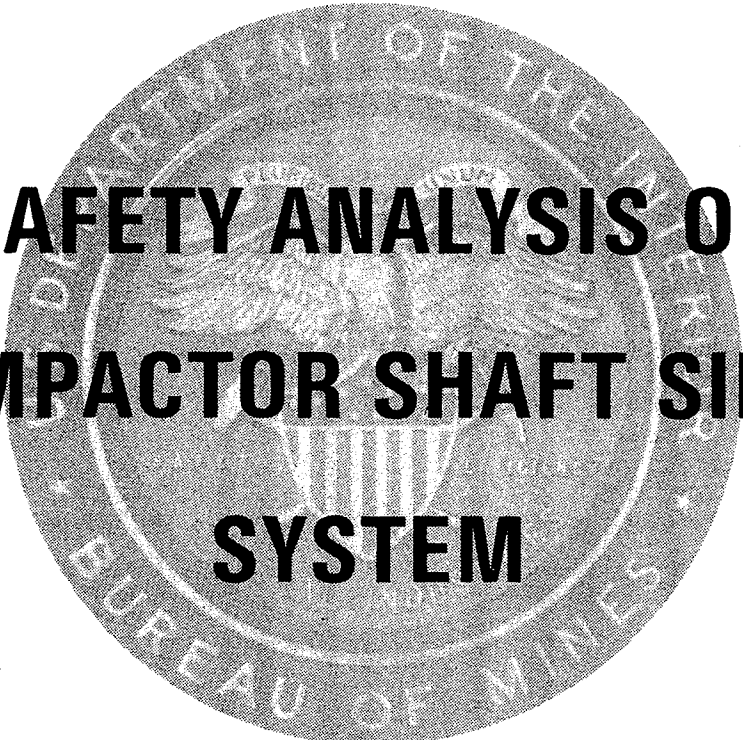


**A minerals research contract report
March 1982**

U.S. DEPARTMENT OF LABOR MSHA



00031292

A large, circular, faded seal of the Bureau of Mines is centered in the background. It features an eagle with spread wings perched on a shield with vertical stripes. The words "DEPARTMENT OF THE INTERIOR" are arched across the top, and "BUREAU OF MINES" is arched across the bottom, separated by two stars.

SAFETY ANALYSIS OF THE IMPACTOR SHAFT SINKING SYSTEM

Contract J0100002
Battelle, Pacific Northwest Laboratories

BUREAU OF MINES ★ UNITED STATES DEPARTMENT OF THE INTERIOR
Minerals Health and Safety Technology

REPORT DOCUMENTATION PAGE		1. REPORT NO.	2.	3. Recipient's Accession No.
4. Title and Subtitle Safety Analysis of the Impactor Shaft Sinking System			5. Report Date March 1982	
7. Author(s) C. A. Geffen, et al.			8. Performing Organization Rept. No. BNW 23111-04112	
9. Performing Organization Name and Address Battelle, Pacific Northwest Laboratories P. O. Box 999 Richland, Washington 99352			10. Project/Task/Work Unit No. 04112	
			11. Contract(G) or Grant(G) No. (C) JO 100002 (G)	
12. Sponsoring Organization Name and Address U.S. Department of Interior Bureau of Mines Washington, D.C. 20241			13. Type of Report & Period Covered Final Report May 1980-Nov. 1981	
14.				
15. Supplementary Notes				
16. Abstract (Limit: 200 words)				
This report, sponsored by the U.S. Bureau of Mines, presents the results of an examination of the safety of the impactor shaft sinking system in comparison to conventional shaft sinking technology. Detailed study of the impactor system was also performed to identify and recommend design changes for optimum safety conditions. A comparison of the impactor machine and its support systems with conventional shaft sinking was made on the basis of relative risk levels. Risk incorporates measures of both the frequency and the potential consequence of accidents. A safety evaluation of the component operations of the impactor shaft sinking system was performed using a Failure Modes and Effects Analysis (FMEA) methodology. The results of this analysis show generally that the impactor shaft sinking system is safer than conventional shaft sinking. The potential risk of conventional shaft sinking operations could be reduced by an average of over 35 percent with use of the impactor shaft sinking system. Design change recommendations to further improve the safety of the impactor system include a revised fire suppression system, improved access to and from the operator cabs, reliable noise attenuation measures, and improved communication systems. An operational safety manual was also developed for the impactor shaft sinking system.				
17. Document Analysis				
a. Descriptors		Safety Analysis		
Impactor Machine		Comparative Assessment		
Pneumatic Hammer		Failure Modes and Effects Analysis		
Shaft Sinking		Exposure to Hazards		
Accidents				
b. Identifiers/Open-Ended Terms				
c. COSATI Field/Group				
18. Availability Statement Unlimited		19. Security Class (This Report) Unclassified		21. No. of Pages 392
		20. Security Class (This Page) Unclassified		22. Price

FOREWORD

This report was prepared by Battelle, Pacific Northwest Laboratories, in Richland, Washington, under USBM contract number J0100002. The contract was initiated under the Minerals Health and Safety Technology Program. It was administered under the technical direction of the Spokane Research Center with Mr. Michael J. Beus acting as Technical Project Officer. Mr. J. P. Connolly was the contract administrator for the Bureau of Mines. This report, in two volumes, is a summary of the work recently completed as a part of this contract during the period May 1980 to November 1981. This report was submitted by the authors in March 1982.

The authors of this document are listed below with specific reference to the separate tasks in this study to which they contributed. The authors gratefully acknowledge the contributions of the people and organizations involved with the development of the impactor shaft sinking machine.

Study Contributors

Project Manager

C. A. Geffen

Technical Contributors

P. M. Daling: Safety Manual (Volume 2)

L. J. Defferding: Appendix F

C. A. Geffen: Impactor System Description
Appendices B, C and D

J. J. Jacobsen: Impactor System Description

J. M. Oylear: Impactor System Description
Appendix C

S. H. E. Phillips: The Cementation Company of America, Inc.
Impactor System Description
Appendix B

D. P. Williams: Impactor System Description
Appendices E and F

CONTENTS

	<u>Page</u>
FOREWORD	2
Study Contributors	2
ABSTRACT	7
EXECUTIVE SUMMARY	8
INTRODUCTION	12
IMPACTOR SYSTEM DESCRIPTION	14
Site Characteristics	15
Impactor Machine Description	22
Support Systems	31
Shaft Sinking Operations	42
Working Environment	52
COMPARATIVE SAFETY ASSESSMENT	55
Breaking Rock	61
Loading Muck	62
Maintenance	63
Summary	63
FAILURE MODES AND EFFECTS ANALYSIS	65
General Findings of the Impactor System FMEA	67
Impactor Machine	68

CONTENTS (cont)

	<u>Page</u>
CONCLUSIONS AND RECOMMENDATIONS	72
BIBLIOGRAPHY	74
APPENDIX A - STATEMENT OF WORK AND PROJECT PLAN	76
APPENDIX B - A DESCRIPTION OF CONVENTIONAL SHAFT SINKING METHODS FOR METAL/NONMETAL MINES	93
APPENDIX C - PRELIMINARY HAZARDS ANALYSIS	128
APPENDIX D - COMPARATIVE SAFETY ANALYSIS OF THE IMPACTOR SYSTEM	168
APPENDIX E - FAILURE MODES AND EFFECTS ANALYSIS OF THE IMPACTOR SHAFT SINKING SYSTEM	261
APPENDIX F - SAFETY-RELATED DESIGN CHANGE RECOMMENDATIONS FOR THE IMPACTOR SHAFT SINKING SYSTEM	343

FIGURES

1	Applicability of Impactor for Shaft Excavation as a Function of Geology	16
2	Site Layout	18
3	General Arrangement of Shaft During Excavation	20
4	General Arrangement of Impactor in a Shaft	23
5	General Arrangement of Major Hydraulic Components	28
6	General Arrangement of Hoists and Headframe	33
7	General Arrangement of Galloway and Impactor	36
8	FMEA System Diagram	66

TABLES

	<u>Page</u>
1 Baseline Risk Values for Conventional Shaft Sinking Systems and Relative Risk Value for the Impactor System	9
2 Recommended Design Changes for the Impactor Shaft Sinking System	11
3 Preshift Maintenance Checks	30
4 Weekly Maintenance Checks	30
5 Monthly Maintenance Checks	31
6 Shift Personnel Requirements	52
7 Additional Day Shift Personnel	52
8 Comparative Tasks, Equipment and Times for Conventional and Impactor Shaft Sinking Systems for a 2500 Foot, 22 Foot Finished Diameter, Concrete-Lined Shaft	52
9 Final Accident Data Distribution for Metal/Nonmetal Shaft Sinking (1978-1980)	58
10 Potential Accident Categories Present in Impactor Shaft Sinking System Functions	59
11 Baseline Risk Values for Conventional Shaft Sinking Systems and Relative Risk Value for the Impactor System . .	62

SAFETY ANALYSIS OF THE IMPACTOR SHAFT SINKING SYSTEM

C. A. GEFFEN
PROJECT MANAGER

ABSTRACT

This report, sponsored by the U. S. Bureau of Mines, presents the results of an examination of the safety of the impactor shaft sinking system in comparison to conventional shaft sinking technology. Detailed study of the impactor system was also performed to identify and recommend design changes for optimum safety conditions. A comparison of the impactor machine and its support systems with conventional shaft sinking was made on the basis of relative risk levels. Risk incorporates measures of both the frequency and the potential consequence of accidents. A safety evaluation of the component operations of the impactor shaft sinking system was performed using a Failure Modes and Effects Analysis (FMEA) methodology.

The results of this analysis show generally that the impactor shaft sinking system is safer than conventional shaft sinking. The potential risk of conventional shaft sinking operations could be reduced by an average of over 35 percent with use of the impactor shaft sinking system. Design change recommendations to further improve the safety of the impactor system include a revised fire suppression system, improved access to and from the operator cabs, reliable noise attenuation measures and improved communication systems. An operational safety manual was also developed for the impactor shaft sinking system.

EXECUTIVE SUMMARY

Shaft sinking, using currently available technology, is one of the most time-consuming and hazardous operations in underground construction and mining. Statistics show the accident frequency rate for shaft sinking to be nearly four times that of all underground mining activities combined for metal/nonmetal mines. The use of an impactor machine to replace the conventional drilling and blasting cycle for fragmenting rock in the shaft bottom could do much to eliminate these hazardous conditions.

The development of the impactor machine has been pursued on the basis of increased sinking rates and reduced costs. The safety of the machine did not receive full emphasis during design. To determine the actual safety advantages of the impactor system over conventional technology, it is necessary to see if the machine mitigates the hazards present in conventional shaft sinking operations. It is also important to determine whether the use of impactor hammer technology introduces new hazards into the working environment.

The objective of this study, sponsored by the Bureau of Mines, is to examine the safety of the impactor shaft sinking system in comparison to conventional shaft sinking in metal/nonmetal mines and to identify and recommend design changes for optimum safety conditions. In addition, an operational safety manual was developed for the impactor system. The manual generally outlines procedures for reducing the possibility of accidents at the construction site.

Detailed safety analysis methodologies were employed in this study to provide a complete assessment of the impactor machine and its support systems. Safety analysis provides a systematic identification and analysis of the hazards of a system, as well as an awareness of system risks. Risk measures incorporate both the frequency and the potential consequence of accidents. These methods allow the elimination or control of undesirable risks before a system is put into normal operation. Risk can be controlled by changes in engineering design, operating procedures, or management policies.

A quantitative comparison of the safety of the impactor shaft sinking technology with conventional shaft sinking was made on the basis of relative risk levels. A safety evaluation of the component operations of the impactor

system was performed using a Failure Modes and Effects Analysis (FMEA) methodology. The safety manual for the impactor system was developed by combining the safety output of the comparative safety assessment and the FMEA with the application of Management Oversight and Risk Tree (MORT) techniques. MORT is a formal, disciplined logic that is used to systematically relate and integrate a wide variety of safety concepts.

The specific results of this study show that:

- Use of the impactor shaft sinking system instead of conventional techniques is expected to reduce risk in shaft sinking operations by about 35%. The use of the impactor machine can significantly reduce risks in the following operations.
 - Breaking rock
 - Loading muck
 - Maintenance

Specific risks for each shaft sinking function in the impactor system are outlined in Table 1.

TABLE 1. Baseline Risk Values for Conventional Shaft Sinking Systems and Relative Risk Value for the Impactor System

Function	Baseline Risk Value (Conventional)	Average Relative Risk Value (Impactor)	Average Difference in Risk with Impactor
Mobilization	4.02	4.02	0
Breaking of Rock	27.95	4.47	-84%
Loading of Muck	122.89	33.53	-73%
Haulage of Muck	202.66	163.24	-19%
Haulage of Men	439.24	343.16	-22%
Maintenance	210.10	58.81	-72%
Haulage of Materials	22.65	27.02	+19%
Pipeline Extension	100.98	80.85	-20%
Shaft Lining	8.40	7.43	-12%
Shaft Wall Support	4.40	4.40	0
Shaft Station Completion	1.50	1.50	0
Ventilation	0.34	0.22	-35%
Shaft Dewatering	0.54	negligible	-99%
Communications	0.34	0.28	-18%
Demobilization	0.10	0.10	0
System Total	1146.11	728.98	-36%

- Primary system safety advantages of impactor shaft sinking technology over conventional shaft sinking methods include the following:
 - Smaller crew, less time downhole
 - No use of drills or explosives
 - Protected working environment
 - No men stationed on the shaft bottom
 - No exposure to blasting fumes
 - Reduced concrete handling requirements
- The use of the impactor hammer technology also presents some additional hazards, however, including:
 - Increased risk of electrical accidents
 - Increased risk of injury from fires
 - Potential occupational hazards from long-term exposure to vibration and noise
 - Increased risk of slip and fall accidents because of difficult access routes to and from the operators cabs
- Safety-related design changes have been recommended for the impactor shaft sinking system to mitigate the potential hazards of the technology. These changes are itemized in Table 2.
- Training of personnel is very important with a new technology such as the impactor machine.
- Emergency evacuation procedures should be instituted at any site employing the impactor system and practiced on a routine basis.

The overall results of this study show that formal safety analysis techniques can provide valuable information in assessing new mining technology. The methods used in this study, while developed for safety applications, can be refined and modified for use in equipment reliability and system efficiency applications. Also, these methods can be applied to existing mining systems to identify the most important areas of risk and assist in formulating research and development programs aimed at reducing these risks and improving the safety of the mining industry.

TABLE 2. Recommended Design Changes for the Impactor Shaft Sinking System

<u>Suggested Design Change</u>	<u>Priority^(a)</u>
● Weatherproof fire detection/extinguishment systems	1
● Develop alternative fire suppression systems	1
● Install interlock systems to avoid collision of the rotating frame with the hoist rope	1
● Design alternative access routes to and from operator cabs	1
● Develop alternative emergency escape routes	1
● Develop reliable noise attenuation measures	2
● Install emergency lighting system	2
● Install antislip/fall components in operator cab and on galloway deck	3
● Redesign transfer ladders for safer use	3
● Shield/clamp high pressure hydraulic hose	3
● Improve telephone system	3
● Develop communications system for machine operators	3

(a) Priority 1: addresses catastrophic hazard
Priority 2: addresses major hazard
Priority 3: addresses minor hazard

Detailed explanations of the methodologies and the actual safety analysis and results are documented in a series of supplementary appendices, A through F, included in this report. An accurate representation of the design and operation of both the impactor and conventional shaft sinking systems was required to perform a detailed safety analysis. This information is included in Appendix B of this study. The comparative safety analysis methodology and details of the procedures and results for the impactor system are presented in Appendices C and D. The results of the FMEA for the impactor system are presented in Appendix E of this study. Design change packages for the impactor system are presented in detail in Appendix F. The safety manual for the impactor shaft sinking system is presented separately in Volume 2 of this study.

INTRODUCTION

Shaft sinking is the single most hazardous operation of all underground mining activities. Statistics show the accident frequency rate for shaft sinking to be nearly four times that of all underground mining activities for metal/nonmetal mines. Recent Bureau of Mines research into the use of an impactor to replace the conventional drilling and blasting cycle for fragmenting rock in the shaft bottom (Contract H0262021, Cementation Company of America) could do much to eliminate hazardous conditions.

The impactor machine was recently tested in Tucson, Arizona, by the Cementation Company. The acceptance of the impactor into commercial use will require a demonstrated and inherent safety as well as its economic demonstration. Safety analysis must show the impactor to be as safe as or safer than conventional shaft sinking technology prior to commercialization. The safety issues are especially pertinent to the acceptance of the impactor by federal and local regulatory bodies.

The Bureau of Mines is responsible for the development of new and improved technology that will increase worker safety and efficiency in mining systems. To fulfill these responsibilities, the Bureau of Mines sponsored the work in this study.

The objective of this study was to examine the safety of the impactor shaft sinking system in comparison to conventional shaft sinking technology and to identify and recommend design changes for optimum safety conditions. The project also included the development of an operational safety manual for the impactor system that outlines procedures for reducing the possibility of accidents at sites where the impactor system is employed. These project requirements are outlined in more detail in Appendix A.

A number of safety analysis techniques were required to fulfill the primary objectives of this study. The comparative safety assessment of the impactor and conventional shaft sinking technologies was performed using a combination of Preliminary Hazards Analysis (PHA) techniques and a quantitative decision-making methodology. The PHA was used to identify potential methods of worker injury or fatality for the impactor system. This information

was then compared with the actuarial data on worker safety in conventional shaft sinking operations using a comparative safety analysis methodology developed at Battelle-Northwest. A safety evaluation of the component operations of the impactor machine and its support systems was performed using a Failure Modes and Effects Analysis (FMEA) methodology. The FMEA results in detailed information on the safety interaction of system components and provides guidance in safety-related design. The safety manual for the impactor shaft sinking system was developed by combining the safety output of the comparative safety assessment and the FMEA with the application of Management Oversight and Risk Tree (MORT) techniques. MORT is a formal, disciplined logic that is used to systematically relate and integrate a wide variety of safety concepts. In addition to the safety analysis efforts, a detailed system description of each of the systems to be analyzed was necessary.

The breakdown of these efforts into separate tasks, in the form of a project plan, is also shown in Appendix A. Each of these tasks required a large level of effort. This document (Volume 1) includes a summary of the overall project results, as well as the details of the specific tasks required to obtain these results, which are incorporated in a series of Appendices, B through F. The safety manual for the impactor shaft sinking system, with an explanation of the methodology used to develop the manual, is presented in Volume 2 of this series.

The remaining sections of this report present the results of the safety analysis efforts for the impactor machine and its support systems. The impactor system description is presented in the next section of this report. This description is followed by a summary of the results of the safety analysis efforts. The final sections of the report discuss the overall conclusions of the study and present some recommendations for future research based on these efforts. Information sources for this study are listed in the Bibliography. Supporting data for this document is incorporated in the appendices with this report.

IMPACTOR SYSTEM DESCRIPTION

An accurate representation of the design and operation of the impactor shaft sinking system is required for use in the system safety analyses. This system description is based primarily on the prototype impactor machine developed by the Cementation Co. for use in a circular shaft. This machine was tested by the Cementation Co. in a field demonstration during the spring of 1980. These design features are incorporated into this description in order to provide a realistic and practical comparative base. Further design detail can be found in the Failure Modes and Effects Analysis in Appendix E.

This section of the report describes the impactor shaft sinking system, which includes the machine itself; the shaft and surface support systems, such as ventilation and hoisting equipment; and a description of the various shaft sinking operations required when using an impactor. A typical site and shaft configuration for the application of the impactor is first defined. This is followed by a technical description of the impactor machine itself and its support systems. The basic shaft sinking operations involved when using the impactor are also described in this section, as well as the personnel requirements and work stations for the system. The safety analysis of the impactor shaft sinking system is presented in the next two sections of this report.

Site Characteristics

Impactor technology could be used to sink shafts in a variety of geological conditions. However, since the use of impactor technology to sink shafts has been field tested in geological conditions typical of southwestern U.S. metal mine conditions, geological conditions representative of this region were assumed for this system description. Use of this reference site will allow the experience and knowledge gained from the field tests to be incorporated into this safety analysis.

Two field tests have been conducted by the Cementation Co. for the Bureau of Mines. The first of these tests took place at the Magma Copper Company's San Manuel mine in Arizona. This test consisted of deepening a rectangular shaft by about 20 ft. during the period from July 20 to October 22, 1977. The second field test was conducted during the spring of 1980. This test consisted of excavating a series of 24 ft. dia. by 20 ft. deep "shafts" at the Duval Corporation's Sierrita/Esperanza Properties near Tucson, Arizona. A total of 148 ft. 6 in. of shaft was sunk in this field test.

Geology

Geology in the area of the test sites (south central Arizona) generally consists of a top layer of Gila conglomerate, a poorly cemented material containing loose soil, gravel, and boulders. The thickness of this strata varies a great deal but it is typically 100 to 1000 ft. thick. Below the Gila conglomerate, the geology consists of Monzonite Porphyry and a mixture of Quartz Monzonite and Monzonite Porphyry. Rhyolite is also present. These types of rock generally have joints spaced from 1 to 6 ft. and have relatively high compressive strengths in the range of from 20,000 to 30,000 psi. In tests the impactor has performed well in excavating these types of materials.

The applicability of existing impactor technology for shaft excavation as a function of geology is shown in Figure 1. As shown, the key

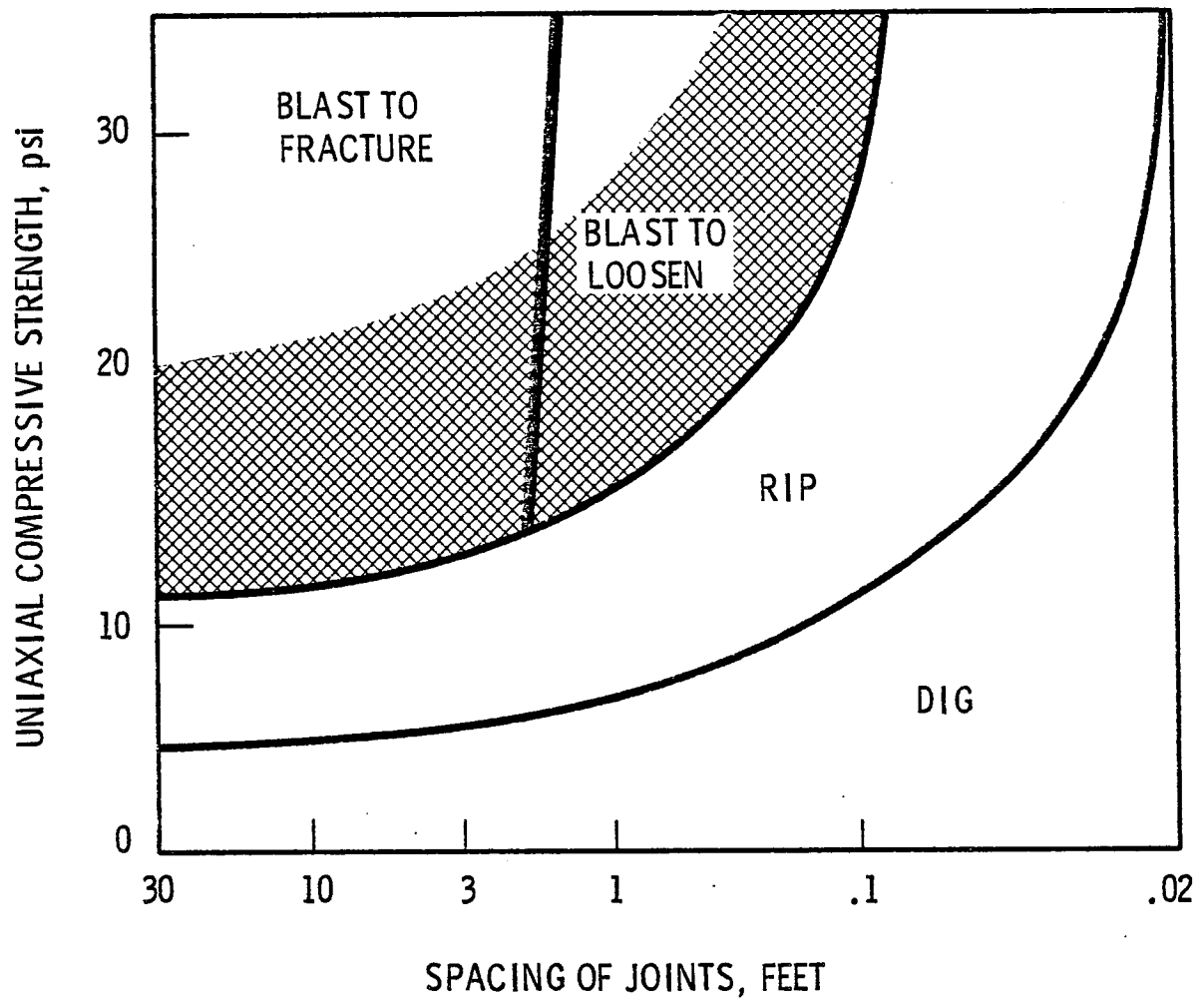


FIGURE 1. Applicability of Impactor for Shaft Excavation as a Function of Geology

factors affecting the workability of rock are the spacing of joints and the uniaxial compressive strength. Material that is either relatively low in strength or well fractured can be excavated by digging. As the material becomes less fractured and stronger, blasting is required to loosen it. If the material is very hard and not fractured, blasting is required to break it.

In general, impactor technology can be used for excavation of rock types within the shaded area shown in Figure 1. Impactor technology can be used to sink shafts in moderately hard rock if the rock is not fractured. As the rock becomes more fractured, an impactor can be used to excavate relatively hard rock. Impactor technology should generally be applicable for both metal/nonmetal and coal mines throughout much of the U.S.

Surface Facilities

In this section a general site is described that would be feasible for an impactor shaft sinking project. The site will contain a number of surface facilities required to support activities during construction of the shaft. These facilities and a possible layout are shown in Figure 2.

The shaft is surrounded by a reinforced concrete collar, the top of which is two feet above the local graded ground elevation. The general arrangement of the shaft is described in more detail in the following section.

The ventilation system for the shaft utilizes one intake fan. The fan is protected by a coarse grate and connected to the shaft ventilation pipes by an underground duct. The fan, as required by law, is placed in a fire proof housing, offset at least fifteen feet from the shaft collar.

The headframe structure extends vertically from the shaft collar and serves as a support for the sheaves that guide the wire ropes used in the various hoisting operations. The hoist building contains the hoists and

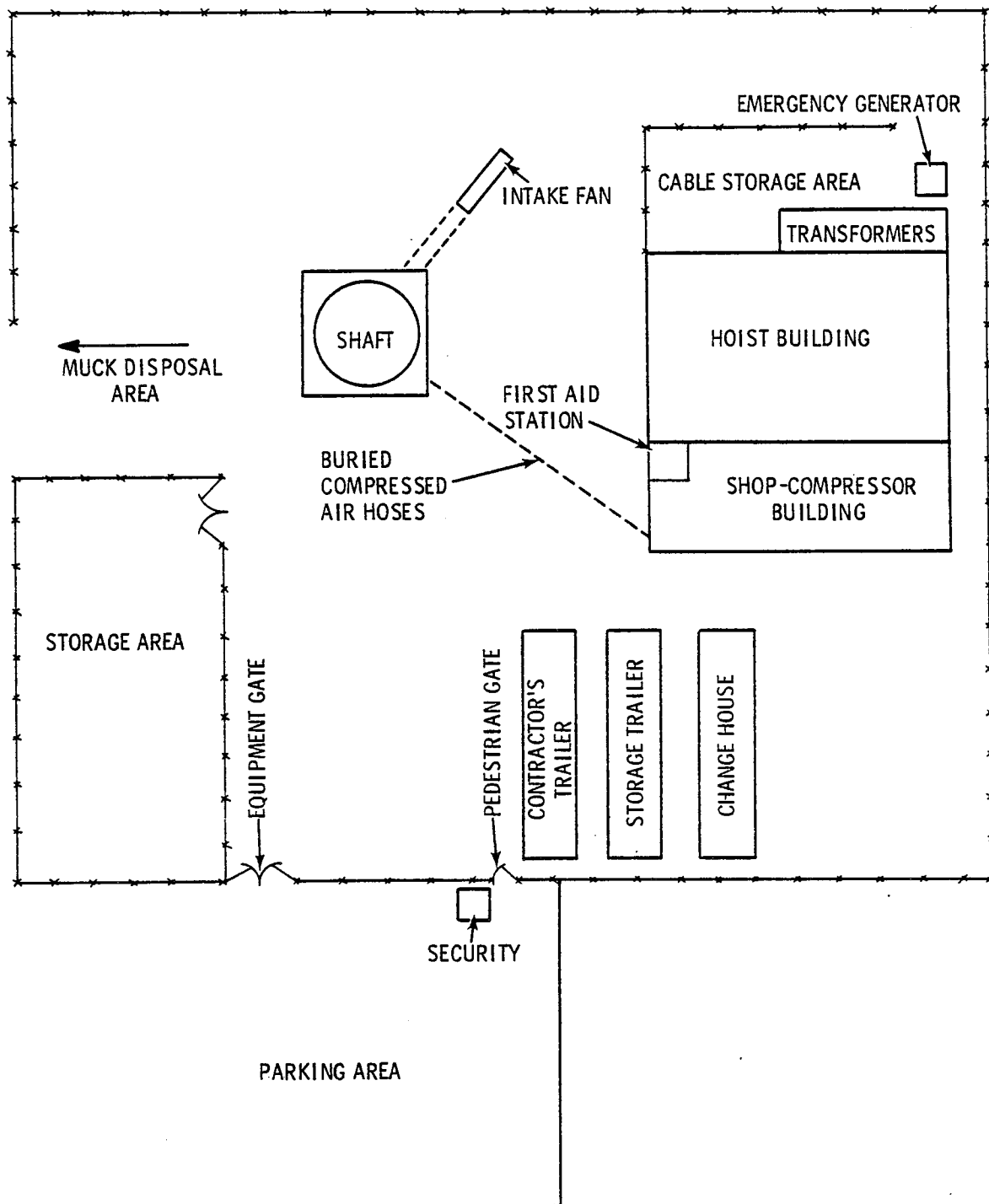


FIGURE 2. Site Layout

hoist operator's station. Traffic into and through the hoist building is limited.

The transformers and emergency generator would be located beside the hoist building. The electrical cable winch and cable storage area would also be located adjacent to the hoist building. Additional equipment or drums may be located along the fences.

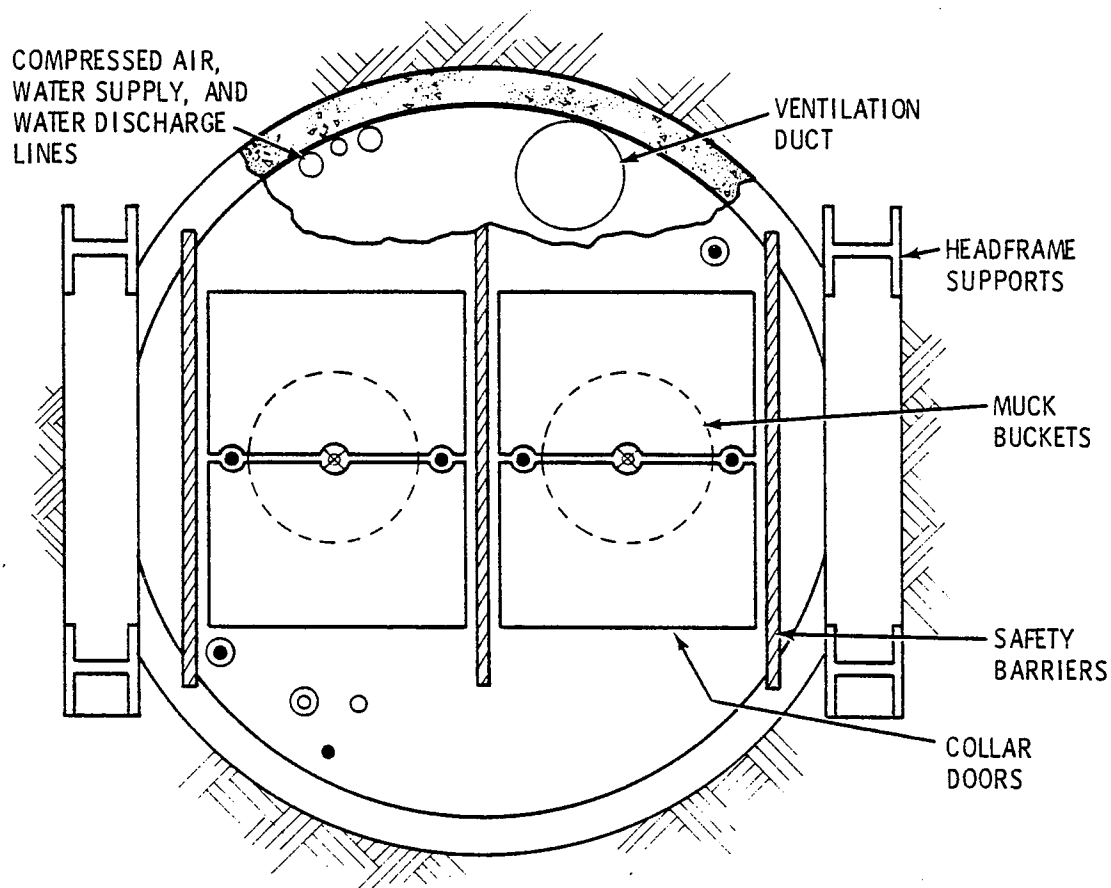
This layout includes a shop and compressor building located beside the hoist house. The shop and compressor building contain a mechanical shop, an electrical shop, a compressor house, and a general work area for the contractors. Flammable materials may be located in the shop area. Fire extinguishers are available. A fenced storage area is located in the site. This area is not covered and may contain such items as equipment parts, drums, cables, etc. It is accessible by a gate that remains open during working hours. A workman's change house, contractor's trailer, and perhaps a truck trailer for storage of spares would also be located within the fenced area.

Shaft Description

The shaft is assumed to have a 22 ft. finished diameter with a non-reinforced concrete lining nominally 12 in. thick. Total shaft depth is to be 2500 ft. The general arrangement of the services in the shaft during the sinking operation is shown in Figure 3.

Federal regulations require that the shaft be guarded to prevent people or materials from accidentally falling into it. The shaft opening is therefore covered with steel plates. Four steel doors provide access into the shaft for man and materials transport. The doors are hinged to open upward. When open, the doors and the safety barriers prevent access to the shaft. The shaft collar also provides support for the headframe structure.

As shown in Figure 3, service lines for compressed air, fresh water, and water discharge are supported from brackets mounted to the



- KEY:
- ✕ MUCK HOIST ROPES
 - GALLOWAY HOIST ROPES
 - ◎ ELECTRICAL POWER CABLE
 - MANUAL BELL LINE
 - ELECTRICAL BELL LINE AND TELEPHONE LINE

EXCAVATION AREA: 452 ft² (24 ft. dia.)

INSIDE LINING THICKNESS: 379 ft² (22 ft. dia.)

LINING THICKNESS: 12 in.

FIGURE 3. General Arrangement of Shaft During Excavation

shaft walls. The ventilation duct is also mounted to the shaft wall.

There are a number of wire ropes extending from the headframe into the shaft. The galloway is supported by 1 1/4 in. lock coil ropes. A total of two ropes are used, each rope having a 3-part purchase. This provides a total of 6 galloway hoist ropes. There are two muck hoist ropes, one for each bucket.

In addition to these ropes, there is an electrical power cable, a mechanical bell line, an electrical bell line, and a telephone line extending into the shaft. These lines are supported from sheaves on the headframe and are extended by means of winches.

Impactor Machine Description

The impactor is a machine designed to sink large diameter (16-25 ft.) shafts through rock. The machine breaks rock using a high energy pneumatic hammer mounted on an articulated boom similar to a backhoe boom. The use of boom mounted pneumatic hammers to break rock is not a new development. Such machines have been used for several years for building demolition and for breaking oversize rock preparatory to feeding the rock into crushers or grizzlies. Several manufacturers make pneumatic hammers for such applications. The muck is loaded in conventional muck buckets using a mucking bucket mounted on a standard backhoe boom.

The machine is mounted beneath the lower deck of a 4 deck galloway. While the galloway would have a similar layout and be the same size as a conventional galloway, it will have to be stronger to support the additional weight of the impactor as well as the loads generated by the impactor during the shaft sinking operations. The machine is advanced to the working face as an integral unit with the galloway.

There are 5 major assemblies that comprise the impactor:

1. The track
2. The rotating frame
3. The breaker unit control cab
4. The breaker boom and pneumatic hammer
5. The mucking boom and bucket.

The general arrangement of these assemblies and the galloway in a shaft is shown in Figure 4.

The track assembly is circular, extending around the circumference of the lower deck of the galloway and rigidly attached to it. The track assembly consists of a circular carrier frame with a rail and a rack

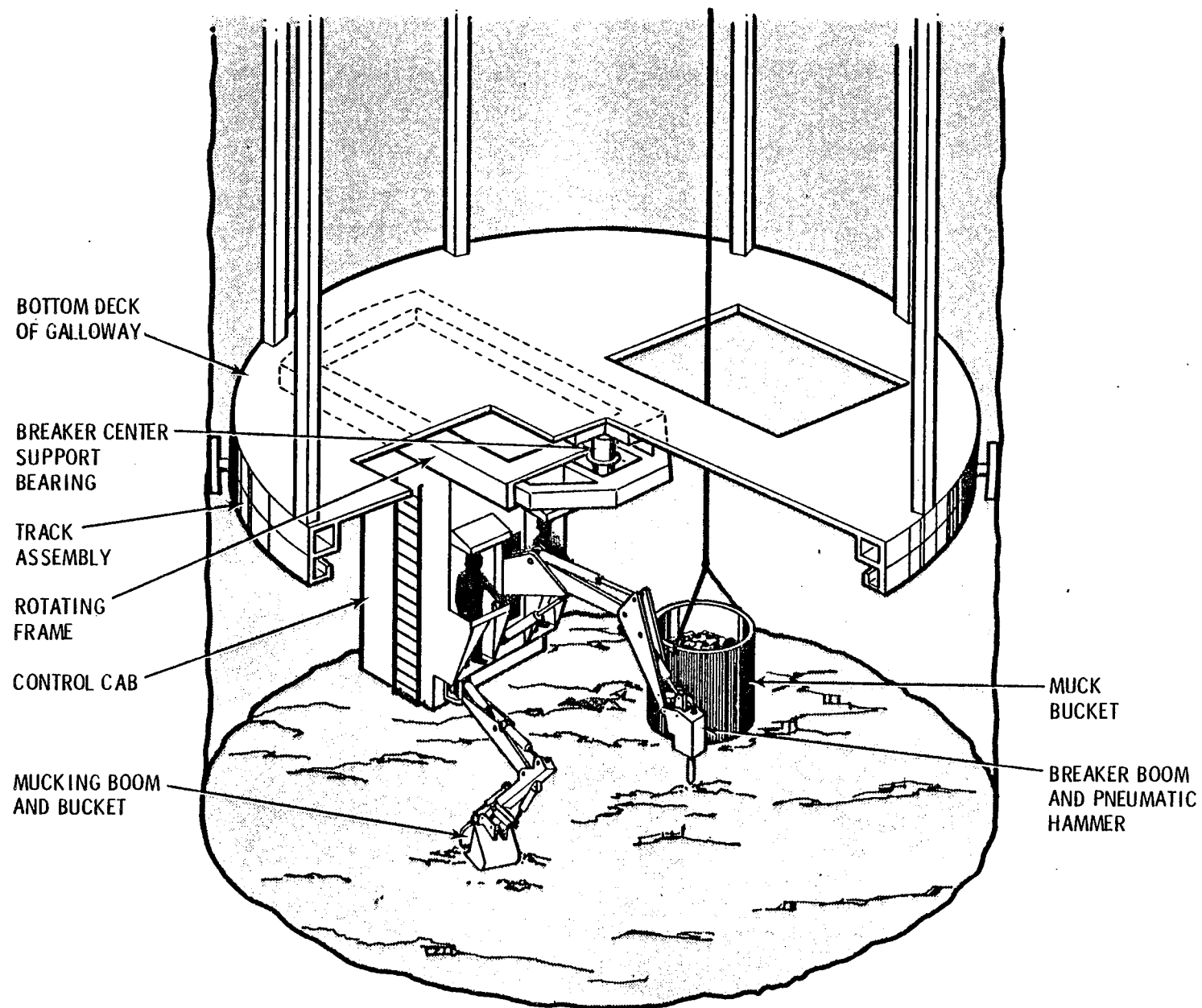


FIGURE 4. General Arrangement of Impactor in a Shaft

around the lower inside edge. The rail provides support for the outer side of the rotating frame.

The rotating frame assembly is attached to the galloway with a bearing and universal joint located at the center of the galloway and is supported at the outer edge on the track assembly. Thus supported, the rotating frame can rotate through 360° on the center bearing. The frame rotation is controlled by means of a horizontal geared air motor that drives a sprocket through a roller chain and drive shaft. The sprocket meshes with the rack on the track assembly. Electrical power, compressed air, and telephone communications are fed through the center of the bearing and universal joint.

The breaker unit control cab houses the operator work stations and the electric hydraulic pumps and controls as well as miscellaneous machine systems such as the lubrication systems. The cab is mounted to the rotating frame with a bearing. A hydraulic drive motor rotates the cab assembly relative to the rotating frame. The cab assembly is free to rotate through 360° relative to the rotating frame. Electrical power, compressed air, and the telephone communications are fed through the center of the bearing similar to the manner in which they are fed between the bottom deck of the galloway and the rotating frame.

There are two operator work stations in the cab, one for the breaker boom operator and one for the mucking boom operator. Each work station has hydraulic pilot valves that allow the operators to control the operation of their respective booms. The mucking boom operator is located immediately above the mucking boom and the breaker boom operator is located to the left side of the breaker boom.

The enclosed portion of the cab behind the operators houses a 150 gallon hydraulic oil reservoir, the hydraulic pumps, the various hydraulic valves and controls. The control cab assembly is mounted to the rotating frame so that it can be removed by hoisting it upward through the rotating frame using the muck hoist. It is anticipated that the unit would be removed from the shaft for major maintenance. The machine is designed such that the mucking and breaker booms can remain attached to the control cab for this operation.

The function of the breaker boom is to position the pneumatic hammer so the correct angle of attack is obtained between the pneumatic hammer tool and the rock face. The pneumatic hammer delivers a blow with an energy of 2000ft.-lbs. at a rate of 600 times per minute, giving a total output of 1,200,000 ft. lbs. per minute. The hammer requires about 750 cfm of air at 95 psi. to deliver the rated output.

The operation of the pneumatic hammer is automatic. The hammer is designed to function whenever the axial force on the tool is greater than 1000 lbs. To break rock, the operator positions the tool using the boom and forces it against the rock. When the force exceeds 1000 lbs. the hammer actuates. The hammer automatically stops when the force on the tool is reduced below 1000 lbs. The operator can override the automatic hammer operation with a foot pedal. This allows him to better position the tool on loose rocks before breaking them.

The mucking boom operator scrapes the muck which has been broken with the pneumatic hammer away from the working area and loads it into muck buckets.

Hydraulic System

This system provides hydraulic power to the following machine systems:

A. Breaker Boom

- Boom Cylinder
- Dipper Cylinder
- Hammer Cylinder
- Side Angle Positioner Locking Cylinder
- Side Angle Position Actuator

B. Mucking Boom

- Rotary Positioner

- Boom Cylinder
- Dipper Cylinder
- Bucket Cylinder
- Clam Cylinder

C. Cab Rotation

- Slew Motor

D. Control System

- Pilot Control Valves
- Directional Control Valves

The general arrangement of the major hydraulic systems components is shown in Figure 5.

The boom, dipper, and hammer cylinders on the breaker boom are used to flex the various links of the breaker boom to position and move the pneumatic hammer. The pneumatic hammer can be rotated relative to the boom using the side angle position actuator. However, the hammer can only be actuated when the tool is positioned in the same plane as the boom. The hammer can only be used when it is positioned relative to the boom as shown in Figure 5 or rotated 180° from that position. The side angle position locking cylinder is used to secure the hammer in one of these positions while in use.

The rotary positioner is used to rotate the mucking boom relative to the control cab. A boom cylinder and dipper cylinder are used to flex the various links of the mucking boom. The bucket cylinder moves the bucket relative to the mucking boom. The clam cylinder rotates the mucking bucket clam cover which is used to hold the muck in the bucket.

The slew motor rotates the control cab relative to the rotating frame. Lower pressure (400 psi) pilot valves are located in the operator cabs to control each of the hydraulic cylinders.

Two 30 horsepower electric motors are used to drive the two 18/7 GPM hydraulic pumps utilized in the system. These are four relief

valves; three limit fluid pressure to 2000 psi for the breaker boom, hydraulic boom and cab rotation systems. The fourth reduces and maintains the control system pressure to 400 psi.

During normal operation of the impactor, neither operator is exposed to any high pressure lines; however, both operator cabs contain low pressure (400 psi/7 GPM) pilot control valve lines to which each operator is exposed.

The control system, side angle position actuator and locking cylinder are supplied 7 GPM of hydraulic fluid. All other system components are supplied with 18 GPM.

The hydraulic fluid tank is located directly behind the mucking boom operator. Nominal capacity of this tank is 150 gallons. The hydraulic fluid used is a standard non-fire resistant type.

Electrical System

Electrical power is supplied to the impactor via a power cable running from the surface to the galloway through the rotating frame center bearing and universal joint and the cab rotation bearing. Slip rings are used in the bearings to conduct the electricity through them. Four hundred eighty volt, 3 phase power is provided to the impactor. A 480/110 volt, 1.5 KVA transformer is located in the control cab to provide 110 volt power for lighting and duplicate rotating frame controls. One hundred ten volt incandescent lamps are used for lighting on the impactor. Lights to illuminate the bottom of the shaft and are located beneath the bottom deck of the galloway and on the front of the cab.

Compressed Air System

Compressed air is used to supply power for three functions on the impactor.

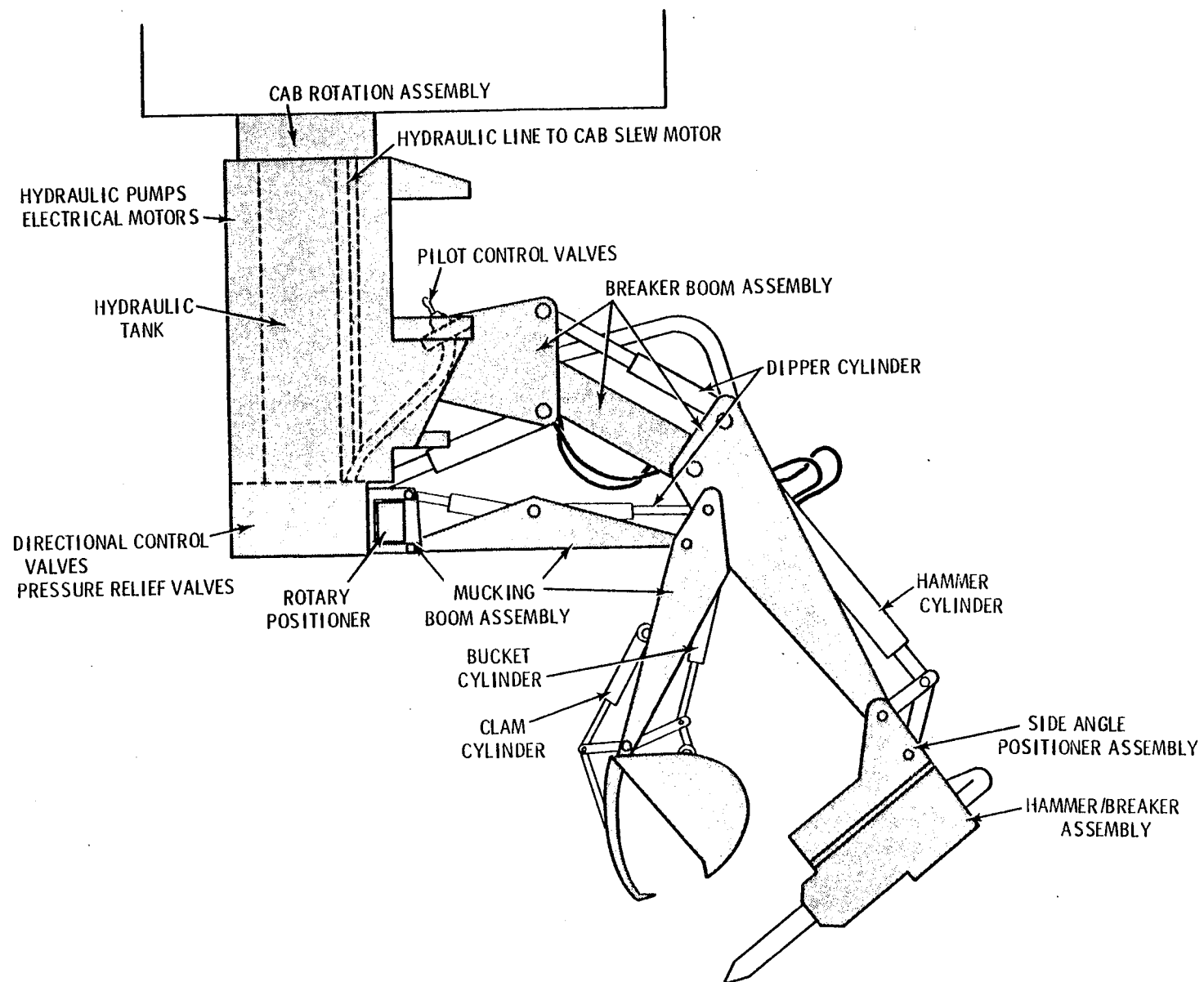


FIGURE 5. General Arrangement of Major Hydraulic Components

1. The pneumatic hammer
2. The rotating frame drive motor
3. The automatic lubrication systems

The pneumatic hammer is designed to operate using about 750 cfm of air at 95 psi. It will operate at reduced pressures with reduced energy and blow rate. Total energy delivered is linearly related to supply pressure.

The position of the rotating frame is controlled by means of an air motor. It is actuated by means of a hand-operated direction control valve located at the breaker boom operators station.

Power to the automatic lubrication systems is also supplied by com-

Lubrication Systems

There are a total of four automatic lubrication systems on the impactor. Two of these provide lubricating grease to various machine components and two inject oil into the air driven equipment on the machine.

One lubricating system provides grease to the mucking and breaker booms; the other supplies grease to the cab rotation ring gear wheel, bearings, and drive sprocket. The power units and grease reservoirs for the lubrication systems are located in the control cab. Small diameter metal grease lines are routed along the top of the two booms to the various lubrication points. Flexible hoses are used at the boom joints. Similar lines run inside the control cab to the lubrication points on the cab rotation system.

One air oiler injects oil into the breaker air line. The other oiler injects into the air line leading to the rotating frame drive motor. Both of these units are located in the control cab.

In addition to the automatic lubrication, some manual lubrication is required. This is discussed in the section on machine maintenance.

Machine Maintenance

Some of the routine maintenance activities required in using the impactor are presented in this section. A variety of procedures will be carried out before each shift (see Table 3). Other routine maintenance activities will take place weekly or monthly (see Tables 4 and 5). The preshift checks on equipment in the shaft are performed by the operators and the shift boss. The mechanic will inspect the winches, ropes, headframe, and collar doors.

Major maintenance on the impactor would be done on the surface. The control cab and boom assemblies are designed to be removed from the rotating frame and hoisted to the surface as a unit. About 15 minutes would be required to remove the cab assembly and hoist it to the surface. It is estimated that this would be done about once a month.

TABLE 3. Preshift Maintenance Checks

- Check hydraulic oil level in main tank - add fluid if necessary.
- Lubricate rotating frame drive motor and drive train.
- Check and refill air oil mist supply reservoirs.
- Drain water from main air line.
- Check air and water supply.
- Visual check of all vulnerable parts on impactor such as hydraulic and air lines.
- Visual check of all vulnerable parts including winches, ropes, headframe, sheaves, and collar doors.

TABLE 4. Weekly Maintenance Checks

- Inspect the winches, ropes, headframe, sheaves, galloway and impactor.
- Lubricate the winches, ropes, and sheaves.
- Lubricate the muck buckets and support pins.
- Lubricate the collar doors, pivots, and cylinder pins.

Table 5. Monthly Maintenance Checks

- Change all hydraulic filters.
- Change or clean all tank breathers.
- Check condition of hydraulic fluid. If condition of oil is in doubt, take a sample for chemical analysis. If contamination is suspected, change the oil. In normal service, hydraulic oil should be changed every 6 months.
- Inspect and lubricate the emergency hoist.
- Service the standby generator.

Support Systems

Shaft sinking using either the impactor or conventional techniques requires a variety of support equipment. In this section, the support equipment and systems required by the impactor are described. This equipment includes surface systems for the operation of the hoists, head-frame, shaft conveyances and ventilation equipment. Subsystems for power transmission, communications, fire control, and shaft dewatering are also required.

Haulage of Men and Materials

Men and materials are raised and lowered in the shaft by means of the hoisting system. Hoists are also used to bring muck to the surface for disposal and lower concrete in buckets for lining the shaft. Water and air are transported down the shaft through pipelines. This section describes the equipment used to provide the necessary haulage support functions in the impactor system.

Hoisting Equipment

The hoisting system is perhaps the most critical system in shaft construction, being the only means of access into and out of the shaft. The hoisting system discussed in this section includes the headframe, the muck buckets, and galloway hoists. Each of these components includes a variety of controllers, ropes and sheaves and conveyances.

Headframe

The headframe is the basic structure that supports the sheaves, pulleys, chutes and such used during the shaft sinking operation. It is made basically of steel and is designed to withstand the breaking loads of one hoist rope and a galloway rope. This ensures that the headframe will be able to support all operating loads with an adequate factor of safety. The sinking headframe stands about 80 feet above the ground. The main sheave wheels are situated on a platform at the top of the headframe, along with the galloway stage rope sheaves. The headframe also contains tipping arrangements and muck chutes that allow muck hoisted from the shaft bottom to be dumped to a temporary muck pile near the shaft collar.

Figure 6 shows the general arrangement of the headframe and hoists. The hoists are enclosed in the hoist house; however, it has been left out in this drawing for clarity.

Hoists

Hoists are mechanically driven drums that raise or lower a load by winding in or paying out a length of wire rope. The drum hoist is driven by an electric motor, from which power is transferred through a set of reduction gears to the hoist drum. Although direct drive hoists (not requiring power transfer through reduction gears) do exist, it is not anticipated that they would be used in the postulated impactor shaft sink-

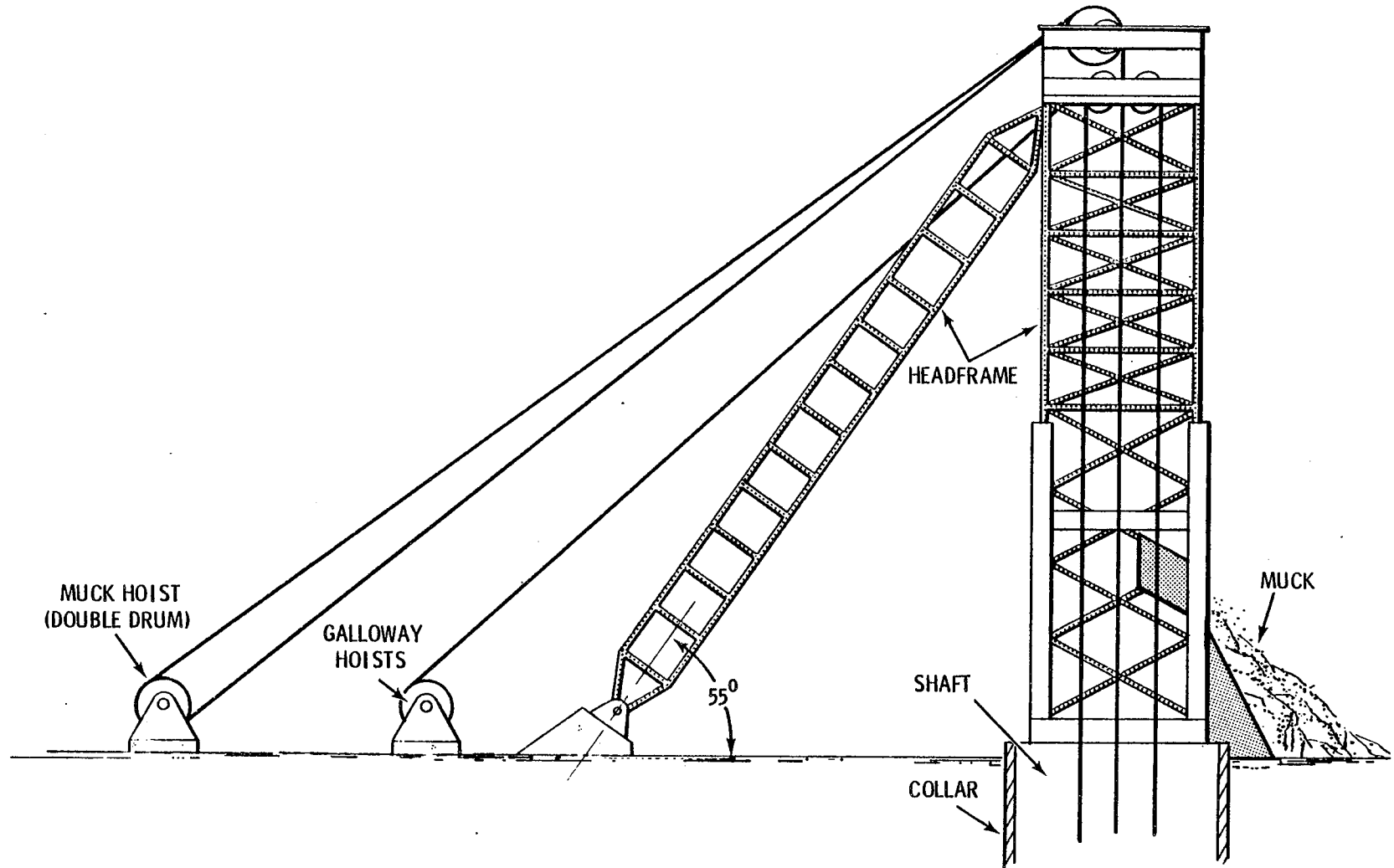


FIGURE 6. General Arrangement of Hoists and Headframe

ing system. The hoist is stopped with a weight-actuated brake system. A hydraulic cylinder and associated control circuitry release the brakes by lifting the weights. The hoists are mounted in concrete footings, and are protected by the hoisthouse.

In hoist operations, equipment failure or human error may cause the hoist to raise or lower its load accidentally with excessive speed or beyond its landings at the shaft bottom or surface. To prevent such accidents, hoists are fitted with limit controls to protect against overspeed and overwinding. These devices are mounted on the hoist and are gear-driven from the hoist drum. Overspeed controls consist of a fly ball governor (Lilly controller), and are set to activate when movement of the conveyance exceeds a predetermined speed. When this speed is exceeded, the controller automatically cuts power to the hoist and applies the brakes. The wind controllers consist of a movable circular metal track and a fixed contact. A wedge-shaped cam is fitted on the circular track at a point which coincides with the desired upper limit of hoist travel. As the conveyance is raised, the circular track rotates beneath the fixed contact point. When the conveyance nears the desired stopping point, the rack's rotation moves the cam under the contact point, causing the contact to rise. Movement of the contact halts the hoist drum by cutting power and applying the brakes. Automatic stop or deadman controls are also provided as a protection against failure by the hoistman.

Muck Bucket Hoists

All haulage, including man hoisting, will be done by means of muck buckets. This hoisting is done using a single-clutched double drum mine hoist. Because the muck buckets will be used for man hoisting, the safety mechanisms described above for the hoist must be implemented. In addition, locking mechanisms on the clutch to prevent accidental disengagement, depth indicators, and equipment to meet a variety of other mandatory federal safety requirements must be installed on the hoist. A maximum speed of 500 fpm must not be exceeded during man hoisting. Buckets must be securely

attached to a crosshead, have overhead protection, allow the person to be hoisted in a standing position and have devices to prevent accidental dumping. These are just some of the requirements for man hoisting. Four of the galloway support ropes are also employed as guide ropes for the buckets. In addition, Federal regulations require that all hoist equipment headgear, ropes, connections and chains be inspected daily, and a test trip of all conveyances is required before each shift and after all hoist repairs.

There are no firm criteria given in the regulations to determine when a rope should be removed. The ANSI specification states that the factors to be considered in examining a rope are a marked reduction in rope diameter, evidence of excessive abrasion on outer wires, broken outside wires or severe corrosion. In general, when corrosion is present, the remaining strength of the rope cannot be readily calculated, and the rope should be removed. Ultimately, however, the ANSI specification leaves the decision to remove a rope to the judgment of the mine officials. In the impactor shaft sinking system, it is anticipated that ropes will be tested for wear every six months, and inspected daily.

Galloway

The galloway stage is a multi-stage work platform that is used to provide a decking from which permanent lining, piping and cable services can be installed. The galloway also provides a second means of escape from the shaft in case of emergency. In the event of a power failure and/or main hoist problems, the standby generator can supply power to the galloway winches, permitting the shaft crew to ride the work platform to the surface. Because the galloway remains in the shaft during shaft construction, the separate decks are fitted with wells to allow the passage of muck buckets and other supplies. The general arrangement of the galloway and impactor in a shaft is shown in Figure 7.

In the impactor shaft sinking system, the galloway also serves as the basic support for the impactor machine. The boom and cab assembly of the machine is mounted on a frame under the bottom deck of the galloway.

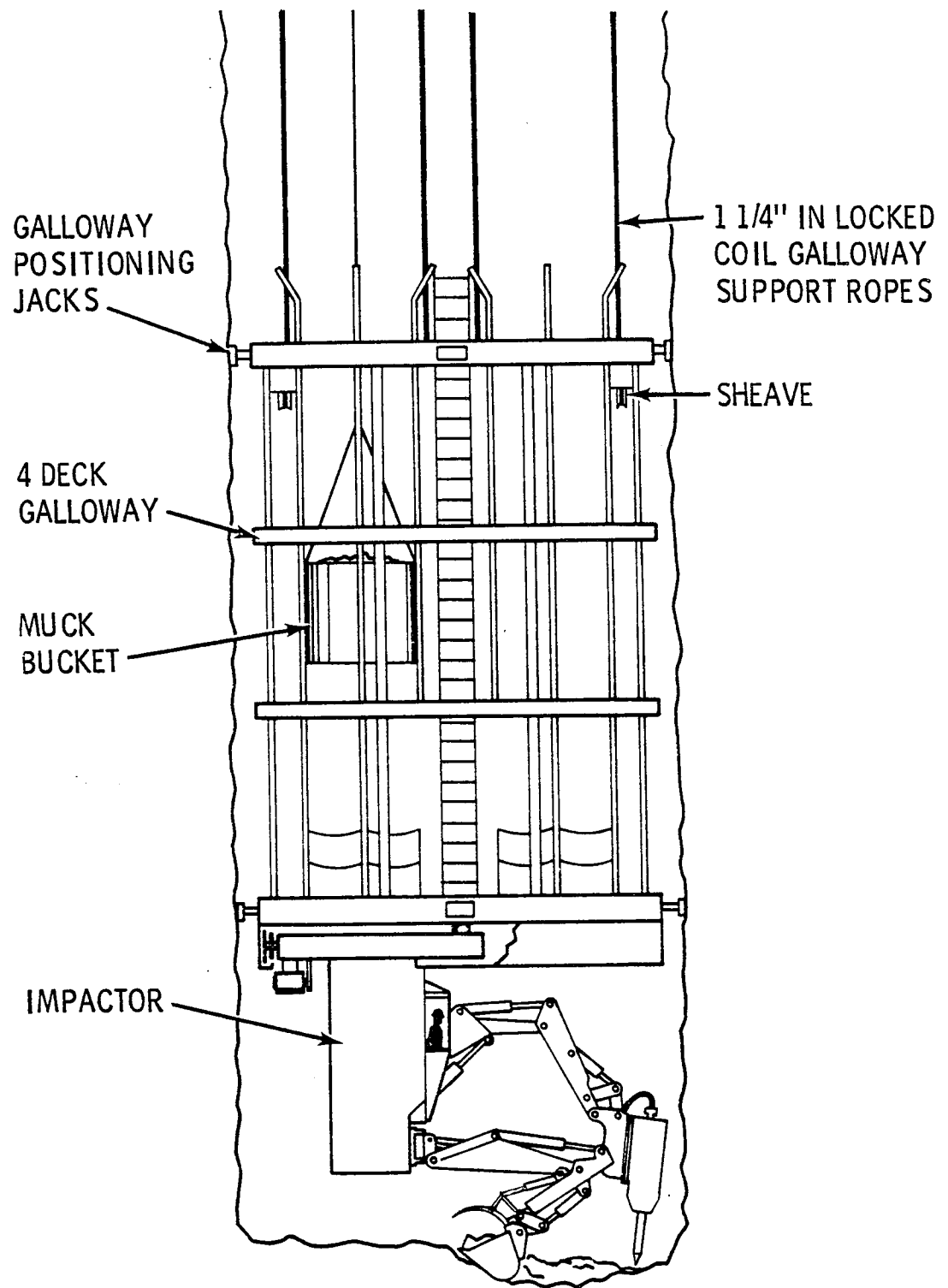


FIGURE 7. General Arrangement of Galloway and Impactor

The outer end of the frame is mounted on two wheels that run on a track that extends around the periphery of the galloway deck. The inner end of the impactor cab frame is mounted on a central bearing. This arrangement allows the unit to rotate through 360° in the shaft. A sprocket, driven by an air motor through a gear box, meshes with a circular track to provide the rotation motion. A universal joint mounted beneath the central bearing ensures that the wheels are always in contact with the rail and that there is a minimum of torsional and bending stresses in the rotation frame. Upward movement of the wheels is restricted by another rail mounted directly above the wheel.

The galloway is stationary during impactor machine operations and is lowered in increments of 6'8" (consistent with the impactor production cycle). When the impactor is operating, the galloway must be restrained by jacks to provide lateral support. There are eight jacks on the galloway to provide this support. Four are near the top and four are near the bottom decks of the stage. A separate hydraulic system on the galloway is required to power these positioning jacks. An air-hydraulic motor and pump, located on a deck of the galloway, provides the necessary power to the galloway hydraulic system.

Two single-drum slow-speed winches, mounted on the surface, are used to raise and lower the galloway. The galloway is suspended by two 1 1/4" diameter locked coil ropes in triple purchase. The suspension ropes are payed out from the winches, pass over sheaves in the headframe down the shaft, around sheaves located under the top deck of the galloway, back up through the shaft and over another set of sheaves in the sheave platform in the headframe and back down to a dead-ended connection on the galloway stage.

Service Lines

The services that are provided downhole include intake ventilation, water, and compressed air, and a pump line for removing water from the shaft. The ventilation duct is a 30-36 in. diameter line,^(a) constructed of a rigid, spiral-weld pipe. The system is a high flow--low pressure system and is attached with clamp-and-bolt couplings. The compressed air supply and water supply and discharge lines (4 in., 2 in. and 4 in. diameter lines, respectively) are made of schedule 40 and schedule 80 victaulic grooved pipe, respectively, and are coupled with victaulic couplings and wall clamps. These lines have relatively high pressures and moderate flows. The compressed air line feeds directly to the impactor machine to perform a variety of functions. The pumped water line carries excess water pumped by the dewatering system to the surface.

Ventilation

The ventilation system is one of the most important safety features of any shaft sinking operation. Adequate ventilation is essential for underground work. Continuous circulation of fresh air removes dust and dilutes gases that may be encountered during shaft construction.

Ventilation of the shaft bottom during shaft sinking activities is obtained using axial flow fans in series to blow air through the 30 to 36-inch diameter thin-wall (spiral weld) pipe. The pipe terminates about thirty feet above the galloway. Precise sizing of the pipe will depend on the volume of air required to keep the shaft bottom adequately ventilated and free of gases. This volume is assumed to be about 30,000 cfm for the impactor shaft sinking system. The number of fans required will depend on shaft depth and the size of fan employed.

^(a) The size of pipe service lines is dependent on available pipe, whether the pipes will serve as permanent services, and the requirements of the client. The suggested sizes have been assumed as generally representative for the required uses.

The ventilation system utilizes intake fans located on the surface. The fan housing and the air duct to the shaft are required to be fire-resistant. The fans must operate continuously, except for scheduled production cycle shutdowns or planned maintenance activities. Fans are electrically powered, and are usually between 40 and 100 HP.

Dust suppression systems are sometimes required in shaft sinking projects to maintain good quality ventilation in the shaft. However, experience to date with the impactor machine shows that it doesn't create a dust generation problem. Furthermore, deeper shafts in the west usually have enough water flow to mitigate any dust problems that could potentially arise.

It is anticipated that future applications of the impactor machine will primarily be in metal/nonmetal rather than coal shaft sinking. Thus, no provision for gas monitoring is made, since in normal operation, no routine monitoring is done for methane or other gases in a metal/nonmetal shaft sinking project.

Power Transmission

Electric power for the impactor system is provided by available power lines to a shaft substation. Power for the downhole equipment is provided by a cable running from the surface to the galloway, which has been stepped down to 480 volts, 3 phase power. The power cable is supported by a rope, or messenger cable, payed out from a winch. The cable is looped to permit the galloway/impactor machine assembly to proceed a minimum of 20 feet before an advance of the cable is required. An interlock ensures that the limits of the cable loop length are not exceeded. The cable is then directed through a protective sheath to the center pivot of the impactor frame to the cab to drive the hydraulic motors and provide power for the lighting system.

Communications

There are basically two forms of communication used in the impactor shaft sinking system. A manual bell wire signal system is used to communicate between the galloway, the top lander at the shaft collar, and the hoist house. The signal is given by means of a wire rope hung through the shaft and connected to a mechanical signal on the collar. An electrical switch on the arm of the mechanical signal relays the signal to the hoist operator both audibly and by an electric light bulb signal. A code of signals is posted in the hoist house and at the top of the shaft. An electrical bell signal system also extends from the galloway to the surface. A two-way telephone system is also available. A telephone is located in the operator's cab, on the lower deck of the galloway and on the surface at the shaft collar. Voice communication is also used between crew members down-hole, primarily during concreting and maintenance operations.

Fire Control

No fire detection system is installed either on the galloway or impactor. The fire control system consists of a fire suppression system as well as hand-held portable dry chemical extinguishers. Two of these portable extinguishers are located on the impactor and there are two on each of the four galloway decks.

The fire suppression system is anticipated to be a water-fog type system. A chemical system that employs foams or other fire-extinguishing agents could also be used; however, the simplicity of the water system makes it preferable for use with the impactor system. The suppression system consists of nozzles at the bottom two decks of the galloway actuated by a manual lever at the bottom deck of the galloway.

Shaft Dewatering

Experience with shafts in metal/nonmetal mines in the Western U.S. indicates that large amounts of water may be encountered in the course of sinking a shaft. If such an aquifer is intercepted, air-driven pumps would be lowered from the galloway. These pumps would be stored on the galloway. The pumps can be lowered and placed on the shaft bottom without a man at the bottom by using galloway-mounted winches or tuggers and the moving capability of the mucker boom. It is also anticipated that the face will be probed for potential water-bearing zones and grouted as necessary to keep water inflow to a minimum.

Water pump stations will be located at approximately 500 ft. intervals in the shaft. They are necessary because a reasonable pumping head for pumps is about 500 ft. These stations would be excavated in the shaft wall either with the impactor or using drill and blast methods.

Guidance

Shaft side lines will be used to ensure that the shaft is plumb. Shaft side lines are small diameter (3/16 in.) cables suspended in the shaft from small winches located at the shaft collar. Typically 4 to 6 of these lines would be used. At least one line would be located in each quadrant of the shaft and about 6 in. inside the finished shaft diameter.

The location of the side lines is carefully established using surveying techniques at the start of the shaft sinking operations. The location of the side lines is maintained by passing the line through a hole in a steel plate that is welded to the shaft collar. Additional guides are located in the shaft approximately every 400 ft.

At the start of the lining cycle, plumb bobs are suspended from the lines and they are lowered using the winches until the plumb bobs are below the section to be lined. In this position, the lines are used to locate the concrete forms. When the forms have been set, the side lines are raised above the galloway until the next lining cycle. As the lines are raised, the plumb bobs are removed and stored on the top deck of the galloway.

Shaft Sinking Operations

During the actual shaft construction period, a number of distinct operations occur that must be evaluated in the safety analysis. These include mobilization and demobilization of the equipment, as well as normal operations of the impactor system such as breaking and loading of muck, muck haulage and removal, pipeline extension, and shaft lining and completion procedures. This section describes these shaft sinking operations.

Mobilization

Mobilization involves the initial preparations that are required to use the impactor machine as a method of excavating shafts. These operations include a geological analysis, including hydrological information; clearing the site; getting the machine and support equipment to the site and assembling it; and initial excavation.

Once the site has been cleared and access roads to the area are constructed, the impactor machine and all support equipment are brought onsite. Work is started immediately on the hoist foundations, since these are often on the critical path for completion of the mobilization phase of the project. Where possible, a used mine hoist will be employed for shaft sinking purposes. These used hoists can require up to 10 to 11 weeks for their installation. They are generally very much larger than the present day equivalent, with heavy-cast metal and bolted connections. The older hoists require more complex foundation work with drum pits, brake pits, sumps for flywheel, etc. to be formed in the concrete foundation. Assembly of the many parts is time consuming. New hoists for shaft sinking can be supplied on a bedplate that needs only to be bolted to a slab foundation. Such a hoist can be transported in only two or at the most three sections with the minimum amount of site assembly being required.

Concurrently with the hoist foundations, initial excavation of the shaft collar will commence, as well as construction of the foundations for the headframe. A vent drift is also often installed within the collar. The impactor machine itself is not used to break rock until bedrock is reached as well as a depth where the complete system (galloway stage and impactor machine) can be installed in the shaft. This level would be reached at about 60 feet.

The initial excavation for the shaft collar is generally done with a backhoe or a crane and clamshell. For the rock conditions where an impactor machine would generally be used, drilling and blasting may also be necessary to reach a depth of 60 feet. The excavated material is mucked with the crane and clamshell. As excavation proceeds, an Eimco 630 loader may be used to load the muck bucket, which is then hauled up by the crane. A conventional shaft collar is then constructed to the 60-foot depth, and lined with concrete.

During shaft collar excavation and construction, the headframe, galloway and impactor machine are assembled. The headframe unit takes about a week to erect onsite.

A temporary work deck is used to provide a work place for setting the forms and pouring the concrete. This deck is lowered into the shaft and raised and lowered in the shaft as required for the various lining operations using the mobile crane. It is suspended from the shaft walls or the concrete forms when in use.

The formwork used in shaft collar lining is generally wooden. Since shaft sizes vary from project to project, the steel lining forms used for shaft lining generally need to be ordered during this phase of mobilization. The forms are lowered in their original segments to minimize handling problems. The form is centered and braced off the excavated shaft walls to prevent any movement during the placement of the concrete.

When the formwork is in position, concrete is lowered into the shaft in a 1.5-cubic yard bottom discharge concrete bucket suspended from the

mobile crane. Working from this platform, the miners discharge the concrete bucket behind the form. It is important to ensure that concrete is distributed evenly around the form. Thus, the miners must have access around the complete periphery of the shaft. The concrete is vibrated during pouring. When the first 10'-0" of formwork has been filled with concrete, the next 10'-0" of formwork is set in place using the mobile crane and workdeck as supports. The formwork is set and centered before filling resumes. Access to and from the shaft for employees is possible in a bucket suspended from the hoist rope of the mobile crane, provided the crane is equipped with all necessary safety and speed controls required by Federal regulations. If such a mobile crane is not available, properly equipped ladders or scaffolding would be used for access to the shaft.

Shaft excavation continues conventionally until adequate clearance for the suspension of the galloway and impactor machine in the shaft is achieved. The fabricated steelwork for the work platform, the shaft collar doors and the steel headframe are assembled alongside the shaft while collar construction and preliminary sinking is in progress. Each item is then set in place in sequence - the work platform, the impactor machine, the collar steel and then the sinking headframe. When the headframe is in place, the wire ropes from the 2 galloway winches are pulled over the sheave wheels on the headframe, down and around the pair of sheave wheels located below the top deck of the work platform, and back up to the headframe and down once more to be anchored in the galloway. These winches are then capable of raising and lowering the work platform as required through the shaft. These winches normally require approximately 50 horsepower to operate, being very slow speed hoists (approximately 15 feet per minute). Consequently, these winches can obtain power in emergency from a relatively small standby generator. At this point, shaft pipes are installed to provide the services required for shaft sinking: namely, ventilation, compressed air, and water into and from the shaft. All pipes for the impactor system are in 20-foot lengths to conform with concrete pour lengths. The pipes are clamped to the wall every 20 feet by a special bracket secured to the wall by 1-inch diameter stud bolts screwed into socket nuts cast into the concrete shaft lining.

In addition to the pipe ranges, the shaft side lines used to plumb the shaft are installed at this time. A winch and wire rope is also installed for shaft signals. This wire rope is connected at shaft collar level to a mechanical (gong) signal which also activates an electrical switch transmitting the signal both audibly and visually to the hoist house.

Other installation work proceeding simultaneously with the shaft collar, fabricated equipment assembly and hoist and winch installation would be site plumbing; wiring; clearing and preparing the muck disposal area including water catchment, clarification and other control requirements. Most buildings are of the mobile variety. Metal buildings are normally erected around the main hoist and winches. The excavation and construction of the shaft collar and the completion of the installation of all of the equipment and fabricated steelwork discussed above will take from four to six months working one to two shifts per day at six days a week. The work force during mobilization consists of 10-20 or even 25 men, because of the many concurrent operations required.

Breaking and Loading Muck

As mentioned earlier, the impactor breaks rock using a high energy pneumatic hammer mounted on an articulated boom similar to a backhoe boom. The pneumatic hammer delivers a blow with an energy of 2000 ft. lbs., 600 times per minute, giving an output of 1,200,000 ft. lbs. per minute. The muck is loaded in conventional shaft sinking buckets using a mucking bucket which is also mounted on an articulated boom. The mucking boom is a standard backhoe arm with a modified bucket.

The breakage of competent rock with impact tools can be thought of as a two part process: 1) the formation of a network of cracks in the rock, thus creating new free surfaces, and 2) the removal of chunks of rocks by forming secondary cracks reaching these free surfaces. In less competent rock containing fractures, bedding planes and planes of weakness, the second mode of fracture will predominate.

Perhaps the most important aspect of breaking rock using impact tools is to have a free surface such as a step or bench to aid the formation of secondary cracks. In the case of the impactor, excavation proceeds with a series of pie-shaped radial trenches approximately 18 inches deep extending from the center of the shaft out to the circumference. As each section is excavated, a free surface is created to facilitate the excavation of the next section.

As a section is excavated, the rotating frame is rotated to allow the breaker boom to have access to the next section. Since the mucking boom is also attached to the cab assembly, it also rotates. This rotation brings it in a position to muck out the excavated material. Since the breaker boom is located to the left of the mucking boom (when viewed from the top), the cab assembly rotates counterclockwise to allow mucking to follow breaking as indicated.

The mucking operation consists of scraping the muck into small piles and then loading it into the muck buckets. Unlike the breaker boom which is not free to rotate relative to the cab, the mucking boom has a rotary actuator allowing it to move somewhat independently from the cab assembly.

In the field demonstrations, the excavation rate was approximately 16 yd³/hr when the machine was working. This is approximately 1 ft. of advance per hour in a 24-foot diameter shaft. While sinking a shaft, it is anticipated that the machine could excavate 20 feet in three shifts. This would be followed by one shift to move the forms and pour the lining and a shift to clean up and extend the service lines. Overall, for a 2500 foot deep shaft, excavation and lining operations should proceed at an average of about 70 feet per week.

Muck Haulage and Removal

Muck haulage and removal is achieved by means of two conventional mucking buckets and a double drum hoist. The cycle of muck haulage is continuous during rock breaking and is halted only during shaft lining. Although

some thought has been given to continue mucking during lining (since breaking is possible during the lining phase), it is not probable this approach would be used since this requires that the concrete be delivered down the shaft by slick lines (to free the muck buckets to handle muck).

Mucking begins when an empty bucket is lowered to the shaft floor. After the bucket is loaded, a signal is given from the shaft crew to the hoist operator by means of a wire rope attached to an electrical switch. The signal to the hoist operator is both audible and visible. The full muck bucket will be raised through the shaft and out the collar skip doors on the surface. The muck is then dumped down a chute to a temporary muck pile next to the shaft collar. A front-end loader or some other equipment will handle the permanent disposal of the muck.

During the raising of the loaded bucket, the empty one will be simultaneously lowered, and the cycle repeats.

The coordination of the movement of the muck buckets and the impactor (i.e., assuring that the impactor is not at the galloway opening or breaking rock below where the bucket will land) is done by the "shift boss" who is stationed in the galloway. No men are required at the shaft bottom during any phase of mucking.

Pipeline Extension

The service lines for the impactor shaft sinking system are extended once every 20 feet, during which time the services provided, including ventilation, compressed air and water, are interrupted. Pipeline extension operations in the impactor system precede the concrete lining cycle. The pipes are secured to the wall by brackets bolted by studs screwed into inserts cast into the concrete lining. Extension operations require from two to four men. To extend the shaft pipelines, the upper deck of the work platform is positioned some two feet below the bottom of the pipes already installed. The manifold on the end of each pipe (i.e., valve assemblies) is then removed and secured to the work platform. Pipes are lowered on the hoist rope one at a time until the tops of the pipes are

immediately below the installed pipes. Rope slings and ratchet jacks are then used to raise the pipes into position. The victualic couplings are then fitted. The work platform is then lowered to permit replacement of the valve manifolds on the bottom of the pipes and secure the pipes to the wall bracket.

Shaft Lining and Completion

Nearly all modern shafts are concrete lined to provide ground support, to seal out excess water, and to protect the wall rock from deterioration. The shaft being constructed by the impactor is lined with unreinforced concrete. The impactor machine can obtain a vertical dig of 6'8" before the galloway has to be lowered. Thus, the impactor completes three excavating cycles before the lining cycle begins. The service lines are extended and the lining forms are lowered preparatory to pouring 20 feet of concrete wall. All men work on the pipe up and lowering and setting of concrete forms.

In bad ground conditions, when the amount of open ground below the concrete has to be reduced, the pour lengths can be shortened. If required, the open ground may be further reduced by folding up the Breaker and mucking boom and lowering the cab on to the sump or taking the cab/boom unit out of the shaft altogether so that the distance between the bottom deck of the galloway (and therefore the forms) and the shaft bottom is minimized. When the pour is complete, the galloway would be raised inside the forms until the breaker was in the correct position relative to the sump and excavation would continue.

The equipment used for lining consists of a curb ring; 8 steel ring forms, each 2 1/2 feet high; and twelve 1 1/8" diameter, 20 foot long hanging rods. At the start of a lining cycle, the curb ring is broken away from the bottom of the previous pour. It is attached to winches on the galloway. The work platform with the curb ring suspended is then lowered to the new position, 20 feet below. The curb ring is then attached to and supported by the hanging rods (which provide for some reinforcement of the concrete lining) and is positioned and centered using the shaft sidelines.

Any annular spaces between the curb ring and the shaft wall are sealed using strips of plywood and/or sandbags to ensure a tight fit. When the curb ring is set, the galloway is raised up to allow removal of the concrete forms from the previous pour. The form has a knife edge that slides behind the adjacent section of the form, so that the form might be pulled together at that location, thereby decreasing its diameter. The form is broken loose by drawing it together on one side using steamboat jacks and, once the form is loose, lowering it with the pneumatic hoists on the galloway. The form is set on top of the curb ring. After installation and alignment, the first 10' section is poured. Concrete is poured behind the forms using elephant trunks from a bottom discharge 1-1/2 cubic yard capacity concrete bucket on the end of the hoist rope. The concrete is either mixed on surface in the contractor's own onsite batch plant or is procured from a subcontractor who delivers to the site in ready mix trucks. Concrete is loaded into the shaft bucket on top of the collar doors. The concrete may have an accelerator added to improve setting time. Compressed air concrete vibrators are used to vibrate the in-place concrete. One miner unloads the bucket; one or two men move the concrete behind the form and/or move the elephant trunk from door to door. One miner operates the vibrator and one man gives signals to the hoistman. During work platform movement, all men are employed guiding the platform. Similarly, during the removal and resetting of the form, all four men are employed. The procedure is repeated for the second 10'-0" form section.

The total operation requires about one shift. Cleanup operations and previous pipeline extension requires roughly another shift. Cleanup consists of hosing down the concrete buckets and other equipment and the decks of the working platform. The final concrete lining is smooth, with a nominal thickness of 12 inches. Extra concrete that may be required as a result of overbreak is not included in this thickness.

The system under consideration also may require water rings, which are constructed in the lining where excessive groundwater is a problem. Water rings are excavations into the shaft wall in which excess water is collected and channeled downhole by pipes to a sump for pumping.

The impactor machine will be used to excavate the shaft down to about 2500 foot depth in 20 foot cycles. The shaft stations, however, must still be completed. The time required for station construction depends on the size of the station.

Station construction is probably the most difficult and potentially dangerous phase of shaft sinking. It involves turning off from the vertical shaft into the horizontal tunnel openings in the mine. The most difficult phase of the operation is excavating and supporting the brow or roof lip of the station in the transition zone. Station excavation and concreting is pursued in a series of small stages dictated by roof control requirements. Temporary support using roof bolts, straps and mesh in some instances may permit complete construction in only one or two phases. Concrete lining of the station is almost always required.

Demobilization

Demobilization, or the removal of the impactor shaft sinking equipment from the shaft and the surrounding area (including foundation removal and site grading) is usually completed by a limited work crew in a three-week period. Once the impactor machine reaches the bottom of the shaft and the shaft station has been completed, the machine is lifted out of the hole. The impactor can be removed as one piece. The shaft pipe ranges may then need to be taken out starting from the shaft bottom and working from the galloway. If the shaft is to be equipped, the galloway stage is then converted to a furnishing stage, which is easier to handle steel through. Then, shaft equipping will take place as required. If not used for equipping, the work platform is dismantled into the largest sections that will pass through the collar steelwork and is sent to the surface on

the hoist rope. The wire ropes are wound onto spools. The headframe is taken down and hoists are dismantled. The collar steelwork is removed and the collar area fenced off. Where necessary, foundations for hoists and winches are removed and the site graded to the client's specifications.

Working Environment

The working environment for the impactor shaft sinking system addresses the interaction of the crew members with the system hardware described in previous sections of this paper. This section describes personnel requirements for shaft sinking operations, personnel work stations and factors contributing to a safe working environment.

Personnel Requirements

The basic personnel requirements for impactor shaft sinking operations are shown in Table 6. This is representative of the workers at the site during each shift. In addition to these, three miners would be on call to help during concrete pouring operations.

TABLE 6.-Shift personnel requirements

- 1 Shift Boss
- 2 Operators
- 1 Front-End Load Operator
- 1 Hoistman
- 1 Top Lander
- 1 Shift Supervisor
- 1 Shift Mechanic

The impactor would normally operate three shifts per day. During the day shift, approximately seven additional people would be on site. Their functions are listed in Table 7.

Table 7.-Additional day shift personnel

- Superintendent (Master Sinker)
- Master Mechanic
- General Mechanic
- Project Manager
- Project Engineer
- Warehouseman
- Electrician

Personnel Work Stations

During normal breaking and mucking operations, only the two operators and the shift boss would be in the shaft. Both operators, one controlling the impact breaker and one, the mucking operation, work in the control cab assembly located beneath the galloway (see Figure 4). Separate work stations with seats and overhead and side protection are provided for each operator. Due to the nature of the rock breaking operation, both operators are subject to intermittent vibration.

The shift boss supervises the operators and the muck haulage operations. From a work station on the galloway, he uses the bell code to signal the hoistman to raise and lower the muck buckets and/or the galloway. It is the responsibility of the shift boss to assure the safe movement of the muck buckets to and from the bottom of the shaft.

The hoistman, top lander and front-end loader operator work at the site surface. The work station of the hoistman is in the hoist building. He is responsible for the operation of the hoists as described in the section discussing the haulage of men and materials. Before each operating shift, the hoistman performs a checkout to test the hoist brakes and interlocks. The front-end loader operator is responsible for the removal of the rock from the muck pile near the headframe to the muck disposal area. The top lander is stationed at the shaft collar and is accountable for the movement of men and material in and out of the shaft. To aid him in this duty, a tagging system is used at the site. Each person who goes down the shaft must move a metal disc from a board indicating he is out of the shaft to a board indicating he is in the shaft. When the person comes out of the shaft, he must return the disc to the other board.

Other personnel are generally at the site surface during normal breaking and mucking operations. The mechanics and electricians are employed doing off-machine maintenance in the shop area. They are in the shaft only when maintenance or repairs are required on downhole equipment. The supervisor, however, may be found either in the shaft or on the surface. He provides direction for crew members and should be able to account for all personnel that report to him and be readily available should problems at the site arise.

As shaft sinking progresses, shaft lining and service line extension operations will be performed. These operations are discussed earlier in this report. Work stations for the personnel involved in these operations are on the galloway. During these operations the functions of the hoistman and top lander would remain the same as previously described.

Contributions to Safe Working Environment

The following items contribute to a safe working environment for the impactor personnel:

- All downhole personnel are continuously protected by an overhead steel deck and in most cases by multiple decks of the galloway.
- No personnel work on the shaft bottom during normal breaking and mucking operations.
- Number of personnel required to be downhole during shaft sinking operations can be kept to a minimum.
- Wall conditions are improved as compared to conventional drill-and-blast methods.
- Since there is no blasting required and as a result no blasting fumes, the air quality for personnel working in the shaft is improved.
- Personnel do not need to handle explosives or be exposed to other drill/blast hazards.

COMPARATIVE SAFETY ASSESSMENT

The safety assessment of the impactor shaft sinking system requires an examination of the safety of the impactor in comparison to conventional shaft sinking technology. A safety comparison of two operating systems is usually relatively easy because injury or accident data are available for both systems. Accident rates and historical operational safety data are available for conventional shaft sinking techniques from the Health and Safety Analysis Center in Denver, Colorado. However, the impactor is a new technology that has not had extensive operating experience, although a full description of the machine exists and it has been tested in the field. A method of analysis was thus required that would allow a comparison between a system with historical operating experience and a developing system technology.

The comparative safety analysis methodology developed at Battelle-Northwest combines an actuarial data analysis and a predictive safety analysis methodology with a simple decision-making process. The safety performance of a conventional system is quantified based on actuarial data. A Preliminary Hazards Analysis (PHA) is performed on the new system, in this case the impactor, to determine the hazards of the system. The results of the two analyses may then be compared using a single-attribute safety judgment. Unique causes of accidents presented by the new system are examined independently. Comparable accident causes within a particular system function are analyzed in an "asset" and "liability" table. A backup section is provided that details why each system characteristic is estimated to be an asset or liability.

The methodology basically consists of the following four steps:

- A detailed description of each system or technology under consideration, including the basic operations required, the equipment used, the time required for each task, and the crew sizes required.
- The identification of system hazards by function, or subsystem, for each technology being analyzed.

- A comparison of system hazards by function for the two technologies, using one system (generally the commercialized system, which has accident statistics available) as a baseline.
- An overall safety judgment of the technology in question (generally the new, developing system) relative to the chosen baseline.

The comparative safety assessment presented in this report is based on the impactor system described in the previous section. A description of the conventional shaft sinking system to which the impactor was compared is presented in detail in Appendix B. A summary of the system description information for both the impactor and conventional shaft sinking technologies is presented in Table 8. This information was used in comparing the two methods of shaft construction.

The identification of hazards for conventional shaft sinking operations was performed by reviewing the available accident data on metal/nonmetal shaft sinking systems currently in use. A review of accident records for a three year period, 1978-1980, revealed the accident breakdown by shaft sinking activity or function represented in Table 9. For each function, the relative contribution of primary accident causes, as defined by the Mine Safety and Health Administration (MSHA), is also listed. These numbers were obtained from the accident reports filed by mine operators with MSHA's Health and Safety Analysis Center in Denver and reflect the number of incidents for each accident category. Although the primary accident cause is catalogued for each report, determination of the activity of the worker at the time of the accident (for sorting by function) required a separate analysis of each report filed.

Hazards for the impactor system were identified by means of a PHA. The PHA methodology is a qualitative assessment technique used to identify the major potentially hazardous conditions of a system that could result in worker injury or fatality. Details on the methodology and the analysis of the impactor system are presented in Appendix C. A sorting of the identified potential accidents into the MSHA primary cause classifications revealed the accident categories for the impactor system listed in Table 10.

TABLE 8. Comparative Tasks, Equipment and Times for Conventional and Impactor Shaft Sinking Systems for a 2500 foot, 22 foot Finished Diameter, Concrete-Lined Shaft

System Tasks	CONVENTIONAL SYSTEM			IMPACTOR SYSTEM		
	Basic Equipment	# of Shifts	Workers Per Shift Total/Downhole	Basic Equipment	# of Shifts	Workers Per Shift Total/Downhole
Mobilization (including excavation and lining to complete system installation depth- 60')	Surface equipment (dozers, trucks cranes). Scaffolds, ladders, work-decks. Collar steel, concrete. Spaders, drills, explosives. Lining equipment (forms, concrete, reinforcing steel).	240(a)	10-20	Surface equipment (dozers, trucks cranes). Scaffolds, ladders, workdecks. Collar steel, concrete. Spaders, drills, explosives. Lining equipment (forms, concrete, reinforcing steel).	240(a)	10-20
Breaking Rock	Junbo, hand-held drills. Explosives, detonators, shot-firing cable. Compressed air hose and pipe	370 (3 per 20' advance)	9/6	Impactor machine and associated subsystems Pneumatic hammer	370 (3 per 20' advance)	9/3
Loading Muck	Mucking machine, handtools Muck buckets (2) Barring tools	250 (2 per 20' advance)	9/5	Impactor machine and associated subsystems. Mucking shovel, muck buckets (2)	(concurrent with rock breaking)	9/3
Hauling Muck	Headframe, hoist, ropes, buckets. Dump system, front-end loader	(concurrent with muck loading)	9/5	Headframe, hoist, ropes, buckets Dump system, front-end loader	(concurrent with rock breaking)	9/3
Hauling Men	Buckets, ropes, hoist	(continuous)	9/5-6	Buckets, ropes, hoist	(continuous)	9/3-5
Hauling Materials	Buckets, ropes, hoist Pipelines	(continuous)	9/5-6	Buckets, ropes, hoist Pipelines	(continuous)	9/3-5
Maintenance	Handtools, materials, supplies	(continuous)	9/5-6	Handtools, materials, supplies	(continuous)	9/3-5
Shaft Lining	Galloway stage, lining forms, rods. Buckets, discharge chutes. Jacks, handtools, concrete	125 (1 per 20' advance)	9/5	Galloway stage, lining forms, rods Buckets, discharge chutes Jacks, handtools, concrete	125 (1 per 20' advance)	9/4-5
Pipeline Extension	Galloway stage, ropes, slings Pipes (5), couplings, handtools	125 (1 per 20' advance)	9/5	Galloway stage, ropes, slings Pipes (4), couplings, handtools	125 (1 per 20' advance)	9/2-4
Shaft Wall Support	Concrete lining, timbers, rock bolts, wire mesh Minimum exposed wall of 40'	(concurrent with pipeline extension)	9/5-6	Concrete lining, timbers, rock bolts, wire mesh Minimum exposed wall of 40'	(concurrent with pipeline extension)	9/2-5
Shaft Station Completion	Drills, explosives Roofbolts, mesh, lining	140(b)	9/6	Drills, explosives Roofbolts, mesh, lining	140(b)	9/5
Ventilation	Fan(s), ducting	(continuous)	9/5-6	Fan(s), ducting	(continuous)	9/3-5
Shaft Dewatering	Pump, water lines, collection rings	(as required)	9/5-6	Pump, water lines, collection rings	(as required)	9/3-5
Communications	Bell rope, lights	(continuous)	9/5-6	Bell ropes, telephone	(continuous)	9/3-5
Demobilization	Hoist, ropes, pipe, handtools Surface equipment (dozers, trucks, cranes)	30-40	7/4	Hoist, ropes, pipe, handtools Surface equipment (dozers, trucks cranes)	30-40	7/4

(a) 2 months @ 1 shift/day, 6 days/week
4 months @ 2 shifts/day, 6 days/week

(b) About 2 months assumed for station construction (water, pump and final)
3 shifts/day, 6 days/week

TABLE 9. Final Accident Data Distribution for Metal/Nonmetal Shaft Sinking (1978-1980)

	Mobilization	Breaking Rock	Loading Muck	McN	Haulage of Materials	Muck	Pipeline Extension	Shaft Lining	Maintenance	Shaft Wall Support	Shaft Dewatering	Shaft Station Completion	Ventilation	Communication	Demobilization	Other	Total
Number of Accidents	21	72	49	51	40	23	8	42	61	23	4	8	2	2	1	7	414
Percent of Total	5	19	10	12	10	6	2	10	15	6	1	2	0.5	0.5	0.2	1.6	100(a)
Primary Accident Causes	--	--	--	--	--	Number of Accidents											
- Fall of Face		5	12				1	3	4	2		2					29
- Sliding/Falling Objects	2						1		5	2							11
- Slips/Falls	7	4	6	6	1	2	2	3	9	3				1		2	45
- Handling Materials	9	21	15		37	1	2	14	16	9	2	2				1	129
- Handtools		3	2					5	12						1		23
- Stepping on Objects		1		4				2	1								8
- Bumping Objects								1								1	2
- Haulage	1		6	33	2	19	1	1	2								63
- Explosions									1								1
- Explosives		2															2
- Electricity				2					3							1	7
- Machinery	2	34	8			1	1	3	8	7	2	4					70
- Suffocation																	
- Fires																	
- Miscellaneous	1	2		5				10					2	1		2	24

TABLE 10. Potential Accident Categories Present in Impactor Shaft Sinking System Functions

Primary Accident Causes	System Functions														
	Mobilization	Breaking Rock	Loading Muck	Men	Haulage of Materials	Muck	Pipeline Extension	Shaft Lining	Maintenance	Shaft Wall Support	Shaft Dewatering	Shaft Station Completion	Ventilation	Communication	Demobilization
- Fall of Face/Wall							X	X		X		X			
- Sliding/Falling	X			X			X	X	X						X
- Slips/Falls	X	X	X	X	X	X	X	X	X					X	X
- Handling Materials	X				X	X	X	X	X		X				X
- Handtools								X	X						
- Stepping on Objects				X											
- Bumping Objects								X	X						
- Haulage	X			X	X	X	X		X						X
- Explosions															
- Explosives												X			
- Electricity		X	X	X					X		X				X
- Machinery	X	X	X			X	X	X	X			X			
- Suffocation													X		
- Fires		X	X												
- Miscellaneous	X	X	X	X				X	X				X	X	

A risk measure was used to compare the safety of the two systems. This risk measure, for the purposes of this study, was the product of the number of accidents occurring within a three year period (1978-1980) for a particular accident cause category and the injury severity produced by that accident. A normalized average days lost figure was used as the measure of accident severity. These risk values were obtained for the conventional shaft sinking system from an analysis of historical accident data, and were used as a baseline for the comparative analysis.

The effect of the substitution of the impactor shaft sinking technology for conventional methods was determined by comparing safety-related system characteristics of the impactor with the corresponding characteristics of the conventional system. Differences in potential exposure to hazards between the systems were identified. A subjective weighting scheme was developed to account for these differences quantitatively in the safety comparisons. Factors contributing to exposure include the number of people present, the amount of time for which they were exposed to a particular hazard or operation, and the number of hazards present in the system. Comparisons were made for each function of the shaft sinking operation, including breaking of rock, loading and haulage of muck, haulage of men and materials, etc. The relevant information for specific hazards within each function was then combined to obtain a relative risk value for functions in the impactor system. The combination of these factors was based on the historical importance of specific accident types to overall injury levels in conventional shaft sinking. These results allowed the calculation of an estimated risk value for the impactor system relative to conventional techniques.

The overall system risk values for both the impactor and conventional systems are listed in Table 11. Risk values are also presented in this table for each shaft sinking function in the systems. The first column in the table presents the baseline risk values for conventional shaft sinking. These numbers were obtained from historical accident data, and represent the product of the number of accidents occurring for that function over a specific three-year period and the injury severity of those accidents. The injury severity values represent average days lost per injury, and were normalized

in this analysis to a scale of 0 to 100 to facilitate data handling. These risk numbers are thus useful only as a baseline from which to compare the impactor system. They should not be taken as absolute risk values for the for the conventional system.

The estimated relative risk values for the impactor are shown in the next column of Table 11. These values were obtained by applying weighting factors to differences between the conventional and impactor system characteristics that contributed to a particular accident type. The uncertainty involved in the subjective assignment of some of the weighting factors does not allow the use of these results as absolute risk values for the impactor system. Rather, the intent of this study is to use these values as indicative of general trends in impactor system risk relative to conventional techniques.

The final column of the table shows the estimated level of risk reduction or increase expected with the use of the impactor system. Specific results for some of the more hazardous shaft sinking functions are presented in more detail below. The calculations and additional details for the entire comparative analysis are presented in Appendix D.

Breaking Rock

Breaking rock was found to be the most hazardous operation in conventional shaft sinking systems. Accidents occurring during conventional excavation were mostly a result of operating machinery, primarily the drills, and handling supplies or equipment. Use of the impactor system may reduce the hazards encountered in conventional rock breaking operations by as much as 85 percent. In the impactor system, men are not required to work on the shaft bottom and are located in protective cabs above the shaft floor. The machine is operated by control levers from the operator cab. There is no requirement in the system to handle or move equipment and/or supplies during the rock breaking operation.

TABLE 11. Baseline Risk Values for Conventional Shaft Sinking Systems and Relative Risk Value for the Impactor System

Function	Baseline Risk Value (Conventional)	Average Relative Risk Value (Impactor)	Average Difference in Risk with Impactor
Mobilization	4.02	4.02	0
Breaking of Rock	27.95	4.47	-84%
Loading of Muck	122.89	33.53	-73%
Haulage of Muck	202.66	163.24	-19%
Haulage of Men	439.24	343.16	-22%
Maintenance	210.10	58.81	-72%
Haulage of Materials	22.65	27.02	+19%
Pipeline Extension	100.98	80.85	-20%
Shaft Lining	8.40	7.43	-12%
Shaft Wall Support	4.40	4.40	0
Shaft Station Completion	1.50	1.50	0
Ventilation	0.34	0.22	-35%
Shaft Dewatering	0.54	negligible	-99%
Communications	0.34	0.28	-18%
Demobilization	0.10	0.10	0
System Total	1146.11	728.98	-36%

However, the impactor system may present some additional hazards. These include potential occupational hazards from long-term exposure to vibration and noise; increased electrical hazards; and increased potential for injuries from fires.

Loading Muck

Accidents occurring during muck loading were fairly frequent in conventional shaft sinking systems, representing about 10 percent of all accidents recorded for metal/nonmetal shafts over an approximate three year period (1978-1980). Although most of the injuries experienced were minor, there were a few more serious injuries evident, including one instance of a fatality. Many of the accidents experienced during muck loading in conventional systems, however, stemmed from causes that are absent in the impactor system, primarily because men are not required on the shaft bottom.

The risk of accidents during muck loading operations in conventional shaft sinking systems may be reduced by over 70% with use of the impactor machine. Because no men are required on the shaft bottom with the impactor, and most operations are performed by the machine, the risk relative to conventional muck loading is very low.

However, use of the impactor machine may result in an increased incidence of slip and fall accidents during muck loading because of the difficulties in getting in and out of the machine. These may also be some potential injuries from noise and vibration effects with use of the impactor.

Maintenance

Maintenance operations during shaft sinking include inspections of shaft sinking and support equipment, lubrication of parts, and replacement of missing or worn components. Accidents occurring during maintenance of shaft sinking equipment were second in frequency only to breaking rock accidents. These accidents represented about 15% of all accidents recorded for metal/nonmetal shafts over a 3-year period. Also, more serious injuries occurred during maintenance operations than were experienced in rock breaking. Although the frequency of maintenance accidents was somewhat less than for rock breaking, the severity of the accidents tended to be greater.

The risk of maintenance operations in conventional shaft sinking systems may be reduced by as much as 70% with the use of the impactor system. This reduction is primarily a result of less crew exposure to hazards because of less time required doing routine maintenance operations. Also, there is less crew exposure to the shaft bottom during maintenance operations with the impactor system, reducing the risks associated with those exposure hazards.

Summary

The impactor system presents both safety advantages and some additional hazards relative to conventional shaft sinking. The advantages of the system include less exposure to hazards (smaller crews, less time downhole, protected working environments), no use of drills or explosives, and reduced concrete handling requirements. However, the system also presents the potential for

increased electrical, fire and slip and fall accidents, as well as an increased risk of occupational injury from high noise and vibration levels.

The results of this analysis show that the use of the impactor system instead of conventional shaft sinking techniques may be expected to reduce system risk by an average of about 36%. Use of the impactor can significantly reduce some conventional sources of risk, such as in rock breaking, muck loading, and man and muck haulage. Maintenance operations also should present a generally reduced risk level in the impactor system, since most major repairs can be done in surface shops. Although the impactor is estimated to increase the risk in some operations relative to those encountered in conventional systems, these functions have generally contributed insignificantly to total system risk.

FAILURE MODES AND EFFECTS ANALYSIS

One objective of this study was to examine the impactor shaft sinking system to identify critical safety items in the systems and develop design change recommendations, based on the results of the safety analysis, to ensure the optimum safety of the systems. Failure Modes and Effects Analysis (FMEA) methods were used to attain these objectives. FMEA is a qualitative technique for analyzing and evaluating a design. It provides a means for a systematic analysis of all potential component failures and their resulting effects on a system. The fundamental steps in the application of the FMEA methodology can be summarized as follows:

- Define the system to be analyzed, and divide the system into convenient working units such as subsystems, functions or components;
- Identify the possible failure modes of each component in a system and their probabilities of occurrence; and
- Evaluate the potential effects of each failure mode identified on the system and delineate the criticality of each failure mode. This step also requires the identification of all failure detection methods and existing corrective measures within the system that will serve to reduce the potential consequences of a failure mode.

To perform an FMEA on a system as complex as the impactor shaft sinking system, it was first necessary to subdivide the overall system for the purposes of analysis. These subsystems were generally chosen to conform to required functions during a shaft sinking project. Figure 8 shows the subdivision used with the impactor system. The three basic system divisions are:

- the Impactor Machine system
- the Haulage and Materials Handling system
- the Support systems.

These basic systems were analyzed in terms of the subsystems and components that are included in each system.

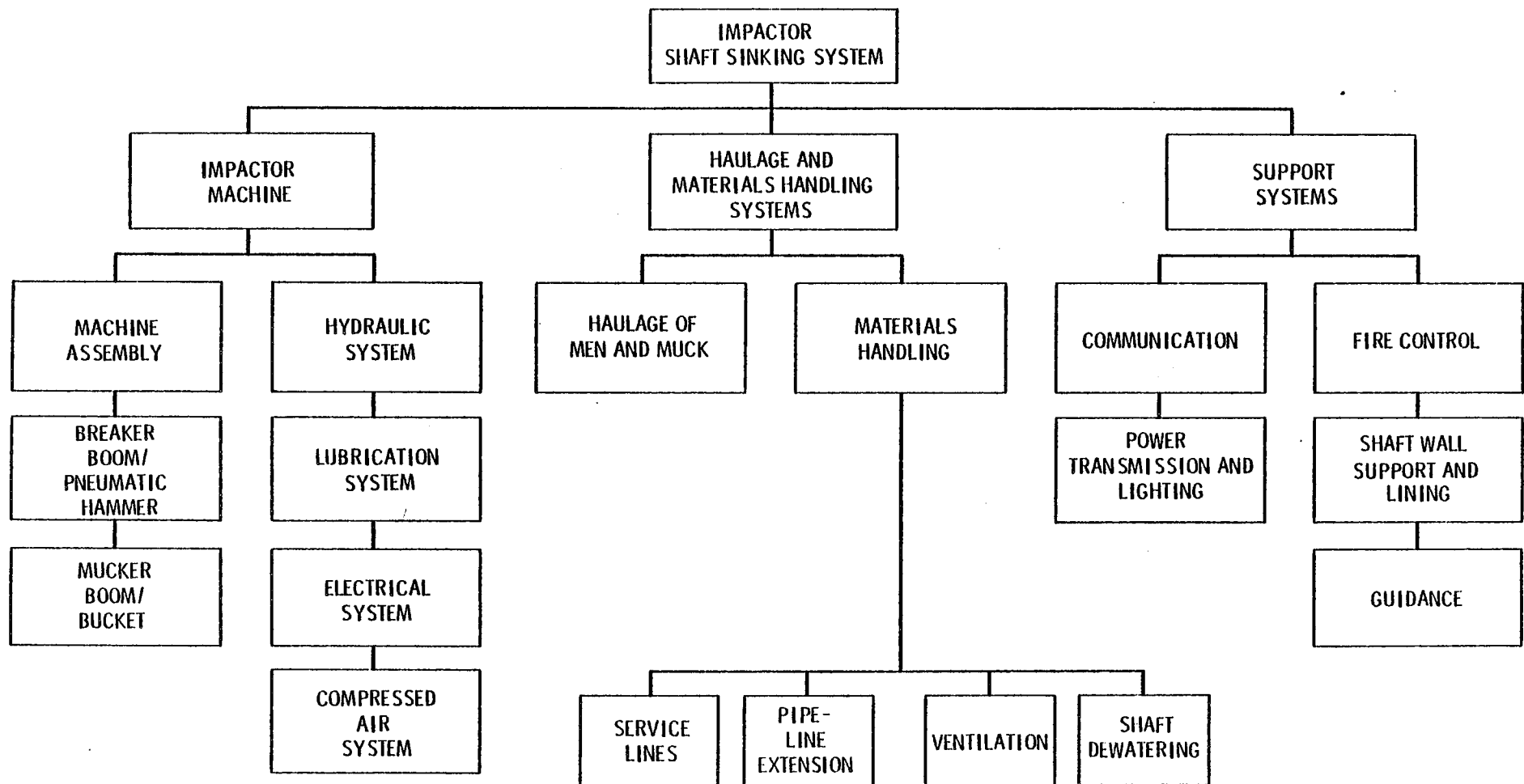


FIGURE 8. FMEA System Diagram

General Findings of the Impactor System FMEA

The objective of this analysis was to locate any components whose failure in any mode would constitute a threat or hazard to the impactor personnel and for which insufficient preventive and corrective measures currently exist. It was found that for the impactor machine and its support systems there are few component failures likely to cause any direct hazard to personnel for which there are not sufficient preventive/corrective measures. The greatest potential hazard in the system is probably in the area of operator access to the impactor cabs, especially in an emergency situation. Entering and exiting the cab require the operator to climb ladders and such suspended directly over the shaft floor. Improvements to the fire control systems may also be required to improve their effectiveness. Changes in inspection techniques of critical cab support components due to their possible susceptibility to fatigue cracking or other failures, and shaft lining form improvements to allow easier removal are among other suggested changes to the system.

As might be expected, the greatest number of potential hazards were found to exist in the haulage system. The greatest single hazard was the use of the muck hoisting system to perform man haulage duties. Haulage of men and muck has traditionally been a source of hazard in conventional shaft sinking systems. Since the impactor shaft sinking system essentially uses a conventional haulage system, it also shares these hazards. However, the hazards of haulage systems have been investigated for a number of years. A great number of preventive and corrective measures to mitigate these hazards have been developed and are in common use. In Appendix B there is a description of many of the hoisting equipment safety features included in most conventional systems. If properly used and maintained, these safety features can be very effective means of reducing the possibility and consequence of many haulage hazards.

Specific results for some of the more critical subsystems analyzed are discussed below. Detailed FMEA tables for all subsystems are presented in Appendix E.

Machine Assembly

A failure of any of the components required to support the impactor could be potentially hazardous, since failure of these components could result in a drop of the impactor machine and possible injury or fatalities to the operators from the fall. However, such an event would require that the components involved suffer a complete structural failure, which is unlikely to occur. Improved inspection techniques using nondestructive testing (NDT) would insure that structural faults in the assembly structure are detected early and corrected.

Breaker Boom and Hammer

None of the boom failures was expected to result in any hazard to personnel (although any component failure was capable of disabling the system) and the only hammer failure able to cause personnel injury was a failure of the muffler. Excess noise from the hammer exhaust could be harmful to the operators and may affect their performance. The muffler is not, however, a difficult part to replace and with proper maintenance and inspection should create few problems.

Hydraulic System

All except one of the failure modes identified for this system which are judged to be potentially hazardous to personnel involved the leakage or rupture of some component. The release of high-pressure, flammable fluid could create a fire hazard, slip/fall potential, or the hazard of being struck by high-pressure fluid or a whipping hose. It is fairly likely that leakage of hydraulic fluid will occur. Slip/fall accidents within the operator's cabs are unlikely to cause serious injuries. However, it is recommended that the cab flooring be made as slip-free as possible, with one of the various coatings and/or gratings that exist, and be kept clean.

The possibility of a hose whip accident and an operator being struck by either the line or high-pressure fluid is small. None of the exposed high-pressure hydraulic lines (2000 psi) run near the operators. The only lines to which the operators are immediately exposed are the lower pressure (400 psi) "control" fluid lines. These lines are partially covered and are below head and eye levels where most of the damage to personnel could occur. With proper tie-downs, these lower pressure lines can effectively be prevented from whipping if ruptured.

The potential for fire from a spill of hydraulic fluid is also quite small. However, the consequences of an accident if a fire occurs are very high. Design changes to the fire control system are recommended to mitigate these potential consequences. Use of nonflammable hydraulic fluids might also be considered to further reduce the probability of fire aboard the impactor machine.

Lubrication System

Failures of this system that could cause harm to personnel involved the fire potential of the lubricant, slip/fall hazards and the possible hazards of breathing the oil mist left in the exhaust of air-operated equipment.

The fire potential of the lubricating oil is probably quite small since there are few ignition sources and it is doubtful that any of these sources will heat the oil to its combustion point (500° to 700°F). However, although the chances of fire are low, the consequences are very high and involve the lives of personnel as well as the potential for extensive machine damage. For this reason, an adequate, workable fire-control system and fast-escape route should be maintained.

The slip/fall hazard of oil accumulated in undesired places can be prevented by periodic cleaning and maintenance. Use of non-slip flooring can also help reduce this hazard.

The possible hazards of having excess oil suspended in the operator's breathing air due to the malfunction of an air oiler are effectively countered by the ventilation system. It is also doubtful that the air oilers could

suspend sufficient oil in the breathing air to cause harm to personnel. Even if this event occurred it would probably require prolonged breathing before harm would be done. This would give ample time for detection of such a fault. Never-the-less, consumption of oil by the air oiler should be monitored to aid in detection of a fault.

Electrical System

Failure of many of the components can cause harm to personnel. Hazards are mostly due to possible electric shock or ignition of flammable oils and lubricants. Neither of these events are likely to occur during normal operation due to the isolation of almost all electrical components from the operators and the low likelihood of an electric spark or short igniting any of the petroleum oils on board.

It is possible for the transformer to fail and disable all of the down-hole lighting. Although each miner carries a lamp on his hard hat, the potential of a slip/fall accident, especially during an emergency, can be greatly increased with failure of the lighting system. For this reason, some sort of emergency lighting system for escape is suggested.

Haulage of Men and Muck

A failure of almost any component can potentially result in a fatality, a serious injury, equipment damage or excess downtime. The primary hazards of concern in the hoisting system include potential injury from falling objects through open collar doors; failure of the hoists and/or safety devices; failure of the wire rope and/or connection; and hazards associated with using ladders. However, a number of preventive or control measures exist to reduce the possibility and/or criticality of such failures. No major changes to this system are recommended.

Fire Control System

The chance of a fire on board the impactor is probably quite remote, although it is a possible event and carries potentially very high consequences. Fires in the operator cabs or on the galloway decks can be effectively countered by use of the hand-held extinguishers, provided that the fire is detected early and the extinguishers are operable. However, fires that start in the machine motor and pump compartment or other remote locations will most likely be difficult to detect and extinguish. The ability of the water fog system to control such a fire is questionable. This system must be activated from the galloway and if activated can create additional hazards to the impactor operators or other downhole personnel caught in the downpour of water.

Conventional exit from the operator cabs will be very difficult in a fire situation. Emergency escape must be by means of a rope ladder provided in the operator cab. Operators must climb down the rope ladder to the shaft floor, enter the muck skips (which most likely would contain muck) and be hoisted up past the burning impactor if they wish to escape the shaft. If the emergency escape rope ladders are not treated to be flame-resistant they may also burn, leaving the operator stranded or causing him to fall to the shaft floor while using the ladder to descend. Another alternative would be for the hoistman to lower the impactor assembly close to the shaft floor; however, if the fire is major, this may be excessively time-consuming.

A better fire control and detection system is highly recommended. A remotely operable or automatic extinguishing system in the machine pump and motor areas is recommended, as well as a better (safer and faster) emergency escape route if possible. Also, if rope ladders are used as a means of escape; they should be fire-resistant and not susceptible to corrosion or weakening during storage. No other design changes or recommendations are suggested.

CONCLUSIONS AND RECOMMENDATIONS

The results of this analysis show that the use of impactor shaft sinking technology may be expected to significantly reduce the risk currently experienced in shaft construction using conventional techniques. The impactor shaft sinking system was shown to be safer than conventional shaft sinking technology. The use of the impactor instead of conventional shaft sinking techniques may be expected to reduce the risk of shaft sinking operations by approximately 35 percent. Use of the impactor and its support systems can significantly reduce some conventional sources of risk, such as in rock breaking, muck loading and maintenance functions. Although the impactor system is estimated to increase the risk in some operations relative to those encountered in conventional systems, these functions are generally expected to contribute insignificantly to total system risk. However, further investigation of the system is needed to determine the potential effects of some of the hazards introduced by the system as they might actually be experienced in the work environment.

Critical safety areas for the impactor shaft sinking systems were also identified in this study to further enhance the safety of the technology. The results of this analysis show that there are very few failures of machine components that can directly expose personnel to any appreciable hazard. Some of the subsystems of the impactor and its support systems that could present a hazard to personnel were reviewed earlier in this report, along with initial design change concepts that might mitigate these hazards.

A safety manual was also developed for the impactor shaft sinking system. The safety manual itself is presented in Volume 2 of this document, and addresses both routine and contingency operations and procedures for the impactor shaft sinking system. The manual specifically outlines safe practices and accident prevention for a postulated shaft construction project using the impactor machine. However, many portions of the manual should prove useful for general applications of impactor technology.

Use of the impactor shaft sinking technology can result in improved worker safety and better working conditions for miners involved in shaft construction operations. It is recommended that some of the design changes

suggested in this report be implemented before further testing of the impactor system in the field. The suggested priority of these changes and further details on possible designs are presented in Appendix F.

The development of the impactor shaft sinking system is being pursued on the basis of increased sinking rates and decreased costs. It is also important to ensure that the machine and associated support systems are reliable in terms of continued performance and productivity for the duration of a shaft sinking project. This study does not attempt to delineate the areas of the system that are critical to continued production or efficiency of the project. That determination should be the subject of future, detailed reliability assessments. An investigation of system reliability in conjunction with a system safety analysis allows an optimal trade-off between safety and reliability in system design. The objective of a reliability analysis is to anticipate potential reliability problems and reveal system configurations that have superior probabilities of success. A reliability analysis of the impactor system could be effectively combined with the results of this or an updated safety analysis to result in a more complete and relevant assessment of the system.

The overall results of this study show that formal safety analysis techniques can provide valuable information in assessing new mining technology. The methods used in this study, while developed for safety applications, can be refined and modified for use in equipment reliability and system efficiency applications. Also, these methods can potentially be applied to existing mining systems to identify the most important areas of risk and assist in formulating research and development programs aimed at reducing these risks and improving the safety of the mining industry.

An assessment of system risk can provide a means of evaluating the impact of specific technological improvements or system inadequacies on the total mining operation, and identifying problems whose solutions will provide the greatest health and safety benefit for the industry.

BIBLIOGRAPHY

- Paul Weir Co. April 1980. "Descriptive Report on Conventional Shaft Sinking Methods for Coal Mines at Depths of 1,500 to 2,000 Feet" Report B. Blind Shaft Borer Safety Analysis. Prepared for the Bureau of Mines.
- Dames and Moore. 1977. Safety Analysis of U.S. Shaft Sinking Operations, prepared for the U.S. Bureau of Mines, Park Ridge, Ill.
- Wilson, J. W. 1976. "Shaft Sinking Technology and the Future Need of the Mining Industry" Rapid Excavation and Tunneling Conference. June 14-16, 1976. Proceedings. Baltimore, MD.
- Provost, A. G. and Griswold, G. G. 1974. "Shaft Sinking Considerations and Problems" RETC Proceedings. Vol. 2.
- Title 30, Code of Federal Regulations, 1978, Chapter 1, Subchapters N and O.
- Phillips, S. H. E. 1978. The Use of a High Energy Impact Breaker for Shaft Sinking - Initial Feasibility and Field Trials in a Rectangular Shaft - Final Report, prepared for the U.S. Department of Interior, Bureau of Mines by the Cementation Company of America, Inc.
- The Cementation Company of America, Inc. 1978. Development of a High Energy Impact Breaker for Shaft Sinking - Report on Circular Shaft Modifications, prepared for the U.S. Department of Interior, Bureau of Mines.
- Lambert, H. E. May 1978. System Safety Analysis and Fault Tree Analysis. Lawrence Livermore Laboratory, prepared for the U.S. Atomic Energy Commission, Livermore, California.
- Egen, R. A. May 1975. Mine Hoisting Inspection, Maintenance and Safety. Battelle Columbus Laboratories, prepared for the U.S. Bureau of Mines.
- Chironis, N. P., ed. 1980. Training Manual for Miners, Vol. 1. Skelly and Loy, McGraw-Hill, New York.
- Nertney, R. J. and Bullock, M. G. 1976. Human Factors in Design. ERDA-76-45-2. Aerojet Nuclear Company, Idaho Operations Office, Idaho Falls, Idaho.
- National Safety Council. 1978. Accident Prevention Manual for Industrial Operations. Seventh Edition. Chicago, Ill.
- Olishifski, J. B., ed. 1979. Fundamentals of Industrial Hygiene. Second Edition. National Safety Council, Chicago, Ill.

Davidson, J. E. June 1977. Safety Inspection Guide. MOD III. SAND77-0857, Sandia National Laboratories. Available from NTIS, Springfield, Virginia.

Ericson, C. A., ed. 1969. System Safety Analytical Technology - Preliminary Hazard Analysis. Report No. D2-113072-1, The Boeing Company, Seattle, Washington.

APPENDIX A
STATEMENT OF WORK AND PROJECT PLAN

ARTICLE I - STATEMENT OF WORK

Background

Shaft sinking is the single most hazardous operation of all underground activities. Recent statistics show the accident frequency rate for shaft sinking is nearly double that of all mining activities combined for coal mines, and nearly 4 times that for metal and nonmetal mines.

Recent Bureau of Mines research into the use of an impactor to replace the drilling and blasting cycle for fragmenting rock in the shaft bottom (H0262021) could do much to eliminate hazardous conditions. However, the project is being pursued on the basis of increased sinking rate and decreased cost. The safety aspects of the machine and its use have only been given cursory examination. A detailed safety analysis of the system will identify areas where design modifications or changes in operational procedures can improve the overall safety of the system. In those cases where the impactor system is only marginally economic, improved safety features may justify its use.

Objective

The objective of this project is to compare the safety of sinking a shaft with the impactor to conventional drill and blast shaft sinking; improve operational procedures to promote maximum safety; recommend design modifications to improve safety; and outline areas where additional research is needed.

Scope of Work

The contractor shall in accordance with the terms and conditions set forth below, furnish all management, personnel, labor, facilities, supplies, and equipment and do all things necessary to perform a safety analysis of the impactor shaft sinking system. The work shall be performed in accordance with the contractor's proposals entitled "Safety Analysis of the Impactor Shaft Sinking System," dated November 6, 1979 and January 4, 1980, incorporated herein by reference and the terms of the contract, provided that in case of conflict between the provisions of the proposals and the terms of the contract, the terms of the contract shall prevail.

- A. The contractor shall compare the safety of shaft sinking with the impactor as developed under Contract H0262021 (Cementation Co. of America) with that of conventional drill and blast shaft sinking. An established method for evaluating the comparative safety aspects shall be selected and utilized by the contractor. The contractor's program plan shall include the following:
- (1) a description of the method to be used and justification for its choice over others, (2) a breakdown of the work into tasks, (3) a schedule for each of the tasks including manpower loading, (4) a detailed description of each task, and (5) a milestone chart.

- B. The contractor shall prepare a work-element breakdown for shaft sinking with an impactor and with conventional drilling and blasting. Related functions shall be compared. Work elements shall include but not be limited to: breaking of the rock, loading of the muck, haulage of muck, haulage of materials, haulage of men, communications, water inflow, shaft-wall support, shaft lining, ventilation, mobilization, and demobilization. Factors such as the number of personnel involved, and their exposure time to hazardous conditions shall also be considered. Functions unique to one or the other shaft sinking method shall be evaluated independently and included in the overall comparison of the two methods.
- C. The contractor shall prepare conceptual design drawings and operational and maintenance procedures which could be proposed as modifications to enhance the safety of the impactor.
- D. The Bureau's Technical Project Officer shall coordinate and be kept fully informed of all meetings and contacts between the contractor and on-site personnel.
- E. The contractor shall prepare a safety manual for the impactor that outlines for the operator procedures for safe operation and reduces the possibility of accidents. This manual shall include, but not be limited to: general housekeeping, arrangement of equipment on the site, power transmission, storage of flammables, personnel accountability, traffic routing, employee training, emergency procedures, first aid and fire fighting facilities, use of the impactor and support equipment, and the impactor operating procedures.
- F. The contractor shall make recommendations for improved safety as they become apparent during the field trials. These recommendations may be informal, but should include a preliminary design if applicable.
- G. The contractor shall transmit recommended design changes formally as a part of the Monthly Technical Report when requested by the TPO. Formal transmittal includes a description of the change, its expected advantages, and a preliminary design if a design change is required. In this case, a preliminary design is defined as one that requires only drafting to prepare shop drawings.
- H. The contractor shall conduct an oral technical review within nine (9) months of the effective date of the contract at the Bureau's facility in Spokane, Washington. This review shall cover the work performed to date and any particular subjects requested by the TPO. The review will also discuss any changes from the original program plan and the status of past and future expenditures. MSHA and industry representatives may be invited by the Bureau to attend.
- I. The contractor shall prepare and submit a draft final report within eighteen (18) months of the effective date of the contract.
 - 1. In addition to the requirements set forth in ARTICLE II-DELIVERY REQUIREMENTS, C.4 Draft Final Report, the final report shall include the Statement of Work and the Program Plan revised to reflect any changes during contract performance. The Safety Manual required by paragraph E above shall be produced as a separate, detached volume.

2. Within two weeks of submission of the draft final the contractor shall conduct an oral review of all contract work at the Bureau's facility in Spokane, Washington. The oral review shall include all portions of the contract work and the final report, particularly pertinent procedures, results, and conclusions. Handouts, exhibits, and other visual aids shall be used as appropriate. MSHA and industry representative may be invited by the Bureau to attend.

PROJECT PLAN

SAFETY ANALYSIS OF THE IMPACTOR

This project will examine the impactor to determine the potential for occupational injuries and fatalities associated with its use. Also, a detailed functional comparison of the impactor and conventional drill and blast shaft sinking techniques will be made to ascertain the comparative safety of the impactor. Through a comprehensive safety analysis, optimum safety design conditions will be identified and design changes will be recommended for the impactor as appropriate. The following specific objectives are presented for this project:

- A comparative safety assessment of the impactor and conventional shaft sinking technology.
- A safety evaluation of the component operations of the impactor and associated equipment.
- A safety manual that outlines procedures for reducing the possibility of accidents at the impactor site.

SCOPE

Program efforts will concentrate on fulfilling the three specific primary objectives outlined in the previous section with respect to the safety of shaft construction. Although the activity in the shaft and on the impactor machine itself will be of primary concern in this safety assessment, related site activities and surface equipment will also be briefly considered, particularly in formulating the safety manual. It is determined that the longer term performance of the shaft and its relation to an operating mine are outside the scope of this study.

A comparative safety assessment of the impactor and conventional shaft sinking technology will be performed using a combination of Preliminary Hazards Analysis (PHA) techniques and a simple decision-making process. The PHA technique is used to qualitatively isolate potentially hazardous conditions that could result in worker injury or fatality. A complete PHA will list the potential hazard, the action or event necessary to convert this into an actual hazard, and the consequences or effects of this

particular hazard occurring, along with contingency and preventive measures. Although a quantitative safety analysis will not result from a PHA, a good estimate of the hazards of a system can be obtained, forming the basis for a decision-making procedure.

This PHA methodology will be applied to the impactor. Concurrently, the safety performance of shaft sinking using conventional technology will be quantified based on the actuarial data. The PHA will generate potential methods of worker injury or fatality for the impactor, which may then be compared with the actuarial data on worker safety in conventional shaft sinking operations. This comparison will indicate any mechanisms of worker injury or fatality that are totally unique to the impactor. These unique causes will be examined independently to ascertain expected worker hazard. Similar or comparable causes of worker insult from the two systems, however, will be evaluated using a single-attribute safety judgment. An "asset" and "liability" table will be constructed for each specific Mine Safety and Health Administration (MSHA) category of worker injury or fatality. A backup section detailing why each system characteristic is estimated to be an asset or liability is provided. The assets and liabilities are then subjectively weighted and a safety judgment is made. After addressing each cause of worker insult, an overall safety judgment will be made.

A safety evaluation of the component operations of the impactor and associated equipment will be made using a Failure Mode and Effects Analysis (FMEA) methodology. The FMEA technique is a systematic safety examination of individual components of a system. The FMEA provides a comprehensive analysis of the ways in which component and system failures will affect worker safety. To apply FMEA techniques, each individual component and sub-system of a system is assumed to fail. The failure is studied to determine 1) how it may occur; 2) the causes and effects of the failure; 3) an estimated failure frequency, if available; and 4) possible remedial actions to reduce either the failure frequency or the consequences of that failure. The FMEA process results in detailed information on the safety interaction of system components and can provide guidance in safety-related design. In applying the FMEA logic to the impactor, the influence of all systems on worker safety will be readily evident. The impactor system may then be comprehensively examined and safety-related design guidance may be formulated. Routine and contingency operational procedures that may influence worker safety will also be examined.

The impactor safety manual will be developed by combining the safety output of the PHA, the comparative safety judgment and the FMEA with the best industrial safety experience available, which is embodied in the judicious application of the Management Oversight and Risk Tree (MORT) techniques. MORT is a formal, disciplined logic that is used to systematically relate and integrate a wide variety of safety concepts. The MORT process represents the synthesis of the best elements of available safety programs. The wealth of industrial safety experience built into the MORT process will allow an in-depth examination of the impactor and its support systems. Combining the MORT analysis with the results of the PHA, the FMEA and the safety comparison, a comprehensive safety manual can be prepared. The safety manual will address impactor shaft sinking routine and contingency operations and procedures.

The work described in the previous paragraphs is to be accomplished over eighteen months, and was initiated at the beginning of May 1980. To accomplish this work, the following seven tasks have been defined:

- Task 1 - Impactor System Description
- Task 2 - Preliminary Hazards Analysis (PHA) of the Impactor System
- Task 3 - Comparative Safety Analysis
- Task 4 - Failure Modes and Effects Analysis (FMEA) of the Impactor System
- Task 5 - Preparation of the Impactor Safety Manual
- Task 6 - Development of Design Changes for the Impactor
- Task 7 - Project Management

These tasks are described in further detail in the following section. The interaction of the work tasks is shown in Figure A-1.

TASK DESCRIPTIONS

Task 1. Impactor System Description

The objective of this task is to develop a description of the design and operation of the impactor shaft sinking system for use in other portions of the analysis. Included in the system description will be details of

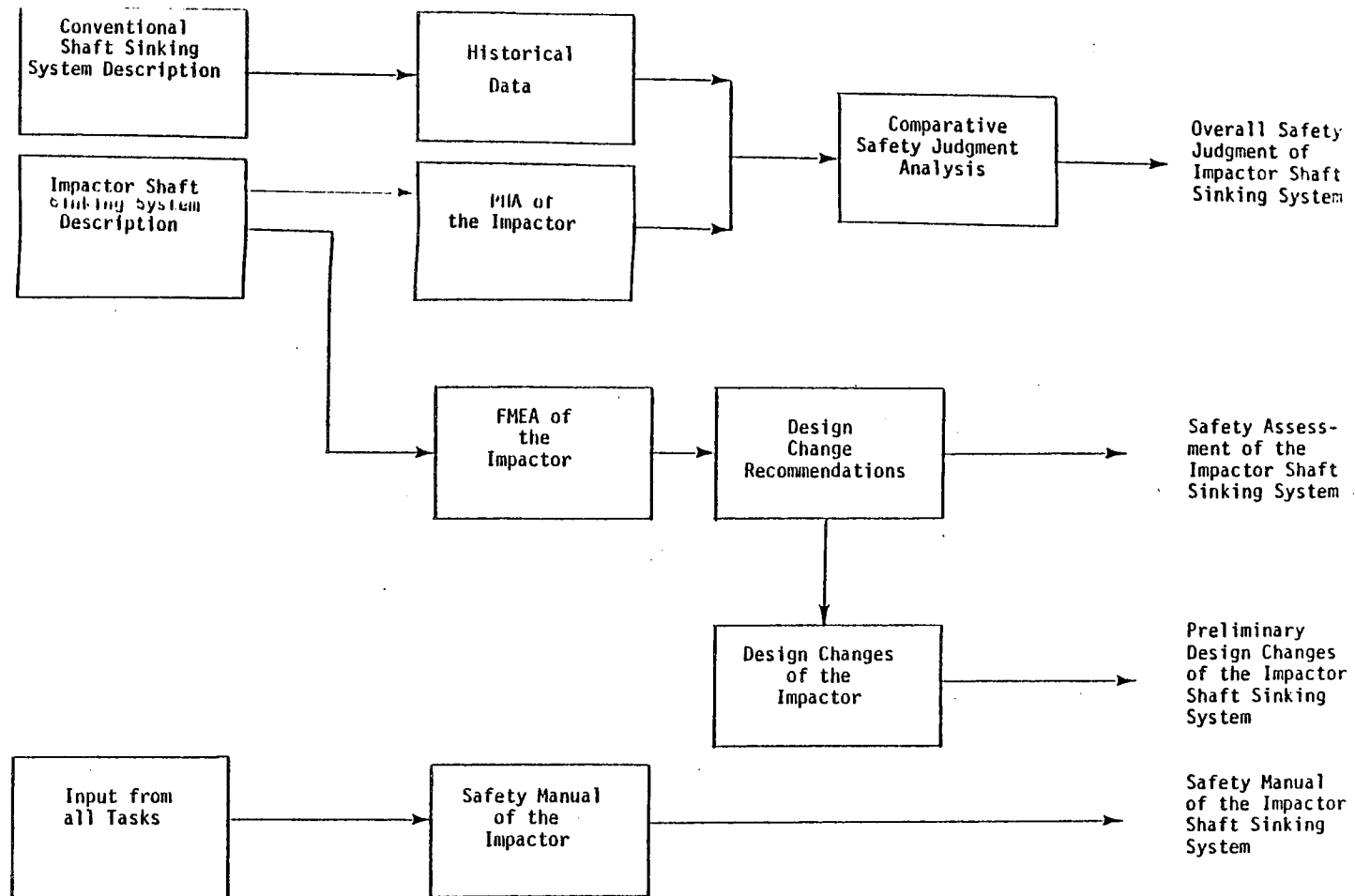


FIGURE A-1. Interaction of Work Elements

routine and contingency operational procedures such as the following: the breaking of rock; loading of muck, materials and men; communications; water inflow; shaftwall support; shaft lining; ventilation; mobilization and demobilization. Factors such as the number of personnel involved, their exposure times, any redundant systems and other safety related data will be provided for these functions. Because the impactor demonstration will initially be a surface test, some additional information will be required to completely describe the spectrum of shaft sinking activities. This information will be obtained from discussions with Cementation and Bureau of Mines personnel, from records of a previous demonstration of a modified impactor in a shaft, and from information on the proposed use of the machine at a New Brunswick site. The impactor shaft sinking system description will be based on the impactor machine as developed under Contract H0262021 (Cementation Co. of America). The description of the machine design and shaft support systems will be updated throughout project performance as information from actual implementation of the system becomes available. This will result in a realistic and practical shaft sinking system for comparison purposes. Travel to the demonstration site is required for this task. This travel will be coordinated with the sponsor's TPO and the demonstration contractor. The primary output of the system description will be a working paper describing the impactor shaft sinking system. This data will be input to the PHA and FMEA, along with the remainder of the tasks. A final version of the working paper will be incorporated into the final report.

The supplementary information required to complete a shaft system description for the impactor should also prove useful in developing a description of a conventional shaft sinking system. A description of conventional shaft sinking operations is required for use in Task 3, the Comparative Safety Analysis. It is anticipated that information on shaft sinking techniques gathered during this task and visits to conventional sites, combined with information from literature, mining experts, and descriptions of proposed and actual shaft sinking operations in metal/nonmetal mines will be sufficient to develop a description of conventional shaft sinking techniques. This description will be compiled as a separate working paper. Any travel required for this task (which will be completed within Task 3 activities) will be coordinated with the sponsor's TPO.

Task 2. Preliminary Hazards Analysis (PHA) of the Impactor System

The objective of this task is to identify potential causes of worker injuries and fatalities in the impactor shaft sinking system. The Preliminary Hazards Analysis methodology described previously will be used for this analysis. Results of this analysis will be used in the safety judgment task, as the starting point for the Failure Modes and Effects Analysis in Task 4, as an input to the development of the impactor safety manual in Task 5 and to assist in identifying possible safety-related design changes for use in Task 6. The PHA will be based on the impactor system description developed in Task 1. Working papers describing the results of the PHA will be prepared for use in the other tasks. The results of the PHA will be included in the final report. No travel is anticipated in performing this task.

Task 3. Comparative Safety Analysis

The objective of this task is to compare the safety of shaft sinking with the impactor to the safety of conventional drill and blast shaft sinking. Initially, the safety of the conventional shaft sinking will be quantified in this task. The conventional shaft sinking system description initiated in Task 1 will be completed here and used as a basis for the safety analysis.

Based on this description of a conventional shaft sinking operation in Arizona, the expected fatalities and injuries will be estimated from the actuaries based on worker function, exposure and equipment used. Expected cause of worker injury and death will be detailed based on available data. The results of the PHA for the impactor, Task 2, will be input to identify the potential causes of worker death or injury that are unique to the impactor, and not common with the drill and blast shaft sinking practices. Any unique causes will be explored in depth using the PHA and other methodologies, as applicable. Using the MSHA principal cause classifications, the safety differences between the impactor and conventional shaft sinking will then be constructed, using Asset/Liability procedures described previously. A detailed backup section supporting each asset and liability will be constructed. For each principal cause classification, safety-related differences in the two shaft sinking technologies will be identified. An integral portion of this comparative process is necessarily the comparison of related functions of the two alternative shaft sinking technologies,

including breaking of rock; loading of muck; haulage of muck, materials and men; communications; water inflow; shaft-wall support; shaft lining; ventilation; and project mobilization and demobilization. Factors such as the number of personnel involved, their exposure time, and use of redundant systems will also be considered.

The output of this task will be a logical overall safety judgment with a detailed rationale for the judgment included. This task will provide the determination of whether the impactor is as safe as or safer than conventional shaft sinking. Safety-related design recommendations will also be an output of this task. The results of this analysis will be included in the final report of the study results. Travel to the demonstration site and one or more conventional sites is required in performing this task. This travel will be coordinated with the sponsor's TPO and the demonstration contractor.

Task 4. Failure Modes and Effects Analysis (FMEA) of the Impactor System

The objective of this task is to perform a detailed analysis of the safety aspects of the impactor to identify and evaluate potential safety-related design improvements. This task will utilize the Failure Modes and Effects Analysis methodology discussed previously. The FMEA will be performed on the impactor, other shaft and surface equipment and all standard operating and emergency procedures. The primary output of this task will be a comprehensive understanding of the interactions of the impactor sub-systems as they relate to worker safety.

The analysis will be based on the impactor system description developed in Task 1 and will utilize information from the PHA performed in Task 2. The results of the FMEA will be used as an input to the safety judgments in Task 3, as an input to the preparation of the safety manual in Task 5 and to identify safety-related design improvements for consideration in Task 6. A working paper will be prepared to provide the results of the analysis of the impactor to the other tasks. These results will be included in the final report of the study. It is anticipated that the task leader for this effort will visit the demonstration site, probably in conjunction with the site visit for Task 1.

Task 5. Preparation of the Impactor Safety Manual

The objective of this task is to identify procedures and practices for the operator that are necessary to the safe operation of the impactor

or can improve the operational safety of the system and incorporate these procedures and practices into an Impactor Safety Manual. The Safety Manual will identify procedures and practices necessary to encourage safe operation of the impactor in actual shaft sinking operations. The impactor operator and other workers in the shaft are the primary individuals exposed to potentially hazardous conditions in a shaft sinking operation using the impactor. The Safety Manual will focus on developing procedures to eliminate or minimize these hazards and to reduce the exposure of workers in the shaft to the hazards that cannot be eliminated. The impactor operator is one of the key individuals in this analysis, and it is expected that a significant portion of the manual will be devoted to assuring that the operator is properly trained and protected from potential hazards. Other topics to be included in the manual are general housekeeping, site security, weather effects, arrangement of equipment on the site, power transmission, storage of flammables, personnel accountability, traffic routing, emergency procedures, first aid and fire fighting facilities, use of the impactor and support equipment, and impactor operating procedures. The Safety Manual preparation will also utilize insights gained from the other work tasks through applying the MORT techniques described earlier. The Safety Manual, along with recommended design changes as appropriate, will be the primary output of this effort.

This activity will be based on the impactor system description developed in Task 1. The results of this task may also be used to identify safety-related design changes for consideration in Task 6. The Safety Manual will be forwarded to the sponsor with the draft of the final report. Travel to the demonstration site by the task leader is anticipated, probably in conjunction with the site visits for Task 1. All travel will be coordinated with the sponsor's TPO and the demonstration contractor.

Task 6. Development of Design Changes for the Impactor

The objective of this task is to develop preliminary design changes for the impactor based on safety-related design change recommendations developed in Tasks 2, 3, 4, and 5. The output of this task will be a series of conceptual design change packages. Each design change package will include a description of the change, and the way in which the design interfaces with other machine components, functions and personnel, as well as illustrations showing the physical size and function of the proposed

change. A discussion of the rationale for proposing the change, the expected benefits of the change, the expected impact on the performance of the impactor and a plan to implement development and testing of the change will be included. Implementation plans will be formulated generically, in cooperation with the sponsor's TPO and the demonstration contractor, for minor, moderate, and major changes, and applied as relevant to design change packages. The package will also include a cost estimate for constructing and implementing the proposed design change. The cost estimates are expected to be based primarily on the engineering judgment of experienced design engineers, and will reflect a reasonable estimate of the costs involved in implementing a particular design change recommendation. All design change recommendations will require a knowledge of the relevant federal regulations.

Task 7. Project Management and Report Preparation

This task will provide overall program planning and direction, coordinate and supervise the efforts of the other tasks, maintain contact with the sponsor's TPO and prepare routine reports and the draft and final reports of the study results. Travel is anticipated in this task to meet with the sponsor's TPO, at his request.

REPORTING REQUIREMENTS

Throughout the period of performance of the project, task leaders and members will maintain close liaison with the Project Manager via frequent personal contacts and informal monthly or periodic reports. Monthly internal reports will be prepared by the Project Manager to identify any problems and to show progress and variance. These reports will be reviewed by the Section Manager.

The Project Manager will prepare formal monthly Financial and Technical Letter Reports and forward them to the sponsor on or before the fifteenth day of each month of the contract period. The Financial Report will summarize the expenditures for the month just completed and present cumulative expenditures through that month. A detailed cost breakdown in the same categories as the cost proposal will be included, along

with a curve showing projected and actual spending versus time. The Technical Report will present a brief summary of the following information for each of the six tasks in the project:

- Progress Summary
- Work Started
- Work Results/Milestones Completed
- Problems Encountered and Corrective Actions
- Work Forecast for Next Month

A copy of any working paper completed during the month will be forwarded with the monthly report, as well as any Preliminary Design Change Packages developed during the month.

Oral reporting will be coordinated by the Project Manager. Two oral technical reviews are tentatively scheduled for the ninth and eighteenth months of contract performance. These reviews will be held at the Bureau's facility in Spokane, Washington.

PROJECT SCHEDULE AND COST

This section describes the schedule of activities in the safety analysis project. An overall schedule for the project showing the approximate time frame during which work on each task would be conducted is presented in Figure A-2. Major milestones for each of the tasks in the project are presented in Figure A-3. Task 1 and the project planning and management activities are initiated immediately at the contract start date. The initial description of the impactor system in Task 1 is to be completed in 6 months. This description will be updated as necessary as relevant information becomes available. A final description will be completed within another 6 months.

Activities in Task 2 would commence when sufficient information is available from the impactor description activities in Task 1. The PHA of the impactor would be completed in about 4 months. Task 4 activities would be initiated during month 6. The FMEA would be completed in about 10 months. Task 5 would commence soon after the start of the project and continue until month 18 with the completion of the safety manual. The comparative safety assessment in Task 3 would start after the PHA of the impactor has been completed and continue until about the fifteenth month of the project. Revisions to the PHA that may be required from new information received on the system description during project performance will be completed by the end of month 15. The final draft report would be prepared during the seventeenth and eighteenth months of the project.

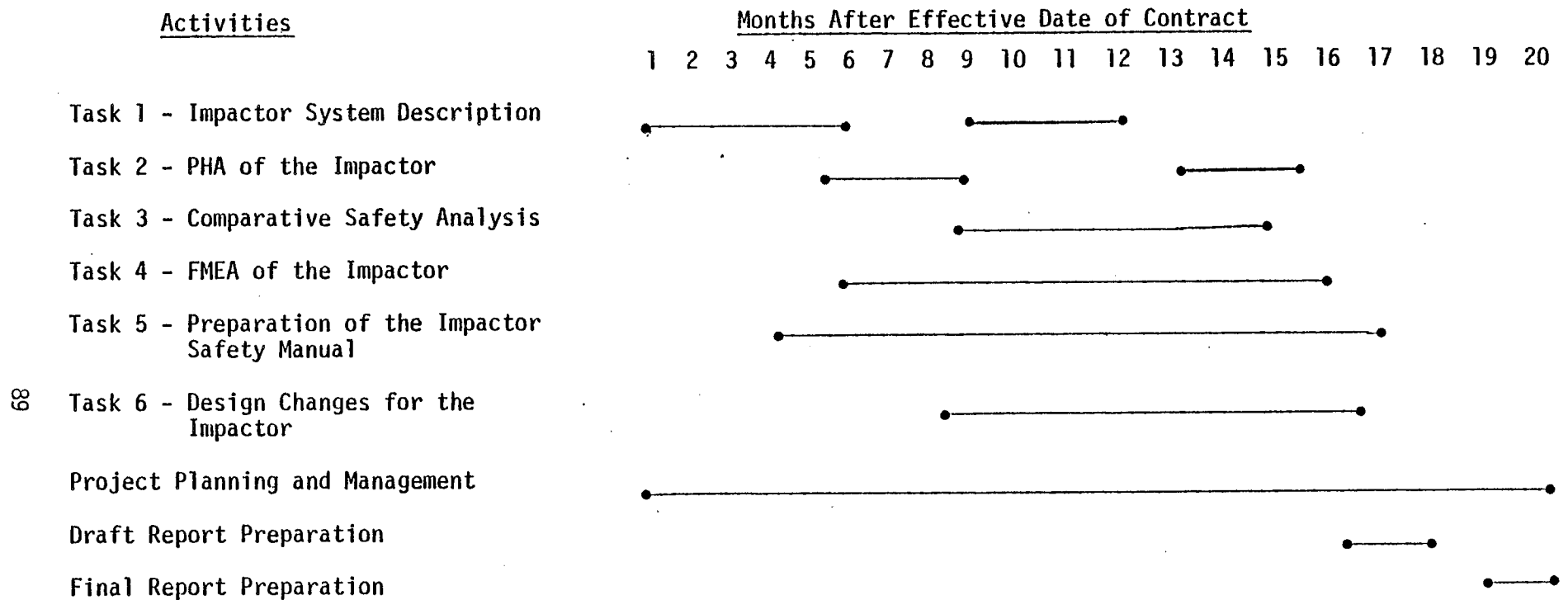


FIGURE A-2. Schedule of Project Work

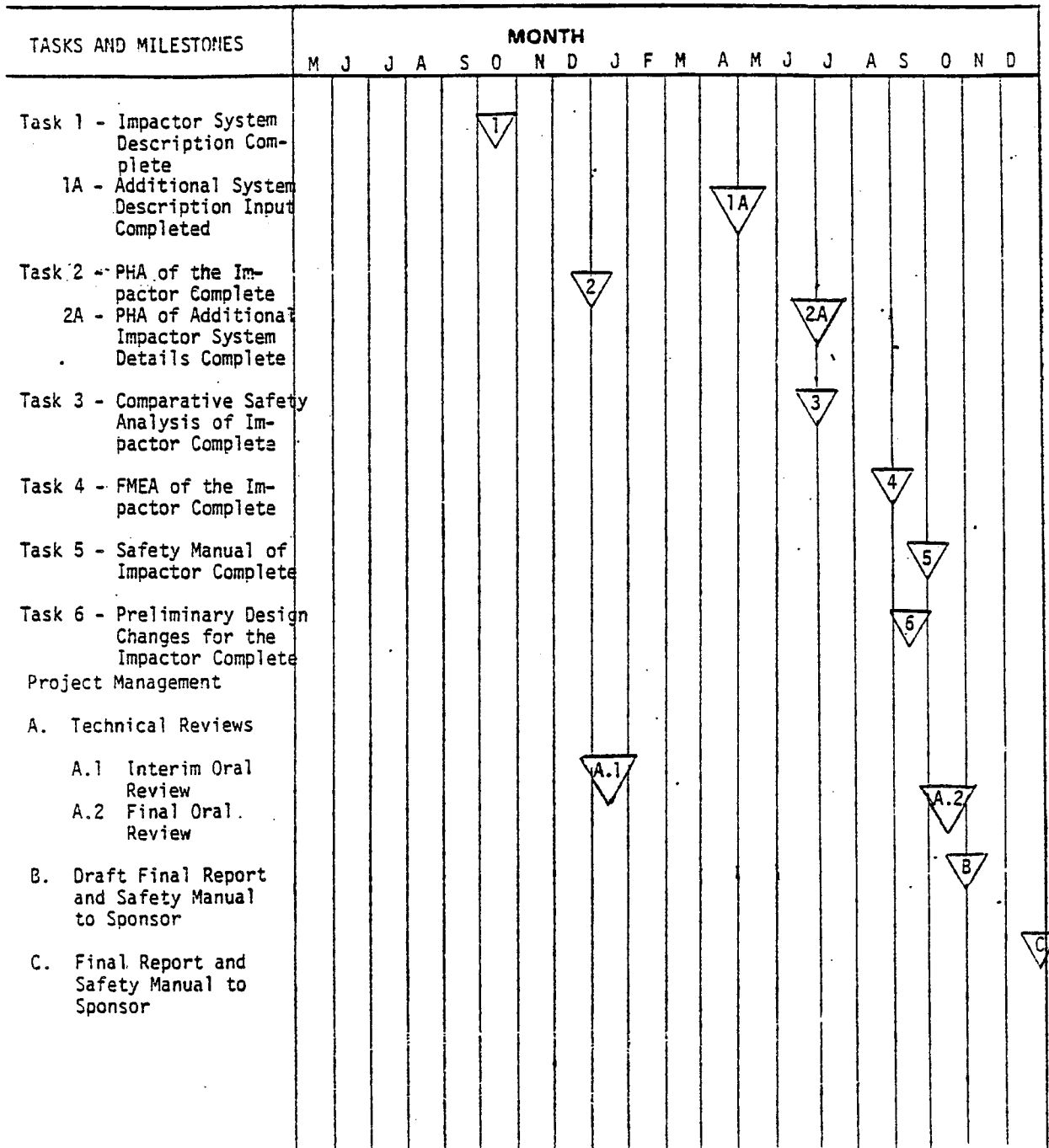


FIGURE A-3. Major Project Milestones

The draft report will contain a summary of conclusions of the study, a copy of the statement of work, a copy of the final program plan, a detailed description of the proposed safety-related design changes for the impactor and the results of the PHA, FMEA and comparative safety analyses. The final report would be submitted within 30 days of receipt of notice of draft approval.

The overall project spending curve is shown in Figure A-4.

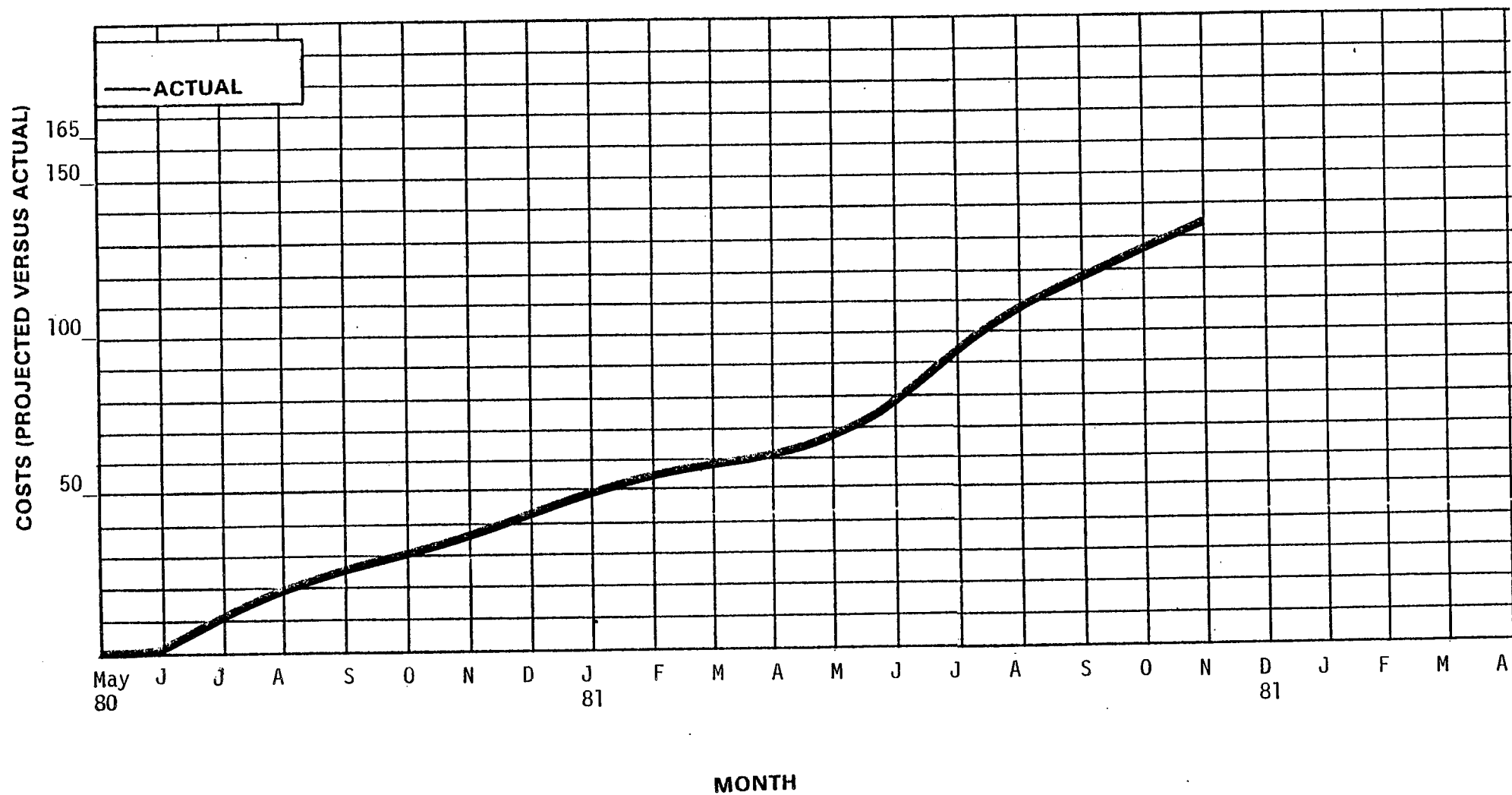


FIGURE A-4. Actual Program Spending Curve (Fees are not included)

APPENDIX B

A DESCRIPTION OF CONVENTIONAL SHAFT SINKING METHODS FOR METAL/NONMETAL MINES

A representative description of current conventional shaft sinking technology in metal/nonmetal mines is required to allow a safety comparison with impactor shaft sinking methods. This appendix provides a general description of the various tasks and equipment involved in the construction of a mine shaft using present state-of-the-art, conventional shaft sinking practices. This description is intended to be representative of a system that might be used to construct a shaft similar to that postulated for construction with the impactor system (22-feet finished diameter, 2500 feet deep, metal/nonmetal mine). Specific equipment and operations used in actual shaft sinking projects will vary according to contractor.

Conventional shaft sinking primarily consists of three basic operations: drilling and blasting; mucking of the broken rock; and placement of a concrete lining or other type of wall support. Support activities such as hoisting, ventilation, dewatering and water control, and scaling of loose rock are also required. These operations will be described in detail later in this section. Before actual shaft sinking operations can begin, however, several initial site planning and preparation steps must be performed. The spectrum of activities included in site set-up and shaft excavation are described in the following sections.

Mobilization

Mobilization involves the initial preparations and construction work required for a shaft sinking project. These operations include a geological and hydrological analysis of the site; clearing the site; obtaining and setting up the required shaft sinking and support equipment; and initial excavation.

Once the site has been cleared and access roads to the area are constructed, the shaft sinking equipment and all support equipment are brought onsite. Work is started immediately on the hoist foundations, since these are

often on the critical path for completion of the mobilization phase of the project. Usually used mine hoists will be employed for shaft sinking purposes. These used hoists can require up to 10 to 11 weeks for their installation. They are generally very much larger than the present day equivalent, with heavy-cast metal and bolted connections. The older hoists require more complex foundation work with drum pits, brake pits, sumps for flywheel, etc. to be formed in the concrete foundation. Assembly of the many parts is time consuming. New hoists for shaft sinking can be supplied on a bedplate that needs only to be bolted to a slab foundation. Such a hoist can be transported in only two or at the most three sections with the minimum amount of site assembly being required.

Concurrently with the hoist foundations, initial excavation of the shaft collar will commence, as well as construction of the foundations for the headframe. A vent drift is also often installed within the collar. Other installation work proceeding simultaneously with the shaft collar, fabricated equipment assembly and hoist and winch installation would be site plumbing; wiring; and clearing and preparing the muck disposal area including water catchment, clarification and other control requirements. Metal buildings are normally erected around the main hoist and winches. Most buildings are of the mobile variety.

Initial Excavation

The initial excavation for the shaft collar is generally done with a backhoe or a crane and clamshell. Where the ground is too firm for the clamshell, the material may be broken up using pneumatic spaders (pneumatic picks fitted with a special spade-shaped tool), some four or five shaft miners being employed in the shaft bottom for this work. The broken material will be thrown by hand into piles for pickup by the clamshell. Mucking with the clamshell cannot proceed with miners at the shaft bottom, so this operation will be intermittent. Some drilling and blasting may also be necessary to reach a depth sufficient to allow installation of the galloway stage and to reach competent bedrock. This depth is assumed to be attained at 60 feet, although the depth to which the initial excavation is carried varies for each project. The shaft must be deep enough to install the galloway and to provide additional distance to protect the equipment against blast damage during the deeper shaft sinking operations.

Material excavated during collar construction is mucked with the crane and clamshell. As excavation proceeds, an Eimco 630 loader may be used to load the muck bucket, which is then hauled up by the crane. A conventional collar is then constructed, and the shaft is lined with concrete.

The method of constructing the shaft collar is dependent on the stability of the subsoil and the self-supporting ability of the excavated shaft walls. The reinforcing steel in the shaft collar concrete lining generally consists of two mats of vertical and horizontal bars set at spacing which, in both directions, might vary from 6 to 12 inches. The inside mat is set 3 inches back from the formwork, the outside mat 3 inches in from the theoretical excavation line. If built in-situ, the bars are lowered by a mobile crane into the excavation as individual bars. The miners set the bars in place by hand and tie them together with light gauge wire. If fabricated on the surface, sections of the front and back mats are built as cages which are picked up by the mobile crane and set in place in the excavation. The fabricated cages are first welded together in a sufficient number of places to ensure their rigidity during the hoisting operation. Once the fabricated sections are set in place, horizontal splice-bars connecting the sections are tied by hand.

A temporary work deck is used to provide a work place for setting the forms and pouring the concrete. This deck is lowered into the shaft and raised and lowered in the shaft as required for the various lining operations using the mobile crane. It is suspended from the shaft walls or the concrete forms when in use.

The formwork used in shaft collar lining is generally wooden. Since shaft sizes vary from project to project, the steel lining forms used for shaft lining generally need to be ordered during this phase of mobilization. The forms are lowered in their original segments to minimize handling problems. The form is centered and braced off the excavated shaft walls to prevent any movement during the placement of the concrete.

When the formwork is in position, concrete is lowered into the shaft in a 1.5-cubic yard bottom discharge concrete bucket suspended from the mobile crane. Miners working on the temporary workdeck discharge the concrete bucket behind the form.

It is important to ensure that concrete is distributed evenly around the form. Thus, the miners must have access around the complete periphery of the shaft. The concrete is vibrated during pouring. When the first 10'-0" of formwork has been filled with concrete, the next 10'-0" of formwork is set in place using the mobile crane and work deck as supports. The formwork is set and centered before filling resumes. Access to and from the shaft for employees is possible in a bucket suspended from the hoist rope of the mobile crane, provided the crane is equipped with all necessary safety and speed controls required by federal regulations. If such a mobile crane is not available, properly equipped ladders or scaffolding would be used for access to the shaft.

Installation of Equipment

In conventionally sunk shafts, it is generally considered prudent to continue shaft excavation below collar level some 20 to 30 feet using the mobile crane, to provide adequate clearance for the suspension of the main work platform, or galloway, in the shaft and the installation of the shaft collar steelwork and sinking headframe over the shaft. Figure B-1 illustrates the relationship of these various items of shaft sinking equipment. The fabricated steelwork for the galloway, the shaft collar doors and the steel headframe are assembled alongside the shaft while collar and preliminary sinking (using the crane) is in progress. Each item is then set in place in sequence - the galloway, the collar steel and then the sinking headframe. When the headframe is in place, the wire ropes from the two drum winch are pulled over the sheave wheels on the headframe down and around the pair of sheave wheels located below the top deck of the galloway and back up to be anchored in the headframe again. The two drum winch is then capable of raising and lowering the galloway as required through the shaft. The galloway may also serve as the second means of escape in the event of sinking hoist failure. A standby generator is available in case of power failure. The two drum winch normally requires approximately 50 horsepower to operate, being a very slow speed hoist (approximately 15 feet per minute). Consequently, this winch can obtain power in emergency from a relatively small standby generator.

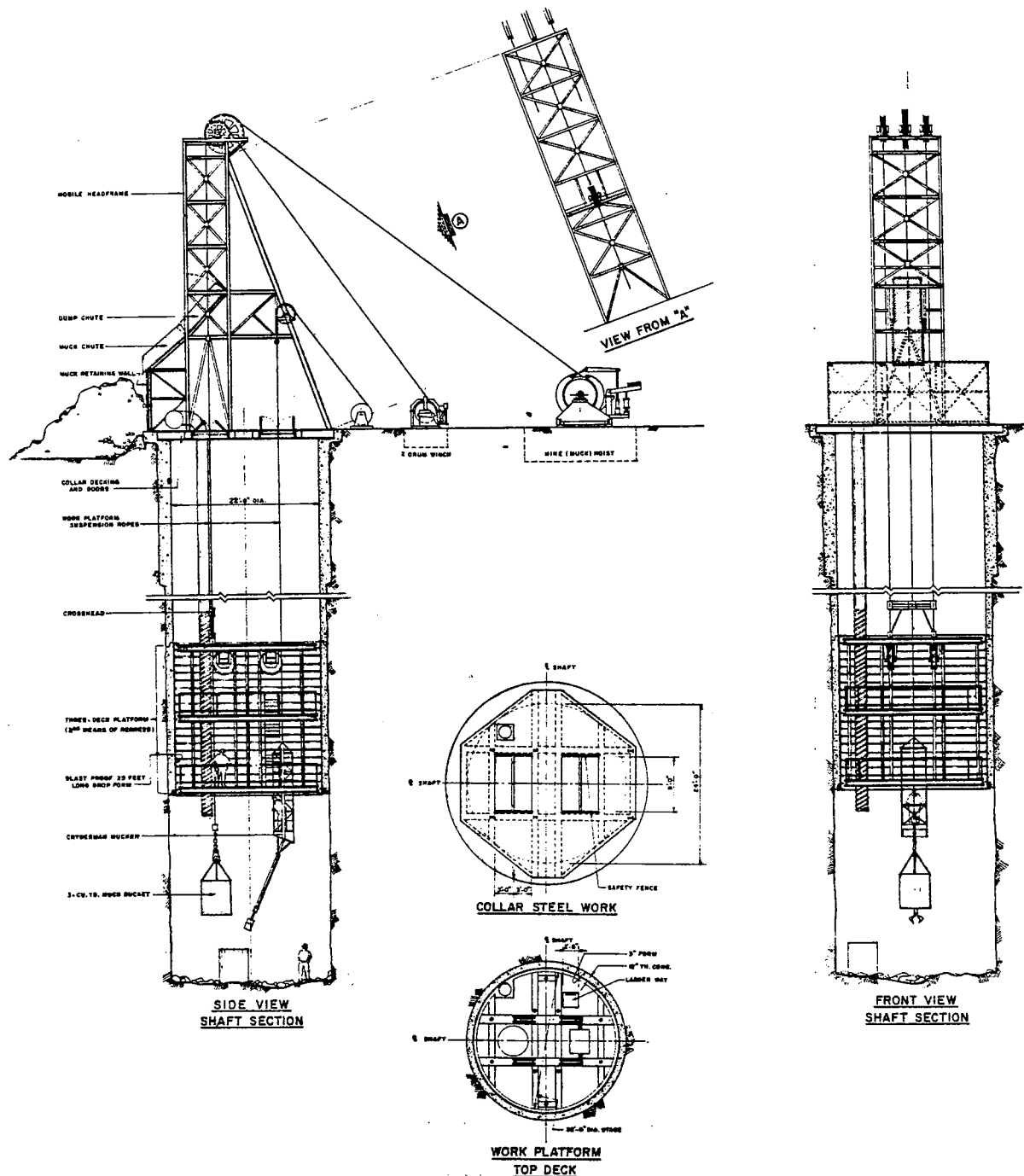


FIGURE B-1. General Arrangement of Conventional Shaft Sinking Equipment in Shaft

At this point, shaft pipes are installed to provide the services required for shaft sinking; namely, ventilation, compressed air for drilling and mucking, water both into and from the shaft and where required, grout lines. The ventilation pipe is generally a thin walled "spiral weld" 30-inch diameter pipe with band-type coupling. The compressed air and pump lines are both 6-inch diameter, schedule 80 pipe with victualic fittings. The pipe bringing water into the shaft (and also any grout line that might be installed) would

be 1-1/2 or 2-inch diameter schedule 80 pipe with victualic fittings. All pipes would be in standard 20-foot lengths to conform with concrete pour lengths. The pipes would be clamped to the wall every 20 feet by a special bracket secured to the wall by 1-inch diameter stud bolts screwed into socket nuts cast into the concrete shaft lining.

In addition to the pipe ranges, the four shaft side lines used to plumb the shaft would be installed at this time. These side lines are 3/16-inch diameter airplane cable. They are wound on small winches located at the shaft collar. The wires are led over small pulleys located under the shaft collar steelwork, one in each quadrant of the shaft and generally 3 to 3-1/2 inches inside the finished shaft diameter. This permits heavy plumb bobs to be fitted to the ends of the wires and clear of the shaft lining. A similar winch and wire rope is also installed for shaft communication signals. This wire rope is connected at shaft collar level to a mechanical (gong) signal which also activates an electrical switch, transmitting the signal both audibly and visually to the hoist house. Two self-supporting armoured coated electrical cables (also wound on special winches located at shaft collar and led over sheaves set in the shaft collar steel) are suspended in the shaft diagonally opposite each other and about 6 inches clear of the shaft lining. One of these cables is used for blasting and the other for shaft lighting. The shaft light or lights are normally mounted on the underside of the galloway decks.

The excavation and construction of the shaft collar and the completion of the installation of all of the equipment and fabricated steelwork discussed above may take from four to six months, working one to two shifts per day at six days a week. The work force during mobilization consists of 10-20 or even 25 men, because of the many concurrent operations required.

Drilling and Blasting

Following completion of the initial excavation, deeper shaft sinking is accomplished by drilling and blasting. Drilling is accomplished using pneumatic percussion drills, either hand-held, or mounted on a shaft drill

jumbo as shown in Figure B-2. Before drilling begins, the rock surface is blown clean with water and air to locate any misfired charges left from the previous blast.

The shape and depth of the blast pattern are extremely important factors in the excavation cycle. The shape of the pattern is determined by the ground condition and by the type of mucking equipment being used. The two basic

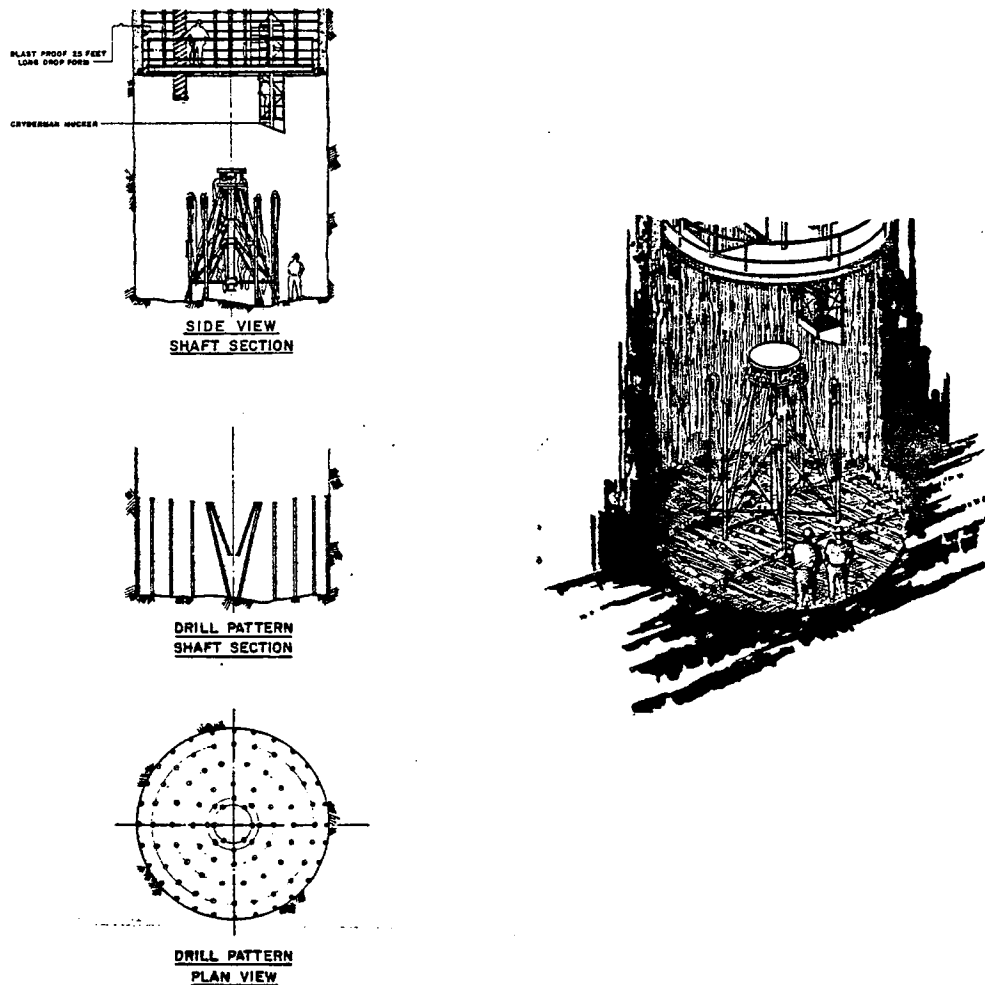


FIGURE B-2. General Arrangement of Drilling Equipment in Shaft

patterns are the full face and bench. With the full face pattern, the entire bottom of the shaft is drilled and blasted in a single lift. This method is generally preferred when using mechanical mucking equipment, and results in a higher advance rate. However, under extremely wet conditions or in areas of high rock pressures, the bench pattern may be preferred. In the bench pattern, half of the face is drilled and blasted in each shot. In this way, the muck is confined to one area and a sump is provided to allow pumping of excess water.

The depth of the pattern is particularly important in achieving the maximum rate of advance. It is, however, limited by the size of the shaft, ground conditions, and overbreak produced.

After drilling the desired pattern, the holes are charged with explosives. The explosives are detonated electrically, using parallel-mains firing. In each round, time-delay electrical detonators permit six to eight (generally 1/2-second) time intervals between the blasting of the individual rings of drill holes.

Drilling

In preparing for the drilling operation, the bucket is removed from the hoist rope and the drill jumbo is attached and lowered into the shaft bottom. Setting up the jumbo can take an average one hour. Adjustment to stabilizing jacks on the base of the jumbo permits vertical alignment. The jumbo is approximately 15-feet high and must be secured in a vertical position to maintain stability. Rough or badly stepped shaft bottoms can create difficulties. Water flushing of drill cuttings from the drill holes during drilling is standard practice. The water from drilling and water entering the shaft from other sources must be pumped out of the shaft during drilling. Compressed air-operated pumps are generally used, the water being pumped into a muck bucket and hoisted to the surface or pumped directly to the surface via water lines and intermediate pump stations. Grouting may also be used to shut off some water inflows to the working area, as well as to help stabilize incompetent ground.

Up to six men are employed in the shaft during drilling. Four men are normally employed as drillers with one supervisor and, when available, one more man attending to water removal, plugging of holes, changing drill steels where necessary, and in general, ensuring continuity of operations. Setting up the jumbo, drilling, and removing the jumbo to the surface, will on average take almost a full 8-hour shift.

Loading and Blasting

Once the drill jumbo has been removed, the explosives and detonators are taken into the shaft in the bottom of the muck bucket. Each drill hole in the shaft bottom is normally "blown out" prior to charging using a compressed-air pipe, some 14-feet long and of small enough diameter to be inserted in the hole. The pipe is bent at right angles at the top end and has a valve to permit operator control. The compressed air is led to the pipe through a 1-inch diameter hose from the air manifold.

The charge in each hole is weighted depending on the strength of the strata being penetrated. Four to five miners are employed during charging. The explosives are made up as cartridges slightly smaller in diameter than the drill holes and 18 inches in length. They are pushed to the bottom of the hole using a wooden tamping stick, one stick at a time, and three or four sticks to a hole. The detonator is normally placed in the bottom stick. The shaft water must be pumped during this entire operation. A small compressed air operated pump with a 15- to 20-foot long 3-inch diameter discharge hose pumps water up into the sinking bucket.

The supervisor and lead miner are normally responsible for connecting the detonator lead wires together and then to the shot-firing cable suspended through the shaft. Prior to blasting, the crew will raise the galloway and the mucking machine out of blasting range (approximately 120 feet from shaft bottom). The crew will come to the surface in the sinking bucket. The shaft collar will be cleared. The collar doors will be left in the open position. The ventilation fan will be turned off. The supervisor will check the wiring circuit of the detonators using an ohmmeter to ensure from the resistance that all of the parallel circuits are connected to the main shot-firing cable prior

to inserting the shot-firing cable leads into the mains circuit to set off the blast. Immediately after blasting, the ventilation fan will be turned on. The charging of a round, wiring and blasting can take an average of one-half shift.

Smoke Clearance and Shaft Inspection

Smoke clearance after blasting generally requires 15 to 30 minutes, and is followed by shaft inspection. The galloway and mucking machine are cleared of all debris that might have been thrown onto either by the blast. Suspension ropes and sheave wheels on the galloway are inspected. If all is in order, the galloway is lowered at approximately 4 or 5 feet per minute with the crew of five men riding on the decks to ensure clearance from shaft pipe ranges and from the mucking machine. The galloway is secured approximately 35 to 40 feet above the shaft bottom as shown in Figure B-3. The Cryderman or other mucking machine, attached to its own surface winch, is lowered into position. A front-end loader, like an Eimco 630, may also be used for mucking, as well as a variety of other machines. The mucking machine operator climbs into position, and the remainder of the crew descends to the shaft bottom in the bucket and gets out on top of the muckpile. The excavated shaft walls are inspected and any loose material is taken down by scaling.

Mucking

Mucking begins when an empty bucket is lowered to the shaft floor. The sinking bucket, still on the hoist rope, is pushed back off-center by two men and lowered onto the muckpile. The hoist rope is then removed from the bucket suspension chains and the empty rope sent back to the surface. While the hoist rope returns to surface, mucking begins. A second sinking bucket is hung on the hoist rope at surface and lowered through the shaft. The hoist operator will stop the hoist with the bucket in the "waiting" position--normally with the bucket in the galloway opening.

Communication from the hoist operator to the shaft bottom (generally by turning the shaft lighting system off and on) lets the shaft supervisor know

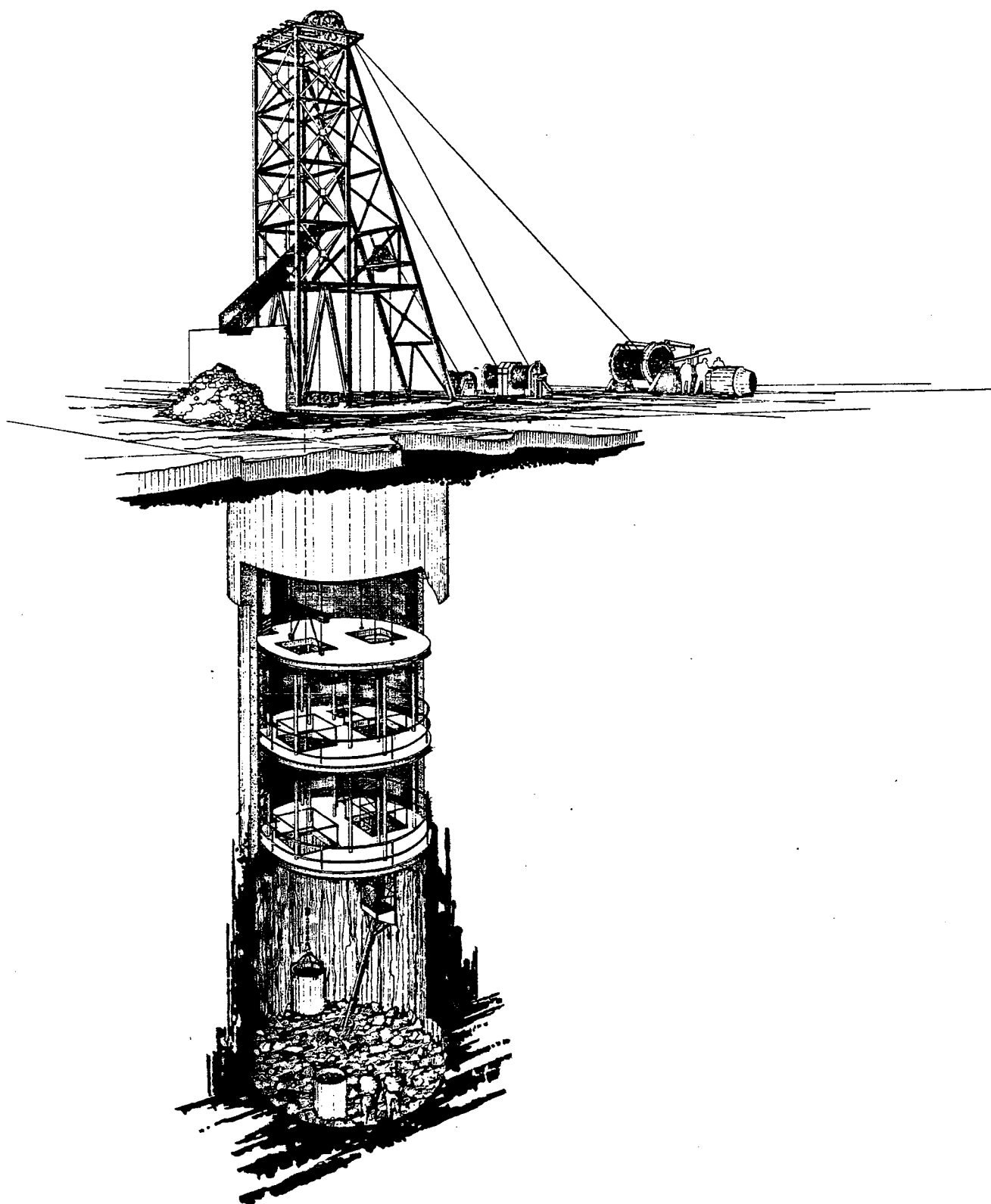


FIGURE B-3. General Arrangement of Conventional Shaft Sinking Equipment During Mucking Operations

the bucket is available. When the first bucket has been filled by the mucking machine, the supervisor will signal the hoist operator to lower the second bucket. The signal is given by means of a wire rope hung through the shaft and connected to a mechanical signal on the collar. An electrical switch on the arm of the mechanical signal relays the signal to the hoist operator both audibly and by an electric light bulb signal. A code of signals is posted in the hoist house and at the top of the shaft.

The bucket is lowered by the hoist and will be stopped by the supervisor signaling when the bucket is approximately 1 foot from the muckpile. Two men will push the bucket off-center generally over a hole created in the muckpile by the filling of the previous bucket. While these two men hold the bucket by leaning their bodies against the side of the bucket, the supervisor signals again to have the hoist operator lower the bucket slowly. The bucket is landed on the shaft bottom, the suspension chains of the bucket are pulled clear to the sides of the bucket, and the safety clevis on the end of the hoist rope is removed from the bucket main suspension ring. The clevis is now pulled across the shaft and attached to the ring of the first bucket. A safety pin is inserted in the clevis to lock the tongue in position. Appropriate signals are again given by the supervisor and the hoist rope is raised until the weight of the full bucket of muck is just taken by the hoist. The hoistman will hold the hoist at this point. While the full bucket is being picked up by the hoist, the two men will lean against the bucket to minimize the oscillation and slow down the movement of the bucket swinging into the center hoisting position. They will clean off the bucket top rim and bottom by hand to ensure no material can fall back through the shaft during its trip to the surface. When the bucket is steady and cleaned off, the supervisor will again signal the hoistman to raise it to the surface. Mucking into the second (empty) bucket will begin when the first (full) bucket has passed through the galloway. Buckets are set off-center to maintain access by the miners to the bucket either coming into or going out of the shaft bottom.

The full bucket of muck will be raised through the shaft. When passing through the collar door opening at surface, the hoist will reduce speed (or automatically cut out through hoist control devices) and continue slowly up through the headframe, coming to rest above the dump door or chute (identified

in Figure B-1). Both the dump door and the collar safety doors will then be closed. They are generally hinged doors connected to and activated by a two-way, compressed-air cylinder. Door operation is also electrically connected to the hoist-signaling system and a light display informs the hoist operator as to their open or closed position. The hoist operator may dump the bucket automatically or a surface deckhand may need to assist, depending on the dump system employed.

Two dump systems are most popular. The automatic dump system employs a ball and chain attached to the underside of the buckets. The ball falls through a retaining key slot built on the dump door when the bucket is lowered off. The ball is trapped in the slot as the bucket continues to lower and holds the bottom of the bucket in one position, causing the bucket to tip. The alternative scheme requires a man standing on a platform at dump-door elevation in the headframe to attach a hook to a ring on the bottom of the bucket before signaling to lower the bucket. The hook is fixed to a wire rope or chain of set length in the headframe. The hook again holds the bucket bottom and permits the bucket to tip and discharge in the correct direction when lowered off. Muck discharged from the bucket is generally dumped onto the surface in front of the headframe (as shown in Figure B-3) and removed by front-end loader as required.

The bucket is raised after being tipped to a position where both sets of shaft doors can be opened and then it returns through the shaft to the "waiting mark" already mentioned. From this point, the mucking cycle is repetitive until the mucking machine begins exposing the solid shaft bottom. Preparation for mucking might take approximately one to two hours. Mucking through to the shaft bottom cleanup cycle might take one full 8-hour shift.

Shaft Bottom Cleanup

Depending on the results of blasting, shaft bottom cleanup can take from 2 hours to 8 hours to complete. During cleanup, the last of the blasted muck is first shoveled into piles for the mucking machine to load into buckets and finally, for the last bucket, the broken material is loaded by hand shovel directly into the bucket. Compressed air blown through a 2-inch diameter

"blow pipe" with a flattened end is generally used effectively to prize away the loose slabbing on the shaft bottom. This is an extremely noisy, wet and uncomfortable part of the operation. Two men at a time hold and direct the pipe (which can be fitted with a bar handle). The force of the compressed air and the bulk of the hose may require change out of personnel during this operation.

When the shaft bottom has been cleaned off to the solid, the drilling and blasting operations are repeated and following again by mucking. In a metal/nonmetal mine, two complete cycles are generally required to expose the necessary 20 feet of excavated shaft for the shaft lining cycle to begin. The lining cycle is usually initiated after blasting and the creation of a full muckpile.

Hoisting Equipment

The hoisting system is perhaps the most critical component in conventional shaft excavation. Men and materials are raised and lowered by means of the hoist. The hoist is also used to raise the broken rock to the surface for disposal. This vital system must be properly installed and maintained to protect the lives of the miners and to speed progress of the work. Hoist operating functions and specifications are discussed in more detail in the final section of this appendix.

The hoisting system is composed of a number of related machines: the hoist, controllers, rope and sheaves, headgear, and conveyances. Each component is vital to the performance of the system. Other equipment related to the hoisting systems includes work decks and winches. Figure B-3 shows the shaft sinking equipment layout and a pictorial view of the shaft during "mucking" operation. The shaft bottom is accessible by means of a shaft sinking bucket (of some 2- to 4-cubic yard capacity), suspended from a safety clevis attached to a suitably sized wire rope. The rope is attached to a single-drum, out-of-balance mine hoist which is capable of raising an approximate 5-ton payload from the shaft bottom and of maintaining speeds through the shaft of something approaching 600 feet per minute. Hoist size and bucket capacity used increase generally with the ultimate depth of the shaft being sunk.

The hoist is equipped with a depth indicator, post brake, auxiliary or emergency brake (normally mounted on the motor coupling) and overspeed and overtravel control. As shown in Figures B-1 and B-3, the hoist rope will be contained while running through the shaft by means of a "crosshead" attached to two wire rope guides. Figure B-3 illustrates the full complement of equipment to be employed. The guide ropes also support the galloway which is suspended at all times in the shaft and which can be raised or lowered by the two-drum winch to which the ropes are attached on surface. The galloway is used to facilitate placing of the concrete lining and can also serve as a second means of egress. In the event of a power failure and/or main hoist problems, the standby generator can supply power to the winch and permit the shaft crew to ride the galloway to the surface.

The wire ropes from both the double-drum (galloway) winch and from the main hoist drum are all routed into the shaft over their respective sheave wheels mounted in the headframe as shown in Figures B-1 and B-3. The headframe shown in Figure B-3 is of a minimum size that will permit all equipment used for sinking to be suspended on the hoist rope and raised high enough above the shaft collar doors to allow the doors to open. As shown in Figure B-1, the shaft collar steelwork, which completely covers the entire shaft area, is equipped with two sets of doors. In the case shown, the second set of doors permits lowering and raising the Cryderman mucking machine from surface. The mucking machine goes into and out of the shaft in one piece.

The emergency hoist can also be used to raise and lower the mucking machine. This hoist would be a slow-speed (single-drum) winch (50 horsepower and 15 feet per minute hoist speed) of the type used to raise and lower the galloway. In an emergency the mucking machine can be lowered to the shaft bottom, the bucket attached to the rope and the hoist used to raise those underground to the surface.

Lining

Nearly all modern shafts are concrete lined to provide support, to seal out excess water, and to protect the wall rock from deterioration. Concrete lining is normally maintained to within a maximum distance of 40 feet above

the shaft bottom (immediately prior to a lining cycle). In the event of any poor or sloughing ground conditions, short lengths of concrete lining can be poured to reduce the length and time that the excavation must be exposed before receiving support. Weak strata may also require temporary wall support.

Temporary support may consist of rock bolts, bolts and wire mesh, or gunite. The exact type of support is determined by ground conditions. When rock bolts are used, they are commonly 5 feet long and placed on centers of 4 and 5 feet. In areas of particularly bad ground, wire mesh may be used in conjunction with the rock bolts. The mesh is anchored to the bolts and aids in retaining base blocks which might otherwise fall into the shaft. Gunite or shotcrete is also commonly used as a means of support. The gunite may be applied directly to the rock or it may be used in conjunction with rock bolts and wire mesh for additional strength.

Lining Equipment and Procedures

Suspended from a double-drum hoist winch (located on surface) by two wire ropes in double purchase (as shown in Figure B-4), the gallows stage is used to enable concrete placement behind the 20-foot long shaft form. The equipment anticipated to be used for lining consists of a curb ring; 8 steel ring forms, each 2 1/2 feet high; and twelve 1 1/8" diameter, 20 foot long hanging rods. This system, while not necessarily standard, is representative of current lining techniques. However, each contractor will probably use different methods or equipment, depending on the project specifications.

At the start of a lining cycle, the curb ring is broken away from the bottom of the previous pour. It is attached to winches on the gallows. The gallows with the curb ring suspended is then lowered to the new position, 20 feet below. The curb ring is then attached to and supported by the hanging rods (which provide for some reinforcement of the concrete lining) and is positioned and centered using the shaft sidelines. Any annular spaces between the curb ring and the shaft wall are sealed using strips of plywood and/or sandbags to ensure a tight fit. When the curb ring is set, the gallows is raised up to allow removal of the concrete forms from the previous pour. The form has a knife edge that slides behind the adjacent section of the form, so that the form might be pulled together at that location, thereby decreasing its diameter. The form is broken loose by drawing it together on one side

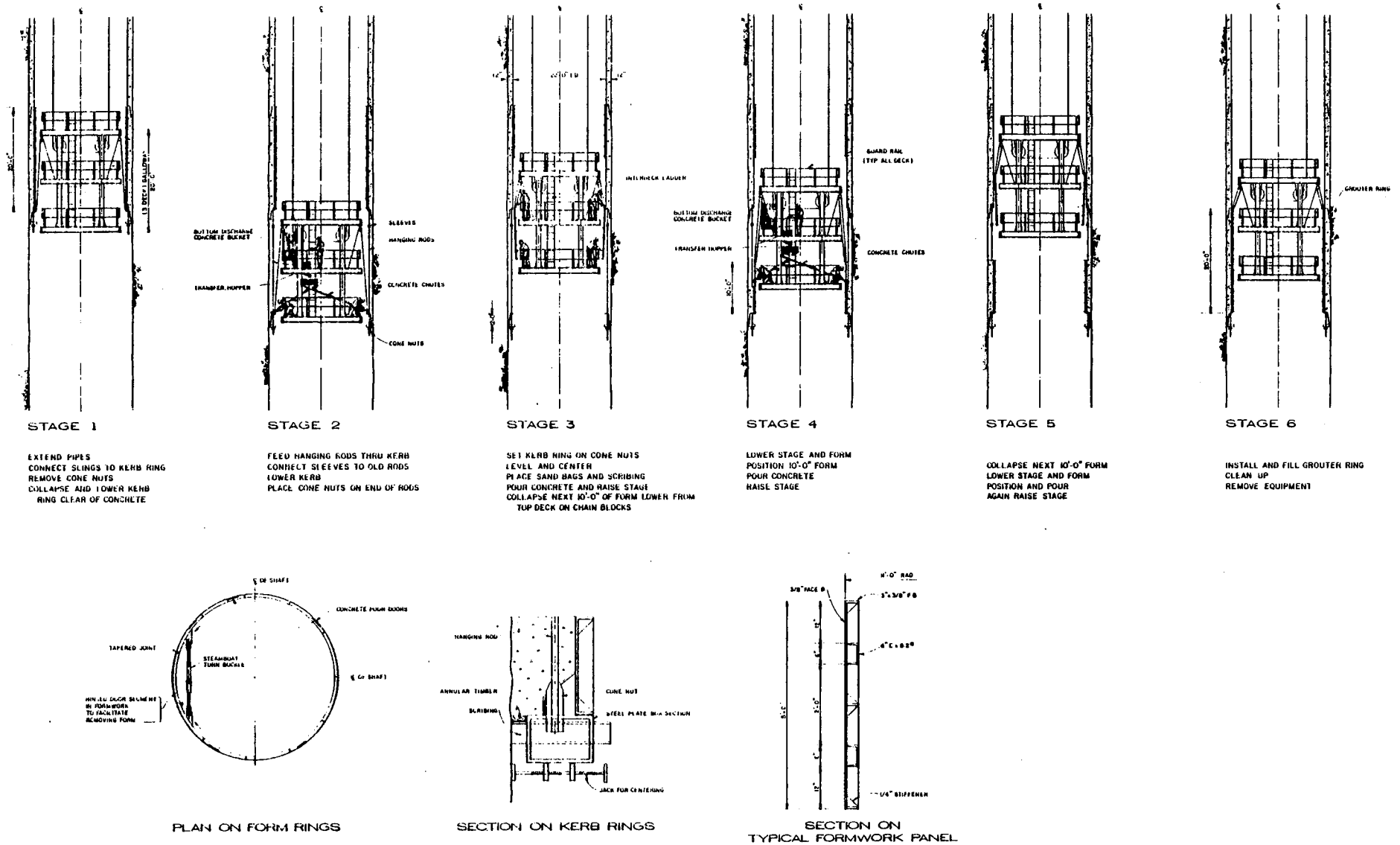


FIGURE B-4. Conventional Shaft Sinking Lining Sequence (20 foot sections)

using "steamboat jacks" and, once the form is loose, lowering it with the pneumatic hoists on the gallows. The form is set on top of the curb ring. After installation and alignment, the first 10' section is poured.

Concrete is poured behind the forms using "elephant trunks" from a bottom discharge 1-1/2 cubic yard capacity concrete bucket on the end of the hoist rope. The concrete is either mixed on surface in the contractor's own onsite batch plant or is procured from a subcontractor who delivers to the site in ready mix trucks. Concrete is loaded into the shaft bucket on top of the collar doors. The concrete may have an accelerator added to improve setting time. Compressed air concrete vibrators are used to vibrate the in-place concrete. One miner unloads the bucket; one or two men move the concrete behind the form and/or move the elephant trunk from door to door. One miner operates the vibrator and one man gives signals to the hoistman. During work platform movement, all men are employed guiding the platform. Similarly, during the removal and resetting of the form, all four men are employed. The procedure is repeated for the second 10'-0" form section.

The total operation requires about one shift. Cleanup operations and previous pipeline extension requires roughly another shift. Cleanup consists of hosing down the concrete buckets and other equipment and the decks of the working platform. The final concrete lining is smooth, with a nominal thickness of 12 inches or greater, depending on shaft depth. Extra concrete that may be required as a result of overbreak is not included in this thickness.

Pipeline Extension

The service lines for conventional shaft sinking systems are usually extended once every 20 feet, during which time the services provided, including ventilation, compressed air and water, are interrupted. Pipeline extension operations are assumed to precede the concrete lining cycle. The pipes are secured to the wall by brackets bolted by studs screwed into inserts cast into the concrete lining. Extension operations require from two to four men. To extend the shaft pipelines, the upper deck of the gallows is positioned some two feet below the bottom of the pipes already installed. The

manifold on the end of each pipe (i.e., valve assemblies) is then removed and secured to the galloway. Pipes are lowered on the hoist rope one at a time until the tops of the pipes are immediately below the installed pipes. Rope slings and ratchet jacks are then used to raise the pipes into position. The victualic couplings are then fitted. The galloway is then lowered to permit replacement of the valve manifolds on the bottom of the pipes and secure the pipes to the wall bracket.

Shaft Dewatering

Experience with shafts in metal/nonmetal mines in the Western U.S. indicates that large amounts of water may be encountered in the course of sinking a shaft. If such an aquifer is intercepted, air or electrically driven pumps would be lowered from the galloway and placed on the shaft bottom. These pumps would be stored on the galloway.

In shafts where excessive ground water is a problem, water rings are constructed in the lining. Water rings (Figure B-5) are recessed areas in the lining in which excess water is collected and channeled to a sump for pumping. The water rings may be drained through pipes inside the shaft leading to a sump, or a well may be used. With this method, a borehole is drilled outside the perimeter of the shaft and other connecting drains are drilled from the water rings to the borehole. An electric submersible pump is then placed in the borehole and the water is pumped to the surface. In this way, the water is handled outside of the shaft and does not interfere with shaft sinking.

Ventilation

Ventilation of the shaft bottom during sinking is obtained using an axial flow fan or fans in series to exhaust air through a 24- to 36-inch diameter, thin-wall (spiral-weld) pipe, which extends through the shaft. The fan is offset at least 15 feet from the shaft collar as prescribed by law. The ventilation pipe is sized dependent on the volume of air required to keep the shaft bottom adequately ventilated (up to 25,000 cfm). The pipe is secured to

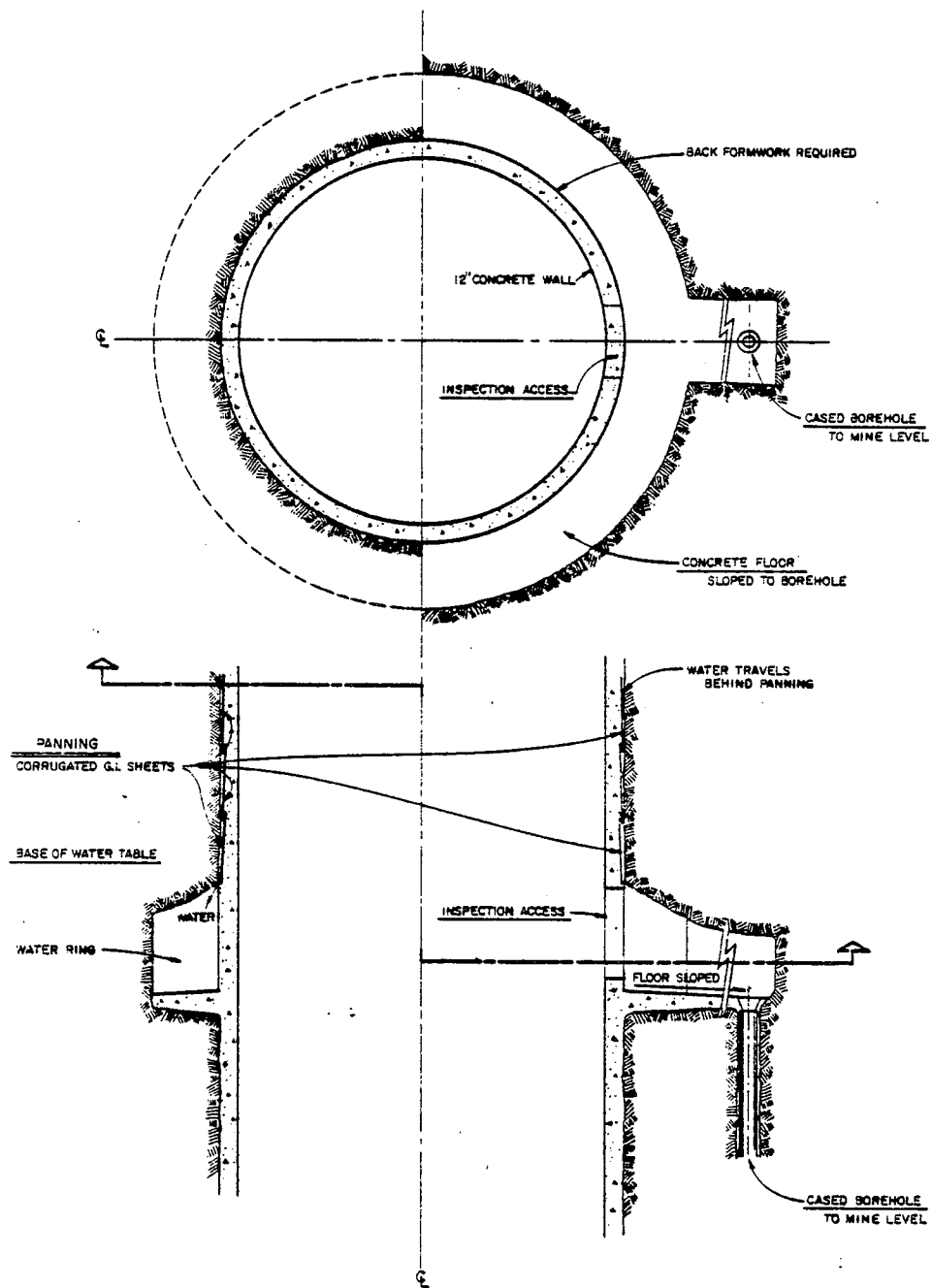


FIGURE B-5. Representation of a Water Ring Constructed in Shaft Lining

the shaft wall in the manner already described. Special band-type couplings are used to secure one pipe to another. The rigid pipe normally terminates some 30 to 70 feet above the bottom of the shaft lining. A wire-reinforced flexible hose is used at the end of the rigid pipe to prevent damage to the steel tubing during blasting.

SAFETY REGULATIONS

Shaft sinking operations are regulated by both state and federal agencies. Federal regulation is accomplished by the Mine Safety and Health Administration (MSHA) in the Labor Department, based on the Federal Mine Safety and Health Amendments Act of 1977. This Act superseded the old coal and metal/nonmetal mine health and safety acts, and brought all mines (both coal and metal/nonmetal) under one set of laws. The regulations implementing these laws are contained in Title 30, Code of Federal Regulations (CFR), Chapter 1. State regulation is accomplished by various state agencies. Most state mining laws are similar to the federal regulations or include them by reference.

Detailed federal regulations and health and safety standards for underground metal and nonmetal mines, including shaft projects, are listed in 30 CFR, Chapter 1, Subchapter N, Parts 57 and 58. Specific areas of interest, such as use of explosives, and respiratory devices, are addressed in other subchapters and parts of 30 CFR, Chapter 1.

Some of the standards in Subchapter N are advisory, while others are mandatory. Extracts from these standards that can be specifically applied to shaft sinking operations in metal/nonmetal mines are included in the Impactor Safety Manual (Volume 2). Other regulations, in addition to those listed in 30 CFR, may be applicable to shaft sinking activities. These include 29 CFR, Part 1926 (1977) on Safety and Health Regulations for Construction and 29 CFR, Part 1910 (1978) on Occupational Safety and Health Standards.

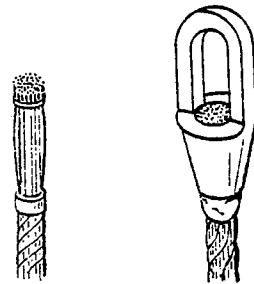
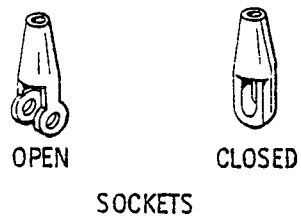
CONVENTIONAL HOIST AND EQUIPMENT SPECIFICATIONS

Hoist Rope

The wire rope is the primary means by which a load is carried in the shaft. The connectors are what attach the rope to the hoisted object (or to the hoist). Many federal regulations exist concerning the use and design of wire rope and connections for shaft haulage systems. Regulations prohibit the use of open hooks and require that only poured sockets, thimble-and-clip, and other approved end connections be used. Figures B-6, B-7 and B-8 show three of the most commonly used conveyance-end connectors. These are the sockets, thimble, and cappel. Secondary safety attachments (to any conveyance suspended by a single rope) are recommended by regulations.

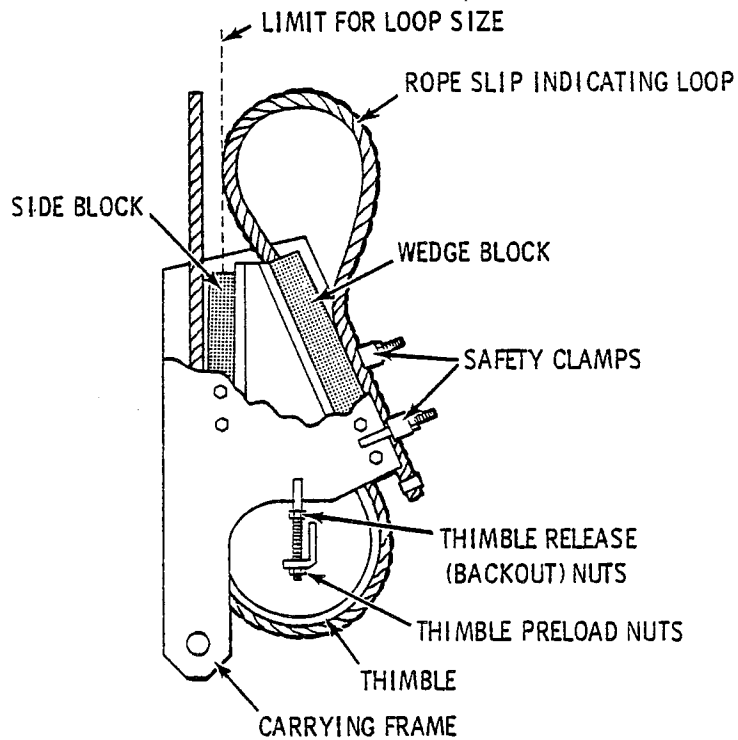
Regulations also exist concerning rope strength, maintenance and removal criterion. Required new rope safety factors range from 4 to 8 with respect to rope breaking strength and maximum static load. Minimum required safety factors are also given for rope removal. It should be noted, however, that it is difficult to accurately determine the breaking strength of a worn rope, especially if corrosion is present. Rope replacement is also required if: there are more than six broken strands anywhere within one lay-length; there is 35% (or more) loss of original crown-wire diameter; marked amounts of corrosion are present, or any dangerous combination of these three. Other rope removal criterion commonly used are:

- Three broken wires in the same strand within one lay length.
- A prediction of from 10 to 15% loss of strength (based upon measurements of rope diameter, wear pattern dimensions, and the number of broken wires), estimated with a series of charts and graphs published in the Roebling Wire Rope Handbook.
- A prediction of 10% or greater loss of rope strength based on the results of electromagnetic nondestructive testing with an alternating-current device manufactured and/or operated by Rotesco, Ltd., Toronto.
- A kink (a pulled-out twist loop); a dogleg (a simple, permanent bend); a birdcage (strands separated and ballooned out); loose or



CLOSED END SOCKET READY TO BE
FILLED WITH MOLTEN ZINC

FIGURE B-6. Socket End Connectors for Hoist Ropes



ASSEMBLY OF SHORT-COUPLED THIMBLE TERMINATION

FIGURE B-7. Short-Coupled Thimble End Connector

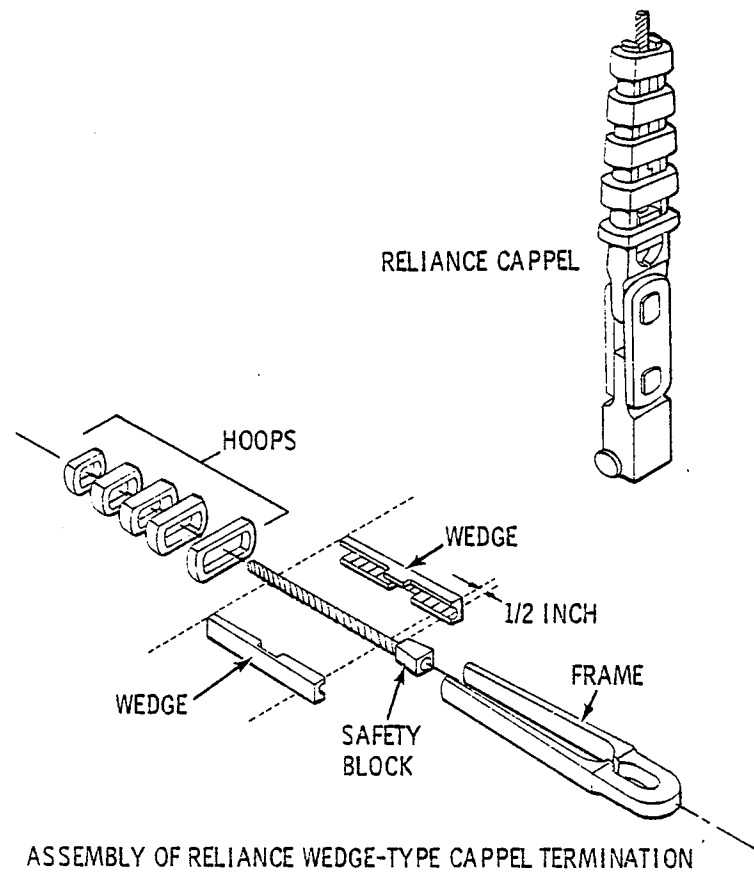


FIGURE B-8. Cappel-type End Connector for Hoist Ropes

high strands(s); a badly out-of-round section; a crushed section with abraded or broken wires; loose wires with no visible breaks; a protruding core; an unusually small diameter locally; or an unusually short or long lay length locally--all too far from the end of a rope to be removed with an end cut. It should be noted that these items are all radical changes--constructional upsets--in the structure of the rope. (The regulatory criterion of marked amounts of distortion usually is taken to mean any of these kinds of structural changes.)

Hoist Operating Functions

The drive system provides 3 modes of operation which are established by a selector switch at the operator's location. Indicating lights identify the mode being used. A transfer between modes while the hoist is running causes an emergency stop. The operator's console location is in the hoist room near the major electrical drive apparatus.

Manual - Full Speed operation from a master switch at the operator's location provides complete control of speed and direction over the 0-1000 feet per minute (FPM) range. The speed regulator relates the hoist drum speed to master switch position. Supervision is exercised by the control to prevent rates of acceleration or deceleration which might be damaging to equipment.

Manual - 500 Hoisting extremely heavy or bulky loads requires extended travel at reduced speed. This mode restrains maximum speed to 500 FPM under the full control of the operator.

Inspection of the hoist shaft or rope requires slow operation under the operator's control. The inspection mode provides manual operation as described above but at full master switch position the rope speed is limited to 120 FPM. The speed regulator provides the controlled, steady speed desirable for this device.

In either mode, as the conveyance approaches the upper end of travel, slowdown is enforced by the electrical system should the operator fail to do so. Should the speed fail to be reduced, the Lilly Controller through its self recalibrating overspeed device causes an emergency stop.

Description of the Mine Hoist Electrical System

The hoist is driven by a D-C motor. Adjustable voltage D-C power for the D-C motor armature is supplied by a static dual converter, thyristor power supply. The D-C motor armature and its static supply are connected together to operate as a regulated adjustable speed drive. Adequate torque and peak load capacity are provided for handling the loads specified.

Hoist Drive Regulator

The hoist drive regulator provides operation of the hoist drive as an adjustable speed system. The regulator is static, and uses high gain, fast response, operational amplifiers to control the motor armature voltage, and therefore, its speed.

The speed regulator incorporates a speed feedback signal from a tachometer generator. The tachometer is mounted on, and driven by, a hoist motor. The fast response regulator maintains the hoist drum speed at the present value, independent of load and temperature changes.

A current limiting function is included in the speed regulator. This feature limits the D-C armature loop current to a safe value, and protects the electrical and mechanical apparatus from excessive current and torque peaks.

A solid state ramp function generator is used in the reference circuit to the speed regulator. This supervises the rate-of-change of the hoist speed during acceleration and deceleration. The ramp function generator protects the equipment from excessive peak currents and torques. The acceleration and deceleration rates have separate adjustments.

Safety Circuit Monitor

Fault indicator units are supplied to help locate the cause of an emergency or protective stop. The fault indicators continue to show the cause of the trouble after the circuit has self-cleared or been manually reset.

Programming

Program signals for automatic override operation at the upper terminal are obtained from two types of position detectors. The first type is a rotating limit switch connected to the hoist machine through gearing. This programmer is an assembly of several cam operated switches that are independently adjustable. The other type is a group of magnetic proximity limit switches which are mounted along the trackway and are tripped by magnets mounted on the conveyances.

This programming equipment initiates acceleration, deceleration, a speed check during deceleration, and stopping of the conveyance.

Lilly Controller

This unit may have a special variable depth dial for shaft sinking purposes. This controller will be driven from the hoist drum and will function for any of the following reasons:

1. In case of overspeed
- 2 In case of overwind
3. In case the operator or electrical control fails to reverse the direction of the hoist after stopping at the end of the trip
4. To warn the operator in case normal speed is exceeded and to stop the hoist if the warning is not heeded
5. To warn the operator if retardation is not being properly conducted within the predetermined limits of safety and will stop the hoist if he fails to respond.

Brake Operation - Detail

The Nordberg disc brake system contains a braking disc attached to the hoist drum. Braking action is secured by spring loaded pads which act in 3 pairs to clamp the brake discs. These pads are released by hydraulic pressure acting against their springs.

The operating oil pressure system has several features:

- a) Operating fluid pressure is generated by 2 pumps, electrically driven. Reservoir pressure is approximately 2100 psi.
- b) The brakes are released when oil pressure is applied through electrically operated valves.
- c) The operation of each brake pad is monitored by two limit switches as follows:

- 1) Should a pad spring be abnormally weak, the pad will release at lower than proper oil pressure. The release of pads is checked to approximately 1400 psi on rising pressure to detect such a weak spring.
 - 2) When full fluid pressure is applied to all cylinders, all brake pads should be fully withdrawn from the disc. Limit switches monitor this condition - a dragging brake pad.
 - 3) When oil pressure has been reduced to the point that the brakes should be set, the brake pad mechanism - if it has overtravelled - indicates excessive lining wear. Limit switches monitor this condition.
- d) The performance of the oil pressure system is monitored during the brake-setting procedure as follows:
- 1) Within a period of 1 to 1.5 seconds after initiating brake setting, the pressure in the release cylinders is checked. It should have dropped quickly to allow the brake pads to contact the disc with enough pressure to retard the hoist. This is indicative that brake setting is proceeding satisfactorily.
 - 2) Within a period of 3-5 seconds the pressure should have dropped to a value that permits the pads to exert maximum braking effort on the discs - be fully set.

Pressure operated switches transmit information to the control system which acts in case of improper performance.

The relationship between brake operation and the hoist control is so established that:

- a) A Weak Spring Condition causes a Controlled Stop. The cause of shutdown will be indicated and the specific faulty brake spring will be identified.
- b) A Dragging Brake Shoe causes a Controlled Stop. The cause of shutdown will be indicated. The faulty brake pad can be identified by repeating the condition and observing the light which remains on while the brake is dragging.

- c) Excessive Brake Lining Wear causes a Protective Warning. The cause of the shutdown will be indicated. The specific worn pad is not identified.
- d) Failure of Fluid Pressure to Drop Quickly (1-1.5 sec.) causes an Emergency Stop. The cause of shutdown is indicated as Brake Pressure PS-1.
- e) Failure of Fluid Pressure to Drop Adequately (3-5 sec.) causes an Emergency Stop. The cause of shutdown is indicated as Brake Pressure PS-2.

Safety and Protective Features

A list of conditions that reflect unsafe hoist operation appears later in this Appendix. These unsafe conditions initiate an emergency stop of the hoist. An emergency stop will set the hoist brakes, reset the speed regulator for zero speed and open the motor armature circuit interrupting device. Then the safety circuit must be reset with the control in the "off" position.

There is another set of conditions listed later that are protective in nature. These conditions initiate a "protective warning." The protective warning circuit permits a trip to be completed but sounds an alarm. The hoist attendant should investigate and clear the condition that caused the warning before engaging in continuing operation.

A third set of conditions require a "controlled stop." This is an immediate stop of the hoist but at the normal rate of deceleration with normal braking procedures. The causes of such a stop are also detailed herein.

Hoist Control

The mode of operation is preselected by means of an operation selector switch at the operator's location. Available modes are Manual-Full speed, Manual-500, which were discussed earlier, or inspection. This latter mode provides manual control from the master switch at the operator's location. The maximum available speed is limited to 120 FPM to facilitate the inspection of the hoist rope and mine shaft.

A backout switch is provided at the operator's location which must be moved to the proper position, before the conveyance can be backed out of an overtravel. Interlocks prevent the operator error of moving the conveyance toward increased overtravel. The switch causes an emergency stop if it is moved while the hoist is running.

Additional points are provided on the backout switch for routine check of the Lilly and final overtravel switches in each direction.

The master switch must be in the "OFF" position to permit a change in the mode of operation.

The hoist brake solenoid valves, provided by the hoist builder are energized by relays to release and set the drum disc brake as required. The brakes are operated automatically in conjunction with manual control of the hoist from the master switch. The hoist brake units are equipped with limit switches that detect:

- excessive lining wear
- the fully released position.

Emergency stop of hoist - immediate setting of the control to regulate for zero speed, opening the main power loop, and setting of the hoist brake is initiated by the safety devices upon occurrence of:

- overcurrent in the D-C armature circuit.
- overvoltage in D-C armature circuit.
- opening of the D-C armature circuit.
- failure of A-C power, including phase failure.
- loss of field excitation of the D-C hoist drive motor.
- operation of any emergency stop button or switch.
- movement of the backout switch when drive is running.
- failure of the hoist to decelerate properly at the terminal levels as detected by the Lilly Controller or the slowdown check circuitry.

- overspeed of hoist as detected by the Lilly Controller.
- overspeed of the drive motor.
- overtravel of the hoist as detected by either the Lilly Controllers or overtravel Limit Switches.
- slack hoist rope.

An immediate "Controlled Stop" using normal braking procedures of setting the drum brake will occur upon:

- loss of ventilation to the thyristor power supply.
- failure of mechanical drive to auxiliary safety devices (Detected by switch on the Lilly Controller).
- movement of the operation mode selector switch when the hoist drive is running.

Automatic protective feature sounds an alarm to warn the operator; but it does not interfere with manual operation of the hoist. This feature is initiated by the following conditions:

- ground detection.
- loss of motor ventilation blower drive.
- operation of a brake wear limit switch.
- overtemperature of D-C motor.
- loss of brake system pump.

An emergency, controlled or protective stop sounds an alarm mounted on the control cabinet, and energizes an indicating light at the operator's location. A pushbutton on the control cabinet silences the alarm, but the indicating light remains on to remind the operator of the abnormal condition.

After an emergency stop, the control must be reset at the hoist control cabinet and the trip completed under manual control.

Acceleration and deceleration in all modes is supervised by the static ramp function generator in the regulator, and is adjustable. This device also ensures adjustable, present and repetitive rates of acceleration and deceleration.

A current limit function is included in the speed regulator. This feature limits the D-C armature loop current to a safe value, and protects the electrical and mechanical apparatus from excessive current and torque peaks.

The following apparatus is included in the hoist control cabinet:

- control logic and regulating equipment.
- 460 volt A-C circuit breaker.
- miniature instrumentation of control and regulator circuits to aid in adjustment and maintenance of the drive system.
- control transformer with circuit breaker.
- static, constant voltage supply, 250 volt D-C, for the motor field and the hoist control circuits.
- test selector switch to permit operating the control and regulating circuits when the hoist motor armature circuit is open, and when the brakes are set.
- the D-C armature circuit has a contactor and breaker in the control enclosure.
- ground detection for the D-C armature circuit.
- ground detection for the D-C auxiliary and control circuit.
- ground detection for the A-C control circuit.
- space heaters - 115 volt, 1 phase, 60 hertz to prevent condensation. These are energized from a customer source and controlled by breakers in the customer's lighting panel. The circuit serving the heaters in the motor and control and rectifier cabinets must be de-energized when the hoist is in use.

Power resistors are mounted on top of the cabinet.

The following equipment is mounted on the hoist control cabinet doors:

- an indicating light type, memory, fault indicating system.
- alarm horn.

- hoist lockout pushbutton with provision for locking in the same position.
- voltmeter for the 250 volt D-C constant voltage supply.
- hoist motor field ammeter.
- regulator reset pushbutton.
- control reset.
- alarm silence pushbutton.
- space heater "ON" light.
- start-stop pushbuttons for 2 brake suppliers.
- start-stop pushbutton for motor blower.
- indicating lights - green - for brake supplier and motor blower on.
- indicating lights for protective warning, emergency stop, controlled stop.

APPENDIX C PRELIMINARY HAZARDS ANALYSIS

METHODOLOGY

The Preliminary Hazards Analysis (PHA) technique is a qualitative assessment of the potential hazards of a system. It is used to identify the major potentially hazardous conditions of a system that could result in worker injury or fatality. The analysis technique identifies the hazardous elements, hazardous conditions and potential accidents within a system, and determines the significance of their potential effects. The PHA is also useful for establishing initial design and procedural safety requirements to eliminate or control these identified hazardous conditions and potential accidents. The data and information derived from a PHA also serve other system safety needs, such as assisting in planning a safety program and delineating problem areas in hardware, procedural and system interfaces.

To initiate the PHA, the system of interest is divided into convenient working sections, such as subsystems or functions. Then, for each function, inherently hazardous elements are identified. These hazardous elements are identified through the use of checklists, from experience with similar systems, and from engineering judgment and intuition. An example of hazardous element checklists is shown in Table C-1. The checklists are intended to stimulate ideas as to how or where an unrealized hazardous element could exist in a system. Experience from related programs also provides information for identifying hazardous elements and safety critical areas.

Experience in the aerospace industry indicates that accidents occur primarily as the result of a dynamic sequence of events that work together to generate a specific outcome. The second step in the PHA, then, is to identify the series of causative factors that could transform the hazardous element into a hazardous condition, and in turn, into a potential accident. These triggering events can be conditions, undesired events, or faults existing within a system.

The final step in a PHA is to examine the effect of the potential accident to determine if any preventive measures have been or should be taken. For preventive measures, there are two courses of action available: 1) corrective action in the form of equipment design or procedural changes; or 2) contingency action in the form of design of reactive protective systems or the training of personnel.

A common format for the PHA is a columnar form with specific entries. The format used for this study is shown in Table C-2, along with a simple example to illustrate the type of information required under each column entry of the form. In filling out the PHA form, the dynamic relationship between the entries should be kept in mind. The hazardous element must be acted upon or influenced by some event or condition to become a hazardous condition. Then, when the hazardous condition exists, it must be acted upon by some event or condition to result in the potential accident. In certain cases, duration may be a factor in triggering the potential accident. That is, if the hazardous condition is allowed to exist without immediate corrective action, it may result in the potential accident without any other event acting upon it.

A separate PHA was performed for each function of interest within the impactor shaft sinking system. These analyses, which provide information on the potential causes of worker injury or fatality in employing the impactor technology, are presented in the following section of this report.

TABLE C-1. Standard Hazardous Energy and Element Checklist for Preliminary Hazards Analysis

<u>Hazardous Energy Sources</u>	
1. Fuels	12. Electrical generators
2. Propellants	13. rf energy sources
3. Initiators	14. Radioactive energy sources
4. Explosive charges	15. Falling objects
5. Charged electrical capacitors	16. Catapulted objects
6. Storage batteries	17. Heating devices
7. Static electrical charges	18. Pumps, blowers, fans
8. Pressure containers	19. Rotating machinery
9. Spring-loaded devices	20. Actuating devices
10. Suspension systems	21. Nuclear
11. Gas generators	
<u>Hazardous Element Sources</u>	
1. Acceleration	11. Oxidation
2. Contamination	12. Pressure
3. Corrosion	high pressure
4. Chemical dissociation	low pressure
5. Electrical	rapid pressure changes
shock	13. Radiation
thermal	thermal
inadvertent activation	electromagnetic
power source failure	ionizing
electromagnetic radiation	ultraviolet
6. Explosion	14. Chemical replacement
7. Fire	15. Mechanical shock
8. Heat and temperature	16. Stress concentrations
high temperature	17. Stress reversals
low temperature	18. Structural damage or failure
temperature variations	19. Toxicity
9. Leakage	20. Vibration and noise
10. Moisture	21. Weather and environment
high humidity	
low humidity	

SOURCE: C. R. James, ed., Systems Safety Analytical Technology-Preliminary Hazards Analysis, Boeing report 02-113072-1, 1969.

TABLE C-2. Preliminary Hazards Analysis Format

Sample Case: Hit by Flying Rock Fragments
During Breaking of Rock

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
This column identifies the hardware or functional element being analyzed.	This column identifies hazardous elements present in the hardware or function	This column identifies conditions, undesired events, or faults that could cause the hazardous element to be transformed into the identified hazardous condition	This column identifies hazardous conditions that could result from the interaction of the system and each hazardous element in the system	This column identifies undesired events or faults that could cause the hazardous condition to be transformed into the identified potential accident	This column identifies potential accidents that could result from the identified hazardous conditions	This column identifies the possible effects of the potential accident, should it occur	This column lists existing preventive or control measures that mitigate identified hazardous conditions and/or potential accidents. It may also be used for recommending measures for mitigation.
Breaking rock	Rock	Impact hammer fracturing rock	Flying rock fragments	Operator downhole	Operator hit by flying rock fragments	Injury; possible machine damage	Height of operator's cab, as well as shielding, should protect operators. Safety glasses should be worn. Machinery is designed to withstand impact from fragments.

PRELIMINARY HAZARDS ANALYSIS OF IMPACTOR SYSTEM FUNCTIONS

In this report, Preliminary Hazards Analysis (PHA) methods have been used to reveal the potential causes of worker injury and death resulting from the use of the impactor shaft sinking system, and to determine if unique causes of injury or death could be encountered. PHA, as described in the previous section of this report, is a qualitative safety assessment procedure used to define potential hazards, their possible effects, and alternatives for mitigating either the hazardous conditions or undesired effects. The procedure is most useful when implemented early in a project and then reiterated or supplemented by more detailed analysis as the project proceeds.

To allow a detailed comparison with conventional shaft sinking methods, a PHA was performed for each of a number of functions within the impactor shaft sinking system. These functions include the following: mobilization; breaking of rock; loading of muck; haulage of muck, men and materials; pipeline extension and shaft lining operations; machine maintenance activities; shaft dewatering; shaft wall support; ventilation; communication; and demobilization. The PHAs for each of these functions are presented in the following subsections, in columnar format, as discussed earlier in this report. Checklists of hazardous processes and elements, supplemented by information on shaft sinking accident experience, were used to insure completeness of the analysis.

Mobilization

Mobilization involves the initial preparations that are required to use the impactor machine as a method of excavating shafts. These operations include site preparation, such as assembling the headframe and other surface facilities, as well as initial excavation of the shaft and the construction of the shaft collar. The PHA for mobilization activities is shown in Table C-3. The primary hazards in mobilization appear to be from rope failure and slippery ladders, resulting in worker falls, or falling objects impacting the workers. Injuries from the use of handtools or welding equipment during assembly activities may also be encountered in mobilization.

TABLE C-3. Mobilization

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Initial excavation	Acceleration	Vehicle in motion	Personnel walking in vehicle traffic areas	Personnel in path of vehicle	Personnel struck by vehicle	Injury/death to personnel	Supervision; restricted movement of personnel and vehicles in work area; enforcement of speed limits; warning bells on construction vehicles.
	Kinetic energy	Caving rock from shaft wall	Personnel in shaft beneath open ground	Personnel in path of caving rock	Personnel struck by caving rock	Injury/death to personnel	Inspection of side walls; temporary ground control measures.
		Material/muck handling by crane in shaft	Personnel in shaft	a) Personnel in path of moving load b) Material dropped from load c) Inadequate warning of approaching load d) Personnel inattentive	Personnel struck by moving/falling load	Injury/death to personnel	Restriction of access to shaft; procedures and checkout system to warn of approaching load; supervision of handling operation.
	Potential energy	Personnel require access to shaft	Shaft access by ladder	Loss of balance or slip	Fall from ladder onto working surface below	Injury/death to personnel	Rubber grips on ladder rungs.

TABLE C-3. Mobilization (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Initial excavation (cont)	Potential energy (cont)	Personnel require access to shaft	Shaft access by bucket	a) Rope failure b) Bucket tilts c) Clutch/brakes fail on crane	Bucket/personnel fall onto working surface below	Injury/death to personnel	Inspection and maintenance of ropes; check and clear path of travel before movement; inspection of clutch/brakes.
		Personnel using/carrying tools	Personnel in shaft	Tools dropped on personnel below	Personnel struck by falling tools	Injury/death to personnel	Tools held in carrying case or belt when not in use; restriction of access to shaft; restriction of work overhead when personnel in shaft.
	Explosion	Excavation requiring blasting	Personnel in shaft	a) Premature ignition b) Ignition while personnel still in shaft	Personnel exposed to explosion, flying rock fragments	Injury/death to personnel	Supervision; procedures; personnel accountability before blasting.
Assembly activities (headframe, galloway, impactor, other fabricated steelwork)	High temperature	Welding, soldering or metal cutting		Personnel too close	Personnel burned	Injury to personnel	Supervision, restricted work areas; workers wear protective equipment.

TABLE C-3. Mobilization (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Assembly activities (headframe, galloway, impactor, other fabricated steelwork) (cont)	Kinetic energy	Movement of materials/supplies	Personnel in assembly area	a) Personnel in path of moving load b) Inadequate warning of approaching load c) Personnel inattentive	Personnel struck by moving material/supplies	Injury/death to personnel	Procedures and system checkout to warn of approaching load; supervision.
		Personnel using handtools	Restricted working areas	Pinch points encountered in assembly activities	Overexertion using tools; hands/fingers caught in tools	Injury to personnel	Operating procedures; supervision.
	Environment	Assembly activities	Poor weather conditions	Personnel exposed to wet, muddy surfaces	Personnel slip or fall on same level	Injury to personnel	---
					Personnel fall from height	Injury/death to personnel	Safety belts should be worn when working at heights.
Shaft collar construction	Kinetic energy	Lowering formwork into shaft	Personnel in shaft	a) Rope failure on crane b) Personnel in path of formwork c) Inadequate warning of approaching formwork d) Personnel inattentive	Personnel struck by moving/falling formwork	Injury/death of personnel	Inspection and maintenance of ropes; procedures and system checkout to warn of approaching load; supervision.

TABLE C-3. Mobilization (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Shaft collar construction (cont)	Kinetic energy (cont)	Placing formwork	Personnel on scaffold	Personnel lose balance or slip	Fall from scaffold onto working surface below	Injury/death to personnel	Safety belts should be worn when working at heights.
	Environment	Pouring concrete	Excess concrete	Personnel in area of excess concrete	Personnel slip/fall on same level or onto working surface below	Injury/death to personnel	Good housekeeping/cleanup procedures
		Construction activities	Poor weather conditions	Personnel exposed to wet, slippery surface	Personnel slip/fall on same level or onto working surface below	Injury/death to personnel	---
Set up head-frame and hoists	Kinetic energy	Assembly activities require movement of components	Personnel in assembly area	a) Personnel in path of moving load b) Inadequate warning of approaching load c) Personnel inattentive	Personnel struck by moving load	Injury/death to personnel	Procedure and system checkout to warn of approaching load; supervision.
	Environment	Assembly activities require movement of personnel	Poor weather conditions	Personnel exposed to wet, muddy surface	Personnel slip/fall from height or at working surface	Injury/death to personnel	---

TABLE C-3. Mobilization (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Set up head-frame and hoists (cont)	Potential energy	Headframe assembly	Personnel on head-frame	Personnel lose balance	Fall from headframe	Injury/death to personnel	Safety belts should be worn when working at heights.
		Personnel attaching hoist ropes	Personnel guiding ropes through sheaves	Fingers caught between rope and sheave	Personnel pinch/cut fingers	Injury to personnel	---
Install service lines	(See Table 8 Pipeline Extension Operations)						
Shaft lining	(See Table 9 Shaft Lining Operations)						

Breaking Rock and Loading Muck

The impactor machine breaks rock using a high energy pneumatic hammer mounted on an articulated boom. Muck is loaded into conventional shaft sinking buckets using a mucking shovel, which is also mounted on an articulated boom. The machine and method of excavation are described in detail in earlier sections of this report. Basic subsystems or functions investigated include the following: breaking rock; the impactor machine; the hydraulic system; the lube oil system; the compressed air system; the electrical system; the fire control system; and the interaction of the workers with the machine environment. The PHA for breaking rock and loading muck with the impactor machine is shown in Table C-4. The primary hazards of the machine appear to be from fire, as well as from the vibration and noise generated by the machine. Slippery decks and ladders could result in injuries from falls. There is also some potential for injury from getting caught in moving machinery parts.

TABLE C-4. Breaking Rock and Loading Muck

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
138 Impactor machine	Rock	Fracturing rock	Flying rock fragments	Operators downhole	Operators exposed to flying fragments	Injury; machine damage	Safety glasses should be worn; machinery designed to withstand impact from fragments; operators stationed above actual rock breaking operations in a shielded cab.
			Dust/particulates	Operators downhole	Operators exposed to high dust level & particulates	Lung injury/eye injury. Impaired breathing	Dust suppression system.
	Vibration	Fracturing rock	Operators downhole	a) Structural failure	Operators fall from machine	Injury/death to personnel; major equipment damage.	Machine designed for vibration forces.
				b) Inattentive operators	---	Potential equipment damage.	---
				c) Long-term exposure to vibration	Physical damage to operator's internal organs	Injury to personnel	Vibration intermittent
	Noise	Fracturing rock	Operators downhole	Long-term exposure to noise	Over-exposure to high noise levels	Loss of/impaired hearing	Ear protection; silencer on impact hammer.

TABLE C-4. Breaking Rock and Loading Muck (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Impactor machine (cont)	Corrosion, stress	Fracturing rock	Operators downhole	Structural failure	Operators fall from machine	Injury/death to personnel	Machine designed for severe environment.
Hydraulic system	Hydraulic oil (flammables)	Structural failure of main oil tank	Oil accumulates on operator cab floor or shaft bottom	Operator on machine plus ignition source downhole	Slip or fall on same level	Injury to personnel	Unlikely that oil would travel into cab; tank well-designed.
					Personnel exposed to fire	Burns/smoke inhalation	Emergency exit/fire control system.
		Hydraulic hose failure	Oil accumulates on operator and cab floor	Operator on machine plus ignition source	Slip or fall on same level	Injury to personnel	Hoses designed for stressful environment.
	High pressure	Hydraulic hose failure	Pipe whip	Operators in cabs	Operators exposed to whipping hose	Injury to personnel	Low pressure hoses in cab area; hose restraints
			High pressure jets of fluid	Operators in cabs	Operators struck by high pressure fluid	Potential eye injuries	Low pressure hoses in cab area; safety glasses should be worn.

TABLE C-4. Breaking Rock and Loading Muck (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Hydraulic system (cont)	Hydraulic pumps	Frictional heat due to bearing failure	Presence of flammable material or oil accumulation	Personnel on Impactor	Ignition of flammables; personnel exposed to fire/smoke	Burns/smoke inhalation	Fire control system; hydraulic pumps and equipment are shielded from the operators.
Lube oil system	Frictional heat	Failure of a lube oil pump bearing	Bearings overheat, causing a fire	Personnel on Impactor	Personnel exposed to fire	Burns/smoke inhalation	Fire extinguishers available; pumps shielded from operators; lube oil is difficult to ignite.
		Loose connection at lube oil outlets	Leak of lube oil	Ignition source	Personnel exposed to fire	Burns/smoke inhalation	Lube oil difficult to ignite; fire extinguishers are available.
	Flammables	Leak in lube oil tank or hoses	Leak of lube oil	Ignition source	Personnel exposed to fire	Burns/smoke inhalation	Lube oil difficult to ignite; fire extinguishers are available.
Compressed air system	High pressure	Pipe break	Pipe whip	Operators on machine	Operator hit by pipe	Injury to operator	Compressed air can be quickly shut off.

TABLE C-4. Breaking Rock and Loading Muck (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Electrical system (main power and lighting)	Electrical	Power source failure	Loss of lighting; electrical power	Personnel downhole on galloway	Confusion - slips/falls	Injury to personnel	Headlights on miner's hats.
		Frayed cable	Exposed cable in wet, damp environment	Personnel downhole	Contact with exposed cable	Injury to personnel	Heavy duty insulation is used.
		Severed cable	Exposed electrical source	Personnel downhole	Contact with electrical source	Electrical shock/burns	Condition of the electrical system is periodically inspected.
			Ignition source	Oily rags or combustible material near spark	Fire - personnel exposed	Injury to personnel; equipment damage	Fire control systems.
Fire control system	Fire	Fire extinguishers unusable	Extinguishers covered with mud/grime - cannot be disconnected for use	Personnel downhole; fire may spread	Personnel caught in fire	Burns/smoke inhalation; major equipment damage	Fire suppression system.
			Unfamiliarity with use	Personnel downhole; fire may spread	Personnel caught in fire	Burns/smoke inhalation; major equipment damage	Fire suppression system.
		Fire suppression system unusable	System failure	Personnel downhole; large fire spreads	Personnel caught in fire	Burns/smoke inhalation; major equipment damage	Evacuation procedures.

TABLE C-4. Breaking Rock and Loading Muck (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Workers	Environment	Water inflow; mud	Slippery floors and ladders	a) Personnel climbing ladder	Fall from height	Injury/death to personnel	---
				b) Personnel working in cab or on galloway deck	Slip/fall on same level	Bumps/bruises	---
	Machinery	Normal operation	Personnel downhole	Personnel exposed to moving machine parts	Personnel caught in machine parts	Injury to personnel	Operators in protected cabs; no reason to approach machinery parts except for repair

Haulage of Men, Muck and Materials

The haulage of men and muck in the impactor shaft sinking system is performed by using conventional mucking buckets and a double drum hoist. A front-end loader handles the final disposal of muck. Other materials required for shaft sinking operations are transported downhole either with a crane or by pipeline. Required pipelines for the impactor system include an intake ventilation line, water supply and discharge lines, and a compressed air line. Concrete is transported downhole in a special bucket.

The PHAs for the haulage of men and muck are shown in Tables C-5 and C-6. The primary hazards for these operations appear to be failure of the wire rope or other supporting structures. Unexpected impacts of the bucket with shaft walls or other structures, as well as worker carelessness, are also postulated to result in some worker injuries. The PHA for the haulage of materials is shown in Table C-7. The primary hazards of the pipeline system stem from a structural failure of the pipes themselves. Other potential worker injuries may be incurred by impacts with moving loads being handled by the crane.

TABLE C-5. Haulage of Men

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Bucket	Kinetic energy	Lowering or raising bucket	Personnel waiting for bucket	Personnel near travel path of bucket unaware of vehicle approach	Personnel struck by the bucket	Serious injury	Approach warning lights
	Potential energy	Normal bucket operation	Bucket loaded	a) Path of the bucket obstructed b) Bucket overloaded	Bucket tilts; men fall from bucket Rope fails	Injury/death to personnel Injury/death to personnel	Few perceived obstacles in pathway; bucket must tilt in excess of 60° to spill passengers. Limited cargo space; rope safety factors.
Shaft collar doors	Electrical	Power source failure	Doors fail to open	a) Bucket (loaded) coming up	Collision of bucket with door/rope failure	Personnel injury/death	---
				b) Bucket (loaded) going down	Collision of bucket with door	Bruises to personnel	Top lander is observing operation - can warn hoistman
Wire rope	Structural damage/failure	1. Corrosion	Weakened rope	Loaded bucket	Rope fails; bucket and personnel fall	Injury/death to personnel; equipment damage	Daily inspection/maintenance
		2. Overstressed	Weakened rope	Loaded bucket	Rope fails; bucket and personnel fall	Injury/death to personnel; equipment damage	Factors of safety/load limit
Sheave	Corrosion	Moisture	Rough surface frays or pinches rope	Loaded bucket	Rope fails	Injury/death to personnel	Daily inspection/maintenance. Test run at shift start

TABLE C-5. Haulage of Men (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Hoist/hoistman	Acceleration	Inattention to bucket speed	Necessity to brake a runaway vehicle	Loaded bucket	Bucket is jolted by braking impact	Bruises to personnel	Lilly controller
	Kinetic energy	Inattention of operator	Overshooting bucket limits				
			1. Upper limit	Loaded bucket	Collision w/top of headframe	Rope failure-death/injury to personnel	Lilly controller; depth indicator
			2. Lower limit	Loaded bucket	Collision w/lower level	Bruises to personnel	Depth indicator; communication
			Failure of brakes	Loaded bucket	Collision	Injuries/deaths	Redundant braking system
	Electrical	Loss of power	No control over system	Loaded bucket in operation	Loss of power/control to bucket	Injuries/deaths	---
			No exit	Personnel in shaft	---	Shock/injuries	Emergency exists/emergency generator
	Acceleration - Kinetic/potential energy	Operator error/carelessness	Mismarking depth indicator	Loaded bucket	Collision of bucket with downhole station	Bruises to personnel	---
			Confusion/disregard of signal	Loaded bucket	Hoisting instead of lowering or vice versa	Bruises to personnel	Communications system-signals repeated by both parties
			Hoisting bucket without proper signal	Riders boarding bucket	Riders fall	Injury/death	---
Riders	Falling object	Unsupported wall	Unsupported wall gives way	Loaded bucket	Object strikes rider	Injury/death	Nature of ground support (lining)
Workers	Falling object	Debris	Debris falls	Personnel waiting for bucket	Worker hit by debris	Injury/death	---

TABLE C-6. Haulage of Muck

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Bucket	Potential energy	Normal bucket operation	Personnel downhole	a) Bucket overloaded	Rope failure; bucket and contents fall on equipment or personnel below	Equipment damage; possible injury or death	Capacity of bucket limited by size; rope safety factors; protective gal-loway decks.
				b) Bucket path obstructed	Bucket tilts; contents fall on equipment and personnel below	Equipment damage; possible injury or death	Few perceived obstacles in bucket pathway; protective gal-loway decks.
Wire rope	Structural damage/failure	1. Corrosion	Weakened rope	Bucket loaded and in operation	Rope failure; bucket and contents fall on equipment or personnel below	Equipment damage; possible injury or death	Rope inspection and maintenance; safety factors.
		2. Overstressed	Weakened rope	Bucket loaded and in operation	Rope failure; bucket and contents fall on equipment or personnel below	Equipment damage; possible injury or death	Rope inspection and maintenance; safety factors.
Sheave	Corrosion	Moisture	Rough surface frays or pinches rope	Bucket loaded and in operation	Rope failure; bucket and contents fall on equipment or personnel below	Equipment damage; possible injury or death	Daily inspection and maintenance.
Shaft collar doors	Potential energy	Power source failure	Doors fail to close	a) Falling objects from headframe or bucket unloading	Objects fall onto personnel and equipment below	Injury/death of personnel	Visual observation of top lander; protective gal-loway decks.
				b) Personnel in collar door area	Fall through open doors	Injury/death of personnel	Visual observation of top lander, other workers.

TABLE C-6. Haulage of Muck (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Shaft collar doors (cont)	Potential energy (cont)	Power source failure (cont)	Doors fail to open	Bucket (loaded) coming up	Bucket collides with door; rope failure or bucket tilts	Bucket and/or contents fall on equipment or personnel below	---
Hoist/hoistman	Kinetic energy	Excess speed	Overshoot bucket limits-upper	Bucket loaded	Collision at head-frame. Rope failure or displaced from sheave	Equipment damage; possible injury or death	Lilly controller; safety factors; protective gallo-way decks.
	Acceleration	Excess speed	Necessary to apply brake suddenly	Bucket loaded	Bucket jolted by braking impact. Partial contents fall on equipment or personnel below	Equipment damage; possible injury or death	Lilly controller
Dump chute	Potential energy	Full bucket in dump chute	Bucket fails to dump due to packing or obstruction	Personnel try to facilitate dumping from headframe	Fall from height	Injury or death to personnel	---
				Bucket operator tries to loosen by movement against dump chute	Rope failure; bucket and contents fall on equipment or personnel below	Equipment damage; possible injury or death	Protective gallo-way decks; rope safety factors.
Front-end loader and operator	Potential energy	Bucket dumping in process	Operator below muck chutes	Operator inattentive or fatigued	Falling muck strikes operator	Injury/death of personnel	---
	Kinetic energy	Removal of muck from muck pile	Vehicle accident	Task performance error	Vehicle accident	Injury/death of personnel	---

TABLE C-7. Haulage of Materials

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Intake ventilation line	Corrosion	Humidity	Leak in line	Personnel in shaft	Insufficient fresh air to personnel downhole	Suffocation/fainting personnel	Inspection; hazardous conditions would require a very large hole in pipe.
	Low temperature	Normal winter weather	Cold working conditions	Personnel in shaft	Hypothermia/carelessness	Inability to perform required task	Warm clothing; miners accustomed to wet, cold working conditions.
		Wet environment			Restriction of movement and agility	Increased potential of accidents at other stations	Warm clothing; miners accustomed to wet, cold working conditions.
Water supply and discharge lines	High velocity air flow	Loose connection (at pipe joints)	Leak in line	Personnel in shaft	Insufficient fresh air to personnel downhole	Suffocation/fainting of personnel	Inspection.
	Corrosion	Water supply (humidity)	Pipe leak	Personnel in shaft	Unpleasant, wet working conditions	Slips/falls - personnel injury	Shaft sinking normally conducted in a wet working environment; water is non-corrosive.
	High pressure	Pipe leak	Water jet	Personnel in shaft	Personnel exposed to high pressure water stream	Knocked off balance; slips/falls	Insufficient flow to cause damage; protective operator cabs.
						Hypothermia	Workers wear water-proofed clothing.

TABLE C-7. Haulage of Materials (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Water supply and discharge lines (cont)	High pressure (cont)	Unstable couplings	Pipe whip	Personnel in shaft	Personnel exposed to whipping pipe or hose	Laceration/falls	Insufficient pressure; protective operator cabs; victaulic coupling.
	Particulates	Pipe leak	Loss of water supply downhole	Personnel in shaft operating impact hammer	Personnel exposed to dust/particles	Eye/lung irritation	Operator cabs provide protective area.
	Electrical	Pipe leak	Water contacts electrical equipment	Personnel contacting equipment	Electrical shock to personnel from shorted equipment	Electrical shock/burns	Electrical equipment protected in enclosed housing.
149 Compressed air supply	High pressure	Pipe leak/break	Air jet	Personnel in shaft	Personnel exposed to high pressure air stream	Knocked off balance; eye injury. Injury by blown objects	Insufficient pressure. Protective operator cabs.
			Loss of air supply to machine	---	---	---	---
		Unstable pipe couplings	Pipe whip	Personnel in shaft	Personnel exposed to whipping pipe or hose	Laceration/falls	Insufficient pressure. Couplings screwed into sockets in concrete. Hose stabilized every few feet at machine. Protective operator cabs.

TABLE C-7. Haulage of Materials (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Crane/operator	Acceleration	Inattention to speed during hoisting	Necessity to brake runaway load	Load jolted, possible release	Personnel hit by falling material	Injury/death	Lilly controllers
Crane cable	Structural damage/failure	Corrosion Overstressed Twisted/weakened	Hoisting equipment or material	Personnel underneath moving load	Cable break during transport. Personnel/equipment hit by falling material.	Injury/death	Inspection, oiling, load limits.
	Kinetic energy	Cable lowered or raised	Swinging cable	Personnel near or in path of cable	Cable hits personnel	Injury/death	Load limits, operating procedures
Crane hook	Structural damage/failure	Overstressed	Weakened hook poorly transporting material	Personnel underneath moving load	Load hits personnel/equipment	Injury/death	Load limits, operating procedures.
		Not properly fastened	Crane transporting material	Personnel underneath moving load	Load hits personnel/equipment	Injury/death	Operating procedures; supervision.
Concrete ^(a) bucket	Potential energy	Normal bucket operation	Personnel downhole	Bucket bottom closure is obstructed	Dump door opens; contents fall on personnel or equipment below	Personnel injury or death; equipment damage	Bucket loaded at surface; inspection and assurance of correct operation are made there.
^(a) Other hazards involved with this component and others in concrete haulage (hoists, ropes, sheaves) are detailed in the PHA for haulage of bucket, Table 6.							

Pipeline Extension and Shaft Lining Operations

The basic procedures for pipeline extension and shaft lining operations are identified and analyzed in Tables C-8 and C-9, respectively, and described in more detail in the earlier section of this report entitled "Impactor Shaft Sinking System Description". The service lines for the impactor system are extended once every 20 feet. Pipeline extension operations are followed by the shaft lining cycle. The primary hazards in both operations include potential injuries from lifting heavy or awkward system components and working in a wet, slippery environment.

TABLE C-8. Pipeline Extension Operations

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
151 							

TABLE C-8. Pipeline Extension Operations (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Replace manifold	Potential energy	Lifting weight	Unsupported weight	Poor working environment	Dropping manifold	Injury	Operating procedures.
	Kinetic energy	Tightening bolts/nuts	Poor working environment	Wrench slips	Personnel struck by tool; hand strikes object	Injury	Gloves; procedures.
Hoist (used to position galloway)	Kinetic energy	Normal use of hoist in galloway positioning	Personnel on board galloway	Brake failure	Galloway and impactor fall down the shaft	Personnel injury/death; equipment damage	Inspection and maintenance; redundant systems; galloway bottom deck less than 40 feet above shaft bottom.
Sheave	Corrosion	Moisture	Rough surface frays rope	Personnel on galloway stage	Rope failure	Death or serious injury to personnel; major equipment damage	Periodic inspection of rope.
Rope	Structural failure or damage	Corrosion Overstress Fatigue cracking due to twisting or bending	Rope is weakened.	Personnel on galloway	Rope failure	Death or serious injury to personnel; major equipment damage	Rope factor of safety; periodic inspections.
	Kinetic energy	Power failure during normal use of galloway	Personnel on board galloway	No electric power to the hoist	Hoist cannot support the galloway	Injury or death to personnel	Hoist brakes designed to be "fail-safe" and will apply immediately on power failure.

TABLE C-8. Pipeline Extension Operations (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Hoistman	Acceleration	Operator inattention	Personnel on board the galloway	Overshoot lower limit	Collision with shaft floor; necessity to brake quickly	Injury; equipment damage	Lilly controller.
		Operator error	Personnel on board the galloway	Confusion of signals or did not hear signals	Collision with shaft floor; necessity to brake quickly	Injury; equipment damage	Lilly controller.
Riders	Falling objects	Unsupported wall	Unsupported wall gives way	Personnel on stage	Objects strike riders	Injury/death	Protective decks Lining/competent ground

TABLE C-9. Shaft Lining Operations

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
155 Attach hanging rods	Potential energy	Hoisting/lowering	Loose attachment to bracket on lowering device	Personnel on stage	Rods drop on worker	Injury (death if from a large height)	Galloway protective decks; hard hats.
			Weakened rope	Personnel on stage	Rods drop on worker	Injury (death if from a large height)	Inspection of rope; galloway protective decks; hard hats.
			Unstable unit	Workers reach to stabilize rods on landing	Hand or arm gets pinched between rods	Injury/loss of hand/arm	---
	Environment	Poor illumination	Working from height in poor environment	Worker attaching rod by hand	Worker drops rod	Injury/death to workers below (if any)	Protective decks.
		Moisture			Worker pinches hand/fingers in attaching rod	Bruise/cuts to hands/fingers; potential loss of member	Gloves.
		Low temperatures					
Lower and align curb ring	Potential energy	Hoisting/lowering	Unstable balance in sling	Workers reach to stabilize unit	Hand or arm gets pinched between stage and ring	Injury/loss of hand or arm	Gloves.
Breaking off forms (lowering same as above)	Potential energy	Workers tugging at forms	Strong adhesion of forms to lining	Rope failure	Personnel fall	Injury to personnel	Oiling of forms.
Assembly of forms	Kinetic energy	Workers assembling forms	Handling of bulky, sharp-edged object	Workers use hands to lift and position forms	Hands cut or crushed by forms	Cuts/injury to personnel	Gloves.

TABLE C-9. Shaft Lining Operations (cont)

156

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Pour forms	Chemicals (accelerator)	Workers pouring concrete	Potential for contact with concrete	a) Hoppers overflow	Concrete contacts worker	Chemical burns	Communications; regulated flow rate; protective decks.
				b) Slicklines or elephant trunks fail	Concrete contacts worker	Chemical burns	Communications; regulated flow rate; protective decks.
				c) Flexible hoses pop from behind forms	Concrete contacts worker	Chemical burns	2-3 men per hose.
	Environment	Workers pouring concrete	Excess concrete on decks; traffic	Workers on deck with accumulated waste	Workers slip/fall	Injury to personnel	Excess spills cleaned up.
	Structural failure	Insufficiently cured base	Premature pour of top ten feet	Workers on/near concrete pour area	Failure of lining--waste concrete impacts men	Chemical burns; injury from flying fragments	Operations should be timed and supervised; protection of overhead decks, cabs
	Cleanup	Environment	Moisture; waste concrete	Slippery decks	Workers on deck	Worker slips/falls	Injury to personnel
Cold; moisture				Workers present	Workers get exposed to low temperature too long	Hypothermia	Protective clothing.
Concrete bucket	Concrete	Spilling of concrete	Slippery working conditions	Lining operations in process	Slip/fall of personnel	Injury to personnel	Cleanup of decks after spills.
	Chemical accelerators	Spilling of concrete	Workers exposed to hazardous chemical	Lining operations in process	Personnel contact with chemical	Chemical burns	Cleanup of decks after spills; protective clothing.

Machine Maintenance

Machine maintenance activities primarily include inspection and adjustment of impactor machine parts, as well as general inspection duties on the shaft sinking support equipment. The PHA for maintenance of the impactor is shown in Table C-10. The major hazards include cuts and lacerations while positioning parts or using tools, worker falls, potential electric shock, and possible bodily strain or injury from working in restricted access areas.

TABLE C-10. Machine Maintenance

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Booms	Height	Boom maintenance (lubrication, inspection, etc.)	Miner at some height above the shaft floor	Loss of balance	Fall to shaft floor	Injury to worker	Most major maintenance is done at the surface.
Hydraulic hoses and fittings	High pressure fluid	Maintenance or inspection of components	Personnel exposed to high pressure lines	Hose or fitting rupture	Pipe whip or injury from high pressure jets of fluid	Injury to personnel	Experienced workmen; hose rupture unlikely; hoses secured.
Air lines or fittings	High pressure air	Maintenance or inspection of components	Personnel exposed to high pressure air lines	Hose or fitting rupture	Pipe whip or injury from high pressure air jets or objects set in motion by air jets	Injury to personnel	Experienced workmen; hose rupture unlikely; hoses secured.
Electrical system	Electricity	Maintenance, inspection of electrical equipment	Live electrical circuits exposed to the miner	a) Inadvertent activation	Electrical shock/burn	Injury/death of personnel	Experienced workmen; lockout procedures.
				b) Insulation less than adequate	Electrical shock/burn	Injury/death of personnel	Experienced workmen; lockout procedures.
Headframe	Height	Maintenance of the sheaves, dump chute, or any other item located on headframe	Miner at some height above ground	a) Loss of balance	Fall to ground	Injury/death of personnel	Safety belt can be worn.
				b) Structural failure of some supporting component	Fall to ground	Injury/death of personnel	Safety belts, headframe structure is built with significant factors of safety.

TABLE C-10. Machine Maintenance (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
General	Moving machine parts	Normal maintenance	Miner's hand placed at pinch point	Inadvertant activation or activation without noticing hand in dangerous area	Fingers, hand caught in machine parts	Serious injury possible	Proper procedures and attention should prevent this accident
	Environment	Normal maintenance	Working in poor, wet environment	Personnel in awkward or tight spaces	Strike hand/head, other part of body during maintenance, strain on muscle/body	Minor injury	---
				Tools slip during use	Strikes self or fellow miner with tool or strikes hand due to bodily motion	Possible serious injury	---
	Potential energy	Normal maintenance	Personnel working with tools; other personnel below	Poor working environment	Tools fall on personnel below	Injury/death of personnel	Protective decks, cabs.
				Carelessness	Tools fall on personnel below	Injury/death of personnel	Protective decks, cabs.
			Personnel working at height	Worker trips or loses balance	Worker falls	Injury/death of worker	---
		Handling materials during maintenance	Lifting or positioning of a heavy part	Incorrect lifting procedure	Undue stress or strain to muscles/body	Possible serious injury	Personnel training; use of slings, tuggers or hoists.
				Miner drops equipment or part	Part or equipment strikes fellow miner or self	Possible serious injury	Personnel training; use of slings, tuggers or hoists.
	High temperature	Welding, soldering		Worker contacts heat source	Worker burned	Injury	Supervision, protective clothing and equipment

Support Activities

Support activities in the impactor shaft sinking system include shaft dewatering, shaft wall support, ventilation and communication. The PHA for the shaft dewatering system is shown in Table C-11. The primary hazard for this function is in handling the dewatering pump and the potential for rising water levels (in the event of system failure) that may wet electrical motors and create a potential for electric shock. The PHA for the shaft wall support system is shown in Table C-12. The primary hazards in shaft wall support are danger from falling objects or unsupported shaft wall. The PHAs for the ventilation and communication systems are shown in Tables 13 and 14, respectively. The primary hazards with these systems appear to result from functional failures of the systems.

TABLE C-11. Shaft Dewatering System

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Air operated pump	Potential energy	Lowering pump down shaft	Worker beneath pump	Pump is somehow dropped (sling fails, operator error, etc.)	Worker struck by the pump	Injury/death	Protective decking.
	Water	Pump fails to operate	Workers in shaft	Power outage; air line failure; basic pump failure	Water level rises; potential for drowning, electrical shock	Injury/death	Water rises slowly. Emergency generators, extra pumps are available; evacuation can be performed should situation become critical.

TABLE C-12. Shaft Wall Support

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Shaft wall - Initial excavation and collar construction (1st 60 feet) - Normal operation - Completing shaft stations	Falling objects (potential energy)	Vibration	Loose, unsupported shaft wall	Personnel lining downhole	Personnel struck by shaft wall piece	Injury/fatality	Steel framework provides some protection; barring.
		Structural failure		Personnel breaking rock downhole			
	Falling objects (potential energy)	Vibration	Unsupported shaft wall	Personnel downhole	Personnel struck by shaft wall piece	Injury/fatality	Concrete lining done every 20 feet; protective decks and cabs.
		Structural failure					
	Falling objects (potential energy)	Vibration	Unsupported shaft wall and roof	Personnel downhole	Personnel struck by shaft wall piece	Injury/fatality	Shaft is completely lined; roof bolts; gunite; barring.
		Structural failure					
	Explosives	Construction of shaft stations using drill and blast.	Personnel handling explosives	Improper or unsafe handling of explosives	Explosion	Death; equipment damage	Operating procedures; supervision.
	Drill bit	Construction of shaft stations using drill and blast	Personnel handling drill bit	Improper or unsafe handling of bit	Miner below struck by bit	Injury to personnel	Operating procedures; supervision.
	Rock fragments	Construction of shaft station	Flying rock fragments	Personnel downhole	Worker struck by flying fragments of rock	Injury to personnel	Protective clothing, eye protection.

TABLE C-13. Ventilation System

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Intake ventilation fan	Contamination	Contaminating substance near fan	Contaminated air funneled into shaft	Presence of personnel in the shaft	Personnel exposed to contaminated air	Suffocation of personnel	Evacuation of shaft; few contaminants stored near intake port.
	Electrical	Power source failure	Lack of air downhole	Personnel downhole	Lack of oxygen downhole	Suffocation of personnel	Emergency generators.
	Structural damage or failure	Power source failure	Failure of fan -- lack of air downhole	Personnel downhole	Lack of oxygen downhole	Suffocation of personnel	Explosion-proof box.
	Noise	Operation of fan	Excessive noise	Personnel exposed on surface	Personnel exposed to noise	Ear/hearing injury	Ability to get away -- not a normal work station.
	Weather	Exposure of fan	Failure of fan -- lack of air downhole	Personnel downhole	Lack of oxygen downhole	Suffocation	Explosion-proof housing.
Duct to shaft	Structural damage or failure	Mechanical impact	Pipe break	Personnel downhole	Lack of air downhole	Suffocation	Pipe runs underground to shaft.
		Severe weather			Exposed to bad air	Lung damage	Pipe runs underground.
Intake duct	Structural damage or failure	Joint failure; pipe break or leak	Loss of excessive amounts of ventilation air through leak	Personnel downhole	Insufficient oxygen downhole	Suffocation/fainting	Inspection of duct; sturdy construction; loss of airflow would be quickly noticed by workers.

TABLE C-14. Communication

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Bell wire for signal system	Structural damage or failure	Mechanical impact	Break in line	Personnel downhole	Loss of escape route; possible error by hoistman	Potential injury, although unlikely	Backup telephone communications system.
	Corrosion	Moisture	Break in line	Personnel downhole	Loss of escape route; possible error by hoistman	Potential injury, although unlikely	Backup telephone communications system.
Bell code	Kinetic/potential energy	Operation of bucket or man-moving elements	Confusion of signals	Loaded mancage or conveyance	Hoistman lowers/raises when he is supposed to do the opposite	Potential for bumps, bruises, or a fall while loading/unloading	Signal code posted in hoisthouse.
					Rider gives inappropriate signal	Potential for bumps, bruises, or a fall while loading/unloading	Signal code posted in cage and in hoisthouse.

Demobilization

Demobilization efforts primarily consist of dismantling the impactor machine, as well as the shaft sinking support equipment such as the galloway, headframe and hoists, and other site completion activities. The PHA for demobilization is shown in Table C-15. The primary hazards in these operations involve the potential of injury from falling or moving objects, the danger of falling from heights, and the possibility of electrical shock or other injuries while disconnecting shaft sinking equipment.

TABLE C-15. Demobilization

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Galloway, Impactor assembly	Kinetic energy	Improper lifting of machine component	Shifting mass	Personnel in path of shifting mass	Personnel struck or crushed by mass	Injury/death of personnel	Supervision; well-established procedures.
	Potential energy	Dismantlement of impactor/galloway	Rope failure	Personnel in path of falling load	Load and/or rope falls on equipment or personnel below	Injury/death of personnel	Daily inspection/coiling of ropes.
	Electrical	Inadvertent activation	Electrical cable exposed	Personnel in contact with cable	Electrical shock, burn	Injury/death of personnel; fire	Protective sheath; electrical supervision during dismantlement.
		Insulation less than adequate	Electrical cable exposed	Personnel in contact with cable	Electrical shock, burn	Injury/death of personnel; fire	Protective sheath; inspection and supervision during dismantlement.
Workers	Kinetic energy	Dismantlement of impactor/galloway	Personnel in path of load movement	a) Inadequate warning of approaching load	Personnel struck by moving load	Injury/death of personnel	Inspect warning system and monitor for adequacy.
				b) Warning of approaching load disregarded	Personnel struck by moving load	Injury/death of personnel	Instruct personnel concerning associated hazard.
				c) Unable to hear warning of approaching load	Personnel struck by moving load	Injury/death of personnel	Inspect warning system and monitor for adequacy; restrict personnel from haulage path.

TABLE C-15. Demobilization (cont)

COMPONENT	HAZARDOUS ELEMENT	EVENT CAUSING HAZARDOUS CONDITION	POTENTIAL HAZARDOUS CONDITION	EVENT CAUSING POTENTIAL ACCIDENT	POTENTIAL ACCIDENT	EFFECT	PREVENTIVE/CONTROL MEASURES
Wire rope	Structural damage/failure	Removal of the impactor/galloway from the shaft	Corrosion	Weakened rope	Rope failure	Injury/death of personnel	Inspection/oiling of rope.
			Overstressed	Rope overstressed	Rope failure; load falls on equipment or personnel below	Injury/death of personnel	Load limits for component removal; rope safety factors.
			Twisted/weakened	Weakened rope	Rope failure; load falls on equipment or personnel below	Injury/death of personnel	Inspection and maintenance of rope; rope safety factors.
Headframe	Potential energy	Headframe dismantlement	Personnel working on headframe	a) Loss of balance	Personnel falls from headframe	Injury/death of personnel	---
				b) Personnel struck by moving or falling component	Personnel falls from headframe	Injury/death of personnel	Supervision.
			Headframe component falls	Components dismantled out of sequence	Headframe component falls on personnel below	Injury/death of personnel	Restriction of personnel below working area; supervision; dismantlement procedures.

APPENDIX D COMPARATIVE SAFETY ANALYSIS OF THE IMPACTOR SYSTEM

There are basically two kinds of safety analysis methods currently available: historical and predictive. Historical methods are based on the analysis of available accident statistics and data on a system with historical operating experience. Safety evaluation based on actuarial data is made by comparing the worker fatality and injury rate based on actual job history to some industry average or to the accident history at another site. Where sufficient actuarial data is available, historical safety analysis methods may be most reliable. For conventional shaft sinking systems, this information has been collected. However, there is no equivalent actuarial data base for the application of impactor shaft sinking technology.

Predictive safety analysis methods are used to estimate worker safety levels when a reliable actuarial data base does not exist, as with the impactor shaft sinking system. Predictive safety analysis uses information available on shaft sinking and similar technologies to estimate risk levels. Risk has two components. It incorporates both the frequency of accidents and the potential consequence of accidents. In this report, the consequence measured is injury or fatality of workers. A Preliminary Hazards Analysis (PHA) was used to determine the major hazards that could potentially be encountered using the impactor. The PHA technique is a qualitative assessment of the potential hazards of a system. It is used to identify the major potentially hazardous conditions of a system that could result in consequences of interest.

The lack of historical operating experience for the impactor system suggested that any comparison between the impactor and conventional shaft sinking technology would have to be made using a combination of historical and predictive safety analysis methods. The methodology that is described in this report was developed to allow a safety comparison to be made between a system with historical operating experience and a developing system technology with little or no actuarial data base.

Methodology

The comparative safety analysis methodology basically consists of the following four steps:

- A detailed description of each system or technology under consideration, including the basic operations required, the equipment used, the time required for each task, and the crew sizes required.
- The identification of system hazards by function, or subsystem, for each technology being analyzed.
- A comparison of system hazards by function for the two technologies, using one system (generally the commercialized system, which has accident statistics available) as a baseline.
- An overall safety judgment of the technology in question (generally the new, developing system) relative to the chosen baseline.

These four components, shown graphically in Figure D-1, are described in more detail below.

System Description

A comparison of the safety of two technologies requires information on respective system characteristics. An outline of the tasks involved with each system is necessary to facilitate a comparison of the two systems. Information that should be outlined in this step includes system tasks or basic operations; the equipment required to complete each task; the number of workers involved with each task; and the amount of time required for task completion.

System Hazards Identification

A safety comparison of two technologies also requires the development of information on the hazards present in each system. These hazards must be identified for both the conventional technique and the developing technology.

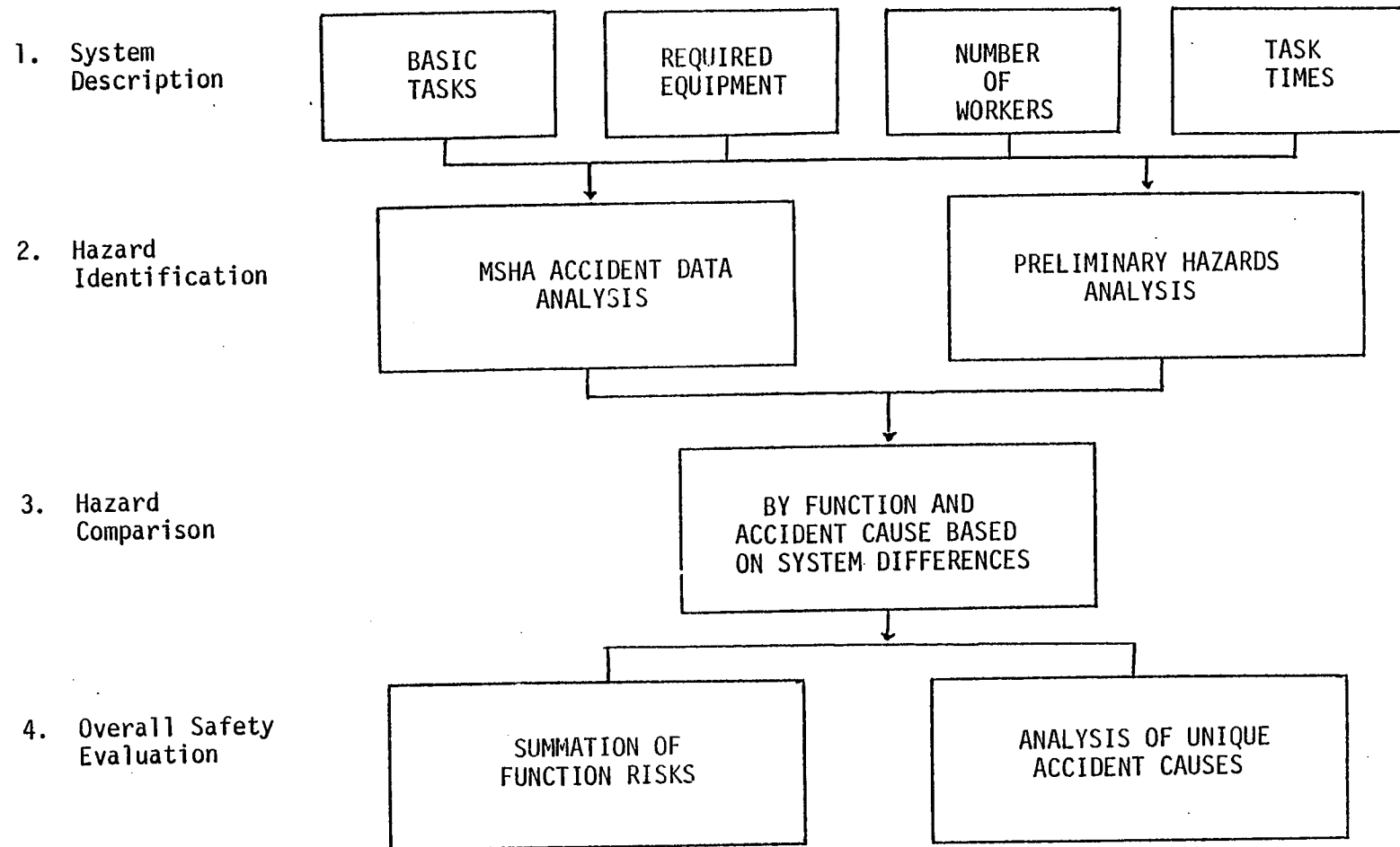


FIGURE D-1. Comparative Safety Analysis Methodology

For conventional shaft sinking systems, accident statistics are recorded at the Mine Safety and Health Administration's (MSHA) Safety Analysis center in Denver, Colorado. This data was analyzed to identify the historically important causes of worker injury and fatality, as well as to create a data base against which to measure the potential performance of the impactor. Accident data were obtained from an analysis of MSHA accident record tapes. These statistics were compiled from accident reports filed by mine operators. The latest available information was obtained for metal/nonmetal mine shaft sinking accidents. This includes the years 1978 through August 1980. This data was used as a baseline for the comparative analysis.

The accident data for conventional shaft sinking were sorted by the phase of shaft sinking operations in which they occurred (i.e., mobilization, haulage of men, loading muck, etc.). This delineation was necessary to allow a comparison of the impactor and conventional shaft sinking operations on a function by function basis. The potential hazards for the impactor shaft sinking system were identified by a Preliminary Hazards Analysis (PHA). To perform a PHA, the system under consideration is divided into convenient working segments, typically subsystems or functions of the overall system. Each subsystem is then investigated individually to identify the hazardous elements of that subsystem and the potential effect on workers. To allow the results of the PHA to be easily compared with historical shaft sinking hazards, the potential hazards for the impactor were categorized by principal MSHA accident cause classification. The results of the PHA for the impactor shaft sinking system and further details on PHA methodology are contained in Appendix C of this report.

At the conclusion of this step in the analysis, information on system characteristics and hazards has been determined for each system. The information is presented in terms of required system tasks and generic accident causes to facilitate comparisons between the two systems.

Hazard Comparison

A comparison of system safety is performed in this application by evaluating the developing technology (the impactor) relative to commercial

systems with historical operating experience. The comparative analysis focuses on the potential for worker injuries and fatalities. The differences between the systems are judged based on the system description information developed in the first step of this analysis.

To compare the impactor and conventional shaft sinking systems, asset and liability tables are constructed for each major system function. A separate table was developed for each major accident cause classification within a particular set of system tasks. The tables outline the assets and liabilities of the impactor for specific accident causes relative to the conventional system hazards. Conventional accident data is used as the baseline for comparison. Injuries and fatalities for conventional shaft sinking are catalogued according to MSHA principal cause classifications, listed in Table D-1. The cause classifications were developed by MSHA to allow a standard for classifying injuries into accident categories that could be used in the comparison and determination of trends. Within each major cause category, accidents were analyzed to determine secondary causes. The specific assets and liabilities directly address an identified secondary cause of accidents for conventional shaft sinking within a primary accident cause category. The importance of the secondary causes to the overall safety of the system is identified by assigning a risk factor to each accident cause. Risk factors (R_i) incorporate measures of both consequence and frequency, as shown in Equation 1.

$$R_i = \sum_{i=1}^n c_i f_i \quad (1)$$

where

R_i = risk factor for a primary accident cause category

c_i = consequences, in terms of average days lost

f_i = frequency, in terms of number of accidents.

The consequence measure of risk assigned (c_i) was based on MSHA accident categories. Accidents were grouped by consequence into those resulting in no or minor injuries; major injuries; permanent disability injuries; or fatalities. The values assigned to these categories were based

TABLE D-1. Principal MSHA Cause Classifications

Falls of Roof
Falls of Face, Rib, or Overburden
Pressure Bumps or Bursts
Inrush of Water or Material
Sliding or Falling Material or Objects
Slips or Falls of Persons
Handling Materials
Handtools
Stepping or Kneeling on Sharp or Loose Objects
Striking or Bumping Against Objects
Haulage
Explosions of Gas or Dust
Explosives and Breaking Agents
Electricity
Machinery
Suffocation
Fires and Suffocation from Fires
Occupational Pneumoconiosis
Miscellaneous

on the average days lost recorded for each injury type. The values used to derive figures for minor and major injuries were obtained from historical data. However, there was less data available on permanent disability injuries and fatalities. These figures were thus based on industry standards for recording and measuring work injuries.

A survey of six years of metal/nonmetal shaft sinking accident data showed an average days lost value of 6.0 for minor or disabling injuries such as cuts and bruises, and an average days lost value of 14.4 for more serious injuries such as fractures (Dames and Moore, 1977 and HSAC accident data, 1978-August 1980). The days lost value for permanent disabilities was obtained as mentioned above, by averaging the standard days lost injury rates established by MSHA for the loss of particular body parts. These rates are

listed in each injury report bulletin issued by MSHA. The days lost value for fatalities used in this report was also obtained from values established by MSHA. To facilitate working with the days lost injury values, these numbers were normalized to a scale of 0 to 100, where 0.10 is associated with a minor injury, 0.24 represents major injury classifications, 15.67 reflects a permanent disability type injury and 100.0 represents a fatality. These results are portrayed in Table D-2.

TABLE D-2. Injury Severities for Metal/Nonmetal Shaft Sinking Accidents

	<u>Average Days Lost</u>	<u>Severity (days lost) on a Scale of 0-100</u>
1. Minor or nondisabling injuries (cuts, bruises)	6.0(a)	0.10
2. Major injuries (fractures)	14.4(a)	0.24
3. Permanent Disability	940(b)	15.67
4. Fatality	6000(c)	100.0

(a) Average value for 3 years of metal/nonmetal shaft sinking data from Dames and Moore report and three additional years (1978-1980) of MSHA metal/nonmetal shaft sinking accident data.

(b) Average value of MSHA standard rates for permanent disabilities.

(c) MSHA standard days lost value recorded for a fatality.

The frequency measure of risk (f_i) was taken to be the absolute number of accidents of a particular type encountered in the three year (1978-1980) data set. The product of the number of accidents for each secondary accident cause and the normalized days lost consequence value results in a measure of risk for each secondary cause.

The first step in constructing an asset/liability table is to list or reference each secondary accident cause within a primary accident category for a particular system task or function. An analysis of the impactor system is then performed to judge whether characteristics of the system will increase or decrease the potential of that accident sequence occurring. If the impactor

system reduces the accident potential, the specific system characteristic involved is listed as an asset for the system relative to conventional shaft sinking. If the impactor potentially increases the possibility of that accident sequence, the contributing characteristics are listed as liabilities. These assets and liabilities are then assigned numerical values to result in a quantitative safety assessment of the impactor, relative to conventional shaft sinking.

The first step in numerically weighing the assets and liabilities developed in the tables is to rank each asset or liability according to the importance of the accident cause that it addresses. For example, if exposed roof area is a primary cause of roof fall injuries, all assets or liabilities of the impactor in that category should be given a higher ranking than those that address lesser accident causes. These ranking factors (R_i) were based on the relative risk numbers discussed earlier. Use of the relative risk level, considering both the frequency and severity of injuries, allows a more complete representation of the potential effects on conventional accident experience of using the impactor.

Secondly, each asset or liability is assigned a weighting factor which is derived from the postulated differences in exposure to hazards between the impactor and conventional shaft sinking systems. Increases or decreases in hazard exposure may be achieved by varying any of the following three factors: the number of people exposed to a hazard; the duration of the exposure; or the number of hazards present in the working environment. Elements of the impactor system that result in reduced exposure levels, such as smaller crew sizes or shorter time requirements downhole, are assigned as assets for the system. There may be more than one factor for a particular accident sequence that contributes to a reduced exposure level. In these cases, each factor is assigned a number based on the expected exposure reduction to be achieved by that factor. The total weight of assets for the impactor system for the i th accident sequence (W_{Ai}) then, is the product of those weighting factors. Similarly, the liabilities for the impactor system are characteristics of the system that result in increased exposure to hazards. The weighted liability value for the impactor (W_{Li}) is based on the product of all the liability factors relevant for the i th accident sequence.

These weighting factors often cannot be assigned as a single value. A representative range may be used in some cases rather than a single value. The total value for the weighted assets (W_{Ai}) or liabilities (W_{Li}) is still obtained by taking the product of all assets or liabilities for the i th accident sequence. The resultant total weight is also a range. This range is obtained by multiplying the lower limit of the range with all other asset or liability values for the i th sequence to obtain the lower weighted exposure value (W_{Ai} or W_{Li}). Then the upper limit of the range is again multiplied by all values to obtain the upper value of W_{Ai} or W_{Li} . An example of the asset/liability table format with assigned weighting factors is shown in Table D-3. The example is from the safety judgment of haulage of men operations. The full details of that analysis are presented later in this report.

Basically, the tables represent all accidents for the function of interest. Primary accident cause categories are identified in the first column. Secondary causes are detailed in a separately attached table, and are referenced by the ordered numbers (i) in the "Assets" column. The importance of the secondary causes is identified by a risk factor, R_i . Specific assets are then detailed for the impactor that reduce the exposure contributing to a specific accident type. These assets may include shielding of the workers, elimination of the hazard by the impactor system design, or lower exposure to hazards by smaller crew size requirements. The amount of risk reduction achieved by each of these factors (W_{Ai}) is presented in the next column. Liabilities for the impactor system, items that could increase conventional risks, are similarly identified and weighed.

For the purposes of this study, it is assumed that an increase or decrease in exposure to hazards is directly correlated to changes in potential accident or injury experience. Thus, increased exposure in the impactor system to a particular hazard may result in increased system risk for the impactor for accidents in which that hazard is a contributing factor.

The calculations performed to obtain the relative risk value for the impactor (R_I) are as shown in Table D-3 and Equation 2.

TABLE D-3. Example Format and Calculations for Weighted Asset/Liability Tables

Primary Accident Cause	R_i	Assets	W_{Ai}	Liabilities	W_{Li}	R_I
Haulage	0.94	1. Less men downhole Less time downhole	0.75-0.83 0.76	None	1.0	1.11-1.22
	0.10	2. Less men downhole Less time downhole	0.75-0.83 0.76	None	1.0	0.06
	100.72	3. Fewer requirements to transport drill with men	0.13	None	1.0	13.09
	117.17	4. Less men downhole Less time downhole	0.75-0.83 0.76	None	1.0	66.79-73.82
	0.48	5. Less men downhole Less time downhole	0.75-0.83 0.76	None	1.0	0.27-0.30
	0.82	6. Less men downhole Less time downhole	0.75-0.83 0.76	None	1.0	0.47-0.52
	<u>15.67</u> 236.90	7. Less time downhole	0.76	None	1.0	<u>11.91</u> 93.70-100.92

$$R_I = \sum_{i=1}^n R_i (W_{Ai})(W_{Li})$$

$$R_{I_1} = R_1 (W_{A1})(W_{L1}) = (1.94) [(0.75-0.83)(0.76)] (1.0) \\ = 1.11 - 1.22$$

$$R_{I_2} = R_2 (W_{A2})(W_{L2}) = (0.10) [(0.75-0.83)(0.76)] (1.0) \\ = 0.06$$

$$R_{I_3} = R_3 (W_{A3})(W_{L3}) = (100.72)(0.13)(1.0) \\ = 13.09$$

$$R_{I_4} = R_4 (W_{A4})(W_{L4}) = (117.17) [(0.75-0.83)(0.76)] (1.0) \\ = 66.79-73.82$$

$$R_{I_5} = R_5 (W_{A5})(W_{L5}) = (0.48) [(0.75-0.83)(0.76)] (1.0) \\ = 0.27-0.30$$

$$R_{I_6} = R_6 (W_{A6})(W_{L6}) = (0.82) [(0.75-0.83)(0.76)] (1.0) \\ = 0.47-0.52$$

$$R_{I_7} = R_7 (W_{A7})(W_{L7}) = (15.67)(0.76)(1.0) \\ = 11.91$$

For haulage,

$$R_I = \sum_{i=1}^n R_i (W_{Ai})(W_{Li}) = 93.70-100.92$$

$$R_I = \sum_{i=1}^n R_i (W_{Ai})(W_{Li}) \quad (2)$$

where

R_I = relative risk factor for impactor shaft sinking system

R_i = risk factor for conventional system for a primary accident cause category

W_{Ai} = weighted value of assets for impactor system (reducing conventional system risk)

W_{Li} = weighted value of liabilities for impactor system (increasing conventional system risk)

This value (R_I) is the risk of using the impactor relative to the baseline of the conventional system risk, as determined from accident data. The value may be in the form of a range of risk values. Comparative risk values for each system function are then derived by summing values from each accident cause classification. Range values are summed by using first all the lowest values for the summation to obtain a lower limit and then obtaining an upper limit of relative risk for the function using the upper limits of each range. This results in a range value as a result for that function. The total system relative risk level is obtained by summing the function values. The final output is a range of risk values which will give an indication of the relative reduction or increase in injury level that can be expected using the impactor machine as compared to conventional techniques.

The outcome of this step of the analysis is a determination of the comparative safety of the impactor relative to conventional shaft sinking systems for comparable tasks. This information comprises the bulk of the analysis and identifies on a detailed level the effects of system differences in terms of safety.

Overall Safety Evaluation

The final steps of the analysis involve summing the estimated relative risks for the impactor system for each function and each accident cause

classification within a function to obtain a comparative risk value for the impactor. This resulting figure or range of values gives a general indication of the relative reduction or increase in injury level that may be expected using the impactor shaft sinking system as compared to conventional techniques.

ASSET/LIABILITY TABLES

This section presents a safety judgment for the impactor system functions relative to conventional shaft sinking functions. For each principal accident cause classification within a function, safety-related differences in the two shaft sinking technologies are identified in an asset/liability table. An integral portion of this comparative process is the comparison of related functions of the two alternative shaft sinking technologies. Factors such as the number of personnel involved, their exposure time, and use of redundant systems are considered in the comparative analysis.

Following the completion of the tables, the assets and liabilities are subjectively weighted and a safety judgment is made for each function in the shaft sinking system. These function safety judgments are combined into an overall safety judgment of the impactor system relative to conventional shaft sinking technology. This safety judgment will allow a determination of whether the impactor is as safe as or safer than conventional shaft sinking. An asset/liability table and safety judgment are presented in this section for each of the following functions:

- Mobilization
- Breaking Rock
- Loading Muck
- Haulage of Men, Materials, and Muck
- Pipeline Extension
- Shaft Lining
- Maintenance
- Shaft Wall Support
- Shaft Dewatering
- Ventilation
- Communication
- Demobilization
- Shaft Station Completion

Mobilization

Mobilization operations for a shaft sinking project include all the initial preparations that are required before full-scale sinking can begin. These efforts include site preparation and setup, initial excavation of the shaft, construction of the shaft collar, and assembly and installation of the shaft sinking and support system equipment.

The accidents experienced in conventional shaft sinking during the mobilization phase of operations are listed in Table D-4. The major source of injuries is encountered during material handling. The potential for being struck by a dropped piece of structural steel or other structural components is very high. Accidents resulting from slips or falls also account for many of the injuries during the mobilization phase of shaft sinking. The operations during mobilization are basically the same for both the impactor and conventional shaft sinking systems. The time and manpower requirements, as well as the amount and kinds of equipment to be handled are similar. Since mobilization operations are alike for both systems, there is no reason to believe that the systems have a difference in safety features. Thus, although the impactor system is not necessarily safer than conventional mobilization operations, the system should be at least as safe. The relative risk of mobilization accidents for the impactor system is anticipated to be the same as that for conventional mobilization operations.

Breaking Rock

In conventional shaft sinking, excavation is accomplished by drilling and blasting. Breaking rock was found to be the most hazardous operation in conventional shaft sinking systems. Accidents occurring during conventional excavation were mostly a result of operating machinery, primarily the drills, and handling supplies or equipment. The specific causes of these accidents are outlined in Table D-5. In the impactor system, rock is broken using a high energy pneumatic hammer mounted on an articulated boom similar to a backhoe boom. The relative assets and liabilities of the impactor system,

TABLE D-4. Mobilization Accident Causes in Conventional Shaft Sinking Systems (from 1978-1980 data)

Primary Cause	Secondary Causes	Number of Injuries (f_i)	Injury Severity (c_i)	Risk (R_i)
Handling Materials	1. Struck by falling rock when setting up scaffold	1	0.10	0.10
	2. Struck by falling steel/wood when handling	2 2	0.10 0.24	0.68
	3. Overexertion moving equipment/supplies	1 2	0.10 0.24	0.58
	4. Struck by falling plumb bob	1	0.24	0.24
Slips/Falls of Persons	1. Slip/fall from ladder	1 4	0.10 0.24	1.06
	2. Slip/fall onto collar when installing collar doors	1	0.24	0.24
	3. Slip/fall against deck when removing collar forms	1	0.10	0.10
Sliding/Falling Objects	1. Struck by falling equipment or supplies	1 1	0.10 0.24	0.34
Haulage	1. Fall with work deck; crane hoist/cables failed	1	0.10	0.10
Machinery	1. Struck by bit using powered spader	1	0.24	0.24
	2. Overexertion using spader	1	0.24	0.24
Miscellaneous	1. Men trapped - electrical malfunction of crane hoist	1	0.10	0.10
				<u>4.02</u>

TABLE D-5. Breaking Rock Accident Causes in Conventional Shaft Sinking Systems (from 1978-1980 data)

Primary Cause	Secondary Causes	Number of Injuries (f_i)	Injury Severity (c_i)	(R_i)
Machinery	1. Caught between drill and rib while drilling	1 1	0.10 0.24	0.34
	2. Caught between drill and drill steel while drilling	1 1	0.10 15.67	15.77
	3. Struck by drill or broken piece of machinery while drilling	6 5	0.10 0.24	1.80
	4. Struck by flying/falling rock while drilling	7 1	0.10 0.24	0.94
	5. Struck by flying rock or particles while blowing out drill holes	1 2	0.10 0.24	0.58
	6. Overexertion while drilling	3 3	0.10 0.24	1.02
	7. Fall while drilling	1	0.24	0.24
	8. Struck against side when using blowpipe	1	0.10	0.10
Handling Materials	1. Overexertion lifting drill/hose/explosives	2 12	0.10 0.24	3.08
	2. Struck by drill/steel when picking up drill/changing steel	3 1	0.10 0.24	0.54
	3. Struck by falling object when working with drill at bottom	2	0.10	0.20
	4. Struck against object when handling drill	1	0.24	0.24
Fall of Face/Wall	1. Struck by falling rock while cleaning/loading drill holes	2 3	0.10 0.24	0.92
Handtools	1. Struck by tool when loading or cleaning drill holes	1 1	0.10 0.24	0.34
	2. Struck by flying particles while blowing out hole	1	0.10	0.10
Slips/Falls of Persons	1. Fall on same level while drilling	2	0.24	0.48
	2. Slipped/fell while blowing out drill holes	1 1	0.10 0.24	0.34
Stepping/Kneeling on Objects	1. Stepped on rock while blowing off bottom	1	0.24	0.24
Explosives	1. Struck by flying muck/objects resulting from blast	1 1	0.10 0.24	0.34
Miscellaneous	1. Struck by whipping hose	1	0.24	0.24
	2. Overexposed to H ₂ S gas while drilling	1	0.10	0.10
				<u>27.95</u>

compared to conventional accident causes, are presented in Table D-6 and discussed below for each accident cause category. The impactor system was also determined to involve primary accident causes in addition to those identified for conventional shaft sinking. The postulated additional accident causes for the impactor shaft sinking system are listed in Table D-7 and also discussed below for each accident cause category.

Machinery

Accidents in this category include injuries received while operating machines or injuries from flying particles set in motion by machinery.

1. Caught between drill and rib. In the impactor system, there are no men required on the shaft bottom who might possibly get in the way of the impact hammer or booms. Also, the operators are located in protected cabs, some distance from the shaft walls. It is difficult to conceive of a situation where an operator might be caught between the machine and the shaft wall. The low likelihood of this event is reflected by assigning a value of 0.01 here.
2. Caught between drill and steel. It is very unlikely that someone in the impactor system would be caught between booms or other pieces of machinery during the rock breaking operation. There are no men stationed on the bottom in the impactor system, and the operators are located in protected cabs at some height above the rock breaking operation. A value of 0.01 is assigned here to reflect the low probability of this event, relative to conventional systems.
3. Struck by drill or machinery parts. Although there are no drills used in the impactor system, it is possible that members of the crew could be struck by other pieces of broken machinery, particularly a broken or whipping hydraulic hose. However, the impactor system has an asset relative to conventional systems in that smaller crews are required downhole. In the impactor system a total of three men are required to operate the machine and supervise the operation. In a conventional shaft sinking system, six men are required downhole

TABLE D-6. Relative Assets and Liabilities for Rock Breaking Operations in the Impactor System

Primary Cause	R_i	Assets	W_{Ai}	Liabilities	W_{Li}	R_i
Machinery	0.34	1. No men required on shaft bottom, operators in a protected work environment	0.01	None	1.0	--
	15.77	2. No men required on shaft bottom; operators in a protected work environment	0.01	None	1.0	0.16
	1.80	3. Less men downhole	0.50	More hose available	1.5	1.35
	0.94	4. Less men downhole; operators at some height above flying fragments	0.50 0.20	Power of impactor action may create more rock fragments	10.0	0.94
	0.58	5. This operation not required in impactor system	0.0	None	1.0	0.0
	1.02	6. Machine operated remotely	0.01	Vibration/fatigue effects	1.0	0.01
	0.24	7. No men required on shaft bottom Operators in a closed cab	0.01	None	1.0	--
	0.10	8. No use of blowpipe, other equipment, during drilling	0.01	None	1.0	--
Handling Materials	3.08	1. No need to lift equipment	0.01	None	1.0	0.03
	0.54	2. No need to manually handle equipment	0.01	None	1.0	0.01
	0.20	3. No men required on shaft bottom	0.01	None	1.0	--
	0.24	4. No need to manually handle equipment	0.01	Operator cab relatively small	10.0	0.02
Fall of Face/Wall	0.92	1. No such operation required	0.0	None	1.0	0.0
Handtools	0.34	1. No such operation required	0.0	None	1.0	0.0
	0.10	2. No such operation required	0.0	None	1.0	0.0
Slips/Falls of Persons	0.48	1. No men required on shaft bottom	0.01	Men stationed at some height above shaft bottom	10.0	0.05
	0.34	2. No such operation required	0.0	None	1.0	0.0
Stepping/Kneeling on Objects	0.24	1. No such operation required; no men required on shaft bottom	0.0	None	1.0	0.0
Explosives	0.34	1. No blasting required Protected work stations	0.0	None	1.0	0.0
Miscellaneous	0.24	1. Less men downhole	0.50	More hose available Men in closer proximity to hose, restricted escape route	1.5 10.0	1.80
	0.10	2. None	1.0	None	1.0	0.10
27.95						4.47

TABLE D-7. Postulated Additional Accident Causes for the Impactor Shaft Sinking System

<u>Primary Cause</u>	<u>Secondary Causes</u>
Fire/Suffocation from Fire	1. Ignition of flammables or oily waste from heat of overworked bearings or other frictional heat. 2. Hydraulic or lube oil hose or tank break or leak plus ignition source. 3. Ignition of flammables or oily waste from electric sparks/shocks. 4. Failure of fire control system
Electricity	1. Contact with frayed/broken cable

during rock breaking activities. The impactor system thus requires only half of the men downhole that a conventional system needs. This factor, 0.50, is applied here as an asset.

There is also a liability for the impactor system, in that more hose is available for breaking relative to conventional systems. A factor of 1.5, developed in Calculations, is used here to reflect this system liability.

4. Struck by flying rock. The potential for being struck by flying rock fragments exists in both shaft sinking systems. However, the impactor system uses only half the men downhole that are required in conventional shaft sinking. A weighting factor of 0.50, developed above, is thus applied as an asset here. In addition, the impactor system requires no men on the shaft bottom. The operators are located in protected cabs some seven to fifteen or twenty feet above the shaft floor. It is estimated that only 20 percent of the rock

fragments generated by rock breaking will reach the crew in their protected environment. In a conventional system, crew members are essentially exposed to all fragments generated. This weighting factor of 0.20 is thus also applied as an asset here.

The impactor system also has a liability, however, in that the power of the impactor hammer may generate more rock fragments than are present in a conventional system using drills. It is estimated that the impactor may generate as much as ten times the flying rock fragments that are present in a conventional system. This factor is assigned as a liability here.

5. Struck by rock while blowing out holes. This operation is not required in the impactor system. A weighting factor of zero is assigned here.
6. Overexertion. The operation of the impactor machine itself is performed remotely, using control levers. It is very unlikely that overexertion on the part of the operator will be experienced during impactor operation. A value of 0.01 is assigned here to reflect this system characteristic. However, the vibration experienced when using the machine may cause some fatigue effects on the crew, which may in turn lead to overexertion during performance of routine tasks. The vibration effects of the impactor machine are absorbed by the operator through the feet, legs and torso. These effects are somewhat dampened by initial shock absorption from the booms and the machine structure. Crew members in conventional shaft sinking also experience direct vibration through the hands, arms and torso when operating the drills. However, in conventional sinking, the vibration is usually experienced on an intermittent basis. It is assumed that the severity of the effects may be approximately the same for both systems, although the area of vibration effects requires more study. A weighting factor of one is applied here.
7. Fall while drilling. There is little opportunity for a fall from the impactor machine once the operators are in position and the operation has begun. There are no men required on the muddy shaft

bottom in the impactor system, and the operators are stationed in closed cabs. A value of 0.01 is assigned to reflect the low relative likelihood of this accident occurring in the impactor system.

8. Struck against side. The impactor system does not require the use of a blowpipe or the handling of other equipment during impactor operation. A weighting factor of 0.01 is assigned here to reflect the low probability of this accident, relative to conventional systems.

Overall, the use of the impactor machine may reduce the risk of machinery-related accidents currently experienced in conventional rock breaking operations by almost 90%. This reduction in risk is achieved by the improved protection of men from the hazards presented by underground working conditions and the relative automation of the operation.

Handling Materials

This accident category refers to injuries incurred while lifting, moving, or installing equipment, supplies or materials.

1. Overexertion lifting materials. There is no need to lift or move equipment or materials in the impactor system once the operation of breaking rock has begun. A weighting factor of 0.01 is assigned here to reflect the low risk of this accident sequence in the impactor system, relative to conventional shaft sinking.
2. Struck by drill/steel when handling. Again, there are no requirements for equipment handling in the impactor system during the rock breaking operation. The risks of changing the tool on the impact hammer are addressed in the section on maintenance operations. A weighting factor of 0.01 is assigned here.
3. Struck by falling object. In the impactor system men are not stationed on the shaft bottom. The machine operators are located in

protected cabs above the shaft floor. The potential for being struck by falling objects is very low. A weighting factor of 0.01 is assigned here.

4. Struck against object. There is no need to manually handle equipment in the impactor system. The booms and the impact hammer are controlled by means of levers available to the operators. Although there is some potential for the operator to strike against the side of his cab should he slip or fall, there is little possibility for injury as a result of operating the machine itself. A weighting factor of 0.01 is assigned here to reflect this system asset.

Overall, the risk of handling material accidents in conventional shaft sinking rock breaking operations is essentially eliminated with use of the impactor system. This reduction in risk is achieved because of the minimal need for equipment handling with use of the impactor during rock breaking.

Fall of Face/Wall

The potential for being struck by falling rock while cleaning or loading drill holes does not exist in the impactor system during rock breaking operations. The rock is broken using the impact hammer, rather than using a drill and explosives. Also, the operators of the machine are located in protected cabs, some distance above the shaft floor. A weighting factor of zero is assigned here to reflect the absence of this accident type in the impactor system. Use of the impactor is anticipated to minimize currently experienced fall of face/wall accidents during rock breaking operations since men are not exposed to the shaft wall or floor.

Handtools

This category of accidents includes injuries received while using nonpowered tools, including injuries from flying particles generated by the tools or the materials being worked on.

1. Struck by tool. In the impactor system, all rock breaking is done by the impact hammer. There is no operation (other than those detailed in the section on maintenance) that requires the use of handtools while breaking rock with the impactor. A weighting factor of zero is thus assigned here.
2. Struck by flying particles. As mentioned above, use of the impactor machine does not require the drilling or blowing out of holes. Injuries from fragments as a result of the hammer's action were discussed in the section on machinery-related accidents. A weighting factor of zero is assigned here.

Use of the impactor machine is expected to eliminate accidents associated with handtools that are experienced in conventional systems during rock breaking operations. This elimination of risk is achieved because there is no need to use handtools during this phase of the operation in the impactor system.

Slips/Falls of Persons

This accident category includes all injuries from slips and falls other than those involving haulage vehicles.

1. Fall on same level. There is the potential for injuries from falls in both shaft sinking systems. However, in the impactor system, men are not stationed on the muddy, uneven shaft bottom, where slips and falls are more likely to occur. A weighting factor of 0.01 is used to reflect this positive system characteristic for the impactor. There is also a liability with the impactor system, however, in that the men are stationed at some height above the shaft bottom. Should an operator slip and/or fall, he could conceivably fall to the shaft bottom or hit his head against the steel cab. Either of these injuries could be more severe, by an order of magnitude, perhaps, than those that might be experienced in other slip/fall situations. A liability weighting factor of ten is thus assigned here.

2. Slip/fall while blowing out holes. As discussed earlier, there is no such operation required in the impactor system. Also, men are not stationed on the shaft bottom. A weighting factor of zero is assigned here to reflect this positive system characteristic.

The use of the impactor is expected to significantly reduce the risk of currently experienced slip/fall accidents in conventional rock breaking operations. This increased safety is obtained by protecting men from the shaft bottom.

Stepping/Kneeling on Objects

The potential for stepping on a rock while on the shaft bottom is eliminated with use of the impactor system because there are no men stationed at the shaft bottom. A weighting factor of zero is thus assigned here.

The protected work environment of the impactor machine should essentially eliminate many stepping/kneeling accidents currently experienced downhole during conventional rock breaking operations.

Explosives

The potential for being struck by objects set in motion by blasting operations is eliminated with use of the impactor system since that technique does not utilize explosives for breaking rock.

Miscellaneous

Accidents in this category include injuries from flying particles and other accidents not elsewhere classified.

1. Struck by whipping hose. The potential for injuries from hose whip exists in both shaft sinking systems. Assets for the impactor system, relative to conventional sinking, include a smaller crew downhole. A weighting factor of 0.50, developed earlier in this section, is assigned to reflect this system asset.

However, the impactor also has some system liabilities. There is anticipated to be more hose present in the impactor system than that that required for conventional shaft sinking equipment. An approximate figure of 1.5 times as much hose, developed in Calculations, is applied as a weighting factor here. Also, the crew members on the impactor machine are generally located closer to the hose routes. The men are located in closed cabs, and have restricted ability to escape whipping hose should a hose in the cab break. It is anticipated that the severity of the injuries that might be experienced with use of the impactor may be increased by an order of magnitude over that currently experienced in conventional systems. A factor of ten is assigned here to reflect this system liability.

2. Overexposed to gas. There is no difference between the two shaft sinking systems that is anticipated to affect this potential accident sequence. Weighting factors of one are thus assigned here.

Use of the impactor system may be expected to increase the risk of accidents during rock breaking from miscellaneous causes by about 6.6 times. In addition, there is a potential risk from long-term exposure to vibration and high noise levels with use of the impactor. The actual effects from these latter causes have not been well-documented. However, the potential severity of the vibration and noise levels on crew members downhole should be further investigated. A brief discussion of these phenomena is included at the end of this appendix.

The following primary accident cause categories are postulated additional accident causes for the impactor shaft sinking system. These are potential accidents that have not historically been encountered in conventional shaft sinking, but could become important with the use of impactor technology. The postulated accidents are discussed below for each primary cause category.

Fires/Suffocation From Fires

This accident category includes injuries received from any fires that might occur on site or in the shaft.

1. Ignition of flammables. The pumps and other equipment on the impactor machine and the use of hydraulic fluids and lubrication oils suggested a potential for fire on the machine. Postulated fire accidents could result when flammable material, such as rags or oily waste, accumulates at the machine stations. The frictional heat from overworked bearings could ignite this material, starting a fire on the machine.

The likelihood of this potential accident is not very great. Although the housekeeping procedures on the machine are less than perfect, the amount of heat generated by working equipment is considered insufficient to start a fire. Before bearings reach a state where they could be overworked, the state of the equipment would probably be noticed and the machine would be stopped. The generally wet working environment underground may further prevent ignition of the material.

2. Hydraulic or lube oil hose or tank leak. The presence of flammable fluid hoses and tanks in proximity to the crew on the impactor machine suggests that leaks from these sources may provide a potential source of fuel for a fire. Should this material ignite, the probability of severe consequences is likely since the tanks are located directly behind the operators cabs in an enclosed area. This enclosure makes the fire difficult to detect and more difficult to extinguish. The usefulness of a water-fog fire suppression system on such an oil or grease fire is questionable. The danger of this accident sequence is increased further because of the lack of a quick, accessible escape route for the machine operators.
3. Ignition of flammables. As discussed earlier in this section, there is the potential for accumulation of flammable waste or other material on the impactor machine. There is some potential for the mixture to be ignited by electrical sparks from a frayed or broken cable. Unlike machines designed for use in coal mines, the impactor has no requirement to be designed using a permissible electrical system, which cannot really spark. The redesign of the electrical

system to meet permissibility standards might serve not only to reduce this potential hazard but also to widen the potential application of the machine in the mining industry.

4. Failure of fire control system. In the event of a fire on the impactor machine, the failure of the fire control system could result in delayed escape from the shaft for crew members and potential injuries and/or fatalities from smoke inhalation or burns.

The fire control system on the impactor consists of a water-fog suppression system and hand-held portable chemical extinguishers, located at various places on the machine. The usefulness of the water-fog system for an oil/grease fire or for localized fires (such as in the closed area of the machine) is questionable. Also, the fire extinguishers are often covered with caked mud and grime during the course of the shaft sinking project, and could be very difficult to remove from their stored location. The extinguishers are not tested for workability. It is also unlikely that all crew members would be familiar enough with the use of these items to allow immediate application to the fire, once the fire location had been determined.

The potential problems with the fire control systems, as well as the probably severe consequences of the failures of these systems when needed, suggests that these systems should be modified for use with the impactor.

Overall, the possibility of a fire occurring on the impactor machine is judged to be significant, although comparable with the risks that might be found in a conventional metal/nonmetal shaft sinking system. However, should a fire occur, the lack of a dependable and effective fire control system and a ready escape route could result in severe consequences for the crew of the impactor. Although the importance of this accident type is not known (and was not evidenced in three years of data) for conventional shaft sinking, the potential consequences suggest that this is an important area of potential risk for the impactor system.

Electricity

Accidents in this category include injuries received from contact with electric current or from electric arcs or flashes.

1. Contact with Frayed or Broken Cable. The amount of electrical equipment and cable on the impactor machine is estimated to be somewhat more than is normally found in a conventional shaft sinking system. There is a potential for worker injuries should a crew member contact an exposed cable. The electric cables are generally not inspected for fraying or weaknesses. This hazard is increased by the wet working environment downhole.

The amount of electrical components on the impactor machine, combined with a wet working environment, suggest that this may be an important area of potential risk for the impactor system.

Summary

Use of the impactor system may reduce the hazards encountered in conventional rock breaking operations by about 85 percent. In the impactor system, men are not required to work on the shaft bottom and are located in protective cabs above the shaft floor. The machine is operated by control levers from the operator cab. There is no requirement in the system to handle or move equipment and/or supplies during the rock breaking operation.

However, the impactor system may present some additional hazards. These include potential occupational hazards from long-term exposure to vibration and noise; increased electrical hazards; and increased potential for injuries from fires.

Loading of Muck

In conventional shaft sinking, a machine is used for loading muck into the sinking bucket. However, men are required on the shaft bottom to manually position the buckets and make connections to the hoist rope. Some

hand-loading of muck is also required. Muck loading in the impactor system is performed by using the mucker boom and shovel on the impactor machine. No men are required on the shaft bottom in the impactor system. A haulage system of two buckets is used, each with its own hoist rope, to avoid having to hook up buckets during loading activities.

Accidents occurring during muck loading were fairly frequent in conventional shaft sinking systems, representing about 10 percent of all accidents recorded for metal/nonmetal shafts over an approximate three year period (1978-1980). Although most of the injuries experienced were minor, there were a few more serious injuries evident, including one instance of a fatality.

Primary accident causes common to the impactor and conventional systems during muck loading include handling materials, machinery, and slips or falls of persons. These causes are listed in Table D-8. Many of the accidents experienced during muck loading in conventional systems, however, stemmed from causes that are absent in the impactor system, primarily because men are not required on the shaft bottom. The assets and liabilities of the impactor relative to conventional systems are presented in Table D-9 and discussed in further detail below. The impactor system was also determined to involve primary accident causes in addition to those identified for conventional shaft sinking. These postulated additional accident causes are associated with the impactor machine itself, and were presented in Table D-7 and discussed in the previous section. Basically, they include accidents from electrical shock, fire, or injuries as a result of the noise and vibration present with use of the impactor machine.

Handling Materials

This accident category includes injuries received while installing, moving, lifting or carrying equipment, supplies or other materials.

1. Caught between hook and bucket. In the impactor system, there is no need to hook up buckets, since each has its own hoist rope and connection and is run continuously during muck loading. Thus, this

TABLE D-8. Loading Muck Accident Causes in Conventional Shaft Sinking Systems (from 1978-1980 data)

Primary Cause	Secondary Causes	Number of Injuries (f_i)	Injury Severity (c_i)	(R_i)
Handling Materials	1. Caught between hook and bucket bail-hooking/unhooking buckets	4	0.10	0.40
	2. Struck by splashing muck or rock when hand loading	4 1	0.10 0.24	0.64
	3. Overexertion steadying or loading buckets	2 2	0.10 0.24	0.68
	4. Struck by cable/tool while running mucker	1 1	0.10 0.24	0.34
Haulage	1. Caught between machine parts or machine and wall while operating mucker	3 1	0.10 0.24	0.54
	2. Struck by muck bucket when mucking	1	0.10	0.10
	3. Struck by falling rock from mucker	1	0.10	0.10
Machinery	1. Struck by mucking machine; worker on bottom	1	0.24	0.24
	2. Struck by mucking machine; operator	3 2	0.10 0.24	0.78
	3. Operator struck by falling rock from mucker (Eimco-type)	1 1	0.10 0.24	0.34
Slips/Falls of Persons	1. Fall while climbing to/from Cryderman mucker	1 1	0.10 0.24	0.34
	2. Fall from muck pile or while loading bucket	1 1	0.24 100.00	100.24
	3. Slip/fall on bottom deck	1	0.10	0.10
	4. Fall while mucking shaft-caught in mucker machine parts	1	15.67	15.67
Fall of Face/Wall	1. Struck by caving rock while mucking or waiting for bucket change	3 4	0.10 0.24	1.26
	2. Struck by falling rock while scaling	2 3	0.10 0.24	0.92
Handtools	1. Struck by shovel when mucking bottom	1	0.10	0.10
	2. Overexertion while scaling	1	0.10	0.10
				<u>122.89</u>

TABLE D-9. Relative Assets and Liabilities for Muck Loading Operations in the Impactor System

Primary Cause	R_i	Assets	W_{Ai}	Liabilities	W_{Li}	P_i
Handling Materials	0.40	1. No need to hook/unhook buckets	0.0	None	1.0	1.0
	0.64	2. No hand loading required	0.0	None	1.0	1.0
	0.68	3. Buckets loaded with mucker boom shovel	0.01	None	1.0	1.01
	0.34	4. Operator stationed in protective cab	0.01	None	1.0	--
Haulage	0.54	1. Operators in protected stations	0.01	None	1.0	1.01
	0.10	2. No men required on shaft bottom; operators in protected work stations	0.01	Potential collision of bucket and impactor machine - 2 buckets	2.0	--
	0.10	3. Operators in protected stations above mucking operations	0.01	None	1.0	--
Machinery	0.24	1. No men required on shaft bottom	0.0	None	1.0	1.0
	0.78	2. Operators in protected stations	0.01	None	1.0	0.01
	0.34	3. Operators in protected stations above mucking operations	0.01	None	1.0	--
Slips/Falls of Persons	0.34	1. None	1.0	More men climbing on machine Increased difficulty of access More time spent mucking	2.0 3.0-5.0 1.48	3.02-5.03
	100.24	2. No men required on shaft bottom	0.01	More time spent mucking	1.48	1.48
	0.10	3. None	1.0	More time spent mucking	1.48	0.15
	15.67	4. Less men downhole	0.60	More time spent mucking More machine parts downhole	1.48 2.0	27.82
Fall of Face/Wall	1.26	1. Operators in protected stations above mucking operations No men required on shaft bottom	0.01	None	1.0	0.01
	0.92	2. Operators in protected stations above mucking operations. No men required on shaft bottom. Scaling performed by machine	0.01	None	1.0	0.01
Handtools	0.10	1. No handmucking required	0.0	None	1.0	0.0
	0.10	2. Scaling performed by machine	0.01	None	1.0	--
122.89						32.52-34.53

accident type has been assigned a weighting factor of zero as an asset to reflect the probability of occurrence of this event when using the impactor. No liabilities for the impactor system were anticipated to exist. A weighting factor of 1.0 is thus applied here.

2. Struck by splashing muck. There is no hand loading required in the impactor system. Buckets are loaded by the mucker shovel, which is operated remotely by a man in a protected work station at some height above the loading operations. Because this accident is essentially eliminated with use of the impactor system, a weighting factor of zero is assigned here.
3. Overexertion steadying buckets. Again, the impactor system uses machines to perform most of the muck loading functions. Although it is possible that an operator could strain a muscle while controlling the mucker boom, this event is highly unlikely. A probability factor of 0.01 is assigned to reflect the unlikeliness of this event.
4. Struck by cable/tool. In the impactor system, the mucker operator is in a protective cab, somewhat removed from the loading operations. There is little to bump against inside the cab itself, and less to strike the operator from outside the work station. The low probability of this event occurring in the impactor system is reflected by a weighting factor of 0.01.

Overall, the use of the impactor system is expected to essentially eliminate material handling accidents during muck loading. This is primarily because muck loading with the impactor is performed by the machine, and no men are required at the shaft bottom or to facilitate the actual loading of the muck buckets.

Haulage

This accident category includes injuries experienced while on moving haulage equipment or incurred by flying particles set in motion by haulage equipment.

1. Caught between machine parts. The potential for this accident in the impactor system is very low. The operator is in a protected work station, which contains few moving parts. The design of the machine precludes the possibility of the operator being caught between the machine and the wall, as long as he remains in his work station. Although there may be some possibility of a finger or hand getting caught in the operating controls, the likelihood of this event is very low. A weighting factor of 0.01 has been assigned here to reflect the low probability of this event.
2. Struck by muck bucket. The severity of this kind of accident should be reduced with use of the impactor system because there are no men required at the shaft bottom and the operators are in a protected work environment, normally outside of the path of the haulage buckets. An asset weighting factor of 0.01 is assigned here to reflect the near elimination of this accident cause with use of the impactor system.

However, the impactor does have a liability in that the machine may at times be in the direct path of one or the other of the muck buckets. There are also 2 buckets presenting a potential for collision rather than one. Although a warning system, in the form of a supervisor, does exist to ensure that the machine is not beneath a bucket well during bucket descent, this system may not be sufficient to prevent a collision. The effect of an empty bucket colliding with the top of the impactor cab may be some injury to the operators as well as potentially serious equipment damage. A factor of 2.0 is assigned here to reflect the potential increased likelihood of this accident type with use of the impactor. Note that the overall risk from this accident sequence when using the impactor machine is still insignificant relative to the risks encountered in a conventional system.

3. Struck by falling rock. The potential for this accident during muck loading in the impactor system is very small. The operators are located in well-protected stations, and are at some height above the mucking operations. A weighting factor of 0.01 is assigned here to reflect the low probability of this event in the impactor system.

Overall, use of the impactor system may be expected to essentially eliminate most haulage-related accidents during muck loading operations. This is primarily because of the protected work stations of the machine operators and the lack of workers on the shaft bottom. However, some injuries could occur if the muck bucket was to collide with the impactor machine on its way down. There is some likelihood of this event occurring. Changes to the system to mitigate the risk of this event occurring might incorporate interlocks to avoid the possibility of collisions.

Machinery

This accident category includes injuries resulting from operating machines, including injuries from flying particles set in motion by the machinery.

1. Struck by machine (on shaft bottom). The use of the impactor machine should eliminate this accident cause since no men are required on the shaft bottom. A weighting factor of zero is thus applied here.
2. Operator struck by machine. The potential for this accident should be greatly reduced with use of the impactor system. The operators are stationed in protected cabs, above the working level of the machinery, and are not exposed to many moving parts. The low likelihood of this accident with use of the impactor is reflected by the assigned weighting factor of 0.01.
3. Struck by falling rock. The potential for being struck by falling muck while loading the muck buckets is very small. The operators are located in protected work stations at some height above the mucking operations. A weighting factor of 0.01 is assigned here to indicate the low probability of this event.

Overall, the use of the impactor may be expected to essentially eliminate machinery-caused accidents that are currently experienced during conventional muck loading operations. This is primarily a result of no men exposed directly to the machinery on the shaft bottom and the protected work environment of the machine operators.

Slips and Falls of Persons

This accident category includes all injuries experienced as a result of slips and falls, other than those involving haulage vehicles.

1. Fall while climbing mucker. The impactor machine is structured somewhat similarly to a Cryderman mucker. There are no anticipated assets for the impactor that may make it easier or safer to climb in or out of the machine cab.

However, the impactor system does have some liabilities that may increase the risk of this accident as it is currently experienced. First of all, there are two operators climbing on/into the machine instead of just one. This factor, 2.0, is the first factor applied as a liability for the impactor. Secondly, the impactor machine may be more difficult to get to than a Cryderman. Not only does the operator have to climb ladders down the side of the machine, and over the steel shields into the cab, but he also must climb down from the bottom deck of the galloway before he even reaches the machine. It is estimated that the design of the impactor increases the difficulty of access to the machine by about 3 to 5 times over that experienced in conventional systems. A factor of 3.0-5.0 is thus also applied as a liability here.

Finally, because of the simultaneous nature of rock breaking and muck loading in the impactor system, more time is spent exposed to the loading operations in the impactor system, relative to conventional shaft sinking. In the impactor system, a total of 370 shifts is required for rock breaking and muck loading (concurrently) to complete the postulated shaft project. Only 250 shifts are required, however, in a conventional system for loading muck. This relative time factor of $370/250$, or 1.48, is thus applied as an additional liability for the impactor system.

2. Fall from muck pile. This accident cause is essentially eliminated in the impactor system because no men are required at the shaft bottom. A weighting factor of 0.01 is assigned here to reflect

this system asset. However, the impactor system also requires more time exposed to the loading operations. A factor of 1.48, developed above, is applied here to reflect this system liability.

3. Slip/fall on deck. Both shaft sinking systems employ a supervisor on the galloway deck during muck loading operations. However, the impactor system requires longer for the mucking operation, creating a greater chance for a personnel slip or fall. A liability weighting factor of 1.48, developed above, is applied here to reflect the greater exposure to this hazard in the impactor system.
4. Fall while mucking shaft. The potential for this accident is somewhat mitigated by use of the impactor system because it requires less men downhole. In conventional shaft sinking, a crew of five people downhole is required for loading muck. The impactor system employs three people downhole during the simultaneous breaking/loading operations. The relative crew size of the impactor, compared to that used in conventional systems, is 0.60. This factor is applied as an asset for the impactor.

However, the impactor system also has some liabilities that are relevant for this accident cause. As mentioned earlier in this section, the crew of the impactor is exposed for a longer time to the muck loading operations. A factor of 1.48, developed earlier, is applied here to reflect that system liability. Also, should a crew member fall, the impactor machine provides more machine parts in which to get caught. In addition to a mucking machine boom and shovel, there is an impactor hammer and an associated boom. An estimated weighting factor of 2.0 is thus applied here as an additional liability for the impactor system.

Overall, the risk of slip or fall accidents during muck loading in conventional systems is estimated to be reduced by about two-thirds with use of the impactor system. This reduction is achieved by requiring no crew members on the shaft bottom.

Fall of Face/Wall

1. Struck by caving rock. The potential for being struck by caving rock is fairly small in the impactor system. The operators are located in protected cabs above the shaft bottom and are protected from the shaft walls by the back of the cab and the machinery contained within. Also, no men are stationed on the shaft bottom, where they might be more vulnerable to rock falls. The expected probability of this event in the impactor system is reflected by a weighting factor of 0.01.
2. Struck by falling rock while scaling. In the impactor system scaling is performed using the hammer and chisel tool, rather than being performed by men. No men are required on the shaft bottom. The operators downhole are protected from falling rock by steel cabs, with both overhead and side protection. The low likelihood of this accident type in the impactor system is reflected by the assigned weighting factor of 0.01.

Overall, the use of the impactor system is expected to essentially eliminate the risk of rock fall accidents during muck loading that are now being experienced in conventional systems. The reduction in risk stems from a more protected work environment as well as reduced crew exposure to the potential hazard by performing some of the required operations using the machine rather than manpower.

Handtools

This accident category refers to injuries incurred while using, and as a direct cause of, a nonpowered handtool.

1. Struck by shovel. This accident type is avoided in the impactor system because there is no need for handmucking. The weighting factor assigned here is zero.

2. Overexertion while scaling. As discussed previously in this section, scaling in the impactor system is performed using the machine. Men operate the impact hammer to perform this function. Although there is a slight chance of straining a muscle while operating the control levers in the small space of the cab, this accident type should essentially be eliminated with use of the impactor. A weighting factor of 0.01 is assigned here to reflect the low probability of this accident sequence.

Overall, the risk of handtool accidents during muck loading in conventional systems should be eliminated with use of the impactor machine, since no use of handtools is required during muck loading in the impactor shaft sinking system.

Summary

The risk of accidents during muck loading operations in conventional shaft sinking systems may be reduced by over 70% with use of the impactor machine. Because no men are required on the shaft bottom with the impactor, and most operations are performed by the machine, the risk relative to conventional muck loading is very low.

However, use of the impactor machine may result in an increased incidence of slip and fall accidents during muck loading because of the difficulties in getting in and out of the machine. These may also be some potential injuries from noise and vibration effects with use of the impactor. These potential injuries were discussed in the previous section on rock breaking operations.

Haulage

Men and materials are transported in and out of the shaft by the haulage system. This system is also used to bring muck to the surface for disposal. Other shaft services, such as water and air supplies, are transported down the shaft through pipelines. All haulage accidents combined in conventional

systems contributed to making this the most hazardous operation in metal/nonmetal shaft sinking for the three year period under consideration (1978-1980). A more meaningful analysis of these operations, however, is achieved by looking at each transport system separately. In this section, we will examine the haulage of men, materials and muck as separate systems. This will allow a more detailed comparison of the various haulage operations in the impactor and conventional shaft sinking systems.

Haulage of Men

In both conventional shaft sinking and the impactor system, men are transported in and out of the shaft in a shaft sinking or muck bucket suspended from a safety clevis attached to a wire rope. The rope is attached to a hoist, which raises and lowers the bucket in the shaft. The bucket has a two to four cubic yard capacity and is entered by climbing up footholds on the outside of the bucket. A variety of required safety features on the hoist regulate speed and other parameters of transport. The galloway stage is also used in both systems for transporting workers during lining or pipeline extension operations.

Haulage of men was the most hazardous of conventional haulage operations, contributing 45% of total haulage accidents. The primary accident causes in conventional systems included haulage, slips or falls of persons, and stepping or kneeling on objects. These causes are detailed in Table D-10. The relative assets and liabilities of the impactor system compared to conventional man haulage functions are outlined in Table D-11 and discussed in detail below.

Haulage

This accident category includes most injuries experienced while on moving haulage equipment, or incurred by flying particles set in motion by haulage equipment.

1. Struck against cage. The potential for this accident exists in both the impactor and conventional shaft sinking systems. However, the impactor system has some assets, relative to conventional systems,

TABLE D-10. Haulage of Men Accident Causes in Conventional Shaft Sinking Systems (from 1978-1980 data)

Primary Cause	Secondary Causes	Number of Injuries (f_i)	Injury Severity (c_i)	(R_i)
Haulage	1. Struck against cage during sudden stop	5 6	0.10 0.24	1.94
	2. Fall to lower level-hoist failure	1	0.10	0.10
	3. Struck by steel caught in wall support while riding cage/skip	3 1	0.24 100.00	100.72
	4. Caught between bucket and passageway object while riding bucket	3 5 1 1	0.10 0.24 15.67 100.00	117.17
	5. Struck by bucket-waiting for or leaving cage/bucket	2	0.24	0.48
	6. Fall to lower levels when riding galloway	1 3	0.10 0.24	0.82
	7. Caught between sheave and cable-riding galloway	1	15.67	15.67
Slips/Falls of Persons	1. Slip/fall entering or leaving bucket	2 2	0.10 0.24	0.68
	2. Slip/fall escaping shaft (communications lost)	2	100.00	200.00
Stepping/Kneeling on Object	1. Stepped on object (rail, rock) when getting out of bucket	2 2	0.10 0.24	0.68
Electricity	1. Trapped underground when electric power failed	2	0.10	0.20
Miscellaneous	1. Struck by flying particle while riding cage	2 2	0.10 0.24	0.68
	2. Hoist failure (mechanical)-men trapped underground	1	0.10	0.10
				439.24

TABLE D-11. Relative Assets and Liabilities of Man Haulage Operations in the Impactor System

Primary Cause	R_i	Assets	W_{Ai}	Liabilities	W_{Li}	R_I
Haulage	1.94	1. Less men downhole Less time downhole	0.75-0.83 0.76	None	1.0	1.11-1.22
	0.10	2. Less men downhole Less time downhole	0.75-0.83 0.76	None	1.0	0.06
	100.72	3. Fewer requirements to transport drill steel with men	0.13	None	1.0	13.09
	117.17	4. Less men downhole Less time downhole	0.75-0.83 0.76	None	1.0	66.79-73.82
	0.48	5. Less men downhole Less time downhole	0.75-0.83 0.76	None	1.0	0.27-0.30
	0.82	6. Less men downhole Less time downhole	0.75-0.83 0.76	None	1.0	0.47-0.52
	15.67	7. Less time downhole	0.76	None	1.0	11.91
Slips/Falls of Persons	0.68	1. Less men downhole Less time downhole	0.75-0.83 0.76	Greater potential for slip/fall if entering bucket from impactor machine	3.0-5.0	1.16-2.14
	200.00	2. Less men downhole Less time downhole Easier escape-no men on bottom	0.75-0.83 0.76 0.50	Greater potential for slip/fall having to leave from machine	3.0-5.0	171.00-315.40
Stepping/Kneeling on Objects	0.68	1. Less men downhole Less time downhole	0.75-0.83 0.76	None	1.0	0.39-0.43
Electricity	0.20	1. Less men downhole Less time downhole	0.75-0.83 0.76	None	1.0	0.11-0.13
Miscellaneous	0.68	1. Less men downhole Less time downhole	0.75-0.83 0.76	None	1.0	0.39-0.43
	0.10	2. Less men downhole Less time downhole	0.75-0.83 0.76	None	1.0	0.06
						266.81-419.51
						439.24

that mitigate the risk of this accident type. First of all, the impactor system requires less men downhole during project performance, resulting in reduced exposure to the haulage operation. A crew of from three to five men is required downhole in the impactor system, while from four to six men are required in conventional shaft sinking. A relative range of 0.75 to 0.83 is thus applied as an asset for the impactor system, reducing exposure to risk.

Secondly, the impactor system requires less time downhole to complete shaft excavation. Excluding the mobilization function, where men are transported using ladders, scaffolding or a crane system, the impactor system requires about 800 shifts to complete shaft construction. The same project would require 1050 shifts using conventional shaft sinking methods. The impactor system thus requires only 76 percent of the time downhole required with a conventional system. This factor is also applied as an asset for the impactor, since it reduces the time that men are exposed to haulage risks. Because of the similarities of the two systems, there were no liabilities anticipated with use of the impactor.

2. Fall to lower level. This accident may occur in the impactor system as well as in a conventional shaft sinking system. However, as discussed above, the impactor system has several assets that help to reduce exposure to risk. These include reduced manpower requirements downhole as well as a shorter time necessary for project completion. The weighting factors for these assets, 0.75-0.83 and 0.76, respectively, are applied here.
3. Struck by steel. The probability of this accident occurring in the impactor system is very small. Unlike conventional systems, there is no need to transport drill steel parts or steel members downhole in the bucket. Although small spare parts of the impactor machine may be replaced downhole, major items would be repaired at the surface. There is a requirement to replace the chisel tool, which could conceivably be transported in and replaced on the machine from the bucket. However, the tool will need replacement on average of

only once every 80 feet, or between 30 and 35 times during project performance. Drill steels, on the other hand, usually require at least one replacement (of one of six or more drills) during each drilling cycle, or about 250 times during project performance. A weighting factor of 0.13 is used to represent the decreased requirements to transport steel downhole with use of the impactor system. There were no liabilities anticipated for this accident type.

4. Caught between bucket and passageway. This accident can occur in the impactor system as well as in conventional shaft sinking. However, the impactor system has some assets that reduce exposure of men to these accident risks. These assets, as discussed above, include smaller crew requirements as well as less time downhole. Weighting factors of 0.75-0.83 and 0.76, developed earlier, are applied as assets to the impactor system.
5. Struck by bucket. The potential for this accident exist in both systems. Although there are no men stationed on the shaft bottom in the impactor system, it is possible that men may enter/leave the bucket directly from the impactor machine. It is possible for them to be struck while waiting for the bucket from the machine should they be positioned at the outside ladders. However, the impactor does have assets which help to reduce risk, including fewer men downhole and reduced shaft construction time requirements. Weighting factors for these assets, 0.75-0.83 and 0.76, which were developed above, are applied here.
6. Fall to lower level from galloway. The potential for this accident exists in both the impactor and conventional shaft sinking systems. However, the impactor requires less men downhole for a reduced period of time. Asset weighting factors of 0.75-0.83 and 0.76, developed previously, are applied here.
7. Caught in sheave on galloway. This accident could occur in either shaft sinking system. However, men are downhole for less time in

the impactor system. This reduced exposure factor of 0.76 is applied as an asset for the impactor. No liabilities were anticipated to exist for the impactor relative to conventional systems.

Overall, the risks of haulage accidents in conventional metal/nonmetal shaft sinking systems are anticipated to be reduced about 60% with use of the impactor system primarily because of reduced man-hour requirements downhole.

Slips/Falls of Persons

This accident category includes injuries experienced from falls from an elevation as well as from falls on the same level.

1. Slip/fall entering or leaving bucket. The potential for this accident exists in both the impactor and conventional shaft sinking systems. The impactor system has several characteristics that reduce the risk of this kind of accident. First of all, there are less men required downhole. The weighting factor for this, 0.75-0.83, developed above, is applied as an asset here. Also, the shaft can be completed in less time using the impactor system, exposing men downhole only 76 percent of the time experienced with conventional systems. This factor is also applied as an asset.

The impactor system also has some liabilities, however, because of the mechanisms by which crew members on the impactor machine itself actually enter the bucket. To get into the bucket, men must either climb up to the galloway landing, using metal and/or rope ladders, or they must climb out over the edge of their work cabs, and enter the bucket without the availability of a landing below them. It is anticipated that this method of entry to the haulage buckets could increase the potential risk for slips and falls by a level of 3 to 5 times over that currently experienced in conventional systems. This factor, 3.0-5.0, is applied as a liability for the impactor system.

2. Slip/fall escaping shaft. This accident can occur in the impactor system as well as in conventional systems. Assets for the impactor

system, however, include a smaller crew and less time required downhole. The weighting factors for these assets, 0.75-0.83 and 0.76, respectively, were developed above and are applied here. The impactor system has an additional asset in that men are not stationed on the shaft bottom. Thus, escape routes begin from the impactor machine, which has ladders and other climbing equipment available, rather than from the shaft floor using improvised scaffolds or ladders. The impactor system should reduce risks of slipping during escape by about fifty percent because of the improved escape route from the shaft bottom, relative to conventional systems. This factor, 0.50, is also applied as an asset here. A liability for the impactor system also exists, however, because there is no firm landing for the haulage bucket at the level of the impactor machine. As discussed above, a factor of 2.0-3.0 is assigned as a liability here to account for the possible increased incidence of slip/fall accidents.

Overall, the potential risk from slip and fall accidents is expected to range from about 14% less than conventional system risks to almost 60% greater than the risks currently experienced in conventional shaft sinking. On the average, the risks involved with using the impactor may increase by about 20% because of the difficulty of access to the operator work stations.

Stepping/Kneeling on Objects

The potential for stepping on objects when getting out of the bucket exists in both conventional and impactor shaft sinking systems. The impactor system does have some characteristics that tend to reduce the risk of this accident type. As mentioned above, the impactor requires less men and less time downhole. Weighting factors developed previously in this analysis of 0.75-0.83 and 0.76, respectively, are assigned as assets for the impactor. There are no liabilities anticipated with use of the impactor system. The potential for stepping/kneeling accidents is expected to be reduced with use of the impactor system in accordance with reduced crew exposure to these hazards.

Electricity

The potential for hoist failure and consequent entrapment exists in both shaft sinking systems. The use of the impactor system is expected to reduce the risks of this accident type by reducing crew exposure downhole. The weighting factors, in terms of man-hours, were developed above and are applied here as assets for the impactor system. No liabilities were anticipated to exist for the impactor.

The risk of entrapment underground should be reduced with use of the impactor system because of reduced crew exposure downhole.

Miscellaneous

Accidents in this category include injuries from flying particles and other accidents not elsewhere classified.

1. Struck by flying particle. The potential for being struck by flying rock or dirt particles during haulage activities exists in both shaft sinking systems. However, the risk of this accident should be reduced with use of the impactor because of less exposure to the underground environment, relative to conventional shaft sinking. The impactor system requires a smaller crew and less time downhole than conventional systems. Weighting factors for these assets that were developed above, 0.75-0.83 and 0.76, respectively, are applied here. No liabilities for the impactor system were expected, relative to conventional shaft sinking.
2. Underground entrapment. As discussed earlier in this section, the potential for hoist failure and entrapment exists in both shaft

sinking systems. Assets for the impactor system include a smaller downhole crew and less time required downhole. Weighting factors developed earlier in this section are applied here.

The potential for accidents from miscellaneous causes should be reduced with use of the impactor system because of a reduction in crew exposure relative to conventional shaft sinking systems.

Summary

Overall, the potential risk for haulage of men accidents using the impactor may be expected to be less than the risk currently experienced in conventional systems by a range of from 4 to about 40 percent. This reduction in risk is primarily due to the reduced exposure of crew members downhole. However, the impactor system also has some liabilities. These include the difficulty of access to the impactor machine and the operator's work stations from a haulage bucket, increasing the probability and potential severity of slip or fall accidents.

Haulage of Materials

Materials and supplies in both conventional and impactor shaft sinking systems are moved by pipeline, transported in buckets from the hoist rope, or handled directly by hoist tuggers or other moving devices. Material and supply handling accounted for over a third of the recorded haulage accidents in conventional systems for the three year period of interest. The primary accident cause categories for these injuries included handling material accidents and slips and falls. These accident causes are detailed in Table D-12. The relative assets and liabilities of the impactor system compared to conventional material haulage functions are outlined in Table D-13 and discussed in detail below.

TABLE D-12. Haulage of Materials Accident Causes in Conventional Shaft Sinking Systems (from 1978-1980 data)

<u>Primary Cause</u>	<u>Secondary Causes</u>	<u>Number of Injuries (f_i)</u>	<u>Injury Severity (c_i)</u>	<u>Risk (R_i)</u>
Handling Materials	1. Struck by supplies/equipment parts when loading or unloading	5 8	0.10 0.24	2.42
	2. Caught between equipment parts being handled and stationary object (cage, wall, etc)	3 2	0.10 0.24	0.78
	3. Struck by falling iron/timber while handling	5 2	0.10 0.24	0.98
	4. Struck by flying particle while handling material	1	0.10	0.10
	5. Overexertion handling equipment/supplies	3 8	0.10 0.24	2.22
Slips/Falls of Persons	1. Slipped/fell on shaft bottom	1	0.24	0.24
Haulage	1. Caught between cables/drum when hoisting	1 1	0.24 15.67	15.91
				<u>22.65</u>

TABLE D-13. Relative Assets and Liabilities of Material Haulage Operations in the Impactor System

Primary Cause	R_i	Assets	W_{Ai}	Liabilities	W_{Li}	R_I
Handling Materials	2.42	1. Less time required to construct shaft	0.81	More equipment required	1.50	2.94
	0.78	2. Less time required to construct shaft	0.81	More equipment required	1.50	0.95
	0.98	3. None	1.0	None	1.0	0.98
	0.10	4. Less time required to construct shaft	0.81	More equipment required	1.50	0.12
	2.22	5. Less time required to construct shaft	0.81	More equipment required	1.50	2.70
Slips/Falls of Persons	0.24	1. Men seldom required on shaft bottom	0.01	None	1.0	--
Haulage	15.91	1. Less time required to construct shaft	0.81	More haulage of equipment required	1.50	19.33
	<u>22.65</u>					<u>27.02</u>

Handling Materials

This accident category includes injuries incurred while installing, moving or lifting supplies or equipment, as well as injuries from flying particles generated by the material being moved.

1. Struck by parts when loading/unloading. The potential for injuries from being struck by equipment parts while loading or unloading exists in both shaft sinking systems. However, the impactor system allows the completion of the shaft project in less time than with conventional sinking, reducing crew exposure to these risks. The total time required to construct a shaft using the impactor system, in terms of shifts, is 1040; about 1290 shifts are required to complete shaft construction in a conventional system. A relative exposure factor of 1040/1290, or 0.81, is thus applied as an asset for the impactor system.

Liabilities also exist for the impactor system relative to conventional methods. An estimate of the amount of supplies and/or equipment that requires handling during the construction project

shows that the impactor system has more equipment required than a conventional system. The impactor system is anticipated to require 50 percent more equipment handling than conventional systems. This factor, 1.50, is developed in Calculations and is applied here as a liability.

2. Caught between equipment parts. As mentioned above, the impactor system has both assets and liabilities relative to this accident cause. Less exposure to the construction environment is required in the impactor system. An asset weighting factor of 0.81, developed above, is applied here. However, the impactor system requires the movement of more equipment than in conventional systems. A weighting factor of 1.50, as discussed above, is applied here as a liability.
3. Struck by falling iron/timber. Both shaft sinking systems require about the same amount of iron and/or timber to be handled. There appear to be no assets or liabilities for the impactor system, relative to conventional shaft sinking, for this accident type. The weighting factors assigned here are 1.0.
4. Struck by flying particle. The crew is exposed to the material haulage function for less time in the impactor system. A weighting factor of 0.81, developed above, is applied here as an asset for the impactor. However, the impactor system also requires the handling of more equipment than in a conventional system. A weighting factor of 1.50, developed above, is applied here as a liability for the impactor.
5. Overexertion handling equipment. The same weighting factors used above are applied here. The reduced exposure time in the impactor system is applied as an asset here. This weighting factor is 0.81. However, the impactor system requires more equipment to be handled during shaft construction. A weighting factor of 1.50, developed above, is applied to reflect this liability.

Use of the impactor system is anticipated to increase the risk of handling materials by 18 percent over that experienced in conventional systems. This increased risk stems primarily from the greater amount of equipment that must be handled in the impactor system.

Slips/Falls of Persons

The potential for slips or falls while on the shaft bottom is very unlikely for the impactor system since men are seldom required on the shaft bottom. A weighting factor of 0.01 is assigned here to reflect the low probability of this accident occurring.

The potential for falls on the shaft bottom should be reduced with use of the impactor system because men are seldom required at the bottom.

Haulage

The potential for being caught between cables and the drum when hoisting exists in both shaft sinking systems. Although the crew is exposed for less time in the impactor system, there is more equipment to be handled. The weighting factors for these assets and liabilities, 0.81 and 1.50, respectively, were developed earlier in this section and are applied here.

The risks of haulage accidents during material handling are anticipated to increase by 22 percent with use of the impactor system because of the greater amount of equipment to be handled.

Summary

Overall, use of the impactor system is anticipated to increase the risks currently experienced in conventional materials haulage operations by about 19%. This increase is primarily a result of the greater amount of equipment to be handled in the impactor system.

Haulage of Muck

Muck haulage in both the conventional and impactor shaft sinking systems is achieved by the use of hoisting systems and buckets. Muck is dumped at the headframe at the shaft surface into a temporary holding pile, and is taken to the final disposal area by trucks. The trucks are filled using front-end loaders. The primary difference between the two systems is that two buckets are used in the impactor system, each with its own hoist rope and connection, while in conventional sinking only one rope may be available for bucket connections. In this case, the buckets must be hooked/unhooked from the hoist rope by crew members stationed at the shaft bottom.

Haulage of muck presented a fairly high risk in conventional operations, accounting for about twenty percent of all haulage accidents. The primary accident causes for muck haulage are detailed in Table D-14. The relative assets and liabilities of the impactor system compared to conventional systems are outlined in Table D-15 and discussed in detail below.

Haulage

Accidents included in this category are from moving haulage equipment or from flying particles set in motion by haulage equipment.

1. Struck by falling muck. Because of the protected working environment downhole, this accident cause is not generally of concern in the impactor shaft sinking system. The operators are stationed in cabs with overhead protection and have the additional overhead protection of the lower galloway deck. Other workers in the system are stationed on the galloway and are protected by the overhead decks. There are no men required to be stationed on the shaft bottom. The low probability of this event occurring in the impactor system is reflected by the weighting factor of 0.01 assigned as an asset.

The impactor system does have a liability, however, relating to the duration of crew exposure to haulage hazards. In conventional muck

TABLE D-14. Haulage of Muck Accident Causes in Conventional Shaft Sinking Systems (from 1978-1980 data)

Primary Cause	Secondary Causes	Number of Injuries (f_i)	Injury Severity (c_i)	Risk (R_i)
Haulage	1. Struck by falling muck from bucket	8 3	0.10 0.24	1.52
	2. Hoist or brake failure	4	0.10	0.40
	3. Struck by falling muck bucket (cable broke)	1 1 1	0.10 0.24 100.00	100.34
	4. Brake failure (surface)--driver hit truck upon impact	1	0.10	0.10
Slips/Falls of Persons	1. Slipped while guiding muck bucket through galloway	1	0.10	0.10
	2. Fall to shaft bottom when pulling/freeing dump chute	1	100.00	100.00
Handling Materials	1. Injured hooking dump chain to dump chute (surface)	1	0.10	0.10
Machinery	1. Caught between moving parts when dumping muck buckets (surface)	1	0.10	0.10
				202.66

haulage, haulage takes place concurrently with muck loading. A total of 250 shifts of muck loading/haulage is assumed to be required to complete the 2500 foot shaft. In the impactor system, rock breaking, muck loading and muck haulage take place concurrently, requiring about 370 shifts of these activities to complete the project. Because of the concurrent operations, workers downhole are exposed to muck haulage hazards for a longer period of time relative to the exposure encountered in conventional operations. This factor, 370/250, or 1.48, is applied as a liability for the impactor system.

TABLE D-15. Relative Assets and Liabilities of Muck Haulage Operations in the Impactor System

Primary Cause	R_i	Assets	W_{Ai}	Liabilities	W_{Li}	R_I
Haulage	1.52	1. Operators in protected cabs. Other workers protected by overhead decks. No men required on shaft bottom	0.01	Exposed longer to mucking operations	1.48	0.02
	0.40	2. Less men downhole	0.60	Exposed longer to mucking operations	1.48	0.36
	100.34	3. Less men downhole Men in protected environment	0.60 0.16	Exposed longer to mucking operations	1.48	14.26
	0.10	4. None	1.0	Exposed longer to mucking operations	1.48	0.15
Slips/Falls of Persons	0.10	1. None	1.0	Exposed longer to mucking operations	1.48	0.15
	100.00	2. None	1.0	Exposed longer to mucking operations	1.48	148.00
Handling Materials	0.10	1. None	1.0	Exposed longer to mucking operations	1.48	0.15
Machinery	0.10	1. None	1.0	Exposed longer to mucking operations	1.48	0.15
202.66						163.24

2. Hoist/brake failure. The potential for this type of accident seems equally likely in both the impactor and conventional systems. The impactor system has both assets and liabilities relating to this accident cause. The impactor system requires a smaller crew downhole during muck loading/haulage than conventional systems. A downhole crew of three is required for the impactor, compared to a crew of five men downhole for conventional systems. This relative factor, 0.60, is applied as an asset for the impactor system. However, as described previously, the impactor system requires a longer crew exposure to haulage hazards. A factor of 1.48, developed previously, is applied as a liability for the impactor system.

3. Struck by falling bucket. The potential severity of this accident in the impactor system is reduced because of fewer men downhole and a protected working environment. As mentioned above, the impactor system requires only 60 percent of the men downhole that are required in conventional systems. This factor is applied as an asset for the impactor system. Also, the crew works in a protected environment. Operators are protected both by cabs with overhead protection and by the rotating frame and structure of the impactor machine, as well as the lower deck of the galloway. Even if the machine happened to be directly below the bucket well, the machine structure should absorb most of the impact, cushioning the operators themselves. It is assumed that this protective effect will reduce the potential severity of an accident from the level of fatalities to permanent disability levels of magnitude, or similar reductions in accident severity. This factor, $940/6000$, or 0.160 , is also applied as an asset for the impactor system.

However, the operational requirements of the impactor system result in a longer exposure to muck haulage activities. This factor, 1.48 , developed above, is applied as a liability to the impactor system.

4. Brake failure (surface). There were no particular assets anticipated to exist for the impactor system for this accident sequence. A system liability regarding exposure time does exist, however, as mentioned above. This factor, 1.48 , is applied here.

The use of the impactor system should reduce risks from muck haulage accidents, even though exposure time is increased. The impactor system is expected to reduce haulage risks encountered in conventional muck haulage by about 86%, primarily because of the smaller crew downhole and the protected working environment.

Slips/Falls of Persons

This accident category includes all injuries from slips and falls other than those involving haulage vehicles.

1. Slipped while guiding bucket. The potential for this accident type does exist in the impactor system. No particular assets for the system, relative to conventional operations, were identified. A liability for the impactor, however, is the increased exposure time to muck haulage activities. A factor of 1.48, developed above, is applied here.
2. Fall to shaft bottom. Again, this accident could occur in the impactor system, which uses essentially the same haulage/dump methods as conventional shaft sinking systems. Although no assets for the impactor were identified, relative to conventional methods, a liability of increased exposure time does exist. This factor, 1.48 is applied here.

Overall, the potential for slips and falls in the impactor system during muck haulage activities may increase by as much as 50 percent over that experienced in conventional muck haulage. This increased risk is primarily a result of greater exposure times to the muck haulage operation when using the impactor system.

Handling Materials

The potential for injuries during muck dumping also exist in the impactor system, since the same general dumping method is used. However, the impactor system does have the liability of a greater exposure time to muck haulage operations. A factor of 1.48, developed above, is applied as a liability for the impactor system. No particular assets for the impactor were determined to exist for this accident cause. The risk for materials handling accidents was estimated to increase by about fifty percent relative to conventional methods because of greater exposure times to the muck haulage activities.

Machinery

The assets and liabilities of the impactor muck dumping activities were described above in the section on handling materials. The same rationale applies here. Again, use of the impactor system may be expected to increase the risk of machinery accidents, perhaps by as much as fifty percent.

Summary

Overall, the use of the impactor system is anticipated to reduce accident risks experienced in conventional muck haulage operations by about twenty percent. This risk reduction is achieved by the smaller crew requirements of the impactor system and the protected working environment downhole.

Pipeline Extension

Service lines for conventional shaft sinking are extended from the galloway. Pipes are lowered to the galloway on the hoist rope using special rope slings or brackets. After connecting pipe lengths, they are secured to the wall by brackets. A crew of four to five people is generally employed downhole for this operation.

The extension operations employed in the impactor system are essentially those used in conventional shaft sinking. Accidents occurring during the extension of shaft service lines include falls of persons and injuries while handling machinery, materials or handtools. The primary causes of accidents in conventional pipeline extension operations are listed in Table D-16. The impactor system was not anticipated to involve additional accident causes. The relative assets and liabilities of the impactor system, compared to conventional accident causes, are presented in Table D-17 and discussed below for each accident cause category.

Handling Materials

The potential for being struck by falling pipe is assumed to be equally likely in the impactor system since extension operations are performed in the same manner as for conventional systems. However, the impactor system requires only four service lines compared to the five needed for conventional systems. It is assumed that less pipe correlates to less exposure time for the men involved in handling the pipe. Thus, a factor of 0.80 is assigned as an asset for the impactor system.

TABLE D-16. Pipeline Extension Accident Causes in Conventional Shaft Sinking Systems (from 1978-1980 data)

Primary Cause	Secondary Causes	Number of Injuries (f_i)	Injury Severity (c_i)	(R_i)
Handling Materials	1. Struck by falling pipe while handling	1	0.10	0.34
		1	0.24	
Machinery	1. Struck by powered drill while drilling bracket holes	1	0.10	0.10
Slips/Falls of Persons	1. Fall to lower level while installing pipe	2	0.10	0.20
Haulage	1. Struck by falling crosshead while installing pipe	1	100.00	100.00
Fall of Face/Wall	1. Struck by caving rock while fitting pipe	1	0.24	0.24
Sliding/Falling Objects	1. Struck by falling object while installing pipe	1	0.10	0.10
				<u>100.98</u>

TABLE D-17. Relative Assets and Liabilities of Pipeline Extension Operations in the Impactor System

Primary Cause	R_i	Assets	W_{Ai}	Liabilities	W_{Li}	R_I
Handling Materials	0.34	1. Less pipe to handle	0.80	None	1.0	0.27
Machinery	0.10	1. None	1.0	None	1.0	0.10
Slips/Falls of Persons	0.20	1. Less pipe to install	0.80	None	1.0	0.16
Haulage	100.00	1. Less pipe to install	0.80	None	1.0	80.00
Fall of Face/Wall	0.24	1. None	1.0	None	1.0	0.24
Sliding/Falling Objects	0.10	1. Less pipe to install	0.80	None	1.0	0.08
						<u>80.85</u>
						<u>100.98</u>

The estimated risks in material handling accidents for pipeline extension are expected to decrease in the impactor system because of the reduced amount of pipe to be handled.

Machinery

The potential for machinery-related accidents appears to be equally likely in both the impactor and conventional shaft sinking systems during pipeline extension operations. There are no assets or liabilities anticipated to exist that might reduce or increase the risk of this accident sequence relative to conventional operations.

Slips/Falls of Persons

The potential for slips and falls of crew members during pipe installation also exists in the impactor system. However, as discussed above, the impactor system requires fewer service lines to be installed. A relative factor of 0.80, developed above, is applied to the impactor system as an asset, reflecting reduced exposure to risks during pipeline extension. The risks of slips or falls during pipeline extension in the impactor system is thus expected to be reduced relative to conventional systems by about 20 percent.

Haulage

The potential for being struck by a falling crosshead during pipeline extension operations is present in both the impactor and conventional shaft sinking systems. However, the impactor system requires the installation of fewer service lines, only 80 percent of those required in conventional systems. This factor is applied as an asset to the impactor system. The risks of haulage-related accidents during pipeline extension in conventional systems may thus be reduced by about 20% with use of the impactor system because of the reduction in pipe handling requirements.

Fall of Face/Wall

Injuries caused by caving rock are possible in both the impactor and conventional shaft sinking systems. There are no assets or liabilities anticipated to exist that might reduce or increase the risk of this accident sequence relative to conventional operations.

Sliding/Falling Objects

The potential for being struck by a falling object while installing pipe is assumed to be equivalent in both shaft sinking systems. However, there is less pipe to be installed in the impactor system. A weighting factor of 0.80 is applied as an asset here. The risks for this accident sequence in conventional pipeline extension are thus assumed to be reduced by about 20 percent with use of the impactor system.

Summary

The risks involved in pipeline extension in conventional shaft sinking are estimated to be reduced by about 20 percent with the use of the impactor system. This reduction of risk is achieved because fewer pipes are required to be installed in the impactor shaft sinking system.

Shaft Lining

Shafts are lined with concrete to provide shaft wall support, to help seal out excess water, and to protect the wall rock from deterioration. Equipment used for lining includes a curb ring, steel ring forms and hanging rods. Concrete lining is normally maintained to within forty feet of the shaft bottom, unless poor ground conditions are encountered. In that case, less wall is left exposed. Concrete is transported downhole by a bottom-discharge concrete bucket on the end of a hoist rope. The concrete moves by gravity flow (assisted by shovels) to behind the steel ring forms.

Lining operations are basically the same for both the impactor and conventional shaft sinking systems. Accidents during shaft lining primarily involved handling of the forms and other materials. Accidents during shaft lining in conventional systems were 10% of the total accidents experienced in metal/nonmetal shaft sinking for the years 1978-1980. The primary causes for these accidents are listed in Table D-18. The relative assets and liabilities of the impactor system, compared to conventional accident causes, are presented in Table D-19 and discussed below for each accident cause category.

Handling Material

This accident category includes injuries incurred while installing, moving, lifting or carrying rock, supplies or materials, as well as injuries from flying particles from materials being handled or moved.

1. Caught between hook and bucket. The potential for accidents while handling the concrete bucket exists in both shaft sinking systems. However, use of the impactor system for shaft excavation generally results in less overbreak than is experienced in conventional systems. It is anticipated that an average of 8 inches of overbreak around the periphery of the shaft will be encountered with use of the impactor system, compared to about 15 inches of overbreak with conventional blasting techniques (Phillips 1978). It is estimated that the amount of concrete required to line the shaft sunk by the impactor is about 12,700 cubic yards; about 17,100 cubic yards of concrete would be required to line a conventionally sunk shaft, including requirements for overbreak^(a). Thus, the impactor system is anticipated to require only 74 percent (12,700/17,100) of

(a) The required volume of concrete is based on the average amount of overbreak around the periphery of the shaft, plus the required 12 inch wall thickness, with an additional ten cubic yards wastage allowed for each 20 foot pour.

TABLE D-18. Shaft Lining Accident Causes in Conventional Shaft Sinking Systems (from 1978-1980 data)

Primary Cause	Secondary Causes	Number of Injuries (f_i)	Injury Severity (c_i)	(R_i)
Handling Materials	1. Caught between hook and bucket-hooking up concrete bucket	1	0.24	0.24
	2. Overexertion removing concrete forms	1	0.24	0.24
	3. Struck by falling object when removing forms	1	0.24	0.24
	4. Struck against wall when removing forms	1 1	0.10 0.24	0.34
	5. Caught between bail and bucket-unloading bucket	1	0.24	0.24
	6. Caught between galloway and forms-installing hanging rods	1	0.24	0.24
	7. Struck against rail when pouring concrete	1	0.10	0.10
	8. Chemical burn while pouring/finishing concrete	6	0.24	1.44
Handtools	1. Struck by tools when removing forms	2 1	0.10 0.24	0.44
	2. Struck by flying particles when removing forms	1	0.24	0.24
	3. Caught between crowbar and forms when jacking in forms	1	0.24	0.24
Slips/Falls of Persons	1. Fall to lower level while removing forms	1 1	0.10 0.24	0.34
	2. Slip/fall on wet surface	1	0.24	0.24
Machinery	1. Struck by wire/nail when installing forms	2	0.10	0.20
	2. Overexertion using cement chipping hammer	1	0.24	0.24
Fall of Face/Wall	1. Struck by caving rock while installing forms	1 2	0.10 0.24	0.58
Stepping/Kneeling on Object	1. Stepped on nail/bar when removing forms	2	0.24	0.48
Striking/Bumping Object	1. Bumped/twisted knee between forms and galloway	1	0.24	0.24
Haulage	1. Struck by broken hoist rope while raising forms	1	0.10	0.10
Miscellaneous	1. Chemical burns from contact with cement during pouring/cleanup	3 6	0.10 0.24	1.74
	2. Struck by falling piece of concrete	1	0.24	0.24

TABLE D-19. Relative Assets and Liabilities of Shaft Lining Operations in the Impactor System

Primary Cause	R_i	Assets	W_{Ai}	Liabilities	W_{Li}	R_i
Handling Materials	0.24	1. Fewer buckets to handle	0.74	None	1.0	0.18
	0.24	2. None	1.0	None	1.0	0.24
	0.24	3. None	1.0	None	1.0	0.24
	0.34	4. None	1.0	None	1.0	0.34
	0.24	5. Fewer buckets to handle	0.74	None	1.0	0.18
	0.24	6. None	1.0	None	1.0	0.24
	0.10	7. Less concrete to pour	0.74	None	1.0	0.07
	1.44	8. Less concrete to pour	0.74	None	1.0	1.07
Handtools	0.44	1. None	1.0	None	1.0	0.44
	0.24	2. None	1.0	None	1.0	0.24
	0.24	3. None	1.0	None	1.0	0.24
Slips/Falls of Persons	0.34	1. None	1.0	None	1.0	0.34
	0.24	2. None	1.0	None	1.0	0.24
Machinery	0.20	1. None	1.0	None	1.0	0.20
	0.24	2. None	1.0	None	1.0	0.24
Fall of Face/Wall	0.58	1. None	1.0	None	1.0	0.58
Stepping/Kneeling on Objects	0.48	1. None	1.0	None	1.0	0.48
Striking/Bumping Object	0.24	1. None	1.0	None	1.0	0.24
Haulage	0.10	1. None	1.0	None	1.0	0.10
Miscellaneous	1.74	1. Less concrete to pour	0.74	None	1.0	1.29
	0.24	2. None	1.0	None	1.0	0.24
	<u>8.40</u>					<u>7.43</u>

the concrete that would be necessary in lining a similar shaft sunk by conventional methods. Since the concrete buckets used in both systems are the same size, the impactor system will also require only 74% of the number of bucket loads of concrete required in conventional systems. This weighting factor is applied as an asset for the impactor. There were no liabilities anticipated to exist for the system relative to conventional sinking methods.

2. Overexertion removing forms. The method of form removal is the same in both shaft sinking systems. The impactor system is not expected to affect the risk of this accident type relative to conventional systems. The weighting factors assigned here are one.
3. Struck by falling object. The method of form removal is the same in both shaft sinking systems. Removal operations are performed from the galloway, affording equivalent overhead protection for the crews in both systems. Weighting factors of one are assigned here.
4. Struck against wall. As explained above, the use of the impactor system is not anticipated to affect this accident type. The weighting factors assigned here are one.
5. Caught between bail and bucket. As discussed earlier in this section, the impactor system will probably require less concrete to line the shaft because of less overbreak with use of that system. Buckets must be handled only 74 percent of the time required in conventional systems. This weighting factor, 0.74, is applied as an asset for the impactor.
6. Caught between galloway and forms. The method of form removal is the same in both shaft sinking systems. The weighting factors assigned here are one.
7. Struck against rail. As explained earlier in this section, the impactor system requires less concrete than conventional systems because of less overbreak. A weighting factor of 0.74 developed earlier in this section is applied as an asset here.

8. Chemical burn. As discussed earlier in this section, the impactor system requires less concrete to be handled. A weighting factor of 0.74, developed above, is applied to reflect this system asset.

The risk of handling materials accidents in conventional systems should be reduced by almost 20% with use of the impactor system because less concrete is required as a result of less overbreak.

Handtools

This accident category refers to injuries incurred while using, and as a direct result of, a nonpowered handtool. Accidents in conventional shaft sinking within this category were experienced during set-up or removal of forms. Since the impactor system uses the same methods for these activities, no change in risk should be expected solely as a result of using the impactor system. Thus, for the three categories of handtools accidents listed in Table D-18 weighting factors of one are assigned.

Because the methods of form set-up and removal are the same in both the impactor and conventional shaft sinking systems, the use of the impactor is not expected to change the risk currently experienced in this accident category.

Slips/Falls of Persons

This accident category includes all injuries due to slips and falls other than those involving haulage vehicles. The potential for slips or falls during shaft lining is not anticipated to be affected by use of the impactor system. Both shaft sinking systems use similar methods for lining the shaft. The risks currently experienced in this accident category are not anticipated to be changed with use of the impactor system.

Machinery

This accident category includes injuries resulting from operating machines, as well as injuries from flying particles set in motion by machinery. Both shaft sinking systems use the same general lining methods. Thus, for the two accident types listed within this category, weighting factors of one are assigned.

The use of the impactor system is not expected to change the risk in this accident category, since the methods used are the same for both the impactor and conventional systems.

Fall of Face/Wall

This accident category primarily refers to persons being struck by caving or broken rock. Both systems have equivalent potential for caving rock. Each crew also has generally the same amount of overhead protection, since lining operations take place from the galloway. The use of the impactor system is not expected to change the risks currently experienced in this accident category. Thus, weighting factors of one are assigned.

The risk in this accident category should be unchanged with use of the impactor system, since it is not significantly different from conventional lining methods.

Stepping/Kneeling on Objects

The potential for stepping on nails or other objects when removing concrete forms exists in both shaft sinking systems. There are no characteristics of the impactor that are anticipated to change the risks currently experienced in conventional systems. Thus, weighting factors of one are assigned.

The use of the impactor system is not expected to affect the risks experienced in this category in conventional systems because of the similarity of the two lining methods.

Striking/Bumping Object

The potential for this accident type exists with equal likelihood in both systems during shaft lining operations. Weighting factors of one are assigned here. The use of the impactor system is not expected to affect the potential risks from this accident type.

Haulage

The potential for being struck by a broken hoist rope while raising concrete forms exists in both shaft sinking systems. The use of the impactor is not expected to affect the likelihood or severity of this accident type.

Miscellaneous

1. Chemical burns. Injuries from chemical burns while handling concrete may occur during shaft lining operations in both shaft sinking systems. However, because there is less overbreak when using the impactor for shaft excavation, it requires less concrete for lining. A weighting factor of 0.74, developed previously in this section, is used to reflect this system asset.
2. Struck by falling concrete. The potential for being struck by falling objects exists in both systems. Lining operations take place from the galloway decks, resulting in equivalent overhead protection for each crew. Because there is no apparent difference between these systems, weighting factors of one are assigned.

Overall, the risk of miscellaneous accidents in conventional systems is anticipated to be reduced by about 23% with use of the impactor system. This reduction in risk is achieved because of reduced concrete handling requirements.

Summary

The use of the impactor system is anticipated to reduce the risks of conventional lining operations by about 12 percent. This reduction in risk is achieved as a result of reduced concrete handling requirements during lining operations with use of the impactor for excavation.

Maintenance

Maintenance operations during shaft sinking include inspections of shaft sinking and support equipment, lubrication of parts, and replacement of missing or worn components. Accidents occurring during maintenance of shaft sinking equipment were second in frequency only to breaking rock accidents. These accidents represented about 15% of all accidents recorded for metal/nonmetal shafts over a 3-year period. Also, more serious injuries occurred during maintenance operations than were experienced in rock breaking. Although the frequency of maintenance accidents was somewhat less than for rock breaking, the severity of the accidents tended to be greater. The primary causes of maintenance accidents in conventional shaft sinking are listed in Table D-20. The assets and liabilities of the impactor system relative to the conventional system are presented in Table D-21 and discussed in detail below.

Handling Materials

This accident category refers to injuries incurred while lifting, moving or installing supplies or materials, including small equipment components.

1. Struck by equipment parts during maintenance. The potential for accidents during maintenance activities exists in both shaft sinking systems. Mechanics and repairmen are exposed for a shorter time in the impactor system, however, because the impactor requires less total time to complete the shaft. It is assumed that this directly correlates to the percentage of maintenance time required, since the longer equipment is in operation, the more routine maintenance is

TABLE D-20. Maintenance Accident Causes in Conventional Shaft Sinking Systems (from 1978-1980 data)

Primary Cause	Secondary Causes	Number of Injuries (f_i)	Injury Severity (c_i)	Risk (R_i)
Handling Materials	1. Struck by equipment parts during maintenance/repair activities	6 3	0.10 0.24	1.32
	2. Caught under/struck by muck during maintenance/repair activities	1 1	0.10 100.00	100.10
	3. Contact with acid	1	0.24	0.24
	4. Fall to lower level during maintenance/repair activities	1	0.24	0.24
	5. Overexertion lifting equipment	1 2	0.10 0.24	0.58
Machinery	1. Burns from welding	4 1	0.10 0.24	0.64
	2. Contact with ammonia (draining compressor)	1	0.24	0.24
	3. Struck by flying particles while cutting metal	1	0.10	0.10
	4. Caught in moving machinery parts during maintenance/repair activities	1	0.24	0.24
Slips/Falls of Persons	1. Fall to lower level during maintenance/repair activities	3 3	0.10 0.24	1.02
	2. Trip/fall over hoses	1	0.24	0.24
	3. Fall from ladders during maintenance/repair activities	1	0.10	0.10
	4. Fall against metal while cutting steel	1	0.24	0.24
Handtools	1. Struck by tools during maintenance/repair activities	6 3	0.10 0.24	1.32
	2. Struck by flying particles during maintenance/repair activities	2	0.10	0.20
	3. Overexertion cutting cable	1	0.24	0.24
Fall of Face/Wall	1. Struck by falling rock during repair/cleanup activities	1 3	0.10 0.24	0.82
	1. Struck by falling tools/objects during repair/cleanup activities	1 3 1	0.10 0.24 100.00	100.82
Stepping/Kneeling on Objects	1. Stepped on nail during repair/cleanup activities	1	0.10	0.10
Haulage	1. Struck by skip during maintenance/repair activities	1	0.24	0.24
	2. Struck by mucker machine parts during maintenance/repair activities	1	0.24	0.24
Electricity	1. Contact with electric current when connecting ground strap	2	0.24	0.48
	2. Electric burn when checking control panel	1	0.24	0.24
Explosion of Gas	1. Methane fire during welding - operations stopped before explosion	1	0.10	0.10
				210.10

TABLE D-21. Relative Assets and Liabilities of Maintenance Operations in the Impactor System

Primary Cause	R_i	Assets	W_{Ai}	Liabilities	W_{Li}	R_I
Handling Materials	1.32	1. Less time required to complete shaft	0.81	More equipment parts to maintain	1.50	1.60
	100.10	2. Less time required to complete shaft	0.81	More equipment parts to maintain	1.50	24.32
		Less time on shaft bottom	0.20			
	0.24	3. Less time required to complete shaft	0.81	None	1.0	0.19
	0.24	4. Less time required to complete shaft	0.81	More equipment parts to maintain	1.50	0.29
Machinery	0.58	5. Less time required to complete shaft	0.81	More equipment parts to maintain	1.50	0.70
	0.64	1. None	1.0	More equipment parts to maintain	1.50	0.96
	0.24	2. Less time required to complete shaft	0.81	More equipment parts to maintain	1.50	0.29
	0.10	3. None	1.0	None	1.0	0.10
	0.24	4. Less time required to complete shaft	0.81	More equipment parts to maintain	1.50	0.29
Slips/Falls of Persons	1.02	1. Less time required to complete shaft	0.81	More equipment parts to maintain	1.50	1.24
	0.24	2. None	1.0	More hoses present	1.50	0.36
	0.10	3. Less time required to complete shaft	0.81	More equipment parts to maintain	1.50	0.12
	0.24	4. None	1.0	None	1.0	0.24
Handtools	1.32	1. Less time required to complete shaft	0.81	More equipment parts to maintain	1.50	1.60
	0.20	2. Less time required to complete shaft	0.81	More equipment parts to maintain	1.50	0.24
	0.24	3. None	1.0	More cable requirements	1.50	0.36
Fall of Face/Wall	0.82	1. Less time required to complete shaft	0.81	More equipment parts to maintain	1.50	0.20
		Less time on shaft bottom	0.20			
Sliding/Falling Objects	100.82	1. Less time required to complete shaft	0.81	More equipment parts to maintain	1.50	24.50
		Less time on shaft bottom	0.20			
Stepping/Kneeling on Objects	0.10	1. None	1.0	None	1.0	0.10
Haulage	0.24	1. Less time required to complete shaft	0.81	More equipment parts to maintain	1.50	0.06
		Less time on shaft bottom	0.20			
Electricity	0.24	2. Less time required to complete shaft	0.81	More equipment parts to maintain	1.50	0.29
	0.48	1. None	1.0	None	1.0	0.48
Explosion of Gas	0.24	2. Fewer routine checks required	0.81	none	1.00	0.19
	0.10	1. Fewer welding operations downhole	0.60	More equipment parts to maintain	1.50	0.09

needed, and the more likely it becomes that major repairs will be required. The impactor system will require about 1040 shifts to complete construction of the assumed shaft. Conventional systems require about 1290 shifts to complete a similar shaft. This relative factor, $1040/1290$, or 0.81, is applied as an asset for the impactor system.

The impactor also has liabilities, however, in that there is more equipment requiring maintenance. The impactor system is estimated to have 1.5 times as many major subsystems requiring maintenance as conventional systems. This weighting factor is applied as a liability for the impactor system.

2. Struck by muck during maintenance. Repairmen are exposed to the maintenance function for shorter periods of time in the impactor system because less time is required to complete the shaft project. The weighting factor for this asset, 0.81, was developed above and is applied here. The impactor system has other assets, however, because crew members are not required on the shaft bottom and are somewhat protected from injuries from falling or sliding muck. The potential for being struck by muck while working on the impactor machine appears to be equivalent to required repairs in a conventional system on a Cryderman mucker or the gallows. However, it is anticipated that the impactor system will require about half as much time on the shaft bottom for repair activities as is required in conventional systems. Assuming that repairmen in conventional systems spend about 40% of their maintenance time at the shaft bottom, the weighting factor for the impactor system becomes $(0.40)(0.50)$, or 0.20. This factor is applied as an asset here.

The impactor system also has a liability since it has more equipment potentially requiring maintenance. This factor, 1.5, which was discussed above, is applied as a liability here.

3. Contact with acid. There is no perceived difference between the two shaft sinking systems for this accident sequence, other than a shorter project completion time for the impactor system. The weighting factor for this asset, 0.81, which was developed earlier, is applied here.
4. Fall to lower level. Slips or falls while handling materials can occur in both shaft sinking systems. However, there is less time required for shaft completion using the impactor system, which is assumed to correspond to less routine-type maintenance. The weighting factor developed above for this asset, 0.81, is applied here. A liability for the system exists, however, since more equipment parts are present that require maintenance, relative to conventional systems. The weighting factor of 1.50, discussed earlier in this section, is applied here as a liability.
5. Overexertion lifting equipment. The impactor system requires less time to complete the shaft than a conventional system. This asset is assumed to correspond to less required maintenance. A weighting factor of 0.81 has been developed to account for this system asset and is applied here. However, the impactor system requires the repair/inspection of more major subsystems than a conventional system. A weighting factor of 1.50 has been developed to account for this system difference, and is applied as a liability here.

Overall, the risk of material handling accidents may be reduced by almost 85% with use of the impactor system. This risk reduction is achieved by fewer requirements for repair activities on the shaft bottom.

Machinery

This accident category includes injuries resulting from operating machines, as well as injuries from flying particles set in motion by machinery.

1. Burns from welding. The amount of major repairs requiring welding are anticipated to be about the same in both systems. However, the

impactor system has more equipment that may require major repair. A liability weighting factor of 1.50, to account for this greater amount of equipment, is assigned here.

2. Contact with ammonia. This activity may be a function of the amount of time the equipment is required to operate. The impactor system has an asset here relative to conventional sinking since it allows faster shaft completion. A factor of 0.81, which was developed above, is applied here to account for this positive system characteristic.

However, the impactor system also requires more equipment than conventional sinking. A relative factor of 1.50, discussed previously in this section, is applied here to reflect this system liability.

3. Struck by flying particles. There is no anticipated difference between the two shaft sinking systems for this accident sequence. The necessity for metal cutting is expected to be similar in both settings. Weighting factors of one are thus assigned here.
4. Caught in moving machinery. As discussed earlier, the impactor system is anticipated to require less routine maintenance because of shorter project completion times. The weighting factor for this asset, 0.81, was developed earlier in this section and is applied here. The impactor system also has a liability, however, in that there are more major subsystems requiring maintenance. The weighting factor applied for this liability, 1.50, is developed in the section on Calculations.

Overall, the use of the impactor system may be expected to increase the risk of machinery-related accidents in conventional maintenance operations by about a third. The increased risk is primarily due to the larger number of equipment parts to be maintained in the impactor system.

Slips/Falls of Persons

This accident category includes all injuries due to slips and falls other than those involving haulage vehicles.

1. Fall to lower level. Because the impactor system allows earlier completion of the shaft project, there will be less routine maintenance required. The weighting factor used for this asset is related to the completion time, or 0.81. This factor was developed earlier in this section and is applied here. A liability for the impactor system also exists, however, since it has more equipment parts that require maintenance. An estimated factor to account for this system characteristic is developed in another section of this report, Calculations. That factor, 1.50, is applied here.
2. Trip/fall over hoses. Although the repair crew in the impactor system is not exposed much to the shaft bottom, it is possible to trip over the many hoses present on the galloway decks. In fact, the impactor system is anticipated to require more hoses than in conventional systems. It was assumed that the increase in hose required was correlated with the increase in major equipment subsystems for the impactor. Thus, a factor of 1.50 is applied to reflect this system liability.
3. Fall from ladders. The impactor system is anticipated to require less routine maintenance than conventional systems, because the shaft is completed faster. The weighting factor for this asset, 0.81, was developed earlier in this section and is applied here. However, there are more equipment parts requiring maintenance in the impactor system. A weighting factor to account for this difference, 1.50, is applied as a liability for the impactor.
4. Fall against metal. There are no system characteristics that are anticipated to reduce the risks of this accident sequence. The weighting factors assigned here are none.

Overall, the risk of slips or falls experienced in conventional maintenance operations is expected to increase by about 23% with use of the impactor system. This increase is primarily a result of more equipment requiring maintenance.

Handtools

This accident category refers to injuries incurred while using, and as a direct cause of, a nonpowered handtool.

1. Struck by tools during maintenance. The impactor system is anticipated to require less routine maintenance than a conventional system, on a total time-spent basis, because the shaft should be completed in less time. The weighting factor applied to this asset is 0.81. This number accounts for the relative shaft completion times between the impactor and conventional systems. However, there are more parts to maintain in the impactor system than may generally be expected to exist in conventional systems. A weighting factor of 1.50, developed in Calculations, is applied here to reflect this system liability.
2. Struck by flying particles. The weighting factors applied to this accident sequence are the same as referenced above. Although the impactor system may require less total time in routine maintenance than conventional shaft sinking systems, it has more equipment components to maintain.
3. Overexertion. There are no assets anticipated for this accident type. However, there may be more cable required in the impactor system. A liability factor of 1.50 is applied here to reflect this potential system liability.

The use of the impactor system may be expected to increase the risk of accidents with handtools associated with conventional systems by about 25%, because there are more equipment parts to maintain.

Fall of Face/Wall

The potential for injuries from a fall of rock are present in both shaft sinking systems. However, less total time is expected to be spent in the impactor system on cleanup and repair work since the shaft is completed faster than with conventional methods. Also, crew members in the impactor system spend less maintenance time on the shaft bottom than in conventional systems. Weighting factors of 0.81 and 0.20, respectively, are applied here to reflect these system assets. These weighting factors were developed earlier in this section.

Use of the impactor system is expected to reduce the potential for injuries from rock falls by almost 45% because of a reduced exposure of crew members to the shaft bottom.

Sliding/Falling Objects

The potential for injury from sliding or falling objects exists in both shaft sinking systems. However, using the same reasoning and weighting factors as discussed above in the Fall of Face/Wall accidents, use of the impactor may reduce the risk from this accident type by as much as 75% relative to the conventional shaft sinking system.

Stepping/Kneeling on Objects

Although crew members are not exposed to the shaft bottom much in the impactor system, there is still a potential for stepping on nails while working on the galloway decks. There are no anticipated differences between the impactor and conventional shaft sinking systems that would affect risks from this accident sequence. Weighting factors of one are thus assigned here. Use of the impactor system is not anticipated to change the risks of stepping on objects that are currently being experienced in conventional systems.

Haulage

This accident category refers to all injuries caused by haulage equipment or during haulage.

1. Struck by skip. Although it is possible to be struck by a skip during maintenance operations in the impactor system, certain characteristics of the system act to reduce the risk of this accident type. First of all, the shaft is completed faster with the impactor system, exposing the crew to less total required routine maintenance operations. Also, use of the impactor requires less time on the shaft bottom during maintenance, where it may be more likely to be struck by a swinging bucket or skip. The weighting factors for these assets were developed earlier in this section. These numbers, 0.81 and 0.20, respectively, are applied here.

The impactor system also has a liability, however, in that there are more equipment parts to maintain in the system. A weighting factor of 1.50 is applied here as a liability.

2. Struck by mucker machine parts. Part of the impactor machine is somewhat similar in basic mechanical operation to a Cryderman mucker. Thus, there is no real difference in the potential for injuries during maintenance. Although the impactor system requires less routine maintenance, because of faster shaft completion, there are more parts to maintain on the more complex impactor machine. Weighting factors of 0.81 and 1.50, developed earlier in this section, are applied here as assets and liabilities, respectively, for the impactor system.

Use of the impactor system is expected to reduce the risks of haulage-related accidents during maintenance operations in conventional shaft sinking systems by over 25%. This reduction in risk is achieved by requiring less time on the shaft bottom.

Electricity

This category of accident refers to injuries incurred as a result of contact with electric current or from electric arcs or flashes.

1. Contact with electric current. The potential for this accident type is present in both shaft sinking systems. There are no differences in system characteristics that are anticipated to affect the risks encountered here. Weighting factors of one are thus applied.
2. Electric burn. Both systems require control panels to be checked. However, fewer routine checks are required using the impactor system since the shaft is completed in less time. A weighting factor of 0.81 is assigned to reflect this system asset. No liabilities are anticipated to exist for the impactor system relative to conventional shaft sinking for this accident type.

Use of the impactor may reduce the risks of electrical accidents during maintenance operations by a small percent because of reduced crew exposure.

Explosion of Gas

The potential for explosions during welding operations from methane gas exists in both shaft sinking systems. However, most major maintenance work on the impactor will be done in surface shops, rather than downhole. It is assumed that the impactor system will require only 60% of the welding downhole that is required in conventional systems. This factor is applied as an asset here. However, there are more equipment parts to maintain in the impactor system. A factor of 1.50 developed in Calculations is applied as a liability here.

The risk of explosion may be decreased slightly with use of the impactor system because more welding will take place in surface shops rather than downhole, as with conventional systems.

Summary

The risk of maintenance operations in conventional shaft sinking systems may be reduced by as much as 70% with the use of the impactor system. This reduction is primarily a result of less crew exposure to hazards because of less time required doing routine maintenance operations. Also, there is less crew exposure to the shaft bottom during maintenance operations with the impactor system, reducing the risks associated with those exposure hazards.

Shaft Wall Support

Shaft wall support is accomplished in the same manner for both conventional and impactor shaft sinking systems. Permanent support consists of a concrete lining. Temporary support, including timbers, rock bolts, wire mesh or gunite, may also be required, depending on the ground conditions. The average height of unlined wall in both systems is about 40 feet.

The accidents experienced in conventional shaft wall support operations are listed in Table D-22. The primary sources of injuries are from material handling. Since shaft wall support activities are the same for both the impactor and conventional systems, there is no reason to believe that the systems have a difference in safety features. Although the impactor system is not necessarily safer than conventional shaft wall support operations, the system should be at least as safe. The relative risk of shaft wall support accidents for the impactor system is anticipated to be the same as that for conventional shaft wall support activities.

Shaft Dewatering

Large amounts of water inflow are often encountered in shaft sinking projects. If an aquifer is intercepted, an electrical or air-driven pump is lowered from the galloway stage and placed on the shaft bottom for dewatering. Both the impactor and conventional shaft sinking systems use

TABLE D-22. Shaft Wall Support Accident Causes in Conventional Shaft Sinking Systems (from 1978-1980 data)

<u>Primary Cause</u>	<u>Secondary Causes</u>	<u>Number of Injuries (f_i)</u>	<u>Injury Severity (c_i)</u>	<u>Risk (R_i)</u>
Handling Materials	1. Caught between steel and bucket-installing supports from bucket	1	0.24	0.24
	2. Struck by drill steel-handling drill	2	0.24	0.48
	3. Struck by falling/flying objects when installing temporary wall support	1 3	0.10 0.24	0.82
	4. Overexertion handling timber	1 1	0.10 0.24	0.34
Machinery	1. Struck by/caught between moving machinery parts	3	0.10	0.30
	2. Struck by falling rock while drilling	1 3	0.10 0.24	0.82
Slips/Falls of of Persons	1. Fall while installing temporary wall support	3	0.24	0.72
Sliding/Falling Objects	1. Struck by falling timber when installing temporary wall support	1 1	0.10 0.24	0.34
Fall of Face/Wall	1. Struck by caving rock while installing temporary wall support	1 1	0.10 0.24	0.34
				4.40

essentially the same set-up for dewatering operations. However, in the impactor system, the pumps can be lowered and placed on the shaft bottom without a man at the bottom by using galloway-mounted winches or tuggers and the moving capability of the mucker boom.

In conventional shaft sinking, accidents during dewatering operations occurred primarily while moving or setting up the pumps. The primary accident causes are listed in Table D-23. The relative assets and liabilities of the impactor system, compared to conventional accident causes, are presented in Table D-24 and discussed below for each accident cause category.

TABLE D-23. Shaft Dewatering Accident Causes in Conventional Shaft Sinking Systems (from 1978-1980 data)

Primary Cause	Secondary Causes	Number of Injuries (f_i)	Injury Severity (c_i)	Risk (R_i)
Machinery	1. Struck by moving pump parts	1	0.10	0.34
		1	0.24	
Handling Materials	1. Overexertion moving pump/hose	1	0.10	0.10
	2. Dropped pump while moving it	1	0.10	0.10
				0.54

TABLE D-24. Relative Assets and Liabilities of Shaft Dewatering Operations in the Impactor System

Primary Cause	R_i	Assets	W_{Ai}	Liabilities	W_{Li}	R_I
Machinery	0.34	1. No men required on shaft bottom	0.01	None	1.0	--
Handling Materials	0.10	1. Pumps moved by machinery, not men	0.01	None	1.0	--
	0.10	2. Pumps moved by machinery; no men required on shaft bottom	0.01	None	1.0	--
					0.54	negligible

Machinery

This accident category includes injuries received while operating machines or from flying particles set in motion by machinery.

1. Struck by moving pump parts. The potential for being struck by moving pump parts during dewatering in the impactor system is extremely small because no men are required on the shaft bottom. An asset weighting factor of 0.01 is assigned here to reflect the low likelihood of this event in the impactor system.

The potential for machinery-related accidents during dewatering in the impactor system is insignificant because men are not required to be on the shaft bottom and are thus not in proximity to the pump, either during placement or operation.

Handling Materials

This accident category refers to injuries incurred while lifting, moving or installing supplies or materials, including small equipment components.

1. Overexertion moving pump. The potential for this accident in the impactor system is extremely small. The pumps are moved using winches and the mucker boom. Men are not required at the shaft bottom to move the pump. A weighting factor of 0.01 is assigned as an asset for the impactor system to reflect the low probability of this event.
2. Dropped pump while moving. The potential for injury from this accident sequence is very low in the impactor system because men are not required at the shaft bottom either during pump placement or operation. A weighting factor of 0.01 is assigned as an asset for the impactor system to reflect the low probability of this event.

The potential for materials handling accidents during dewatering is insignificant in the impactor system, relative to conventional techniques, because men are not required at the shaft bottom either during pump placement or pump operation.

Summary

Overall, the potential for accidents during shaft dewatering in the impactor system is very low compared to conventional systems. This is primarily because of a reduced crew exposure to the pumps. The dewatering pumps are moved to the shaft bottom using machinery. Also, during pump operation and consequent shaft sinking, men are not required at the shaft bottom. Thus, the risk of accidents and injury during dewatering operations in conventional shaft sinking is greatly reduced by use of the impactor system.

Ventilation

The ventilation function in shaft sinking basically involves getting sufficient air down the shaft to dilute any noxious gases and provide the men with an adequate level of oxygen for work downhole. This is done, for both the conventional and impactor systems, by using an axial flow fan or fans in series to blow air through a 24 to 36 inch diameter pipe that extends through the shaft.

In almost three years of accident data examined for metal/nonmetal shafts, there were two injuries directly attributable to inadequate ventilation. These accidents are listed in Table D-25. It was determined that the impactor system could experience accidents from suffocation, in addition to those classed under miscellaneous. However, because suffocation is also possible in conventional systems, and is really the most severe result of the listed miscellaneous causes, it will not be listed separately here. The relative assets and liabilities of the impactor system, compared to conventional accident causes during ventilation, are presented in Table D-26 and discussed below for each accident cause category.

TABLE D-25. Ventilation Accident Causes in Conventional Shaft Sinking Systems (from 1978-1980 data)

<u>Primary Cause</u>	<u>Secondary Causes</u>	<u>Number of Injuries (f_i)</u>	<u>Injury Severity (c_i)</u>	<u>Risk (R_i)</u>
Miscellaneous	1. Overexposure to gas	1	0.10	0.34
		1	0.24	
				0.34

TABLE D-26. Relative Assets and Liabilities of Ventilation Operations in the Impactor System

Primary Cause	R_i	Assets	W_{Ai}	Liabilities	W_{Li}	R_I
Miscellaneous	0.34	1. Less men downhole Less time downhole	0.75-0.83 0.81	None	1.0	0.21-0.23
	<u>0.34</u>					<u>0.21-0.23</u>

Miscellaneous

This category of accident refers to injuries incurred in shaft sinking that do not fit into any other primary cause category.

1. Overexposure to gas. The potential for exposure to noxious gases is present in any underground environment. However, the impactor system has some characteristics, relative to conventional shaft sinking, that reduce exposure factors to the underground environment.

First of all, the impactor shaft sinking system generally requires fewer men downhole during project performance. A downhole crew of from 3 to 5 men is expected to be required, as compared to the crew of from 4 to 6 men required downhole in conventional systems. This relative factor, 0.75-0.83, is applied as an asset for the impactor system.

Secondly, the time required to complete a shaft using the impactor is less than that required using conventional shaft sinking methods. The total number of shifts required from mobilization through demobilization using the impactor machine is about 1040 shifts; 1290 shifts are required to complete the shaft with conventional methods. The relative time requirement is used as measure of relative exposure to the underground environment. This number, 0.81, is assigned as an asset for the impactor system. No liabilities were determined to exist for the impactor system relative to conventional shaft sinking.

The potential for accidents as a result of ventilation operations is estimated to be reduced in the impactor system by the relative reduction in exposure, or by a range of from 61 to 67%.

Communication

Conventional shaft sinking operations use a communication system consisting of a wire rope connected at the shaft collar level to a mechanical (gong or bell) signal. An electrical switch on the arm of the mechanical signal relays the signal to the hoist operator through an electric light bulb. Signals are thus transmitted to the hoist operator both audibly and visually.

The same bell-wire communications system is used in the impactor shaft sinking system. In addition, an electrical bell signal system extends from the galloway to the surface. A two-way telephone system is also available as a backup communications system.

Historically, only two accidents have occurred over almost three years as a result of communication efforts in metal/nonmetal shafts. These accidents are listed in Table D-27. The relative assets and liabilities of the impactor system, compared to conventional accident causes, are presented in Table D-28 and discussed below. Potential accidents during communications were attributed to events where the act of communication was the source or cause of injury. Accidents caused by unclear communication during other shaft sinking activities are discussed in the relevant sections of this report.

TABLE D-27. Communication Accident Causes in Conventional Shaft Sinking Systems (from 1978-1980 data)

Primary Cause	Secondary Causes	Number of Injuries (f_i)	Injury Severity (c_i)	Risk (R_i)
Slips/Falls of Persons	1. Fall from ladder - ringing hoistman	1	0.24	0.24
Miscellaneous	1. Struck by broken bell cable	1	0.10	0.10
				<u>0.34</u>

TABLE D-28. Relative Assets and Liabilities of Communications Operations in the Impactor System

Primary Cause	R_i	Assets	W_{Ai}	Liabilities	W_{Li}	R_i
Slips/Falls of Persons	0.24	1. Less men downhole Less time downhole	0.75-0.83 0.81	None	1.0	0.15-0.16
Miscellaneous	0.10	1. Less men downhole Less time downhole	0.75-0.83 0.81	Additional cable system	2.0	0.12-0.13
	<u>0.34</u>					<u>0.27-0.29</u>

Slips/Falls of Persons

The potential for slips or falls while climbing to reach the bell rope is present in both the impactor and conventional shaft sinking systems. Both systems require that the men climb ladders or other structures from some working stations to reach the communication system. However, the impactor system does have some assets relative to the conventional system in terms of a decreased exposure to hazards. First of all, the impactor system requires less men downhole. A crew of from three to five men is required, as compared to a crew of from four to six men downhole in conventional systems. This relative factor, 0.75-0.83, is applied as an asset for the impactor system.

Secondly, the time required to complete a shaft using the impactor is less than that required using conventional shaft sinking methods. The total number of shifts required for project completion using the impactor system is about 1040; with conventional techniques, about 1290 shifts are required. This relative time requirement, 0.81, is used as a measure of exposure to the underground environment, and applied as an asset for the impactor system. No liabilities were determined to exist for the impactor system relative to conventional shaft sinking.

The potential for slip/fall accidents in communication efforts is estimated to be reduced in the impactor system by a range proportional to the reduction in general exposure, or from 61 to 67%.

Miscellaneous

The potential for being struck by a broken bell cable also exists in the impactor shaft sinking system. However, the impactor system has several assets relative to the conventional system in terms of reduced exposure to accidents. As discussed above, these include smaller downhole crew requirements and less time underground. The weighting factors developed above, 0.75-0.83 and 0.81, respectively, are applied as assets for the impactor system. Liabilities for the impactor system include a second cable communication system. A weighting factor of 2.0 is assigned as a liability for the impactor system, since there is twice as much chance for a broken cable, relative to a conventional system. The risk for this accident sequence may be increased in the impactor system by from 20 to 30%, because of the increased potential source for cable breakage.

Summary

Overall, the use of the impactor system is expected to reduce the risk of accidents experienced during communication by a range of from 15 to 21%. The reduction in risk stems primarily from the reduced exposure, in terms of man-hours, experienced with the impactor system relative to conventional shaft sinking.

Demobilization

Demobilization activities involve the removal of all shaft sinking and support equipment from the shaft and the surrounding area (including foundation removal and site grading). These activities are accomplished in a similar manner for both the impactor and conventional shaft sinking systems.

The accidents experienced in conventional demobilization operations are listed in Table D-29. Additional accidents that could occur during these operations include injuries from slips and falls; material handling accidents; being struck by sliding or falling objects; haulage-related accidents; or

TABLE D-29. Demobilization Accident Causes in Conventional Shaft Sinking Systems (from 1978-1980 data)

<u>Primary Cause</u>	<u>Secondary Causes</u>	<u>Number of Injuries (f_i)</u>	<u>Injury Severity (c_i)</u>	<u>Risk (R_i)</u>
Handtools	1. Struck by tool when removing piping from shaft	1	0.10	0.10
				<u><u>0.10</u></u>

electrical shock. Although these accidents were not experienced during the years of the available data base, they should be as likely to occur in the impactor system as in conventional sinking. The impactor system, while not necessarily safer than conventional demobilization, should be at least as safe, since there are no discernable differences in demobilization techniques or hazard exposure. The relative risk of demobilization operations in the impactor shaft sinking system is thus anticipated to be the same as that for conventional demobilization activities.

Shaft Station Construction

The construction of a shaft station is done basically in the same way regardless of the sinking technique used for the shaft. Station construction is probably one of the most difficult phases of shaft sinking. It involves turning off from the vertical shaft into the horizontal tunnel openings in the mine. Wire mesh, roofbolts and gunite, a mixture of cement, water and aggregate, is required for roof and wall support. Timber props and/or lattices may also be required.

Accidents occurring during shaft station completion efforts include machinery-related injuries, accidents while handling materials, and being struck by falling or caving rock. These accidents and secondary causes are outlined in Table D-30. The operations in station completion are basically the same for both the impactor and conventional systems. There is no reason to believe that the systems have a difference in safety features, since both

TABLE D-30. Shaft Station Construction Accident Causes
in Conventional Shaft Sinking Systems
(from 1978-1980 data)

<u>Primary Cause</u>	<u>Secondary Causes</u>	<u>Number of Injuries (f_i)</u>	<u>Injury Severity (c_i)</u>	<u>Risk (R_i)</u>
Machinery	1. Struck by drill while rock bolting	1	0.10	0.34
		1	0.24	
	2. Struck by rock or flying particles while drilling	2	0.24	0.48
Handling Materials	1. Overexertion handling drill	1	0.24	0.24
	2. Struck against metal installing roof bolt	1	0.10	0.10
Fall of Face or Wall	1. Struck by falling rock while scaling	1	0.24	0.24
	2. Struck by falling rock loading drill holes	1	0.10	0.10
				<u>1.50</u>

operations are alike. Thus, although the impactor system is not necessarily safer than conventional shaft station completion, the system should be at least as safe. Some improvement in ground integrity may also be achieved by the use of the impactor for shaft sinking efforts, rather than explosives. Basically, the relative risk of shaft station completion for the impactor system is anticipated to be similar to that of conventional shaft station construction.

Miscellaneous

As at any construction site, some accidents occur while men are getting to or from work, or while they are simply moving around the working environment. The accidents occurring in conventional metal/nonmetal shaft sinking activities that could not be determined to occur during any required sinking operation are listed in Table D-31.

The use of the impactor system is not expected to affect the risks involved with these accidents other than a reduced exposure because of a faster project completion time. A conventional shaft sinking project may require about 1290 shifts to complete the postulated shaft. Use of the

TABLE D-31. Other Accident Causes in Conventional Shaft Sinking Systems (from 1978-1980 data)

<u>Primary Cause</u>	<u>Secondary Causes</u>	<u>Number of Injuries (f_i)</u>	<u>Injury Severity (c_i)</u>	<u>Risk (R_i)</u>
Slips/Falls of Persons	1. Fall on ice (surface)	1	0.24	0.24
	2. Fall off galloway	1	0.24	0.24
Handling Materials	1. Horseplay with hoses	1	15.67	15.67
Striking/Bumping Object	1. Caught on pump	1	0.24	0.24
Electricity	1. Contact with electric current	1	100.00	100.00
Miscellaneous	1. Bruised lower back	1	0.24	0.24
	2. Temperature below freezing (in shaft)	1	0.24	0.24
				<u>116.87</u>

impactor system should reduce the required construction time to about 1040 shifts, or about 81% of the time required in conventional systems. This weighting factor is appropriate for all listed accidents in this category, and will be used here.

Thus, use of the impactor system may reduce the risk of accidents from miscellaneous causes in shaft sinking by almost 20% (from 116.87 in the conventional system to 94.66 for the impactor system). This reduction in risk is achieved by a reduced exposure of men to the hazardous working environment of shaft construction because of faster project completion.

Calculations

The calculations performed for the Comparative Safety Analysis are presented in this section. These calculations were performed to provide an approximation of the amount of equipment present and requiring maintenance on the impactor relative to the amount present in conventional systems. Recognizing the simplistic approach to the calculation, these results are not meant to provide an exact value. However, the numbers are useful for generally indicating the differences between conventional and impactor shaft sinking systems.

The information used in these calculations is from system description papers developed earlier in this project.

Amount of Equipment Requiring Maintenance Downhole

The same kind and amounts of equipment are used for most shaft sinking functions in both conventional and impactor systems. The only functions where significant differences in equipment are found are rock breaking and muck loading. The equipment required for these functions that may require downhole maintenance is listed both for conventional and impactor shaft sinking systems.

The impactor system has somewhat more equipment that needs to be maintained relative to conventional shaft sinking systems. Also, because a second impactor machine cannot be available (as can a drill or another mucker) this maintenance takes on an even greater importance relative to the production schedule of the project. A general ratio for the amount of equipment required for the impactor relative to that required for conventional shaft sinking is 1.5.

Conventional (6 major items)

Jumbo drill
Air lance
Explosives/detonators
Air/water supply

Mucking machine
Hoisting system

Impactor (9 major items)

Impact hammer and boom
Rotating frame motor/drive train
Track Assembly
Center support bearing
Hydraulic system
Lube oil system
Air/water supply

Mucking boom and clam
Hoisting system

Potential Health and Safety Impacts of Occupational Exposure
To Vibration and Noise

The potential health and safety effects of occupational exposure to vibration and noise may be of some concern for the impactor system, although these impacts are also encountered in conventional shaft sinking and other mining and/or construction operations. Some research has been done in both these areas; however, it appears that use of the impactor machine may present potential health and safety impacts that have not yet been explored by ongoing research.

Vibration

Recent studies on the effects of mechanical vibration on workers has concentrated on the effects of hand-held drills and other similar tools. When using these cutting or drilling tools, a condition known as "dead fingers" or "white fingers" may occur, primarily in the fingers of the hand used to guide the cutting tool. This condition occurs when the circulation in the hand becomes impaired, and the fingers become white and numb when exposed to cold. Although this affliction is usually temporary, some cases can be sufficiently disabling that the men are forced to seek other types of work. The condition is produced by vibration while the fingers are held in a strained position, and is aggravated by chilling of the fingers at the same time.

Obviously, the above condition is much more likely to occur in conventional shaft sinking than with use of the impactor machine. However, there may be other long-term effects as a result of vibration loading absorbed by a person's legs and torso. While the health effects themselves may be minimal, such as inducing premature fatigue during a shift, the potential effects on workman productivity could be noticeable. Also, a lowered level of awareness due to fatigue could foster careless work habits and make accidents at the worksite more likely, particularly while getting out of the machine at

the end of a shift. It appears that more data is needed to fully clarify the potential effects of vibration from the impactor on the operators of the machine.

Noise

Noise levels in any shaft construction project may be extremely high, especially during drilling and mucking. Experience with the impactor machine in surface tests indicates that the muffler on the hammer is effective in keeping the noise level to below 90 dBA at 7 meters. However, it is difficult to assess the potential noise levels that may be achieved when the hammer is in the confines of a shaft, with other working equipment.

There are a variety of effects that may be experienced from noise that have a potential for affecting the health and safety of the crew. These include the masking of wanted sounds, such as communication signals or speech; auditory fatigue and damage to hearing; excessive loudness; and annoyance. If the ear is subjected to high levels of noise for a sufficient period of time, some loss of hearing may occur. Impairment of communication by noise may result in more serious accidents during the shaft sinking operation. A set of criteria for noise levels allowed in the workplace have been established to try to mitigate some of these hazards. The noise exposure standard for all mine workers is given in Table D-32. Briefly, noise becomes an occupational health problem for a miner if he is exposed to noise levels in excess of 90 dbA for more than eight hours. Moreover, exposure to noise levels higher than 115 dbA is not permitted.

The noise levels experienced with use of the impactor system may exceed these recommended exposures when in a shaft, particularly if the muffler on the hammer is damaged in any way, reducing its' effectiveness. Noise produced by the hammer will travel out in all directions; the sound waves will be reflected by the shaft walls. The total noise level in the shaft will probably be higher than anticipated because it will be a combination of both the direct and the reflected noise, as well as noise from other equipment operating in the shaft.

TABLE D-32. Permissible Noise Exposure, per Day

<u>Duration, hours</u>	<u>Noise Levels, dbA</u>
8	90
6	92
3	97
2	100
1-1/2	102
1	105
3/4	107
1/2	110
1/4 or less	115

APPENDIX E FAILURE MODES AND EFFECTS ANALYSIS OF THE IMPACTOR SHAFT SINKING SYSTEM

FMEA METHODOLOGY

The Failure Modes and Effects Analysis (FMEA) is a qualitative technique for analyzing and evaluating a design. It provides a means for a systematic analysis of all component failures and their resulting effects on a given system. First, the failure or malfunction of each component in the system is considered. The effects of the failure are then traced through the system and the ultimate effect on the system is evaluated. The FMEA methodology can be used for a variety of applications. For example, the FMEA can be used to compare competing designs; for establishing a lower bound on system reliability; as a means of identifying critical component failures; or to assist in recommending design changes for a system. For this report and for the goals of the overall safety analysis project of which this report is a part, the primary objectives of the FMEA will be to identify those components of the impactor system whose failure could be critical to the safety of the personnel and to suggest design changes to reduce the criticality of such component failures.

The main thrust of this analysis is towards those types of component failures that produce a direct hazard to personnel. However, component failures that result in major system damage or loss of system function are also considered because these failures can cause increases in maintenance and repair requirements, with resulting increased worker exposure to these operations. Although maintenance and repair hazards are not addressed in this particular analysis, they will be noted for use in other safety analyses that are being performed in this series of working papers dealing with the safety of the impactor system.

The first step in performing an FMEA is to divide the system of interest into convenient working sections, such as subsystems or functions. The components within each subsystem must also be delineated. The level of detail required in describing the system components depends on the purpose of the

analysis. For this safety analysis, which concentrates on the effects of equipment failures on personnel, it is sufficient to know that a certain piece of equipment, such as a pump, has failed. In a reliability or equipment design analysis, it may be of interest to address the failure potential of each of the pump's separate components.

It is important to achieve only that limit of resolution required to accomplish the particular analysis goal. This is especially necessary in complex systems, since the analysis effort will increase sharply with finer component resolution.

Once the components of a system have been outlined, the possible basic failure modes for each component must be identified. These failure modes are identified through the use of checklists, from experience with similar systems and from engineering judgment and intuition. A fairly comprehensive list of component failure modes is shown in Table E-1. Also included in the analysis is a listing of probable failure causes for each mode of failure and their respective probabilities of occurrence. Knowledge of component failure causes may be used as an aid in developing possible system design changes.

The final step in an FMEA is the evaluation of the effects of each failure mode identified for a component on other components in that subsystem, as well as potential effects on overall system operation. An investigation of the potential effects of component failures allows the determination of whether preventive measures should be taken. These measures are most often in the form of equipment redesign or procedural changes, although contingency action may also consist of the design of worker protection systems or the training of personnel.

Decisions on system design changes are guided by the level of criticality of a component failure. This criticality is based on the severity of effects of a particular system or component failure. For the purposes of this safety analysis, component failures that potentially result in personnel fatalities were judged to be the most severe. The criticality code used in this study is shown in Table E-1. Postulated effects of system failures ranged from potential minor injuries to potential fatalities. There was also a category

TABLE E-1. A Listing of Potential Failure Modes and
Criticality Categories for the Impactor System

Potential Failure Modes

- a. Failure to open
- b. Failure to close
- c. Failure to start when required
- d. Failure to stop when required
- e. Failure to continue operation
- f. Spurious (false or apparent) failure
- g. Degradation (excessive wear)
- h. Erratic operation
- i. Premature operation
- j. Scheduled service
- k. Scheduled replacement
- l. Scheduled downtime

Criticality Categories

- I - Potential Fatality
- II - Potential Serious Injury
- III - Potential Minor Injury
- IV - Potential Equipment Damage
or Major Downtime

for potential equipment damage. A common format for the FMEA is a columnar form with specific entries. The format used for this study is shown in Table E-2.

The first two columns of the form list the component under consideration and its function within the system. The next entry lists the basic failure modes for that component. The fourth and fifth columns list the probable causes of each failure mode and their potential likelihood of occurrence. The probability code is a means of establishing a ranking of the failure causes

TABLE E-2. FMEA Format: Sample Case

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Compressed Air Operated Pumps	Pumps stored on galloway and lowered as required to remove water in shaft	Failure to operate as required	L	- Mechanical fault (seized bearings, cracked case, etc.)	Pump cannot remove water	Shift dewatering hindered	Shaft flooding is possible	Personnel and equipment evacuation may be required if flooding occurs.	II IV	- Workman recognition	- Pumps are reliable components - Shaft flooding will be fairly slow, allowing ample time for remedial action - Pumps can be replaced easily and quickly in most cases - Periodic maintenance and inspection	Emergency evacuation procedures should be developed and practiced should unusual circumstances force shaft evacuation.
			U	- Lack of sufficient air supply								
The component whose failure is to be considered is listed here	The component's function is explained	Its specific mode of failure is identified		- Probable causes of the failure mode are listed; its probability of occurrence is listed in the previous column	The next higher assembly of component affected is identified	The effect of the failure on the subsystem	The effect of the failure on the subsystem to the entire impactor system is noted here	The effect of the subsystem failure on interfacing systems is considered here	An evaluation of the criticality of the subsystem failure on the entire system and crew is marked here	The possible ways of detecting malfunction are listed here	Existing measures which can reduce the criticality and effect of failure on the system are noted here	Any comments on unusual circumstances or effects and recommended design changes are noted in this final column.

based on their frequency of occurrence. This information can be presented in a number of ways, depending on the analysis objectives and the availability of relevant data. For example, in a reliability study, component failure rate data may be used. For the purposes of this analysis, a qualitative system of assigning probabilities was considered to be adequate. The following probability codes are used in this report:

- H - High probability of occurrence during the sinking of a typical shaft.
- M - Moderate probability of occurrence during the sinking of a typical shaft.
- L - Low probability of occurrence during the sinking of a typical shaft.
- U - Unlikely probability of occurrence during the sinking of a typical shaft.

These codes are assigned to each probable failure cause based on the analyst's knowledge of the system and engineering judgment.

The next four columns of the table deal with the effects of a component failure on other components within a subsystem, on the subsystem itself, and on the entire shaft sinking operation. An additional column is used to specify the potential effects of a component failure on any interfacing subsystems.

The tenth column of the FMEA outlines the criticality of the component failure in question. The final columns of the form list the existing failure detection mechanisms and preventive or corrective measures within the system.

Failure detection methods are identified to determine the means available to the operator or personnel on board to recognize that a component failure has occurred. Effective failure detection methods can lower the criticality of a component failure considerably, (e.g., early detection of a dewatering pump failure will allow ample time to lower replacement air pumps from the surface and prevent flooding of the shaft and damage to the impactor).

The preventive and corrective measures are those mechanisms already existing in the system (i.e., redundancies, limit switches, automatic safety devices, etc.) that work to either eliminate failure causes or to reduce their criticality. The comments section provides for a discussion of any unusual circumstances or related information which does not fit in the other columns. This column also contains any suggested design changes that might mitigate the criticality of the failure mode and component.

A separate FMEA was performed for each function of interest within the impactor system. These analyses are presented in the following section, with a brief review of relevant system description information. Summary tables are also presented for subsystems that contain critical items. These tables contain only those components found to produce hazardous effects of criticality levels I or II and for which it is not thought that sufficient mitigating measures presently exist. Design and procedural change recommendations to help mitigate these effects are listed after each component. Figure E-1 is a simplified flow chart of the decision process used to determine critical safety items in the impactor system.

The analysis of the subsystems and components of the impactor machine are presented in this section. The subsystems analyzed include the following:

- the machine assembly
- breaker boom and hammer
- mucker boom
- hydraulic system
- lubrication system
- electrical system
- compressed-air system.

The Machine Assembly

The machine assembly consists of the basic structural-mechanical components of the impactor. These include:

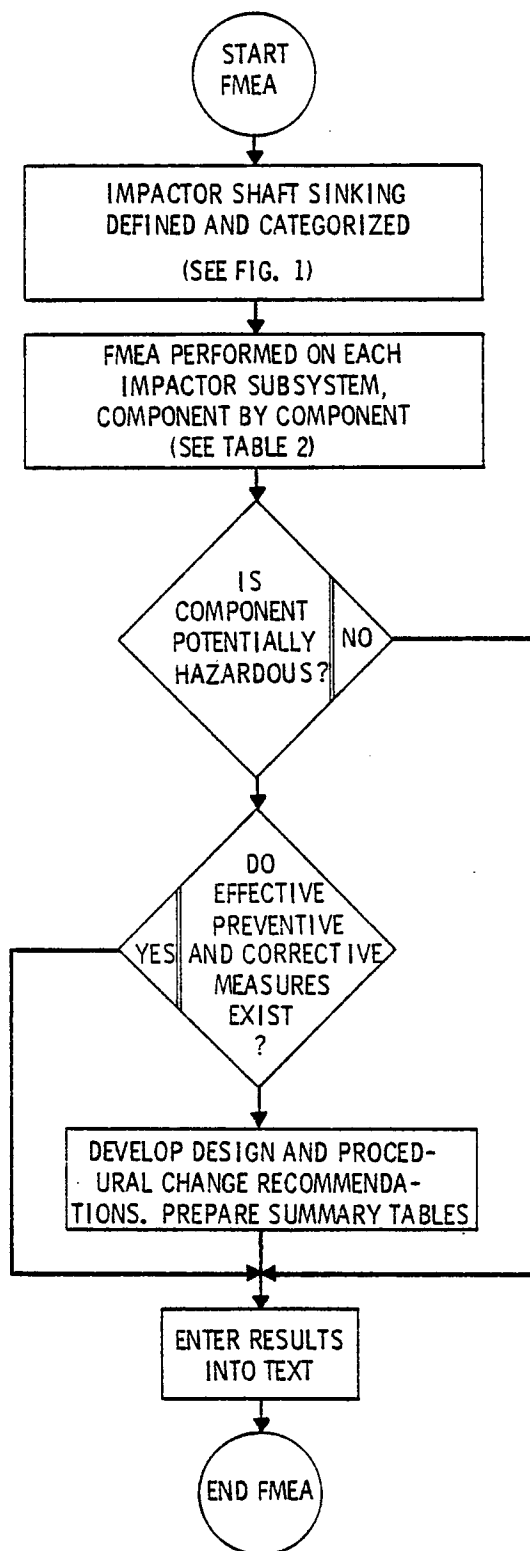


FIGURE E-1. Impactor FMEA Flowpath

1. The circular track assembly, which is mounted on the underside of the bottom galloway deck and serves to support the outer end of the rotating frame as well as provide a track in which the frame wheels rest;
2. The rotating frame assembly, which is supported in the center by a center support bearing and universal (u) joint by the galloway deck, and on the outer end is supported on wheels by the circular track; and
3. The control cab assembly, which supports the operator cabs, the motors, pumps, the pneumatic hammer boom arm, and the muck shovel arm.

The failure modes and effects analysis of this system is presented in Table E-3. The summary table of critical items is given in Table E-3S along with a brief list of any suggested design and procedural changes.

From the FMEA it was found that a failure of any of the components required to support the impactor could be potentially hazardous, since failure of these components could result in an impactor drop and possible injury or fatality to the operators from the fall. Such an event would require that the components involved suffer a complete structural failure. Fatigue failure may be a major cause of any structural failures because of the vibrational loads on the impactor system. Overstress and corrosion are also thought to be potential causes of failure. All of the structural components are, however, designed with structural safety factors and the support parts are visually inspected on a regular basis. It is therefore unlikely that an impactor drop incident will occur.

There are, however, no effective corrective measures in existence to lessen the criticality of such a structural failure if one should occur. Existing use of safety factors and proper design and fabrication is probably sufficient as a preventive means; however, at least for the first few shafts sunk, better failure detection methods are suggested to assure the detection of possible faults that may lead to structural failure later in the life of

TABLE E-3. Machine Assembly

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Circular Track Assembly	Support impactor and provide a track on which which impactor can be rotated	Track Failure	U	- Fatigue cracking	Track severely damaged	Substantial increase of load on center support. Center support failure is possible.	Impactor will pivot on universal joint until rotational limit of joint is realized or impactor strikes ground	Certain systems on board the impactor may be affected; however lighting, haulage and ventilation will remain unaffected.	I IV	- Operator recognition	- Periodic track inspection - Design safety factors - Competent engineering, testing and fabrication	
			U	- Overstressed								
			U	- Separation from galloway								
			U	- Corrosion								
		Track bent or warped	U	- Overstressed	Excess track wear and stress	Increased wear and stress on drive assembly components; universal joint will prevent bending moments from damaging center support	Impactor rotation may be hindered.	Minor	IV	- Any major track bends should be visually detectable	- Universal joint - Track-to-wheel tolerances	Track tolerances are great enough to allow some degree of track warpage without causing excessive stress or binding
			U	- Manufacturing fault								
			U	- Assembly fault								
		Track blockage	U	- Excessive dirt, etc. in drive rack	Excessive track wear and stress	Increased wear and stress on drive assembly components	Impactor rotation may be hindered; rock breaking in certain parts of the shaft may become difficult or impossible	Minor	IV	- Operator recognition	- Periodic track maintenance	
			U	- Crimping due to bent track								
			L	- Tool, etc. left in rack during maintenance, repair or assembly								
		Out-of-round track	U	- Manufacturing fault	Cyclic stress on track can cause increased wear and eventual fatigue damage	Cyclic stresses on center support and drive assembly can result in eventual support failure and wear damage to drive assembly components	Long term fatigue damage is likely (dependent on degree of track out-of-roundness) Probability of impactor drop is increased	Minor	I IV	- Visual detection (some cases)	- Periodic track inspection - Competent engineering and fabrication	Track tolerances allow for some degree of out-of-roundness without causing excessive stresses or binding
			U	- Assembly fault								
Center support assembly of the rotating frame	Provide impactor support and allow rotation of impactor	Complete structural failure of bearing or universal joint	U	- Fatigue failure	Severe damage to center support	Rotating frame cannot support impactor; impactor drop	Severe damage to impactor can result from fall	Compressed air, electrical service and telephone communication disabled	I IV	- Visual; operator recognition	- Design safety factors - Periodic frame inspection - Competent engineering, testing and fabrication	Periodic inspection of all critical support mounts, bolts, bearing, etc. should be required
			U	- Improper assembly or fabrication								
			U	- Overstressed								
			U	- Track failure								
			U	- Separation from galloway								
		Seizure of universal joint	U	- Corrosion	Bending moments from support frame, transferred to center support can cause additional stress and increase the likelihood of fatigue damage (esp. to universal joint correcting pin).	Increased stresses and bending of rotating frame and bearing	Increased probability of support failures and impactor drop	Minor	I	- Visual	- Periodic inspection - Regular maintenance	Any fatigue damage will require extended use of machine and should allow substantial time for detection
			L	- Excessive wear due to contaminants								
			L	- Loss of lubricant								
		Seizure of center support bearing	U	- Corrosion	Center support severely damaged	Rotating frame cannot rotate, increased wear on drive assembly	Impactor operation greatly hindered	Minor	IV	- Operator recognition	- Periodic inspection - Regular maintenance	
			U	- Excessive wear due to contaminants								
			U	- Loss of lubricants								

TABLE E-3. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Drive Assembly	Provide impactor support at circular track and provide motive power to rotate impactor	Failure of axle mounts or bolts	L	- Fatigue	Excess stress on wheel axles; excess wear on drive sprocket and on motor. Drive assembly damage likely	Increased likelihood of axle failure. Frame rotation hindered	Impactor rotation may be hindered.	Minor	IV	- Visual detection; inspection	- Periodic inspection	
			L	- Overstress							- Regular maintenance	
			L	- Loss of lubricant							- Design safety margins	
			L	- Poor workmanship							- Competent engineering, testing and fabrication	
		Drive motor failure to operate	L	- Basic mechanical failure	Drive assembly disabled	Frame rotation not possible	Impactor rotation hindered	Minor	IV	- Operator recognition	- Regular maintenance	
		Drive chain breakage	L	- Fatigue	"	"	"	Minor	-	"	"	
			U	- Overstress								
			L	- Wear damage								
			L	- Loss of lubricant								
		Motor or drive shaft sprocket	L	- Fatigue	"	"	"	Minor	-	"	"	
			U	- Overstress								
			L	- Wear damage								
		Wheel/sprocket axle failure (drive-shaft)	U	- Corrosion	Increased stress on drive gear. Increased stress on second wheel axle	Rotating frame not evenly supported. Increased probability that second wheel will fall and drop impactor	Impactor rotation very difficult/impossible	Minor	I IV	"	- Periodic inspection	Nondestructive testing (NDT) methods recommended during regular inspection
			L	- Fatigue							- Regular maintenance	
			U	- Overstressed							- Design safety margins	
		Drive sprocket failure	L	- Fatigue	Drive assembly disabled	Minor	Impactor rotation hindered.	Minor	IV	- Operator recognition; inspection	"	
			U	- Overstress								
			U	- Corrosion								
Rotating Frame	Support impactor cab on circular track and center support.	Structural failure	U	- Fatigue cracking	Frame severely damaged	Rotating frame cannot support impactor; impactor drop	Severe damage to impactor	Compressed air, electrical service and telephone communications disabled to impactor	I IV	- Visual; operator recognition	- Periodic inspection	
			U	- Overstressed							- Design safety margins	
			U	- Poor workmanship							- Competent engineering, testing and fabrication	
Control cab support bearing assembly	Provide support to cab and allow cab rotation.	Structural failure of bearing housing, mounts or bolts	U	- Fatigue damage	Excessive play or looseness, noise and heat. Loss of structural strength of bearing assembly	Rotation of cab could be difficult. Excess play may be noticed during impactor operation.	Likelihood of support bearing dropping; impactor is increased. Impactor fall could be fatal to operators	If impactor drops compressed air, electric and telephone service will be disconnected. Excessive play may cause problems with the slip rings.	I IV	- Visual observation	- Cab design safety factors	Periodic inspection of support bearings, mounts and bolts should be performed
			U	- Overstressed							- High margins of safety in design	
			U	- Corrosion							- Regular inspection and maintenance	
		Bearing seizure	L	- Loss of lubricant	Bearing will not rotate; excess stress on mounts and mount bolts should cab slew be attempted.	Cab cannot be rotated by cab slew device (rotating frame can still be used)	Impactor operation hindered	Minor	IV	- Operator recognition; inspection	- Regular inspection and maintenance	
			L	- Excessive contaminants							- Automatic lubrication system	
Operator's Cab	Provide work areas for operators	Structural failure of cab support, cab floor.	U	- Fatigue failure of mounts, welds or bolts due to excessive vibration	Cab loosens; excessive vibration to operator. Eventual failure and drop of cab if no remedial action is taken.	Control cab disabled	Impactor disabled	Minor	I IV	- Visual observation	- Cab design safety factors	Periodic visual inspection of cab mounts and welds should be assured.
			L	- Poor fabrication							- Cab is not a highly stressed part	
			U	- Overstress								
			U	- Corrosion								

TABLE E-3.S. Summary of FMEA Results from Table E-3

<u>Potentially Hazardous Component</u>	<u>Hazard</u>	<u>Prob.</u>	<u>Crit.</u>	<u>Do Effective Prev./Corrective Measures Exist?</u>	<u>Suggested Design Change Number (see below)</u>
Circular track assembly	Impactor drop	U	I	Y/N	1
Center support assembly	Impactor drop	U	I	Y/N	1
Drive assembly	Impactor drop	L	I	Y/N	1
Rotating frame	Impactor drop	U	I	Y/N	1
Control cab center bearing	Impactor drop	U	I	Y/N	1
Operator cabs	Operator fall	U	I	Y/N	1

-
1. The regular use of nondestructive testing techniques to evaluate the condition of critical support parts and thereby further decrease the chance of a structural failure is recommended (every 6 months).

the components. A regular inspection schedule using currently available nondestructive techniques (NDT), such as dye penetrants, magna fluxing or ultrasonic inspection would further insure the detection of any system damage. These techniques are therefore highly recommended for use with the impactor system, at least for the first few shafts to assure the design to be "fatigue-proof" or to locate fatigue-susceptible areas.

Breaker Boom and Pneumatic Hammer

The breaker boom is a hydraulically operated arm attached to the impactor cab on the end of which a pneumatic hammer is mounted. The purpose of the

assembly is to enable the impactor operator to move the hammer and apply pressure so that the rock on the shaft floor can be broken up and removed. The boom is mounted to the cab assembly by means of two welded connecting pin mounts (one for the arm and one for the main lifting cylinder).

Table E-4 shows the FMEA for the boom and hammer. None of the boom failures was expected to result in any hazard to personnel (although any component failure was capable of disabling the system) and the only hammer failure thought to be able to cause personnel injury was a failure of the muffler. Excess noise from the hammer exhaust could be harmful to the operators and may affect their performance. This critical item is shown in Table E-4.S. The muffler is not, however, a difficult part to replace, and with proper maintenance and inspection should create few problems. Ear plugs could also be considered to further reduce the noise exposure to the operators.

It is also recommended that nondestructive testing for corrosion and fatigue cracking be done periodically (every 4 months) to aid in the detection of cracks before structural failure of a boom or hammer component can occur.

Mucker Boom

The mucker boom is the second of two hydraulically operated arms attached to the impactor cab. A bucket or scoop is mounted on the end of it. The arm is connected to the impactor cab through a rotary positioning motor so that it is capable of motion both vertically and circumferentially. This enables the mucker boom operator to position the scoop behind the impact hammer while it is breaking rock or in the vicinity of the muck bucket, without having to rotate the entire cab. The mucker boom is also capable of tipping the muck scoop to aid in muck pickup and loading into the buckets stationed on the shaft floor.

The FMEA for the mucker boom is shown in Table E-5. Although failure of any of the components analyzed in Table E-5 can stop the mucking operations, none of them should create any hazard to the operators or other personnel. Periodic NDT inspection for cracking and other structural faults is recommended to aid in early detection of faults before failure can occur.

TABLE E-4. Breaker Boom

Component	Function	Failure Mode	Prob. Code	Failure Causes	Failure Effects On:			Crit. Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System				
Breaker boom	Position and hold pneumatic hammer in place during breaking	Fracture or shearing of boom pivot pins or cylinder connecting pins	L	- Fatigue	Shearing of a boom pivot pin will allow boom sections supported by this pin to disconnect. Further damage to boom and to the cylinder could result.	Pneumatic hammer disabled	Impactor cannot perform rock breaking function	Minor	IV	- Visual inspection	- Design safety margins in pin sizing - Regular maintenance and inspection - Automatic lube of pivot bearings and connecting pins
			L	- Overstress							
			L	- Excessive wear							
				- Loss of lubricant							
		Failure of main lift cylinder and boom mounts	L	- Fatigue	Failure of cylinder mounts will disable the boom. Failure of the boom mounts will disconnect the boom from the impactor and can cause further damage to boom and cylinder.	Pneumatic hammer disabled.	"	"	IV	- Visual inspection	- Design safety margins
			U	- Overstress							
			L	- Inadequate design, lubrication or assembly.							
		Failure of hammer tilt link assembly	L	- Overstressed	Boom cannot properly support the pneumatic hammer.	Pneumatic hammer disabled	Impactor cannot perform rock breaking function	Minor	IV	- Operator recognition - Visual inspection	- Design safety margins - Periodic inspection
			L	- Fatigue							
			U	- Damage by collision w/slusher boom.							
		Failure of main boom sections.	U	- Overstress	Boom bent or otherwise damaged; cannot properly support the pneumatic hammer.	Pneumatic hammer disabled.	"	Minor	IV	"	- Periodic visual checks for fatigue, corrosion or stress cracking (especially around pin holes) should be taken to aid in early detection before failure.
			U	- Fatigue							
			U	- Damage by collision w/slusher boom.							
Side Angle Positioner	To rotate hammer	Failure to operate	L	- Side angle positioner actuator failure	Side angle positioner disabled	Hammer still operable but may not be as versatile. Operation hindered.	Rock breaking hindered	Minor	IV	- Operator recognition; inspection	- Periodic inspection and maintenance
			U	- Loss of hydraulic power							
			L	- Seizing or tightening of rotating parts							
			L	- Control system failure							
			L	- Mechanical failure (i.e., axle pin, etc.)							
			L	- Locking cylinder failure							
		Failure to lock into position	L	- Locking cylinder failure	Side angle positioner disabled	Hammer cannot be used since hammer torque has no resistant force.	Rock breaking not possible	Minor	IV	"	
			L	- Seizing or binding of moving parts due to contaminants, lack of lube oil, etc.							

TABLE E-4. (Continued)

Component	Function	Failure Mode	Prob. Code	Failure Causes	Component	Failure Effects On:			Crit. Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
						Subsystem	Whole System	Interfacing System				
Pneumatic hammer	Break-up and loosen rock	Hammer failure to operate	L	- Inadequate compressed air supply	Repair of hammer may be required.	Minor	Rock breaking cannot be done	Minor	IV	- Operator recognition	- Periodic maintenance	
			L	- Internal defect or failure							- Reliable component	
		Chisel failure	U	- Material defect (i.e., improper heat treatment, inclusions, etc.)	Hammer disabled; failed chisel could create flying fragments. Hazard to operators would be minimal due to distance.	Minor	"	"	--	- Visual inspection - Operator recognition	- Quality assurance of chisel manufacture	
		Muffler failure	L	- Disconnects or is broken off.	Minor	Minor	Minor	Excess noise from hammer exhaust; potential hazard to operators	II	- Operator recognition	- Periodic inspection and maintenance	Ear protection devices may be desirable
			L	- Internal failure, wear.								

TABLE E-4.S. Summary of FMEA Results from Table E-4

<u>Potentially Hazardous Component</u>	<u>Hazard</u>	<u>Prob.</u>	<u>Crit.</u>	<u>Do Effective Prev./Corrective Measures Exist?</u>	<u>Suggested Design Change Number</u>
Pneumatic hammer	Excess noise	L	II	N/N	1, 2

1. Use of ear plugs might be considered to reduce noise level of normal operation and hazard of muffler failure.
2. Keep spare muffler parts on hand.

Hydraulic System

The impactor hydraulic system provides power to both of the hydraulically operated booms and to the cab slew (rotating) motor. Power is provided to the hydraulic system through two 30-horsepower electric motors powering two 18/7-GPM hydraulic pumps. One of the 7 GPM outlets from one of the pumps is used to provide low pressure (400 psi) fluid to the toggle or joy stick valves located in the operator cabs. These valves direct the low pressure "control" fluid to various directional control valves, which in turn direct the flow of high-pressure (2000 psi) working fluid from the other three outlets of the pumps. Figures E-2 and E-3 are simplified schematics of the impactor hydraulic system analyzed.

Table E-6 shows the FMEA for this system. The critical items from this analysis are outlined in Table E-6.S. All except one of the failure modes which are judged to be potentially hazardous to personnel involved the leakage or rupture of some component. The release of high-pressure, flammable fluid could create a fire hazard, slip/fall potential, or the hazard of being struck by high-pressure fluid or a whipping hose. It is fairly likely that leakage of hydraulic fluid will occur. Slip/fall accidents within the operators' cabs are unlikely to cause serious injuries. However, it is recommended that the cab flooring be made as slip-free as possible, with one of the various coatings and/or gratings that exist, and be kept clean.

TABLE E-5. Mucker Boom

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Mucker or Slusher Boom	Support and position muck shovel as required to remove rock broken by hammer	Fracture or shearing of boom pivot pins or cylinder connecting pins	L	- Fatigue	Shearing of a boom pivot pin will allow boom sections to disconnect. Further damage to the boom and to the cylinder could result.	Mucking shovel disabled.	Mucking operations cannot be performed	Minor	IV	- Visual Inspection - Operator recognition	- Regular maintenance and inspection	
			L	- Overstress							- Design safety margins in pin sizing.	
			L	- Excessive wear							- Automatic lube of pivot bearings and connecting pins	
			L	- Loss of lubricant								
	Failure of main cylinder and boom bracket	Failure of main cylinder and boom bracket	L	- Fatigue	Failure of cylinder bracket will disable boom. Failure of boom bracket will disconnect boom from impactor and can cause further damage to the boom and cylinder	Mucking shovel disabled	Mucking operations cannot be performed	Minor	IV	"	- Regular maintenance and inspection	Periodic NDT inspection for fatigue corrosion and stress cracking to aid in early detection before failure
			L	- Overstress							- Design safety margins	
			L	- Inadequate design, fabrication or assembly								
	Failure of rotary positioner mount	Failure of rotary positioner mount	L	- Fatigue	Boom will disconnect from impactor and drop to shaft floor, possibly further damaging boom	"	"	"	IV	"	"	"
			L	- Overstress								
			L	- Inadequate design, fabrication or assembly								
	Failure of bucket tilt assembly	Failure of bucket tilt assembly	L	- Fatigue	Boom cannot properly support or position the bucket	"	"	"	IV	"	"	"
			L	- Overstress								
			U	- Damage by collision with impactor boom								
	Failure of main boom section	Failure of main boom section	U	- Overstress	Boom bent or otherwise damaged; cannot properly support muck shovel.	Mucking shovel disabled.	Mucking operations hindered	Minor	IV	"	"	"
			U	- Fatigue								
			U	- Damage by collision with impactor boom								

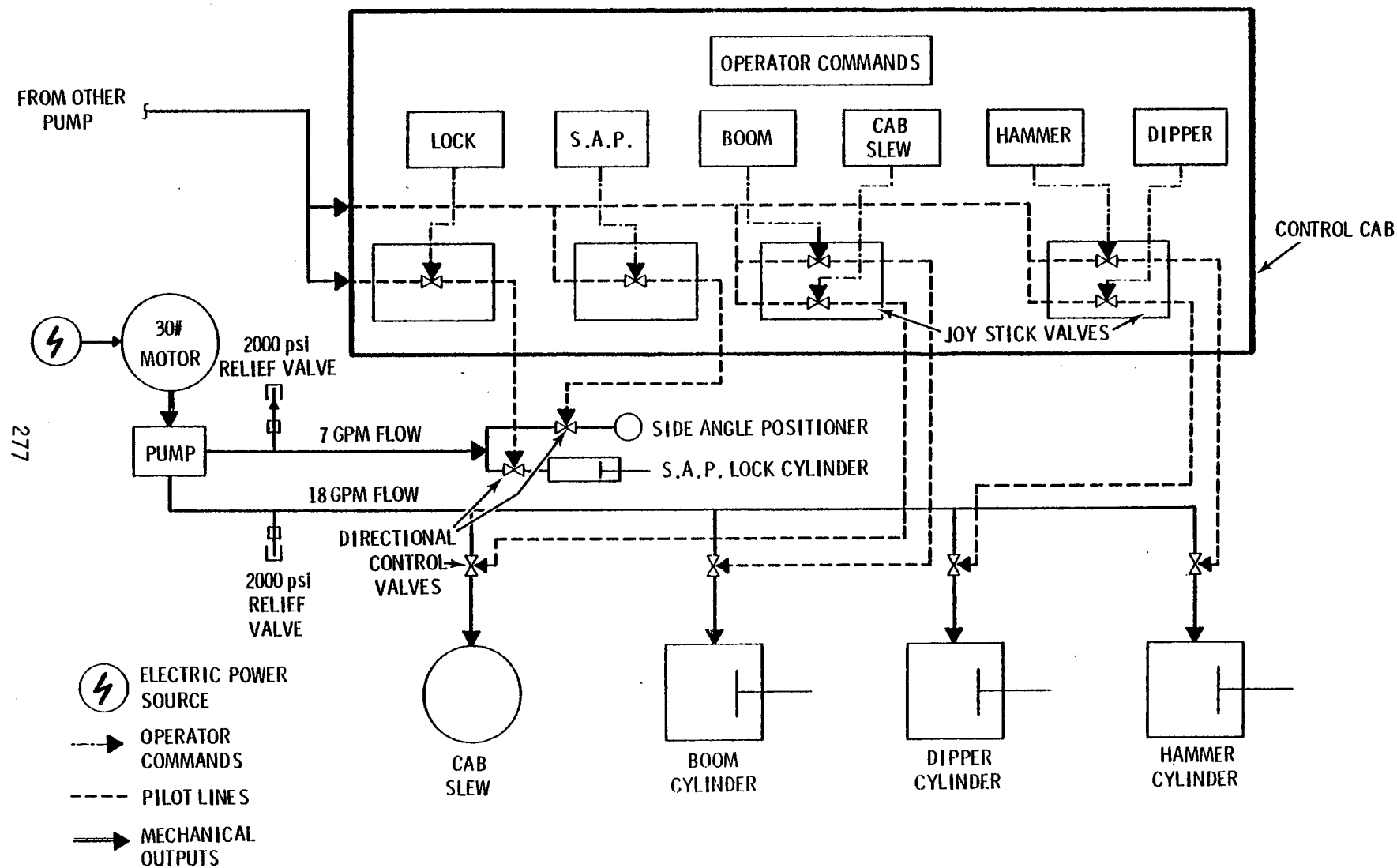


FIGURE E-2. Impactor Hydraulic Circuit

FIGURE E-3. Mucker Hydraulic Circuit

TABLE E-6. Hydraulic System

Component	Function	Failure Mode	Prob. Code	Failure Causes	Failure Effects On:			Crit. Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System				
Toggle Pilot Valves	Meter low pressure control fluid to the pilot controlled directional valves in response to a manual command	Fails in neutral mode	L	- Basic mechanical failure	Directional control valve cannot be operated	Disabling of respective cylinders or motors (i.e., failure of cab slew/impactor boom toggle valve disables cab slew motor and/or impactor boom cylinder)	Impactor operation greatly hindered	Minor	IV	- Operator recognition	- Well developed technology; well tested components
			U	- Fluid contaminants bind or plug valve							- Periodic inspection and maintenance
			U	- No pilot fluid or pressure (i.e., pump disabled)							- Fluid filtered and changed regularly to help prevent contamination
		Fails in extend or forward mode	U	- Excessive leakage of pilot fluid through valve seats	Directional control valve given extend or forward command	Respective cylinder or motor in extend or forward mode	Impactor operation greatly hindered		IV	- Operator recognition	- Pumps can be shut off quickly
			L	- Basic mechanical failure				Operator escape from cab could become hazardous			- Well developed technology; well tested components
			U	- Fluid contaminants bind valve							- Periodic inspection and maintenance
											- Fluid filtered and changed regularly to help prevent contamination
		Fails in retract or reverse mode	L	- Basic mechanical failure	Directional control valve given retract or reverse command	Respective cylinder or motor given retract or reverse command	Impactor operation greatly hindered	Cab slew stuck in reverse could damage swivel connections, etc. Operator escape could be hazardous	IV	- Operator recognition	- Well developed technology; well tested components
			U	- Fluid contaminants bind valve							- Periodic inspection and maintenance
Directional control valve	Meters high pressure hydraulic fluid to cylinders or motors in response to command from pilot valve.	Fails in neutral mode	L	- Basic mechanical failure	Valve may need repair or replacement	Respective cylinders or motors served by the valve will be inoperative	Impactor partially disabled	Minor	IV	- Operator recognition	- Well developed technology; well tested components
			U	- Fluid contaminants bind or plug valve							- Periodic maintenance and inspection
			L	- Lack of pilot fluid or pressure							- Fluid filtered and changed regularly to remove contaminants
	Fails in extend or forward mode		L	- Basic mechanical failure	"	Respective cylinders or motors served by valve will be placed in extend or forward mode.	Impactor partially disabled	If cab slew motor stuck 'on,' swivel connections, etc., could be damaged	IV	- Operator recognition	"
			U	- Fluid contaminants bind or plug valve							- Pumps can be shut off quickly
	Fails in retract or reverse mode		L	- Basic mechanical failure	"	Respective cylinders or motors served by the valve will be placed in retract or reverse mode.	Impactor partially disabled	If cab slew motor stuck 'on,' swivel connections, etc., could be damaged	IV	- Operator recognition	"
			U	- Fluid contaminants bind or plug valve							

TABLE E-6. (Continued)

Component	Function	Failure Mode	Prob. Code	Failure Causes	Failure Effects On:			Interfacing System	Crit. Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System					
Low pressure hydraulic lines and fittings	Transfer of hydraulic fluid from pumps to low pressure (400 psi) joy stick valves in operator cab.	Rupture	L	- Fatigue	Lines or fittings cannot contain pressurized fluid.	Respective control valve or equipment becomes inoperative	Impactor partially disabled	Minor	II	- Operator recognition	- Periodic inspection and maintenance	Assurances should be taken to minimize hose whip potential
			U	- Overpressure					IV			
			M	- Loose or overtightened fittings	Operator injury from fluid spray; potential fire hazard	Hose whip potential due to closeness of operators to lines					- Safety factors in hose design - Protective clothing	
		Hydraulic fluid leakage into cab work areas	M	- Loose fittings or improperly connected to hose	Minor	Excessive leakage can disable specific impactor components	Impactor operation may be hindered	Fluid is at 400 psi and could harm personnel.	III	- Operator recognition	- Hydraulic line safety factors	Assurances should be taken that all hydraulic lines are tied down to prevent hose whip injury. Cab flooring should be made as slip-free as possible.
			U	- Overpressure				Hose whip possible.	IV		- Protective clothing	
			L	- Hose fatigue				Leaking hydraulic fluid can make cab area slippery.				
Pressure relief valves	Assure that pressure in low pressure lines does not exceed 400 psi; pressure in high pressure lines does not exceed 2000 psi	Failure to open as required	L	- Gaskets, seals, etc.				Potential fire hazard.				
			U	- Sticking or binding by contaminants	Relief valve fails to release excess pressure in lines as required	Line overpressure potential increased	Potential hazard to equipment and personnel	Minor	II	- Operator recognition	- Periodic inspection and maintenance	Assurances should be taken to minimize hose whip potential
			U	- Basic mechanical fault		Line rupture hazard and hose whip potential			IV		- Safety factors in hose design - Protective clothing	
Hydraulic pumps (2)	Supply hydraulic fluid to various impactor components	Falls to supply required fluid pressure or flow	U	- Electric motor falls "off"	Pump replacement or repair may be required	Low fluid pressure	Impactor disabled	Minor	IV	- Operator recognition	- Periodic inspection and maintenance	
			L	- Excessive pump leakage (i.e., seals, etc.)		Impactor boom and/or mucker boom disabled					- Pressure gauges	
			L	- Mechanical failure								
High pressure hydraulic lines and fittings (2000 psi)	Transfer of hydraulic fluid from pumps to cylinders or motors	Rupture	L	- Fatigue	Lines or fittings cannot contain high pressure fluid.	Respective cylinder or motor disabled	Impactor partially disabled	Operator injury from high pressure fluid spray; hose whip potential, potential fire hazard	II	- Operator recognition	- Periodic inspection and maintenance	Assurances should be taken to minimize hose whip potential
			U	- Overpressure					IV		- Safety factors in hose design.	
			M	- Loose or overtightened fitting							- Operators are at a substantial distance from any high pressure lines	

TABLE E-6. (Continued)

Component	Function	Failure Mode	Prob. Code	Failure Causes	Failure Effects On:				Crit. Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Hydraulic fluid	Transmission of energy from pumps to cylinders and motors	Ignition of spilled or leaking hydraulic fluid.	U	- Electrical source (i.e., motor overheat, spark, shorts, etc.)	Burning hydraulic fluid can cause extensive damage to all machinery in control cab.	Fire hazard to personnel; fire is in a hard-to-reach area.	Impactor system disabled and most likely destroyed or severely damaged	Telephone communication could be disabled	I IV	- Operator recognition	- Hand-held extinguishers are available, but may be of little use since machine area may not be accessible by operators.	Machine area fire control system (either remotely or automatically operable) may be necessary
			L	- Mechanical source (i.e., friction, overheated bearing, etc.)	If hydraulic tank and fluid reach flash point temperature, tank fluid could also catch fire and possibly rupture tank	Should the hydraulic storage tank overheat, fluid inside may also catch fire.		Extensive harm or death could result to operators			- Water fog system available	More effective and safe emergency escape route may be required. More effective and safer fire control apparatus should be considered.
			M	- Operator error (i.e., smoking, etc.)	Toggle valves most likely destroyed if fire occurs						- Flash point of petroleum oils vary from 350°F to 450°F and spontaneous combustion will not occur until between 500°F and 700°F.	
			U	- Fire starts elsewhere and spreads to cab area (i.e., pump area, etc.)							- Emergency rope ladder to shaft floor provided so operators can exit by means of the buckets.	
			U	- Heat and/or sparks from rocks breaking								
			U	- Heat and/or sparks from rocks breaking								
Hydraulic cylinders	Provide motive power to impactor and mucker boom systems	Seized, binds	U	- Misalignment	Cylinder damage; repair or replacement required	Loss of function (i.e., impactor boom cylinder loss will result in loss of impactor boom)	Impactor partially disabled	Minor	IV	- Operator recognition	- Well developed technology; well tested components	
			L	- Excess lateral loads							- Periodic maintenance and inspection.	
			U	- Contaminants in fluid							- Fluid filtered and changed regularly to remove contaminants	
			L	- Bent rod								

TABLE E-6. (Continued)

Component	Function	Failure Mode	Prob. Code	Failure Causes	Failure Effects On:			Crit. Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System				
30 H.P. electric pump motors (2)	Supply shaft power to hydraulic pumps	Fails to hold fluid pressure	L	- Excess leakage (i.e., seals, etc.)	Cylinder inoperative; repair or replacement required	"	"	Minor	IV	"	"
		Does not respond to command	L	- Lack of or no fluid pressure (pump failure, etc.)	Cylinder inoperative	"	"	Minor	--	"	"
			L	- Control system failure							
		Rod failure	L	- Bent due to overload.	Cylinder inoperative; repair or replacement required	"	"	Minor	IV	"	"
			M	- Rod eyes fail							
		Failure to operate on demand	L	- Faulty contacts, switches, wiring	Motor damage; replacement or repair required	Impactor boom and/or mucking boom disabled	Impactor disabled	Minor	IV	- Operator recognition	- Regular maintenance and inspection
	Motor or bearing overheat		L	- Mechanical failure (i.e., bearings, shaft, etc.)							
			L	- Excessive load	Motor damage; replacement or repair may be required	Heat generated may produce a fire hazard	Impactor or mucking boom disabled	Minor	I IV	"	"
			L	- Electrical fault							
	Failure to shut off on demand		L	- Bearing failure							
			L	- Faulty contacts, switches, wiring	Minor	Emergency shut down hindered if required.	Potential hazard to personnel if emergency shut down required	Minor	III IV	"	- Regular maintenance and inspection. - Alternate means to cut power to motor exist.
150-gal Hydraulic Tank	Storage of fluid and to provide a means of fluid cooling	Leakage of tank	U	- Puncture	Spillage of hydraulic fluid, potential fire hazard	Eventual loss of hydraulic fluid	Impactor disabled	Minor	II IV	- Operator recognition	- Tank built to specific safety codes
			U	- Faulty tank							- Periodic inspection and maintenance
			U	- Corrosion	Slip-fall hazard for maintenance personnel	Low tank level may cause rise in fluid temperature					- Tank is not pressurized

TABLE E-6.S. Summary of FMEA Results from Table E-6

<u>Potentially Hazardous Component</u>	<u>Hazard</u>	<u>Prob.</u>	<u>Crit.</u>	<u>Do Effective Prev./Corrective Measures Exist?</u>	<u>Suggested Design Change Number</u>
Low pressure hydraulic lines and fittings	Hose whip	L	II	Y/N	1
	Slip/Fall hazard	M	III	N/N	3
Hydraulic fluid	Fire hazard	U	I	Y/N	1, 4
Electric motor	Fire hazard	U	I	Y/N	2

1. Assurances should be taken that all hydraulic hosing exposed or potentially exposed to personnel is tied down to prevent hose whip accidents.
2. Revised fire-control system (see "Fire detection and control" FMEA Table 15).
3. Use of non-slip floor coatings or gratings.
4. Use of nonflammable hydraulic fluid should be considered to reduce fire hazard.

The possibility of a hose whip accident and an operator being struck by either the line or high-pressure fluid is small. None of the exposed high-pressure hydraulic lines (2000 psi) run near the operators. The only lines to which the operators are immediately exposed are the lower pressure (400 psi) "control" fluid lines. These lines are partially covered and are below head and eye levels where most of the damage to personnel could occur. With proper tie-downs, these lower pressure lines can effectively be prevented from whipping if ruptured.

The fire potential from a spill of the hydraulic fluid is also quite small. Petroleum oils generally used as hydraulic fluids are not especially easy to ignite. Flash points (where the oil vaporizes) of these oils vary from 3500 to 4500F and spontaneous ignition will not occur until a temperature of 5000 to 7000F is reached. These are very unlikely

temperatures to be found in the impactor system. Although it is possible for an electric short or an overheated bearing to produce these temperatures, it is unlikely that conditions will exist long enough for ignition and sustained burning to occur. Although fire is an unlikely event, it is a possible event and carries potentially very high consequences. Changes in the fire-control system are highly recommended to mitigate these potential consequences (for details see the section on "Fire detection and control") and use of nonflammable hydraulic fluids might be considered as an alternative. No other design changes to the hydraulic system are recommended.

Lubrication System

The lubrication system is used to automatically provide lubricating oil to the rotating frame and control cab components. It basically consists of two air oilers and two air-operated lubrication pumps. A timer to trigger the pumps at pre-set intervals and injectors to meter the amount of lube oil dispensed to each station also exist in the system. Table E-7 is the FMEA of this system. Failures of this system that could cause harm to personnel involved the fire potential of the lubricant, slip/fall hazards and the possible hazards of breathing the oil mist left in the exhaust of air-operated equipment. These critical items are outlined in Table E-7.S.

The fire potential of the lubricating oil is probably quite small since there are few ignition sources and it is doubtful that any of these sources will heat the oil to its combustion point (500° to 700°F). It is unlikely that sparks or an overheated bearing would be available to or could cause ignition. Although the chances of fire are low, the consequences are very high and involve the lives of personnel as well as the potential for extensive machine damage. For this reason, an adequate, workable fire-control system and fast-escape route should be maintained. More detail on the fire hazards of the impactor is contained in the hydraulic and fire-control sections of this report.

The slip/fall hazard of oil accumulated in undesired places can be prevented by periodic cleaning and maintenance. Use of non-slip flooring can also help reduce this hazard.

TABLE E-7. Lubrication System

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Lube pumps (2)	Air operated pumps which pump grease to rotating frame and impactor cab gears, pins, bearings, etc.	Failure to pump as required	L	- Timer failure	Pumps do not supply lube oil as required.	Excessive wear of critical components (i.e., gears, pins, bearings, etc.)	Prolonged use without detection/correction will greatly damage machine.	Minor	IV	- Operator recognition	- Periodic maintenance and inspection	Some type of lube oil monitor is recommended to aid in quick detection of failures and to prevent use of machine during malfunction or failure
			L	- Out of grease						- Testing and inspection		
			L	- Pump mechanical failure								
			L	- Lack of air pressure								
		Failure to stop on demand	U	- Timer malfunction	Lube unit pumps excessive oil	Excessive use of lube oil	Minor	Minor	-	"		Detection of a spurious failure may be very difficult, allowing damage to occur before detection
Air Oilers (2)	Provide lubricated air for the frame rotation motor and the impact hammer	Underfeeds oil to air line (or no feed)	L	- Out of oil	Oiler does not suspend required oil into air stream	Respective components not lubricated. Wear damage is likely. Excess heat buildup possible with prolonged use	Eventual loss of use of frame rotation motor or hammer. Impactor system operation is hindered	Minor	IV	- Inspection and testing	- Periodic maintenance and inspection	Oil flow monitoring (especially of hammer oiler) is recommended to detect clogging or other failure as soon as possible.
			L	- Oil feed line clogged, restricted						- Operator recognition of failure.	- Oil is clean and filtered	
			L	- Improper adjustment of oil feeder							- Simple reliable components	
		Overfeeds oil to air line	L	- Improper adjustment of oil feeder (operator fault, accidental or feed valve malfunction)	Excess oil fed to air	Minor	Excess oil consumption; excess oil in air motor, hammer exhaust	Excessive oil in exhaust can be harmful to operators if breathed for a prolonged period. Oil films may accumulate on decking, ladders, controls, etc., increasing likelihood of slip/fall or other accident.	II	- Inspection and testing	- Considerable oil overfeed for a prolonged time would be required to create a hazardous environment for the operators.	
										- Operator recognition of failure	- Periodic maintenance and control	
											- Simple reliable components.	
											- Effective ventilation	
Timer	Triggers compressed air lube pump at pre-set intervals of time	Failure to operate as required	L	- Electrical fault	Timer does not trigger pump as required	Insufficient lube oil to components. Excessive wear of machine components. Premature failure of parts.	Impactor hindered or disabled.	Minor	IV	"	"	Malfunction of the timer may not be easy to detect and damage could result before detection. Some sort of pump or timer monitor would be useful.
			L	- Basic mechanical fault								
Lube oil	Provide lubrication to machine components	Ignition of lube oil	U	- Overheated components	Fire may spread and ignite hydraulic fluid	150 gal hydraulic tank may overheat, igniting fluid.	Impactor disabled. Severe damage could result; fire hazard to personnel	Telephone, compressed air and electric lines disabled	I	- Operator recognition	- See "Ignition of Hydraulic fluid" in Hydraulic section	- See "Ignition of Hydraulic fluid" in Hydraulic section
			U	- Operator error					IV			
Lube Oil Lines	Transfer of lube oil to required points	Excessive leakage	M	- Loose or over-tightened fitting	Lines allow escape of lube oil, slip/fall hazard. Fire hazard	Accumulation of lube oil on machine, insufficient lube oil pressure to lubricate specific machine components	Excessive wear of impactor components. Impactor hindered or disabled	Minor	II	- Operator recognition	- Periodic inspection and maintenance	- Reliable equipment
			U	- Hose rupture					IV			
			L	- Fatigue								
Injectors	Meters the amount of lubricant to each pin bearing on the booms	Failure to allow sufficient flow of lubricant	L	- Misadjustment	Minor	Insufficient lubrication to bearings will cause premature failure of pinned joints and bearings. Boom will be disabled should any bearing or pin fail	High frequency of pin and bearing replacement for bearing with failed injector. Impactor operation hindered	Minor	IV	- Inspection	- Periodic inspection and maintenance	- Reliable equipment
			L	- Clogging or plugging						- Operator recognition		
			L	- Insufficient pressure from lube pump								

TABLE E-7.S. Summary of FMEA Results from Table E-7

<u>Potentially Hazardous Component</u>	<u>Hazard</u>	<u>Prob.</u>	<u>Crit.</u>	<u>Do Effective Prev./Corrective Measures Exist?</u>	<u>Suggested Design Change Number</u>
Lube oil	Fire hazard	U	I	Y/N	2
Air oiler	Harmful exhaust	U	II	N/Y	1

1. Air oiler, pump, timer monitor to detect under- or over-lubrication failures.
2. Revised fire control system (see Fire detection and control).

The possible hazards of having excess oil suspended in the operator's breathing air due to the malfunction of an air oiler are effectively countered by the ventilation system. It is also doubtful that the air oilers could suspend sufficient oil in the breathing air to cause harm to personnel. Even if this event occurred it would probably require prolonged breathing before harm would be done. This would give ample time for detection of such a fault. Never-the-less, consumption of oil by the air oiler should be monitored to aid in detection of a fault.

A lube pump intermittent failure or complete failure to operate may be difficult to detect, allowing machine damage before detection. A general lube pump monitor (i.e., pressure gauge to assure that the pump receives sufficient air at proper intervals) could help to detect any major lube system failures. Individual monitoring of each injector for proper flow would not be practical; however, general monitoring of lube oil usage may give an indication of injector clogs or misadjustment (provided the lube pump is not a positive displacement type), since lube oil consumption will change with system malfunctions. Frequent inspection and testing is also recommended, since an undetected failure of this system (which lubricates many of the critical impactor support parts) could cause extensive machine damage and possible structural failures, resulting in potential injury/fatality to the operators.

Electrical System

The impactor electrical system is used mainly to provide electric power to the hydraulic pump motors and to provide downhole lighting and power to the impactor machine and controls. All power comes into the impactor by means of a transmission cable from the surface. Two sets of slip rings (one in the rotating frame and one in the cab support-bearing assembly) conduct the power from the cable to the impactor machine to allow full rotation of the impactor and rotating frame. The pump motors operate at the 480 V, 3-phase power supplied to the impactor. All lighting and the frame rotation controls operate at 110 V. A transformer in the control cab provides the necessary voltage step-down.

Table E-8 presents the results of the FMEA for this system. Failure of many of the components can potentially cause harm to personnel. This is mostly due to possible electric shock or ignition of flammable oils and lubricants. Neither of these events are likely to occur during normal operation due to the isolation of almost all electrical components from the operators and the low likelihood of an electric spark or short igniting any of the petroleum oils on board. The potentially critical items in this subsystem are highlighted in Table E-8.S.

It is possible for the transformer to fail and disable all of the downhole lighting. Although each miner carries a lamp on his hard hat, the potential of a slip/fall accident, especially during an emergency, can be greatly increased with failure of the lighting system. For this reason, some sort of emergency lighting system for escape is suggested (i.e., battery-operated lights, etc.). Most of the actual hazard of a failed electrical component, however, probably occurs during its repair. Potential accidents during repair activities are beyond the scope of this analysis.

Compressed-Air System

Compressed air is supplied to the impactor from surface air compressors. The air is transferred down the shaft by a pipe, through the galloway and into

TABLE E-8. Electrical System

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:			Interfacing System	Crit Code	Failure Detection Methods	Preventive/ Corrective Measures	Comments		
					Component	Subsystem	Whole System							
Upper & lower slip rings	Transfer electric power through rotating joints	Insufficient conduction of power	L	- Excessive corrosion	Excessive heating of slip rings can result	Loss of electrical power	Impactor hydraulic system possibly hindered or disabled; lighting system & rotation system possibly disabled; lube pump timer may be disabled	Minor	IV	- Operator recognition - Inspection	- Periodic inspection & maintenance			
			L	- Loose/faulty connections										
			L	- Excessive wear	Increased fire potential									
Transformers	Step down voltage for lighting and frame rotation controls	Failure to step down power	U	- Faulty wiring	If internal short in transformer exists replacement or repair will be necessary. Shock potential may exist	High-voltage/ amperage should trip breakers to protect 110 V-rated components	Impactor disabled; No downhole lighting or frame rotation; slip/fall potential increased; rock breaking difficult with no light.	Minor	I IV	"	- Periodic inspection and maintenance - Miners have lights on hard hats	Emergency lighting system		
			U	- Internal short										
		Failure to operate	U	- Faulty wiring	Transformer may have to be repaired or replaced	All 110 V rated components disabled	"	Minor	II IV	"	"			
			U	- Open circuit in transformer										
		Electrical wiring and switches	To provide operator control of specific impactor functions and for transfer of electric power	Loose/ faulty connection	L	- Poor installation	Faulty connections can result in overheating and excessive power consumption; fire hazard, shock hazard	Electrical equipment may not operate properly.	Impactor hindered or disabled.	Minor	I IV	- Operator recognition - Inspection	- Periodic maintenance & inspection	
					L	- Wear or fatigue from movement								
Pump motors	Provide shaft power to hydraulic pumps	Failure to operate as required	L	- Loose connection	Motor does not provide pumps with power. Loose connection or motor fault can result in overheating, shock potential, fire hazard	Minor	Impactor disabled; loss of hydraulic power	Minor	I IV	- Operator recognition - Inspection	- Periodic inspection & maintenance - Overload breaker to prevent motor wiring burn-out & excessive current draw.			
			L	- Basic motor electrical fault (i.e., brushes, etc.)										
			L	- Basic mechanical fault										

TABLE E-8.S. Summary of FMEA Results from Table E-8

<u>Potentially Hazardous Component</u>	<u>Hazard</u>	<u>Prob.</u>	<u>Crit.</u>	<u>Do Effective Prev./Corrective Measures Exist?</u>	<u>Suggested Design Change Number</u>
Transformer	Slip/fall potential	L	II	Y/N	1
Electrical wiring and switches	Fire hazard	U	I	Y/N	2
Pump motor	Fire hazard	U	I	Y/N	2

-
1. Emergency lighting system stationed near escape routes.
 2. Revised fire control system (see "Fire detection and control" FMEA).

the rotating frame by means of an air swivel. In the rotating frame are located two disc brakes (to prevent rotation of the frame during trenching, cab slewing or other impactor operations); an air motor (for frame rotation); an air-operated lubrication pump (for frame pins and gear lubrication); an air oiler (to lubricate the air supply to the air motor); and all associated valves for control. A second swivel is used to direct air into the impactor cab assembly. A second lubrication pump and air oiler are located on the cab to provide lubrication to the boom pins, hammer, cab bearings, gears, etc. The impact hammer and an override foot valve for it, which are also powered by compressed air, are also on board the cab assembly. Figure E-4 shows a simplified schematic of this system.

As can be seen from the FMEA in Table E-9, loss of almost any component analyzed can cause system damage or excess downtime. Nearly all of the possible failure causes are, however, of low probability or unlikely to occur. With proper inspection and maintenance, it is likely that all of the failure causes can be repaired during scheduled downtimes (i.e., shaft lining phase) before they would cause component failure. Few components were

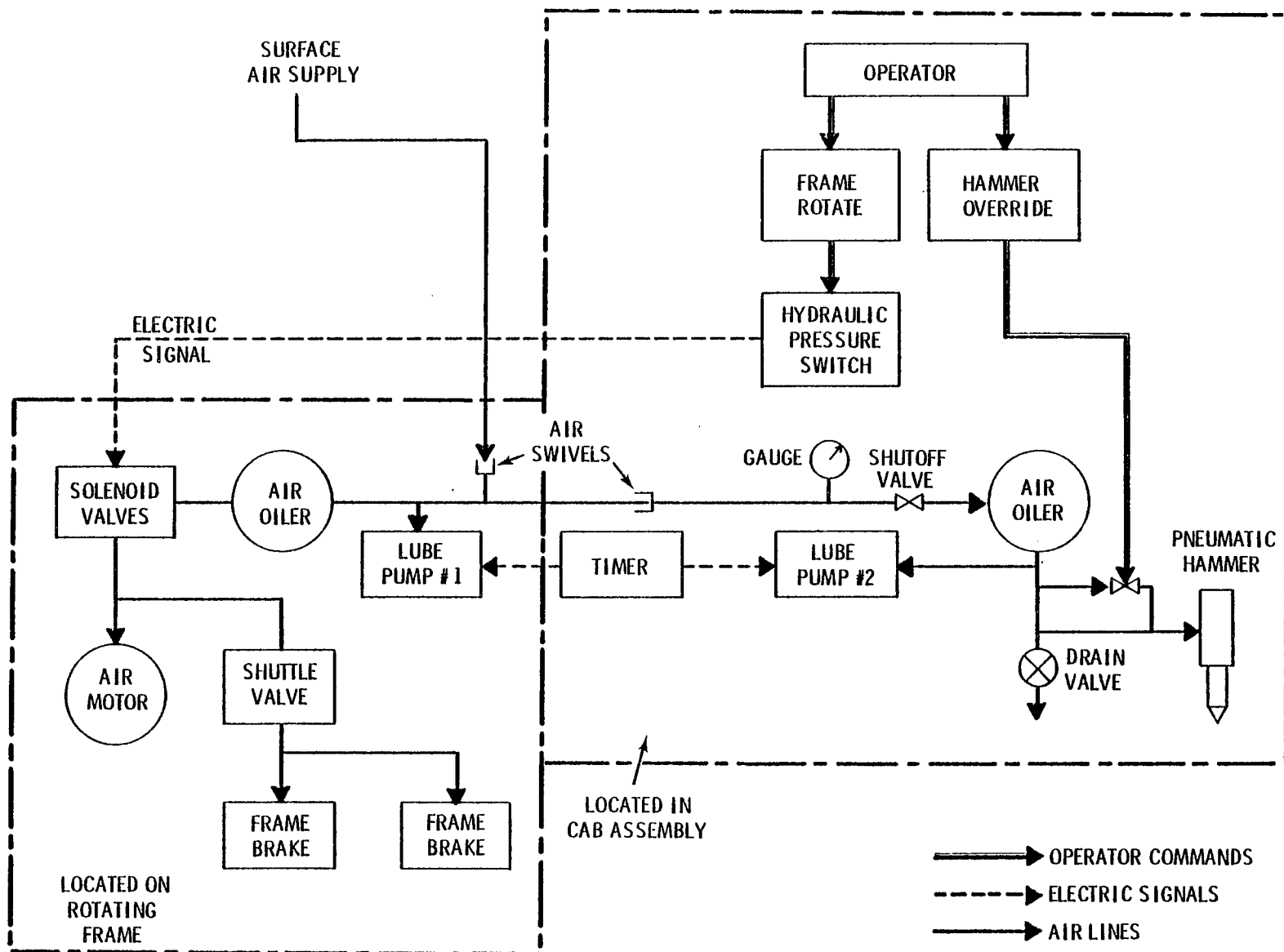


FIGURE E-4. Compressed Air System

TABLE E-9. Compressed Air System

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Air swivels	Transfer compressed air through a rotating joint	Failure to transfer air to impactor	L	- Excessive leakage (i.e., seal failure, cracked housing, etc.)	Swivel requires replacement or repair. Rotating frame drive motor disabled.	Impact hammer disabled; lube oil system disabled.	No rock breaking can occur	Minor	IV	- Pressure gauge - Operator recognition	- Periodic maintenance & inspection - Reliable component	
			U	- Plugged/clogged								
Air supply hosing and fittings	Transfer of compressed air to impact hammer, rotary position motor, and lube oil system	Hose rupture	U	- Overpressure	Hose cannot contain pressurized air.	Loss of respective system function (i.e., rupture of 2" hammer line disables hammer).	Impactor disabled or hindered	Minor	III IV	- Operator recognition	- Periodic inspection & maintenance	
			L	- Hose fatigue								
			L	- Excessive wear	Hose whip potential.						- Hose safety factors	
			L	- Fittings/clamps overtightened	Flying particles hazard (i.e., dust, small stones, debris, etc.)	Loss of air to lube pump may be difficult to detect immediately; specific impactor components could be damaged.					- Operators are not directly exposed to air hoses	
		Hose clamp failure	U	- Clamp overstressed	Clamp does not provide good seal between air hose and equipment.	Leakage of air can affect performance of air-operated equipment.	Impactor may be disabled or damaged	Minor	III IV	- Operator recognition - Inspection	- Periodic inspection & maintenance - Reliable component	
			U	- Faulty clamp								
			L	- Loose clamp	Hose whip potential	Excess leakage can disable system.					- Operators are not directly exposed to air hoses.	
		Fitting failures	L	- Fitting overtightened causing damage & leakage of hose	Fitting does not provide an efficient transfer of air from hose to equipment; increased hose whip potential				II IV	- Operator recognition - Inspection		
			M	- Loose fitting								
			M	- Hose fatigue at fitting								
Air compressor(s) (on surface)	Supply compressed air to the impactor	Failure to operate on demand	L	- Loss of power to surface facilities	Air compressors cannot keep compressed air storage tanks pressurized	Compressed air equipment downhole disabled	Impactor disabled	Minor	IV	- Operator recognition - Pressure gauges - Surface personnel	- Periodic inspection & maintenance	
			L	- Basic mechanical failure of compressor or motor								
			L	- Basic electrical fault (i.e., switches, relays, etc.)								
	Failure to stop on demand		U	- Faulty pressure relay (does not open on demand)	Air compressor runs too long.	Air supply may be overpressurized; excess strain may result on air operated equipment	Tank rupture possible but highly unlikely; hosing rupture and fitting failure more likely	Minor	I IV	- Surface personnel - Operator recognition - Pressure gauges both downhole and on surface will reveal any abnormal pressures	- Periodic inspection & maintenance - Tank & compressor safety features to prevent overpressurization - Hose safety factors	
			U	- Internal short of switch/relay to compressor motor								
	Failure to supply full power		L	- Compressor motor overheat	Compressor may not be able to keep up with required load demands.	Compressed air equipment will lack air pressure.	Impactor disabled	Minor	--	- Operator recognition - Surface personnel - Pressure gauges	- Periodic maintenance & inspection	
			L	- High altitude								
			L	- Compressor wear (i.e., rings, valves etc.)								

TABLE E-9. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Compressed air storage tanks	Provide storage for compressed air from the compressor	Rupture	L	- Fatigue	Tank cannot hold pressure.	Compressed air equipment disabled	Impactor disabled	If personnel are near tank at time of rupture, injury or death could result.	I	- Pressure gauges - Surface personnel	- Periodic inspection & maintenance - ASME pressure vessel codes & safety factors - Pressure relief valve(s)	Inspection by NDT methods
			L	- Corrosion					IV			
			L	- Overpressure								
			L	- Faulty design/workmanship/material								
Air-operated impact hammer	Break rock	Failure to operate on demand	L	- Insufficient air pressure	Hammer does not break or loosen rock as required.	Minor	Impactor disabled	Minor	IV	- Pressure gauges	- Periodic inspection & maintenance	Failure of air oiler or lube pump may be difficult to detect allowing time for damage to occur before detection.
			L	- Basic mechanical fault						- Operator recognition		
	Muffler failure		L	- Corrosion	Minor	Minor	Minor	Excessive noise from the hammer can be harmful to downhole personnel.	II	- Inspection	- Prolonged exposure will be required.	Muffler spare parts should be kept on hand. Use of ear plugs should be considered
			L	- Age, wear, degradation						- Operator recognition		
			M	- Broken off inadvertently								
Rotating frame air motor	Provide motive power to rotating frame	Failure to operate on demand	L	- Insufficient air pressure	Rotating frame cannot be rotated	Minor	Impactor operation hindered	Minor	IV	- Operator recognition	- Periodic inspection & maintenance	Failure of air oiler or lube pump may be difficult to detect allowing time for damage to occur before detection.
			L	- Basic mechanical fault								
Brakes	Brakes are automatically applied when air motors are not in use to prevent any unwanted frame rotation during rock breaking or mucking operations	Failure to disengage	L	- Shuttle valve failure	Brakes do not disengage	Rotating frame will not rotate	Impactor operations are hindered	Minor	IV	- Operator recognition	- Periodic maintenance & inspection	
			L	- Brake mechanical failure								
		Failure to engage	U	- Brake mechanical failure	Brakes do not engage	Rotating frame is not properly fixed	Impactor operations are hindered	Minor	IV	- Operator recognition	- Failsafe design. Air pressure is required to keep brakes disengaged - Periodic maintenance & inspection - Brake redundancy (both must fail)	
Solenoid Valves (4)	Used to switch air motor on	Failure to open on command	L	- Failure of pressure switch	Valve does not allow air flow to air motor	Rotating frame cannot be rotated as required	Impactor operations are hindered	Minor	IV	- Operator recognition	- Periodic maintenance & inspection	
			L	- Loose electrical connection								
			U	- Basic valve failure (sticks, etc.)								
		Failure to close on demand	L	- Failure of pressure switch	Valve cannot prevent air flow to motor	Frame rotation cannot be stopped by conventional means.	Impactor operations are hindered	Minor	IV	- Operator recognition	- Valves are designed to fail in the closed or "off" position	
			U	- Basic valve failure								

TABLE E-9. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:			Interfacing System	Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System					
Shuttle valve	Allows flow of air from high pressure side of air motor to disengage brakes.	Failure to allow flow as required	U	- Sticks in wrong position (i.e., neutral or allows flow from low pressure side only)	Shuttle valve does not allow required air flow to brakes.	Brakes remain engaged	Frame rotation hindered/not possible.	Minor	IV	- Operator recognition	- Periodic maintenance & inspection - Reliable component	
Override valve (Foot operated)	Prevents automatic operation of hammer during hammer positioning	Failure to allow flow of air to hammer on command	U	- Excessive air leakage to remote air regulator	Valve does not allow air flow to hammer	Hammer cannot be operated.	Impactor disabled	Minor	IV	- Operator recognition	- Periodic maintenance & inspection - Reliable component	
			L	- Basic valve failure (sticks, etc.)								
		Failure to stop flow to hammer	L	- Basic valve failure	Valve does not stop flow to hammer as required	Hammer positioning is hindered	Impactor hindered	Minor	--	- Operator recognition	- Periodic maintenance & inspection	
										- Operator recognition	- Periodic maintenance & inspection	

foreseen to be able to cause possible injury to the miners. The potential hazards identified were from pipe whip, flying particles set in motion as a result of pipe leak or rupture, tank rupture and excessive noise.

Pipe whip injury is an unlikely occurrence. It can be caused by anything that causes the line to rupture and freely whip about as compressed air escapes. Because there are no compressed air lines located close to the operator (except one near his feet for the hammer override valve) it is unlikely that the operator could be harmed even if a hose did rupture. Hose rupture might also cause flying particles since the compressed air is at a high pressure and can cause dust, dirt and small rocks present in the working environment to be flung at the operators. Again, however, the distance between the operators and the hoses should protect these personnel, since most flying particles will lose a considerable amount of their energy as they fly through the air. Protective clothing is also worn by the operators (i.e., gloves, eye glasses, hard hats, etc.).

The hazard presented by tank rupture is highly unlikely to occur. There are pressure-relief valves both on the compressor and on the air tanks of most conventional systems. All pressure vessels must be built to specific safety codes and be inspected regularly. They should also be designed to fail by leakage rather than by rupture so that an explosive rupture is highly unlikely. Failure of the pneumatic hammer muffler is the cause of the potential noise hazard. This component is handled in the previous Breaker Boom and Pneumatic Hammer FMEA section.

No design change recommendations were made for this system.

Haulage and Materials Handling

The haulage and materials handling system is that system involved with the transfer of personnel, muck, air and water into and out of the shaft. The system is composed basically of two subsystems. These are:

- the man/muck haulage system
- the materials handling system.

These two systems are described and their analysis presented on the following pages.

Haulage of Man and Muck

Haulage of men and muck in and out of the shaft is done primarily by means of a double drum hoist and two "shaft sinking" buckets. The galloway decks and various ladders on the galloway and impactor machine allow for transport of men within the shaft. A description of the main components analyzed for the haulage system is given in the first section of this report. These subsystems include the following:

- the headframe
- the main hoist (double-drum)
the galloway hoists
- the galloway stage
- the shaft sinking buckets
- the wire ropes and connections
- safety interlocks, such as Lilly controllers and clutch locks.

Additional information on the last two subsystems listed may be found in Appendix B.

Table E-10 presents the results of the FMEA for the impactor man and muck haulage system. Because haulage has historically been a major source of worker injury, many safety devices have been engineered into haulage systems. As can be seen from the FMEA, and the summary of critical items in Table E-10.S., a failure of almost any component can potentially result in a fatality, a serious injury, equipment damage or excess downtime. However, a number of preventive or control measures exist to reduce the possibility and/or criticality of such failures.

Headframe and/or sheave failure in such a way as to allow dropping of the galloway or buckets is very unlikely. Headframes are generally massive structures and built to withstand loads greater than that of the rope breaking strength (per M/Nm(a) regulation 57.19-35). Several federal regulations exist regarding sheave design and inspection. Any failures that might occur will most likely be due to fatigue or corrosion rather than poor design, assembly or overloading. Fatigue cracking and corrosion weakening are both

(a) M/Nm = Metal/Nonmetal.

TABLE E-10. Haulage of Men and Muck

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:			Interfacing System	Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System					
Headframe	To provide structural support to all hoist ropes, sheaves and hoisted or suspended loads	Failure of critical support struts, beams, welds or bolts	L	- Unusual loading (i.e., shock loading due to sheave failure)	Headframe may fail to support suspended loads. Collapse of headframe possible (but unlikely)	Droppage of muck buckets, muck and/or riders, galloway-impactor assembly can result.	No haulage can continue	No shaft lining, rock breaking, can be done. Extensive harm to personnel and equipment is possible.	I IV	- Inspection - Visual detection of failure by surface personnel	- Daily inspection of haulage equipment should include headframe. (However, no regulations exist which specifically require daily headframe inspection) - Structural design safety factors.	Regular inspection of headframe components for fatigue crack damage and corrosion is recommended.
			L	- Fatigue, corrosion, etc.								
			U	- Overload								
			U	- Impact (i.e., by front-end loader, truck, etc.)							- Regulations recommended (but not mandatory) that headframes be built to withstand pull by the hoist exceeding that of normal loads plus the breaking strength of one or more ropes.	
			L	- Faulty assembly								
Headframe sheaves (also axles, mounts and bearings)	Guides rope to change its direction and provides support to rope (or cable) between the load and hoist.	Skip bucket head sheave structural failure. (Includes failure of mounts or axle)	L	- Excessive wear of flange due to misalignment.	Sheave cannot bear rope.	Abrupt bucket drop is likely	Haulage functions are not possible	Extensive harm to personnel is possible	I IV	- Visual detection by top lander, hoistman or other surface personnel	- High margins of safety in sheave and rope design. - Daily sheave inspection and maintenance recommended by M/MH regulations 57.19-134 - Specific safe design specifications are given in regulations	Regular inspection by NDT technique for fatigue of mounts, axles and sheaves is recommended.
			L	- Fatigue								
			L	- Corrosion								
			U	- Overburden								
		Galloway support head sheave(s) structural failure (includes failure of mounts or axle)	L	- Excessive wear of flange due to misalignment	Sheave cannot bear rope.	Severe tipping or droppage of the galloway	Galloway haulage is not possible; bucket haulage hindered (i.e., bucket trapped under tipped or fallen galloway, etc.)	No shaft lining, rock breaking, muck loading can be done. Extensive harm to personnel and equipment is possible.	I IV	- Visual detection by top lander, hoistman or other surface personnel	- High margins of safety in sheave and rope design. - Daily sheave inspection and maintenance recommended by M/MH regulations 57.19-134 - Specific safe design specifications are given in regulations.	Regular inspection by NDT technique for fatigue of mounts, axles and sheaves is recommended.

TABLE E-10. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Shaft collar doors	Prevents men, muck or materials from accidentally falling down the shaft.	Failure to close as required	L	- Control system failure	Minor	Collar doors left open during muck dumping, man loading or unloading	Muck, materials or personnel may fall down shaft.	Death and injury hazard to personnel.	I IV	- Hoistman recognition	- Toplander can visually see the collar doors and should not allow muck dumping or man loading/unloading to occur.	Interlocks exist which prevent muck dumping while collar doors are open. Use of these should be considered
			L	- Hoistman error				Downhole equipment damage possible		- Indicator lights on control console.		
			L	- Mechanical failure (i.e., opening cylinders, hinges, etc.)							- Periodic inspection and maintenance	
		Failure to open as required	L	- Control system failure	Damage to collar doors can result (i.e., collision with skip.)	Galloway or skip could be hoisted into the collar doors.	Muck, materials or personnel may fall down shaft.	Death and injury hazard to personnel.	I IV		- Periodic inspection and maintenance	Interlocks are available which alarm or shut down hoist if conveyance approaches a closed door. Use of these should be considered
			L	- Hoistman error		Strain on haulage rope can result in rope failure.		Downhole equipment damage possible				
			L	- Mechanical failure (i.e., opening cylinders, hinges, etc.)								
Double drum hoist	Provide power to raise and lower buckets for haulage	Failure to operate as required	U	- Electric motor fails to operate as required.	Cannot move the buckets	Buckets will not move; stop in midpoint of mission	Haulage cannot continue	Men may be trapped in buckets part way up or down the shaft and attempt to escape (i.e., climb rope, jump to a nearby station, etc.)	I IV	- Hoistman recognition	- Galloway can be used to raise and lower men.	
			U	- Drum structural failure							- If properly maintained, electric motors reliable (Failure to start on command 1 x 10 ⁻⁴ to 1 x 10 ⁻³). Failure to continue operations estimated at 3 x 10 ⁻⁶ /hr to 3 x 10 ⁻⁵ hr.	
			U	- Gear reducers fail, seize							- Inspection of hoist each shift is mandatory by federal regulations	
			L	- Poor assembly or maintenance.							- Many mandatory hoist design specifications for safety are in regulations.	
			L	- Power outage								
		Failure to stop as required (overtravel)	U	- Brake failure	Minor	Conveyance overtravel can result in collision, equipment damage, rope failure, injury to personnel	Haulage system can be damaged. (i.e., bucket hoisted into head sheave, etc.)	Collision of bucket with other downhole equipment is possible. Overtravel of a landing during rider loading or unloading can put riders in a hazardous situation	I IV	- Hoistman recognition	- Lilly controller with overtravel protection.	Rider communication means to surface may be desired.
			L	- Operator error						- Rider recognition	- Inspection of hoisting apparatus each shift is mandatory per federal regulations.	
			L	- Overtravel device fails to operate							- Hoist safety devices	

TABLE E-10. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:			Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System				
Double drum hoist	Provide power to raise and lower buckets for haulage	Lowers or raises load too quickly (overspeed)	U	- Overload	Damage to hoist is possible	Rope damage, sheave damage. Overspeed can result in overtravel of landing. Safe stopping can be difficult	Haulage system can be damaged.	I IV	- Hoistman recognition - Rider recognition	- Lilly controllers are equipped with overspeed devices. - Overtravel devices	
			U	- Motor fault							
			L	- Operator error							
			L	- Overspeed device fails to operate as required.							
Main hoist overtravel device	Device (generally built into the Lilly, Simplex or other controller) which automatically cuts power to hoists and applies brakes if overtravel occurs.	Fails to stop hoist and apply brakes as required.	L	- Misadjustment	Will need repair or replacement	Conveyance overtravel can cause equipment damage as well as injury/death to personnel.	Haulage system is unsafe and should not be used.	I IV	- Visual inspection and frequent testing.	- Testing of overtravel device each shift mandatory per federal regulation.	- Dual capability system required for man haulage and muck haulage (with indicator light or interlock to indicate which mode it is in.)
			U	- Loose, worn or broken internal drive components							
			L	- Faulty limit switches (mechanical or electrical failure).							
			L	- Overtravel device in wrong mode.							
Main hoist overspeed device	Device which automatically cuts power to hoist and applies brake should overspeed of conveyance occur.	Fails to stop hoist and apply brakes as required.	L	- Contacts corroded	Will need repair or replacement	Overspeed can result in hoist, sheave, rope and other equipment damage.	Haulage system may be unsafe and should not be used.	I IV	- Visual inspection	- Testing of overspeed device each shift mandatory per federal regulation	- Overspeed device with two settings should be installed (one speed for man haulage, another for muck haulage). An indicator light should be supplied to indicate which mode device is in.
			L	- Misadjustment							
			U	- Mechanical failure of drive unit, etc.		Bucket may approach landing target too quickly for safe stopping.				- Lilly controllers are reliable and have been well proven by long use.	
			L	- Electrical or mechanical failure of switch.							
			L	- Overspeed device in wrong mode.							
Main hoist brakes	Slows or stops the motion of the conveyance.	Failure to activate on command.	L	- Structural failure of a critical component (i.e., pivot pins, pin holes, etc.)	Buckets cannot be stopped by conventional means. Motor can be used to apply some braking force.	Haulage cannot continue. Loss of control of bucket motion can result in harm to men and equipment (i.e., overtravel overspeed, etc.)	Haulage system hazardous to use.	I IV	- Hoistman recognition - Brake wear detectors	- Brake limit switches - Brake inspection mandatory each shift per federal regulations - Mandatory design regulations to ensure safe design.	
			L	- Excess pad wear							
			L	- Excess moisture (or lubricant) on pads						- Double drum hoists are equipped with one brake per drum.	

TABLE E-10. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Galloway Winches (2)	Raise and lower the galloway and impactor during shaft lining and impactor positioning.	Failure to operate on demand.	U	- Winch motor fails to start	Winch(es) will not take in or pay out rope as required	Galloway cannot be properly positioned. If one winch fails unnoticed galloway tipping can occur.	Galloway haulage is hindered	Impactor operation is hindered	II IV	- Visual	- Emergency generators can power galloway winches	Winches should be interlocked such that failure of one hoist will keep others from operating.
			L	- Sticking or binding of winch gears								
			L	- Power failure								
		Failure to stop as required (overtravel)	U	- Brake failure	Will need repair or replacement	Galloway overtravel can result in collision of impactor with the shaft floor.	Haulage system can be damaged (i.e., galloway hoisted into head sheave)	Overtravel of galloway during shaft lining can hinder operations and may put workmen in a hazardous situation	I IV	- Hoistman recognition	- Lilly controller with overtravel protection.	
			L	- Overtravel device fails to operate as required.						- Galloway personnel recognition	- Deadman brakes	
			L	- Operator error							- Inspection of hoisting apparatus each shift is mandatory per federal regulations.	
		Lowers or raises load too quickly (overspeed)	U	- Overload	Damage to hoists is likely	Rope damage, sheave damage. Overtravel and unsafe stopping can result.	Haulage system can be damaged	Personnel on galloway or in impactor may be endangered.	I IV	- Hoistman recognition	- Lilly controllers are equipped with over-speed protection and overtravel devices	
			U	- Motor fault								
			L	- Operator error						- Galloway personnel recognition		
			L	- Overspeed device fails to operate as required.								
Galloway winch overtravel device	Device which automatically cuts power to hoists and applies brakes if overtravel occurs.	Fails to stop hoist and apply brakes as required	L	- Misadjustment	Will need repair or replacement	Galloway overtravel can cause equipment damage as well as injury to personnel	Haulage system is unsafe and should not be used.	Collision of impactor with shaft floor is possible.	II IV	- Visual inspection and frequent testing	- Testing of overtravel devices each shift mandatory per federal regulations.	- Backup system
			U	- Loose, worn, broken internal drive components.								
			L	- Faulty limit switches (mechanical or electrical fault)								
Galloway winch overspeed device	Device which automatically cuts power to winches and applies brakes should overspeed occur.	Fails to stop hoist and apply brakes as required.	L	- Contacts corroded	Overspeed can damage winches	Galloway may reach end of travel too quickly to allow a safe stop.	Galloway hoisting is more hazardous without an overspeed device.	Collision of impactor with shaft floor is possible	II IV	- Visual inspection and frequent testing	- Testing of overspeed devices each shift mandatory per federal regulations	- Winches are designed for slow speed movement
			L	- Misadjustment								
			U	- Mechanical failure of drive unit, etc.		Personnel injury and equipment damage can result.						
			L	- Electrical or mechanical failure of switch								

TABLE E-10. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:			Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System				
Galloway winch brakes	Slows or stops the motion of the galloway	Failure to stop on command	L	- Brake Controller failure	Brakes cannot stop	Galloway travel likely.	Galloway damage, haulage system damage possible.	II	- Hoistman recognition	- Winch motor can be used to provide some braking force.	
			L	- Brake failure (i.e., structural, wear, wet, etc.)	Galloway as required.	Galloway haulage is unsafe		IV			
Double drum hoist wheelshaft and gears	Transmission of power from the electric motor to the drum	Structural failure of drive shaft or gears during hoisting (i.e., brake disengaged)	L	- Fatigue	Motor cannot transmit power to drum	Drum abruptly loses lifting and restraining torque. Unexpected momentary fall of bucket is likely	Loss of main haulage system. Possible further damage to system	II	- Hoistman recognition	- Overspeed, over-wind devices.	It is recommended that inspection for fatigue cracking be done regularly (especially with older hoists)
			U	- Corrosion				IV			
			U	- Excess wear							
			L	- Shock or impact loading							
Hoist clutch	Transmission of motor torque to the drum	Disengaged while hoisting (i.e., brake disengaged)	L	- Operator error	Motor cannot transmit power to drum	Drum abruptly loses lifting and restraining torque. Unexpected momentary fall of bucket is likely	Possible damage to haulage system	II	- Hoistman recognition	- Overspeed, over-wind devices.	
								IV			
		Structural failure	L	- Fatigue	Motor cannot transmit power to drum	Drum abruptly loses lifting and restraining torque. Unexpected momentary fall of bucket is likely	Loss of skip haulage system. Possible further damage to system	II	- Hoistman recognition	- Overspeed, over-wind devices.	Older band type clutches are especially susceptible to fatigue.
			U	- Corrosion				IV			
			U	- Excess wear							
			L	- Shock or impact loading							
Hoist Operator	To oversee and control all hoisting operations	Fails to stop double drum main hoist as required	M	- Operator does not see or hear bell code signals.	Bucket is not stopped at the appropriate landing.	Haulage system can be damaged	Increased possibility of collision with galloway-impactor assembly	I	- Top lender recognition	- Depth indicators	
			U	- Instrument failure (i.e., communication bell, light.)				IV			
									- Rider recognition	- Wind controller	
										- Overtravel device	
									Shift boss recognition	- Federal regulations (many mandatory) regarding hoistman and his environment for safe operations	
										- A minimum of two communication devices is required to hoistman.	

TABLE E-10. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Hoist Operator	To oversee and control all hoisting operations	Fails to stop galloway winches as required	M	- Operator does not see or hear bell code signals	Galloway not stopped at appropriate level.	Haulage system can be damaged	Increased probability of galloway collision with shaft floor	Riders can be placed in a hazardous situation	I IV	- Top lander recognition	- Depth indicators	
			U	- Instrument failure (i.e., communication bell, light.)						- Rider recognition	- Wind controller	
		Failure to decelerate bucket as required	L	- Operator inattention	Hoistman does not properly slow bucket	Safe stopping of the bucket may not be possible.	Overtravel can cause damage to haulage components	Sudden high decelerations required to rectify lack of proper deceleration can be harmful to riders and stressful to haulage ropes, etc.	I IV	- Shift boss recognition	- Overtravel device	- Federal regulations (many mandatory) regarding hoistman and his environment for safe operations
			U	- Position indicator is inoperative or defective.	stop at its landing.	Overtravel is more likely.				- Hoistman recognition	- Lilly controller or slow down check circuitry.	
		Loss of hoistman	U	- Fire in hoist house, etc.	Hoistman can no longer oversee hoisting operations	Deadman controls will cause automatic stop of hoisting system	All hoisting operations cease	Shaft sinking operations greatly hindered	--	- Shift boss recognition	- Federal regulations (many mandatory) regarding periodic physicals of hoistman, etc.	
			U	- Medical disability (i.e., heart attack, stroke, etc.)						- Surface personnel recognition	- Surface personnel can hoist men from shaft	
Manual controls	Provide a means of hoist control, collar door control and safety interlock control	Failure of control mechanism (levers, cables)	L	- Mechanical failure	Specific controls not usable.	Loss of specific hoisting functions and/or safety interlocks.	Dangerous combinations of failures could result.	Possible hazards to personnel	I IV	- Hoistman recognition	- Deadman controls	
			L	- Electrical failure						- Instrumentation	- Fall-safe designs	
Back out switches	Provide a means of overriding tripped automatic overtravel or hoist rope end-of-travel interlocks when backing hoist out.	Incomplete or improper wiring	L	- Installer error	Back out switch may override overtravel and end-of-travel interlocks during normal operation.	Loss of overtravel and/or end-of-travel protection.	Haulage without overtravel and end-of-travel protection is dangerous.	Hazard to personnel	I IV	- Hoistman recognition	- Maintenance and inspection of safety devices each shift	Warning lights should be required to indicate when the switch is "on"
			L	- Manufacturer fault								

TABLE E-10. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/ Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Bucket depth indicators	Relay bucket depth to hoistman	Loss of true indication (i.e., mis-calibration) or failure of indicator device	H	- Rope stretch	Proper depth of bucket not known.	Buckets are not stopped at the proper level.	Partial loss of control of haulage system	Collision hazard; rider entry and exit can be hazardous	I IV	- Hoistman and rider recognition	- Periodic visual calibration is standard procedure	It is recommended that overwind and indicator systems be completely independent of each other.
			L	- Indicator drive failure	Haulage should be stopped as soon as possible						- Overwind, overspeed devices (however they often share critical drive components and may fail with the indicator)	
			L	- Other mechanical failure								
			L	- Pointer broken off								
Galloway position indicator	Indicate galloway position to hoistman	Loss of true indication (i.e., mis-calibration) or failure of indicator device	H	- Rope stretch	Proper depth of galloway is not known to hoist operator	Galloway may not be properly positioned for personnel to work effectively.	Galloway and impactor positioning hindered.	Collision hazard increased.	II IV	- Downhole personnel recognition	- Downhole personnel can inform hoistman by bell code communication and telephone.	
			L	- Indicator drive failure								
			L	- Pointer broken off							- Hoistman recognition	
			L	- Other mechanical failure								
Clevis or galloway support chains (at each anchored end of suspension ropes)	Act as main connectors between the wire rope and the galloway	Failure of clevis or chains to support load (one clevis or chain)	U	- Overload	Wire rope has no means of supporting galloway	Galloway not supported evenly. Sudden and abrupt tipping can harm personnel and equipment.	Galloway positioning not possible, man-hoisting by skips may not be possible	Impactor operation not possible	I	- Hoistman and downhole personnel recognition	- Galloway wall jacks	- High safety factors in clevis and chain sizing - Inspection and maintenance done daily or more often.
			L	- Fatigue								
			L	- Shock or impact								
			U	- Corrosion								
		Failure of clevis or chains to support load (both fail)	U	- Overload	Wire rope has no means of supporting galloway	Galloway abruptly dropped downhole; extensive damage to galloway-impactor assembly.	Muck buckets may become trapped beneath the galloway leaving no means to transport personnel out of the shaft.	Shaft sinking activities not possible; extensive harm to personnel is possible	I IV	- Hoistman and downhole personnel recognition	- Galloway wall jacks	- High safety factors in clevis and chain sizing. - Inspection and maintenance done frequently.
			L	- Fatigue								
			L	- Shock or impact								
			U	- Corrosion								

TABLE E-10. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Bucket haulage clivvy	Main connection between the chain sling on the bucket and the wire hoisting rope.	Falls to support required load	U	- Overload	Replacement or repair of clivvy required	Wire rope has no means of supporting the bucket.	Bucket and rider or muck dropped down shaft.	Collision with impactor is possible. High hazard to personnel.	I IV	- Visual	- Inspection of all hoisting equipment must be done each shift per federal regulations	Periodic NDT(a) for fatigue
			U	- Faulty clivvy (i.e., manufacturer fault, etc.)							- Safety chains	
			L	- Fatigue or corrosion							- Design safety factors	
Bucket chain sling	Connects the bucket to the clivvy	Sling Falls	U	- Faulty chain or connecting ring	Immediate replacement or repair of failed chain(s) is required	Bucket may tip excessively	Haulage is not possible. Buck or rider may be spilled from bucket.	High hazard to personnel	I IV	- Visual	- Inspection of all hoisting equipment must be done each shift per federal regulations	Periodic NDT for fatigue Use of safety chains as a reliable backup
			L	- Corrosion or fatigue		Wire rope may have no means of supporting the bucket					- Safety chains	
			U	- Overload							- Design safety factors	
			L	- Impact or shock loading								
			L	- Excess strain due to failure of another chain.								
Safety chains and attachment to rope	Support bucket should clivvy, chain sling or rope connection fail	Structural failure	M	- Impact or shock loading exceeds chain strength	Chain does not support bucket as required.	Bucket and rider dropped down shaft	Haulage not possible	Collision hazard	I IV	- Visual	- Chain and attachment safety factors	Use of safety chains as a reliable backup to primary connector failure is of questionable value (Mine Hoisting Inspection, Maintenance and Safety R. A. Egan pg. 5-17)
			L	- Corrosion								
			U	- Faulty chain								
			M	- Attachment failure								
Bucket canopy	Provides overhead protection to riders	Structural failure	U	- Corrosion	Canopy may detach and fall down shaft.	Loss of overhead protection to riders	Men haulage is unsafe.	Falling canopy can be a hazard to both riders and other down-hole personnel.	I	- Visual	- Periodic inspection and maintenance	
			U	- Loose/faulty mountings								
			L	- Improper installation								

(a) NDT = Nondestructive testing.

TABLE E-10. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Bucket dump locks	Lock to prevent tipping of the bucket during man haulage	Lock failure	M	- Personnel failure to reset lock.	Lock cannot restrain motion of bucket	Bucket is not restrained from tipping and can be a hazard to personnel.	Man haulage is unsafe	Minor	I	- Rider recognition	- Buckets are fairly stable and not apt to tip easily	
			U	- Structural failure of lock							- Overwind device should be set lower than the dump chute for man haulage so there is little chance of dumping the men into the chute.	
Crosshead and guide ropes	Provides guidance to buckets	Crosshead "hangs up" during bucket descent	L	- Lack of lubrication	Crosshead does not follow bucket down	Loss of bucket guidance	Crosshead can jar loose later, dropping uncontrolled down the shaft	Equipment damage and harm to personnel are possible.	I	- Visual detection	- Guide ropes must be of locked coil construction per federal reg. 57.19-54 (to decrease chance of crosshead sticking)	Use of "locking" crossheads (crosshead rigidly attached to bucket.)
			U	- Frayed rope								
			M	- Other miscellaneous causes								
Bucket hoisting wire ropes	Support muck buckets	Rope breakage	L	- Sudden impact or shock loading	Rope cannot hold bucket	Bucket and riders or muck dropped down shaft	Damage could result from collision with bucket. Death and injury to riders or other personnel possible	Collision with bucket	I	- Visual	- High safety factors in rope sizing (7.6 < S.F. < 9.5)	Use of non-destructive testing (NDT) techniques (i.e., ultrasonics, dye penetrants, magnafluxing) can greatly aid in rope condition evaluation.
			L	- Wear/fatigue/corrosion					IV	- Frequent inspection	- Wire ropes are generally very well maintained and inspected	
			L	- Overstressed							- Rope will generally give evidence of faulty conditions before actual failure, leaving time to detect and replace	
			L	- Structural damage (kinks, dog-legs, broken strands, etc.)								
			L	- Poor inspection and/or maintenance								
			L	- Damage by rope termination								
Galloway wire ropes (2)	Supports galloway-impactor assembly and connects them to the winches	Rope failure (one rope)	L	- Sudden impact or shock loading	Rope cannot support galloway, excessive strain on second rope.	Galloway not supported evenly. Sudden and abrupt tipping can result in harm to personnel and equipment	Galloway positioning not possible, man-hoisting may not be possible	Impactor operation not possible.	I	- Hoistman recognition	- Galloway wall jacks	
			L	- Wear/fatigue/corrosion					IV	- Downhole personnel	- High safety factors in rope sizing (7.6 < S.F. < 9.5)	
			L	- Overstressed							- Miners are very aware of hoisting dangers; ropes are well-maintained	
			L	- Structural damage (kinks, dog-legs, broken strands, etc.)							- Inspection and maintenance done daily or more often	
			L	- Poor inspection and/or maintenance							- Cappels generally designed to a safety factor of at least 2.5.	

TABLE E-10. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:			Interfacing System	Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System					
Galloway wire ropes (2)	Supports galloway-impactor assembly and connects them to the winches.	Rope failure (both ropes)	L	- Sudden impact or shock loading	Ropes cannot support galloway	Galloway abruptly dropped down hole; extensive damage to galloway and impactor likely	Galloway positioning not possible.	Impactor damaged	I IV	- Hoistman and top-lander recognition	- Galloway wall jacks	
			L	- Wear/fatigue/corrosion			Injury and death of personnel likely.				- High safety factors (7.6 < S.F. < 9.5)	
			L	- Overstressed			Men haulage may not be possible; muck bucket may become trapped below galloway leaving no means to transport personnel out of the shaft				- Miners are very aware of hoisting dangers; ropes are well-maintained	
			L	- Structural damage (kinks, dog-legs, broken strands, etc.)							- Inspection and maintenance done daily or more often	
Rope terminations	Provides a connection between the rope and the bucket or galloway	Structural failure	L	- Poor inspection and/or maintenance							- Cappels generally designed to a safety factor of at least 2.5.	
			L	- Corrosion	Termination cannot support load.	Bucket droppage or partial galloway droppage.	Haulage system impaired, damage to equipment likely. Death and/or injury of personnel possible	Collision potential for impactor	I IV	- Visual	- Daily inspection of terminators	- Periodic NDT for fatigue cracks is recommended
			L	- Fatigue							- Safety factors in termination design	
			L	- Overload							- White-metal cappels on galloway anchors are generally designed to a 250% efficiency. (force required to fail terminator, i.e., remove it from rope, is 2-1/2 times that of the rope strength).	- Use of high efficiency terminators only is recommended (i.e., wedge cappels, sockets, etc.)
Galloway structure	Support impactor assembly, galloway work decks, personnel and equipment.	Failure of sheave axle or mounts	L	- Improper fabrication, assembly or design.								- Using galvanized terminators can decrease corrosion incidents
			L	- Improper fabrication, assembly or design.								
			L	- Improper fabrication, assembly or design.								
			L	- Improper fabrication, assembly or design.								
Galloway structure	Support impactor assembly, galloway work decks, personnel and equipment.	Failure of a deck support beam/strut or bolt	U	- Fatigue	Galloway will be either dropped (if both sheaves fail) or tipped	Personnel can be harmed by sudden abrupt tipping or dropping of galloway.	Galloway hoisting not possible. Men hoisting by buckets may be hindered or not possible.	Impactor can be severely damaged	I IV	- Visual detection	- High safety factors in design	
			U	- Corrosion							- Inspection and maintenance of all hoisting components done daily or more often	
			U	- Overstress								
			U	- Improper fabrication, assembly or design.								
Galloway structure	Support impactor assembly, galloway work decks, personnel and equipment.	Failure of a deck support beam/strut or bolt	U	- Fatigue	Partial or complete collapse of a deck possible (failure of a bolt would probably have no immediate effect except to strain other bolts)	Personnel below or on failed deck can be harmed or killed.	Galloway structure weakened; increased likelihood that it will not support impactor	Loss of assurance that impactor is adequately supported.	I IV	- Visual detection	- Periodic inspection and maintenance of all structural components	
			U	- Corrosion							- Safety factors in design	
			U	- Overstress								
			U	- Improper fabrication, assembly or design.								

TABLE E-10. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:			Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System				
Galloway structure (continued)		Failure of an impactor support mount or bolt	U	- Fatigue	Partial or complete failure of impactor support structure	Impactor drop is possible; personnel can be harmed or killed.	Galloway structure may not be capable of hoisting impactor assembly.	I IV	- Visual detection	- Periodic inspection and maintenance of all structural components - Safety factors in design	
			U	- Corrosion							
			U	- Overstress							
			L	- Improper fabrication, assembly or design							
		Hangs up in shaft	U	- Hoisted or lowered crooked	Galloway may bind up in the shaft.	Excess haulage rope stress or looseness can result. Sudden unexpected freeing of the galloway can occur	Galloway binding will prevent any galloway haulage from occurring.	I IV	- Hoistman and galloway personnel recognition	- Galloway is generally hoisted slowly, allowing ample time to warn hoistman should signs of binding occur. - Galloway winches are coupled in such a way as to assure even hoisting.	
			U	- Shaft wall protrusion							
Galloway ladders	Primary means of man transfer between galloway decks	Rung failure (structural)	L	- Fatigue	Rung cannot support personnel	Possible slip/fall of personnel to deck.	Increased probability of personnel fall from ladder to deck.	II ¹	- Visual recognition	- Design safety factors - Periodic maintenance and inspection - Ladder access doors	Maximum fall height is 8 ft provided ladder access doors are properly closed.
			U	- Corrosion							
		Rung failure to provide sufficient traction	M	- Slippery contaminants accumulated on rung or on shoe of user.	Rung does not provide necessary traction to hold climber's foot or hand.	Possible slip/fall hazard of personnel to deck.	Increased probability of personnel fall from ladder to deck.	I	- Visual detection	- Ladder access doors	Rungs should be made as slip-resistant as possible.
			M	- Smooth spot worn into rung by use							
Galloway to impactor ladder	Provide a means of personnel transfer from the galloway to the impactor	Rung failure (structural)	L	- Fatigue	Rung cannot support personnel	Slip/fall in excess of 20 ft to shaft floor is possible	Increased probability of personnel fall to shaft floor	I	- Visual detection	- Design safety factors - Periodic inspection	Lowering of impactor close to shaft floor before operator transfer to or from cab may lessen hazard of fall.
			U	- Corrosion							
			U	- Improper design, fabrication or assembly							
		Rung failure to provide sufficient traction	M	- Slippery contaminants accumulated on rung or on shoe of user.	Rung does not provide necessary traction to hold climber's foot or hand.	Slip/fall in excess of 20 ft to shaft floor is possible	Increased probability of personnel fall to shaft floor	I	- Visual detection	- None	Lowering of impactor close to shaft floor before operator transfer to or from cab may lessen hazard of fall. Also, rungs should be made as slip-resistant as possible
			M	- Smooth spot worn into rung by use.							

TABLE E-10. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Rider		Arm/limb in travel area of bucket	L	- Does not hear bucket descending.	Bucket can strike/cut/sever limb of rider	Minor	Minor	Minor	I	- Rider recognition	- Visual recognition and rider reaction - Bucket travel path not close to personnel	Some type of audio/visual warning should be implemented to warn of bucket descent
Rope ladder	To provide an emergency exit for operators to the shaft floor where muck buckets are located.	Rope breakage	L	- Aged, worn rope	Rope cannot support personnel	Slip/fall hazard during escape.	Emergency transfer of personnel hindered	Alternate means to transfer personnel may have to be found. (i.e., lowering impactor to shaft floor)	I	- Visual observation	- Rope safety factors	Periodic inspection of safety rope should be required.
			L	- Damaged during storage								Personnel training in rope use.
Bucket dump mechanism	Provides means of automatic bucket dump.	Structural failure of the ball chain or retaining slot	L	- Corrosion	Dump mechanism does not operate	Bucket does not dump muck as required	Muck haulage is hindered	Manual dumping of the bucket (i.e., hooking remaining chain to some part of the headframe) can be hazardous.	I	- Visual	- Safety belts	
			L	- Overload								
			L	- Fatigue								
Dump chute	Directs muck dumped from the bucket to muck pile	Fails to allow flow of muck	L	- Dried muck obstructs chute	Chute cannot properly direct muck flow	Dumped muck can overflow chute.	Falling muck and debris can be a hazard to surface personnel	Corrective action to clean out chute can expose miner to hazards.	II	- Visual	- Safety belts	Muck chute water flush system to keep chute free of possible obstructions may be advisable.
			U	- Corrosion	Chute may bend or collapse	Muck can be dumped into the wrong area	Muck haulage is hindered	Corrective action to repair chute can expose miner to hazards.	II	- Visual	- Safety belts	
			U	- Overload							- Design safety factors	
Front-end loader or dump truck	Transfer of muck from muck pile to final disposal area	Momentary loss of control	L	- Operator error	Operator momentarily loses control of machine	Muck transfer momentarily hindered	Probably minor, unless a collision or personnel injury occurs	Loss of control of the loader (even for a short time) can result in a hazard to surface personnel, driver and a possible collision with the headframe or other surface facilities	I IV	- Operator recognition	- Regular equipment maintenance and inspection	
			U	- Machine fault (i.e., throttle sticks, steering or brakes fail, etc.)								

TABLE E-10. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Galloway hydraulic pump	Provide hydraulic power to galloway stabilizing jacks	Failure to continue operation or operate on demand	U L	- Power failure - Basic mechanical fault	Hydraulic fluid cannot be pressurized	Stabilizing jacks can lose pressure	Loss of galloway stabilization	Excess motion or vibration of galloway can hinder shaft sinking or lining operations	IV	- Personnel recognition	- Periodic maintenance and inspection	
Hydraulic lines	Transfer of pressurized fluid to and from wall jacks	Line rupture	U	- Overpressure	High pressure fluid is not properly contained; fluid spray or hose whip hazard; slip/fall hazard.	"	"	"	II IV	"	"	Hose tie downs recommended to prevent hose whip.
			L	- Fatigue								
			L	- External damage								
Hydraulic fittings	Connect hydraulic lines to pumps, wall jacks, etc.	Fitting leakage	M	- Faulty installation	"	"	"	"	II IV	"	- Periodic maintenance and inspection	
			L	- Damaged fitting							- Most fitting leakage will be minor and produce little hazard	
Wall jacks	Hydraulic jack which exerts force on the shaft wall to stabilize the galloway stage	Failure to operate or continue operation as required	L	- Worn seals	Jack cylinder does not operate	Stabilizing jack does not operate	Partial loss of galloway stabilization	Minor	--	"	- Failure of several wall jacks will probably be required for any noticeable loss of stabilization	
			L	- Damaged/ scored rods/ cylinder							- Periodic inspection and maintenance	
Hydraulic fluid	Transfer of power to wall jacks	Ignition	U	- Overheated motor, pump, bearing	--	Severe damage to hydraulic components	Loss of galloway stabilization	Smoke and fire hazard to workmen	I	"	- Fluid requires high ignition temperature	
			U	- Electric spark								
			U	- Other								

TABLE E-10.S. Summary of FMEA Results from Table E-10

Potentially Hazardous Component	Hazard	Prob.	Crit.	Do Effective Prev./Corrective Measures Exist?	Suggested Design Change Number
Headframe and sheaves	Personnel dropped down shaft	U	I	Y/N	1
Collar doors	Muck, material strike downhole personnel	U	I	Y/N	2
	Personnel fall down shaft	U	I	Y/N	2
Hoist over-travel device	Collision of bucket	U	I	Y/N	3
Hoist over-speed device	Collision of bucket	U	I	Y/N	3
Safety chains for bucket	Collision of bucket	?	I	?	4
Crosshead	Strikes personnel	U	I	Y/N	5
Galloway ladders	Personnel slip/fall	L	II	N/N	6
Impactor ladders	Personnel slip/fall	L	I	N/N	6
Hydraulic hoses	Pipe whip	L	II	?	9
Hydraulic fluid	Fire hazard	U	I	Y/N	10
Rope ladder	Personnel drop	L	I	?	7
Dump chute	Personnel drop	L	I	N/Y	8

1. Use of nondestructive techniques for periodic headframe inspection.
2. Collar door open and closed indicator lights and interlock to prevent skip and door accidental collision.
3. Clear indicator lights to indicate to the hoistman in which mode his overspeed/overtravel controls are set.
4. Use of specific man haulage system with safety brakes/installation of some type of safety brakes on buckets if they must be used for man haulage or at minimum careful design of safety chains to withstand considerable impact loading and use of proper chain attachments to prevent rope damage and conveyance connector dependence.
5. Use of crosheads which "lock" to bucket.
6. Redesign of ladder rungs on galloway and impactor to reduce the chance of slipping (i.e., knurling rungs, use of slip resistant grates or coatings, etc.).
7. Rope ladder should be stored in a protective area to prevent damage and corrosion. Rope material should be fire resistant.
8. Muck chute flush system to prevent accumulation of frozen or dried muck in the chute.
9. Assure use of proper tie downs on hydraulic lines.
10. Revised fire control system.

slow-growing type failures which would allow ample time for detection should they occur. Effective nondestructive testing (NDT) techniques exist to aid in detection of faults and evaluation of remaining structural strength of the headframe, sheaves and the axles, bearing, and supports. Such NDT techniques as magna fluxing and dye penetrants are effective at crack detection and use of ultrasonics can aid in both crack detection and evaluation of corrosion damage. Use of such techniques in inspection is therefore highly recommended.

Failure of the collar doors to either open or close as required can ultimately create a hazard to downhole personnel. Failure to close (especially during muck dumping) can allow objects to fall down the shaft and strike downhole personnel. Failure to open as required (if unnoticed by the hoistman) can lead to collision of the conveyance with the collar door, which in turn can cause rope failure and dropping of the conveyance with its riders down the shaft. Indicator lights should be provided to the hoistman to indicate when a shaft collar door is open or closed. An interlock to stop the conveyance should it approach a closed collar door is also recommended.

Failure of the hoists or any of its critical components and/or safety devices can cause serious injury or death to downhole personnel. The galloway winches and skip hoists provide the main reactive force and motive power to the buckets and galloway. Loss of this reactive force (i.e., brakes) can result in bucket or galloway drop. This can be quickly countered by use of the hoist motors to brake the fall and raise the conveyance; however, damage and injury may still occur. Loss of motive power (i.e., loss of the motors, clutch, gears, shafts, drums or such) during active haulage can also cause an abrupt fall of a conveyance. This fall can be countered by use of the brake.

Failure of both brake and hoist power can result in catastrophic results, including personnel death and extensive equipment loss. However, failure of both systems simultaneously is very unlikely, as the two systems are basically independent of one another. Failure of the overtravel or overspeed devices can also result in hazard to personnel. Failure of either device will result in a greatly increased possibility of a collision due to overspeed or

overtravel. Failure of these safety devices is, however, unlikely. These devices are tested and inspected at each shift so that failure can quickly be detected.

In a hoisting system where the man hoist is used also as a muck hoist, it is common for two sets of limits to be installed for overtravel and overspeed, since overtravel or overspeed for man haulage will have different values than the limits set for muck haulage. Use of two sets of limits is recommended. A clear indicator to inform the hoistman as to which mode the devices are in is also highly desirable. Without clear indication it would be possible for the hoistman to transport men with the overtravel/speed values set for muck haulage. This can be very hazardous to the riders and would be the equivalent of man haulage with no overtravel/speed devices at all.

The hoistman is another source of potential hazard to downhole personnel during haulage operations. It is the hoistman's responsibility to start and stop the hoist, set its speed, and track the position conveyance of the shaft. The hoistman must hear and interpret the bell code from the downhole shift boss and control his hoist accordingly. Failure to interpret the bell code correctly, to respond properly to it or other indicators and failure to keep track of hoist conditions can all result in various degrees of hazard to downhole personnel. Almost all safety interlocks, however, are used to counter possible hoistman error. For example, the overspeed device will cause hoist stoppage if the hoistman fails to slow a speeding conveyance and the overtravel device will stop the conveyance if the hoistman fails to properly stop it. Brake limit devices can prevent the use of hoists with faulty or worn brakes. Other specialized interlocks and devices exist for special circumstances (see Appendix B). By the use of these interlocks, most operator errors can be effectively mitigated. There are also federal regulations requiring the use of only experienced hoistmen (except in case of emergency or training). Another regulation recommends physical fitness examinations once a year for the hoistmen and use of extreme caution when lowering men. Other regulations concerning man haulage also exist, all designed to minimize the potential of an operator error and minimize the effects should such an error occur. It is thought that if all required interlocks (as well as a brake

limit switch) are used and properly maintained, and if all regulations are followed by operator and riders, the possibility and consequence of operator errors can be effectively minimized.

Wire rope, terminators, connectors and safety chains are another source of hazard to underground personnel. Wire ropes and end connectors work together to attach the hoisted object to the hoist. The wire rope and connector are the means by which the hoists lifting and holding forces are transmitted. Failure of a rope or connector will essentially detach the hoisted object from its source of support and motive force. With no supporting force, the object will fall down the shaft, potentially causing extreme hazard to personnel and damage to equipment. Failure of support devices during man haulage will most likely result in death of the riders. Failure of the galloway ropes can possibly cause death or serious injury to personnel on board the galloway and impactor and probable severe damage to the impactor. Wire ropes and connectors are, however, designed with these hazards in mind. Large rope strength safety factors are used in rope sizing and regulations restrict the use of connectors to those which have been shown to be very effective. (See Appendix B)

Wire rope removal criterion are given in federal regulations. There are also other effective rope evaluation methods presently used in modern shafts. Rope maintenance is usually well kept up, as the importance of the rope is generally respected by mine personnel. With proper maintenance, inspection and design, it is probably unlikely that a rope or connector will fail. However, if a rope failure does occur there are no corrective measures provided (conveyance emergency brakes do not exist on muck buckets used as man carriers). It is therefore even more essential that preventive measures to prevent rope failure be applied.

Safety chains are required in coal mines and recommended for use in metal/nonmetal mines (57.19-27). The basic intent is to protect against connector failure or rope failures close to the connector. Safety chains can, however, present a hazard in that the fittings used to connect safety chains to the rope may damage the rope. Safety chain connectors are often dependent on the conveyance connector for its support, so that a failure of the rope is

not really mitigated. Chains are often not sized with impact loading in mind. Safety chains are invariably slack under normal conditions and if suddenly called into action will experience impact loadings of at least twice (typically far more) the weight of the conveyance and its load. Proof tests of these chains are not required and are rarely (if ever) made. Field observations indicate that the vast majority of these devices are probably not safe and would not function properly if required. The ideal solution would be to use separate conveyances for man haulage or to install conveyance emergency brakes onto the buckets if they must be used. Proper designing and inspection of safety chains and their attachments are a minimum recommendation.

The bucket canopy and crosshead are two other sources of potential hazard. It is possible for the canopy to detach and to fall down the shaft due to some structural failure of attachment bolts or welds or poor workmanship. This is, however, very unlikely and periodic inspection should reveal any loosening before such an event could occur. A crosshead hanging up in the shaft, however, is not an uncommon problem. A crosshead can hang up somewhere and later jar loose, falling uncontrolled down the guide ropes and potentially striking personnel and damaging equipment. Guide ropes are required by regulation to be made of a locked coil construction, as these are smooth and should offer no means for the crosshead to hang up. Crossheads should also be used which physically lock onto the bucket so that they cannot become separated until the galloway stage is reached, allowing the bucket to lower unguided.

The galloway structure can also present some potential hazards. Structural failure of a deck or such can very possibly cause a fatality. The galloway also acts as a type of connector between the galloway hoist ropes and the impactor machine since the machine is suspended off of the bottom galloway deck. Structural failure of a critical galloway component could result in the drop of the impactor machine and possible death to its operators. The galloway is, however, a very sturdy and rigid structure designed with considerable structural safety factors. It is also regularly inspected. It is suggested that NDT techniques be implemented where possible especially at critical impactor and galloway support connections.

The galloway and impactor ladders also present potential hazards to personnel. The present ladder design can easily allow slippage of footing and possible body strain or fall. The galloway decks are provided with ladder access doors so that (provided the climber properly closes them) the maximum fall height from a ladder on the galloway would be the height of one deck (8' - 10'). Falls from the impactor ladder could be of greater distance and onto a much more dangerous surface, potentially resulting in death. Use of some type of slip-resistant coating on the ladder rungs is highly recommended. Redesign of the rungs (i.e., knurling or using flat antislip grating) would also be effective. To reduce the hazard of a fall from the impactor it is also recommended that the galloway and impactor be lowered close to the shaft floor before the operators board or leave it. A rope ladder is also kept in the impactor for emergency use. Personnel training, proper storage and proper material for construction of the ladder should be considered (see Fire control FMEA section for more detail on this).

Because the galloway also has a hydraulic system, personnel may be exposed to many of the same hazards present in the impactor hydraulic system. The galloway system is required to provide power to the wall jacks which stabilize the galloway decks during shaft sinking and lining. Possible hazards include hose whip, slip/fall potential, fluid spray and fire, as mentioned in the "Impactor Hydraulic System" section. The galloway system is more exposed to personnel, however, making these hazards more likely to affect personnel. Preventive measures such as hose clamping to prevent hose whip and proper shielding where hoses may be in a well-traveled area to protect the hose from damage and the miner from high pressure spray should rupture occur are highly recommended. An alternative fire control system (i.e., local dry chemical spray system) is also recommended.

Other hazards in the haulage system are presented by the bucket dump mechanism and the dump chute. These hazards are mostly encountered in taking corrective action as required for failures of these two components. Sufficient preventive and corrective measures exist to protect personnel against these hazards. The only recommendation here is the possible addition of a muck chute flush system in shafts where the muck is apt to either freeze up or dry up in the chute causing an obstruction in the chute.

The last possible hazard considered is the possibility of a front-end loader or dump truck running into the headframe or other object and causing injury to the drivers. No corrective measures exist; however, the use of experienced and trained operators and drivers and the basic reliability of these machines (with proper maintenance) should effectively mitigate this hazard. No design or procedural changes were therefore suggested.

Materials Handling

The materials handling system is that system which provides compressed air, fresh water and ventilation to the miners and removes excess water from the shaft. The system is divided as follows:

- the service lines
- the ventilation system
- the dewatering system
- the pipeline extension system.

The Service Lines

The service lines include a compressed air and a fresh water supply line. The compressed air line is a 4" schedule 40 victaulic pipe. The water line is a 2" schedule 80 victaulic pipe. Victaulic couplings are used between pipe sections and wall clamps embedded in the concrete lining support the lines.

Table E-11A shows the FMEA for these two lines. Failure of any of the components is potentially capable of disabling the system and causing personnel injury. Although system faults are likely to occur, injury of personnel is not. Basically, this is because personnel are not likely to be close to the failure point and air or water spray should thus not be especially hazardous to the miner. Pipe whip is not likely with the pressures and pipe sizes involved, nor is a pipe drop onto personnel likely from wall clamp failure due to the protective galloway decks and the requirement of several wall clamps to fail before the pipe would be free to drop.

TABLE E-11A. Service Lines

Failure Effects On:												
Component	Function	Failure Mode	Prob Code	Failure Causes	Component	Subsystem	Whole System	Interfacing System	Crit Code	Failure Detection Methods	Preventive/ Corrective Measures	Comments
4-in. Sch. 40 victaulic pipe	Supply compressed air to the impactor	Leakage	U	- Pipe corrosion	Air leakage and loss of pressure	Air is not properly transported by service lines.	Pipe whip potential; high pressure air can be a hazard to personnel	Sufficient air leakage will hinder or stop shaft sinking operations.	II IV	- Air pressure gauges on impactor	- Pipe whip unlikely due to wall clamps and strength of pipe	- Personnel are not generally in the vicinity of the pipe
			L	- Rupture								
			U	- Faulty pipe (i.e., manufacturing fault, cracks, etc.)								
2-in. Sch. 80 victaulic pipe	Supply water to the impactor	Leakage	U	- Pipe corrosion	Water leakage and loss of pressure	Water is not properly transported by service lines	High pressure water can be a hazard to personnel	Sufficient water leakage will hinder or stop shaft sinking operations	II IV	- Visual inspection	- Pipe whip unlikely due to wall clamps and strength of pipe	- Personnel are not generally in the vicinity of the pipe
			L	- Rupture								
			U	- Faulty pipe (i.e., manufacturing fault, cracks, etc.)								
Victaulic couplings	Couples victaulic pipe for an air-/water-tight fit. Provides some structural strength to support pipe	Leakage	L	- Faulty seals	Air or water leakage	Air or water is not properly transported by service lines	High pressure air or water can be a hazard to personnel	Sufficient air or water leakage will hinder or stop shaft sinking operations	II IV	- Visual inspection	- Personnel are not generally in the vicinity of the service lines	
			L	- Improperly installed								
			L	- Faulty pipe (bent, out-of-round, etc.)						- Air pressure gauges		
Wall Clamps	Holds pipe to concrete shaft walls	Failure to hold	U	- Faulty clamp	Clamps do not properly support service lines	Increased stress on couplings; Increased probability of coupling failure and pipe drop.	Loss of services is more likely.	Falling pipe hazard increased; impactor operations can be hindered.	I IV	- Visual inspection	- Periodic inspection of clamps	- Pipe should fall down outer perimeter of shaft. Unlikely personnel would be in its path.
			L	- Faulty installation								

Sufficient preventive and corrective measures exist for failures of each of the components. No design or procedural changes are therefore thought necessary in this subsystem.

Ventilation

The ventilation system is one of the most important safety features of any shaft sinking operation. Ventilation of the shaft bottom during shaft sinking activities is obtained using axial flow fans in series to blow air through a 30 to 36-inch diameter thin-wall (spiral weld) pipe. The pipe terminates about thirty feet above the galloway.

The ventilation system utilizes intake fans located on the surface. The number of fans required will depend on shaft depth and the size of the fan employed. The fan housing and the air duct to the shaft are required to be fire-resistant. The fans must operate continuously, except for scheduled production cycle shutdowns or planned maintenance activities. Fans are electrically powered, and are usually between 40 and 100 HP.

Table E-11B shows the FMEA for this system. Failure of any of the components is potentially capable of producing a fatality by stopping or greatly reducing the supply of fresh air and ventilation to those workers below. Failures that cause total loss of ventilation are easily detectable by downhole personnel since ventilation noise and air motion would cease. Failures that result in partial losses of airflow would not be so easy to detect and could exist for considerable time before found. Insufficient ventilation and fresh air will cause a depletion of O_2 and may allow accumulations of harmful or suffocating gases. Depletion of O_2 should be noticable to the personnel downhole before any appreciable harm could result and in a shaft this size will allow ample time for escape. It is, however, possible that detection could be delayed or evacuation hindered and a fatality could occur. Accumulation of harmful or suffocating gases (i.e., hydrogen sulfide, methane) in metal/nonmetal shafts is unlikely but has occurred. Should such a gas be encountered while the ventilation system is fully or partially failed a possibly fatal situation could quickly arise. Shaft gas monitoring is required only on coal shafts and no monitoring is either required or done in metal/nonmetal shafts. It is recommended that airflow

TABLE E-11B. Ventilation System

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/ Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Intake fan(s)	To generate a fresh air supply	Failure to continue operation	L	- Power failure	Fan stops	Loss of ventilation	System shutdown. Suffocating or toxic gases may accumulate.	Lack of O ₂ and accumulation of other gases can produce a hazardous environment to downhole personnel	I	- Worker recognition	- Emergency generators	Emergency evacuation plans should be developed/practiced
			U	- Mechanical failure					- Fan stop alarms	- Gas accumulation and O ₂ consumption will occur at slow rates, giving ample time for personnel escape provided it is detected quickly) - Fan reliability is very good (est. failure rate of 9 x 10 ⁻⁶ /hr)		
	To dilute methane and other gases if encountered	Fails to generate adequate fresh air	U	- Insufficient fan size	Decrease in fan performance	Partial loss of air flow	Gases may accumulate in shaft unnoticed by workmen	Lack of O ₂ may go unnoticed. Possible health effects to workmen	I	- Worker recognition (may not be readily detectable)	- Periodic inspection and maintenance	Gas/O ₂ testing should be conducted regularly. Air flow alarms are recommended
			L	- Duct leakage								
			L	- Fan degradation								
	Generates contaminated air		L	- Intake of excess surface dust, other particulates	Fan degradation possible	Lack of fresh air supply	Excess dust, dangerous fumes, or other contaminants downhole	Highly hazardous environment could result	I	- Worker recognition (may not be readily detectable)	- Dangerous chemicals are not generally used onsite, especially around intake fan - Surface dust control measures	Area around fan should be kept clean and clear.
			U	- Intake of hazardous fumes (i.e., sulfuric acid, exhaust of diesel engines, etc.)						- Muck piles, would not be put close to intake fans		
		Scheduled service/repair	H	- Extension of ventilation duct during pipeline extension	Fan stops	Loss of ventilation	System shutdown	Possible health effects on extension crew if ventilation is down for prolonged periods	III	Normally scheduled operation	- Time of ventilation loss during extension is kept to a minimum	
			U	- Maintenance/repair of fan								
	Underground duct	Directs airflow to shaft ventilation pipes	Degradation	L	- Corrosion	Loss of pipe integrity	Partial loss of airflow/pressure. Contaminants from ground may be carried downhole	Potential accumulation of dust/gases downhole may go unnoticed	Possible health effects on workmen	I	- Worker recognition (may not be readily detectable)	- Duct is corrosion resistant - Construction is inspected and supervised
U				- Poor construction								
Duct collapse		L	- Corrosion	Pipe blocked/clogged	Severe loss of airflow. Loss of ventilation	Potential accumulation of dust/gases	Lack of fresh O ₂ to workmen	I	- Worker recognition (easily detectable)	- Duct is corrosion resistant - Duct structural safety factors		
		L	- Faulty duct									
		U	- Overload over duct area									
Shaft ventilation pipe	Directs airflow to shaft bottom	Degradation	L	- Corrosion	Loss of pipe integrity. Pipe air leakage	Partial loss of airflow/pressure	Potential accumulation of dust/gases downhole may go unnoticed	Partial loss of ventilation may go unnoticed by workmen. Possible health effects on workmen	I	- Worker recognition	- Periodic inspection and maintenance - Duct is corrosion resistant	Airflow alarms are recommended. Gas/O ₂ testing should be conducted regularly.
			U	- Poor construction						- Any substantial duct leakage will not be difficult to detect (i.e., during man-trips, etc.)		

monitoring or alarms be installed to detect low airflow quickly. O_2 and gas testing would be an effective alternative or backup to this. Both are recommended due to the importance of proper ventilation to worker health and performance. It is also highly recommended that general emergency evacuation procedures be developed and practiced.

Shaft Dewatering

Experience with shafts in metal/nonmetal mines in the Western U.S. indicates that large amounts of water may be encountered in the course of sinking a shaft. If such an aquifer is intercepted, air-driven pumps would be lowered from the galloway. The pumps can be lowered and placed on the shaft bottom without a man at the bottom by using galloway-mounted winches or tuggers and the moving capability of the mucker boom. It is also anticipated that the face will be probed for potential water-bearing zones and grouted as necessary to keep water inflow to a minimum.

Table E-11C presents the FMEA for this system. A component thought to be able to cause a hazard is the water pipe line. This line contains fairly high pressure water which could spray out and injure a miner. This is not, however, a likely occurrence, since personnel are not generally close to the pipe. Also, the victaulic pipe and couplings used are designed to withstand pressure. Shaft flooding is another possible but unlikely hazard since replacement pumps can be lowered quickly should a pump fail. Shaft flooding will also be relatively slow should it occur and leave ample time for personnel evacuation. Ample preventive and corrective measures presently exist for any possible hazards from these components. No design or procedural changes are recommended.

Pipe Line Extension

The service lines for the impactor shaft sinking system are extended once every 20 feet, during which time the services provided, including ventilation, compressed air and water, are interrupted. Pipeline extension operations in the impactor system precede the concrete lining cycle. The pipes are secured to the wall by brackets bolted by studs screwed into inserts cast into the concrete lining. Extension operations require from two to four men. To extend the shaft pipelines, the upper deck of the work platform is positioned

TABLE E-11C. Shaft Dewatering

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Compressed air pumps	Pumps stored on galloway and lowered as required to remove water from the shaft	Failure to operate as required	L	- Mechanical fault (seized bearings, cracked casing, etc.)	Pump cannot remove water	Water removal is hindered	Shaft flooding is possible	Personnel evacuation required if flooding occurs	--	- Workman recognition	- Pumps are reliable components	
			U	- Lack of sufficient compressed air							- Pumps can be replaced quickly and easily	
Water line to pump stations & surface	Guides flow of water to pump stations and to surface pond	Pipe or coupling rupture or leak	U	- Faulty pipe or coupling	Pipe allows leakage of water	Excessive leakage of water will hinder water removal	Water spray onto wire rope or galloway parts can accelerate corrosion	Water spray can be a hazard to personnel	III IV	- Workman recognition	- Victaulic couplings and pipe designed to withstand high pressures	
			L	- Poor installation							- Victaulic couplings are not difficult to install	
Water pump stations	Pump stations located each 500' to assist in water removal	Pump failure	U	- Mechanical fault (seized bearings, cracked casing, etc.)	Pump cannot remove water from temporary reservoir	Water removal may be delayed until second pump can be lowered	Minor	Minor	--	- Inspection - Workman recognition	- Pumps are reliable components	
			L	- Lack of sufficient power to pump							- Pumps can be replaced quickly and easily	
											- Periodic inspection	

some two feet below the bottom of the pipes already installed. The manifold on the end of each pipe (i.e., valve assemblies) is then removed and secured to the work platform. Pipes are lowered on the hoist rope one at a time until the tops of the pipes are immediately below the installed pipes. Rope slings and ratchet jacks are used to raise the pipes into position. The victaulic couplings are then fitted. The work platform is then lowered to permit replacement of the valve manifolds on the bottom of the pipes and secure the pipes to the wall bracket.

Table E-11D shows the FMEA for the components used in this process. Failure of any of the components can potentially result in a worker injury. However, with the present preventive and corrective measures it is unlikely that a failure will actually cause an injury.

No design changes are recommended here, except that slip resistant flooring be used (i.e., slip resistant coatings, grating) to help prevent worker slip/fall hazards.

A summary of the potentially critical items identified for the materials handling subsystems is outlined in Table E-11.S.

Support Systems

The following subsystems were defined as the support systems:

- communication system
- power transmission and lighting system
- shaft wall support/lining systems
- fire control systems
- guidance system.

These are systems necessary to produce a completely lined shaft and provide the required support to downhole equipment directly involved in shaft sinking. Brief discussions of each subsystem analysis will follow.

TABLE E-11D. Pipeline Extension

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/ Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
SECTION LOWERING												
Galloway deck	Support workers during extension operations	Failure to support workmen properly	L	- Unexpected galloway shifting	Deck repair may be necessary	Extension operations hindered	Workmen can be injured or killed.	Shaft sinking is hindered	I	- Visual recognition	- Guard rails	- Galloway decking should be made as slip-proof as possible and kept uncluttered.
			L	- Workman slip or fall due to lack of traction on deck							- Structural safety factors	
			U	- Structural failure of a deck								
Pipe sections	20-ft lengths of pipe used to extend services.	Unexpected pipe shifting or motion	L	- Strikes object	Pipe damage is possible	Minor	Minor	Shifting pipe can injure personnel	III	- Visual	- Gloves	
			L	- Pipe hoisting bracket too loose							- Hard hats	
			L	- Hoistman error								
Hoist Rope	Used to lower pipe down shaft	Structural failure	U	- Overload	Wire rope cannot support pipe section	Minor	Pipe droppage will hinder extension process	Personnel installing pipe or below can be injured or killed by falling pipe	I	- Visual	- Ropes are well maintained	
			U	- Frayed or weakened rope (i.e., fatigue, corrosion, etc.)							- Galloway decks can provide overhead protection	
Pipe hoisting brackets	Used to attach pipe to hoist rope	Structural failure	U	- Overload	Bracket cannot support pipe section	Minor	Pipe droppage will hinder extension process	Personnel installing pipe or below can be injured or killed by falling pipe	I	- Visual	- Maintenance and inspection of all hoisting equipment	
			L	- Improper attachment to pipe or rope							- Galloway decks can provide overhead protection	
			U	- Fatigue								
			U	- Corrosion								

TABLE E-11D. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:			Interfacing System	Crit Code	Failure Detection Methods	Preventive/ Corrective Measures	Comments
					Component	Subsystem	Whole System					
PIPE ASSEMBLY												
Manifold	Valve assemblies at the end of each pipe	Dropped during removal or replacement	U	- Slippery due to water or other fluids	Manifold can be damaged if dropped	Minor	Pipeline extension hindered	Manifold could be dropped down shaft causing a hazard to personnel below	II	- Visual	- Galloway can provide overhead protection	
			L	- Installer error								
Rope sling	Used in conjunction with the ratchet jack to position pipes for installation	Allows pipe to slip or fall	U	- Contaminants on pipe	Pipe can be damaged if dropped	Minor	Pipeline extension hindered	Dropped pipe can be a hazard to personnel.	I	- Visual	- Galloway can provide overhead protection	
			U	- Improperly attached				Pipe slip could create a pinch point for installer			- Gloves	
			U	- Structural failure of sling								
Ratchet Jack	Used to position pipe for coupling and pipe wall clamp fastening	Allows pipe to slip or fall	U	- Jack structural failure	Pipe can be damaged if dropped	Minor	Pipeline extension hindered	Dropped pipe can be a hazard to personnel	I	- Visual	- Galloway can provide overhead protection	
			L	- Operator error				Pipe slip could create a pinch point for installer			- Gloves	
Hand tools	Used to tighten clamps, couplings and various other components during pipe line assembly	Tool slippage	U	- Tool structural failure	Minor	Minor	Minor	Sudden slip of tool can cause minor to lose balance; strike hand, self or others with tool; or drop tool.	II	- Visual	- Inspection of tools	
			L	- Operator misuse, misadjustment								
				- Failure of component being worked on								

TABLE E-11.S. Summary of FMEA Results from Tables E-11A-11D

Potentially Hazardous Component	Hazard	Prob.	Crit.	Do effective Prev./Corrective Measures Exist?	Suggested Design Change Number
Intake fan	Loss of Ventilation	L	I	Y/N	1
	Partial loss of ventilation	L	I	Y/N	2, 3
Underground duct	Partial loss of ventilation	L	I	Y/N	2, 3
Shaft ventilation pipe	Partial loss of ventilation	L	I	Y/N	2, 3
Galloway decking	Slip/fall	L	I	N/N	4

1. Emergency evacuation plans should be developed and practiced.
2. Gas/O₂ testing should be done regularly.
3. Low airflow alarms at duct exits are recommended.
4. Galloway decking should be made as slip-free as possible.

Communication Systems

There are basically two forms of communication between downhole personnel and the surface crew. There is a manual bell wire signal code and a two-way telephone system. These systems are described in detail in the section on the impactor system description.

Table E-12 presents the results of the FMEA of this system. Any component failure can hinder communications and cause a potential accident. Most of these accidents involve some component failure which results in the hoistman not receiving proper hoisting commands and therefore creating a potential for a haulage accident. As mentioned in the haulage of men and materials section, interlocks exist to aid in decreasing the possibility of many types of haulage accidents. The communication system itself is designed

TABLE E-12. Communication Systems

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:			Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System				
Manual Bell Wire Rope Signal or Electric Bell Wire Signal System	Provide audible and visible communication between shaft and surface	Wire rope fails	U	- Wear/breaks	Switch not activated	No signal to hoistman	Hoistman cannot respond to crew needs/commands	I	- Operator recognition	- Telephone--Alternate Bell Wire System available	Rope should be periodically inspected
		Mechanical failure (rope to switch connection)	L	- Mechanical failure	Switch not activated	No signal to hoistman	Hoistman cannot respond to crew needs/commands	I	- Operator recognition	- Telephone--Alternate Bell Wire System available	
		Electric switch fails open	U	- Contacts corrode	No electric current to bell and light bulb	No signal to hoistman	Hoistman cannot respond to crew needs/commands	I	- Operator recognition	- Telephone--Alternate Bell Wire System available	
			L	- Faulty electric connections							
			L	- Mechanical failure							
		Electric switch fails closed	U	- Contacts fuse together	Constant current to bell and bulb	Constant signal to hoistman	Hoistman cannot respond to crew needs/commands	I	- Hoistman recognizes signal failure	- Telephone--Alternate Bell Wire System available	Electric switch should be periodically inspected
			L	- Mechanical failure							
		Bell fails	U	- Electro-magnetic coils fail	Bell hammer does not operate	No audible signal to hoistman	Increased likelihood that hoistman will not receive or interpret code correctly	I	- Hoistman recognizes signal failure	- Visual signal - Telephone - Emergency generators	
			L	- Faulty electric connection							
			L	- Mechanical failure							
		Bulb fails	U	- Power outage							
			U	- Overcurrent	Bulb does not light	No visual signal to hoistman	Increased likelihood that hoistman will not receive or interpret code correctly	I	- Hoistman recognizes signal failure	- Audible signal - Emergency generators	
			L	- Faulty electric connection							
			U	- Power outage							
			M	- Bulb burns out							

TABLE E-12. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Electronic Controls and Display Lights in Hoist House	Provide communication between shaft and surface about specific shaft conditions (i.e., shaft door open). To serve as a warning system.	Bulb(s) fail off	U	- Overcurrent	Display panel does not light	No visual signal to surface	Specific system condition may be unknown to surface	Controlled system may not be operated properly	I	- Operator recognition	- Safety interlocks are provided so that dangerous hoisting conditions cannot occur	A complete test run of all hoisting equipment is done each shift.
			U	- Power outage								
			L	- Faulty electrical connections								
			M	- Bulb burns out								
		No signal given from switching mechanism/sensor	L	- Mechanical failure	Instruments do not register properly	No or wrong visual signal	Specific system condition may be unknown to surface	Controlled system may not be operated properly	I	- Operator recognition	- Emergency generator can provide power in case of power outage	
			U	- Contacts corroded								
			L	- Faulty electrical connections								
			U	- Power outage								
		Instruments fail	U	- Mechanical failure	No or incorrect display of condition	No or wrong visual signal	Specific system condition may be unknown to surface	Controlled system may not be operated properly	I	- Operator recognition	- Instruments are well-tested and reliable	
			U	- Faulty electrical connection								
			U	- Power outage								
Voice Communication	Transfer information or warnings	Voice not heard	M	- Heavy background noise	Workman does not hear command/warning	Proper response may not occur	Specific duties not performed. Hazardous system condition may continue to exist	None	I	- Operator recognition	- Visual communication	
Two-way Telephone	Provide audible communication between shaft and surface	Telephone bell (or whatever announces an incoming call) fails	U	- Internal electrical or mechanical failure	Telephone not answered	Proper response may not occur	Communication between shaft and surface impaired	No longer provides backup to bell code		- User recognition	- Bell code	Bell code is the primary method of communication. Importance of telephone communication not great as long as bell code is operative.
		Telephone speaker microphone fails	U	- Faulty electrical connection - Mechanical failure	Messages cannot be given to party with failed device.	Proper response may not occur	Communication between shaft and surface impaired	No longer provides backup to bell code		- User recognition	- Bell code	
		No or partial transmission of signals	M	- Interference	Commands not understandable	Proper response may not occur	Communication between shaft and surface impaired	No longer provides backup to bell code		- User recognition	- Bell code	

with some redundancies. The bell-wire system produces both a visual and audible signal output. The telephone system can also provide a communication backup. The depth indicator can keep the hoistman aware of when the skip is approaching a dangerous level and control panel indicator lights can be provided for various interlocks and to relay shaft condition information (i.e., collar door open or closed, slack hoist rope, etc.)

The bell-wire signal system has historically been a reliable means of communication. The two-way telephone system would provide a much more direct means of communicating hoisting needs and commands. However, it is presently a fairly unreliable system and produces much static and noise during communication. It is suggested that the telephone system be improved (as technology allows) as this form of communication can provide a better primary communication system than the present bell-wire system. No other design changes are suggested.

Power Transmission/Lighting

Electric power for the impactor system is provided by available power lines to a shaft substation. Power for the downhole equipment is provided by a cable running from the surface to the galloway, which has been stepped down to 480 volts, 3-phase power. The power cable is supported by a rope, or messenger cable, payed out from a winch. The cable is looped to permit the galloway/impactor machine assembly to proceed a minimum of 20 feet before an advance of the cable is required. An interlock ensures that the limits of the cable loop length are not exceeded. The cable is then directed through a protective sheath to the center pivot of the impactor frame and from there to the cab to drive the hydraulic motors and provide power for the lighting system.

Table E-13 is the FMEA of this system. Besides the lighting system, the electric pump motors and the electric solenoid valves (of the compressed air system) there are few other electrical components. The scarcity of electric components in the impactor system reduces the chance of electric shock to the

TABLE E-13. Power Transmission/Lighting

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Power cable (surface to galloway) (480 V, 3-phase)	Transfer of electric power from surface to galloway and Impactor	Fails to transmit power	U	- Cable severed	No electric power transmission to galloway or Impactor	Loss of downhole lighting and all electrically operated components (i.e., hydraulic pumps, etc.)	Shaft sinking activities must stop	Live severed cable can be a hazard to personnel within shaft; hazardous environment due to darkness	I	- Workman recognition	- Miners all have lighted helmets - Cable has a 20-ft coil to allow advance of the galloway - An interlock exists to prevent cable loop over-stretch	
Messenger cable	Provides support to power cable	Structural failure	U	- Overstress	Messenger cable will no longer support weight of the power cable below the break	Excess stress on power cable (especially at point of break). Power cable severance is more likely	Shaft sinking activities may have to stop (especially if power cable severs)	Live severed cable can be a hazard to personnel. Transfer of personnel within shaft can become hazardous due to darkness (should power cable sever)	I	- Workman or hoistman recognition (immediate detection may not be possible)	- Miners all have lighted helmets - Messenger cable safety factors - Cable inspection and maintenance	
			U	- Corrosion								
			U	- Fatigue								
			U	- Rope damage								
Slip ring connectors (both Impactor and revolving frame rings)	Provide a rotating electrical connection for power transmission to the Impactor	Failure to conduct required electric power	L	- Corroded brushes	Corroded brushes can result in excessive heat buildup creating a possible fire ignition source	Loss of power to Impactor electrical components	Possible loss of downhole lighting	Loss of Impactor functions; increased slip/fall hazard if lighting fails	II	- Operator recognition	- Lubricants have a high spontaneous ignition point - Periodic maintenance and inspection	
			U	- Structural failure								
			U	- Assembly fault								
Protective sheath	To protect power cable from damage where it runs through the galloway decks to the rotating frame pivot	Structural failure	L	- Corrosion		Power cable more susceptible to damage; increased shock hazard	Minor	Minor	III	- Workman recognition	- Periodic maintenance and inspection	
			U	- Assembly fault								
480/110 V 1.5 VA transformer	Used to drop voltage of incoming power to that used for downhole lighting	Failure to continue operation	U	- Transformer coils fail (i.e., over-heat, short, etc.)	Transformer cannot provide power to lighting system. Transformer over-heat can cause a fire or shock hazard to personnel.	Downhole lighting is disabled	Shaft sinking activities cannot continue	Slip/fall hazard to miners is increased due to darkness	II	- Workman recognition	- Miners all have lighted helmets	Emergency lighting system recommended to minimize slip/fall hazard should miners need to leave cab or decks during emergency
110 V incandescent lamps	Provide light downhole for shaft sinking operations	Failure to continue operation	H	- Burnout (due to age, etc.)	Lamp disabled	Downhole lighting is decreased	Shaft sinking activities may be hindered	Minor	--	- Workman recognition		Heavy duty lamps and protective housings to protect lamp are suggested.
			L	- Lamp damage (struck by some object)								
Control panel and lighting wiring	Provide power to control panel indicator lights, switches and to downhole lighting system	Failure to operate as required	L	- Internal shorting	Indication lights may not operate properly. Switches may be disabled. Specific lamps may not light	Hydraulic pumps could be disabled; lighting system and tube system may also be disabled	Shaft sinking could be hindered or stopped	Any faulty wiring can potentially be an electric shock hazard to workman	II	- Inspection	- Failsafe switches	- Periodic maintenance and inspection
			L	- Loose/faulty wiring					IV	- Operator recognition		
			L	- Power failure								

miners. The main power cable, transformer and miscellaneous lighting/control panel wiring are about all that can create a shock hazard. It is unlikely that the power cable or transformer can fail in such a way as to create such a hazard and even less likely that a miner would touch such a component and receive an electric shock. Lighting wiring and operator controls wiring are much more exposed to the miner. However, these are low voltage sources (110 V) and with competent wiring should produce no shock hazard to personnel.

It is possible for the slip rings or the transformer to overheat. Any overheated component carries the potential of a fire hazard, especially since there are flammable oils in the system that could be exposed. However, the possibility of the slip rings or transformer to overheat to the temperature and for the length of time necessary to ignite these oils is remote and present safety measures are judged to be sufficient. It is also likely that slip rings may create sparks to some extent. This can create hazards if a flammable gas is present; however, this is unlikely in a metal/nonmetal mine. Minor sparking will produce no hazard to standard lubrication oils.

Slip/fall hazards due to a loss of lighting by a failure of this system carry a low probability of occurrence. Miner hats must have a light attached to them. Light from these hats is not, however, as effective a means of lighting and can increase slip/fall hazards, especially if emergency evacuation is necessary. For this reason, some type of emergency lighting system should be provided at the operator escape routes and at any loading station for men. Other than this, no design changes are suggested.

Shaft Wall Support and Lining

Nearly all modern shafts are concrete lined to provide ground support, to seal out excess water, and to protect the wall rock from deterioration. The shaft being constructed by the impactor is lined with unreinforced concrete. The lining procedures and equipment requirements were described earlier in this report.

The FMEA for shaft lining in Table E-14 identifies many component failures that could result in a miner being injured. Most of these are failures that result in the hazard of falling objects. However, the galloway provides some overhead protection for the workers and most items will fall either down the perimeter of the shaft or down the bucket openings (both unlikely work stations for the miners). Another possible accident is for the miner to slip or fall on a deck due to a wet, slippery deck surface. Guard rails are provided around each deck to help prevent this accident type.

There is also the possibility that workers may be inundated by large amounts of wet concrete and that considerable damage could be done to the impactor machine by this wet concrete. This failure sequence could occur by structural failure of the hanging rods. An analysis of the hanging rods, which could allow the forms to drop and thus release concrete, shows a factor of safety of around 2 (see Calculations). The possibility of inundation of the workers by wet concrete is even more unlikely since most of the concrete would fall down the perimeter of the shaft.

The only component in the lining system which is judged to have a reasonable potential for failure is the lining form. The failure mode considered is that the forms do not release from the shaft wall. This can present a hazard to the miner if the form should suddenly release while the miner is exerting force on it or if the miner resorts to using other than normal means to free the form. In either case, a minor injury may be expected. Because the rest of the failure modes for this system are unlikely, the only recommendation for change would be that the forms be redesigned for easier removal, if possible. Procedurally, workers may need to ensure that the forms are properly oiled prior to use.

The potentially critical items for the shaft wall support and lining system are outlined in Table E-14.S.

Fire Control

Fire control in the impactor system is achieved mainly by the on-board, hand-held fire extinguishers and a water fog system. Fire detection must be solely by the personnel downhole. No automatic detection system or fire control system exists.

TABLE E-14. Shaft Wall Support and Lining

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Hanging rods	Supports kerb ring and concrete lining pour.	Fails to support kerb ring	U	- Connections between rod sections fail	Kerb ring not supported properly.	Concrete leakage. Lining cannot be properly made.	Shaft sinking delayed.	Should complete failure of rods occur, large amounts of concrete will fall down shaft, endangering down-hole personnel	II IV	- Workman recognition	- Hanging rod safety factor - Protective decks	
	Provides reinforcement to concrete.		U	- Structural failure (excess corrosion, overstress, etc.)	Increased chance of failure of other rods.							
Kerb ring	Main support for form work.	Structural failure	U	- Corrosion		Excessive concrete leakage. Lining cannot be completed.	Shaft sinking delayed.	Spillage of large amounts of concrete is possible	II IV	- Workman recognition	- Protective decks - Design safety factors	
	Suspended on cone nuts by the hanging rods.		U	- Overstress								
			U	- Damaged or faulty material, workmanship.								
Cone nuts	Primary means of load transfer from kerb ring to hanging rods.	Structural failure	U	- Overstress	Increased stress on other cone nuts and increased probability of failure	Kerb ring will be improperly supported.	Concrete lining cannot be properly made.	Failure of all cone nuts will allow kerb ring and concrete to fall down the shaft, possibly inundating workmen and equipment	II IV	- Workman recognition	- Accelerators are often used to harden concrete quickly in kerb ring - Concrete should fall down perimeter of shaft. Personnel are not likely to be in its path - Protective galloway decking	
			U	- Fatigue								
			U	- Corrosion		Concrete leakage.						
			U	- Improper installation								
Plumb bobs and centering jacks	Used to center kerb ring in shaft before concrete pour	Failure to center ring	L	- Screw jack seized (i.e., dirt, mud buildup, damaged threads, etc.)	Minor	Kerb ring cannot be properly centered.	Concrete lining either cannot be made or will be off center.	Shaft wall support may be inadequate in areas; off center lining is produced	IV	- Workman recognition	- Centering jack can be easily repaired or replaced - Shaft alignment is checked often	
		Failure of plumb bob support	L	- Structural failure		Kerb ring cannot be properly centered.	Concrete lining either cannot be made or will be off center.	Falling plumb bob may injure personnel	II	- Workman recognition	- Support cable safety factors	
			M	- Slip of component while lowering								
Forms	Provide structural support to wet concrete as it hardens.	Difficult to remove	N	- Form sticks to concrete	Form cannot be lowered for the next pour.	Minor	Shaft lining hindered	Workers loosening the forms may resort to a more hazardous means to force release of the forms.	III	- Workman recognition	- Forms are oiled to help prevent form sticking	Some turnbuckle or form redesign to reduce effort of form removal.
			L	- Hinged door will not release								
			M	- Turnbuckle sticks, hard to turn								
			U	- Corrosion	Loss of form	Concrete cannot be set up	Lining cannot be produced against shaft wall.	Possible inundation of workmen and equipment.	III	- Workman recognition	- Steel forms are used. Failure is unlikely	
		Structural failure	U	- Fatigue			Excessive leakage can occur.				- Protective galloway decking	
			U	- Overstress								

TABLE E-14. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:			Interfacing System	Critt Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System					
Steamboat Turnbuckle	Turnbuckle used to collapse kerb ring and forms.	Structural failure (fracture, stripped or damaged threads, etc.)	L	- Overstressed	Turnbuckle cannot be used to collapse kerb ring or form	Freeing form from walls is very difficult	Shaft lining hindered	Workers loosening the form or kerb ring may resort to a more hazardous means to force release	III	- Workman recognition	- Turnbuckles can be easily replaced	
			L	- Fatigued								
			L	- Corrosion								
			L	- Excess contaminants built up in threads								
Form sling and winches	Sling and winches used in lowering and positioning the forms and kerb ring	Failure to support the form or kerb ring	U	- Rope failure (fatigue, corrosion, overstress, etc.)	Kerb ring or form cannot be properly supported during positioning or fastening	Unexpected kerb ring or form slippage or drop is very likely.	Shaft lining hindered	Workers may be positioned in a pinch point. Form or kerb ring slippage can cause injury.	II	- Workman recognition	- Wire rope and winches are well maintained and inspected. - Wire rope safety factors	Workmen should be informed of the dangers of putting hands, feet, etc., in possible pinch points.
			U	- Winch failure (gear fracture or stripping, clutch or brake failure, etc.)								
Hand tools	Fastening cone nuts, attaching hanging rods, forms, etc.	Slips off object being tightened, adjusted, etc.	U	- Structural failure of tool	Minor	Minor	Shaft lining is hindered.	Sudden detachment of tool can result in worker striking fellow worker or himself. Tool could also drop down shaft causing hazard to workman below.	II	- Workman recognition	- Galloway deck may protect miners below from any falling tools	
			L	- Structural failure of nut, bolt, etc.								
			L	- Workman error								
Bottom Dumping Bucket	Transfer of concrete from surface to galloway hopper	Discharge door opens unexpectedly during lowering of concrete	L	- Catch or lock failure	Bucket dumps wet concrete	1 1/2 yds of concrete spilled down shaft Galloway may be damaged.	Shaft lining is hindered	Falling concrete will be a hazard to personnel on the galloway top deck.	I	- Visual (immediate detection may be difficult)	- Personnel are not generally on the top deck of the galloway during concrete lowering	Personnel traffic on galloway top deck should be held to a minimum during any hoisting operation

TABLE E-14. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Transfer chutes and elephant trunks	Transfer of wet concrete from bucket to forms	Hopper outlet or elephant trunk plugged	U	- Kinked hose (elephant trunk)	Minor	Minor	Shaft lining slowed	Minor	--	- User recognition	- All shaft lining equipment is cleaned up after use.	
			U	- Obstruction in outlet or hose (i.e., dried concrete)								
Vibrating poker	Used to achieve even distribution of in-place concrete	Air hose rupture or separation from vibrator	U	- Overpressure	Vibrator made ineffective.	Concrete cannot be properly distributed	Shaft lining slowed	High pressure air leaking from hose can spray dirt, wet concrete and other particles creating a hazard; separated hose can be a hose whip hazard.	II	- User recognition	- Protective clothing is worn by the workmen.	
			L	- Hose fatigue								
			L	- Hose damage								
			L	- Fitting failure								
Concrete	Provides support to shaft wall when dry.	Leaks onto work deck during pouring operations.	H	- Leaky components	Contact with concrete may cause chemical burn.	None	Some waste of concrete.	Workman may slip and fall on wet concrete. Fall from work deck is possible.	I	- User recognition	- Protective clothing, gloves, rinsing of excess spillage. Guard rails.	
			H	- Worker error								
Water and Hoses	Used to clean up after shaft lining pour is complete.	Spilled onto work deck.	H	- Worker splashes water or rinses deck.	None	None	Workman may slip on water or trip over the hoses. Fall from work deck possible.	None	I	- User recognition	- Guard rails will help prevent falls from deck.	

TABLE E-14.S. Summary of FMEA Results from Table E-14

<u>Potentially Hazardous Component</u>	<u>Hazard</u>	<u>Prob.</u>	<u>Crit.</u>	<u>Do Effective Prev./Corrective Measures Exist?</u>	<u>Suggested Design Change Number</u>
Galloway deck	Slip/fall from work deck	L	I	N/Y	1
Water and hoses	Slip/fall from work deck	L	I	N/Y	1
Formwork	Worker strain or other injury	M	III	N/N	2

1. Use of slip-resistant coating or grating on galloway decks.
2. Some redesign of turnbuckle or form to facilitate easier, safer form removal.

Table E-15 shows the FMEA of this fire control system. Because this system is a corrective measure to a very hazardous condition, the failure of any of the three main components (personnel, extinguisher or water fog system) can be devastating in both lives and equipment damage. This can be seen in the FMEA as every failure mode has the potential for producing a fatality or major equipment damage. The critical items in this subsystem are summarized in Table E-15.S.

The chance of a fire on board the impactor is probably quite remote, although it is a possible event (all necessary ingredients are present on board) and carries potentially very high consequences. Fires in the operator cabs or on the galloway decks can be effectively countered by use of the hand-held extinguishers, provided that the fire is detected early and the extinguishers are operable. However, fires that start in the machine motor and pump compartment or other remote locations will most likely be difficult to detect and extinguish. The ability of the water fog system to control such

TABLE E-15. Fire Control System

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Water-fog fire suppression system	To control/extinguish fire	Failure to start on demand	U	- Water lines broken or clogged	Suppression system ineffective	Portable extinguishers must be used for fire control	Fire may not be controllable; operations cease	Potential injury to workers; equipment damage	I IV	- Operator awareness	- Regular inspection and maintenance - Portable extinguisher as backup	
			U	- Nozzles clogged broken or	"	"	"	"	"	-	"	
			L	- Water supply tank not filled	"	"	"	"	"	-	"	
			U	- Water supply tank fails	"	"	"	"	"	-	"	
			L	- Operator cannot reach or pull lever	"	"	"	"	"	-	- Install system redundancy; portable extinguishers as backup	Second activation lever should be installed on Impact machine
			U	- Lever fails when pulled	"	"	"	"	"	-	- Regular inspection and maintenance; portable extinguishers as backup	
		Failure to stop on demand	L	- Valve actuated by lever fails to open	"	"	"	"	"	-	"	
			L	- Valve actuated by lever fails to close	Suppression system ineffective	Portable extinguishers must be used for fire control	Area potentially flooded; operations cease; dewatering begins	"	IV	-	- Limited water supply	
		Failure to extinguish fire	L	- Poor coverage design	Suppression system ineffective	Portable extinguishers must be used for fire control	Fire may not be controlled; shaft sinking operations cease	"	I IV	-	- Good design procedures; portable extinguishers as backup	
			H	- Inability to reach small local fire	"	"	"	"	"	-	"	Small fires would best be handled by portable extinguishers
			L	- Insufficient water supply to extinguish fire	"	"	"	"	"	-	- Portable extinguishers as backup	Secondary water supply should be made available
			M	- Water ineffective extinguishing agent	"	"	"	"	"	-	- Extinguishers should be used on grease/electric fires	Training procedures to ensure more effective use of equipment

TABLE E-15. (Continued)

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:			Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System				
Portable hand-held fire extinguishers	To control/ extinguish fire	Faulty extinguisher	M	- Low charge	Operator must locate another extinguisher	None	Delay in finding extinguisher will give fire more time to do damage	I IV	- Operator recognition	- Many extinguishers are available, evacuation procedures known	Personnel must enter affected area to quench fire
			L	- Mechanical fault							
			H	- Dirt/mud bind switch							
		Extinguisher cannot be obtained	M	- Smoke or flame makes extinguisher inaccessible	Operator must locate another extinguisher	None	Delay in finding extinguisher will give fire more time to do damage	I IV	- Operator recognition	- Many extinguishers are available, evacuation procedures known	Covers over or around extinguishers to protect against dirt/mud buildup are recommended
			H	- Caked dirt or mud makes extinguisher inaccessible							
		Extinguisher does not put out fire	M	- Fire too large	Operator call for additional help or evacuate	None	None	I IV	- Operator recognition	- Evacuation procedures are known	Operator training suggested
			L	- Operator does not know how to operate extinguisher							
			H	- Location of fire inaccessible to operator							

TABLE E-15.S. Summary of FMEA Results from Table E-15

Potentially Hazardous Component	Hazard	Prob.	Crit.	Do Effective Prev./Corrective Measures Exist?	Suggested Design Change Number
Water-fog	Fire hazard remains (given fire, water fog fails to operate/ extinguish)	L	I	Y/N	1, 2, 4
Hand-held extinguishers	Fire hazard remains (given fire, extinguisher fails to operate/ extinguish)	L	I	N/N	1, 2, 3, 4

1. Fire control system should be revised. An automatic or remotely operable extinguishing system for the cab motor and pump area is recommended. Use of smoke detectors should be considered. A second lever to activate the water fog system from the control cab should be installed. Water may not be the most appropriate extinguishing agent for most fires.
2. A simpler and safer emergency escape route for the impactor operators is required (if possible). Rope ladders must be fire-resistant.
3. Fire extinguishers should be kept sufficiently covered from possible contaminants (i.e., dirt, mud, etc.) which could render extinguisher useless.
4. Proper training of what to do in case of a fire is highly recommended, especially training in how and when to use the fire control equipment.

a fire is questionable. This system must be activated from the galloway and if activated can create additional hazards to the impactor operators or other downhole personnel caught in the downpour of water.

Conventional exit from the operator cabs will be very difficult in a fire situation. Emergency escape must be by means of a rope ladder provided in the

operator cab. Operators must climb down the rope ladder to the shaft floor, enter the muck skips (which most likely would contain muck) and be hoisted up past the burning impactor if they wish to escape the shaft. If the emergency escape rope ladders are not treated to be flame-resistant they may also burn, leaving the operator stranded or causing him to fall to the shaft floor while using the ladder to descend. Another alternative would be for the hoistman to lower the impactor assembly close to the shaft floor; however, if the fire is major, this may be excessively time-consuming.

A better fire control and detection system is highly recommended. A remotely operable or automatic extinguishing system in the machine pump and motor areas is recommended, as well as a better (safer and faster) emergency escape route if possible. Also, if rope ladders are used as a means of escape they should be fire-resistant and not susceptible to corrosion or weakening during storage. No other design changes or recommendations are suggested.

Guidance

Shaft side lines will be used to ensure that the shaft is plumb. At the start of the lining cycle, plumb bobs are suspended from the lines and they are lowered using winches until the plumb bobs are below the section to be lined. In this position, the lines are used to locate the concrete forms. When the forms have been set, the side lines are raised.

Table E-16 presents the results of the FMEA of this system. Shaft side line breakage causing the fall of a plumb bob onto a miner is the only failure envisioned to be capable of harming personnel. This is an unlikely failure due to the load safety factors of the suspending cable, although it can occur.

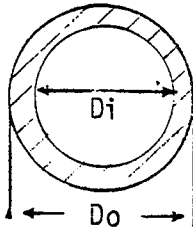
No design changes were suggested for this system.

Component	Function	Failure Mode	Prob Code	Failure Causes	Failure Effects On:				Crit Code	Failure Detection Methods	Preventive/Corrective Measures	Comments
					Component	Subsystem	Whole System	Interfacing System				
Winches	To hold and advance shaft sideline	Failure to operate when required	L	- Jamming of mechanical parts	Winch can not be used	Loss of or impaired guidance functions	Potential for constructing crooked shaft	Lining forms cannot be aligned/set	--	- Worker recognition	- Regular inspection/maintenance	
			L	- Mechanical failure								
Shaft Sidelines	To ensure shaft is plumb To support plumb bobs	Cable breaks	U	- Overloaded	Loss of one or more side lines	Loss of or impaired guidance functions	Potential for constructing crooked shaft	Lining forms cannot be aligned/set	--	- Worker recognition	- Load safety factors in cable design	
			L	- Weak/frayed				Plumb bob may fall on worker	1			

CALCULATIONS
Hanging Rod Factor of Safety

WEIGHT CALCULATIONS:

CONCRETE:



Nominal thickness ~1'
Nominal length ~20'
 D_i = Inside diameter ~22'
 D_o = Outside diameter ~24'
Density (p) .0841b/in³

AREA (A)

$$A = \frac{\pi}{4} (D_o^2 - D_i^2) = \frac{\pi}{4} (24^2 - 22^2)$$
$$= \frac{\pi}{4} (92) = 72 \text{ ft}^2$$

VOLUME (V):

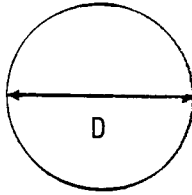
$$V = 72 \times 20 = 1440 \text{ ft}^3$$

$$p = .0841 \text{ b/in}^3 \times \frac{(12)^3 \text{ in}^3}{1 \text{ ft}^3} = 145.15 \text{ lb/ft}^3$$

WEIGHT (W):

$$W = 1440 \text{ ft}^3 \times 145.15 \text{ lb/ft}^3 = 210 \text{ KIPS}$$

STEEL FORMS:



8 rings each 2 1/2' high

DIAMETER (D): 22'
MAT'L: 1020 steel
DENSITY: .284 lb/in³
THICKNESS (T): 3/16"

AREA (A):

$$A = \pi Dt = \pi(22') \left(\frac{1}{12}\right) = 1.08 \text{ft}^2$$

VOLUME (V):

$$V = (1.08 \times 2.5) 8 = 21.6 \text{ft}^3$$

WEIGHT (W):

$$W = 21.6 \text{ft}^3 \times .284 \text{lb/in}^3 \times \frac{12^3}{1 \text{ft}^3} =$$

10.6 KIPS

FORMS

$$10.6 + 10\% \cong 12 \text{ KIPS}$$

← misc extras

$$\text{TOTAL LOAD} = 210 + 12 = 222 \text{ KIPS}$$

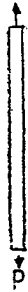
distributed over 11 rods

$$222/11 = 20.2 \text{ KIPS/rod}$$

Total Force, P = 20.2 KIPS per rod

RODS:

rods



Mat'l: 1020 steel, ultimate strength,
 $R_u = 68$ KSI yield strength, $R_y = 42$ KSI

11 rods, each 20' x 1-1/8" in diameter

Total Stress, $S = P/A$ $P = 20.2$ KIPS

$$A = \frac{\pi D^2}{4}$$

$$D = 1 \frac{1}{8}'' = 1.125''$$

$$A = \frac{\pi(1.125)^2}{4} = .994 \text{ in}^2$$

$$R_y = 42 \text{ KSI}$$

$$S = 20.2 / .994 = 20.3 \text{ KSI}$$

$$S < R_y$$

$$\text{factor of safety} = \frac{R_y}{S} = \frac{42 \text{ KSI}}{20.3 \text{ KSI}} \cong 2$$

DESIGN CHANGE PACKAGE NO. 1

Subject: Fire Detection and Extinguishment Systems

Priority: 1

Costs: MOD.

Dev/Test Reqmnts: MOD.

Introduction

Fire control on board the impactor system is provided by means of a water fog system and hand held fire extinguishers. Both systems must be manually activated. No automatic detection system exists. Fire detection must be done by personnel on board.

Possible sources of ignition in the impactor system include arcing or heating from damaged power cables, overloaded or shorted electric motors, frictional heat from bearings, spontaneous combustion or oily rags which have not been disposed of properly, and welding or cutting with a torch. These ignition sources, combined with flammable hydraulic fluids and lubricants as well as other combustibles that may be present as a result of poor housekeeping, provide the necessary ingredients for a fire to occur.

The probability of a fire occurring in the impactor system is considered to be relatively low. Laws governing welding, cutting and housekeeping, the probability of the other ignition sources occurring, and the high combustion point of hydraulic oils and lubricants all serve to lower the chance of a fire occurring on board.

Though the probability of fire is low, the consequence of such an event could be high, especially if detection or remedial action is hindered. In the present system, the most likely place for a fire would be on board the galloway deck near the hydraulic system or the impactor hydraulic motor and directional control valve compartment. These areas contain both possible ignition sources and combustible materials (namely the hydraulic fluid). Fires on the galloway stage should be easily detectable and accessible for extinguishment. However, fires in the impactor motor or valve compartments would be both difficult to detect and difficult to access for extinguishment with the hand-held extinguishers. There is also

some question as to the operability of these extinguishers as they are exposed to muck and spilled concrete which could cake onto the extinguisher or holder rendering them inaccessible and/or inoperable. The water fog system would also be of questionable value in such a case where the fire is enclosed and protected from the water spray.

Change Description

To improve the reliability of the hand-held extinguisher system, protective enclosures are suggested. Figure F-1 shows an environmental enclosure that can completely protect the extinguishers from any moisture, muck, concrete or other contaminants which may affect extinguisher operability.

To mitigate the problem of an inaccessible fire occurring in the cab pump or valve areas, a remote dry chemical system is suggested. This system would consist of some type of smoke or heat detector, an alarm to the operators and a dry chemical extinguishment system. Although detector systems, such as smoke detectors, have performed somewhat unreliably in the past due to the moisture and dust in the atmosphere downhole, this may not be a problem in this application, since the detector system would be enclosed in the cab pump and valve areas and partially protected from such contaminants.

A dry chemical system is also suggested for the galloway hydraulic pump area. However, since detection by personnel should not be difficult, a manually activated system would be sufficient.

Figures F-2 and F-3 show the areas considered for nozzle placement for the chemical extinguishment systems. Exact number of nozzles and optimum placement locations within each area will require more detailed design efforts as space constraints and other structural design details will need to be considered.

Figure F-4 is a simplified schematic of the suggested fire extinguishment system for the impactor. System components would basically include a storage tank for the extinguishment (one central tank is shown but multiple

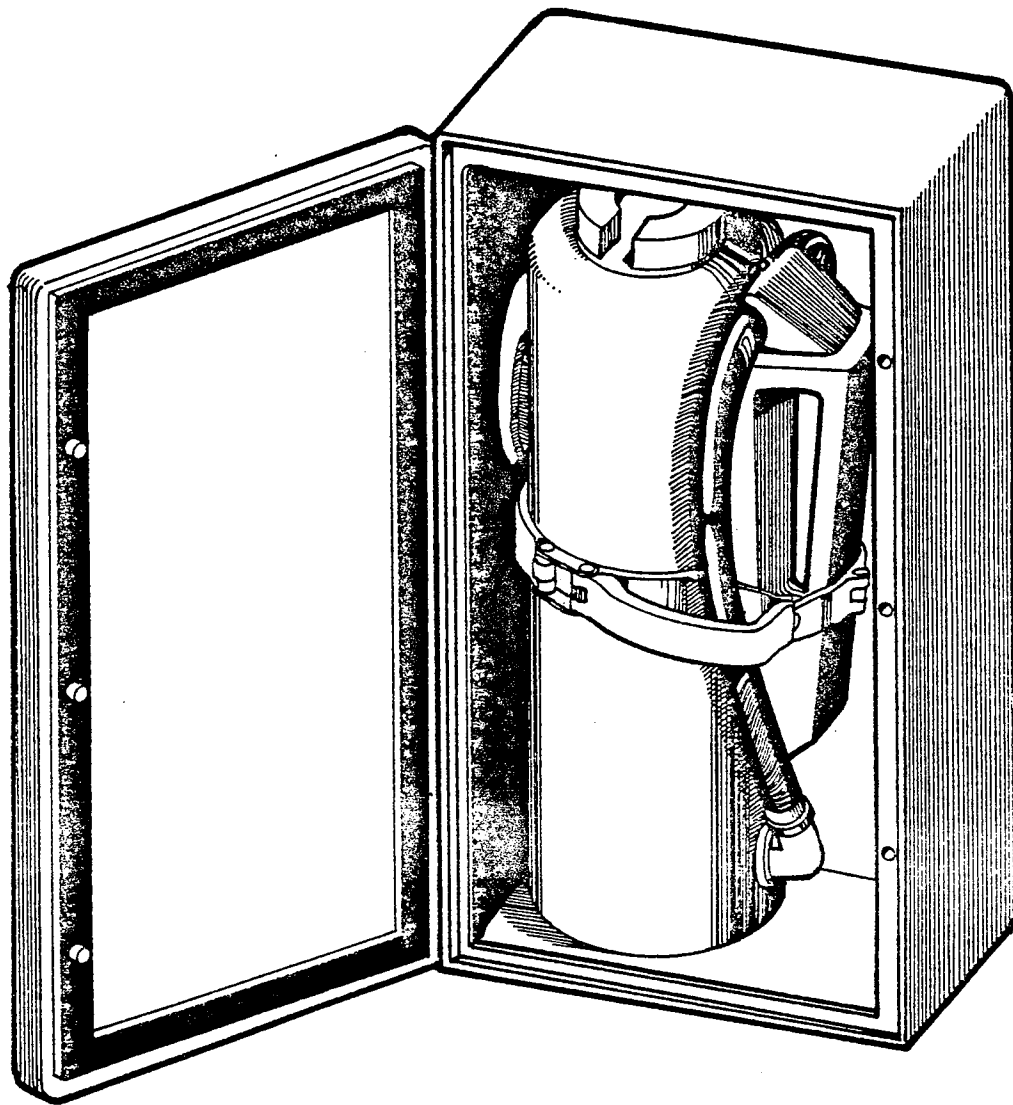


FIGURE F-1. Fire Extinguisher in Environmental Housing

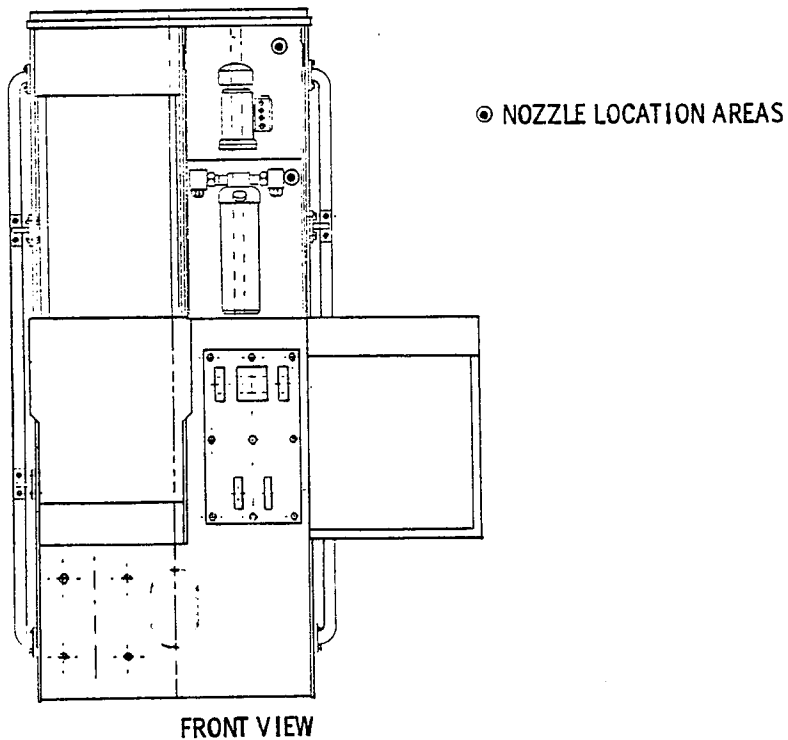
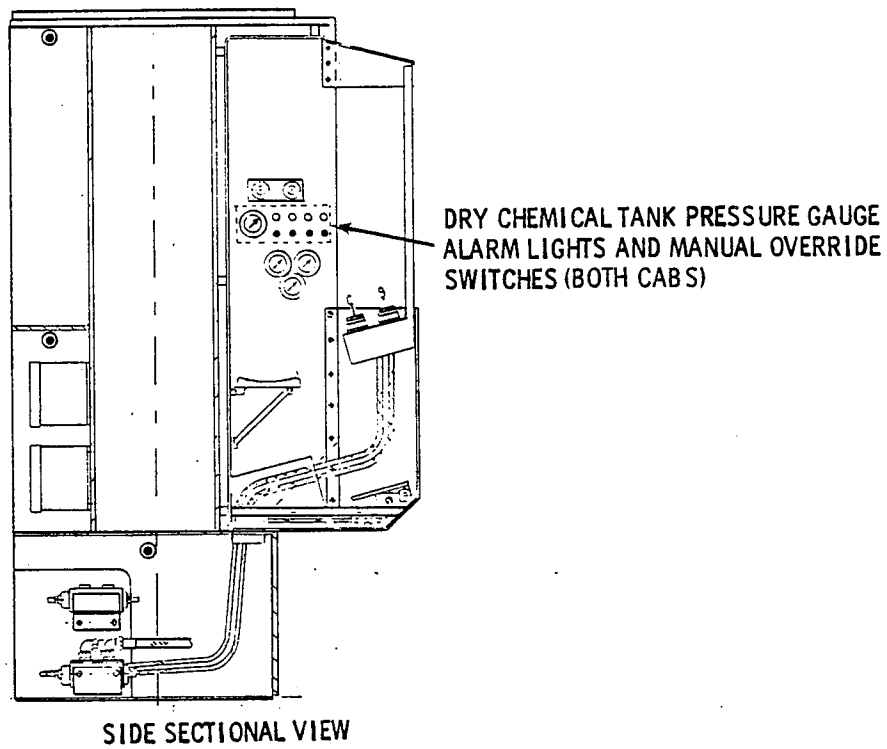


FIGURE F-2. Suggested Nozzle Placement Location

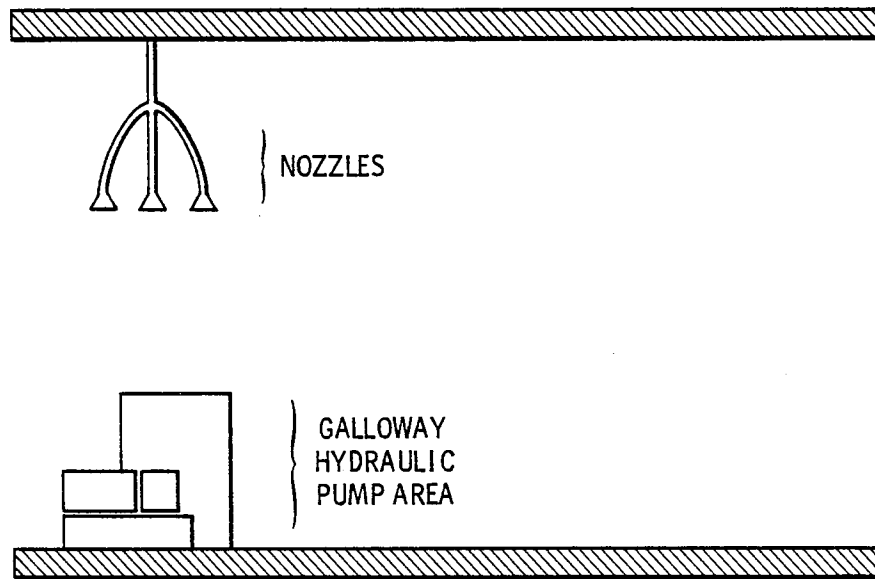


FIGURE F-3. Suggested Nozzle Placement of Remotely Operable Dry Chemical Extinguishment System

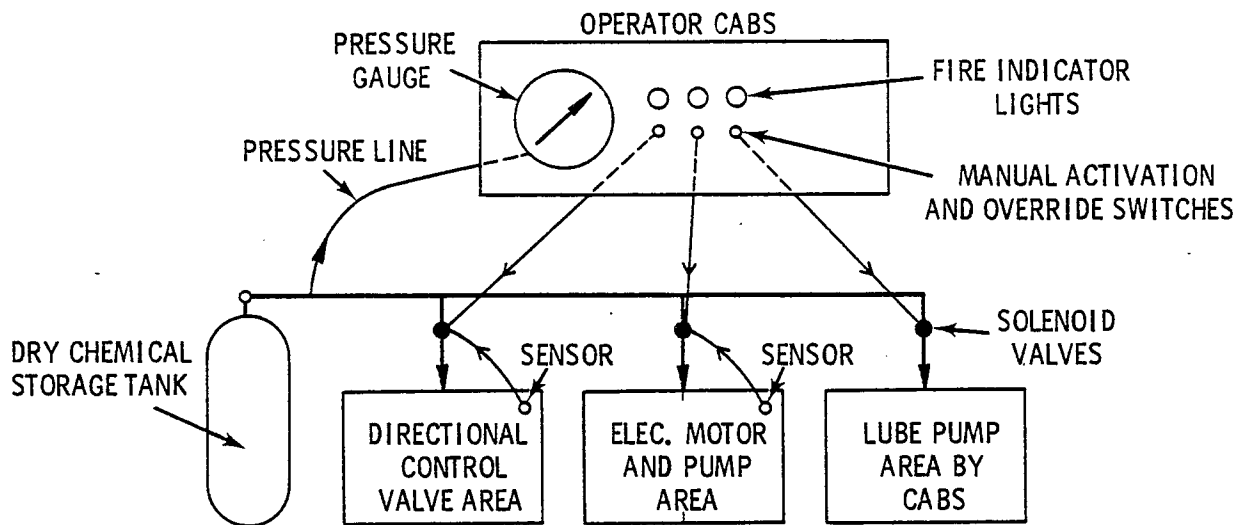


FIGURE F-4. Schematic of Remote Dry Chemical Extinguishment System for Hard-to-Access Impactor Locations

smaller tanks would also be acceptable); fire sensors (except at the lube pump area, as this area would be visible to operators); solenoid valves to be activated either manually or automatically by the sensors; indicator lights; an alarm to warn of fire; manual activation switches; and a tank pressure gauge(s). The galloway would also require a similar system. Automatic activation would not be required here since a fire in this area should be easily detectable.

Change Interface

Change interface would be minimal for use of the revised environmental housings for the extinguishers and would consist basically of modifying wall mounts and attachment parts. Change interface for the dry chemical extinguishment system in the cab pump and valve areas should not require more than a moderate level of effort. Small "off-the-shelf" type extinguishment systems exist and should be readily modifiable to suit impactor requirements. Space restrictions will determine whether a single storage tank or multiple tanks will need to be used. Nozzle placements will have to be determined for optimum effect in fire control within the machine areas. Nozzle placement and number will be strongly limited by component space constraints. Periodic maintenance and testing of these systems will also be required to derive the maximum benefits.

Change Rationale and Benefit

By providing localized extinguishment systems at critical areas, as well as hand-held fire extinguishers for smaller blazes, the use of the water fog system can be drastically reduced and the reliability of fire control substantially increased. It is anticipated that with implementation of the dry chemical system it may be permissible to abolish the water fog system entirely or at least to greatly reduce the size of the system. Also, the chemical system appears to be a more effective extinguishing agent than water against the type of fires likely to occur in the impactor system. Benefits derived would be a safer system to the

personnel downhole. Some decrease in repair downtime in the event of a fire may also be possible because of faster detection and extinguishment limiting the potential extent of fire damage.

Impactor Performance

Effect on day-to-day impactor performance will be minimal. However, as noted above, decreases in repair downtime are probable should a fire occur.

DESIGN CHANGE PACKAGE NO. 2

Subject: Operator Cab Entry and Exit

Priority: 1

Costs: MOD. to MAJ.

Dev/Test Reqmnts: MOD.

Introduction

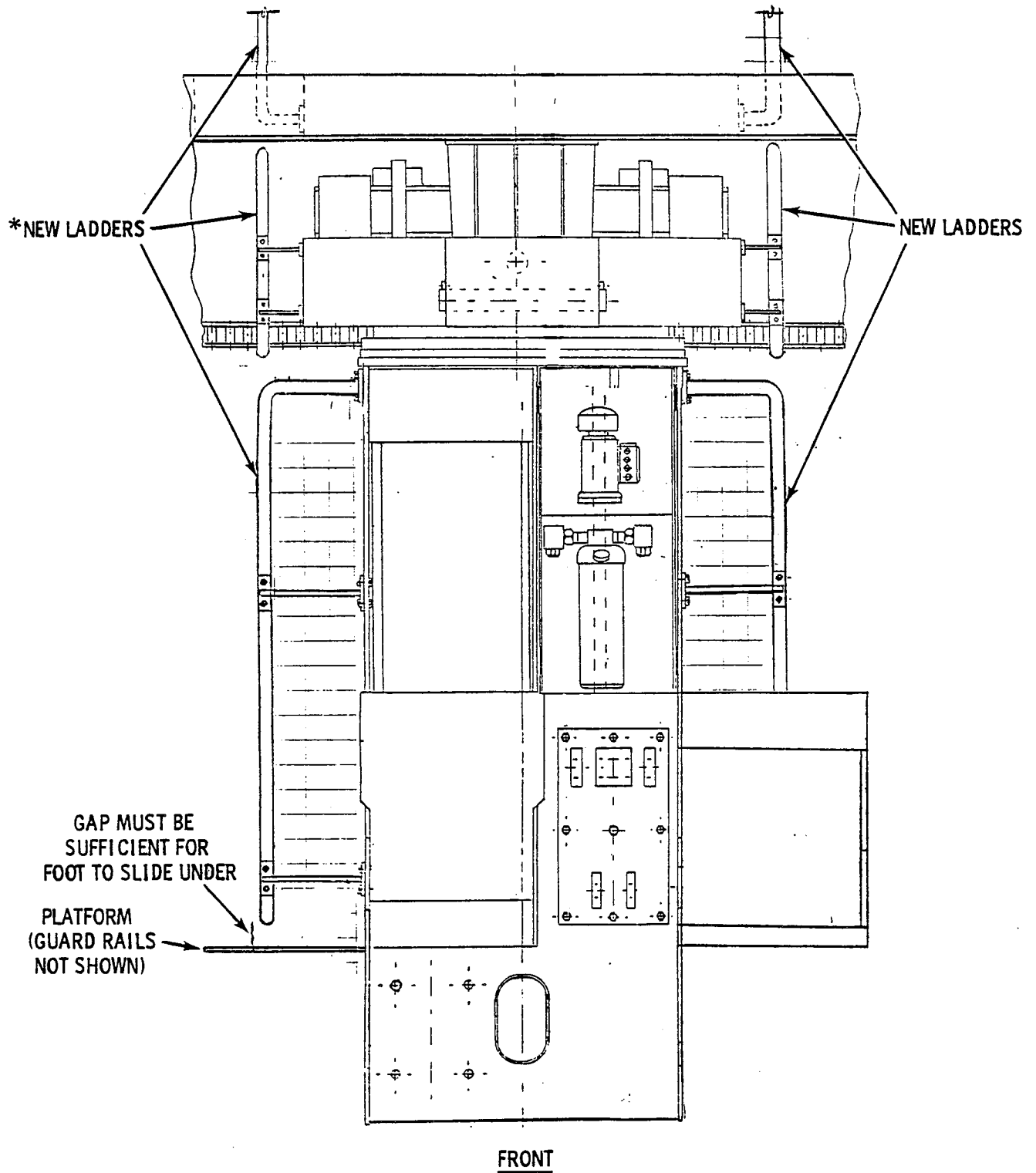
Present operator entry and exit procedures require that the operator climb down a ladder suspended below the bottom galloway deck, transfer himself to the impactor machine by stepping onto an exterior railing, slide sideways across the side of the impactor using foot and hand railings until he reaches the cab opening, and then step into the cab. All of this must be done while he is suspended directly over the shaft floor, which may be as far as 15' below him.

Change Description

Two possible alternative arrangements are envisioned as changes to the present system. The first arrangement requires a minimal amount of interfacing or modifying of existing structures, consisting basically of additional access holes in the galloway deck and the addition of a platform to the impactor machine. The second alternative arrangement is more complicated and would possibly require a redesign of the rotating frame.

Figure F-5 shows the access path for the first alternative. Here a ladder for each of the operators is provided. A platform and guard rail are mounted on the machine itself for safety and ease of ladder access. Another variation of this alternative system would be to add a ladder only on the impactor hammer side of the machine. This is shown in Figure F-6. This alternative design has the advantage of lower cost and a narrower platform requirement on the mucker side of the machine. Figure F-7 is a sectional plan view of the impactor as redesigned with this option.

In this arrangement, before an operator could exit the impactor, he would have to rotate the frame to position the ladder under the galloway access hole and ladder and then rotate the cab so that the impactor ladder(s) also align. This position, in which all ladders are aligned, will be



* NOTE: ALL LADDERS ALIGN WHEN IMPACTOR PLACED IN "PARKED" POSITION

FIGURE F-5. Dual Ladder Access Alternative to Impactor Machine

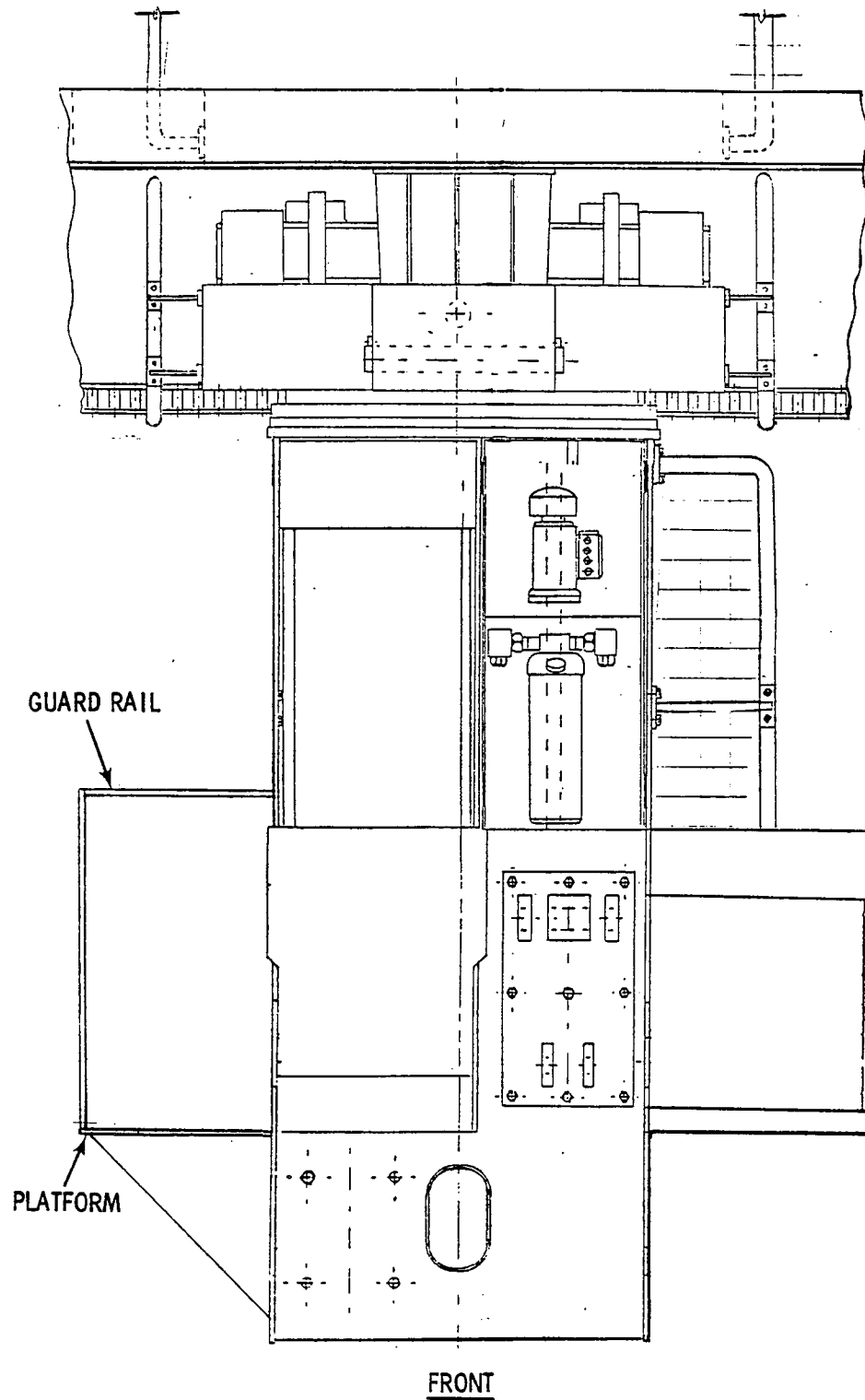


FIGURE F-6. Single Ladder Access Option

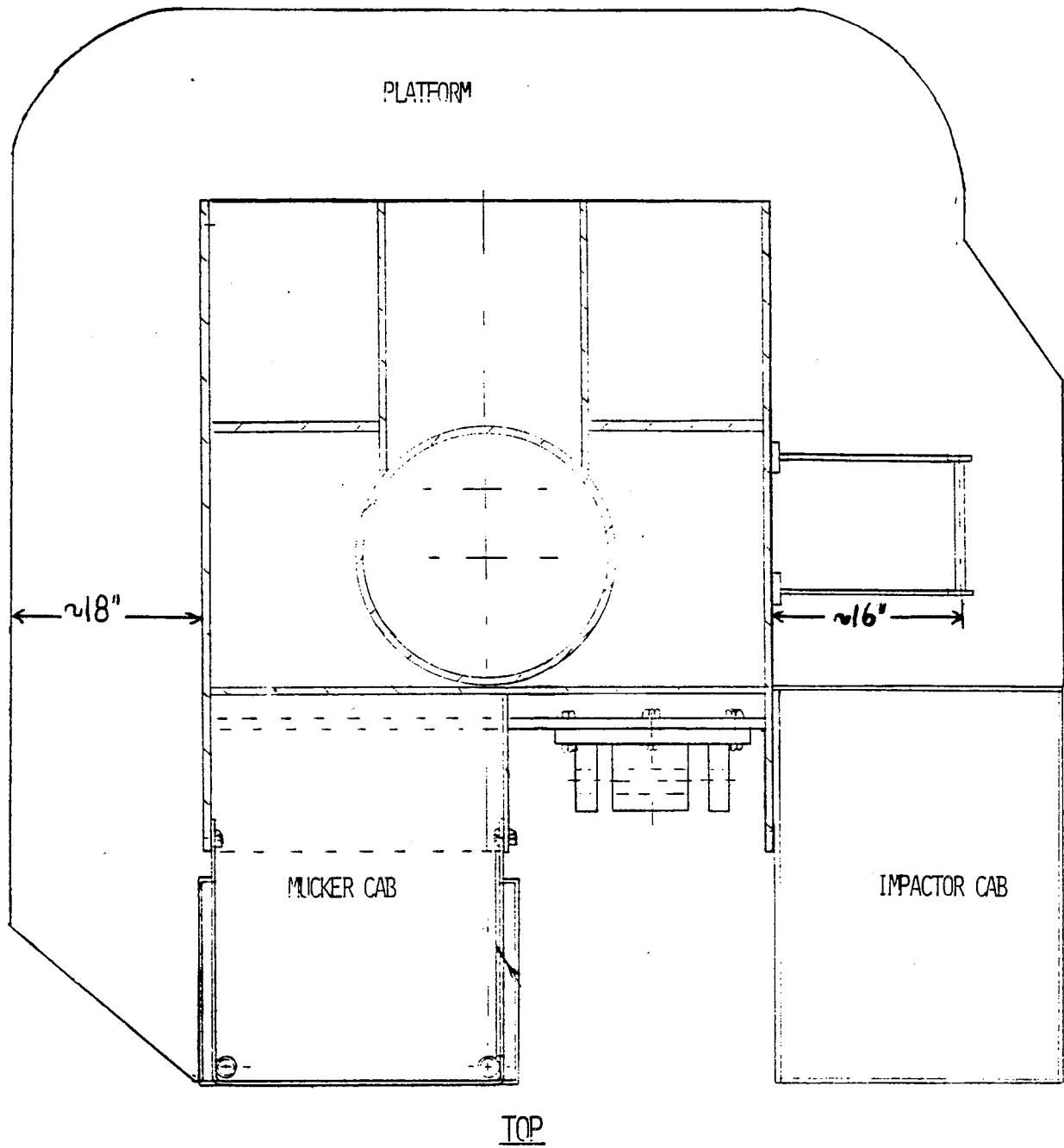


FIGURE F-7. Single Ladder Access Option - Top View

called the "park" position. Microswitches and an indicator light in the operator console would be used to inform the operator when the frame and cab are properly parked. A minimum of two park positions would be required. Figure F-8 shows a possible placement of the required access holes for two different parked positions. Use of two ladders on the impactor would require four manholes in the deck (two for each park position). Two is thought to be a minimum because one galloway channel will always have a muck bucket below it. The hoist rope connecting to the bucket and passing through the channel would prevent the rotating frame from parking on that side of the shaft without striking and damaging the bucket rope. Figure F-9 outlines the "park" position in more detail, showing the top view of the machine as it would appear under the galloway access hole.

The second alternative design would require some changes to the present system. These changes include relocating the access ladders into the operator cabs so that after the galloway-impactor assembly was "parked," the operator could climb up to the galloway decks directly from the cab, through the rotating frame. One ladder for each cab would be required, as well as major frame redesign to accommodate man passage through the rotating frame. This alternative design is especially recommended for use with the machine if the operator cabs are combined into one as suggested in Design Change Package No. 7.

Figure F-10 shows a sectional view of the mucker operator's cab with its access ladder designed according to this second alternative. It should be noted that the operator cab access ladder may not have to go through the rotational frame. With some structural change it should be possible to provide the impactor operator with a ladder that goes up the outside of the frame. However, the details of this alternative design will require further engineering effort.

Change Interface

Change interface of the first alternative design consists of the addition of a platform to the impactor machine, addition of ladders and addition of two or more manholes on the galloway deck. Consideration will

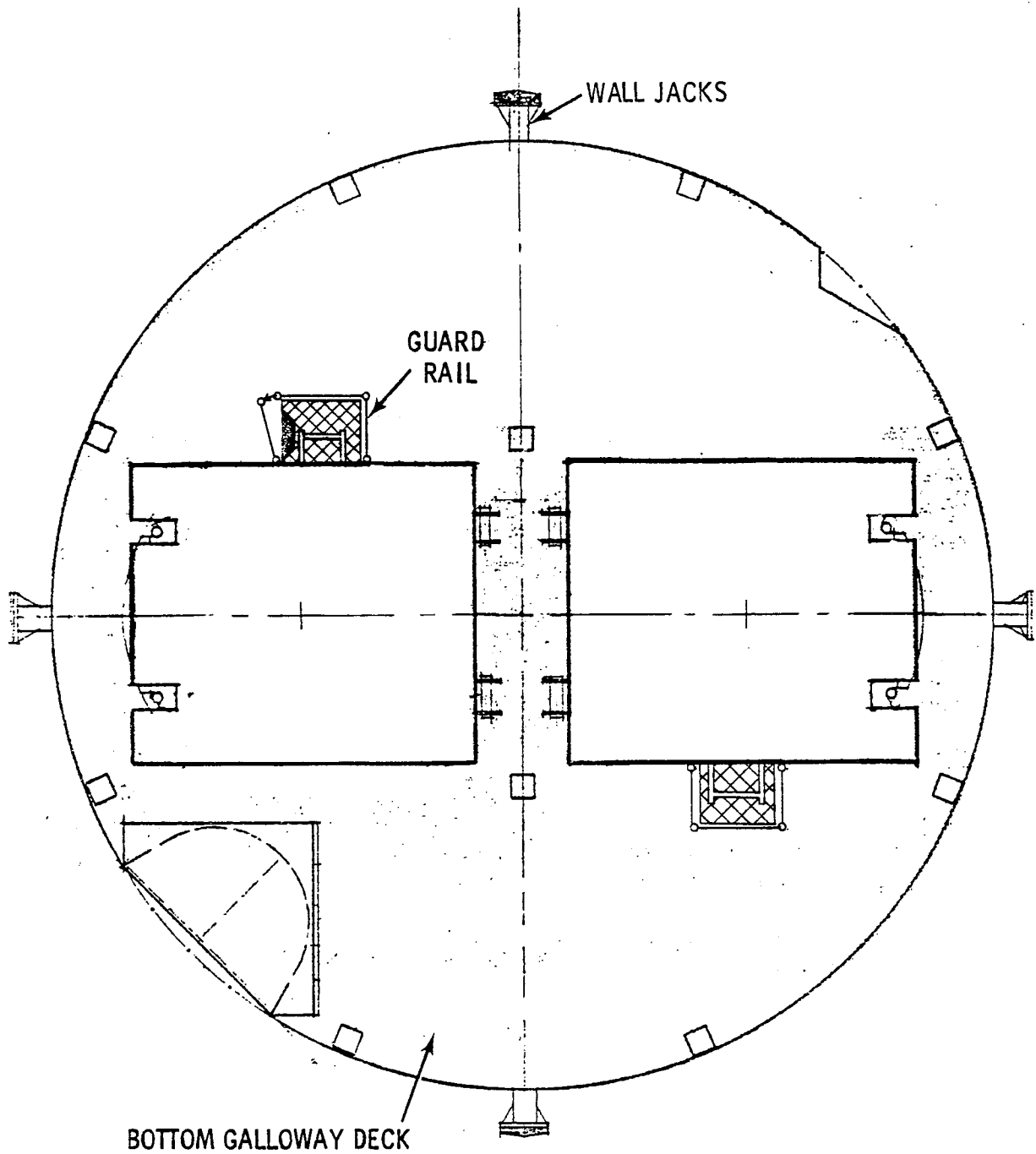


FIGURE F-8. Single Ladder Alternative Design

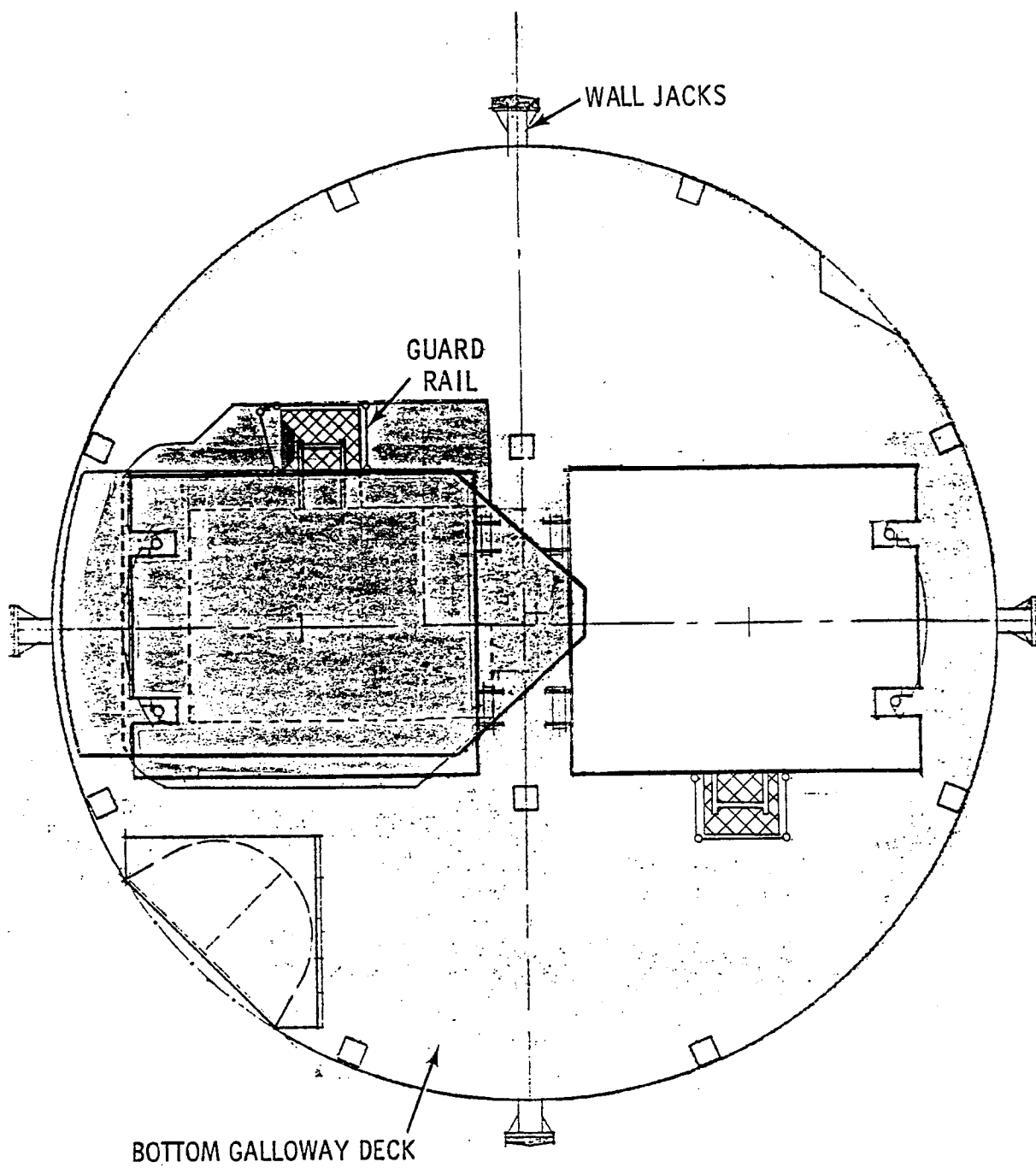


FIGURE F-9. Top View Showing Impactor Machine in "Park" Position

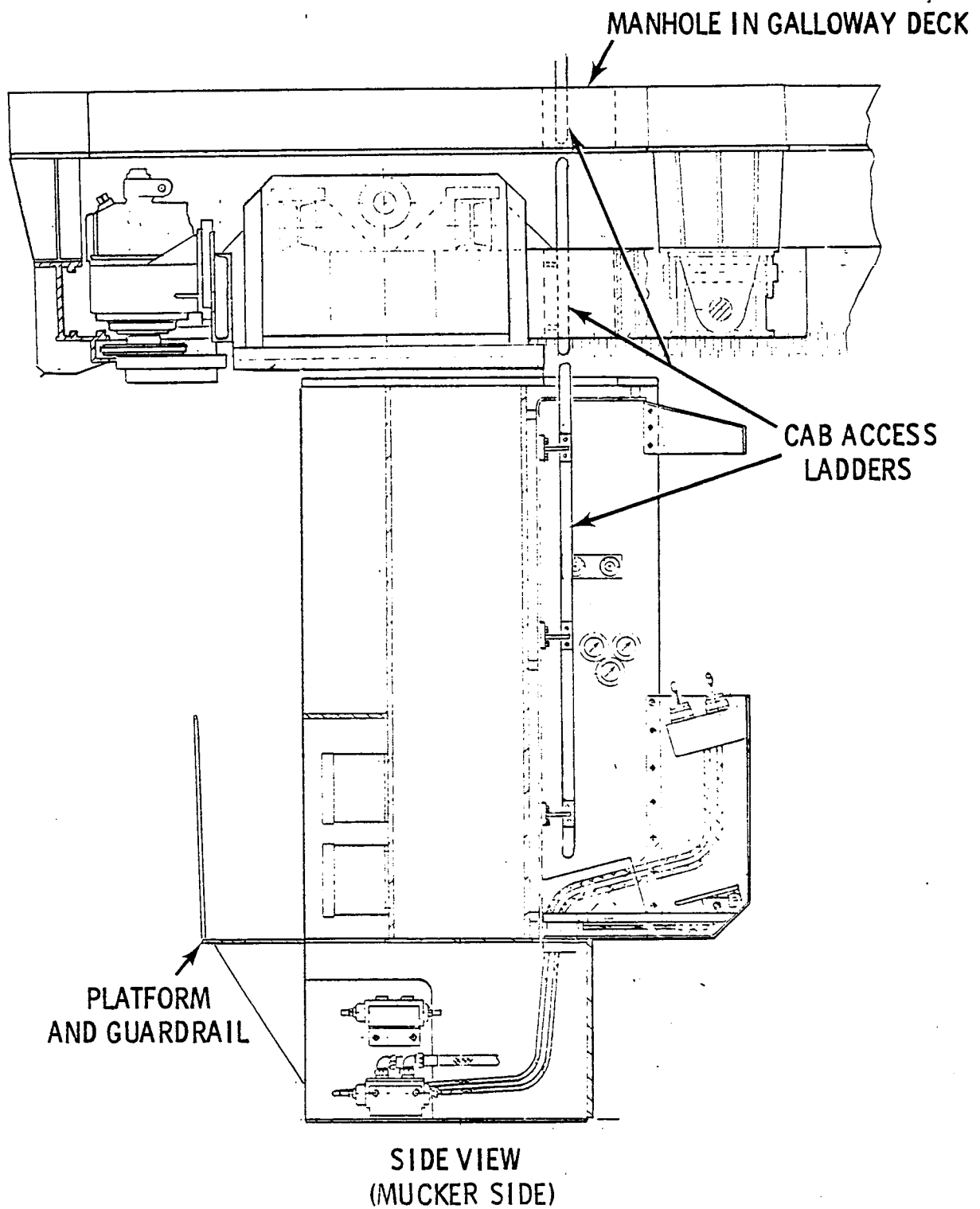


FIGURE F-10. Alternative Cab Access Design

have to be given to the arrangement of the access holes and ladders so that getting on or off the ladder from the galloway will not be hazardous. Guard rails are suggested as superior to doors for protection from potential falls, since the opening of the doors from a vertical ladder is a difficult operation that is inherently hazardous. Space constraints downhole because of the platforms are not anticipated to be a problem because of the large clearance between the shaft wall and the impactor machine. Operator visibility should not be affected because the platforms are constructed at the sides of the machine and are not very wide.

Change interface required for the second alternative could be fairly extensive as far as rotational frame redesign is concerned. Relocation of the ladders into the operator cabs will have to consider operator working space and may require some increase in the cab size.

Change Rationale and Benefits

By not requiring the operators to enter and exit the cab while suspended directly over the shaft floor, the hazard of operator transfer to and from the machine can be substantially reduced. The platform also allows some potential access between operators in case of emergency situations. In the present design, access between operators is difficult and hazardous to achieve.

Impactor Performance

Impactor performance should not be affected by an improved access means to the operator cabs. Impactor maintenance may be somewhat easier if the platforms are installed, as access to the machine compartments will be increased.

DESIGN CHANGE PACKAGE NO. 3

Subject: Operator Emergency Escape Route

Priority: 1

Costs: MOD.

Dev/Test Reqmnts: MIN.

Introduction

For the most part, operator emergency escape will be the same as the conventional exit and can be substantially improved by implementation of the design change package No. 2 for easier operator cab access. However, in the event an emergency escape is required, the operator cab and frame may not be able to be put into the "parked" position so that escape by conventional means or even with Design Change Package No. 2 is not possible. Currently designed procedures require that operator lower a rope ladder, climb out of the cab and down the ladder, walk across the shaft floor to a parked muck bucket (which is most likely at least partially full of muck), climb into the bucket and be hoisted up to the lower galloway stage where other personnel are loaded. The whole process involves many potential slip/fall hazards and delays. There are also hazards associated with man haulage in a muck bucket partially full of muck. With the present cab design, operator access to one another is very difficult. Should one operator be injured or suffer a medical disability (i.e., heart attack, etc.) access to help him and remove him from the shaft would be slow and difficult. Even if Design Change Package No. 2 is implemented, since only one operator has the proper controls to "park" the cab, loss of this operator would force the other operator to use the emergency rope to exit his cab.

The probability of an emergency evacuation even being required is judged to be low and the probability that the operators will be forced to use the emergency rope ladder method to exit is thought to be even lower, particularly if Design Change Package No. 2 is implemented.

Events such as fire and excess smoke, loss of ventilation, accumulations of harmful gases, shaft flooding and such, however, may require a quick evacuation of personnel. The present system design utilizes a

rope ladder for emergency escape. In Design Change Package No. 2, emergency escape by the rope ladder will be required only if the cab slew and/or frame rotate mechanisms fail so that the park position could not be achieved. Non-emergency rope escape would be required if these mechanisms failed at a time other than during an emergency situation.

With proper maintenance and design the reliability of the parking devices should be quite high and required use of the emergency rope, therefore, kept low. However, to further increase the availability of the parking mechanisms and to decrease the hazards involved with rope escape should it be required, the following design changes are suggested.

Change Description

One method of reducing the possibility of injury due to use of the rope ladders is to reduce the probability that they will have to be used. Since the only time the rope ladder will have to be used is if the conventional exit route cannot be used, improving the reliability of the conventional route would be an effective means of hazard control. Reducing the hazards of the conventional route is discussed in the previous section, Design Package No. 2.

To improve the availability of the escape route outlined in Design Package No. 2, some sort of pneumatic and hydraulic reservoir system should be considered to allow one final parking of the cab and frame should the hydraulic or pneumatic supply systems fail. (See Figures F-11 and F-12.) In this way, operator exit by the route outlined in the previous section can be assured in case of a power outage, air supply failure or any number of other possible system failures.

Use of an emergency reservoir system would not, however, assure against all possible component failures and exit by means of the emergency rope ladder may still be required in some instances. For this reason, steps should be taken to assure the quality and usability of the rope ladder system. A protective enclosure for the rope, out of the way of

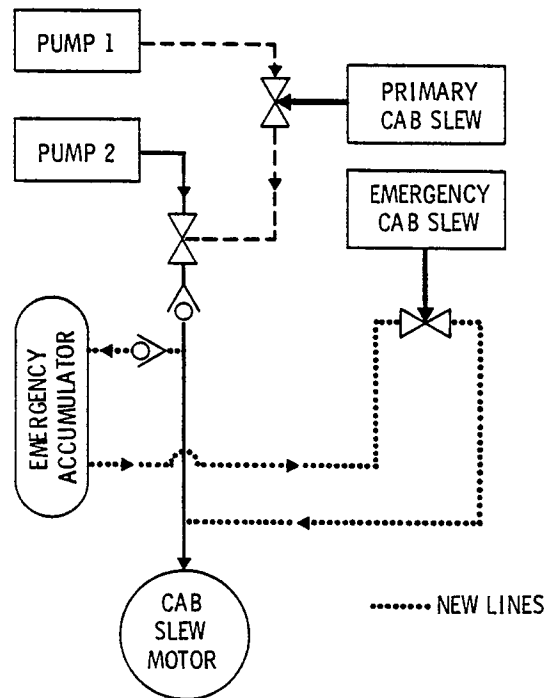


FIGURE F-11. Cab Slew Emergency Reservoir Conceptual Schematic

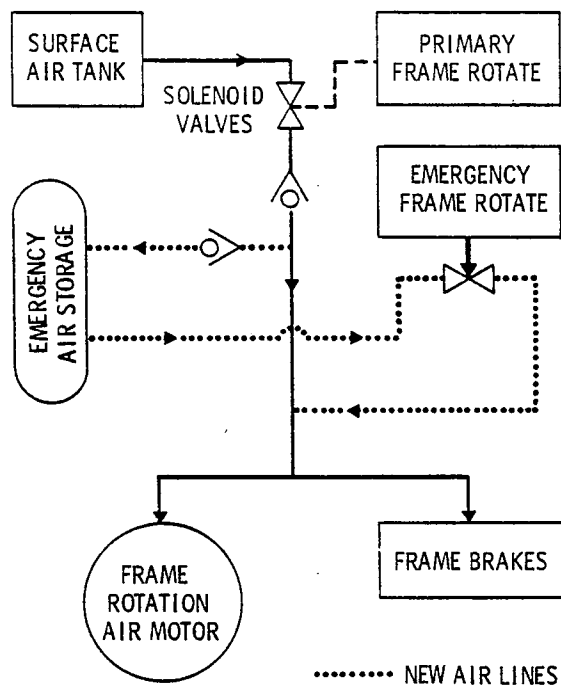


FIGURE F-12. Frame Rotation Emergency Reservoir Conceptual Schematic

the operator, to protect the rope against damage and deterioration should be supplied. The rope should be made fire/heat resistant in case escape is required during a fire. It should be easily lowered and it should be easily and safely accessible (i.e., it should require no dangerous maneuvers to climb onto the rope or to climb down). Figure F-13 shows a possible arrangement of an emergency ladder assembly in conjunction with the platforms suggested in the previous design change package. The emergency rope is rolled up into a box. When the release lever of the box is pulled, the hinged bottom opens, allowing the rope to unroll. The rope material is chemically treated so as to be fire resistant and waterproof. The rungs are of tubular aluminum or steel construction for ease of use (an all-rope ladder can be tricky to use). Figure F-14 shows the postulated operation for the quick release of the emergency ladder from its storage box.

Change Interface

Change interfacing for the suggested rope placement is minimal and consists only of mounting the box to the impactor wall. Although two rope ladders (one on each side for each operator) would be optimum, one rope to be shared by the operators would probably be sufficient. This scheme does, however, require the use of the platforms previously described in Design Change Package No. 2 so that one operator can readily get to the second operator's cab.

Change interfacing to improve the "parking" system on availability generally consists of the addition of a hydraulic and an air emergency accumulator and the required lines and valving. Placement of the accumulators will depend on their required size. It is not anticipated that they will have to be very large since they only need to store sufficient energy for one emergency parking.

Change Rationale and Benefit

By reducing the possibility of having to use the rope escape and by improving the rope escape system, the hazards of having to use this escape

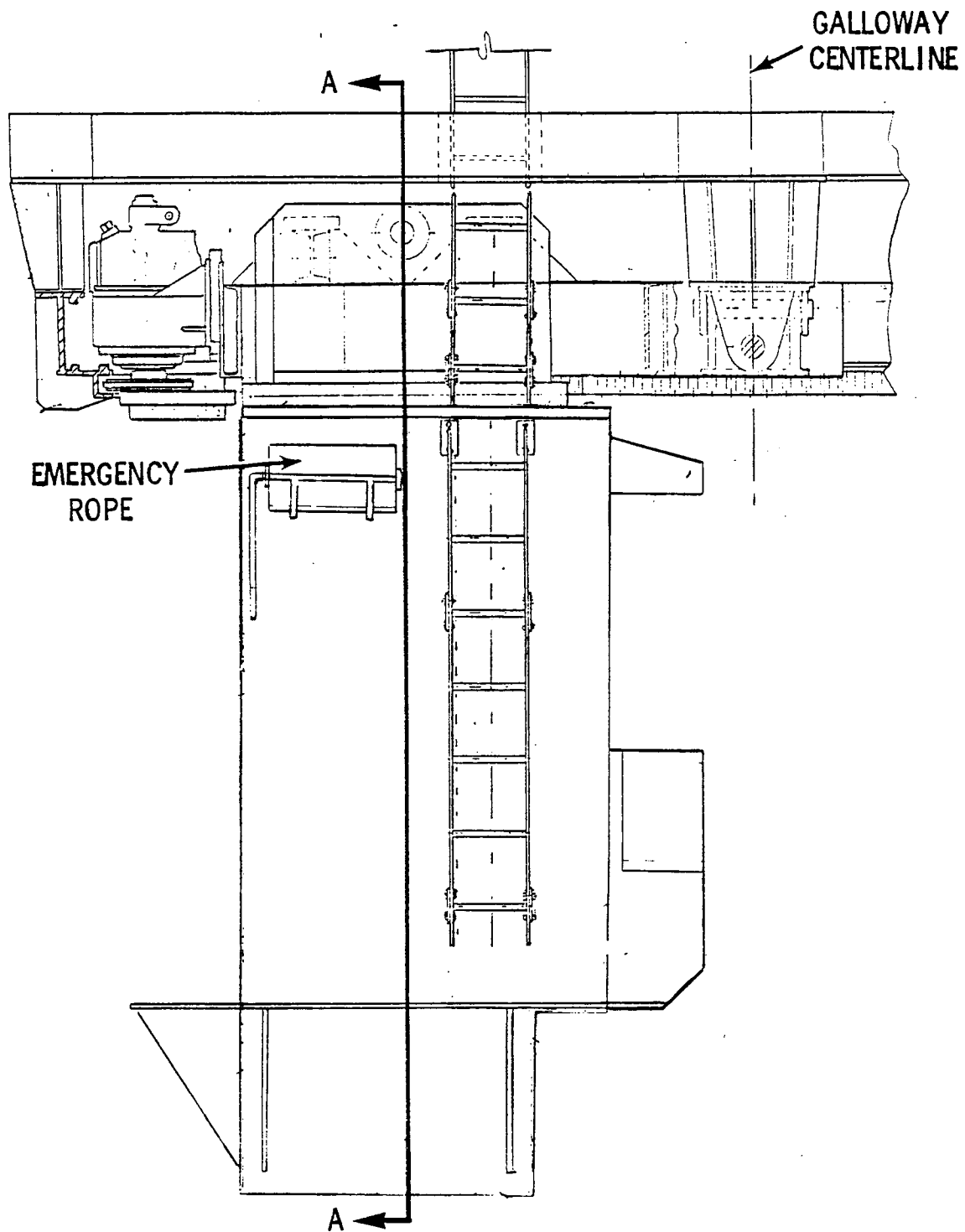


FIGURE F-13. Emergency Rope and Storage Box Placement Conceptual Drawing

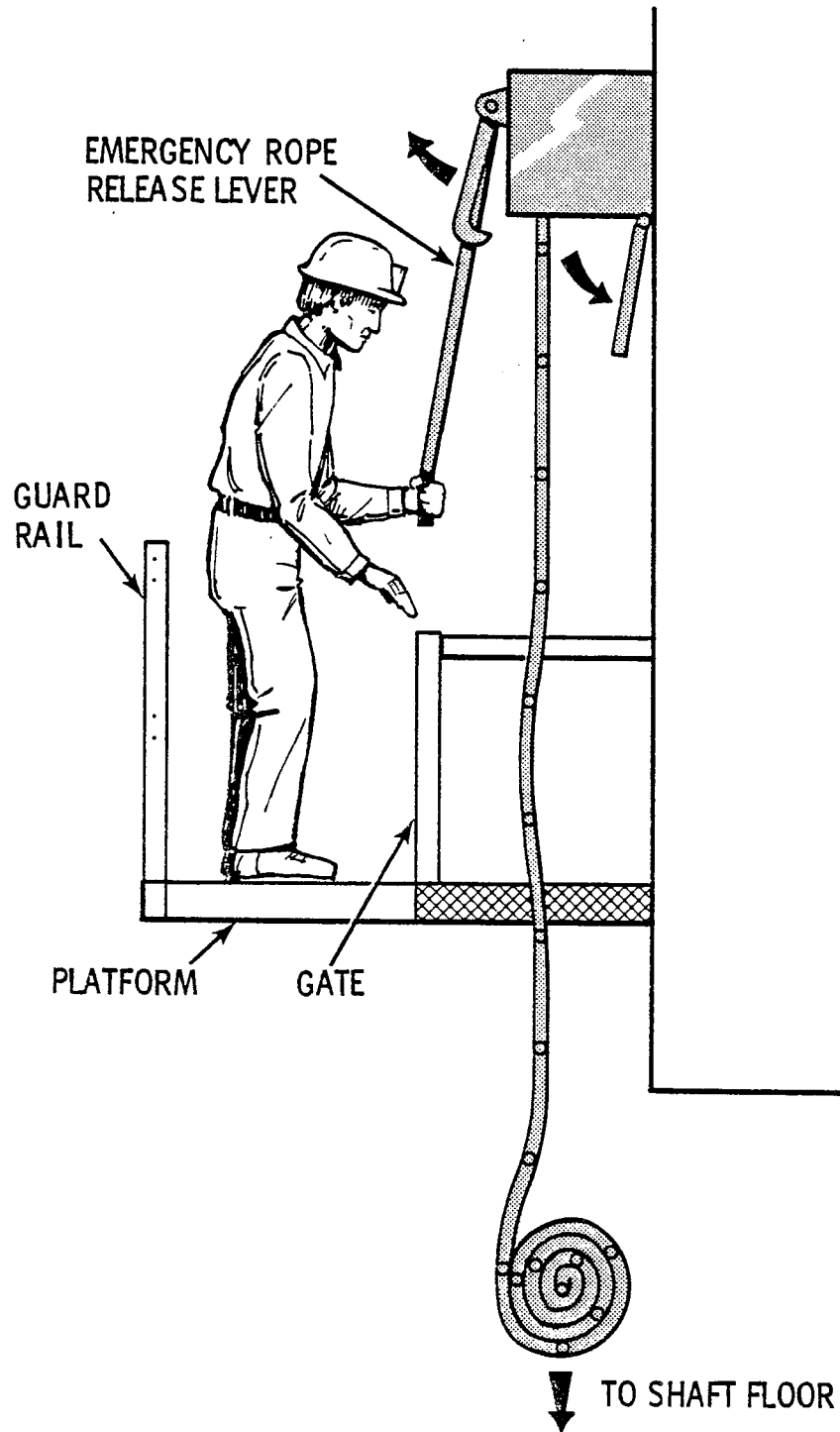


FIGURE F-14. Sectional View at A'-A' (Figure F-13) of Emergency Rope Ladder Release

route can be reduced. Hazards involved in requiring the operators to ride in partially filled muck buckets is not reduced by this design alternative.

Impactor Performance

Effect on impactor performance will be minimal.

DESIGN CHANGE PACKAGE NO. 4

Subject: Hoist Rope, Rotating Frame Collision Interlock

Priority: 1

Cost: MIN.

Dev/Test Reqmnt: MIN.

Introduction

During rock breaking and mucking operations, the muck bucket is placed at the shaft floor and its hoist rope passes through the galloway channel door holes (see Figure F-15). There is the potential for the operator to rotate the frame and strike the hoist rope by accident. Such an accident could damage and weaken the rope severely, creating a rope failure potential. Should rope failure occur during man haulage, fatalities are likely. There are probably no practical ways to eliminate this potential hazard, as this would require either removal of the rope during rock breaking or considerable rework and redesign of the track, frame and center support of the impactor machine assembly to avoid the rope. The best solution is thought to be to supply proper interlocking or warning devices to prevent the operator from accidentally striking the wire rope.

Change Description

Installing an interlock/warning device could probably be done at the center pivot. Microswitches could be installed at the center support bearing. These switches would activate a warning light should the frame rotate too close to the wire rope and stop the frame if the operator continues to rotate it. Since the muck bucket can be on either side of the shaft, two sets of microswitches may be required to stop rotation into whichever side the bucket and rope were in. Some sort of switching device to turn "off" one set and "on" the other set of interlocks will be required. Choosing the appropriate set of interlocks could either be done automatically or manually by the operator.

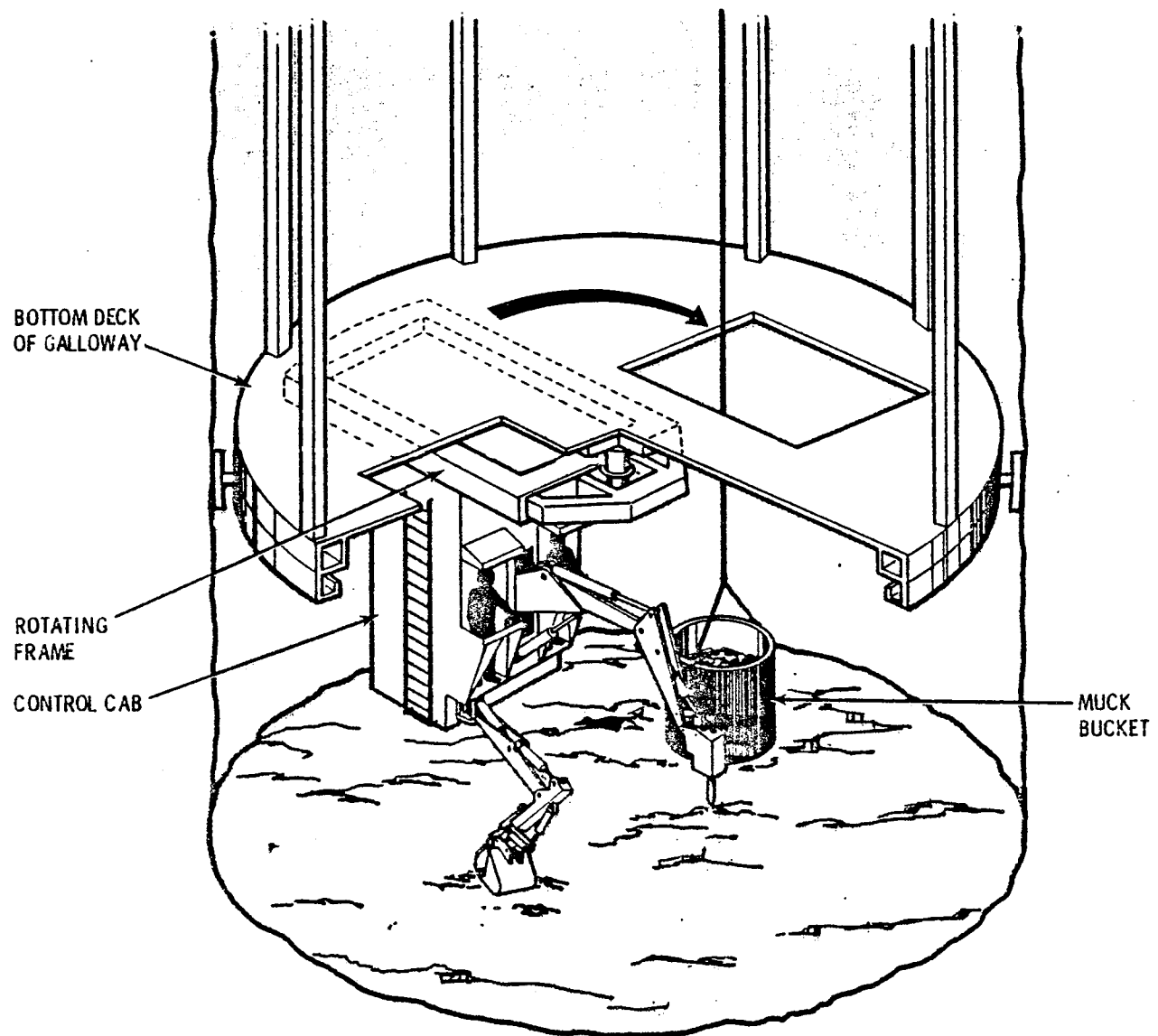


FIGURE F-15. Rotating Frame Potential to Strike Hoisting Rope

Change Interface

Change interface will require some small structural changes to mount the switches and activators and some fairly moderate changes to the air motor control system and operator control panel to install the warning/interlock devices.

Change Rationale and Benefit

Accidental damage to the rope can produce costly downtime for repair. It is also possible that the rope could be struck and weakened unknowingly. This would increase the risk of injuries or fatalities during man and muck haulage. By installing an interlock/warning device the probability of such an event can be substantially reduced.

A second benefit would be that these interlocks could possibly be adapted to provide a warning to the operators and shift boss should an empty bucket be lowered while the impactor frame is in the bucket path. This would aid the shift boss in avoiding muck bucket and impactor collisions.

Impactor Performance

Installation of a rotational interlock and warning device should have no appreciable effect on day-to-day performance, although somewhat lower sinking rates than anticipated may be experienced as a result of position changes each time a muck bucket is brought down. There is, however, the risk that the interlock device could fail, stopping frame rotation and causing downtime.

DESIGN CHANGE PACKAGE NO. 5

Subject: Excessive Noise

Priority: 2

Cost: MIN. - MOD.

Dev/Test Reqmnt.: MIN. - MOD.

Introduction

During normal operation of the impact hammer, noise exposure to the operators from the pneumatic hammer is estimated to be 90 dBA or less. If total downhole noise is within this level, MSHA regulations will allow full 8-hour shifts with no ear protection or other protective measures (see Table F-2). It is, however, uncertain how the noise of the hammer, as well as the noise of other combined sources, will react when put together in a downhole situation. It is not unreasonable to assume that the total noise exposure to the downhole personnel could easily go beyond the 90 dBA limit for an 8-hour shift. This is especially true when the reliability of the pneumatic hammer silencer is taken into account. There is a reasonable chance that the silencer can be broken off or otherwise rendered useless due to collision with the shaft walls, with the mucker boom or by the excessive vibrational loads imposed on it. Should the silencer be abruptly broken off or its effectiveness diminished, noise levels could rise sharply, exposing the operators to potentially harmful noise levels.

Change Description

Because noise effects and levels downhole are currently unknown, it is highly desirable that noise monitoring be done. Noise dosimeters and various inexpensive noise meters are currently available and the use of these will greatly aid in determining what degree of ear protection and machine noise dampening will be necessary for personnel safety. Federal mine safety requirements describe noise level measurement procedures (see Table F-3) and set noise limits allowable per hours of exposure. OSHA regulation 29 CFR 1910.95 also sets forth noise exposure regulations.

Table F-2 shows the acceptable levels set by the Department of Labor for continuous noise in occupational settings. These figures specify an

TABLE F-2. Permissible Noise Exposure

<u>Duration per day, hours</u>	<u>Sound Level, dBA</u>
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
1/2	110
1/4 or less	115

TABLE F-3. Summary of Noise Level Measurement Procedures

- (a) Noise level measurements shall be made at locations where the noise is typical of that entering the ears of the miner whose exposure is under consideration.
- (b) Five measurements shall be made for each type of noise exposure producing operation to which the miner under consideration is exposed.
- (c) Each measurement shall be made by observing the readings for 30 seconds and recording the noise level.
- (d) The average of the five noise level measurements shall be considered as the noise level measurement which is representative of the operation.
- (e) Where different and distinct noise levels occur at various phases of an operation, noise level measurements shall be made in accordance with this section for each distinct phase.
- (f) The noise levels and the estimated length of time the miner is exposed to each level during a normal work shift shall be reported for the operation. The range of the five noise level measurements used in paragraph (d) of this section shall also be reported.

allowable level for noise levels that, in effect, permit a 5 dBA increase for each halving of the exposure time. Note that Table F-2 defines permissible noise exposure, with "exposure" being a function of both sound level and duration (in hours per day). Thus, for example, an employee can be exposed to 90 dBA for a full 8 hours a day. But, if the sound level increased to 95 dBA, maximum permissible exposure time drops to 4 hours per day. Every 5 dBA increase in sound level halves the allowable exposure time.

When employees are exposed to different sound levels during the day, the "mixed exposure" must be calculated by using the formula:

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} + \dots + \frac{C_n}{T_n} = D$$

where each "C" is the total exposure time at a given noise level and each "T" is the total exposure time permitted at that level. If the sum of the fractions equals or exceeds 1, then "the mixed exposure is considered to exceed the limit value."

For example, an employee is exposed to the following noise levels during his work day:

85 dBA - 3.75 hours
 90 dBA - 2 hours
 95 dBA - 2 hours
 110 dBA - 0.25 hours

Thus, the sum of the fractions is as follows:

$$\frac{3.75}{\text{No limit}} \text{ or } 0 + \frac{2}{8} + \frac{2}{4} + \frac{0.25}{0.50} = 1.25$$

Since the sum is greater than 1, the employee received an excessive noise exposure during his work day.

The exposure table assumes continuous noise rather than impulsive or impact noise. By definition, "if the variation in noise level involve maxima by intervals of 1 second or less, it is considered to be continuous."

Should downhole noise exceed allowable limits, several mitigating measurements can be taken. One effective method of minimal cost is the use of ear muffs. However, this should be used only as a temporary, emergency measure until the system can be properly repaired. Typical attenuation capabilities range from 15 to 50 dBA depending on the noise frequency (low frequency noise is often more difficult to attenuate). Ear muffs should be supplied to the operators for their use only during periods of high noise levels or for their own comfort. They should be regarded solely as a temporary mitigation measure. Other more costly design change alternatives include cab sound-proofing, hammer redesign (of silencer, etc.), and possible use of acoustical absorbing materials to aid in sound attenuation (i.e., in machine areas, on outside of cab, galloway, etc.). It should also be noted that some simple maintenance assurances such as replacement of worn parts and proper lubrication can substantially aid in machinery noise control. Reduction of the noise by only 3 dBA's will reduce the intensity to one half its previous level.

Change Interface

Amount of change interface will depend to a great extent on how much noise reduction will be necessary. Ear muffs will require minimal system changes, requiring only some type of storage compartment, whereas hammer redesign and cab sound-proofing can require substantially greater costs and system changes. However, remember that ear muffs are not satisfactory for use as a permanent mitigation measure.

Change Rationale and Benefits

Reduction of excess noise is necessary by Federal regulations for the protection of hearing ability among operating personnel. Figure F-16 is a graph of incidents of hearing loss among specific age groups versus their occupational noise exposure. Reduction of occupational noise exposures can reduce the incidence of hearing loss among exposed personnel. Other benefits could be increased personnel productivity and ease of verbal communication.

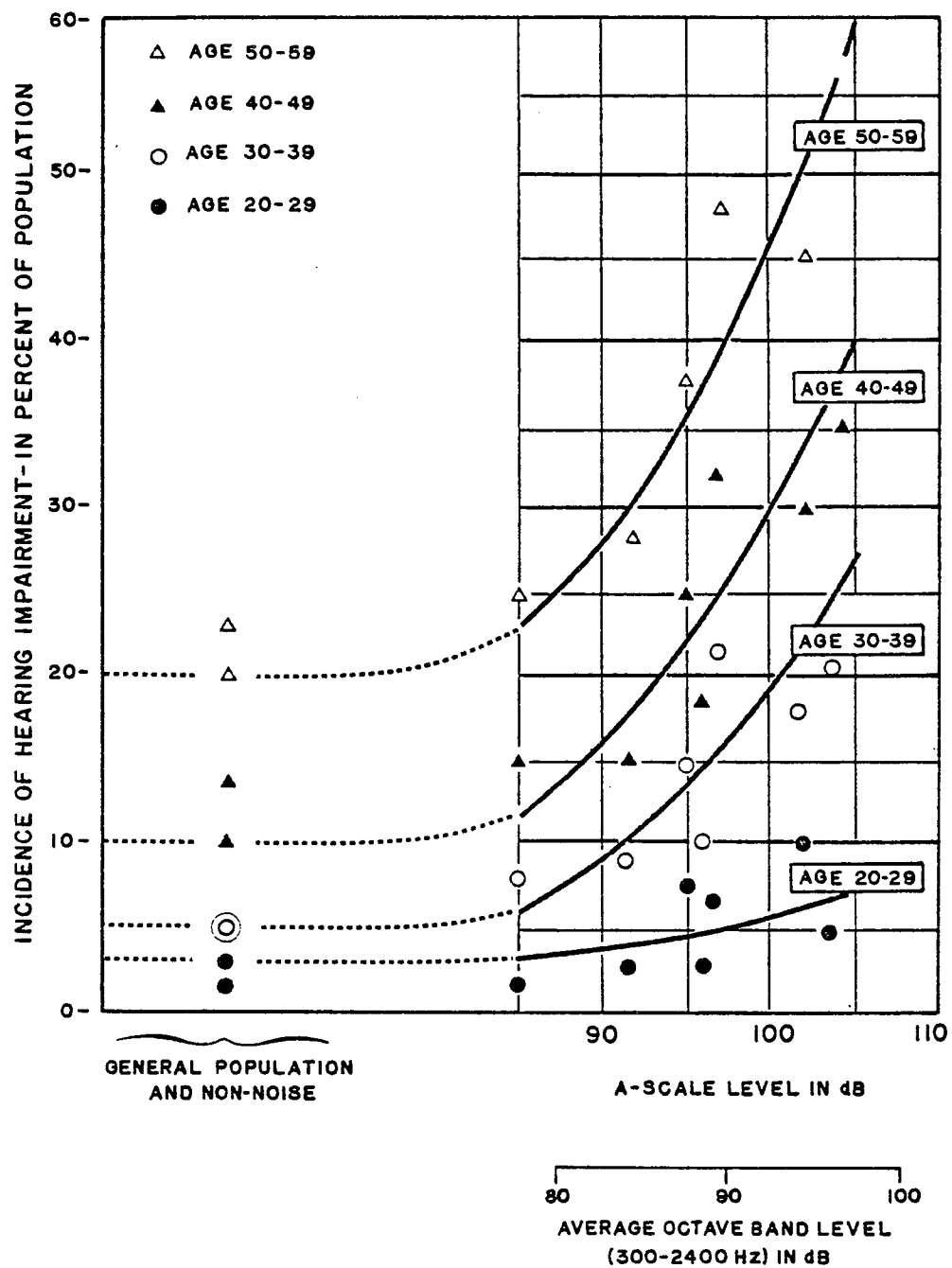


FIGURE F-16. The Incidence of Hearing Impairment in the General Population and in Selected Populations by Age Groups and By Occupational Noise Exposure

Impactor Performance

Effect on impactor performance is greatly dependent on what measures must be taken to achieve noise attenuation goals. However, it is not anticipated that noise control will have too great an effect on daily impactor performance.

DESIGN CHANGE PACKAGE NO. 6

Subject: Emergency Lighting

Priority: 2

Cost: MIN.

Dev/Test Reqmnt: MIN.

Introduction

Current emergency lighting relies basically on the miner's helmet light. These lights illuminate objects only in the direction that the miner is looking and can be inadequate in illuminating other hazards. Emergency escapes could be especially hazardous in this situation since the climbing of ladders from the impactor or galloway and boarding of the muck bucket, as well as other hazardous maneuvers are required in escape situations.

The probability of a loss of lighting in the impactor system is considered to be low. Such an accident could occur in the event of a power failure, transformer failure, main power cable severage or possible short circuits causing fuse or breaker fault.

Change Description

Change to the impactor system would be relatively minor and consists basically of adding battery-powered emergency lights at critical escape stations (i.e., bucket boarding station, ladders, etc.). These lights would be set to automatically light should the conventional system fail (i.e., through interlock systems or set to turn on at a predetermined darkness level). Figure F-17 is a drawing showing the proposed location of such lights.

Change Interface

The interface requirements of these lights would be minimal and would require only the installation of mounting brackets and periodic light aiming and testing.

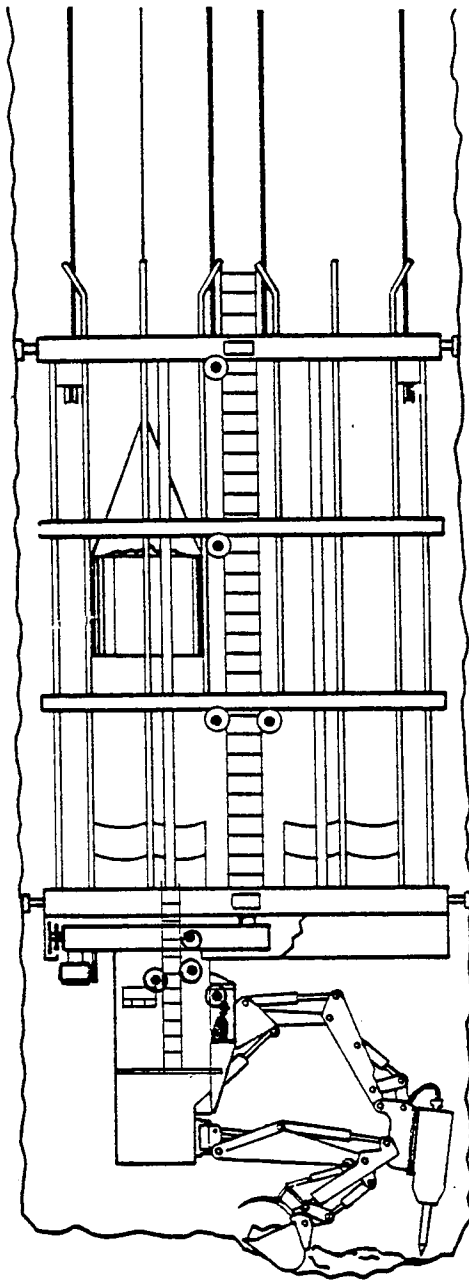


FIGURE F-17. Proposed Location of Emergency Lights

Change Rationale

During a loss of lighting accident, the likelihood of hazard of many routine activities would be considerably increased even with the use of miner's hat lights. Such activities as boarding and leaving the impactor, climbing vertical ladders, and boarding the buckets would carry increased risk. The addition of emergency battery-operated lighting is judged to be an effective and inexpensive method of mitigating these risks.

Change Benefits

The change benefits would be a lower risk to miners during a loss of lighting accident and possible increased speed in emergency evacuation during such an accident.

Impactor Performance

The day-to-day working of the impactor would be affected very little. However, if a loss of lighting accident occurred due to a fault of some component on board the impactor, remedial action and repair of the component could be greatly aided if proper emergency lighting were supplied, possibly reducing the downtime.

DESIGN CHANGE PACKAGE NO. 7

Subject: Operator Cab

Priority: 3

Cost: MIN. - MAJ.

Dev/Test Reqmnt.: MIN. - MOD.

Introduction

A disadvantage of the present cab design is that, for the most part, it requires the operator to be in a fully standing position bending his head forward to effectively see the shaft floor and operate the machine. This is a somewhat hazardous position, but even more importantly, one that contributes to operator fatigue and possible back, neck and leg strain, as well as potentially poor performance. Although complete cab redesign using human factors analysis in addition to productivity and technical efficiency would be an optimum solution, the following design change suggestions also provide some solutions to this potential problem.

Change Description

To avoid operator fatigue and strain as well as to increase cab safety, a "stand-up" seat is suggested to allow the operator to take a partial load off his feet (see Figure F-18).

An alternative cab design for increased safety and productivity is suggested in Figure F-19. This alternative cab design uses a tilting seat with a full harness; wall sound absorption for noise attenuation; and in-cab exit ladder and an in-cab emergency escape rope (not shown); emergency lighting (not shown); fire extinguishers (not shown); and various other features shown in the conceptual drawing.

Another variation of this cab design would be to join both the mucker and impactor cabs together in one large cab. This is shown in Figure F-20. The emergency ladder and standard exit ladder are located within the cab. Features listed previously are also incorporated in this design alternative. Installation of a platform as suggested in Design Change Package No. 2 may still be desirable (not shown on conceptual drawing) for ease and safety in maintenance (i.e., window cleaning pump maintenance, etc.).



FIGURE F-18. Operator "Stand-up" Seat

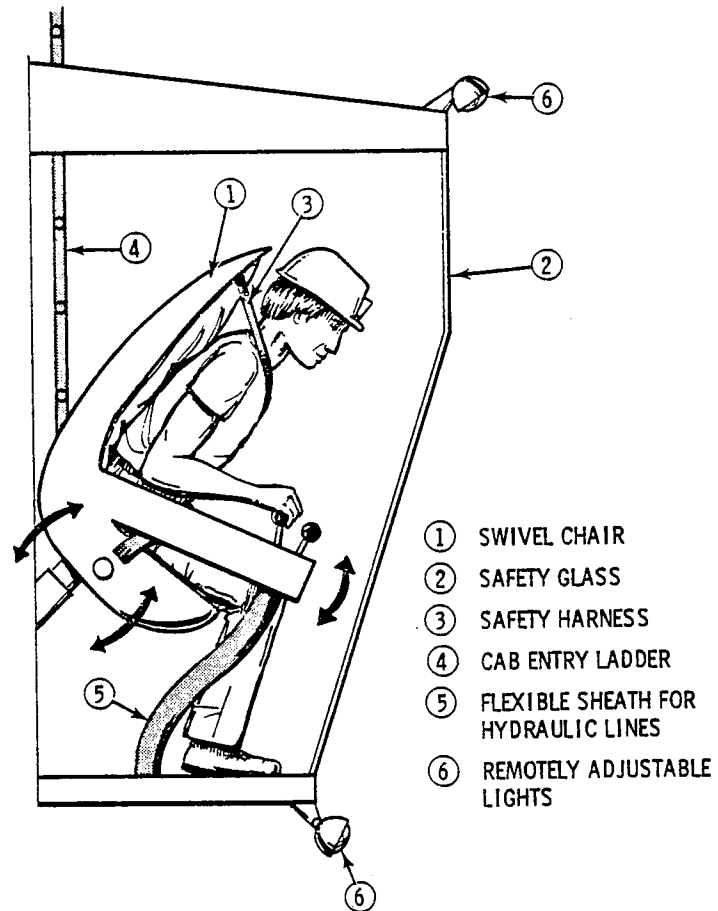


FIGURE F-19. Alternative Cab Design - Side View

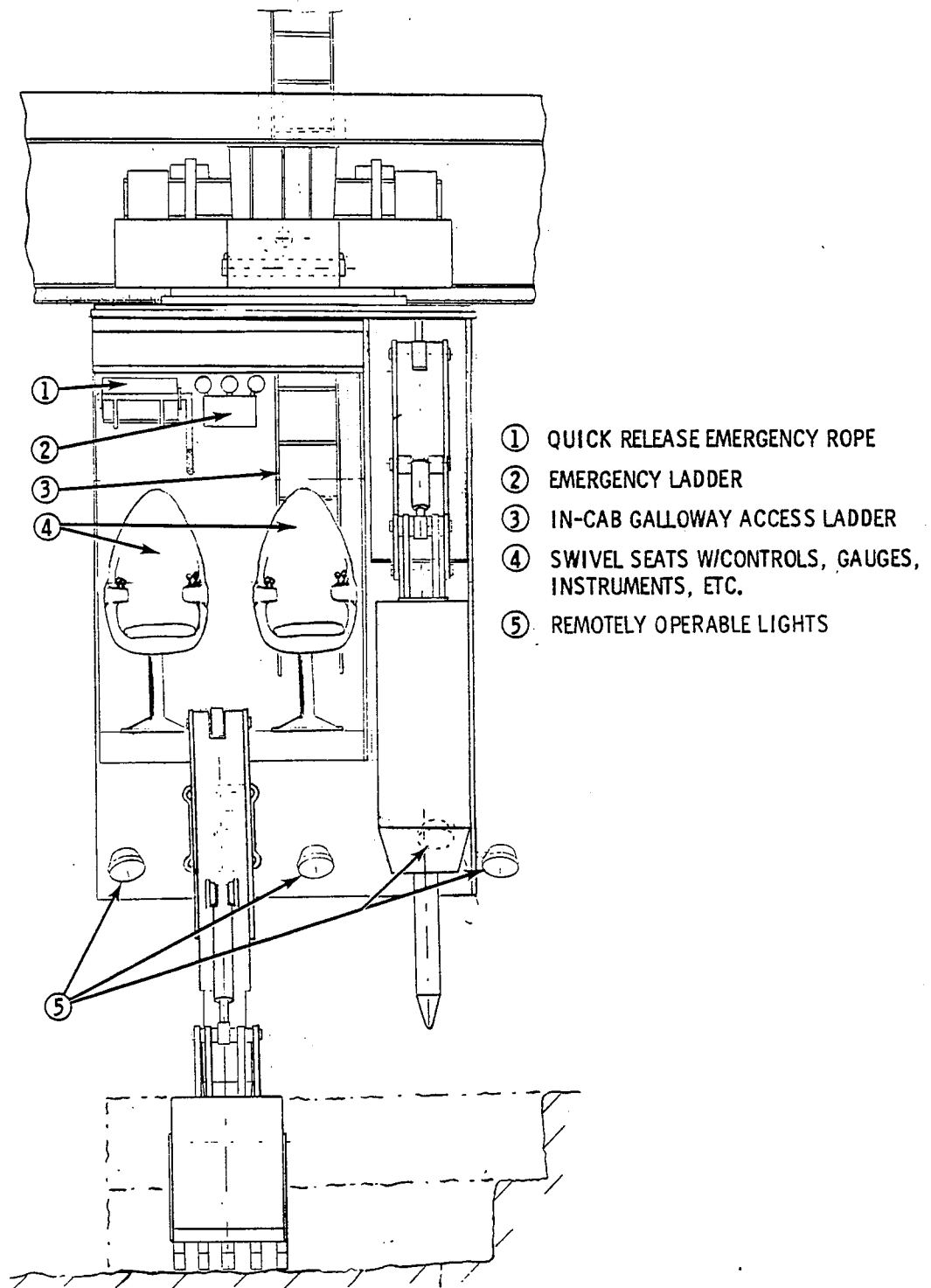


FIGURE F-20. Alternate Muckers Impactor Cabs Combined

Change Interface

Change interface to accommodate these design changes range from minimal (i.e., stand-up seat) to major (i.e., mucker and impactor cabs combined). Addition of stand-up seats should require little interfacing or modification of the present system. Implementation of the most complex cab design would require much cab rework; joining of the cabs will require extensive system redesign and probably major costs.

Change Rationale and Benefit

The final postulated cab redesign offers seating designed to reduce operator fatigue; safe cab access and emergency exit; and other miscellaneous benefits. Cab joining allows ease of operator communication and easy access to one another (should one operator be injured or otherwise need help) as well as all of the advantages offered by the final cab design alternative outlined above.

Impactor Performance

Use of a stand-up seat is anticipated to improve performance somewhat. The operator may require fewer shift breaks and will not be as prone to fatigue as he will be if standing all day. Use of the postulated cab design alternative should have this same effect as well as possible noise reduction that may improve impactor operator performance.

Cab joining could have some effects on impactor performance. The change of operator position with respect to his tools should have no major impact on performance. But increased communication between operators could serve to improve their cooperation and increase their productivity as well as reduce the chance of mucker and impactor boom collisions.

DESIGN CHANGE PACKAGE NO. 8

Subject: Deck Transfer and Operator Cab Transfer Ladders

Priority: 3

Cost: MIN.

Dev/Test Reqmnt: MIN.

Introduction

Current design of ladders for personnel transfer from deck to deck or deck to operator cab is done primarily by means of vertical steel ladders. The construction of these ladders is very sturdy and structural failure is highly unlikely. However, a moderate potential for injuries from slips and falls does exist. The rungs of the ladder are smooth tubular steel and will offer little tractive resistance should they become coated by spilt oils, muck or other such contaminants.

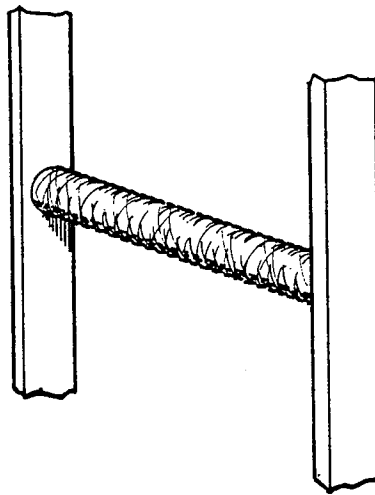
Change Description

Suggested design changes are primarily to improve ladder traction. Two fairly simple alternative methods are suggested.

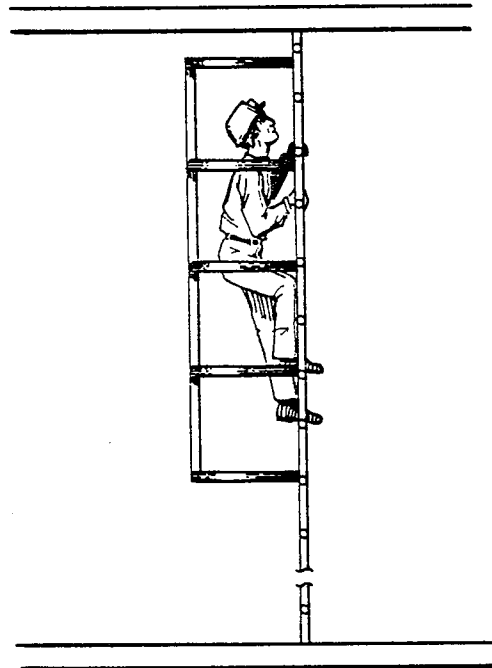
- Method 1: The use of knurled ladder rungs would most likely provide sufficient traction to eliminate most potential slip accidents (see Figure F-21.). Knurling should not be so rough as to hurt hands. For vertical ladders the use of circular cages is also suggested to mitigate a fall hazard due to an accidental loss of hand-hold.
- Method 2: The use of flat grated rungs and hand rails would provide optimum protection against slips. These would require that the ladders be sloped (for ease of climbing) to some extent and may not be adaptable for the impactor-to-galloway transfer ladder (see Figure F-22).

Change Interface

Interface requirements would be small. Space restrictions for sloped ladders and for circular ladder guards would have to be considered. These alternatives may not be feasible given the space constraints within the shaft.

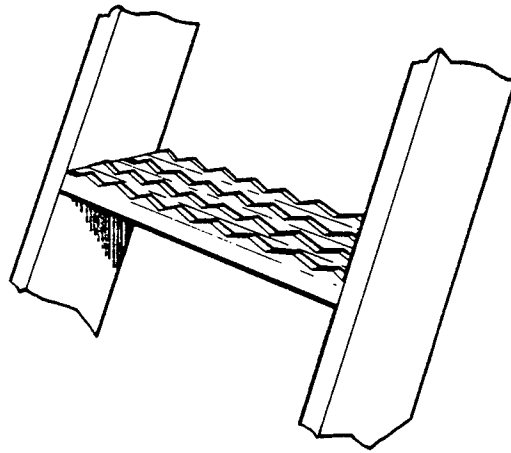


DETAIL OF KNURLED RUNG

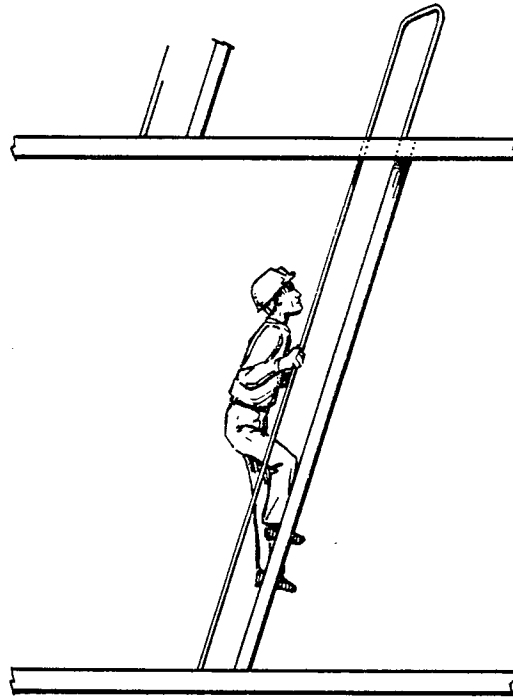


CIRCULAR GUARD RAIL

FIGURE F-21. Method 1 - Ladder Redesign



DETAIL OF FLAT GRATED RUNG



SLOPED LADDER WITH HANDRAIL

FIGURE F-22. Method 2 - Ladder Redesign

Change Rationale

The possibility of a workman's foot slipping off of a rung and resulting in a fall or a strain can be reduced considerably at a relatively small expense.

Change Benefits

Change benefits would be a safer and possibly faster transfer system.

Impactor Performance

Impactor performance would be affected very little.

DESIGN CHANGE PACKAGE NO. 9

Subject: Hydraulic Hose

Priority: 3

Cost: MIN.

Dev/Test Reqmnts.: MIN.

Introduction

The installation and maintenance of hydraulic hoses on the galloway (and impactor to a lesser extent) have been identified as potential hazards. Hazards with the hydraulics system stem from high pressure jets of fluid that may escape from small leaks in the hose or fitting and injure a worker by entering the eye or impregnating the skin. Hose assembly failure could occur either from mechanical damage to the hose or by failure at the connection of the hose to the fitting. Failure of the hose/fitting connection can be caused by incorrect tightening of the fitting, incorrect assembly of the hose and hose fitting, or flexing of the hose at the fitting, which could result in fatigue failure.

Change Description

Various means to prevent or reduce the effect of hose whip and fluid leaks are possible. Protection against hose and fitting separation and the resulting hose whip can be provided by clamping the hose a short distance from the connection. When clamping is not possible or practical, protection can be provided by shrouding the hazardous area with a sheet metal barrier. This shielding would also protect personnel from any high pressure leaks of hydraulic fluid. It should be noted that these changes are only applicable to connections that are in an area that is frequently traveled by mine personnel, such as walkways and ladders. Areas of high maintenance requirements should also be protected as mentioned above. Protection against hose abrasion from rubbing together or from some external source can be accomplished by the use of steel or plastic protective hose sleeves. Selection of the steel or plastic sleeve is based on the particular application and severity of the abrasion expected.

Change Interface

The changes required to the impactor in providing protection from the hose whip hazard are relatively minor, primarily consisting of clamps such as those shown in Figure F-23. Placement of shields over some hydraulic hoses would require interface with current work areas.

Change Rationale and Benefits

Impactor technology requires the use of some pressurized fluids. Protecting personnel downhole from these pressure systems by shields or hose clamps would help reduce exposure to the potential hazards previously described.

Impactor Performance

Impactor performance would not be affected by providing hose whip protection. Performance should not be affected by providing shielding over pressurized hoses either, although there may be some space constraints encountered in implementing the changes.

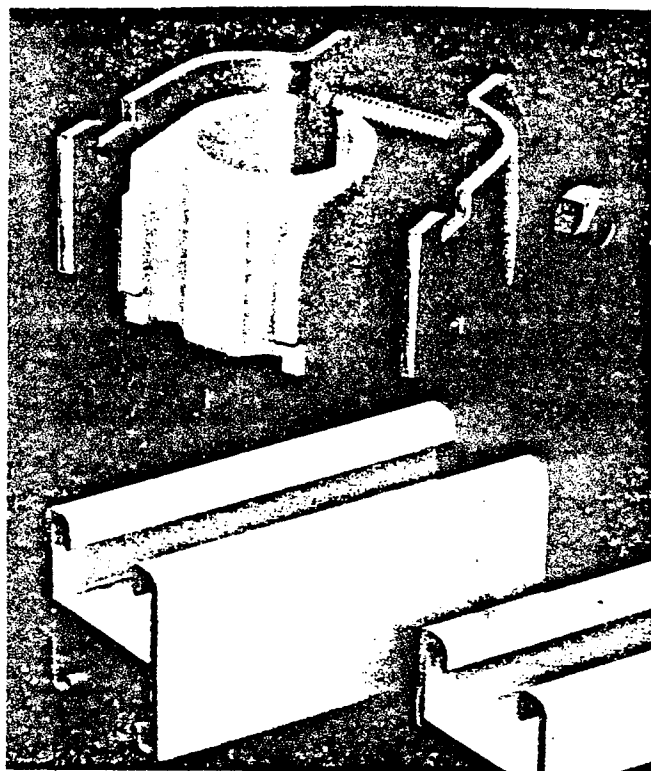


FIGURE F-23. Hose Clamp

DESIGN CHANGE PACKAGE NO. 10
Subject: Communications System

Priority: 3
Costs: MOD.
Dev/Test Reqmts: MIN. (MAJ. for
telephone redesign
and improvement)

Introduction

The telephone system on the impactor machine can serve an important function as a back up to the bell code, which is the primary means of communication, and as a way of communicating more complex messages. However, the state-of-the-art in underground communications has not allowed the implementation of an effective system. The messages transmitted by the telephone system are often garbled and difficult to understand. System changes may be required to ensure that the telephone system functions effectively as a back up communications system. It would also be desirable to have an emergency alarm back up system installed.

There are also currently no means of intercommunication between the two operators except visual or verbal. With the fairly high level of noise expected downhole and the separation distance between cabs, verbal communication will be difficult. As visual communication in these circumstances will be of limited value it is recommended that some other means of verbal communication between the two operators be installed.

Change Description

It is recommended that the telephone system be updated as new technology becomes available. Current research by the Bureau of Mines and other organizations is addressing the problems of underground communications. This research should be monitored for new developments in telephone or other appropriate back up communications systems for application with impactor technology.

It is also suggested that an emergency alarm/warning system be incorporated into the system design. This emergency system would be wired on an independent circuit, so that it would remain functional in the event of other communication system failures. The signaling device should consist of a button or lever that could be activated even by an injured worker. When the emergency button is pushed, visual/audible warning signals at all decks and at the surface would warn crew members of an immediate emergency. Training procedures and emergency evacuation drills would be a necessary part of this system design change to ensure appropriate worker response to the signal.

It is also suggested that the present telephone system be modified so that open communication between the two operators can be achieved. Some type of intercom system should be considered. Perhaps interconnected headsets and microphones could be used to aid in communication between the operators in the high noise environment downhole.

Change Interface and Impact on Impactor Performance

Implementation of a new telephone emergency alarm system and intercom system would require some change to the electrical circuitry on the impactor. Impactor performance should be improved by the ability for crew members downhole to transmit relatively complex messages to the surface crew and the operators to communicate more effectively with each other.

Change Rationale and Benefits

The improvement of the telephone communications system and the addition of an emergency alarm would provide effective back up to the primary bell-code system. Redundant communications systems are important, since failure of communications in the shaft could hamper escape attempts or other emergency actions. The current telephone system does not transmit messages very clearly, and may not be an effective communications tool if needed in an emergency situation. Besides providing system redundancy, an improved

telephone system could result in better production performance with the impactor, since the ability to transmit complicated messages between the surface and downhole crews would be enhanced. Installation of an operator intercommunication device can aid in operator cooperation and improved performance. It would also give the operators a means of calling for help or of issuing warnings to each other.