72-11

TESTING OF RESPIRATOR SYSTEMS IN COAL MINES

Contract HSM 99-72-88

First Quarterly Progress Report

30 June 1972 - 30 September 1972

30 September 1972

SYNSIS, INC.
1845 SAN FERNANDO ROAD
LOS ANGELES, CALIFORNIA 90065

FOREWORD

Presented herein is the Synsis, Inc., first quarterly progress report for Contract HSM 99-72-88. This eighteen month effort concerns the testing and evaluation of ten different powered respirators for use in underground coal mines. During this period Mr. S. Tobey was the Program Director and Dr. T. P. Crooks was the Principal Investigator for Synsis, Inc. Mr. Richard M. Lester was the Contract Project Officer for the National Institute for Occupational Safety and Health.

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1845 San Fernando Road
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90065

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Evaluation methods for powered respirators for use in underground coal mines are discussed. Characteristics of ten candidate respirator systems are summarized together with their individual maintenance and support requirements. The basic considerations for mine test site selection are reviewed such as mining method, crew size, mine operation and management practices, size and productivity, geologic and environmental factors, and accessibility. Test methodology development with consideration to mines and task compatibility, task and respirator interactions, test scheduling, and acceptability measures is reviewed. The development of interview methods and questionnaires for obtaining the subjective opinions of miners are described.

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INTRODUCTION

In this, the first quarterly report of the subject contract, summaries of the major activities and findings are reported. As proposed, activities during this quarter proceeded along two primary avenues: requirements development, and mine test site survey and evaluation. For the purposes of this report these activities are discussed under three major headings, respirator systems analysis, mine test site selection and test methodology development.

The scope of work and approach to the program remain as set forth in the technical proposal and subsequent letter of clarification, and will not be discussed further in this report. The work is proceeding according to schedule and no major problems have arisen.

PROGRAM OBJECTIVE

By various estimates, from twenty to thirty percent of all underground bituminous coal miners suffer from pneumoconiosis, commonly called "black lung". This disease is caused by respiration of air laden with coal dust and results in a variety of symptoms ranging from reduced ventilatory capacity to severe respiratory distress. Routine use of respiratory protective devices (respirators) by coal miners would reduce the incidence of the disease, as would engineering control of the dust concentration in the mine environment. The Federal government is attacking this problem on both fronts, with legal limits to coal mine airborne dust concentrations and with research into improved respiratory protection.

Respirators commonly used in underground mining and in other industries are of the passive type in that air is moved through the device by the normal inspiratory and expiratory processes using "lung power". The resulting breathing resistance has been cited by researchers as being contributory to poor overall acceptance by the miners. A potential solution to the problem is to use external power sources to move air through the filter elements thus reducing the breathing resistance.

Although a number of respirator systems of this type are available they are almost never used in coal mines. Probable reasons for this include lack of permissability approvals, reluctance on the part of miners to try untested devices and, perhaps, certain operational constraints associated with the respirators themselves.

The purpose of the present study is to introduce ten powered respirators into actual underground coal mines and to determine their suitability for use by miners. The primary aspect of these respirators to be studied is their acceptability by the individual miners. The postulate to be tested is that because of their ease of breathing, they will be worn more often than passive respirators.

In addition to measuring miner acceptance of the candidate respirators, the program has a number of supportive objectives including the determination of:

- the impact of the respirators upon miner productivity,

- preferential suitability of each unit for various job descriptions found in coal mines,.

- potential design modification for improving acceptance, protection, operational suitability or safety within the coal mine environment.

The ten candidate respirator systems include six battery-powered units involving blowers providing a continuous flow of clean respirable air, two cryogenic stored air systems operated on a "demand" basis, and two hydraulically powered units, one a continuous flow type, and one a demand type.

BACKGROUND

The passive type dust respirators have been used by underground miners for many years. Currently the most popular respirators are of the "quarter face" type sealing to the face from the bridge of the nose to just below the mouth leaving the chin exposed. These units typically employ a fabric filter to remove dust from inspired air. The units are small and light weight but perhaps exhibit excessive breathing resistance when the filter has collected heavy dust loads. The Code of Federal Regulations, 30 CFR 14, under which such respirators are approved requires that inspiratory resistance be less than 30 mm H_2O at an air flow rate of 85 liter/min. when the filter is clean, and no more than 50 mm H_2O when the filter has absorbed approximately 140 mg milligrams of silica dust. A study by Revoir and Yurgilas (Ref. 1) demonstrated that many currently available respirators indeed meet this requirement. However, a worst case analysis (Ref. 2) involving the highest dust levels commonly found in coal mines and high work levels by miners showed that respiratory resistance can quickly become objectionable for the hard working miner.

Researchers have never been able to state a value for an "acceptable" level of breathing resistance. Work by Silverman (Ref. 3) and other researchers (Ref. 4) indicate that <u>any</u> breathing resistance (to inhalation or exhalation) is objectionable and the work of Thompson and Sharkey (Ref. 5, 6) indicate that the use of the passive type of dust respirators can affect human work capacity.

Based on this experience it must be concluded that powered respirators in which the work of breathing is reduced by use of external energy sources will result in respirators which are more acceptable to miners - other factors being unchanged. If this is indeed the case then the use of respiratory protection would become more prevalent and the incidence of pneumoconisis among underground miners would decline from its present alarming rate.

SUMMARY

RESPIRATOR SYSTEMS ANALYSIS

During the quarter, suppliers of each of the ten respirator systems were contacted and when appropriate, purchase orders were written. Four of the systems, (Airesearch, Synsis, Draper Labs, and MSA) are still under development and consequently their deliveries, although scheduled to be on time, are somewhat uncertain. Some suppliers require prices significantly higher than previously indicated in the proposal. These matters will be discussed with the NIOSH Project Officer as appropriate.

Since some of the units were not designed for underground use, a careful analysis is being made regarding their safety and operational compatibility in order to reduce potential problems of this type during the conduct of the underground experiments. Similar analyses have been conducted regarding system installation and maintenance requirements.

MINE TEST SITE SELECTION

The efforts in this area were extremely rewarding in that essentially all of the required statistics describing coal mines in the U.S. were available. This data will permit selection of a representative sample of mines in which to conduct the tests. A field survey involving two working sections in one West Virginia mine was quite fruitful. The response by miners and management was quite positive in that all agreed that improved respiratory protection was needed and that the proposed approach to the problem would be productive.

Preliminary choice of the number and location of test sites will be made in the near future. Several likely candidate mines have already indicated a willingness to cooperate.

TEST METHODOLOGY DEVELOPMENT

Considering that 1,200 subject-days of testing are to be conducted, it is essential that the amount and quality of the data gathered be optimized. Seeing that the subjective opinion of the miners is the most important and as well the most difficult data to gather, activities during this quarter have centered upon development of interview and questionnaire techniques. Research and consultation with experts in the field has lead to a solid understanding of the problem and the appropriate forms will be produced and submitted for approval by mid October.

Section I

RESPIRATOR SYSTEMS ANALYSIS

With some exceptions, each of the ten respirator systems to be tested was designed to provide protection in a variety of dusty industrial atmospheres. Consequently, great care must be exercised when introducing them into the underground coal mine environment. In this regard, we are concerned with the operational aspects of the three design factors shown in figure 1.

- safety
  - fire hazard
  - operational hazards
- installation
  - on mining machines
  - on miners
- maintenance
  - daily
  - during the shift

Figure 1. Respirator System Design Factors Important to Operational Aspects of the Underground Test Program

Safety considerations center upon reduction of the explosion hazard inherent in electrical motors found in six of the respirators. As more details on each of the systems becomes available, the permissibility aspects of each unit will be discussed with Bureau of Mines personnel and it is expected that some modifications will be performed on most units in order to render them safe for use.

Another type of system safety being considered has to do with the interface between the miner's tasks, the mine environment, and the configurations of the respirator system. Because some of the units were intended for less stressful environments we are analyzing the safety aspects of such items as belts, hoses, cables and other components which might present a safety hazard. Examples of the hazards include entanglement with conveyor belts or other moving objects, inadvertent operation of controls, or prevention of hasty retreat from the face area.

Since interference with normal operations of the test mines must be minimized, the installation and maintenance of each system must be carefully worked out to insure that the burden to miners and mine operators is not objectionable. A particularly significant factor concerns attachment of the respirators to the miners and the mining machinery. We have essentially three conditions with which to contend:

- battery powered-miner mounted,
- hydraulic powered-machine mounted,
- cryogenic-machine mounted.

Each of the six battery-powered units incorporates a separate belt on which is mounted either a battery or a battery and a blower-filter unit. All underground miners currently wear belt mounted lamp batteries and self rescuers. Since, in routine use, only one belt is worn, methods for incorporating all accessories on one belt are being developed. Since only a few of the candidate respirators are currently available for such development, this activity has only begun.

For this report, the general characteristics of each respirator system are presented in as much detail as is currently feasible.

CHARACTERISTICS OF CANDIDATE RESPIRATOR SYSTEMS

FENZY AERATEUR, BOUCLY-QUINOT

The Aerateur is a continuous-flow system, powered by a 6-volt dry cell suspended on a web belt. An electric cable runs to the integrated blower/filter unit mounted on the front of the oral-nasal mask. The battery and belt weigh 2 lb, the battery assembly being 2-3/4 inches x 2-3/4 inches x 4 inches. The blower/filter unit as shown in figure 2 is irregularly shaped, approximately 5-1/4 inches x 4 inches x 3-1/2 inches deep and weighing 0.75 lb (including the mask, straps, and cord). The duty cycle is said to be 60-70 hours when used one shift per day.

The filter is Amainte-Alfa pleated paper and is claimed to be cleanable without removing from the unit. A gravimetric efficiency of 98.5% is specified for 0.8 (μ) silica dust at a concentration of 160-200 mg/m^3. The flow rate is continuous and high enough so that inhalation resistance is claimed to be 0.08-0.16 inches of water at an inhalation flow rate of 3.53 SCFM.

MARTINDALE POSITIVE PRESSURE POWERED RESPIRATOR MARK II

The Martindale is also a continuous-flow system, with a 6-volt rechargeable nickel-cadmium battery. The battery, blower, and filters are worn on the back of a web belt. From a Y-connector on the belt pack two 3/4-inch diameter air hoses lead up the back, over the shoulders and attach by means of a T-connector to the front of the oral-nasal face mask. The belt-mounted air processing unit weighs 4-1/4 lbs. and measures 8-3/4 inches x 5-3/4 inches x 4 inches deep while the battery pack also weighs 4-1/4 lb. and measures 5 inches x 4 inches x 2 inches. The facepiece and hoses weigh 2.2 lbs. The claimed duty cycle for the battery is 7 hours.

Figure 2. Fenzy Aerateur Respirator

The pre-filter is a felt pad and the main filter is an electrostatically charged, resin-impregnated merino wool pad. The claimed efficiency is 99.8% for 0.5 (μ) particles, evaluated at a flow rate of 4.25 SCFM which is the advertised minimum continuous flow rate. The maximum flow rate is 7.0 SCFM when the filters are clean and the batteries fresh. The positive pressure in the mask is 0.5 to 0.65 inches of water during operation and the inhalation resistance that would be encountered in case the blower should fail is claimed to be 1.0 inch of water at a flow rate of 1.06 cubic feet per minute. The unit does not have Bureau of Mines approval. The unit is shown in figure 3 in the front mounting configuration which is also available.

3M WHITECAPSUL II SYSTEM # 255

The system #255 is continuous-flow, with a rechargeable 12-volt battery. The battery is belt-mounted as is the integrated blower/filter unit. A large diameter air hose leads up the back where it attaches to the back of the full head coverage helmet which, as shown in figure 4, includes a flip-up visor and a shroud for the upper torso. The air enters the plenum space between the inner and outer shells of the helmet, from which it is distributed down to the face and exits through the chest shroud. The battery weighs 5 lbs and is 7-1/2 inches x 3 inches x 5 inches; the blower/filter also weighs 5 lbs and is 8-1/2 inches x 12 inches x 7-1/2 inches deep. The duty cycle is 4 hours for a single battery.

Filtering is done by a three-stage system: a centrifugal air cleaner to remove visible particulate matter, a foam prefilter to remove particles down to 5.0 μ in diameter, and a pleated paper final filter rated at 99.97% efficient for 0.3 μ particles. Filter life is estimated to be a few months. Due to the high air supply flow of 8 SCFM, zero breathing resistance is claimed. The unit does not have Bureau of Mines approval at present.

BURGESS (HARVARD-LRL) RESPIRATOR

This is a continuous flow system powered by four rechargeable "D" cell batteries. The battery, motor, and filter in one casing are worn on the back of a web belt. A large-diameter air hose leads to one of several available mask configurations, non of which is supplied. The back-pack is approximately 5 inches x 7 inches x 2-3/4 inches deep and weighs 2-3/4 lbs including batteries. Duty-cycle is over 12 hours with alkaline batteries.

Various filter elements, such as felt, are used and 99.9% efficiency in the respirable range is claimed. Filter life is unknown. The flow rate is approximately 5 SCFM. The inhalation resistance is unknown but probably very low. The unit does not have Bureau of Mines approval.

DRAPER LABORATORY (M.I.T.) RESPIRATOR

The Draper system is a continuous-flow system powered by silver-zinc batteries. The integrated battery, blower, and filter unit is 5-1/2 inches x 7-1/2 inches x 4-1/2 inches deep and is worn on the back of the belt. The air hose attaches to the helmet which has a plenum chamber and a

Figure 3. Martindale Respirator (Chest-mounted Configuration Shown in Photo. Test Will be Conducted with Back Pack Configuration.)

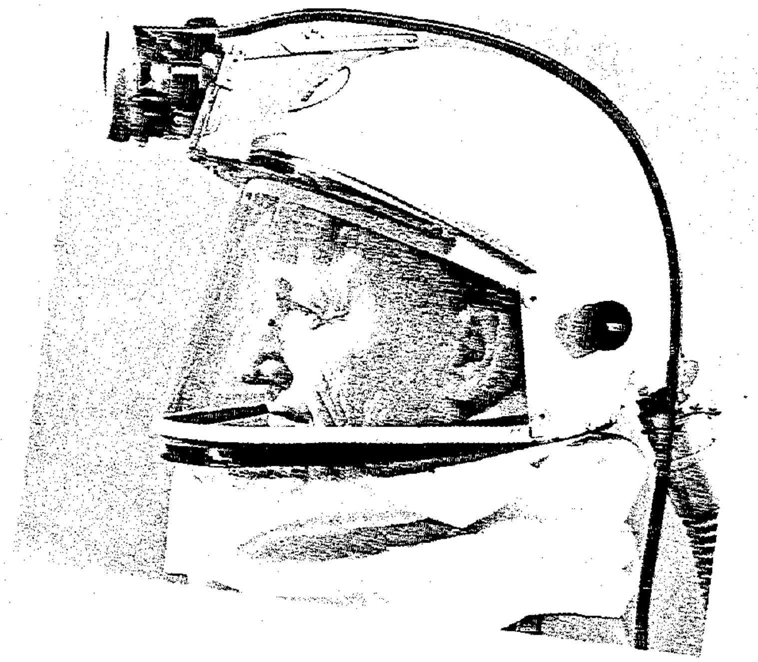

Figure 4. Helmet for 3M Systems

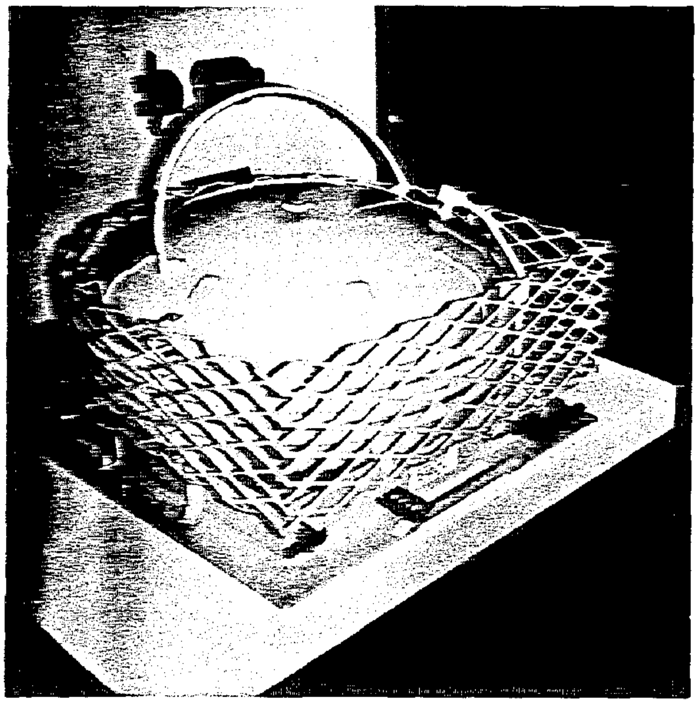

Figure 5. Essex Cryogenics Liquid Air System

on which it is mounted. It will be powered by either the electrical or hydraulic system of the mining machine, depending on which is more readily available. The hydraulically-powered configuration consists of:

- a hydraulic motor, measuring approximately 4-1/8 inches x 5-1/8 inches x 8-1/2 inches and weighing about 10 lbs.,
- an air compressor, 12 inches x 12 inches x 7 inches, weighing 20 lbs. including the centrifugal pre-filter at the compressor inlet,
- a final filter unit of undetermined dimensions, and a 130 cubic inch plenum chamber consisting of 14 inches of one-inch inside-diameter plastic hose.

Running from the machine-mounted components is 20 feet of 1/2-inch outside diameter air hose which clips to the wearer's belt and then runs to two demand regulators on the oral-nasal mask. The motor will require semi-annual maintenance.

The prefilter and the first stage of the final filter are conventional reverse-flow cyclonic-separators requiring no maintenance other than a daily flushing with compressed air (supplied by the compressor).

The prefilter will remove particles down to a few microns to protect the compressor. In the main filter, the cyclone separator section will remove about 90% of the particles at 1.0μ in diameter, and the pleated-paper final filter cartridge is claimed to remove 100% of particles at 0.08μ and to be 98% efficient at 0.008μ. Cartridge life is estimated to be 6 to 12 months. The compressor is capable of delivering a continuous flow of 2.7 SCFM but due to the plenum chamber, short periods of heavy breathing involving a flow rate of 8 SCFM can be accommodated. Inhalation resistance is dependent upon supply pressure and flow rate, but it is expected to be less than one inch of water at 7 SCFM flow and 70 psig supply pressure. The unit does not have Bureau of Mines approval.

MINE SAFETY APPLIANCES RESPIRATOR

The MSA unit is a belt-mounted, battery-powered, continuous-flow system. The battery pack, worn on the back of the supplied belt is of presently unknown dimensions and type. The mask is of the half-face variety. The duty cycle will be 8 hours of continuous use.

The filter type and characteristics are unknown, as are breathing characteristics. The unit will meet Bureau of Mines respirator performance specifications, but presently does not have approval.

GARRETT AIRESEARCH CRYOGENIC RESPIRATOR

The Garrett unit is a demand-flow system supplying air from a liquid air storage device mounted on the mining machines and requiring no power source. The units will be prototypes and are currently being designed and developed.

No filtration system is required and no data is available on inhalation resistance or available flow rates. This type is inherently permissible to the Bureau of Mines.

SYSTEM PROCUREMENT

The planned schedule of procurement includes one unit of each system to be received as soon as possible in order to begin laboratory testing. Following that is another unit of each system to be received in January 1973 and the remaining two units of each system in February 1973. Procurement information is given in Table 1.

SYSTEM MAINTENANCE AND SUPPORT REQUIREMENTS

Knowledge of each system's maintenance and support requirements is important, not only for the design of the testing program, but also in predicting what impact on operational procedure would occur in mines which adopted one of the systems. The requirements will be listed individually for each respirator. Essentially, the requirements fall into three categories:

- maintenance and support requirements for a system operating as standard equipment in a mine,
- maintenance and logistics requirements during the conduct of the in-mine testing, and
- exceptional installation requirements, required changes in mining procedures, and the like.

The projected amount of replacement and spare parts required for the test program is based upon a maximal estimate of 400 man-days of testing for each type of system or 100 days of use for each unit, of which about one-fifth will be done in the laboratory and the rest in the mines.

FENZY AERATEUR, BOUCLY-QUINOT

No filter life is specified; the recommended cleaning procedures are gentle tapping and/or using a hose-type vacuum cleaner. The battery should need replacing after 8 to 10 shifts, assuming use for one shift per day. The unit can be opened by use of a special key so that the lamphouse attendent can service malfunctioning units. Replacement parts are available from U.S. distributors. Since the battery, in the present configuration, is held in place by a spring-loaded clamp, estimated replacement time is less than one minute every two weeks. If the filter elements prove to need periodic replacement, the time would increase to approximately five minutes every two weeks.

The estimated numbers of replacement parts that will be needed for the test program is 40 batteries and 20 filter elements. Required service time will be negligible.

Table 1. RESPIRATOR SYSTEMS PROCUREMENT

SYSTEM	UNIT PRICE	EQUIPMENT INCLUDED IN PURCHASE PRICE	DELIVERY 1st	DELIVERY 2nd	DELIVERY 3rd & 4th	COMMENTS
FENZY AERATEUR	$ 53.95	COMPLETE SYSTEM	ARRIVED	ARRIVED	Feb. 73	FRENCH DESIGN
MARTINDALE	£ 62.83[1]	COMPLETE SYSTEM	ARRIVED	Jan. 73	Feb. 73	BRITISH DESIGN
3M SYSTEM #255	$ 450.00	COMPLETE EXCEPT FOR LAMP BRACKET, EXTRA BATTERY AND CHARGER	Oct. 72	Jan. 73	Feb. 73	TECHNICAL ASSISTANCE READILY AVAILABLE
BURGESS	$ 179.00	INCLUDES BATTERY CHARGER, MASK NOT INCLUDED	Oct. 72	Jan. 73	Feb. 73	
DRAPER	$1,000.00 $ 150.00 $ 150.00	RESPIRATOR & HELMET BATTERIES BATTERY CHARGER	Nov. 72	Jan. 73	Feb. 73	
ESSEX	$ 821.76	COMPLETE, EXCEPT FOR INSTALLATION	Oct. 72	Jan. 73	Feb. 73	TECHNICAL ASSISTANCE READILY AVAILABLE
3M SYSTEM #350 HYD	$ 435.00	COMPLETE, EXCEPT FOR INSTALLATION	Oct. 72	Jan. 73	Feb. 73	TECHNICAL ASSISTANCE AVAILABLE
SYNSIS	$ 575.00	COMPLETE, EXCEPT FOR INSTALLATION	Mar. 73	Mar. 73	Mar. 73	IN DEVELOPMENT STAGE
MINE SAFETY APPLIANCES	$ 200.00	COMPLETE SYSTEM	UNKNOWN	UNKNOWN	UNKNOWN	COMMUNICATION WITH MANUFACTURER HAS BEEN POOR
GARRETT AIRESEARCH	$1,000.00	COMPLETE SYSTEM	UNKNOWN	UNKNOWN	UNKNOWN	IN DEVELOPMENT STAGE

1. *Synsis has one unit on loan from 3M Company*

No installation problems or alterations in mining procedures are anticipated. The battery unit can be altered for suspension from the miner's belt quite easily.

MARTINDALE POSITIVE PRESSURE POWERED RESPIRATOR MARK II

Replacing the filter elements involves opening the power pack and replacing a fibre pad. The prefilter is claimed to last one day or less; the main filter, perhaps several times as long. The battery requires overnight charging with the supplied charging unit. Motor life is guaranteed for 1,000 hours and is claimed to last longer; no motor maintenance is required and the unit is replaced upon failure. A daily disassembly and washing of the facepiece components is recommended, but whether this would be achieved during regular use is unknown.

Approximately 5 cartons (100 each) of the pre-filter pads and 10 to 15 cartons (12 each) of the main filter pads will be needed during the testing. An additional battery for each unit may be purchased as a spare. Maintenance time, including the washing, is estimated at 20 minutes a day for each unit.

No changes should be required in mining procedures unless the bulk of the unit interferes with the miners' mobility.

3M WHITECAPSUL II SYSTEM # 255

The prefilter is made of foam and should be washed in detergent when contaminated; probably daily in a mine environment. The centrifugal air cleaner collects dirt in a pair of slots and should be cleaned once a week with a pipe cleaner. The high efficiency filter is disposable but should last two to six months. As the duty cycle of the battery is only 4 to 4-1/2 hours, two freshly-charged batteries will be required for each shift. In addition, the charging time is 12 to 14 hours, so two battery chargers will be needed for each unit. The motor has replaceable brushes that are claimed to last 500 hours. Daily maintenance is estimated to require 10 to 15 minutes.

Required spare parts for the test program include two sets of motor brushes for each unit and an additional high-efficiency filter for each unit. No service other than the usual daily and weekly maintenance will be needed.

No machine installation is necessary. The miner's lamp is worn on the supplied helmet instead of the standard helmet. This will require fitting the helmet to the miner prior to each new subject test.

BURGESS (HARVARD-LRL) RESPIRATOR

The pad of filter material in this respirator requires daily changing. The "D" cell (flashlight-type) batteries must be recharged overnight. Motor and blower life figures are unknown. Daily maintenance should not take more than five minutes.

A minimum of 400 filter pads, four battery chargers, and a few dozen batteries will be required for the testing. The maintenance will be as described above.

No procedural changes or machine installation will be called for.

DRAPER LABORATORY (M.I.T.) RESPIRATOR

The filter is of the throwaway type and should be changed daily. The silver-zinc batteries require overnight charging with a special charger unit and are very intolerant of discharging completely, over-charging, or improper voltage and current inputs. However, the battery manufacturer has apparently developed some improved models that will be used in production models. The motor life is estimated at 500 hours. Motor service consists of brush replacement. Estimated daily maintenance on the unit requires approximately 5 minutes.

During the test program, we will use approximately 400 filter pads and four replacement motors. Maintenance time during the test should be the same as for regular use.

No installation is required. The supplied helmet has its own built-in miner's lamp, so the regular lamps and batteries are not required.

ESSEX, CRYOGENIC (LIQUID AIR) UNIT

No filter elements are used in this system. The liquid air container (the "Dewar") is removable and hand-portable for remote filling before each shift. The unit was extensively tested in a U.S. Steel coal mine at Gary, West Virginia.

The following (Ref. 6) is quoted from a paper given at the National Safety Council meeting in Chicago of 27 October 1970. Their experience should be generally applicable to the use of this unit:

> "To provide the liquid air, there are two basic methods available: (1) purchase of pre-mixed air, and (2) manufacture of liquid air on the site with the use of a cryogenerator. We have used both methods and each has its advantages. Purchase of pre-mixed air air reduces capital outlay and labor, and probably operating and technical assistance would be more readily available.
>
> The cryogenerator insures rapid on-site production of quality air at a reasonable cost. The cryogenerator that we are using operates from a 440 v, AC, 3 ph, 60 Hz source and uses 4 gallons of cooling water per minute to produce approximately 8 liters of liquid air per hour. A helium refrigerant reduces the output temperature ~~of the liquid air to about -320° F.~~ The lamphouse attendant spends approximately 4-1/2 hours daily to satisfy the liquid-air requirements for 18 mining machine shifts per day. He spends his time making routine checks on the machine, together with handling, cleaning, inspecting, purging and filling of Dewars. Purging removes the moisture from the container. Filling time for six units is about 30 minutes. After filling, the container is weighed to assure a full capacity of 10 liters or 20 lb of liquid. The total weight of the unit and contents is 38 lb. A Beckman oxygen analyzer is used to check for an

acceptable oxygen range of 21 to 28%.

In the case of supplied pre-mixed air, it would be up to the customer to decide at what point he prefers to receive the material. We received ours in large bulk containers (156 liters) and transferred it into the individual Dewars. This reduces the out-of-pocket expense but increases plant controls. We have not come to any conclusion yet as to which is the best method of supply, and in the end the magnitude may be the determinant."

It is clear from the above that it would require a relatively large operation to warrant the expense of a cryogenerator. In addition, there is the third possibility of the mine operator purchasing liquid oxygen and liquid nitrogen, both of which are often more readily available than liquid air, and mixing them himself. The machine operator takes the unit down into the mine and attaches the respirator system to it himself.

With respect to the latter possibility there is a cautionary note. The preparation of breathing gas mixtures is an interface where extreme hazards may develop. In the mixing of nitrogen with oxygen to obtain breathable air, errors in measurement could result in deficiency of the pO_2 with an attendant hypoxic condition for the user. Similarly excessive pO_2 could present a fire hazard. It is not unreasonable to assume that an error could result in complète refilling with only one of the ingredients to the complete exclusion of the other.

Another unknown is the mixing properties of liquid oxygen and liquid nitrogen. Synsis has previously studied the effect of mixing gaseous helium and oxygen. Although it had been assumed that complete mixing would be immediate time tests showed that the time period was measured in hours. If liquid mixing is indicated for logistics reasons it will be necessary to determine the safety of this procedure.

During the test program, the procedure will probably be to purchase pre-mixed air daily and fill each of the cryogenic units at the mine site. Daily maintenance time is estimated to be that required to fill the Dewars, about 10 minutes. Additionally, the main liquid air storage Dewar must be refilled weekly or bi-weekly.

Installation requirements for this unit include provision of space on the mining machine and the attachment of some type of mounting bed. The demand regulator is also machine-mounted. It is know from previous underground experience that the mining-machine operator is capable of taking the Dewar in and out of the mine with him in addition to his other equipment.

3M WHITECAP SYSTEM # 350 HYD

The prefilter in this system is disposable, but being a back-up filter for the centrifugal air cleaner, it should only require changing every few months. Daily cleaning by gentle tapping is recommended. The centrifugal air cleaner needs approximately weekly cleaning. The high-efficiency filter is disposable, and is estimated to last six to twelve months. The hydraulic motor requires only semi-annual maintenance. Daily maintenance for the entire system is estimated at five minutes.

Replacement parts for the test program consists of 10 spare pre-filter cartridges. No other maintenance will be necessary, excepting weekly inspection of the hydraulic connections to the mining machine. If the system is to be used while the mining machine is not in use, it will be necessary to keep the machine's hydraulic power operating.

Installing the system # 350 will require 10 to 15 man-hours plus materials. As with the system # 225, the miner's lamp is worn on the helmet integral with the respiratory system.

SYNSIS AIR-SUPPLIED RESPIRATOR

The centrifugal separator mounted on the compressor inlet collects dust in a small hopper which will require daily purging with compressed air (supplied by the system). The centrifugal separator in the high-efficiency filter unit must be flushed daily by operating a dump valve momentarily while the compressor is running. The cartridge-type final filter is estimated to last six to twelve months. The motor will require semi-annual maintenance. Daily maintenance should require about two to three minutes, and is to be performed by the user.

No replacement of parts should be required for normal maintenance during the test program, but extra final filter elements will be kept on hand as a precaution. No daily maintenance other than that performed by the user should be required.

Installation is estimated to require 15 man-hours plus materials for mounting. If the respirator is to be worn while the mining machine is not operating, it will be necessary to maintain its hydraulic power. No other changes in mining procedure are anticipated.

MINE SAFETY APPLIANCES RESPIRATOR

Filter replacement or cleaning requirements are unknown. The promised duty cycle is 8 hours, but whether the batteries require charging or replacing is also unknown. Motor maintenance requirements are also unknown. Finally, no estimate of daily maintenance time is available. Due to the lack of information available to us, maintenance requirements for the test program have not been formulated.

GARRETT AIRESEARCH CRYOGENIC RESPIRATOR

No filters and hence no replacement is required for this system. As with the Essex unit, the liquid air container is removable and is replenished at the surface prior to taking into the mine and mounting on the machine. Again, depending upon the size of the operation and inclination of the manager, the liquid air can be either produced on-site or purchased in bulk. The reader is referred to the discussion of maintenance logistics for the Essex unit, as the Garrett unit is similar in concept.

Liquid air will be purchased weekly or bi-weekly during the test program and the filling of the units will take place daily at the mine site. Maintenance time is estimated to be 10 minutes per unit each day.

Installation requirements are not yet available, but should be similar to those for the Essex unit.

TOTAL DAILY MAINTENANCE REQUIREMENTS

The daily maintenance required during the test program to service one each of all 10 systems is an hour to an hour and a half. This figure does not include work that is performed on a less frequent basis such as motor maintenance, or refilling the liquid air storage Dewar, nor does it include an allowance for servicing malfunctioning units.

Section II

MINE TEST SITE SELECTION

The basic problem addressed in this section of the program is to select twelve to sixteen representative test sites from the more than three thousand underground coal mines in the United States. Site selection activities during the first quarter involved analysis of the requirements to be met by the test sites, a rationale for site selection, preliminary analysis of potential candidate mines, and a field survey of continuous mining sections.

A field site survey of the Slab Fork # 8 mine near Beckley, West Virginia yielded important observations regarding both site selection and methods of conducting the experimental portions of the program. Two working sections were observed, both in a 35 inch to 38 inch seam; an auger mining section (Wilcox) involving belt face haulage, and a "ripper" section (Lee Norse) involving shuttle car face haulage. The observations and conclusions will be integrated with the appropriate sections of this report.

OBJECTIVES AND REQUIREMENTS

Since underground coal mines are each different from the other in many respects it is essential that respirator testing be conducted at locations from which results can be generalized as much as possible. However, a number of factors such as accessibility, management receptivity and productivity constrain free selection of mining sections for testing.

Mining method and seam height are, of course, the two main parameters which must be considered. A more extensive exposition of the factors affecting mine site selection is shown in figure 6. It is obviously not within the scope of this program to perform a factor analysis on each of the factors listed which might affect respirator acceptance. The relative importance and feasibility of testing the effects of each factor, or class of factors will be discussed in the following paragraphs.

MINING METHOD

The processes involved in underground coal mining vary considerably among various mines and these differences impact quite strongly upon the design of the experimental program. Essentially, two components of the coal extraction process must be addressed separately: 1) how coal is extracted or broken from the seam, and, 2) the methods of transporting coal from the immediate face area to primary transport systems a few hundred feet from the face. Workers in these areas encounter the most severe dust hazards and are, therefore, the subject of this test program.

COAL EXTRACTION

Underground coal is extracted by either conventional or continuous methods. Conventional mining involves the use of explosives while continuous mining employs a continuous mining machine to cut or "up" coal from the seam. Although both methods result in similar dust production rates the tasks required of mining crew members and the working environment are quite different.

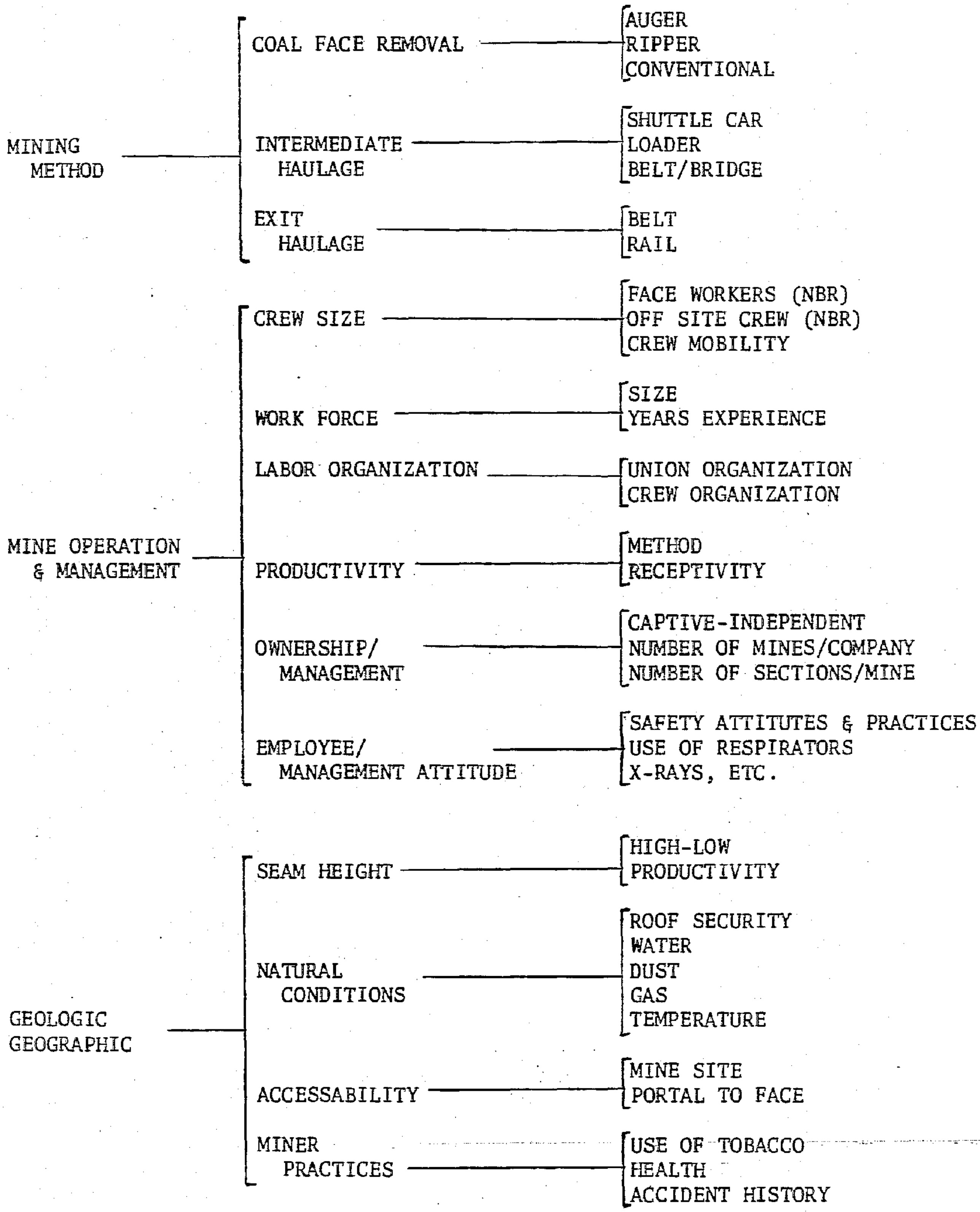

Figure 6. Factors to be Considered in Selecting Underground Test Sites

In conventional mining, several faces may be active at one time, the various processes being rotated from face to face. The processes include:

- undercutting, using a machine such as the one shown in figure 8, which removes a shallow slice of coal on the bottom extending some distance forward into the seam;

- face drilling in which a number of holes are drilled into the seam for subsequent --

- loading and firing by the shotfirer in which the explosives are packed into the holes and detonated;

- loading in which the broken coal is loaded into a shuttle car or conveyor belt by hand or by use of a loading machine of the type shown in figure 9.

These four processes occur in rotation and thus several faces can be serviced by a single mining crew.

Continuous mining is simpler in concept. A single continuous mining machine extracts coal from the seam by use of rotating blades and transports it to the rear of the machine. At this point the coal is loaded onto a belt or a shuttle car or is left in piles for subsequent loading by a loader.

In addition to the operators of each piece of machinery two to five additional miners are necessary at the face to install roof support, tend the machine power cables, and various other support functions.

As shown in Table 2 a slightly larger number of miners are employed in continuous mining sections than in conventional sections. If conventional sections with hand loading are ignored the percentages become 54% for continuous methods and 46% for conventional methods. Besides showing that the use of conventional methods with hand loading is decreasing, figure 10, shows that the trend is toward more frequent use of continuous methods. This is not surprising in view of the productivity figures shown in Table 2. Given that tests will be conducted in sixteen different sections, these data would indicate that seven sections should be of the conventional type and nine should be continuous miner sections.

Obviously, other factors affect this decision and they are discussed in subsequent paragraphs.

HAULAGE

Once removed from the seam, by either continuous or conventional methods coal must be transported outside the mine to a tipple. Transportation methods commonly used include conveyor belts and haulage by rail. The type of haulage of concern to this program concerns transport of coal from the face area to one of the primary haulage methods a hundred or so feet from the face. Two primary methods of face haulage are in use today: shuttle cars, and conveyor belts. The type used depends upon the method of mining and upon the type of mine development being employed, and varies widely from section to section. With continuous miners, particularly the auger type of mining, a system of conveyor belts termed bridge units may be attached directly to the continuous mining machine (auger machine). These are, essentially, extendable conveyor

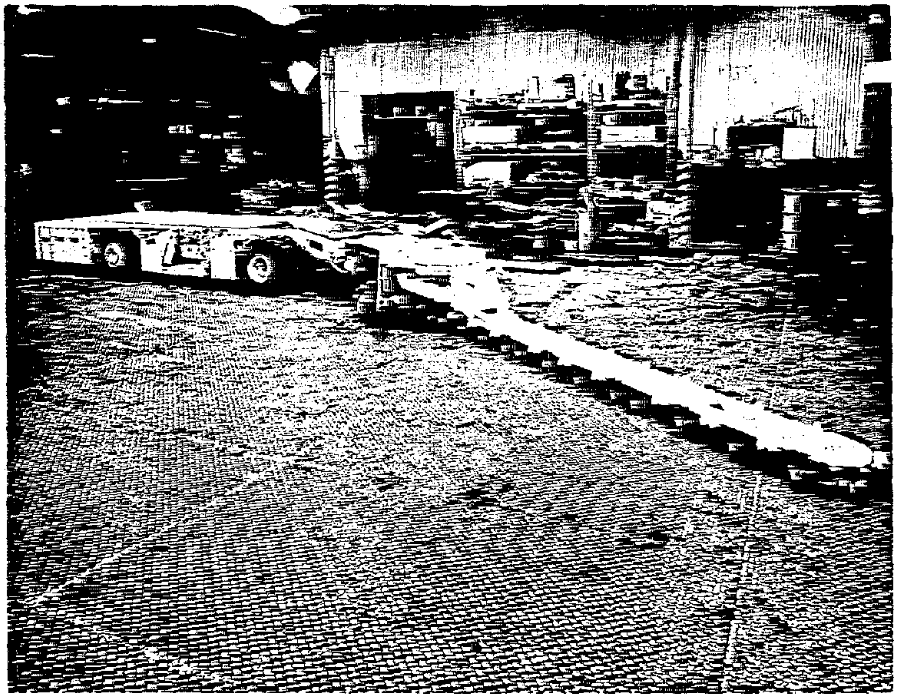

Figure 8. Joy Undercutting Machine Used in Conventional Mining

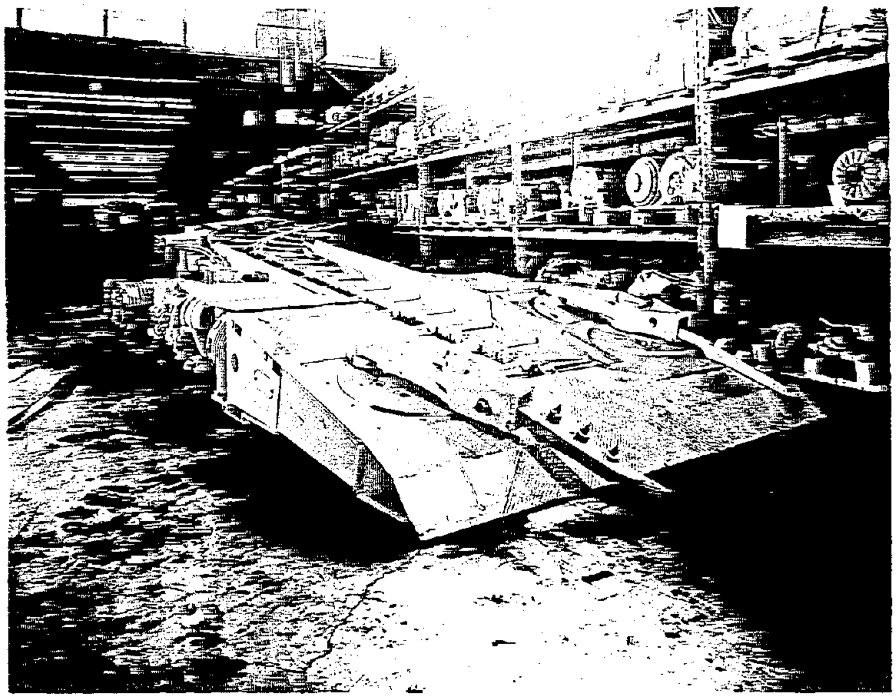

Figure 9. Joy Loader Used in Conventional Mining

Table 2. NUMBER OF MINERS EMPLOYED AND PRODUCTIVITY BY MINING METHOD IN 1971 (Ref. 7)

METHOD	EMPLOYMENT	PERCENT OF TOTAL[1]	PRODUCTIVITY (MILLIONS OF TONS)	PERCENT OF TOTAL[1]
CONVENTIONAL, HAND LOADING	2,538	2.7	8.4	2.8
CONVENTIONAL, MECHANICAL LOADING	42,146	44.8	130.4	43.1
CONTINUOUS	49,442	52.5	163.6	54.1

1 Percent of total figures represent fraction among these three methods of mining. Surface mining (strip) amounts to an additional 32,445 employees and 257.6 million tons of coal produced in 1971.

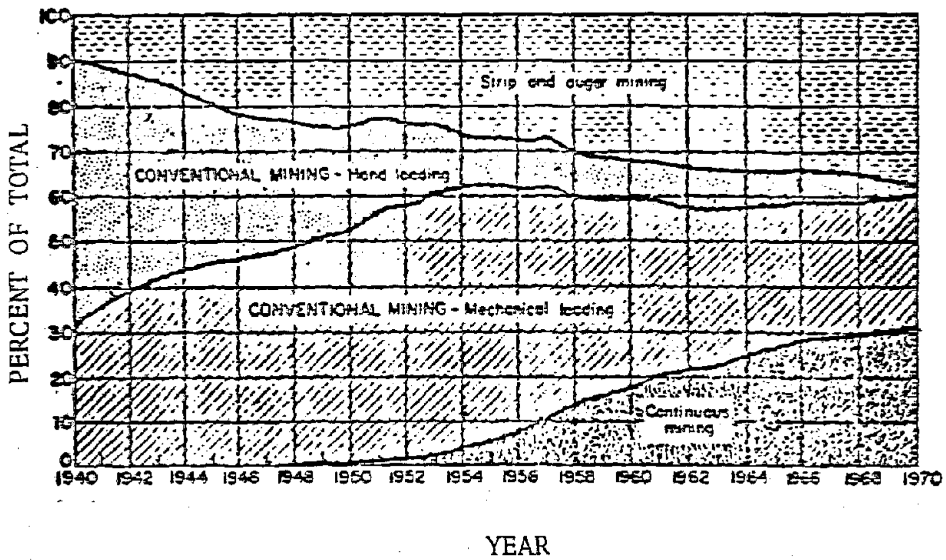

Figure 10. Trend in Coal Production by the Major Methods Since 1940. (Ref. 8)

belts designed to advance as the machine advances and to terminate at a main haulage conveyor head. Shuttle cars are not used in this method.

Two or more shuttle cars are commonly used in conjunction with the continuous mining machine known as a ripper such as the Lee Norse continuous miner. The shuttle car, which serves as a truck, collects coal directly from the output of the continuous mining machine. When the shuttle car is full, the continuous miner stops cutting coal while the shuttle car hauls the coal to another loading point (conveyor head). In the meantime a second shuttle car moves into place at the output of the continuous miner which then resumes its operation.

In a third type of operation, the shuttle cars are filled by a loader. The loader essentially scoops coal from the floor (bottom) and into a shuttle car. The sequence of events is the same as was described when the shuttle cars service a continuous miner. This method is used with conventional mining because after blasting, the coal is strewn about the bottom. In some cases the loader is used with continuous mining machines, which, instead of loading a belt or a shuttle car, merely transports the coal out the read of the machine to the bottom.

Data regarding the prevalence of use of the various methods of face haulage are not currently available. Efforts will continue to locate this data and use it in selecting the sections to be studied.

CREW SIZE

Based upon the preceding discussion it is apparent that the number of persons employed in the face working area, the number of machines, and the tasks required of the personnel can vary widely from place to place. Since each of the three haulage methods and the two coal removal methods are indeed commonly employed it is essential that the test program encompass all possible situations. This may be done most directly by insuring that operators of each of the possible machines are included in the program. This goal may be met most simply by performing each test upon large-sized crews. Crew size near the working face, can range from a minimum of four (continuous miner operator and helper, shuttle car operator, timber man) to as many as ten or twelve. A requirement in selecting test sites then is to select sites in which the number of machines operating and the number of miners at the face is as large as possible.

A more detailed statement of machine operators tasks and suitability for respirator acceptance testing appears in a subsequent section of this report.

MINING MACHINES

Mining machinery is manufactured by a number of companies. Fortunately, for each kind of equipment, two or three manufacturers supply the large majority of machines in use today. As shown in table 3, Jeffrey, Joy, and Lee Norse, account for 87% of the continuous mining machines now in service; Jeffrey, Joy, and Wabco account for 90% of the undercutting machines and 93% of the loaders; while Jeffrey, Joy, National Mine Service, and Wabco account for 90% of the shuttle cars. While it is not known at this time whether or not there are sufficient differences among manufacturers of each type of machine

Table 3. APPROXIMATE PERCENTAGE OF MARKET FOR VARIOUS MINING MACHINES FOR SELECTED MANUFACTURERS[1] (Ref. 7)

	TYPE OF MINING MACHINE				
MANUFACTURER	CONTINUOUS MINER	CUTTING MACHINE	LOADER	SHUTTLE CAR	ROOF BOLTER
ACME					13
FLETCHER					22
GALIS				1	41
JEFFREY	9	14	6	7	
JOY	24	66	80	67	6
LEE NORSE	54				
NATIONAL MINE SERVICE	2			11	
WABCO	3	10	7	5	
WILCOX	6				
OTHER	2	10	7	9	18

1. Data based upon percentage of total number of machines involved in major mine accidents.

in regard to factors which might affect respirator acceptance by their operators, these must be accounted for, and if indeed such differences are important, must be considered in selecting test sites. Preliminary results along this line are already available. One class of continuous miner is the auger produced by Wilcox. As shown in table 3, these machines represent only 6% of the continuous mining machines now in service, and indeed account for less than 13% of the continuous coal miner population in this country today (6,576 people). Furthermore there is a trend away from the use of auger miners. The same type of reasoning applies to excluding the long wall style of continuous mining which, although used extensively abroad, accounts for only a very small percentage of United States coal miner population (2,625 people, 5.3%).

We may summarize the objectives and requirements regarding the impact of mining methods upon mine test site selection as follows:

- approximate equal distribution of test sites between continuous and conventional methods of mining (9 to 7 sections)

- selection of working sections which involve crews of large numbers of miners

- selection of working sections in which the largest possible number of machines are utilized

- selection of working sections utilizing machines representative of the type and manufacture most commonly found in underground coal mining in the United States.

In this way we may achieve the highest generality of test results, as well as producing considerable economy in terms of subject test days per test section.

MINE OPERATION AND MANAGEMENT

Perhaps no other class of factors is more important to miners' attitudes regarding the use of respirators than the operational and management practices of an individual mine. Mine operations vary from large highly organized mines employing more than 250 individuals to the often cited one-man operations. As might be expected, and as is reported in reference 9, management attitudes regarding health and safety practices, especially the use of respirators, vary widely throughout the country. Despite recent legislative efforts, interest in practices pertaining to the use of respirators appears to remain rather primative in the majority of mines. For example, in the mine visited in a recent field trip there was only one brand of respirator available to the miners. Most of the miners interviewed appeared to be unaware of the other brands of passive respiratory protection available. Two other brands presented to the individuals drew considerable interest. One miner for example tried on both of the other respirators and commented that one of them fit him much better than the one he was currently wearing. However, he was not willing to use it. On the contrary the response of the majority of miners appeared to be one of genuine interest in a "better" respirator. All miners interviewed were well aware of the problems of pneumoconiosis and seemed to be interested that someone was going to do something about it. When powered respirators were described, the common response was, "Why don't you bring them down here and let us try them".

While the attitude of the individual miners is certainly an important parameter upon which to base mine site selection, there are other factors related to mine operation and management including size, productivity, ownership, and geographic location. These factors will be discussed in the following paragraphs.

SIZE OF MINE

The number of people employed in an individual mine bears upon test site selection, both in terms of achieving a representative sample and in the feasibility of conducting lengthy acceptance testing. As shown in table 4 the largest number of miners is employed by mines having between 50 and 100 employees. Therefore, choosing mines of this size for a large number of the tests would achieve a sample which could be generalized to a large number of miners in the United States. Furthermore, mines of such size are likely to be unionized, which is true of the majority of mines in this country. An additional factor which will be discussed later making this size of mine particularly desirable is the fact that such mines operate a number of sections (working faces) at one geographic location. This practice makes it possible for one observer team to conduct several tests (observation of one crew for twenty days) at the same time. At the same time, this permits the exposure of a large number of miners to powered respirators during an individual test, a highly desirable secondary goal of this project.

PRODUCTIVITY

As shown in table 5, mines having from 50 to 100 employees have on the average a higher productivity, tons of coal produced per man hour, than mines of any other size. While productivity probably does not affect a miner's attitude towards the use of powered respirators, it most certainly does make a difference in the attitude of management toward permitting our test program to be conducted. The introduction of powered respirators to a mining crew must result in some loss of productivity, at least temporarily. This stems from the fact that some of the mining machines must be altered in order to accommodate the machine-powered respirators, and that some period of time must be allocated to familiarization of the miners with each of the respirators. Furthermore, should a respirator malfunction during the course of a working shift, some period of time for one or more crew members would be required to either repair the respirator or to dispose of it properly. Considering these and other potential problems in conducting the test, such as the presence of an observer, or the time required for interviews and questionnaires, the net result on productivity for that particular crew during the test, must be a diminished production of coal. It stands to reason that a mine with a higher productivity would have a higher margin of profit and thus, perhaps, somewhat more flexibility in permitting the tests to be conducted. Certainly a mine with a low productivity, and thus a marginal profitability, might find the loss of a few tons of coal for four weeks to be a considerable burden and reason enough to deny permission for the test.

Table 4. TOTAL NUMBER OF MINERS EMPLOYED BY MINES OF VARIOUS SIZES, TOTAL NUMBER OF MINES OF VARIOUS SIZES (Ref. 7)

	1968				1969				1970			
RANGE OF EMPLOYMENT PER MINE (NUMBER OF MEN)	TOTAL NUMBER	MEN PERCENT OF TOTAL	NUMBER OF MINES	AVERAGE EMPLOYMENT (WITHIN CLASS)	TOTAL NUMBER	MEN PERCENT OF TOTAL	NUMBER OF MINES	AVERAGE EMPLOYMENT (WITHIN CLASS)	TOTAL NUMBER	MEN PERCENT OF TOTAL	NUMBER OF MINES	AVERAGE EMPLOYMENT (WITHIN CLASS)
ALL	94,532	100	3,850	24.6	94,421	100	3,450	27.4	90,409	100	3,053	29.6
1 to 4	3,510	3.7	1,223	2.9	2,835	3.0	1,015	2.8	2,487	2.8	856	2.9
5 to 9	7,091	7.5	1,122	6.3	6,521	6.9	1,017	6.4	5,669	6.3	882	6.4
10 to 19	8,078	8.5	685	11.8	6,825	7.2	577	11.8	6,269	6.9	523	12.0
20 to 49	9,347	9.9	363	25.7	8,325	8.8	332	25.1	7,381	8.2	317	23.3
50 to 99	8,561	9.1	134	63.9	8,745	9.3	201	43.5	8,701	9.6	154	56.5
100 to 249	28,185	29.8	237	118.9	27,857	29.5	196	142.1	28,195	31.2	212	133.0
205 or more	29,760	31.5	86	346.0	33,313	35.3	112	297.4	31.707	35.1	109	290.9

Table 5. COAL MINE PRODUCTIVITY VERSUS NUMBER OF PERSONS EMPLOYED (US Underground Coal Mines) (Ref. 7)

	PRODUCTIVITY (Tons/man-hour)		
YEAR	1968	1969	1970
MEN EMPLOYED			
1 to 4	1.38	1.41	1.62
5 to 9	1.71	1.75	1.83
10 to 19	1.75	1.91	2.17
20 to 49	1.88	2.05	2.1
50 to 99	2.34	2.14	2.09
100 to 249	2.24	2.14	2.09
250 or more	2.15	2.12	2.08

OWNERSHIP AND MANAGEMENT

While most mines are owned and operated by mining companies engaged strictly in coal mining, some mines, called captive mines, are operated as part of larger industries such as the steel industry. Since captive mines are primarily oriented toward providing the required amount of coal to the parent industry and less interested in "making a profit" they maybe expected to be somewhat more receptive to respirator testing programs. Furthermore, it appears that captive mines in general have more vigorous health and safety programs. These two factors indicate that captive mines might be ideal locations for our testing program. However, the statistics currently available are not sufficient for us to determine whether captive mines can be selected to provide sufficient representation in mining methods, size, machinery, and other factors deemed necessary. This matter will be explored more fully in subsequent months.

EMPLOYEE/MANAGEMENT ATTITUDES

As discussed in reference 9, health and safety practices and attitudes vary widely among mines. While a respirator test program might be better received in a mine in which both management and miners are keenly aware of the need for availability of respiratory protection, our desire to achieve a representative sample dictates that tests be conducted as well, at mines in which health and safety practices are not particularly stringent.

In addition to health and safety attitudes and practices it is important to consider the management and the miners' attitudes in regard to visits by outsiders. In some of the larger and more accessible mines, visitors from mining equipment manufacturers and by government inspectors are sometimes quite common. Therefore, one would consider that these mines would be more likely to accept our visits in good faith. Certainly it is true that if the miners do not accept our observers with a spirit of cooperation, then the tests cannot be considered valid. Our initial findings along this line, resulting from recent field surveys, were quite rewarding. Apparently the miners felt that anybody who was willing to go underground in a 35-inch coal seam was worthy of some respect. Management attitudes were quite favorable as well. Both supervisory personnel and individual miners went out of their way to accommodate our desires.

GEOLOGIC-GEOGRAPHIC FACTORS

A number of factors having to do with the location of mines and the nature of the deposit are important to the selection of mine test sites. As with the previous class of factors, these come into play both in achieving a representative sample and in the feasibility of conducting the test. In addition to the obvious factors of seam height, dustiness, and the in-mine climate, certain demographic parameters appear to be important.

SEAM HEIGHT

Coal seams currently being exploited in the United States range in thickness from 20 inches to well over six feet. It is obvious that a miner's attitude toward the use of powered respirators is affected by the seam height in which

Table 6. NUMBER OF MINERS EMPLOYED IN UNDERGROUND COAL MINES OF VARIOUS SEAM HEIGHTS DURING 1968, 1969, 1970 (Ref. 7)

SEAM HEIGHT (INCHES)	1968		1969		1970		TREND
	NUMBER	% OF TOTAL	NUMBER	% OF TOTAL	NUMBER	% OF TOTAL	
0 to 36	11,720	12.8	10,101	11.1	7,618	9.0	DECREASE
37 to 48	22,536	24.7	22,273	24.5	20,848	24.6	NIL
49 to 60	21,788	23.9	22,710	25.0	21,891	25.9	INCREASE
61 to 72	14,277	15.6	15,093	16.6	13,126	15.5	NIL
73 to 84	10,485	11.5	9,686	10.7	9,984	11.8	NIL
85 to 96	4,735	5.2	6,337	7.0	6,376	7.5	INCREASE
97 to 108	3,004	3.3	2,099	2.2	1,976	2.3	NIL
109 or more	2,708	3.0	2,476	2.9	2,763	3.3	NIL
TOTAL	91,253	100	90,775	100	84,582	100	DECREASE

Table 7. COAL MINE PRODUCTIVITY VERSUS SEAM HEIGHT (Tons/man-hour) (Ref. 7)

YEAR	1968	1969	1970
SEAM HEIGHT (inches)			
0 to 36	1.57	1.68	1.60
37 to 48	1.80	1.78	1.72
49 to 60	2.21	2.19	2.19
61 to 72	2.31	2.11	2.17
73 to 84	2.44	2.46	2.30
85 to 96	2.41	2.25	2.38
97 to 108	2.68	3.01	3.14
109 or more	2.37	2.36	2.21

he works. This is especially true of some of the battery-powered respirators which have fairly cumbersome back packs which might be expected to impede the miner's mobility in low seam coal. Since the basic question in this study is whether or not a miner is willing to pay the price of added weight and bulk suspended from his person in return for dust-free air to breathe, it is easy to see that the matter of seam height, which in some way affects the price paid, can be a very important parameter to mine test site selection.

Since, as shown in table 6, more than one third of US coal miners are employed in seam heights of less than four feet, it is essential that a significant proportion of the tests be run in seam heights in this range. However, it is important to note from the data in table 6, that the trend is toward a larger number of mines in the 49 to 60-inch category. For this reason one would want to perform a slightly larger proportion of the tests in these seam heights than would be indicated from the current values.

Reference to table 7 presents one potentially serious problem regarding seam heights. Productivity in tons per man-hour in seam heights from 37 to 48 inches is significantly less than with higher seam coal. Therefore, as discussed earlier regarding size of mines, there might be some reluctance on the part of mine operators to permit observations to be made in lower seam coal.

Another factor reflecting the difficulty in conducting tests in low seam coal involves mounting of the machine-mounted respirator systems on the mining equipment. Continious miners, shuttle cars, loaders, and roof drills are all very compactly designed and constructed. It is difficult, if not impossible, to find space within the confines of the machine for mounting bulky pieces of equipment. Components such as the cryogenic Dewars, the filter unit for the 3M 350 HYD unit, and the compressor for the Synsis system may have to be mounted outside of existing machine space envelopes. Such an increase in machine clearance envelope may prevent the machine from operating in low coal and thus, in fact, prevent the mounting of the equipment. This is especially true when one considers that in some mines the top and the bottom of the seam (ceiling and floor) tend to move together somewhat now and again. This phenomenon is called "hooving up" by the miners. For instance in the mine visited in the field survey the first hour of one shift was spent cutting rock from the bottom with the continuous mining machine in order to provide sufficient clearance for the other pieces of machinery to work.

In reviewing the test respirators with industrial engineers imtimately associated with underground operations (Theodore Barry and Associates), it became readily apparent that certain of the respirator systems could not be worn by miners performing certain tasks in low coal. This and other task--environment-machine interactions will be discussed in a subsequent section.

NATURAL ENVIRONMENT CONDITIONS

There are a number of factors within the environment of a coal mine although not necessarily of the type to be varied in order to achieve a representative sample, which must be accounted for in one way or another. These include some of the natural safety factors such as the likelihood of a roof fall, the amount of water, dust, or gas within a mine. Statistical data regarding the distribution of these types of factors within coal mines are not available and therefore we must rely upon the judgement of experts who have observed them in a number of mines and are thus able to judge the relative importance of the factors as well as "normal" values for them.

Roof Security

The likelihood of a roof fall may alter a miner's judgement of the utility of the particular respirator, in that he may find a particularly cumbersome unit objectionable because it would impede a rapid escape in the event of a roof fall. However, this factor is not felt to be particularly important in mine site selection. Furthermore, descriptive statistics regarding such things are not available, thus prohibiting the selection of "representative" samples. At the same time it appears prudent for us to avoid mines in which roof falls are common. While experienced miners are quite adept at sensing an impending roof fall and evacuating the area, our observers might constitute a hazard both to themselves and to the other miners. For this reason, underground mines with particularly hazardous roof conditions will be excluded from the samples.

Water

Water is produced in coal mines both from natural seepage within the seam, and as the product of water infusion or water spraying devices installed on the mining machine. While all mines have some dampness there is a considerable variation from mine to mine or from section to section. One requirement in mine site selection will be to achieve some samples of very wet mines and very dry mines. The dry mines will be selected because they are usually dusty. Wet mines derive their importance from the fact that the abundant water frequently results in respirator filter elements becoming soaked and thus developing extremely high breathing resistance. This phenomenon could cause powered respirators to achieve a higher acceptance. At the same time the moist environment will produce a hazard to the mechanical operation of the respirators thus providing a test of their reliability in wet coal mines.

DISTRIBUTION AND ACCESSIBILITY

The vast majority of underground coal mines lie in the Appalachian mountains from Pennsylvania through Kentucky. Since there are important differences in the attitude of miners and in the geology of the coal seams, as well as in mining methods, depending upon the location of mines, it is desirable to sample underground operations in a number of different geographic areas. Operational necessities of the test program, however, dictate certain requirements for the mines in which tests will be conducted. These might be termed accessibility requirements. All other factors being equal of course, it would be desirable to conduct tests in mines which are relatively close to major population centers. This would facilitate travel of test personnel as well as certain logistic requirements of the tests. Chief among these logistic requirements is the necessity of providing liquid air for two of the units to be tested. The ten systems to be tested and associated equipments are sufficiently heavy and bulky that they must be transported to the test site by commercial freight carriers. A considerable savings can be effected if the transport from major railheads is not excessive.

An additional requirement of the test, as discussed in Section 3, is that a single observer make observations in more than one working section during the same period of time. Unless two or three working sections can be selected from the same mine, it is required that the observer travel from one mine to another over night. Thus if one working section is selected from each of two or three different mines the two or three mines must be moderately close together. The same is of course true regarding the installation and servicing requirements for the ten respirator systems. The most efficient operation would be such that a single individual can service and install as many respirators as possible, benefiting each time from his experience.

The logistics regarding transportation of personnel, respirators and service equipment from the mine portal to the face area are equally important. Transport of personnel and tools to the working face commonly involves initial transport from the portal by rail, and subsequent travel to the face by conveyor belt. At least during the testing program, possibily not in routine use, the respirators and the required maintenance equipment must be transported to and from the face during each shift. If the distances traveled are excessive, the impact upon mine operation and the inconvenience to the working crew might adversely affect both the miners' acceptance of the respirator system and the mine operators tolerance of the test program. Therefore, it is desirable to select mines in which the portal to face travel distances are as short and convenient as possible.

We may summarize these requirements for test site selection as follows:

1. The mine selected should be as close as possible to a major transportation center,

2. The faces selected for study should be as convenient to the mine portal as possible,

3. If more than one mine is selected in a single test series, these mines should be as close together as possible.

GEOGRAPHIC FACTORS IN MINE OPERATION AND MINER PRACTICES

Within the Appalachian area, the northern-most mines tend to be larger, better organized, and more unionized. The southern mines, therefore, are less subject to outside influence and availability of knowledge regarding health hazards and the use of respirators. While firm statistics regarding these factors are not yet available, it would appear desirable to conduct the majority of tests in the more northern mines thus achieving, perhaps, a more representative sample regarding the total miner population.

One factor regarding miner acceptance of respirators that has been said to be geographic in nature is the use of tobacco. It is said that the southern miners tend to chew tobacco more frequently than do those in the north. During the site selection field survey conducted this quarter, several miners were interviewed regarding this notion. The mine visited being in West Virginia, it was interesting to note that nearly everyone carried chewing tobacco and its use seemed quite prevalent. However, when interviewed, many miners said they only chewed tobacco while they were in the coal mines, and rarely if ever on the surface. Chewing tobacco, it was reported, reduced the unpleasant

Table 8 DUST CONCENTRATION LEVELS AS A PERCENT OF TOTAL NUMBER OF SECTIONS IN 29 MINES (Ref. 7)

DUST CONCENTRATION	PRIOR TO OCCUPATIONAL HEALTH & SAFETY ACT	FISCAL YEAR 1971	FISCAL YEAR 1972
GREATER THAN 3 mg/m^3	71.62	40.63	25.91
LESS THAN 3 mg/m^3	28.38	59.37	74.09
LESS THAN 2 mg/m^3	20.64	35.41	49.83

taste of dust in the mouth as well as satisfying the craving for tobacco by those who otherwise would be smoking tobacco. Therefore, to some extent it seems reasonable to speculate that improved and more convenient respiratory protection within the coal mine environment would reduce the need and therefore the prevalence of tobacco chewing. Nevertheless, for the short duration of our tests, the use of tobacco must be considered as an important parameter of respirator acceptance. The impact of this parameter on acceptance of various respirators must be explored by interview and questionnaire techniques

DUST PRODUCTION

Airborne coal dust is produced by both the continuous and conventional methods of extracting coal from the seams, as well as by various processes involving transporting the coal away from the area. Engineering control of the airborne dust consists of essentially three methods. Application of water to the coal either by spraying on the cutting surface by mining machine or by infusion into the coal seam prior to extraction, results in lessing the amount of dust which becomes air borne. Outside air is forced into the mine by large fans and its flow is controlled so that it passes over the working face by means of flow control curtains, called brattice, sweeping the coal dust out of the face area. A third method, concerned as much with fire prevention, is the application of rock dust to the walls, tops and bottoms of the seams. Methods of application of each of these techniques are governed by law and are aimed at achieving dust concentrations, within the respirable range, of 2 mg per cubic meter as established by the Occupational Health and Safety Act. As illustrated in table 8 and several other references these methods are only partially able to meet the respirable dust concentration requirements.

Airborne dust ranges from sub-micron sized particles up to an aerodynamic diameter of several hundred microns. Only that fraction of the dust between one half and 10 microns in diameter is considered to be a health hazard. Unfortunately, dust in these diameters is not visible to the naked eye. While dust of the larger sizes is indeed visible within the coal mine environment, it tends to settle more quickly indicating that the threat is reduced when in fact it is not. Observations by ourselves and others indicate that miners typically employ respiratory protective devices only when they are able to visually observe airborne dust in the environment. As discussed in reference 9 the common practice is for only those miners who perceive a particularly serious dust hazard to wear their respirators. For instance, in the auger mining section observed recently, the timberman and the jack setter who were down stream (regarding the ventilation flow) and who were within 15 feet of the working face wore their respirators while the auger machine was actually cutting coal. When the machine stopped cutting coal, as it does periodically, these individuals immediately removed their respirators. Other individuals including the up-stream jack setter and timberman, the auger miner operator, the belt man, and other personnel more distant from the face area never wore their respirators while we were observing.

These practices which we consider to be typical, have very important bearing upon the subject of respirator acceptance. Once the cutting had begun and throughout the remainder of the shift, dust was always visible in the beam of the miner's lamp. During the cutting operations the down-stream jack setter and timberman were surrounded by such a concentration of dust that their position could only be determined by observing the beam from their cap lamp. Subsequent questioning of the majority of the crew members as to why they did not wear their respirators produced very interesting results. Some indicated it was just too much bother, while others indicated they could not wear them because their pulmonary function was so reduced they could not breathe through them. Some miners indicated they already had black lung and it no longer made any difference. Another problem sited was that the donning and doffing of the respirator was problematic.

The impact of these observations upon mine site selections is quite significant. We have essentially three different conditions. In the very dusty mine and/or for the jobs in which the dust exposure is very high, the real need and the observed need for respirators is quite high. Therefore, we might find greater acceptance of powered respirators. In terms of supply and demand as discussed earlier, the miners might be willing to pay a higher price in regard to the burden of wearing a powered respirator in return for achieving respiratory protection. In the second case, of a mine in which the dust concentration is quite low, there is still a great need for respiratory protection from the airborne dust which is not visually observable but is still present. In this environment the preceived need of respiratory protection is much less, possibly reducing the acceptance (time of wear) of powered respirators. Since respiratory protection might not be worn routinely, a less burdensome passive respirator might be more desired. In the third case, in either environment, we have the individual with some degree of pneumoconiosis whose pulmonary function is so reduced that passive respirators are unacceptable. Due to the ease of breathing produced by the powered respirators, this individual might find a powered respirator considerably more appealing.

Certainly the most critical case is the man who is exposed to high dust concentration and perceives he needs respiratory protection. If he can be provided with a respirator which he will wear more often, then our goal has been met. However, it is assumed that a much larger proportion of underground coal miners fall into category two in which the perceived need is not particularly great, but in which the health hazard is still quite severe. In the third case, it is important to note that the degree of pneumoconiosis depends upon the cumulative exposure of the lungs to dust in the respirable range. Advancing pneumoconiosis can be arrested if the exposure of the lungs to dust is curtailed.

Therefore, we have a definite requirement to select sections as well as job descriptions, for experimentation in which each of the three categories may be observed. Data permitting delineation of dust exposure by job description are available and will be discussed in Section 3. However, data regarding dust concentrations within particular sections of the several thousand underground coal mines in the United States is not readily available at this time. Efforts will be expended during the next reporting period to acquire such data to aid in the selection of the test sites.

Section III

TEST METHODOLOGY DEVELOPMENT

As part of Phase I activities during the quarter, preliminary test schedules have been formulated and test methodology development activities have been conducted. Because of the lead time required for Bureau of Budget approvals, primary emphasis has been given to development of questionnaire and interview techniques. Since this aspect of the program is particularly critical, considerable attention has been devoted to research and to consultation with experts in the field. A digest of results of this effort appears in the appropriate paragraphs of this section.

Other factors dealt with include scheduling of equipment and manpower resources, and operational constraints regarding test subjects and test respirators. Discussion of laboratory test techniques, dust concentration sampling devices, and related topics will be reported in the next quarter when they can be more fully developed.

INTRODUCTION

Acceptance testing of personal protective equipment is a difficult task in any environment. Measuring the acceptance of ten respirators divided among two separate classes in the underground coal mine environment is therefore a matter requiring considerable care and planning. The interdependency of the measurement techniques and the operational necessities of the coal mine environment must be carefully considered so as to achieve the required results without ambiguity and with the smallest chance of failure.

Operational constraints regarding the scope of the program and the receptivity of independent mine operators and miners dictate a number of factors including:

- number of days during which an observer can be present at the test site,
- type of respirator that can be used by miners employed at the various tasks,
- time available for interviews and questionnaire completion,
- cooperation to be expected of miners in utilizing the test respirators,
- number of miners at each site who can be used as test subjects.

Within this environment essentially four methods of gathering acceptance data are available:

NON-INTERACTIVE TECHNIQUES
- PHYSICAL MEASURES (time of use, etc.)
- VISUAL OBSERVATION (Task interference, use practices)

INTERACTIVE TECHNIQUES
- UNSOLICITED COMMENTS (during breaks, etc.)
- SOLICITED OPINIONS (interviews, questionnaires)

A preliminary analysis of the above topics has been completed and is discussed in the following pages.

MINER/TASK COMPATIBILITY

The mining crew has been characterized by some observers as one of the hardest working groups of people to be found. Our own observations during the recent field trip confirmed this to be true. Even the simplest task of locomotion in the stooped or crawling posture has been demonstrated as being extremely strenuous on the few occasions that it has been measured (Ref. 10). Unlike many forms of industrial work crews, the tasks performed by each crew member are highly heterogeneous. While each man has a job title and performs a primary, well defined function, each crew member does whatever is necessary to get the job done and there is often much overlap in the duties performed. As well, the nature of each task varies considerably depending upon the specific methods employed at a particular working section. For example roof bolting may be performed during the actual coal cutting operations or, as in the sections observed in the field survey, at the conclusion of each shift after coal extraction processes had ceased.

The same type of reasoning applies to the miner's location relative to the face and the ventilation air flow which commonly flows parallel to the face. While a timberman is commonly required on each side of a continuous miner, the "upstream" timberman receives fairly clean air while the "downstream" timberman is exposed to heavy dust concentrations.

The above discussion must be considered in regard to the data presented in table 9. While this data presents average dust exposures for individuals of various job titles in 29 mines, it would not be appropriate to suggest that any particular job classification should be excluded from the study because of low average dust concentrations in this particular study.

Therefore, in the acceptance testing program, test respirators will be made available to all those at a particular section whose activities involve exposure to dusty air. A goal of the site selection, and the selection of individuals at each test section, will be to incorporate as many different job descriptions as possible.

Table 9. AVERAGE RESPIRABLE DUST EXPOSURE BY JOB TITLE (Ref. 11)

JOB TITLE	DUST CONCENTRATION (milligrams/meter^3)		
	PRIOR TO JUNE 30/70	JULY 1/70 JUNE 30/71	JULY 1/71 JUNE 30/72
CONTINUOUS MINER OP.	6.5	3.1	2.6
UNDERCUTTER OP.	5.9	2.9	2.2
LOADER OP.	6.0	2.7	2.2
LOADER OP. HELPER	5.0	1.3	2.1
ROOF BOLTER	3.9	2.3	1.9
CONTINUOUS MINER HELPER	5.5	2.3	1.8
UNDERCUTTER HELPER	7.1	2.3	1.7
SHOT FIRER	5.0	2.1	1.7
ROCK DUSTER	6.0	1.8	1.7
TIMBERMAN	3.9	1.7	1.7
UTILITY MAN	1.9	1.0	1.6
SHUTTLE CAR OP.	2.3	1.6	1.5
VENTILATION MAN	5.4	0.8	1.4
FACE DRILLER	5.6	2.9	1.3
LABORER	10.4	2.9	1.2
MECHANIC	1.7	1.2	1.2
CONVEYOR BELTMAN	2.7	1.7	1.1
FOREMAN	2.7	1.3	1.0
BRATTICE MAN	2.1	1.2	1.0
SUPPLYMAN	2.5	1.8	0.9
MOTORMAN	0.5	0.7	0.7

TASK-RESPIRATOR INTERACTIONS

Of the ten respirators to be tested, six are portable battery-powered units while four are strictly machine-mounted units. In general it might be said that the battery-powered units could be used by anyone while the machine-mounted units are appropriate only for the machine operators. Unfortunately, this is not, in our opinion, the case. Some of the battery-powered units, particularly the 3M and the Martindale incorporate fairly large and cumbersome belt-mounted filter-blower components. In low coal seams especially, the operator station requires a semi-recumbent position in extremely close quarters. In our opinion the more cumbersome units would present such an impediment to the operator that no tests should be conducted on these subjects when the impediment exists. The same is true for certain non-operator job descriptions. Furthermore, it appears prudent to employ the machine-mounted units predominately for machine operators and the portable units predominately for support personnel. These concepts are tabulated by major job descriptions in table 10. The battery powered-small units are segregated from the battery powered-large units by the size of the belt-mounted portion of the system. A blank square on the chart indicates that a job description does not appear in that method of mining. The utility of this scheme of testing will be further explored by consultation with miners and in the pilot study.

TEST SCHEDULING

Preliminary restrictions on the scheduling of each individual test have been formulated. The basic constraint is that it is both scientifically unsound and economically unfeasible to have an observer at each test site on each day of a test. The reasoning for this conclusion will be presented at a later time. The basic result is to conduct the 1,200 man days of testing in from twelve to sixteen individual "tests".

A "test" is defined as the use of test respirators by members of a single work crew (at one section) for twenty days. Thus each test will produce acceptance and protection measures on from six to ten respirators. The number and the types of respirators to be utilized for each test is of course dependent upon the method of mining and the crew size. Tests will be conducted in blocks of three tests each with a single observer servicing each test in rotation.

In order to allow adequate time for system installation and demands upon the observer during the initial parts of each test, the second test in a block will begin one week after the first, and the third one week after the second. This will result in each block of testing being approximately seven weeks in duration.

Obviously it is required that the three (or two if necessary) test sites of a block be sufficiently close together to facilitate travel of the observer from one site to another. In the same way each test site in a block may benefit from the services of a single installation and maintenance person.

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In order to allow adequate time for system installation and demands upon the observer during the initial parts of each test, the second test in a block will begin one week after the first, and the third one week after the second. This will result in each block of testing being approximately seven weeks in duration.

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ACCEPTABILITY MEASURES

Perhaps the most significant measure of the acceptance of respirators is the time of wear per shift. Such measures will be made using electronic devices, and will permit comparisons between the various respirators used in the test program. However, a basic question involved is whether or not powered respirators are more acceptable than passive dust respirators. Although some data on frequency of wear of passive respirators is available (Ref. 9), it will be difficult to compare these results with time of wear measures under the more controlled conditions of the planned test program. While methods are being considered to make such "paired comparison" tests, there are other ways to achieve the desired goal. To a large extent these methods involve measurement of the opinions of the test subjects of their test respirators.

REQUIRED DATA

As shown in figure 11 a great number of factors are involved in an individual's acceptance or rejection of a particular respirator. It is an unfortunate fact that particularly poor performance by a respirator on any one of these factors can cause a total rejection of the system. This fact leads to a basic goal of the test program. If the reason for poor acceptance can be isolated; then perhaps it will be an easy one to remedy and the respirator in question can simply be made to be acceptable. For example it would be totally remiss to exclude from further consideration a respirator whose only point of disfavor concerned breathing hose routing, a matter easily rectified. Therefore, an important part of this test program will be to determine the strong points and the weak points of each respirator system.

To this end, attempts will be made to gather opinions concerning as many of the factors in figure 11 as possible. The techniques for collecting such data are rather complicated and are discussed in the following paragraphs.

NON-INTERACTIVE TECHNIQUES

Non-interactive techniques for gathering data are those in which the subject is not required to express an opinion in any form. Data is taken by some other means, such as electronically, photographically, or by visual observation. At this point in time only preliminary plans for the conduct of this type of testing are available.

Time of Wear Measurement

Perhaps the most valid measure of the acceptance of a respirator is how much it is worn. There are essentially three ways to gather that data:

1) ask the subject at the end of each shift to estimate the time of use each day,

2) have an observer record the time of use by visually observing each miner,

3) measure electrically the time that the respirator is on the face of the subject.

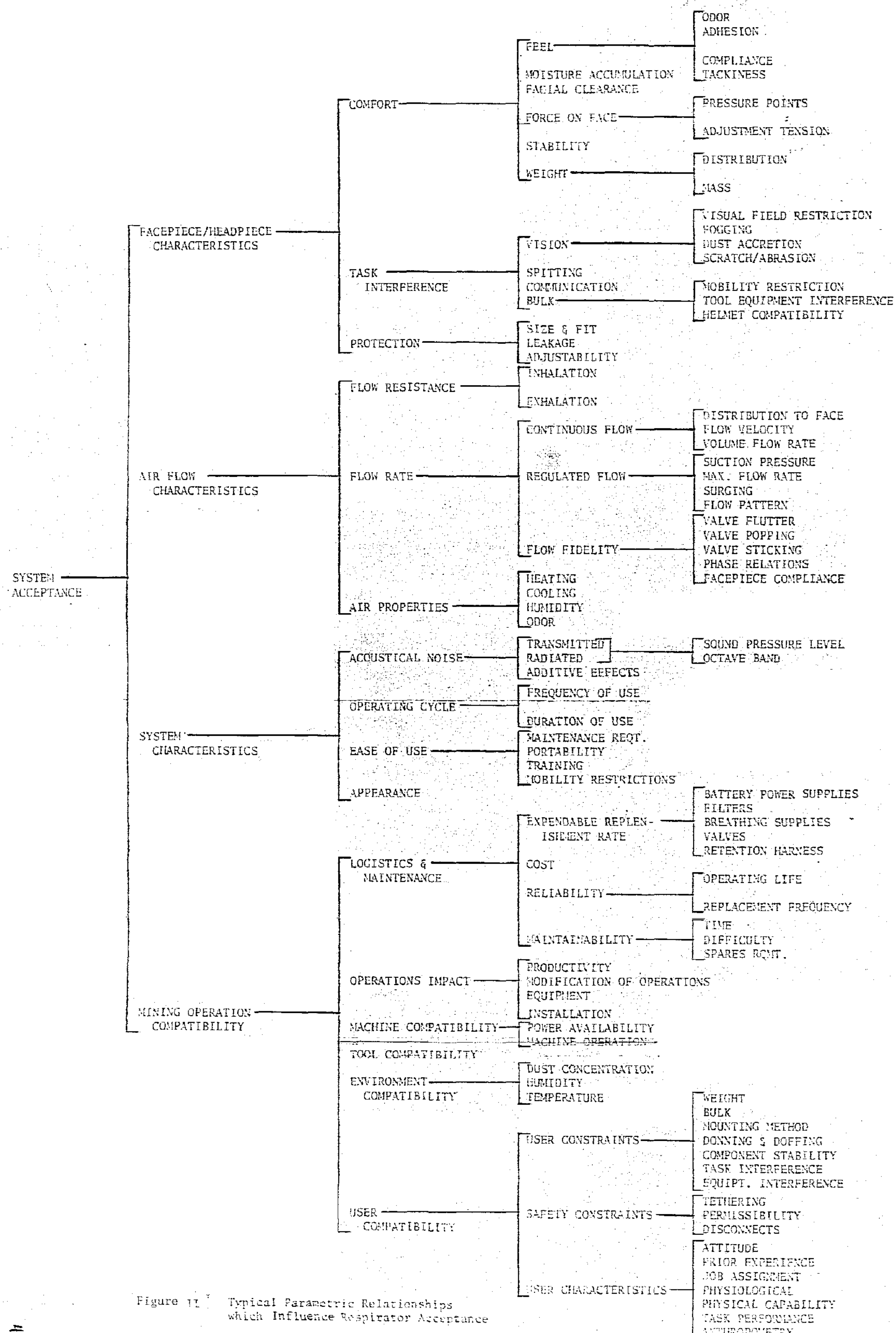


Figure 11 Typical Parametric Relationships which Influence Respirator Acceptance

The first method lacks reliability, and the second is both too costly and liable to error (the Hawthorne effect). Therefore, electrical methods will be used to record the amount of time that each respirator is used during each shift.

The one basic problem in this method is that ~~the measuring device must necessarily interfere with respirator acceptance.~~ Effort has been expended during the quarter to find some reliable means of measuring time of use with the smallest amount of subject interference, however, no firm choices of method have been made. A detailed account of this activity will appear in the next quarter's progress report when it can be discussed more fully.

Visual Observation

Another important non-interactive technique is the use of on-site observers. In addition to certain regulatory capacities in seeing that the respirators are properly used and cared for, the observer has several data collection duties of considerable importance. Although detailed observer strategies have not been worked out, several observer functions should be mentioned at this time:

- delineation of respirator design defects and recommended improvements,
- correction of poor use practices,
- observation of actual or potential task interference by the respirator,
- judgements of the suitability of various features of each design,
- judgements of the suitability of each respirator for each job description.

INTERACTIVE TECHNIQUES

The above observer functions were essentially non-interactive in that no communication was required. Observer functions involving communication with the test subjects is termed interactive and falls into two categories, solicited and unsolicited.

Unsolicited Interactions

Part of the observer's function will be to insure proper use of the respirators and to maintain the support of the miners. At the same time he should be receptive to, and able to record the spontaneous comments of the miners regarding the suitability of the test respirators. To do this a thorough understanding of each unit, including periods of wear, is necessary.

Previous experience in such matters has demonstrated the utility of this type of data and it should be regarded with considerable importance.

Solicited User Evaluations

Perhaps the most important data to be utilized in the program are solicited user evaluations of the respirators.

Work on a system for acquiring user evaluations has centered about research into how to maximize the reliability and validity of questionnaires and interviews. The primary motivation for such a study is the fact that a poorly-designed program could be marginally informative or, worse yet, yield misrepresentative results. In addition, there is the consideration of practicality. For example, specifying a four-page questionnaire to be filled out daily by each test subject would be cumbersome, expensive, and unpopular with all parties concerned. Specific pros and cons will be discussed individually for each method under consideration.

Introduction to Methodology

Interviews and questionnaires are the two methods used for solicited, interactive user evaluations and can both be categorized by the type of questioning strategy employed. Such categorizing can be accomplished by visualizing a particular strategy as fitting into a two-dimensional matrix of directedness and standardization. Directedness is the degree of channelling of responses that is placed upon the test subject. For example, a question which permits only a "yes" or "no" response is highly directed while a question like "What is your opinion of this system?" is highly non-directed. Standardization, on the other hand, is in this context the degree of structure or rigidity to which the wording of questions is held. It would naturally follow that a questionnaire is completely standardized unless more than one version is used.

Questionnaires. In contrast with an interview, a questionnaire is, as a rule, less expensive to conduct. This is due to the fact that it is generally less time-consuming, both to administer and to evaluate. It is also less subject to interviewer bias. By the use of a questionnaire, the variations due to social interaction are minimized, leaving the wording of the questions as the major source of interviewer bias. This allows a less skilled person to administer the questionnaire with less fear of introducing bias. In addition, reliability (repeatability) is enhanced by the structured (highly standardized) nature of a questionnaire.

Again in contrast with an interview, the questionnaire is more effective when the questions are highly directed. The subject is not obligated to compose answers and the experimenter does not have to analyze subjective responses which makes the information easier and less time-consuming to quantify. However, the price to be paid for simplicity and reliability is in the validity of results. For example, the non-literate or semi-literate population is excluded from testing. The lack of interaction means that information that isn't asked for isn't obtained and, equally serious, the importance that the test subject places on each question is lost. Similarly, it is very difficult to separate a good question from a bad question or recognize a confusing order of questions.

Interviews. As stated previously, interviews are more time-consuming, more expensive, more subject to interviewer bias, and need to be conducted by more highly-trained personnel than is the case for questionnaires. However, they are far more suitable for asking undirected ("opened-ended") questions. The inhibiting association with a "test" is removed, making possible a greater validity in lengthy answers. The degree of literacy of the subject also ceases to be an important restriction. However, the major advantage of the interview as a method of information gathering is the greater validity of results that can be obtained. This is mostly due to increased flexibility in the nature of the relationship between interviewer and interviewee, and in the wording and content of the questions. Feedback is obtained on the effectiveness of the questions, unanticipated topics can be discussed, and non-verbal or connotative communication (which is often more important than the verbal or denotative communication) can be recognized. The price to be paid for flexibility in administration is in the difficulty of evaluation. Some aspects of the tradeoffs between questionnaires and interviews will be discussed in the following section.

Application to Respirator Acceptance Testing

The study of strategies is outlined in the previous section to illustrate the fact that a combination of methods must be employed to meet the various objectives of the respirator acceptance study. To meet the objective of a non-comparative evaluation of user acceptance, every test subject will be interviewed at least once. This will permit the advantages of flexibility discussed previously, particularly that of gathering information about unanticipated aspects of using each respirator in particular mine environments. Questionnaires, on the other hand, will be employed with essentially directed questions for rapid collection of background-type information and with graded questions (e.g. - a 0 to 10 scale) about specific respirator characteristics. The latter type of question can be used in comparative evaluations of the various respirators. Figure 11 illustrates factors relevant to respirator acceptance that will be used as a guide in questionnaire and interview construction. The remainder of this section will expand upon the advantages of the two techniques.

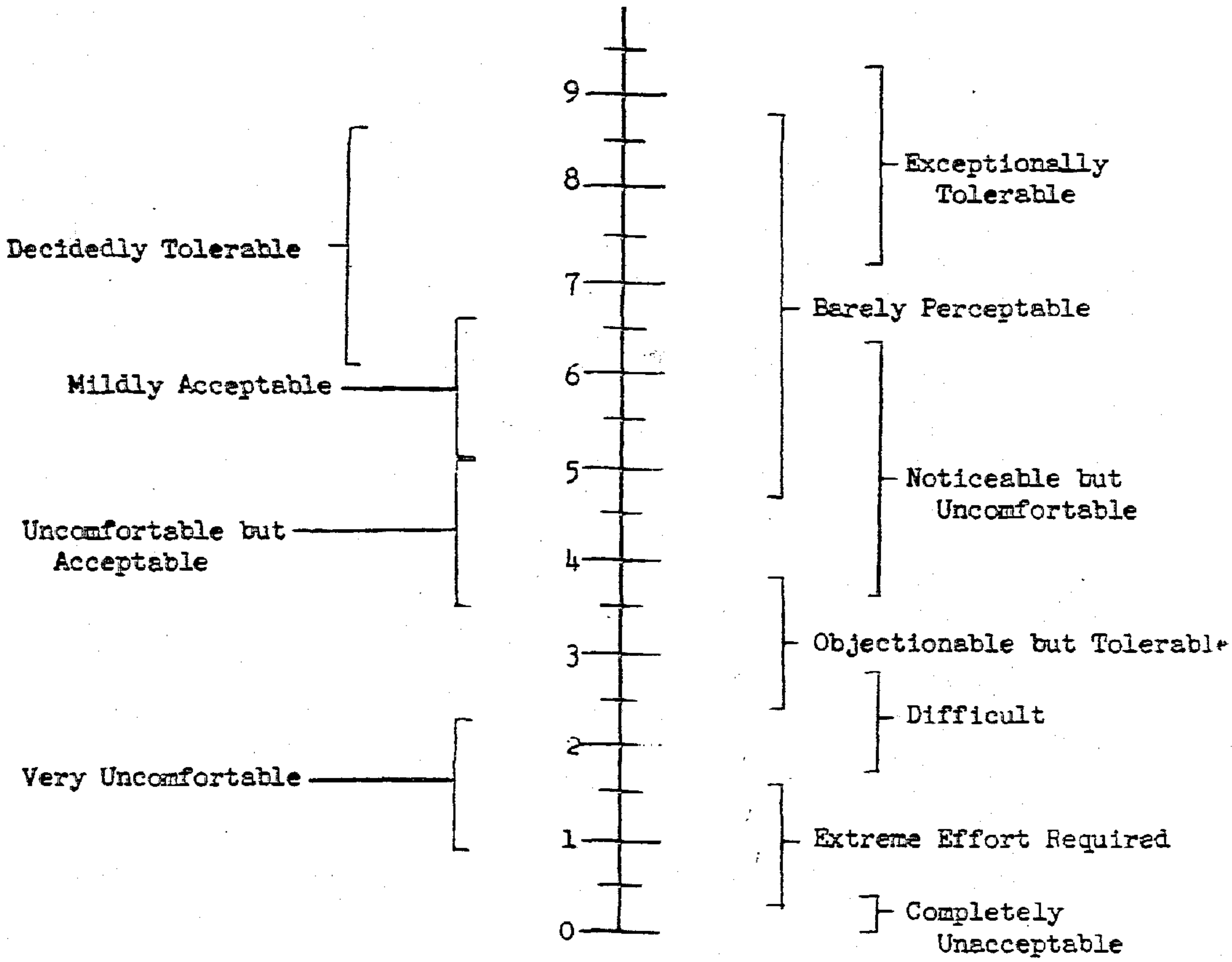
Questionnaires. Besides its suitability for gathering background material, the questionnaires to be administered each wearer will probably consist of multiple choice and forced choice techniques. One type of questionnaire used by Synsis personnel in other studies is shown in figure 12.

Here a rating scale is shown on which the subject is requested to indicate his perception of each parameter in question. To assist the subject, descriptive adjectives are used, and he is requested to make relative value judgements. For example, if the parameter of concern is breathing difficulty then the scale might use the following descriptive adjectives as anchors:

1. Completely unacceptable (located at the zero point)

2. Exceptionally comfortable (located at the maximum point in the scale).

This type of scale can be used to evaluate any number of parameters including visibility, interference with hearing, tightness, mobility restrictions, sensations of flow over the face, confidence in protective characteristics, weight and bulk, donning difficulty, etc.



NOTE: Ranges indicate mean locations and standard deviations for each descriptor evaluated by a group of eight subjects.

Figure 12. Relative Numeric Ratings Attached to Various Descriptors

Selection of scale dimensions (e.g. 10-point scale, 7-point scale) or whether the scale is numbered are matters for further study with respect to this program. Shown in the same figure are a series of descriptive terms which we have investigated. The length of the range and overlap of the ranges for the descriptive terms are indicative of semantic ambiguity determined by a small subject group. Our experience indicates that the best results (ie. - repeatability) occur when this type of scale is anchored only at the two extremes. Another type of questionnaire used in the past is to have the subject rank order a number of parameters. This can be used to determine the relative importance the wearer places on various characteristics of a system.

Interviews. The interview will be used for asking the type of question to which a subjective response is desired, basically those which would not work well on a questionnaire. Rather than come with a prepared list of questions, the interviewer might have a checklist of topics to cover during the interview. The emphasis will be upon maximizing the validity of acceptance evaluations by double-checking the results of the questionnaire and getting the subject to volunteer information on topics that might have been overlooked by the investigators. Comments on especially desirable system characteristics or suggestions for improvements will also be solicited.

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