Deficiency
Compressor Trailer	• Bald tires • Gouged tires • Bent wheel rim • No barricades/fall protection on work platforms • Leaking fuel/oil
Mist Pump	• Inadequate guarding on rotating equipment
Portable Generator	• Rotating equipment not guarded • Leaking oil • Makeshift lifting attachment – no load rating
Wire Rope Slings	• Inadequate Storage • Compressed eyes • Birdcaging • Kinks • Crushing • Abrasions • Broken cores • Shortened/attached to hook by knotting • No regular inspections • No rated capacity – damaged slings not removed from service
Synthetic Web Slings	• Markings and codings illegible • Discoloration • Distortion • Cuts • Abrasions • Damaged slings not removed from service • No regular inspections
Welded Alloy Steel Chains	• Missing permanently affixed, durable identification of size, grade, rated capacity and sling manufacturer • Deformed links
Inadequate Eelectrical Installations	• Electrical extension cords not designed for construction applications (hard or extra hard usage) • Electrical extension cords not protected from damage (damaged extension cords on the ground) • Ground fault circuit interrupters not used • Makeshift light string – leads inadequately terminated • Insulation worn off power cord for submersible sump pump • Extension cord not protected from damage when run through trailer door pinch point
Inadequate Fall Protection	• Fall protection not used when climbing or working at or above six feet • Fall protection equipment (harness) not fit for use • Work surfaces at or above six feet not guarded
Inadequate Walking/working Surfaces	• Wooden pallets used for walking surfaces present tripping hazard • Slipping hazards due to oil or other fluids on rig/equipment deck

health regulations. Consequently, ineffective and insufficient controls were established for unanalyzed hazards, including potential imminent-danger situations of which site personnel were unaware. Neither FAO, Fermilab, S. A. Healy, nor Layne-Western personnel identified the many job-site deficiencies during job-site observations and inspections.

The Board communicated safety concerns (some of which were potential imminent-danger situations, listed in Table 3-1 and illustrated in Exhibits 3-1 and 3-2) to the FAO Manager via memorandum on July16, 2001, when the Board relinquished custody of the accident scene. This information was also verbally communicated to the FAO, Fermilab, S. A. Healy, and Layne-Western representatives during a job-site walkdown before site turnover.

In regard to training, FESHM 7010 required all subcontractors to provide safety training, medical surveillance, and safety equipment for their employees. FESHM 7010 also required all subcontracts to contain a statement formally notifying the subcontractor and all sub-tier contractors that they were required to maintain records of training completed by all personnel working at Fermilab.

S. A. Healy was required to provide a job safety orientation to all subcontractor and sub-tier contractor employees, based upon the hazard assessment. Subcontractors performing work at the Laboratory were required to provide their employees with any ES&H training required by Federal, state, and Fermilab regulations, and as appropriate for their subcontracted operations. Examples of training deficiencies included:

- The S. A. Healy Safety Director did not meet the contractual minimum requirements specified for that position, which consisted of one of the following: (1) current registration as a professional engineer by the state of Illinois, (2) professional certification as a certified safety professional, (3) professional certification as a certified industrial hygienist and three years of underground professional experience in the area of safety, or (4) a minimum of 10 years of heavy underground construction experience in safety management in similar projects.

- A Competent Person was defined in the S. A. Healy-Fermilab contract as the designated subcontractor employee with knowledge of OSHA and other related safety standards, and who had the authority to enforce such standards. Fermilab also required the subcontractor Competent Person to have completed a 30-hour construction safety course, or equivalent. Neither Fermilab, S. A. Healy, nor Layne-Western ensured that Layne-Western employees assigned to the EAV-2/EAV-3 work were trained and qualified in accordance with the Competent Person training requirements. This situation was further evidenced by the employees' inability to recognize some safety concerns at the job site.

- Layne-Western personnel were not adequately trained as required by 29 CFR 1926 or as necessary in accordance with all requirements pertinent to the hazards associated with the job, such as personal protective equipment, fall protection, hazard communication, hearing conservation, hoisting and rigging, and first aid.

- Layne-Western personnel were not adequately trained and qualified as Competent Persons to recognize safety hazards at the job site and perform

Exhibit 3-1. Damaged Wire Rope Sling

Exhibit 3-2. Electrical Wiring Deficiences at the Drill Site

hazard analyses, or to abate the several potential imminent-danger situations identified by the Board following the accident. Although recent efforts were made by Fermilab and S. A. Healy to increase subcontractor knowledge of hazard analysis, the information was not shared with Layne-Western employees since they were not included in the two safety stand-downs and the related training.

The Board concluded that the occupational safety and health policies, programs, and procedures for worker safety and health were not routinely implemented or enforced.

3.1.4 Perform Work Within Controls

Controls must be identified and implemented before starting work. Examples where necessary controls were not implemented on the Layne-Western EAV-2/EAV-3 drilling activity being performed at the time of the accident included:

- S. A. Healy did not impose controls equivalent to those specified by FESHM 7010 to assure that Layne-Western would operate safely. S. A. Healy did not require Layne-Western to perform a number of expected operations equivalent to Fermilab ES&H contract submittal requirements specified in FESHM 7010, before initiation of work.

- S. A. Healy did not require Layne-Western to summarize its past safety performance as required under "Qualification of Subcontractors." Layne-Western did not submit a copy of its ES&H Plan as required under FESHM 7010, "Safety Plan Review." Layne-Western did not complete a pre-construction checklist equivalent to ES&H Administrative Form #19.

- The hazard analyses included in the Layne-Western Safety and Health Manual were generic and not tailored to the specific drilling activity for EAV-2/EAV-3.

- The hazard analysis generated the day of the accident did not address either the hazards of the drilling operations or the appropriate controls, nor was it reviewed or approved.

- Layne-Western performed work from September 25, 2000, until the day of the accident without a hazard analysis.

- Fermilab procedures required current excavation permits and burn permits to be attached to the hazard analysis. These permits were not attached to the Layne-Western job hazard analysis. Although an excavation permit was issued for the EAV-2/EAV-3 drilling activity on October 6, 2000, the permit expired seven days after it was issued, and the permit was not extended or updated.

- Fermilab and S. A. Healy did not compare the work operations being conducted to the hazard analysis generated on the day of the accident to verify that safety hazards were adequately identified and appropriate controls established. Evidence indicated that neither the FAO, Fermilab, S. A. Healy, nor Layne-Western line and safety management had reviewed the work activity to evaluate occupational safety hazards, hazard control and abatement, or performance of work since Layne-Western began drilling operations on September 25, 2000.

- Pre-job briefings were informal, not documented, and not effective in conveying the extent of hazards. A work package with a step-by-step review process was not used.

- Work was not performed using appropriate controls, and actions that would be expected as a condition of formally authorizing initiation of work were not implemented.

The Board concluded that because the scope of work was not adequately defined, task-specific hazards could not be analyzed and work could not be performed within controls.

3.1.5 Feedback and Improvement

Feedback and improvement processes for Fermilab subcontractor construction projects consisted of the following mechanisms: assessment processes, analysis of performance information, reporting DOE accident/incident information, corrective action processes, and lessons-learned processes. These mechanisms formed the core of a continuing improvement process for Fermilab subcontractor construction projects.

The Office of the Deputy Assistant Secretary for ES&H Oversight had responsibility for performing independent ES&H oversight of DOE sites. This office had not performed oversight of Fermilab or the NuMI Project.

The Office of High Energy and Nuclear Physics in the Office of Science had the responsibility for the programmatic and technical overview of the NuMI Project. Since November 1998, the Office of Construction Management Support within the Office of Science had conducted six reviews of the NuMI Project, including ES&H. These reviews included ES&H recommendations to the Fermilab Director, although they were not communicated in ISM terms.

Subsequent reviews by the Office of Construction Management Support evaluated the effectiveness of the actions to address the recommendations of the previous review. However, corrective actions addressing recommendations made by the Office of Construction Management Support were not tracked in the Fermilab Environment Safety Health Tracking (ESHTRK) database, or in any other database.

No corrective action plans were developed, although some corrective actions were undertaken. For example, the draft May 22-24, 2001, review report indicated that the Fermilab organizational structure for the NuMI Tunnel and Halls Project was "complex and unwieldy," and that responsibilities and authorities were "confused, and a number of people involved do not have relevant underground construction experience." The review report also noted that the current management structure "is not effective for managing this critical stage of the S. A. Healy tunnels and halls construction contract." A reorganization was under way at the time of the accident.

The Chicago Operations Office Safety and Technical Services organization provided ES&H support to the FAO, as requested. The Chicago Operations Office Manager did not perform independent ES&H oversight of Chicago Operations Office line organizations. Since participating in the October 1999 combined Phase I and II ISM verification of Fermilab, Safety and Technical Services had not been asked to provide technical support to the FAO, or independent oversight on behalf of the Chicago Operations Office Manager. In particular, Safety and Technical Services had not been asked to provide support of safety oversight of NuMI Project construction operations or review of subcontractor safety management at Fermilab.

The Office of Science Functions, Responsibilities, and Authorities Manual, dated June 30, 2000, identified the Office of Science as primarily involved in providing direction and defining scope of work, while Operations Office managers oversee their contractors' performance in analyzing hazards, developing and implementing controls, providing feedback, and pursuing improvement. The document noted that the Chicago Operations Office Manager had responsibility for "day-to-day" oversight of contractor operations, but that organizational elements of the Office of Science had responsibility for appraising the performance of the Chicago Operations Office Manager and maintaining "executive-level" awareness of contractor operational performance.

In describing how the Office of Science exercised the functions, responsibilities, and authorities for measuring the adequacy of line management oversight, the document noted that monitoring of the Chicago Operations Office Manager and associated contractors would be accomplished by (1) reviewing information provided by the Chicago Operations Office; (2) when appropriate, participating in Chicago Operations Office appraisals; and (3) conducting onsite reviews of Chicago Operations Office performance, including verification of appraisal of the contractors.

FAO had line management oversight responsibility for programs, projects, and facilities at Fermilab. For the NuMI Project, the FAO Manager assigned, with the approval of the Director of High Energy Physics, a project manager who was responsible for day-to-day execution of the project. The DOE NuMI Project Manager's responsibilities included monthly project performance reviews and assurance that the NuMI Project complied with ES&H and contracting regulations. He performed bi-weekly inspections of the project using a standard form to document ES&H concerns. The concerns identified during each inspection were reviewed during subsequent inspections to ensure that corrective actions were implemented. Inspections conducted by the DOE NuMI Project Manager addressed general project safety, but lacked in-depth information on the status of compliance with 29 CFR 1926 and Fermilab requirements. Inspection forms were contained in project files but were not used as input to the ESHTRK system or any other project database. An FAO staff member performed two inspections of the EAV-2/EAV-3 job site, but these inspections concentrated on environmental protection issues and were not documented. FAO operational awareness reviews did not cover the NuMI Project. Figure 3-2 displays the DOE organizational relationships for management of the NuMI Tunnels and Halls Project.

Feedback and improvement processes at Fermilab were described in the Fermilab Integrated Safety Management Plan, Revision 3, August 2000. For subcontractor construction projects, performance evaluations and self-inspections were used as feedback mechanisms. The FESHM required that all

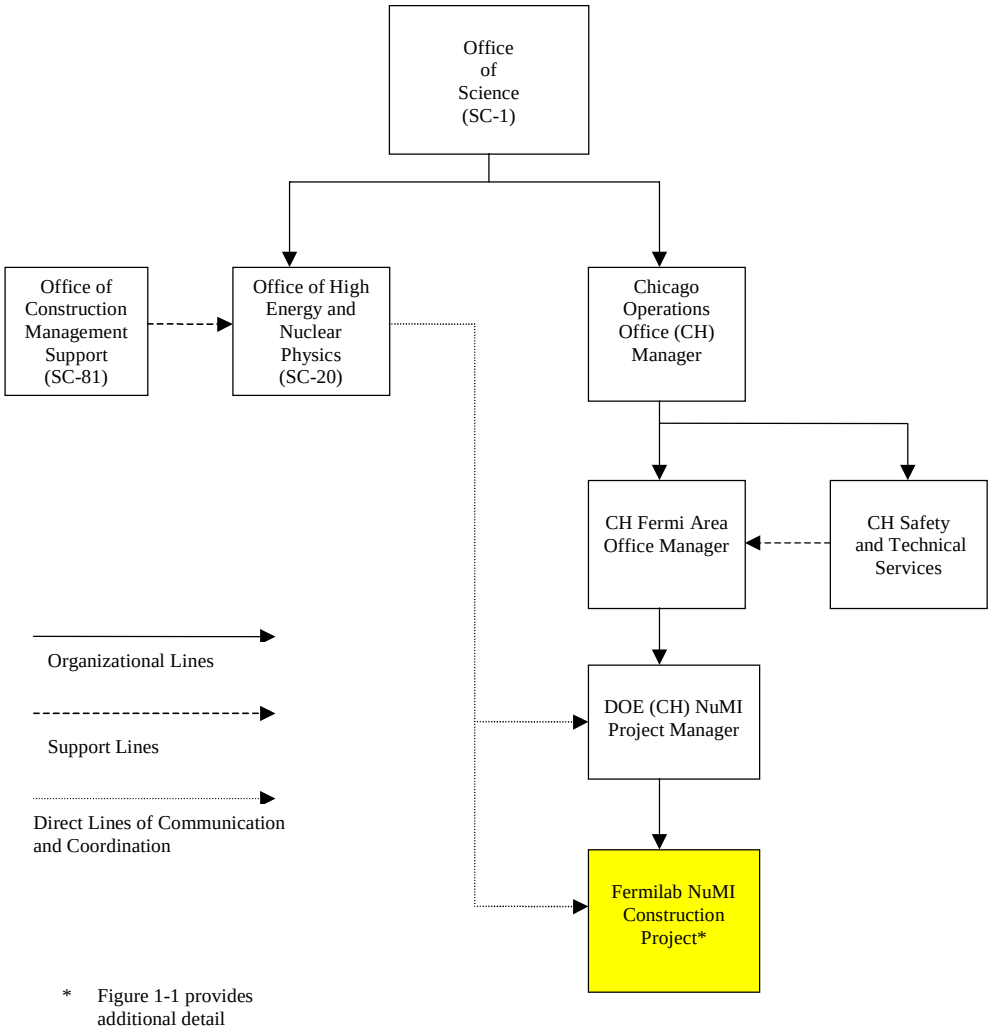


Figure 3-2. DOE NuMI Organizational Chart

subcontractors have their past safety performance evaluated and approved before award of any construction contract equal to or greater than $25,000. The fixed-price subcontract agreement executed by S. A. Healy and Layne-Western, effective September 13, 2000, exceeded $25,000 and therefore required a safety evaluation, but no evaluation was performed for Layne-Western. The Board requested safety statistics to evaluate Layne-Western's safety performance before award of the Layne-Western contract, and was provided with incomplete information. The documentation provided indicated that the recordable injury rate for one year before award of the Layne-Western contract was 4.55.

S. A. Healy lacked a formal evaluation process for selecting subcontractors to perform work under their control. Selection of Layne-Western to perform drilling operations for the NuMI Project was based on S. A. Healy's knowledge of Layne-Western. In addition, Fermilab had not used the evaluation process documented in FESHM 7010 to evaluate and approve Layne-Western's past safety performance. Fermilab management considered it the responsibility of S. A. Healy to select its own subcontractors.

The Fermilab Self-Assessment Program Plan assigned the responsibility for performing assessments of ES&H performance to Fermilab divisions and sections. The Beams Division, which had responsibility for the NuMI Project, assigned management of civil construction to the Facilities Engineering Services Section. According to this plan, the assessments were to be conducted by comparing performance against established requirements. Findings were to be tracked in the ESHTRK system, and analyzed for root causes and trends. Action plans were to be prepared and tracked until all corrective actions were completed. The Facility Engineering Services Section had not conducted a construction safety assessment of the NuMI Project

to evaluate the performance of S. A. Healy and Layne-Western against requirements contained in the Fermilab-S. A. Healy contract, FESHM, or 29 CFR 1926.

FESHM 7010 required construction subcontractor safety performance to be monitored using inspections performed by the construction coordinators in accordance with the Fermilab Subcontractor Construction Safety Program. The Subcontractor Construction Safety Program in FESHM 7010 required the ES&H Section and/or the Senior Safety Officer of the landlord division—in this case, the Facility Engineering Services Section—to perform oversight inspections of construction sites.

Program requirements stipulated that non-conformance with safety standards must be documented, along with the corrective actions determined by line managers. Inspections and surveillances of work performed by S. A. Healy and Layne-Western were conducted by both the NuMI Project construction coordinators and a safety engineer from the ES&H Section. The inspections of Layne-Western focused on environmental issues and not occupational safety. FESHM 7010 also required that random inspections of subcontractor owned tools may be performed by the construction coordinators and ES&H Section construction safety personnel. No inspections of contractor-owned tools associated with the Layne-Western drill rig were performed either by the construction coordinators or by Fermilab ES&H.

In accordance with their company safety manuals, both S.A Healy and Layne-Western assigned responsibilities to safety personnel to conduct job site safety inspections. The S. A. Healy Safety Officer had not recorded observations resulting from daily safety inspections. The Operator, who was the designated Competent Person and safety supervisor, documented two semi-annual inspections of the drilling rig. Layne-Western was unable to provide documentation of the required daily inspections, nor was there evidence that any inspections identified the existing safety deficiencies at the job site. Prior to the accident, Fermilab personnel had not documented any job site safety inspections of drilling operations by Layne-Western.

The Board analysis of feedback and improvement processes indicated that:

- The requirements for ES&H line management oversight by the Office of Science Functions, Responsibilities, and Authorities Manual were not being fully implemented.

- Since participating in the October 1999 combined Phase I and II ISM verification of Fermilab, Safety and Technical Services Support was not requested to provide technical support to the FAO, or to perform independent oversight on behalf of the Chicago Operations Office Manager.

- The Facility Engineering Services Section had not conducted any requirements-based assessments of the NuMI Project.

- The DOE NuMI Project Manager performed ES&H inspections and documented the results of the inspections of the NuMI Project, but the inspection results were not incorporated into the ESHTRK database or another system to show trends in the results of the inspections.

- Layne-Western's past safety performance was not evaluated before awarding their contract.

- FAO, Fermilab, S. A. Healy, and Layne-Western inspections of work site safety at the EAV-2/EAV-3 job site were not rigorous, formal, or documented. Consequently, important safety information that would have provided indications of the degraded condition of the drill rig, safety and health noncompliance, and adverse trends was not collected, compiled, and provided to management.

The Board concluded that Department of Energy and Fermilab oversight programs had not been effective in identifying fundamental weakness in Fermilab subcontractor construction safety and health programs.

In evaluating how the site had analyzed performance information, the Board reviewed recent occurrences at Fermilab to determine whether precursor events existed before the accident. Fermilab had more than 20 occurrence reports between January 1, 1998, and the day of the accident, 6 of them related to construction operations (in one report there are two separate occurrences yielding seven construction safety occurrences). The Board identified similar underlying causes for all six construction occurrences, which are summarized in Table 3-2:

- Work planning and control processes were inadequate to perform work within controls.

- Inadequate hazard analyses were performed.

Table 3-2. Analysis of Previous Fermilab Construction Occurrences

Accident	Type B Accident Electrical Arc Blast at Building F-Zero	Type B Accident Flammable Liquid Fire/Explosion	Construction subcontractor saw cut electrical conduits	Falling Rock injured worker in NuMi Target Hall	NuMI construction workers received 2nd degree chemical burns to legs	NuMI construction worker received contusion to face, rigging deficiency moving transformer	NuMI construction rigging deficiency, worker received broken ribs	Equipment failure causing Personal Injury and work suspension
Date	**October 22, 1997**	**September 4, 1998**	**August 28, 1999**	**January 31, 2001**	**March 14, 2001**	**June 2, 2001**	**June 13, 2001**	**June 21, 2001**
Hazard Analysis and Control	Informal – expert based No JHA* "Routine Maintenance"	Informal – expert based No JHA "Routine Maintenance"	Informal – expert based No JHA "Routine Maintenance"	Informal – expert based No JHA "Routine Maintenance"	Informal – expert based No JHA "Routine Maintenance"	Informal – expert based No JHA "Routine Maintenance"	Informal – expert based No JHA "Routine Maintenance"	Informal – expert based No JHA "Routine Maintenance"
Procedures and Procedure Adherence	Inadequate, no procedure used	Inadequate, no procedure used	Inadequate, no procedures used	Not followed	Inadequate, not followed	Inadequate, no procedure used	Inadequate, no procedure used	Inadequate, no procedure used
"Skill of the Craft"	Over reliance	Over reliance	Over reliance	Over reliance	Over emphasis	Over emphasis	Over emphasis	Over reliance
Training and Competencies	Inadequate for hazard	Not trained on hazard	Inadequate on use of scanning equipment	Inadequate on hazard and controls	Inadequate training on hazard	Inadequate improper rigging	Inadequate improper rigging	Inadequate training on hazard analysis
Pre-job Briefing	Inadequate to identify and control hazard and response	No safety briefing	No safety briefing	No safety briefing	No safety briefing	No safety briefing	No safety briefing	No safety briefing
Use of MSDS*	NA*	MSDS not used for hazards analysis or control	NA	NA	MSDS not used for hazard analysis or control	NA	NA	NA
Provision and use of PPE*	Inadequate PPE & staging	Inadequate PPE	NA	NA	Inadequate PPE	NA	NA	NA
Lessons Learned Corrective Actions	Inadequate response to previous events	Inadequate response to previous events	Inadequate response to previous events	Inadequate response to previous events	Inadequate response to previous events	Inadequate response to previous events	Inadequate response to previous events	Inadequate response to previous events
Institutionalization and communication of hazard and controls	Not adequately defined institutionalized or communicated	Not adequately defined institutionalized or communicated	Not adequately defined institutionalized or communicated	Hazards ignored and controls not followed	Requirements not institutionalized or communicated	Not adequately defined or communicated	Not adequately defined or communicated	Not adequately defined or communicated
Management/ Supervisory Involvement/ Control Oversight	ISM not implemented inadequate oversight/ accountability	ISM not implemented Inadequate oversight/ accountability	Inadequate management of work planning and control	Inadequate management oversight control of work and hazard controls and processes	Inadequate management of work planning and control	Inadequate management of work planning and control (Not reported)	Inadequate management of work planning and control (Safety stand-down directed by Fermi)	Inadequate management of work planning and control

* JHA = Job Hazard Analysis
MSDS = Material Safety Data Sheet
NA = Not Applicable
PPE = Personal Protective Equipment

- Procedures were inadequate or not used to perform work.

- Corrective actions developed in response to previously identified events did not effectively prevent recurrence of similar problems.

The Board concluded that Fermilab had a series of construction safety events with similar systemic causes before the accident. Fermilab did not analyze available construction occurrences to identify trends and root causes. As a result, the systemic weaknesses underlying these events were neither identified nor addressed.

The Board evaluated how the site reported accident information. A majority of the Fermilab construction occurrences involved personnel injuries that required medical treatment and, in some cases, hospitalization. Even though most of these occurrences met the significance threshold for reporting in the DOE Computerized Accident/Incident Reporting System (CAIRS), none of these occurrences were found in the system.

In addition, the Board evaluated Fermilab Construction Subcontractor Lost Workday Case rates to identify reporting and construction trends associated with this data. The Board used CAIRS Lost Workday Case rates from March 1993 to June 2001. This time period includes construction of Fermilab's two major tunneling projects, the Main Injector Tunnel and NuMI Tunnels and Halls. The Board compared the Lost Workday Case rate information for Fermilab Construction Subcontractors provided to the Board during the inbriefing to Lost Workday Case rate information in CAIRS for the period August 27, 1998, to September 15, 2000. Although Fermilab data shows 750 days without a lost workday case during this time period, the Board identified that a subcontractor pipe fitter dislocated his shoulder on November 11, 1998, resulting in 6 lost workdays. Additionally, for six months during the same period of time, Fermilab did not perform any fixed price construction work, thus minimizing the possibility that a lost workday case would have been experienced by subcontractors. Finally, a review of Lost Workday Case rates for the first six months of construction activities on each tunneling project indicated the Lost Workday Case rate approached 20 during the initial phases of construction as shown in Figure 3-3.

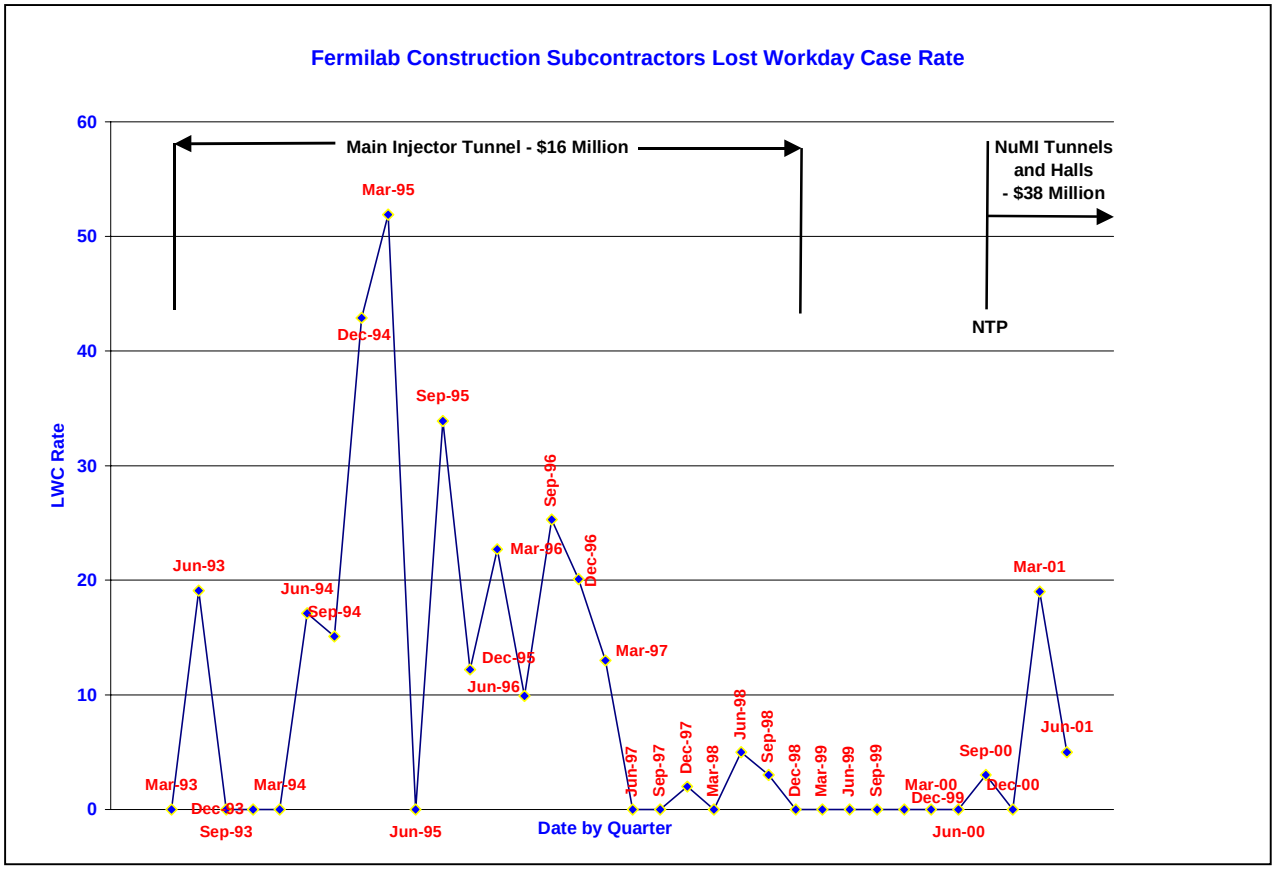


Figure 3-3. Fermilab Construction Subcontractors Lost Workday Case Rate

The Board concluded that Fermilab had not consistently and effectively reported accident and injury information pertaining to construction subcontractors into CAIRS.

To determine whether corrective actions were effective in preventing recurrence of similar problems, the Board reviewed a sample of Fermilab corrective action plans. The plans included two Type B accident investigations conducted by the Chicago Operations Office for accidents involving subcontractors that occurred on October 22, 1997, and September 4, 1998, and the Fermilab investigation report for the NuMI accident of March 12, 2001. Both Type B accident investigations identified causal factors that recurred in this accident as shown in Table 3-2. The site developed and implemented corrective actions for the causal factors for both Type B accidents, and by December 22, 2000, the FAO had verified that all were closed.

Fermilab had performed investigations of other safety events that occurred on the NuMI Project. The Board reviewed the report of the March 12, 2001, concrete placement-burn accident, and the January 31, 2001, accident where a subcontractor was struck by a falling rock in the NuMI Tunnel, to understand the process for identifying and implementing corrective actions for these investigations. The Fermilab accident investigation team's report indicated that the safety plan: (1) was not being fully implemented or enforced, (2) lacked an effective written fall protection and scaling program, (3) did not address corrective actions and lessons learned, and (4) did not assign responsibility for a corporate safety auditing function.

In a memorandum to the Fermilab Director dated April 30, 2001, the Fermilab investigation team recommended that S. A. Healy implement corrective actions to address these deficiencies. Fermilab incorporated the corrective actions into the ESHTRK system. However, according to an ESHTRK report dated June 29, 2001, every action item related to this investigation still remained open.

A Harza consultant performed independent safety reviews and audits of underground construction work and aboveground work related to the tunnel construction, except for the Layne-Western drilling operations. Four audits of S. A. Healy during 2001 identified deficiencies in the company's hazard analysis program. Reviews and audit reports documented general comments, deficiencies, and suggestions for improvement. One report dated March 19, 2001, to March 21, 2001, included a trend analysis evaluating project-related injuries. The consultant recommended that S. A. Healy develop a proactive program to address areas that contributed increased recordable injuries on the NuMI Project. Results of these reviews and audits were not input to the ESHTRK system, and no corrective action plan was developed to address the recommendations resulting from the trend analysis.

The causal factors identified in two previous accident investigations contributed to the June 21, 2001, accident. Recurrence of the causal factors in this accident indicated that Fermilab corrective action processes were ineffective and did not assure necessary improvement of construction subcontractor safety management systems.

The Board concluded the following:

- *Corrective actions implemented by line management in response to identified deficiencies, adverse trends, occurrence reports, and recurring events—including improvements in subcontractor safety management systems and processes—were not effective in preventing recurrence of these deficiencies.*

- *NuMI Project line management had neither established an effective formalized process to capture and track ES&H-related deficiencies and associated corrective actions from investigations, inspections, and audits, nor implemented mechanisms, such as independent verification and performance-based evaluations, to ensure that corrective actions were timely, complete, and effective.*

The Board reviewed Fermilab mechanisms for communication, dissemination, and use of lessons learned involving construction subcontractors and sub-tier contractors. The Subcontractor Safety Subcommittee (S-3) and processes of FESHM 7010 and FESHM 7020, *Subcontractor Safety – Other Than Construction (Interim)*, were used to provide an interface between Fermilab and the subcontractor for sharing lessons learned from both onsite and offsite incidents. The Board reviewed the minutes of the S-3 committee meetings from March 2000 to April 2001. The minutes indicated that the meetings were useful for facilitating communication between Fermilab divisions, but no subcontractors or sub-tier contractors attended the meetings. Additionally, the minutes indicated that there were no discussions of lessons learned from either onsite or offsite incidents, although numerous construction-related OSHA-recordable injuries occurred on the NuMI Project during this time

period. The focus of these meetings indicates missed opportunities to discuss lessons learned.

The processes of FESHM 7010 and FESHM 7020 afforded subcontractors many opportunities to interface with Fermilab safety personnel while planning and executing work. However, these chapters lacked guidance and direction regarding the use of lessons learned for subcontractors.

Section 4.5 of the Fermilab ISM Plan addressed the core function "Feedback and Continuous Improvement." One of the mechanisms that Fermilab used to implement this core function was the Fermilab lessons- learned program. Central to this program was the use of the Fermilab ES&H website. The Board searched the website and found many construction-related lessons learned applicable to NuMI Project subcontractor construction safety management systems. Of particular note are February 23, 1998, lessons learned from the Idaho National Engineering and Environmental Laboratory discussing the use of formal joint collaborating safety surveillances to prevent accidents, increase communications between general and sub-tier contractors, and promote compliance with OSHA requirements. Use of this lesson learned by NuMI Tunnels and Halls line management would have assisted in identifying OSHA deficiencies, improving communications between organizations, and formalizing the process of obtaining safety information for tracking and trending.

Similarly, other safety lessons-learned information readily available to Fermilab from internal and external sources was never communicated to either Layne-Western or S. A. Healy.

The International Association of Drilling Contractors website contained public information that discussed safety measures to be employed for operating drilling equipment. The information addressed the proper positioning of a drilling crew when making or breaking pipe string. Use of this lesson learned might have mitigated or prevented the Operator injury.

The Board concluded that Fermilab processes were ineffective in ensuring that lessons learned were understood and applied by construction subcontractors and sub-tier contractors.

During the investigation, Layne-Western was unable to provide a variety of records and documents requested by the Board, indicating a lack of rigor and formality in managing safety documents. The following documents required by OSHA, DOE, and/or Fermilab were not generated or maintained:

- Hazard analyses
- Inspection records/equipment maintenance records
- Training records for training associated with Competent Persons, site orientation, hazard communications, personal protective equipment, fall protection, hazard assessment, and ladder safety
- Welding, cutting, and brazing permit requirements
- Fire watch training records
- Inspection requirements for slings
- Hazardous energy isolation records
- Work and excavation permits
- Welder qualification records
- Rigger qualification records.

The Board concluded that management had not enforced requirements for maintenance of records documenting the conduct of hazards analyses, inspections, training, and permitting.

3.1.6 Management Systems

Integrated safety management was first introduced at Fermilab in 1997, and the system has evolved since that time to incorporate improvements. The program was most recently changed in August 2000 to incorporate changes suggested by a combined Phase I and Phase II ISM verification review that was completed in October 1999. The verification team noted two key opportunities for improvement among those listed in the verification report, the hazard analysis process and feedback and improvement, and recommended that they be given high priority.

The Office of Science conducted a review of the NuMI Project in May 2001. That review characterized the management structure for the NuMI Project as not effective and concluded that responsibilities and authorities were "confused." The organizational structure for controlling the NuMI construction subcontractor provided several parallel lines of authority. The report provided a number of examples demonstrating that contract requirements were not

followed and that ISM was not embodied in the safety culture. Moreover, the impact of not instituting an effective ISM program was highlighted by the series of injuries that occurred at the NuMI Project since January 2001. Those injuries, taken collectively, amounted to a breakdown in all of the ISM core functions and guiding principles.

The Board also noted deficiencies in all components of ISM as applied to the NuMI Tunnels and Halls Project. For example, responsibilities were not clearly assigned, safety training was insufficient, safety programs and procedures were deficient, and, oversight was inadequate to validate implementation of the five core functions of ISM.

Fermilab demonstrated a lack of clarity in contract requirements and their subsequent flowdown to construction subcontractors and sub-tier contractors. The absence of clarity was exemplified by the inconsistent responsibilities of construction coordinators. Under FESHM 7010, NuMI construction coordinators were assigned responsibilities for ensuring that construction operations were completed in accordance with the safety plan and the hazard analysis. This assignment of responsibility was inconsistent with Condition 4.2 of the Harza contract with Fermilab, which stated, in part, that Harza "shall not have control of and shall not be responsible for safety." However, Sections 2.4 and 2.5 and Exhibit A of the contract required Harza construction coordinators to accomplish safety audits. This dichotomy contributed to NuMI construction coordinators not having a clear understanding of their safety oversight responsibilities. The ability of management to effectively manage the NuMI Project, including the ability to enforce compliance with contracts, was compromised by unclear lines of authority in the project organization. Fermilab and S. A. Healy management had not clearly and properly communicated safety responsibilities to their staffs.

Fermilab and S. A. Healy management also failed to ensure that individuals involved with hazard analysis for the NuMI Project had the necessary knowledge and skills to perform their jobs safely. They failed to administer controls to ensure that effective hazard analysis would be performed on the NuMI construction operations. The S. A. Healy contract with Fermilab required hazard analyses for the operations of S. A. Healy and its subcontractors. Fermilab managers expected S. A. Healy and its subcontractors to administer hazard analysis programs in accordance with the requirements in FESHM 7010, but the Fermilab contract with S. A. Healy did not invoke this manual or make it clear that responsibilities and procedures in FESHM 7010 applied to subcontractors of S. A. Healy. The term *subcontractor*, as used in this document, was applicable to the construction contractors of Fermilab, but was not tailored to apply to contractors of S. A. Healy, such as Layne-Western.

The Chicago Operations Office Manager delegated line oversight responsibility as described in DOE Policy 450.5, *Line Environment, Safety and Health Oversight*, to the FAO Manager, but did not provide independent evaluations consistent with DOE oversight policy as described in DOE Order 414.1A, Change 1, *Quality Assurance*.

FAO and the NuMI Project management's failure to correct previously identified deficiencies in management systems contributed to continuing performance deficiencies. Neither organization made sure that corrective actions were effective in preventing additional accidents, or that common causal factors related to the ISM core functions and guiding principles were effectively addressed. Specifically, neither organization identified that Layne-Western performed drilling operations from September 2000 until June 21, 2001, without a hazard analysis, or that responsibilities for preparation and approval of hazard analyses were not clearly assigned. The FAO did not assign a staff member to monitor the safety of Layne-Western drilling operations until June 2001, even though drilling had been in progress since the previous fall, and the review of Layne-Western operations by this staff member did not focus on safety. The S. A. Healy Safety Director and NuMI construction coordinator who had visited this site also failed to identify safety deficiencies.

Causal factors identified in the 1998 Type B accident investigation appear to be recurring. This situation was noted in the May 2001 semiannual safety performance reviews of the construction project by the Office of Science. Additionally, the same causal factors have been identified as weaknesses in more than 20 injury reports over the last 12 months, 2 of which prompted safety stand-downs.

The effectiveness of feedback and improvement processes applied to construction operations was reduced by documentation deficiencies. Results of safety inspections were not consistently documented and reported, and workplace injuries were not documented in CAIRS. Without such documentation, feedback to management was inaccurate and management decisions were based on incomplete safety information. Performance feedback processes were not adequate to support needed improvements in safety for the NuMI Project. The FAO did not perform

sufficient oversight of safety practices at the job site, or of the safety program applied to Layne-Western by S. A. Healy, to identify significant deficiencies. Fermilab line management did not effectively monitor or control the operations of its subcontractor, S. A. Healy, to assure that S. A. Healy met the terms and conditions of its contract with Fermilab or the provisions of the Fermilab ISM Plan. Line management oversight was not adequate to identify significant safety deficiencies at the Layne-Western job site or to identify the poor condition of the drill rig.

Continuing weaknesses existed in the Fermilab ISM program, as it was applied to construction subcontractors on the NuMI Project. Specifically, Fermilab management had not established sufficiently formalized management systems or work control processes or procedures, but instead relied primarily on expert-based knowledge, skills, and abilities to assure that work was done safely. For example: (1) roles and responsibilities were not well understood, (2) qualifications were not commensurate with assigned duties, (3) the workforce was not held accountable for strict compliance with requirements, and (4) performance feedback systems were not adequate to support needed improvements.

The Board concluded that deficiencies in the construction safety management systems at Fermilab indicated a need for increased commitment by line management to ensure effective implementation of the ISM framework for all subcontractors and sub-tier contractors.

Guiding Principles of Integrated Safety Management

Implementation Deficiencies

Guiding Principle 1: Line Management Is Directly Responsible for the Protection of the Public, Workers, and the Environment.

- The FAO did not provide effective line management for the NuMI Project.
- Neither S. A. Healy nor Layne-Western prepared an ISM plan, and the Fermilab ISM system was not effective in assuring that Layne-Western met the FAO safety expectations.
- S. A. Healy line management did not assure that the condition of Layne-Western equipment met contractual requirements, did not assure that Layne-Western was providing safety oversight of its drilling operations, and did not clearly convey expectations to Layne-Western for preparation of job hazard analyses.
- Layne-Western line management did not set standards for the material condition of the drill rig that were sufficient to prevent equipment failure, did not assure that operators performed required safety inspections or appropriate maintenance of the rig, and did not provide oversight of drilling operations by a safety professional.

Guiding Principle 2: Clear and Unambiguous Lines of Authority and Responsibility for Ensuring Safety Shall Be Established and Maintained at All Organizational Levels Within the Department and Its Contractors.

- Fermilab did not establish clear lines of responsibility or authority for management of S. A. Healy and its subcontractors, and did not enforce compliance with safety requirements.
- Fermilab assigned Harza employees responsibilities for ES&H oversight and control, even though the Harza contract with Fermilab stated that Harza employees were not responsible for safety.
- S. A. Healy assigned administrative and non-ES&H responsibilities to their Safety Director, limiting his time to monitor the safety operations in the field.

Guiding Principle 3: Personnel Shall Possess the Experience, Knowledge, Skills, and Abilities That Are Necessary to Discharge Their Responsibilities.

- Fermilab and S. A. Healy personnel assigned to provide oversight of Layne-Western drilling operations were not fully trained and/or qualified for this assignment.

- Layne-Western employees were not trained in how to prepare job hazard analyses.
- The Layne-Western Operator, classified as a "Competent Person," had not received the training required by contract for that classification.

Guiding Principle 4: Resources Shall Be Effectively Allocated to Address Safety, Programmatic, and Operational Considerations. Protecting the Public, the Workers, and the Environment Shall Be a Priority Whenever Operations Are Planned and Performed.

- The single individual initially assigned to the S. A. Healy safety staff was not sufficient to provide effective safety oversight.
- Construction safety received less attention than cost, schedule, and environmental matters.

Guiding Principle 5: **Before Work Is Performed, the Associated Hazards Shall Be Evaluated and an Agreed Upon Set of Safety Standards Shall Be Established That, If Properly Implemented, Will Provide Adequate Assurance That the Public, the Workers, and the Environment Are Protected from Adverse Consequences.**

- Fermilab did not require S. A. Healy to perform pre-use inspections of drilling equipment.
- Processes have not been established to translate safety requirements in the S. A. Healy contract into procedures for hazard analysis and control by Layne-Western.

Guiding Principle 6: Administrative and Engineering Controls To Prevent and Mitigate Hazards Shall Be Tailored to the Work Being Performed and Associated Hazards.

- Layne-Western management did not assure that operators included appropriate hazards in job hazard analyses.
- The implementation of the Fermilab hazard identification and analysis process was inadequate to identify and mitigate the hazards associated with defective drilling equipment.

Guiding Principle 7: The Conditions and Requirements To Be Satisfied for Operations To Be Initiated and Conducted Shall Be Clearly Established and Agreed Upon.

- Layne-Western was not included on the Fermilab list of safety-qualified subcontractors, and S. A. Healy did not evaluate or approve the past safety performance of Layne-Western, as required by FESHM 7010, before awarding a contract to that company.
- Neither Fermilab nor S. A. Healy reviewed or accepted the Layne-Western ES&H program as required by FESHM 7010.
- S. A. Healy allowed Layne-Western drilling operations to proceed even though the Fermilab construction coordinator had not reviewed or accepted a hazard analysis for this work as required by FESHM 7010.
- Fermilab and S. A. Healy allowed Layne-Western to proceed with drilling operations even though a Notice to Proceed had not been issued by the Fermilab Business Services Section as required by FESHM 7010.
- Layne-Western did not provide contractually required formal work plans to S. A. Healy 30 days before commencement of operations.
- Neither Fermilab nor S. A. Healy established controls to assure a pre-use inspection of the Layne-Western drill rig were conducted to determine whether the condition of the rig met contractual requirements.
- Neither Fermilab nor S. A. Healy established controls to assure that Layne-Western drill rig operators were adequately trained before allowing them to begin drilling.
- Neither Fermilab nor S. A. Healy established controls to assure that Layne-Western had appropriate procedures for operation of the drill rig.

Core Functions of Integrated Safety Management

Implementation Deficiencies

Core Function 1: Define the Scope of Work

- DOE project execution, Fermilab project management, and S. A. Healy work plans lacked detailed provisions for occupational safety.
- Layne-Western did not define specific work steps to be accomplished in planning documents, job letters, or work procedures.
- Responsibilities were not clearly assigned by Fermilab or S. A. Healy for management of construction operations performed by Layne-Western. FESHM 7010 was not fully implemented.
- Safety management systems did not convey DOE safety expectations to Layne-Western.

Core Function 2: Analyze the Hazards

- The hazard analysis prepared for drilling on June 21, 2001, was inadequate.
- Requirements for preparation, review, approval, and use of job hazard analyses were not clearly conveyed to operators, and the job hazard analysis generated on the day of the accident was not reviewed or approved before starting work.
- Layne-Western operators were not trained in the preparation of job hazard analyses.
- No project job hazard analysis was submitted to Fermilab or S. A. Healy for approval before initial drilling by Layne-Western.
- The condition of Layne-Western drilling equipment was not determined before use as specified by the Fermilab Subcontractor Training Manual.
- Layne-Western operators did not perform or document daily checks of safety or equipment condition as required by the S. A. Healy/Layne-Western contract.

Core Function 3: Develop and Implement Controls

- Hazard controls were not established in job letters, work procedures, or job hazard analyses.
- Layne-Western drilling equipment was not inspected or maintained in accordance with the Layne Christensen Health and Safety Program, vendor recommendations, or OSHA requirements.
- Rigging equipment associated with the drill rig was not tested in accordance with OSHA requirements for hoisting and rigging equipment.
- Electrical equipment at the drill site did not meet OSHA requirements.
- Layne-Western had no process to assure engineering review and control over design changes to the drill rig.
- No training or qualification requirements were established for the operator making rig weld repairs.
- Neither the FESHM, nor the S. A. Healy Safety Manual, nor the Layne Christensen Safety Manual was provided at the drill site.
- Layne-Western provided little line supervision over drilling operations.
- The Operator designated as a “Competent Person” did not meet contract requirements for that designation.

Core Function 4: Perform Work Safely

- The wire rope, which extended from the tong handle to the hydraulic ram, was apparently routed around structural interferences on the drill rig, increasing tension on the cable and stress on the connection that failed.
- The injured Operator did not stand clear of the tongs, as recommended in industry guidance, while using the hydraulic cylinder to apply torque to the drill stem.

- Operators were exposed to several OSHA non-compliances at the drilling site.
- Operators did not routinely inspect drilling equipment as specified by the Layne Christensen Health and Safety Program.

Core Function 5: Feedback and Improvement

- DOE, Fermilab, S. A. Healy, and Layne-Western provided ineffective safety oversight.
- Previously-identified deficiencies in Fermilab and S. A. Healy safety programs were not fully addressed.
- Information from previous accidents at the NuMI Project (23 incidents involving worker injuries) was not used to identify and trend safety issues.
- Layne-Western did not take action to prevent recurrence of a previous failure of the eyebolt-cable/piston rod connection.
- Safety deficiencies have not been consistently documented in inspection reports, and workplace injuries have not been documented in CAIRS.
- Corrective actions for previous Type B accidents did not adequately address causal factors.

3.2 Barrier Analysis

Barrier analysis is based on the premise that hazards are associated with all tasks. A barrier is any management or physical means used to control, prevent, or impede the hazard from reaching the target (i.e., persons or objects that a hazard may damage, injure, or harm). The results of the barrier analysis are integrated into the events and causal factors chart to support the development of causal factors. Table 3-3 contains the Board's summary of physical and management barriers that did not perform as intended and thereby contributed to the accident. Appendix D contains the complete barrier analysis.

3.3 Change Analysis

Change analysis examines planned or unplanned changes that caused undesirable results related to the accident. This process analyzes the difference between what is normal, or expected, and what actually occurred before the accident. The results of the change analysis conducted by the Board are integrated into the events and causal factors chart to support the development of causal factors. The results reinforced the barrier analysis results presented above.

3.4 Causal Factors Analysis

A causal factors analysis was performed in accordance with the DOE Workbook, *Conducting Accident Investigations*, Revision 2.

Causal factors are the events or conditions that produced or contributed to the occurrence of the accident and consist of direct, root, and contributing causes.

The **direct cause** is the immediate event or condition that caused the accident. The Board determined that the direct cause of the accident was the failure of the welded connection between the piston rod and the wire rope, releasing the stored energy of the breaking mechanism.

Root causes are events or conditions that, if corrected, would prevent recurrence of this and similar accidents.

The Board also identified contributing causes. **Contributing causes** are events or conditions that collectively with other causes increase the likelihood of the accident, but that individually did not cause the accident.

The root and contributing causes summarizing the Board's causal factors analysis appears in Table 3-4.

Table 3-3. Barrier Analysis Summary

HAZARD	**Energy released from the breaking mechanism due to the failed weld**
BARRIERS	
Define the Scope of Work	Work package (job letter) Communication and flowdown of ISM to sub-tier contractors Contract administration Roles and responsibilities
Analyze Hazards	Hazard analysis
Develop and Implement Controls	Maintenance Inspection of equipment Testing of weld repair Accepted industry practices Training
Perform Work Within Controls	Procedure use and adherence Work readiness and equipment condition
Feedback and Improvement	Corrective action processes Lessons learned Performance feedback processes
Physical System Barriers	Human-machine interface Limit on tong movement Connection of eyebolt to piston
TARGET	**Drilling Rig Crew**

Table 3-4. Causal Factors Analysis Summary

Root Cause	Discussion
Fermilab failed to implement a hazard analysis process that was effectively applied to task-specific hazards for construction subcontractors and sub-tier contractors.	• Layne-Western did not provide a hazard analysis plan before commencing drilling operations. • Drilling began in September 2000 without development of a hazard analysis. • Drill personnel were not requested to develop a hazard analysis for their work until June 2001. • The hazard analysis dated June 21, 2001, did not comprehensively address drilling hazards to which personnel were exposed. • Forms used for the June 21, 2001, hazard analysis did not match S. A. Healy or Fermilab hazard analysis documents. • The Layne-Western hazard analysis process was too generic to identify task specific drilling hazards and was not used. • The S. A. Healy hazard analysis process was not used; if used, it would not have resulted in an adequate task specific hazard analysis. • FESHM 7010 was not used. Instructions in the attachment to ES&H Administrative Form #17 were not required to be used for development of a hazard analysis. • The Fermilab hazard analysis process did not provide clear procedural guidance for evaluating task-specific hazards.
Contributing Causes	**Discussion**
FAO and Fermilab failed to adequately analyze prior occurrences to identify and correct root causes and systemic weaknesses underlying these events.	• Causal factors from two previous Type B accidents contributed to the June 21, 2001, accident. (e.g., inadequate work planning, hazard analysis, work controls). • Recurring deficiencies from prior occurrence reports involving worker injuries indicated that inadequate work planning, hazard analysis, and work controls were allowed to continue to exist at the NuMI Project. • Corrective actions taken by line management in response to identified deficiencies, adverse trends, and recurring events, including improvements to subcontractor safety management, were not effective. • NuMI line management neither established a formalized process to capture and track ES&H-related deficiencies and associated corrective actions from investigations, inspections, and audits, nor implemented mechanisms, such as independent verification and performance-based evaluations, to ensure that corrective actions were timely, complete, and effective. • Processes were ineffective in disseminating lessons learned to construction subcontractors and sub-tier contractors, and to ensure that lessons learned were understood and applied. • Work site safety inspections were not rigorous, formal or documented, so important safety information was not collected or entered into the ESHTRK database or another system to show systemic trends. • Reportable accidents and injury reports from construction accidents on the NuMI Project were not entered into CAIRS.
Fermilab failed to establish and implement processes to translate safety and health requirements into subcontractor procedures. Fermilab did not establish controls to assure that sub-tier contractors were adequately prepared to work safely before authorizing the start of work.	• Drilling personnel began work in September 2000 without formal work authorization. • The Layne-Western job letter did not address occupational safety requirements. • S. A. Healy did not enforce contract requirements for hazard analysis on drilling work. • Fermilab did not enforce contract requirements for hazard analysis.

Table 3-4. Causal Factors Analysis Summary (Continued)

Contributing Causes	Discussion
Fermilab failed to tailor the system for managing subcontractor construction safety to address sub-tier contractors.	• S. A. Healy did not enforce safety and health requirements for Layne-Western work. • S. A Healy adopted the FESHM by reference but did not tailor it for sub-tier contractors. • NuMI construction coordinators' responsibility for acceptance of hazard analysis was not clear. • FESHM 7010 requirements did not translate to sub-tier contractors. • Fermilab did not ensure implementation of the FESHM 7010 hazard analysis process by sub-tier contractors.
DOE and Fermilab oversight programs failed to identify fundamental weaknesses in construction subcontractor and sub-tier contractor safety and health programs.	• Layne-Western inspections did not identify safety deficiencies. • Layne-Western equipment inspections did not identify existing safety concerns. • NuMI construction coordinators were confused on roles and responsibilities related to safety oversight. • Health and safety professionals focused on environmental issues because of the April 26, 2001, wetlands issue. • Fermilab oversight was limited to S. A Healy operations and did not include Layne-Western drilling operations. • FAO, Fermilab, and S. A. Healy safety personnel failed to identify job site safety hazards during numerous visits to the drill site. • Fermilab did not conduct a safety inspection of the Layne-Western equipment (drill rig) upon arrival at the site.
Fermilab failed to effectively communicate roles, responsibilities, and clear lines of authority to ensure the adequate protection of all workers, including construction subcontractors and sub-tier contractors.	• S. A Healy did not require Layne-Western drilling personnel to conduct a hazard analysis until June 20, 2001. • NuMI construction coordinators were not aware of their responsibility for safety at Layne-Western drilling site. • Fermilab safety and health professionals focused on environmental issues because of the wetlands issue. • There is no evidence that Fermilab safety professionals conducted safety and health walkthroughs of the Layne-Western site. • Fermilab believed that review of sub-tier contractor safety programs was the responsibility of only S. A. Healy. • FAO conducted only two inspections of Layne-Western operations before the accident, both with a focus on wetlands environmental issues.
Fermilab failed to ensure that the construction subcontractor and sub-tier contractors had systems in place to train employees in recognizing and mitigating operational hazards.	• Layne-Western drilling personnel were not trained in the Fermilab hazard analysis process before starting work. • Layne-Western drilling personnel were not adequately trained as required by 29 CFR1926, or as necessary in accordance with the hazards associated with the job. • Layne-Western personnel were not asked to participate in the June 9, 2001, safety stand-down training. • Layne-Western personnel did not participate in the June 13, 2001, safety stand-down that included hazard analysis training. • Records did not indicate that Layne-Western personnel attended Fermilab site training. • The S. A. Healy Safety Director was not trained in preparing hazard analyses. • Fermilab and S. A. Healy failed to ensure that Layne-Western personnel were adequately trained and qualified to perform work.

Table 3-4. Causal Factors Analysis Summary (Continued)

Contributing Causes	Discussion
Chicago Operations Office and Fermilab failed to effectively utilize contracting, procurement, and project management mechanisms to consistently convey, oversee, and enforce safety and health expectations to the subcontractor and sub-tier contractors.	• The Layne-Western Operator, who was designated as the "Competent Person," did not meet contract requirements. • Layne-Western did not provide a hazard analysis plan before start of drilling, as required. • The S. A. Healy Safety Director did not meet minimum qualification requirements specified in the contract.
Chicago Operations Office and Fermilab failed to properly implement and ensure the flowdown of the ISM framework to subcontractors and sub-tier contractors.	• Roles and responsibilities were not well understood. • Qualifications were not commensurate with assigned duties. • The workforce was not held accountable for strict compliance with requirements. • Performance feedback systems were not adequate to support needed improvements.

4.0 Judgments of Need

Judgments of need are managerial controls and safety measures believed necessary to prevent or minimize the probability of a recurrence. They flow from the causal factors and are directed at guiding managers in developing corrective actions. Table 4-1 summarizes the Board's causal factors and judgments of need.

Table 4-1. Judgments of Need

Causal Factors	Judgments of Need
Fermilab failed to implement a hazard analysis process that was effectively applied to task-specific hazards for construction subcontractors and sub-tier contractors.	Fermilab needs to improve the existing hazards analysis process in Fermilab Environment, Safety and Health Manual 7010 by developing instructions and guidance to ensure that it applies to sub-tier construction contractors at the work activity level. Fermilab needs to implement a revised hazards analysis process such that: • Detailed procedures are established to formalize the process for conducting task-level job-specific hazard analyses (job hazard analyses). • Personnel are trained on the task-level hazard analysis processes to ensure implementation by all assigned persons. • The process is revised to ensure that all work operations at Fermilab are subjected to formal and effective hazard analyses. This would include all potentially hazardous operations planned for subcontractors and sub-tier contractors. • The process is revised to ensure that hazard analyses involve both the appropriate technical expertise and workers, and receive appropriate review and approval before work begins.
The Fermi Area Office and Fermilab failed to adequately analyze prior occurrences to identify and correct root causes and systemic weaknesses underlying these events.	Fermilab needs to ensure that root and contributing cause(s) from incidents and occurrences are thoroughly evaluated against integrated safety management core functions and guiding principles, and that resulting lessons learned are disseminated and communicated to all appropriate personnel. Additionally, Fermilab needs to conduct follow-up reviews to ensure that the information is used to improve the level of safety at the site. Fermilab needs to ensure that incidents and occurrences at Fermilab are reported through the appropriate DOE

Table 4-1. Judgments of Need (Continued)

Causal Factors	Judgments of Need
	reporting systems (i.e., the Computerized Accident/ Incident Reporting System and the Occurrence Reporting and Processing System), evaluated, analyzed, and trended to ensure that systemic weaknesses are identified and corrected in a timely manner. The Fermi Area Office needs to revise its process for validating closure and effectiveness of corrective actions. Additionally, FAO needs to conduct follow-up reviews to ensure that corrective actions are effectively implemented. The Chicago Operations Office Manager needs to develop and implement a process to provide assurance that effective corrective actions are implemented, and establish a method to obtain feedback on corrective actions taken.
Fermilab failed to establish and implement processes to translate safety and health requirements into subcontractor procedures. Fermilab did not establish controls to assure that sub-tier contractors were adequately prepared to work safely before authorizing the start of work. Fermilab failed to tailor the system for managing subcontractor construction safety to address sub-tier contractors.	Fermilab needs to establish and implement a process to ensure that all safety and health requirements flow down to subcontractors and sub-tier contractors such that: • Procedures are adopted by subcontractors and sub-tier contractors that are tailored for the specific roles and responsibilities for each contracting organization. • Specific procedures are validated to ensure that safety and health requirements are properly implemented. • Improved controls are established to assure that subcontractors and sub-tier contractors are adequately prepared to work safely before authorization to start work is issued. The FAO needs to ensure that Fermilab establishes and implements processes to verify and validate that safety and health requirements are translated into subcontractor and sub-tier contractor procedures. The Chicago Operations Office Manager needs to validate the processes and procedures used by FAO and Fermilab to verify that work controls are established and implemented before the start of work.
DOE and Fermilab oversight programs failed to identify fundamental weaknesses in construction subcontractor and sub-tier contractor safety and health programs.	Fermilab needs to ensure that a program is established and implemented for comprehensive environment, safety, and health oversight of all construction subcontractor and sub-tier contractor work operations. The FAO needs to ensure that oversight of Fermilab is effectively performed as specified in DOE Policy 450.5, *Line Environment, Safety and Health Oversight*.

Table 4-1. Judgments of Need (Continued)

Causal Factors	Judgments of Need
	The Chicago Operations Office Manager needs to ensure that line management and independent oversight are being performed and are effective as specified by DOE Policy 450.5, *Line Environment, Safety and Health Oversight*, and DOE Order 414.1A, *Quality Assurance*. The Office of Science needs to ensure that formal corrective actions are developed and implemented for ES&H issues resulting from programmatic and technical reviews of the NuMI Project. The Office of Science needs to implement the requirements established in the Office of Science Functions, Responsibilities, and Authorities Manual for measuring line ES&H oversight effectiveness of the Chicago Operations Office.
Fermilab failed to effectively communicate roles, responsibilities, and clear lines of authority to ensure adequate protection of all workers, including construction subcontractors and sub-tier contractors.	Fermilab needs to establish and implement a formalized safety management system with clearly defined roles, responsibilities, and authorities when multiple organizations, subcontractors, and/or sub-tier contractors are involved in a construction project.
Fermilab failed to ensure that the construction subcontractor and sub-tier contractors had systems in place to train employees in recognition and mitigation of operational hazards.	Fermilab needs to strengthen the training and competence of all workers, managers, engineers, and safety professionals responsible for construction safety. Fermilab needs to establish processes to assure that hazard recognition and training are in compliance with applicable requirements (Occupational Safety and Health, DOE, and industry standards).
Chicago Operations Office and Fermilab failed to effectively utilize contracting, procurement, and project management mechanisms to consistently convey, oversee, and enforce safety and health expectations to the subcontractor and sub-tier contractors.	The Chicago Operations Office and Fermilab need to revise contracting, procurement, and project management processes to ensure that safety and health requirements associated with construction operations (by subcontractor and sub-tier contractors) are clearly conveyed.
Chicago Operations Office and Fermilab failed to properly implement and ensure the flowdown of the integrated safety management framework to subcontractors and sub-tier contractors.	Fermilab needs to strengthen implementation of the integrated safety management core functions to assure that all potentially hazardous work and operations are subjected to effective, formal, and documented hazard analysis. Fermilab needs to establish and implement a process to ensure that the framework of ISM flows down to all subcontractor and sub-tier contractors. The Chicago Operations Office Manager needs to ensure that the Fermilab process for flowdown of the ISM framework to subcontractors and sub-tier contractors is effective.

5.0 Board Signatures

Patricia Worthington

Date: 08/01/2001

Patricia Worthington, Ph.D., Chairperson
DOE Accident Investigation Board
U. S. Department of Energy
Office of Environment, Safety and Health

Bruce Breslau

Date: 08/01/2001

Bruce Breslau, Member
DOE Accident Investigation Board
U. S. Department of Energy
Office of Environment, Safety and Health

Date: 08/01/2001

William Cooper, Member
DOE Accident Investigation Board
U. S. Department of Energy
Office of Environment, Safety and Health

Date: 08/01/2001

Robert Crowley, Member
DOE Accident Investigation Board
U. S. Department of Energy
Office of Environment, Safety and Health

Don Galbraith

Date: 08/01/2001

Don Galbraith, Member
DOE Accident Investigation Board
U. S. Department of Energy
Carlsbad Field Office

Date: 08/01/2001

Justin Zamirowski, Member
DOE Accident Investigation Board
U. S. Department of Energy
Chicago Operations Office

6.0 Board Members, Advisors, and Staff

Chairperson	Patricia Worthington, Ph.D., DOE-HQ, EH-22
Member	Bruce Breslau, DOE-HQ, EH-21
Member	William Cooper, DOE-HQ, EH-22
Member	Robert Crowley, DOE-HQ, EH-24
Member	Don Galbraith, DOE-Carlsbad Field Office
Member	Justin Zamirowski, DOE-Chicago
Advisor	Matt Cole, DOE HQ, Office of Science
Advisor	Al Gibson, Eagle Research Group
Advisor	Steve Kirchhoff, Battelle Columbus
Advisor	Mike Lambert, Eagle Research Group
Advisor	Karl Moro, DOE-Chicago
Advisor	Dennis Vernon, DOE-HQ, EH-21
Consultant	Thomas Groeneveld, Battelle Columbus
Consultant	Norm Malcosky, Battelle Columbus
Medical Advisor	Joseph Falco, M.D., M.P.H.
Legal Advisor	Vicki Prouty, DOE-Chicago
Technical Writer	Bob McCallum, Battelle Columbus
Technical Writer	Jim McNeil, Eagle Research Group
Administrative Support	Vikki Hanks, Battelle Columbus
Administrative Support	Barbie Harshman, DOE-HQ, EH-21
Administrative Support	Marcia Taylor, Battelle Columbus

APPENDIX A
BOARD APPOINTMENT MEMORANDUM

Department of Energy
Washington DC 20585

June 25, 2001

MEMORANDUM FOR: Marvin E. Gunn, Jr., Manager Chicago Operations Office

FROM: Steven V. Carr, Acting Assistant Secretary
Office of Environment, Safety & Health

SUBJECT: Investigation of the June 22, 2001, Worker Injury at FERMI National Accelerator Laboratory

Based on your recommendation, a Type A Accident Investigation Board is hereby established to investigate the June 22, 2001, worker injury at FERMI National Accelerator Laboratory.

The Office of Environment, Safety, and Health (EH) will lead the Accident Investigation. I have appointed Dr. Patricia Worthington, Director, Office of Environment, Safety, and Health Evaluations (EH-22), as the Accident Investigation Board Chairperson. The Board will be composed of Justin Zamrowski from DOE Chicago, Don Galbraith, DOE-Carlsbad, and William Cooper, Bruce Breslau, and Robert Crowley from EH. Advisors and other personnel as deemed necessary by the Board Chairperson will assist the Board.

The scope of the Board's investigation will include, but is not limited to, analyzing causal factors, identifying root causes resulting in the accident, and determining Judgements of Need to prevent recurrence. The investigation will be conducted in accordance with DOE Order 225.1A, Accident Investigation. The Board will also focus on management roles and responsibilities and application of lessons learned from similar accidents on site or within the Department.

The Board will provide my office with periodic reports on the status of the investigation by keeping Dr. David Stadler, Deputy Assistant Secretary for the Office of Environment, Safety and Health Oversight (EH-2), informed of the status and progress of this investigation. These periodic reports should not include any findings or arrive at any premature conclusions until an analysis of all the causal factors have been completed. Discussions of the investigation and copies of the draft report will be coordinated until I accept and authorize release of the final report.

The report should be provided to my office 20 calendar days from the date of this memorandum.

cc:
R. Card, CS
J. Decker, SC-1
M. Johnson, SC-1
D. Stadler, EH-2
J. Mumaw, CH-FERMI
R. Hardwick, EH-2
P. Worthington, EH-22
J. Zamrowski, CH
D. Galbraith, AL-WHIPP
B. Breslau, EH-22
W. Cooper, EH-22
Robert Crowley, EH-24
T. Rollow, EH-21
E. Blackwood, EH-24

APPENDIX B
DRILL RIG ACCIDENT EVENT CHRONOLOGY

Drill Rig Accident Event Chronology		
Date	**Time**	**Event**
1969	-	Drill rig is manufactured and purchased by Layne-Western.
Early 1970s	-	Drill rig modified, hydraulic cylinder and tongs installed for making and breaking pipe joints.
October 22, 1997	-	Two Fermilab subcontractors injured while working on 480 volt alternating current motor control center (Type B accident investigation).
September 4, 1998	-	Three Fermilab subcontractors injured by vapor fire/explosion while stripping floor. (Type B accident investigation).
February 1999	-	Project Execution Plan approved by the Director of the Office of Energy Research.
March 2, 1999	-	Eyebolt on the end of the hydraulic piston broke, weld repair performed in the field.
March 8, 1999	-	NuMI Project Management Plan “approved provisionally pending peer review” by the Office of Science.
September 27 -October 8, 1999	-	Fermilab Integrated Safety Management System verification conducted by the Chicago Operations Office.
March 6, 2000	-	Notice to Proceed issued for NuMI tunnels and experimental halls.
September 13, 2000	- -	S. A. Healy and Layne-Western contract signed for vent and survey riser shafts: SR-2, SR-3, EAV-1, EAV-2, EAV-3, and EAV-4.
September 18, 2000	-	Layne-Western commenced mobilization on site.
September 21, 2000	-	Wire rope sling for the hydraulic breaking mechanism is replaced.
September 25, 2000	-	Layne-Western started drilling SR-3 survey riser.
October 16 - November 28, 2000	- -	Layne-Western completed drilling survey risers SR-3 and SR-2, and vent shaft EAV-1.
November 28-30, 2000	-	DOE Office of Science Review Committee conducted semiannual review of NuMI Project.
January 31, 2001	-	S. A. Healy employee struck by falling rock.
February 2001	-	Site preparation for EAV-2, EAV-3, and EAV-4 is completed.
March 12, 2001	-	Layne-Western started drilling EAV-3.
March 12, 2001	-	Three S. A. Healy employees receive concrete-chemical burns.
March 15, 2001	-	Lab Director conducts investigation of concrete-chemical burn accident.
April 20, 2001	-	USDA inspected EAV-2/EAV-3 job site and Layne-Western was ordered to stop drilling.
April 26, 2001	-	USDA inspected and approved environmental improvements.
April 30, 2001	-	Layne-Western resumed drilling of EAV-3.
May 2, 2001	-	Layne-Western completed drilling of EAV-3.
May 3, 2001	-	S. A. Healy begins excavation using the tunnel boring machine.
May 4, 2001	-	Layne-Western started drilling EAV-2.
May 22-24, 2001	-	DOE Office of Science Review Committee conducts semiannual review of NuMI Project.

Drill Rig Accident Event Chronology		
Date	**Time**	**Event**
June 2, 2001	-	S. A. Healy employee injured due to improper rigging.
June 9, 2001	-	S. A. Healy conducted full safety stand-down but did not include Layne-Western.
June 13, 2001	-	Two S. A. Healy employees injured due to improper rigging.
June 13, 2001	2:15 PM	Safety stand-down for S. A. Healy work instituted by Fermilab and S. A. Healy.
June 15, 2001	8:00 AM	Work resumed by S. A. Healy.
June 15, 2001	-	Fermilab Director assigned team to investigate S. A. Healy safety performance and safety management.
June 21, 2001	~7:00 AM	Layne-Western drilling crew started the day continuing to drill EAV-2.
June 21, 2001	-	Fermilab construction coordinators visited EAV2/3 drill site.
June 21, 2001	~9:40 AM	Weld connection between eyebolt and piston rod failed, releasing tension on tong handle.
June 21, 2001	**~9:40 AM**	**Layne-Western drill rig Operator injured when struck by tong handle.**
June 21, 2001	-	Layne-Western drill rig Helper attends to the injured Operator, and then seeks emergency response.
June 21, 2001	-	Fermilab employee is driving on Giese Road past EAV-2/EAV-3 job site.
June 21, 2001	9:44 AM	Fermilab employee called 3131, site emergency number for assistance. Two
June 21, 2001	9:48 AM	Fermilab Fire Department EMTs arrived at scene. Two additional Fermilab firefighters arrived with basic life support ambulance.
June 21, 2001	9:48 AM	Fermilab Fire Department Captain arrived and established incident command center on Giese Road.
June 21, 2001	~9:50 AM	Fermilab ES&H personnel responded to emergency call.
June 21, 2001	9:57 AM	Fermilab fire fighters secured injured Operator on backboard and carried Operator to the road. Simultaneously, advanced life support (Geneva Fire Department) ambulance arrives at scene.
June 21, 2001	~10:00 AM	Fermilab ES&H Section personnel restrict access into job site by requesting site security subcontractor on scene to tape off job site entrance and control crowd.
June 21, 2001	10:02 AM	Incident Command Center declares emergency secured and turns scene over to Fermilab Facility Engineering Services Section.
June 21, 2001	10:15 AM	Geneva Fire Department ambulance leaves scene and transports injured Operator to Delnor Community Hospital in Geneva, Illinois.
June 21, 2001	10:00 AM-12:00 PM	Fermilab ES&H Section Safety Coordinator and others inspect the accident scene and take photographs.
June 21, 2001	~12:00 PM	Fermilab security posted at job site to restrict access.
June 21, 2001	1:30 PM	Formal Stop-Work Order issued to S. A. Healy by Fermilab.

APPENDIX C
EVENTS AND CAUSAL FACTORS CHART

CAUSAL FACTORS IDENTIFIED ON THE EVENTS AND CAUSAL FACTORS CHART

A Fermilab failed to implement a hazard analysis process that was effectively applied to task-specific hazards for construction subcontractors and sub-tier contractors.

B FAO and Fermilab failed to adequately analyze prior occurrences to identify and correct root causes and systemic weaknesses underlying these events.

C Fermilab failed to establish and implement processes to translate safety and health requirements into subcontractor procedures. Fermilab did not establish controls to assure that sub-tier contractors were adequately prepared to work safely before authorizing the start of work.

D Fermilab failed to tailor the system for managing subcontractor construction safety to address sub-tier contractors.

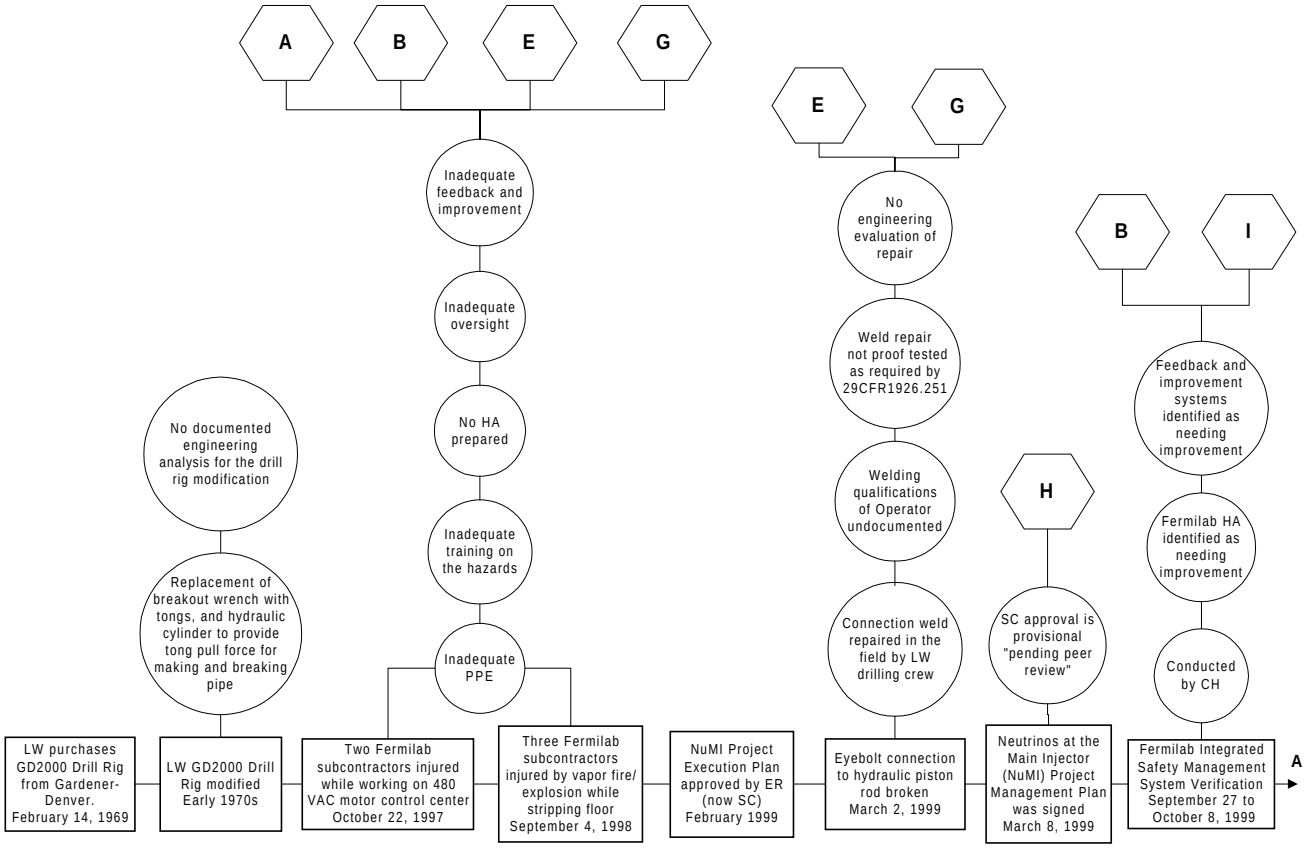
E DOE and Fermilab oversight programs failed to identify fundamental weaknesses in construction subcontractor and sub-tier contractor safety and health programs.

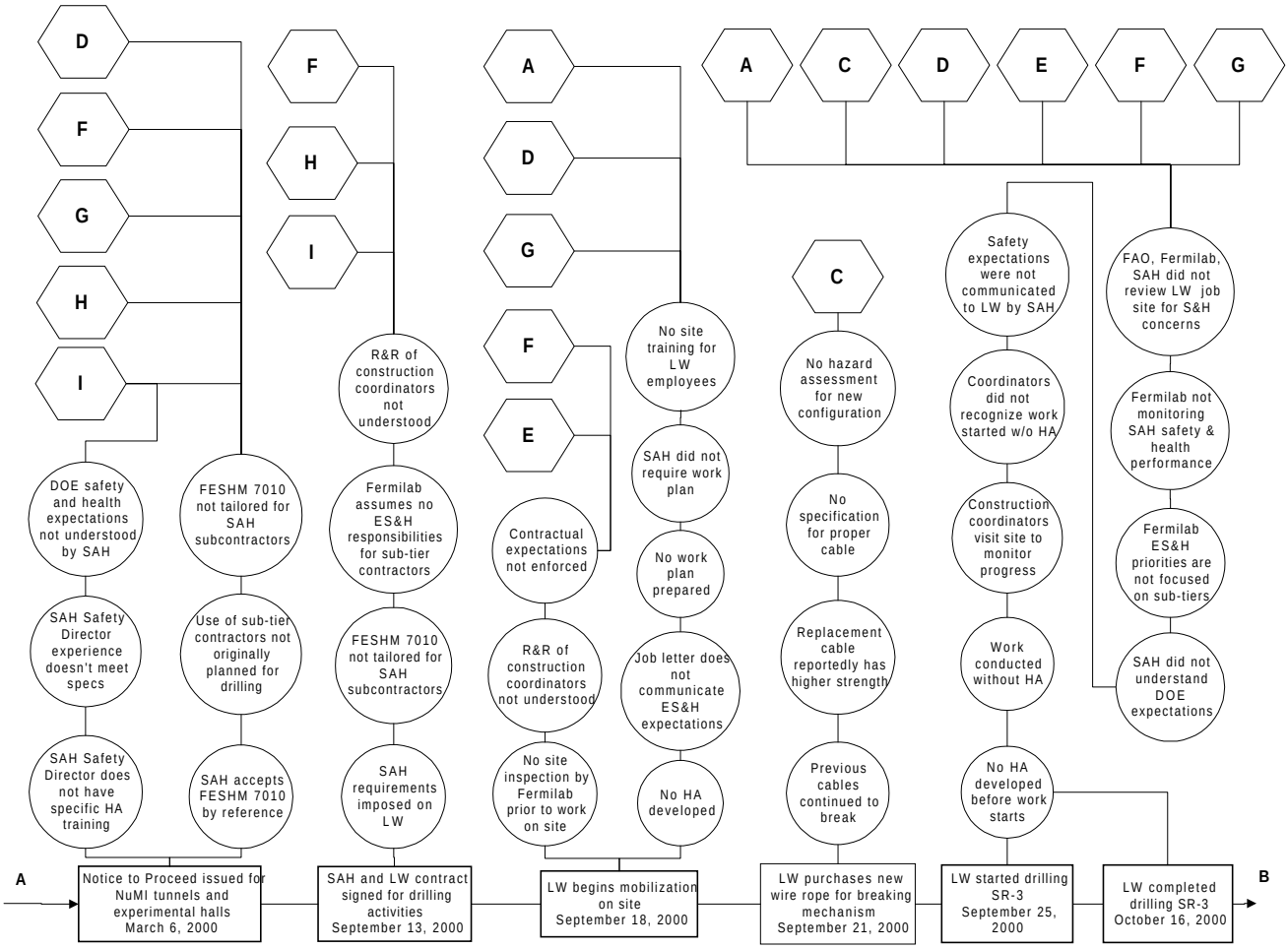
F Fermilab failed to effectively communicate roles, responsibilities, and clear lines of authority to ensure the adequate protection of all workers, including construction subcontractors and sub-tier contractors.

G Fermilab failed to ensure that the construction subcontractor and sub-tier contractors had systems in place to train employees in recognition and mitigation of operational hazards.

H Chicago Operations Office and Fermilab failed to effectively utilize contracting, procurement, and project management mechanisms to consistently convey, oversee, and enforce safety and health expectations to the subcontractor and sub-tier contractor.

I Chicago Operations Office and Fermilab failed to properly implement and ensure the flowdown of the integrated safety management framework to subcontractors and sub-tier contractors.




D
F
G
H
I
DOE safety and health expectations not understood by SAH
SAH Safety Director experience doesn't meet specs
SAH Safety Director does not have specific HA training
FESHM 7010 not tailored for SAH subcontractors
Use of sub-tier contractors not originally planned for drilling
SAH accepts FESHM 7010 by reference
F
H
I
R&R of construction coordinators not understood
Fermilab assumes no ES&H responsibilities for sub-tier contractors
FESHM 7010 not tailored for SAH subcontractors
SAH requirements imposed on LW
A
D
G
F
E
Contractual expectations not enforced
R&R of construction coordinators not understood
No site inspection by Fermilab prior to work on site
No site training for LW employees
SAH did not require work plan
No work plan prepared
Job letter does not communicate ES&H expectations
No HA developed
A
C
D
E
F
G
C
No hazard assessment for new configuration
No specification for proper cable
Replacement cable reportedly has higher strength
Previous cables continued to break
Safety expectations were not communicated to LW by SAH
Coordinators did not recognize work started w/o HA
Construction coordinators visit site to monitor progress
Work conducted without HA
No HA developed before work starts
FAO, Fermilab, SAH did not review LW job site for S&H concerns
Fermilab not monitoring SAH safety & health performance
Fermilab ES&H priorities are not focused on sub-tiers
SAH did not understand DOE expectations
A
Notice to Proceed issued for NuMI tunnels and experimental halls March 6, 2000
SAH and LW contract signed for drilling activities September 13, 2000
LW begins mobilization on site September 18, 2000
LW purchases new wire rope for breaking mechanism September 21, 2000
LW started drilling SR-3 September 25, 2000
LW completed drilling SR-3 October 16, 2000
B
A
C
D
E
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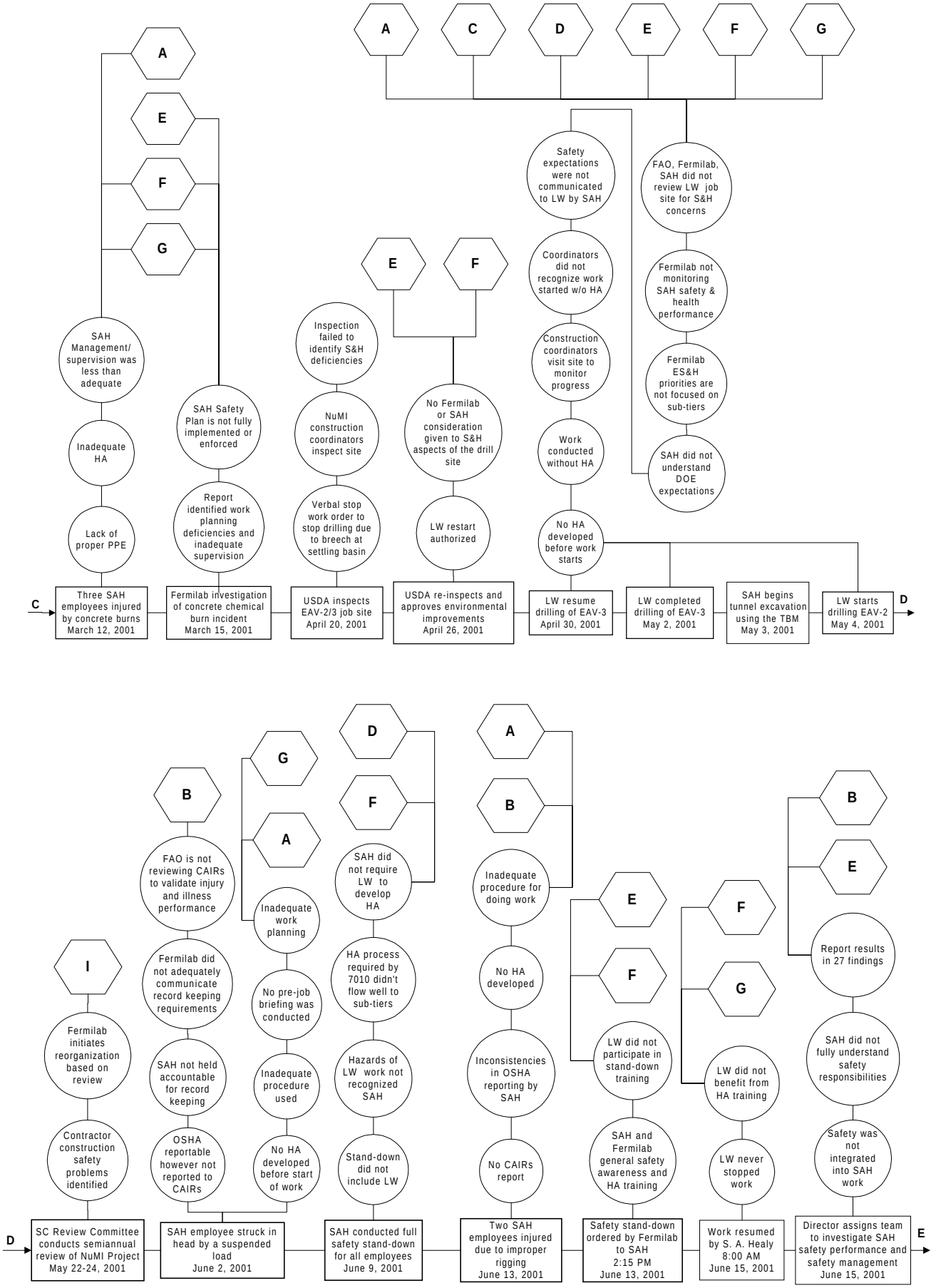
G
Safety expectations were not communicated to LW by SAH
Coordinators did not recognize work started w/o HA
Construction coordinators visit site to monitor progress
Work conducted without HA
No HA developed before work starts
FAO, Fermilab, SAH did not review LW job site for S&H concerns
Fermilab not monitoring SAH safety & health performance
Fermilab ES&H priorities are not focused on sub-tiers
SAH did not understand DOE expectations
Safety expectations were not communicated to LW by SAH
Coordinators did not recognize work started w/o HA
Construction coordinators visit site to monitor progress
Work conducted without HA
No HA developed before work starts
FAO, Fermilab, SAH did not review LW job site for S&H concerns
Fermilab not monitoring SAH safety & health performance
Fermilab ES&H priorities are not focused on sub-tiers
SAH did not understand DOE expectations
B
E
F
No formalized system for tracking recommendations
Recommendation for strict oversight of ES&H
Event caused by inadequate supervision and procedures not used
Fifth event in January
Safety expectations were not communicated to LW by SAH
Coordinators did not recognize work started w/o HA
Construction coordinators visit site to monitor progress
Work conducted without HA
No HA developed before work starts
First work by LW since November 28, 2000
FAO, Fermilab, SAH did not review LW job site for S&H concerns
Fermilab not monitoring SAH safety & health performance
Fermilab ES&H priorities are not focused on sub-tiers
SAH did not understand DOE expectations
B
LW started drilling SR-2 October 17, 2000
LW completes drilling of SR-2 November 7, 2000
LW started drilling EAV-1 November 8, 2000
LW completed drilling EAV-1 November 28, 2000
SC Review Committee conducts semiannual review of NuMI Project November 28-30, 2000
SAH employee struck by falling rock January 31, 2001
Site preparation for EAV-2, 3, and 4 completed February 2001
LW started drilling EAV-3 March 12, 2001
C


A
C
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E
F
G
A
E
F
G
Safety expectations were not communicated to LW by SAH
FAO, Fermilab, SAH did not review LW job site for S&H concerns
Coordinators did not recognize work started w/o HA
Fermilab not monitoring SAH safety & health performance
Construction coordinators visit site to monitor progress
Fermilab ES&H priorities are not focused on sub-tiers
Work conducted without HA
SAH did not understand DOE expectations
No HA developed before work starts
E
F
Inspection failed to identify S&H deficiencies
NuMI construction coordinators inspect site
Verbal stop work order to stop drilling due to breech at settling basin
No Fermilab or SAH consideration given to S&H aspects of the drill site
LW restart authorized
SAH Management/ supervision was less than adequate
Inadequate HA
Lack of proper PPE
SAH Safety Plan is not fully implemented or enforced
Report identified work planning deficiencies and inadequate supervision
C
Three SAH employees injured by concrete burns March 12, 2001
Fermilab investigation of concrete chemical burn incident March 15, 2001
USDA inspects EAV-2/3 job site April 20, 2001
USDA re-inspects and approves environmental improvements April 26, 2001
LW resume drilling of EAV-3 April 30, 2001
LW completed drilling of EAV-3 May 2, 2001
SAH begins tunnel excavation using the TBM May 3, 2001
LW starts drilling EAV-2 May 4, 2001
D
D
I
B
G
D
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F
B
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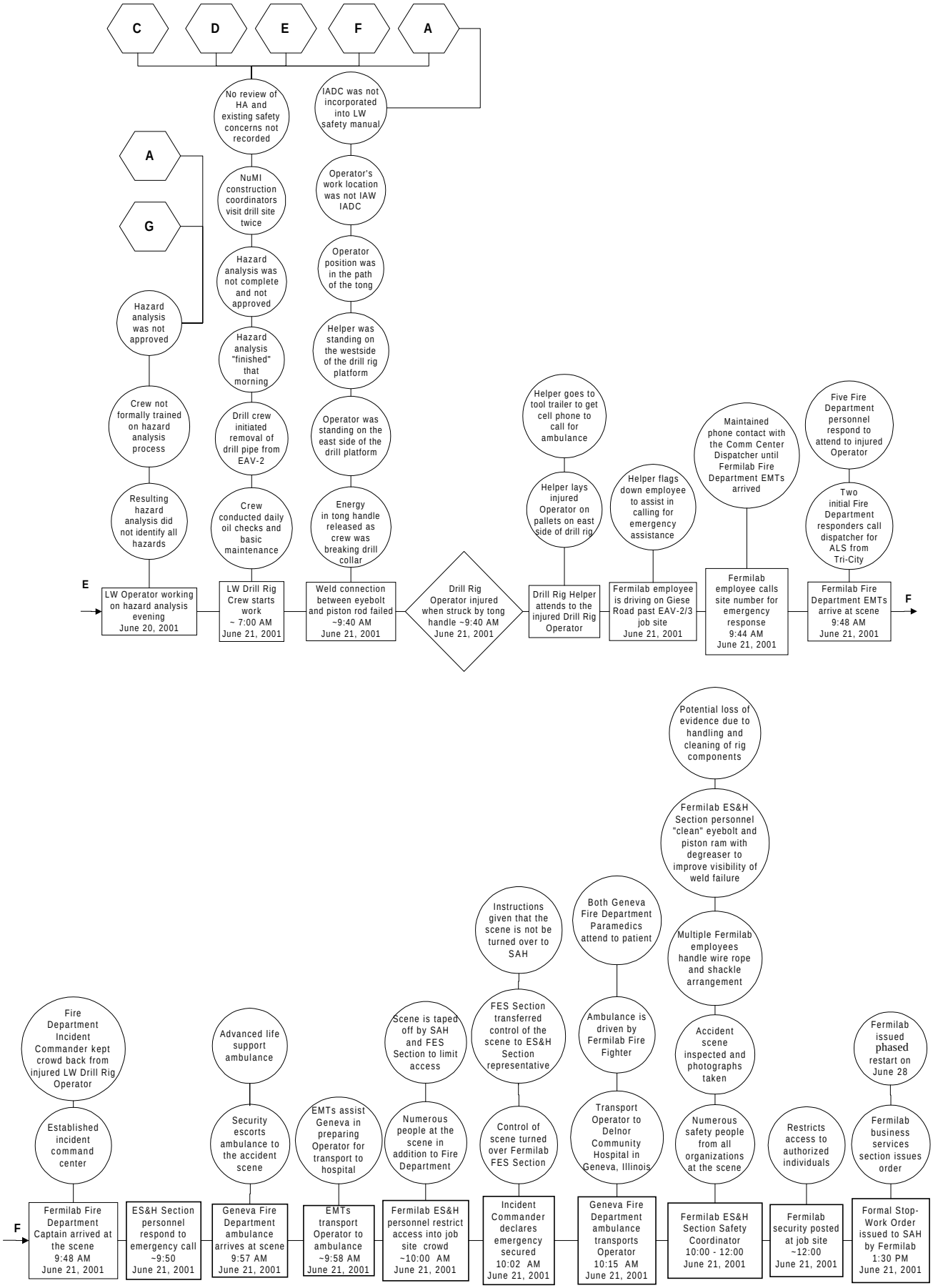
F
A
Fermilab initiates reorganization based on review
FAO is not reviewing CAIRs to validate injury and illness performance
A
Inadequate work planning
SAH did not require LW to develop HA
Inadequate procedure for doing work
No HA developed
Inconsistencies in OSHA reporting by SAH
No CAIRs report
LW did not participate in stand-down training
SAH and Fermilab general safety awareness and HA training
LW did not benefit from HA training
LW never stopped work
Report results in 27 findings
SAH did not fully understand safety responsibilities
Safety was not integrated into SAH work
Fermilab did not adequately communicate record keeping requirements
No pre-job briefing was conducted
HA process required by 7010 didn't flow well to sub-tiers
Contractor construction safety problems identified
SAH not held accountable for record keeping
Inadequate procedure used
Hazards of LW work not recognized SAH
OSHA reportable however not reported to CAIRs
No HA developed before start of work
Stand-down did not include LW
D
SC Review Committee conducts semiannual review of NuMI Project May 22-24, 2001
SAH employee struck in head by a suspended load June 2, 2001
SAH conducted full safety stand-down for all employees June 9, 2001
Two SAH employees injured due to improper rigging June 13, 2001
Safety stand-down ordered by Fermilab to SAH 2:15 PM June 13, 2001
Work resumed by S. A. Healy 8:00 AM June 15, 2001
Director assigns team to investigate SAH safety performance and safety management June 15, 2001
E


C
D
E
F
A
No review of HA and existing safety concerns not recorded
IADC was not incorporated into LW safety manual
A
G
NuMI construction coordinators visit drill site twice
Operator's work location was not IAW IADC
Hazard analysis was not complete and not approved
Operator position was in the path of the tong
Hazard analysis was not approved
Hazard analysis "finished" that morning
Helper was standing on the westside of the drill rig platform
Crew not formally trained on hazard analysis process
Drill crew initiated removal of drill pipe from EAV-2
Operator was standing on the east side of the drill platform
Resulting hazard analysis did not identify all hazards
Crew conducted daily oil checks and basic maintenance
Energy in tong handle released as crew was breaking drill collar
Helper goes to tool trailer to get cell phone to call for ambulance
Maintained phone contact with the Comm Center Dispatcher until Fermilab Fire Department EMTs arrived
Five Fire Department personnel respond to attend to injured Operator
Helper lays injured Operator on pallets on east side of drill rig
Helper flags down employee to assist in calling for emergency assistance
Two initial Fire Department responders call dispatcher for ALS from Tri-City
E
LW Operator working on hazard analysis evening June 20, 2001
LW Drill Rig Crew starts work ~ 7:00 AM June 21, 2001
Weld connection between eyebolt and piston rod failed ~9:40 AM June 21, 2001
Drill Rig Operator injured when struck by tong handle ~9:40 AM June 21, 2001
Drill Rig Helper attends to the injured Drill Rig Operator
Fermilab employee is driving on Giese Road past EAV-2/3 job site June 21, 2001
Fermilab employee calls site number for emergency response 9:44 AM June 21, 2001
Fermilab Fire Department EMTs arrive at scene 9:48 AM June 21, 2001
F
Potential loss of evidence due to handling and cleaning of rig components
Fermilab ES&H Section personnel "clean" eyebolt and piston ram with degreaser to improve visibility of weld failure
Instructions given that the scene is not be turned over to SAH
Both Geneva Fire Department Paramedics attend to patient
Multiple Fermilab employees handle wire rope and shackle arrangement
Fire Department Incident Commander kept crowd back from injured LW Drill Rig Operator
Advanced life support ambulance
Scene is taped off by SAH and FES Section to limit access
FES Section transferred control of the scene to ES&H Section representative
Ambulance is driven by Fermilab Fire Fighter
Accident scene inspected and photographs taken
Fermilab issued phased restart on June 28
Established incident command center
Security escorts ambulance to the accident scene
EMTs assist Geneva in preparing Operator for transport to hospital
Numerous people at the scene in addition to Fire Department
Control of scene turned over Fermilab FES Section
Transport Operator to Delnor Community Hospital in Geneva, Illinois
Numerous safety people from all organizations at the scene
Restricts access to authorized individuals
Fermilab business services section issues order
F
Fermilab Fire Department Captain arrived at the scene 9:48 AM June 21, 2001
ES&H Section personnel respond to emergency call ~9:50 June 21, 2001
Geneva Fire Department ambulance arrives at scene 9:57 AM June 21, 2001
EMTs transport Operator to ambulance ~9:58 AM June 21, 2001
Fermilab ES&H personnel restrict access into job site crowd ~10:00 AM June 21, 2001
Incident Commander declares emergency secured 10:02 AM June 21, 2001
Geneva Fire Department ambulance transports Operator 10:15 AM June 21, 2001
Fermilab ES&H Section Safety Coordinator 10:00 - 12:00 June 21, 2001
Fermilab security posted at job site ~12:00 June 21, 2001
Formal Stop-Work Order issued to SAH by Fermilab 1:30 PM June 21, 2001

APPENDIX D
BARRIER ANALYSIS

Hazard: Energy released from the breaking mechanism due to the failed weld

Target: Drill Rig Crew

What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
Management Barriers			
Core Function 1 Work package (job letter)	Failed	"Job letter" was the extent of the work package. No task-specific breakdown of the work was performed to identify hazards and associated controls to satisfy safety and health expectations.	Job letter did not provide specific procedural controls to identify the hazards associated with the job or provide controls for the work hazards.
Core Function 1 Communication and flowdown of ISM to sub-tier contractors	Failed	Systems and processes were inadequate to implement management safety expectations or to influence change for subcontracted construction projects. Line management did not ensure that the ISM framework was clearly communicated to the sub-tier contractor. Line management did not verify that subcontractors and sub-tier contractors were utilizing the ISM framework in day-to-day work operations.	Fermilab has not demonstrated the commitment to implement ES&H requirements for operations involving contractors, as illustrated by the severity and frequency of past accidents, incidents, and near misses over the past year at the NuMI Project. The flowdown of ISM processes to S. A. Healy and Layne-Western, the sub-tier contractor, could have prevented this accident.
Core Function 1 Contract administration	Failed	There were multiple levels of contracts from DOE to Fermilab to subcontractor and sub-tier contractor. The set of requirements was adequate, but administration of the various tier contracts from the Office of Science (SC), to the Chicago Operations Office (CH), to the FAO, to Fermilab, and to S. A. Healy to Layne-Western was not adequate.	Administration of all aspects of all contracts would have resulted in application of safety and health requirements specified in those contracts, thus preventing the use of substandard equipment and thereby preventing the accident.
Core Function 1 Roles and Responsibilities: EH-2 SC CH FAO Fermilab S. A. Healy Layne-Western	Failed	DOE roles and responsibilities are established by the respective Functions, Responsibilities, Authorities Manuals for the Office of ES&H Oversight (EH-2), the Office of Science (SC), the Chicago Operations Office (CH), and FAO. Many of these responsibilities for both line and independent oversight were not implemented at Fermilab. CH delegated oversight role to the FAO through the CH Functions, Responsibilities, Authorities Manual. FAO documentation identifies oversight responsibilities for the NuMI construction project. NuMI Project Management Plan identified roles and responsibilities for the NuMI Project but was only "provisionally approved pending peer review" by the Office of Science on March 8, 1999. FESHM 7010 defined Fermilab ES&H roles and responsibilities for subcontractor construction safety.	Lack of independent oversight and effective line management oversight by all organizations and management levels permitted hazards to go unrecognized and unmitigated. Lack of line management oversight allowed inconsistent imple-mentation of FESHM 7010. Its application to sub-tier contractors remained unclear, so safety oversight responsibility for sub-tier contractors was not clear. The construction coordinators for the NuMI Project did not understand and therefore did not implement their safety and health roles and responsibilities. S. A. Healy and Layne-Western line management did not actively engage in safety oversight.

Hazard: Energy released from the breaking mechanism due to the failed weld

Target: Drill Rig Crew

What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
		However, the manual was not based on the project management organization at the time of the accident, nor did it address the roles and responsibilities when sub-tier contractors were involved. S. A. Healy and Layne-Western roles and responsibilities were clearly defined, but they were not executed as specified in the respective safety and health manuals.	
Core Function 2 Hazard Analysis	Failed	FESHM 7010 established a hazard analysis process for construction subcontractor work. However, this process was not implemented for the Layne-Western job. The project was drilling its fifth hole before S. A. Healy requested a hazard analysis, even though one was required before the start of work.	The Layne-Western work package ("job letter") for the drilling operation did not identify the job-specific tasks or analyze the hazards. The hazard analysis developed just before the accident did not identify the specific job tasks or the hazards associated with those tasks. A detailed, task-level hazard analysis would have identified the potential hazard of the tong handle and would have prescribed appropriate controls. This would have prevented the accident.
Core Function 3 Maintenance	Failed	Drill rig equipment maintenance and inspection were not performed in accordance with Fermilab and Layne-Western corporate requirements, resulting in the drilling rig arriving at Fermilab in a degraded condition. Documents were not being maintained and therefore did not accurately inform management of equipment maintenance status.	Implementation of an effective equipment maintenance program would have identified the substandard condition of the drill rig before use. This identification could have led to proper maintenance of the drill rig and associated tools, thus preventing the accident.
Core Function 3 Inspection of equipment	Failed	Neither Fermilab nor S. A. Healy conducted a pre-use inspection of Layne-Western equipment when it was brought on site. Fermilab subcontractor training required equipment inspection before use. This training was not provided to the Layne-Western employees. ES&H manuals established equipment inspection and maintenance safety requirements. Vendor manuals established equipment specification and recommendations. Hoisting and rigging equipment was not tested; electrical installations were not to code; operations and maintenance guides were not with the drill rig or vehicle; and drill rig equipment modification and repair were not controlled.	Implementation of the equipment inspection program requirements would have identified the substandard condition of the drill rig and associated tools before use.
Core Function 3 Testing following repair	Not Used	An incomplete weld repair was made to the eyebolt and piston rod connection in 1999. There was no documentation to verify the adequacy of the weld.	Testing and inspection of the weld before use would have identified the substandard weld and resulted in a more

Hazard: Energy released from the breaking mechanism due to the failed weld

Target: Drill Rig Crew

What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
			controlled repair process, thus eliminating the direct cause of the accident.
Core Function 3 Accepted industry practice	Not Used	Public documents from the International Association of Drilling Contractors discussed the proper positioning of the drilling crew to safely make or break a pipe string. These public documents were available on the organization's website. The drill rig crew did not implement recommended industry practice at the time of the accident.	The Operator's position at the time of the accident resulted in the breaking mechanism (tong handle) striking the Operator.
Core Function 3 Training	Failed	The S. A. Healy Safety Director position required certain qualifications and/or experience that were not met by the individual filling this position. Two stand-downs on June 9 and June 13 did not include Layne-Western personnel. Layne-Western did not participate in site-specific training (i.e., FEHSM site orientation). Layne-Western management appointed the drill rig Operator as the Competent Person. The Operator also served as the safety supervisor for the drilling operation. This person did not meet the S. A. Healy contractual definition of a Competent Person. Training records for the designated Competent Person did not include any training on hazard analysis or recognition, nor did he receive the 30-hour OSHA construction safety course or equivalent, as required by the contract. Layne-Western personnel did not receive training on hazard analysis before the start of work.	The Competent Person designated by Layne-Western was not provided with training to ensure that he was knowledgeable of Fermilab-specific requirements, OSHA, or other related safety standards; therefore, Fermilab management systems (FESHM 7010) did not flow down to the sub-tier contractor. No formal training was provided to the designated Competent Person before starting work to ensure that the hazard analysis process at Fermilab was understood.
Core Function 4 Procedure use and adherence	Failed	There is an appropriate set of ES&H requirements in the contracts between Fermilab, S. A. Healy, and Layne-Western (FESHM 7010, S. A. Healy safety manual, Layne-Western safety manual). The associated documents were not provided to Layne-Western (FESHM 7010 and the S. A. Healy safety manual), nor was the manual found at the job site. S. A. Healy did not receive a copy of the Layne-Western safety manual so S. A. Healy could determine whether the company met contract safety requirements. Layne-Western was unaware of the safe work practices specified in the contract and the S. A. Healy safety manual before the start of work for the NuMI Project. Layne-Western, S. A. Healy, and Fermilab did not implement inspection procedures for OSHA compliance.	Fermilab, S. A. Healy, and Layne-Western did not implement the procedural requirements of FESHM 7010 or their respective safety manuals to ensure safe operation.

Hazard: Energy released from the breaking mechanism due to the failed weld

Target: Drill Rig Crew

What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
Core Function 4 Work readiness and equipment condition	Failed	The notice to proceed for the Layne-Western work was not approved by contract administration as required by FESHM 7010. The notice to proceed required hazard analysis and appropriate permits (excavation, burn permit, etc.). Fermilab did not ensure that all work was being performed consistent with Fermilab safety and health requirements.	Fermilab did not ensure that a hazard analysis was developed, reviewed, and approved before work. Fermilab did not verify that the drill rig equipment met safety expectations before drilling work.
Core Function 5 Corrective Action processes	Failed	Two Type B accident investigations of subcontractors at Fermilab identified hazard analysis and identification of safety requirements as causal factors. Implementation of corrective action processes at Fermilab was ineffective to ensure that: • Effective hazards analysis processes were developed and implemented for work involving subcontractors and sub-tier contractors. • Safety requirements were effectively communicated, understood, and implemented by subcontractors and sub-tier contractors. The Fermilab investigation of the cement burn incident (March 2001) and the Fermilab-initiated review of S. A. Healy safety performance and safety management (completed on April 30) identified findings similar to the two Type B investigations and the combined Phase I and II ISM verification conducted in October 1999. All findings related to the investigation that are tracked in ESHTRK remain open. Corrective action plans for the March 2001 independent safety audits were not developed and therefore not tracked in ESHTRK.	Corrective action implementation from previous Type B accident investigations and the ISM verification was not adequate to prevent recurrence. Previous accidents identified that hazard analysis processes were not effectively implemented for work operations conducted by sub-tier contractors. For the Layne-Western drilling operations, a hazard analysis was not requested or developed before the start of work. Preparation of the hazard analysis, at the job and task level, might have identified tong handle rotation as a hazard and proper controls could have been established, thus avoiding the accident.
Core Function 5 Lessons learned	Not used	Fermilab lacked requirements, direction, or guidance on the use of lessons learned for construction subcontractor operations. Layne-Western, a sub-tier contractor, did not participate in the June 2001 S. A. Healy safety stand-downs. Neither S. A. Healy nor Fermilab ensured their participation in the hazard analysis training session. Feedback and improvement processes documented in Fermilab ISM Plan were ineffective for subcontractor and sub-tier contractor operations.	The lessons-learned program failed to disseminate information to the appropriate subcontractor levels. The mechanism for communicating lessons learned to construction subcontractors was inadequate to assure continuous feedback and improvement. Layne-Western was not given an opportunity to improve its hazard analysis process based on Fermilab lessons learned. The drill crew was not properly prepared to identify and mitigate all operational hazards associated with the drill rig.

Hazard: Energy released from the breaking mechanism due to the failed weld

Target: Drill Rig Crew

What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
Core Function 5 Performance feedback processes	Failed	Review Committee semi-annual reviews provided oversight on behalf of the Office of Science. The DOE NuMI Program Manager was getting only limited information on ES&H status from the DOE NuMI Project Manager, who collected only limited safety and health information. The Chicago Operations Office's delegation of the oversight role to FAO was not effectively implemented for safety oversight. Fermi ES&H did only environmental reviews for compliance with the wetlands permit. Construction coordinators did not focus on safety during their daily reviews of the job site, and there were no documented safety audits. Therefore, trend analysis for safety was not possible. S. A. Healy and Layne-Western observations of safety were informal and not documented. The NuMI Project had experienced at least 23 incidents involving worker injuries, at least 15 of which were recordable incidents that had not been reported through CAIRS. As a result, management was not provided with an accurate assessment of injury trends.	Line Management did not use feedback and assessment processes to maintain accurate information on the status of worker health and safety. The lack of assessment and feedback, through documenting safety observations of the drill sites and the Layne-Western tools and equipment, removed a method of assuring that Layne Western drilling operations conformed to safety requirements.
Physical Barriers			
Physical human-machine interface	Failed	The location of the operating station used to control hydraulic pressure to the piston rod placed the Operator near the danger zone of tong handle rotation. No safety bulletin or operating procedure was available at the job site to alert the Operator of the potential hazard.	The Operator was physically located inside the danger zone of tong handle rotation while he was attempting to break pipe when the weld failure occurred.
Physical limit on tong movement	Not Effective	The reported physical location of the Operator just before the accident placed him within the range of motion of the tong handle, inside the physical stop on the drill rig.	The Operator was inside the danger zone of the range of motion of the tong handle. When the weld failed and the tension was released on the tong, the tong was rapidly rotated by the torsional energy stored in the pipe string, striking the Operator.
Physical connection of eyebolt to piston	Failed	Weld repair of the eyebolt connection to the piston rod was conducted with no evidence of engineering review of the existing design (threaded connection). No engineering analysis of the adequacy of the weld repair.	Failure of the welded connection released the tension on the wire rope and tong handle. Stored energy in the pipe then caused the tong handle to rotate and strike the Operator.

Tables, Figures, and Exhibits

Tables

Figures

Exhibits

Abbreviations Used in This Report

CAIRS	**Computerized Accident Information Reporting System**
CFR	**Code of Federal Regulations**
DEAR	**Department of Energy Acquisition Regulation**
DOE	**U. S. Department of Energy**
EAV	**Exhaust Air Vent**
EMT	**Emergency Medical Technician**
ES&H	**Environment, Safety, and Health**
ESHTRK	**Environment, Safety and Health Tracking (system)**
FAO	**DOE Fermi Area Office**
Fermilab	**Fermi National Accelerator Laboratory**
FESHM	**Fermilab Environment, Safety, and Health Manual**
HA	**Hazard Analysis**
ISM	**Integrated Safety Management**
JHA	**Job Hazard Analysis**
MSDS	**Material Safety Data Sheet**
NuMI	**Neutrinos at the Main Injector**
OSHA	**Occupational Safety and Health Administration**
PPE	**Personal Protective Equipment**
SC	**DOE Headquarters Office of Science**