



**ENVIRONMENTAL TEST
CRITERIA FOR THE
ACCEPTABILITY OF
MINE INSTRUMENTATION**

Bureau of Mines Open File Report 1-82

Contract JO100040
Dayton T. Brown, Inc.

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16. Abstract (Limit: 200 words) <p style="text-align: center;"> This report describes the two-phase effort that went into developing environmental test criteria for general mine instrumentation. Phase I consisted of research and mine visits to develop an environmental profile for mine instrumentation. The profile was translated into general requirements and into test requirements. A review of existing government and commercial specifications was performed to determine if they matched mine instrumentation test requirements. Finally, a set of environmental test procedures was developed to test mine instrumentation. Phase II consisted of selecting and purchasing sample mine instrumentation and subjecting them to the previously developed tests. The purpose was to evaluate the criteria developed for use as an instrumentation test document and to determine the effects of the various criteria on a representative sample of both proven and newly developed instrumentation. The test criteria were then modified, based on test results, and are included in the report. </p>			
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In reference to specific brands of instrumentation or trades; these references are made to facilitate background and understanding of the task and to document field conditions. Mention of these references shall not be constituted as an endorsement by the U.S. Bureau of Mines.



FOREWORD

This report was prepared by the Engineering Services Department of Dayton T. Brown, Inc., Bohemia, New York, under USBM Contract Number J0100040. The contract was administered under the technical direction of the Pittsburgh Mining and Safety Research Center; Mr. Dean Ambrose was the Technical Project Officer. Mr. John Connelly was the contract administrator for the Bureau of Mines.

This report is a summary of the work completed under this contract during the period from 18 January 1980 to 18 June 1981. This report was submitted by the author in June 1981.



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SUMMARY

An investigation was conducted by Dayton T. Brown, Inc. to identify instrumentation and environments in the mining industry today. From this, instrumentation was classified in general categories and environmental tests were specified and developed for each general category. The detailed test methods include test limits developed from research into the mining environment, test setups, equipment to be used, test item preparation, data needed to be taken during testing and interpretation of the test results.

The general classifications of instrumentation are: underground coal mine instrumentation, underground metal mine instrumentation, and surface mine instrumentation. Under each general classification there are three subclassifications; personal/portable instrumentation, wall-mounted instrumentation, and machine-mounted instrumentation.

The following tests with their limits were selected as being representative of a mine atmosphere:

(1) Electric Power Variation

- ±25% of nominal voltage variation for underground coal machine-mounted equipment
- ±10% of nominal voltage variation for all other equipment
- ±5% of nominal frequency variation

(2) High Temperature

- Underground coal: +37.8°C (100°F)
- Underground metal: +60°C (140°F)
- Surface: +60°C (140°F)

(3) Low Temperature

- Underground coal: 4.4°C (40°F)
- Underground metal: 4.4°C (40°F)
- Surface: -40°C (-40°F)

(4) Solar Radiation

- Surface equipment: Maximum of 94 watts/ft² of radiant energy

(5) High Pressure

- Underground coal: atmospheric pressure equivalent to 10,000 feet below sea level
- Underground metal: atmospheric pressure equivalent to 10,000 feet below sea level

(6) Low Pressure

- All equipment: atmospheric pressure equivalent to 10,000 feet above sea level

(7) Thermal Shock

- All personal/portable equipment
- Underground coal: 37.8°C (100°F) to 4.4°C (40°F)
- Underground metal: 60°C (140°F) to 4.4°C (40°F)
- Surface: 60°C (140°F) to -40°C (-40°F)

- (8) Shock
 - (a) All personal/portable/wall equipment
Drop Test maximum height 36 inches
 - (b) All machine-mounted equipment
Sawtooth impulse shock of 40 g's for 11 milliseconds duration
- (9) Vibration
 - (a) All personal/portable/wall equipment
Transportation Sine Vibration 5-200-5 Hz, 1.5 g
 - (b) All underground Continuous Miner Instrumentation
Sine Vibration, 5-2000-5 Hz, 4 g on the cutter arm, 1.5 g on the frame
 - (c) All Haulage Vehicle Instrumentation
Sine Vibration, 5-92 Hz with 2.5 g, 92-500 Hz with 3.5 g
- (10) Sand and Dust
 - All equipment
 - Concentration: 10 mg/m³
 - Velocity: 1750 fpm, 300 fpm
 - Type: AC Fine Dust classified from Arizona Road Dust
- (11) Moisture
 - (a) Surface wall-mounted and machine-mounted equipment
Rain at 2 inches per hour with 40-mph velocity
 - (b) All other equipment
Rain at 2 inches per hour, no wind
- (12) Temperature-Humidity
 - All equipment
 - Maximum humidity of 100%
 - Maximum operating temperature combined with humidity of 37.8°C (100°F)
- (13) Corrosion
 - All equipment
 - Acidified salt-spray test for 120 hours, 5%
 - Salt concentration, pH of 3.1 to 3.3
- (14) Electromagnetic Compatibility
 - Conducted and radiated susceptibility test using National Bureau of Standards developed spectral densities and individual testing at power line frequencies and hand held radio transmitter frequencies.
- (15) Reliability
 - All machine-mounted equipment combined environments testing (temperature, humidity, vibration, electric power variation) to the limits developed in previous tests.

After developing environmental test criteria for the acceptability of mine instrumentation during Phase I of the subject contract, Phase II was started. It consisted of selecting, in concert with the Bureau of Mines, four pieces of instrumentation and subjecting them to the environmental testing that had been developed. Samples were selected to cover all classifications of instrumentation, these being: (1) portable/personal type, (2) wall-mounted type, and (3) machine-mounted type, for underground and surface coal and metal mines. The purpose of the testing was twofold: (1) to evaluate the specification as a testing document and (2) to determine the effects of testing on the instrumentation.

The following instruments were subjected to environmental testing:

<u>Type</u>	<u>Classification</u>
Methane Monitor	Machine-Mounted Underground Coal
CO Detector	Personal/Portable Underground Coal/Metal
Deluge System	Wall-Mounted Underground Coal/Metal
Time Domain Reflectometer (TDR)	Personal/Portable Surface, Underground Coal/Metal

The environmental testing, where applicable, consisted of low temperature, high temperature, electric power variation, low pressure, high pressure, thermal shock, sand and dust, moisture, temperature-humidity, sunshine, shock, vibration, acidified salt-spray, and electromagnetic compatibility. The types of tests each instrument received depended upon its intended application. The following chart summarizes the results:

<u>Test</u>	<u>Instrument</u>	<u>Results</u>
Low Temperature	All	Methane Monitor and CO Detector readings out of tolerance after testing.
High Temperature	Methane Monitor	Satisfactory.
Electric Power Variation	Deluge System, Methane Monitor	Satisfactory.
Low Pressure	All	TDR did not function after test.
Thermal Shock	TDR CO Monitor	Satisfactory.
Sand and Dust	All	Satisfactory.
Moisture	All	TDR did not function after test.
Temperature-Humidity	All	Methane Monitor reading out of tolerance after test; TDR intermittently functioned after test.

<u>Test</u>	<u>Instrument</u>	<u>Results</u>
Sunshine	TDR	Satisfactory.
High Pressure	All	Satisfactory.
Vibration	All	TDR did not function after test.
Shock	All	TDR and Deluge System did not function after test.
Salt-Spray	All	TDR and CO Monitor did not function after test.
Electromagnetic Compatibility	All	During certain frequencies of the electric field compatibility portion, readings of the Methane Monitor and TDR were out of tolerance and the trip circuit activated in the Methane Monitor.

The interpretation of the detailed results of the testing shows that the specification is realistic in all areas except acidified salt-spray for portable/personal equipment. It is felt that this equipment would only be used temporarily in this kind of an atmosphere and the evidence of any corrosion problems would be picked up during the temperature-humidity test. It is therefore recommended that corrosion testing be deleted for personal/portable equipment.

The testing did show the TDR to have numerous problems, most traceable to design deficiencies. The other instruments did have minor design problems but could certainly be removed with little effort.

1.0 INTRODUCTION

This report contains the results of a research program conducted for the U.S. Department of the Interior, Bureau of Mines, Pittsburgh, Pennsylvania. The objectives of this program were to provide environmental criteria and suggested procedures for the testing of instrumentation used in surface and underground mining.

At this time, there is no single document that specifies environmental test criteria and methods that have been developed exclusively for mine environments. Surface and underground mine environments are unique in many respects, such as the type of dust and corrosive atmosphere encountered, temperature variations, and electromagnetic interference conditions. These conditions must be considered during the evaluation of any instrument to be used in mines if the instrument is to operate reliably with minimum maintenance.

Phase I sought to: (1) document, through research and mine visits and measurements, the environments and instrumentation found in the various types of mines; (2) classify these as to the types of conditions necessary for evaluation of a particular generic type of equipment; and (3) develop actual test procedures for evaluation of any instrumentation to be used in mines. The procedures, where possible, were derived from standardized proven procedures used by other government organizations. This helped to produce one uniform standardized test document which can be used by manufacturers, mining companies, or the government in the evaluation of various types of instrumentation for use in mines.

It should be noted that this is an environmental test document. Although this document contains some general guidelines for design and construction, detailed design and performance requirements such as operational characteristics are not included and must be obtained from other documents or from the individual instrumentation manufacturers.

This was Phase I of a two-phase contract with the U.S. Bureau of Mines. Phase II consisted of selecting various instrumentation used in the mining industry today and subjecting them to the various tests specified in this document. This will provide the first basis for evaluating the test specification as being a realistic test document for mine instrumentation. The purpose was twofold: (1) to evaluate the criteria developed for use as an instrumentation test document and (2) to determine the effects of the various criteria on a representative sample of both proven and newly developed instrumentation. The test criteria were then modified, based on the results of the testing, and the modified criteria are listed in Section 5 of this report (Detailed Environmental Test Procedures).

2.0 BACKGROUND FOR DETERMINATION OF TESTS

A single unified document has not yet been developed that covers all phases of testing for evaluating the applicability and determining the acceptability of instrumentation to be used reliably in the mining atmosphere for a specified period of time. The tests are used for several purposes:

- a. To evaluate the expected life or reliability of equipment through exposure of the test item to test levels for a duration significantly less than the design life;
- b. To increase confidence in equipment reliability during the actual life cycle;
- c. To discover susceptible design features in a relatively short period of time;
- d. To reduce test costs.

While the need for and value of testing is apparent, in the past this testing has not been implemented for mine instrumentation in a controlled and scientific manner. This is partially due to the lack of research which correlates equipment life and reliability during testing to that at actual conditions. Also, no single test procedure or test stress can be employed for mine instrumentation to uniformly produce all of the actually occurring failure mechanisms of all the different component parts. Since many failure mechanisms can occur, any test will result in a compromise between undertesting some failure mechanisms and overtesting others. The analysis of failure mechanisms becomes a sensitive consideration. The test must serve to produce degradation in a controlled manner such that correlation to actual service is possible, but it must not induce mechanisms which would never occur in normal environments.

Dayton T. Brown, Inc. has conducted a program to define the mine atmosphere and the type of instrumentation used with definition of failure mechanisms. From this program, specifications for accelerated testing were developed.

The background information was collected in three ways: a literature search; discussions with various organizations and personnel involved in mine instrumentation research; and various mine visits that provided firsthand field information, including field measurements.

A computerized literature search was conducted for Dayton T. Brown, Inc. by the University of Connecticut New England Research Applications Center in the areas of mine instrumentation, testing, and environmental conditions. The data base for this search included the following information sources: (1) Metals Abstracts (ASM), (2) National Technical Information Service (NTIS), (3) Engineering Index (EIX), (4) National Aeronautics and Space Administration (NASA), (5) Mechanical Engineering (ISM), (6) Energy Files (ERDA), and (7) INSPEC File (INS). Over 1,000 abstracts were received from the search and were reviewed. Approximately 60 of the abstracts were deemed pertinent to this effort, and full reports were obtained for detailed evaluation. These are listed in the reference section of this report.

In addition, the following agencies were contacted for their input concerning mine instrumentation and specification development:

- (1) MSHA, Pittsburgh, PA – Mr. T. Tomb
- (2) USBM, Pittsburgh, PA – Mr. J. Kovac
- (3) Colorado School of Mines – Dr. R. King
- (4) DOE, Carbondale, IL – Mr. H. Parkinson
- (5) Lee Engineering, PA – Mr. J. Bers
- (6) Eastern Associated, Pittsburgh, PA – Mr. J. Tillsdale
- (7) W.V.U. Dept. of Electrical Engineering – Dr. R. Nutter
- (8) USBM, Denver, CO – Mr. M.J. Greenaway
- (9) MSHA, Denver, CO – Mr. M. Venters

- (10) USBM, Pittsburgh, PA – Dr. G. Schnakenburg
- (11) USBM, Tech. Transfer Office, Pittsburgh, PA – Mr. R. Chufo
- (12) USBM, Washington, DC – Mr. D. Ralston
- (13) USBM, Pittsburgh, PA – Mr. T. Fisher
- (14) NIOSH – Mr. R. Wheeler
- (15) Santa Barbara Research Center, CA – Mr. L. Falberg
- (16) SANDIA Lab, Albuquerque, NM – M.C. Davidson
- (17) Naval Research Lab, Washington, DC – Mr. R. Volin
- (18) National Bureau of Standards, Washington, DC – Mr. W. Slattery
- (19) USBM, Technology Transfer Office, Twin Cities Research Center – Mr. R. Dick

Discussions with each of these individuals provided much valuable information used in the preparation of this document.

A field survey of seven active mine sites was conducted, including four underground coal mines, one surface coal mine, and two surface metal mines. The purpose of the surveys was to:

- a. Identify specific types of instrumentation in use, including manufacturers and model numbers;
- b. Determine reliability, maintainability, and safety problems associated with specific types of instrumentation;
- c. Evaluate general causes of failure if possible;
- d. Assess the environmental factors affecting the instrumentation during its life cycle (e.g., moisture levels, corrosive atmosphere, rough handling in transport and usage for portable items, vibration levels for vehicle-mounted items, or storage conditions);
- e. Determine any general design and maintenance guidelines that should be included in a specification;
- f. Determine the scope of instrumentation categories used in the specific types of mines which will allow classification of instrumentation for various tests by mine types (surface coal, underground metal, etc.) and/or method of use (machine mounted, portable, etc.);
- g. Measure temperature and humidity conditions using a sling psychrometer and measure shock values using an impactograph. (These instruments were used because they are strictly mechanical and their use does not require MSHA approval. The other measurements that might have been taken require the use of electronic instrumentation for which MSHA approval is required. The contract schedule precluded waiting for MSHA approval.)

The following mines, which were considered representative of typical mining operations, were visited:

- (1) Jim Walters Resources, Birmingham, AL (underground coal)
- (2) Cannelton Industries, Cannelton, WV (underground coal)
- (3) Island Creek Coal Co., Oakwood, VA (underground coal)
- (4) Florence Mining Co., Seward, PA (underground coal)
- (5) U.S. Steel, Mintac Operation, Mt. Iron, MN (surface metal)
- (6) Eire Mining Co., Hoyt Lake, MN (surface metal)
- (7) Kemmerer Coal Co., Frontier, WY (surface coal)

A representative surface non-metal mine was not visited but was contacted. In conversations with representatives of the Rock of Ages Granite Quarry and the Wells-Lomson Quarry, both of Barre, Vermont, it was determined that only communications equipment was used and that conditions and equipment were similar to those of surface coal and metal mines. It was therefore unnecessary to visit a surface non-metal mine. The results of the mine visits follow.

Jim Walters Resources #4 Mine, Birmingham, Alabama (Underground Coal)

Shaft Mine 1000–1200 feet deep

Persons Contacted: Jack Stevenson – General Manager Ventilation
Fred Rozel – Ventilation Engineer

The instrumentation at the #4 mine consists of a centralized recording system, hand-held methane detectors, and machine-mounted methane detectors. All mining is currently being done by continuous miners. (Jim Walters Resources is in the process of developing the mine for longwall mining.) Two mine sections were visited, and the coal belt removal system was viewed. The coal consists of two seams, each 3 feet, separated by about 1 1/2 feet of rock. In the process of mining, both coal and rock were removed.

Section 2 Face 7

Continuous Miner – Joy 12CM5

Shock measurements, using impactographs, were taken on the methane monitor sensor heads and indicator meters during mining. (Impactograph shock indicators, which are adhesive backed for easy attachment, provide an irreversible visual indication of shock value when they sustain an impact which exceeds their factory preset g level from any direction.) Standard 5 g and 10 g units were used for evaluation. During mining, levels exceeded 5 g's when the cutter contacted the rock interface. The mine shuttle car often collided with the rear of the continuous miner. During these collisions, shock values exceeded 10 g's. A dust sample was taken from the top of the indicator meter to Dayton T. Brown, Inc. for analysis. The mine's electrical maintenance crews reported that most of the monitor problems resulted from dust clogging the sensor head. Their solution to the problem was to replace the sensor.

At the face, temperature and humidity were measured:

Dry bulb 58°F
Wet bulb 51°F
Relative Humidity 61%

The relative humidity of 61% during this time of year is considered normal and is also considered the “dry period”. The crews report that during late summer a condensing atmosphere is normal.

Problems of electronic PC board corrosion were not experienced by this mine; however, the mine has been in operation only 1 1/2 years.

The belt system CO monitor model was the Ecolozier 4060 manufactured by:

Energetic Sciences, Inc.
85T Executive Blvd.
Elmsford, NY 10523.

The CO monitors are mounted in carbon steel NEMA 12 enclosures, which are on portable frames. This allows the monitors to move with the advancing belt head. The systems are used to detect fires at the belt head where the coal is loaded onto the conveyor belt. If the CO level increases beyond 15 ppm, a local alarm and remote alarm at the shaft head are sounded. Additionally, a continuous signal is transmitted to the surface where a recorder keeps a continuous record of CO concentration. RFL Industries (Boonton, NJ) frequency transmitters and receivers are used to send all signals over a common line.

Limestone dust is sprayed on the ribs and roof to keep the coal dust down. Coal and limestone dust penetrate instrumentation enclosures when they are opened to disconnect and connect cables each time a belt move is made. A sample of dust from the top of an enclosure was taken. The monitors have been installed since October 1979, and some external corrosion was evident.

Vibrations from the belt head were minimal while shock loads in excess of 10 g's were experienced when the units were moved from one place to another. Temperature and humidity were measured at the belt head:

Dry bulb 64°F
Wet bulb 58°F
Relative Humidity 70%

Section 5 Face 2
Continuous Miner – Joy 12CM5

Conditions were identical to the previous face. Face conditions were:

Dry bulb 58°F
Wet bulb 52°F
Relative Humidity 66%

At the belt system, it was noted that some of the connections on the NEMA 12 enclosure were damaged. The general condition of the enclosure was poor with much corrosion present. The enclosure had been previously used for a methane monitor which was still installed in the enclosure. Dust was very evident inside the enclosure. The CO monitors again had been performing very reliably except for sensor clogging which maintenance personnel would “clear off” by giving the sensor a series of “sharp raps.” Conditions at the belt head were:

Dry bulb 61°F
Wet bulb 54°F
Relative Humidity 63%

Portable methane monitors Model G-70 are used in the mine. These are manufactured by:

USE National Mine Service
600 Grant Street
Pittsburgh, PA 15219

These units are housed in plastic cases and draw in a specific air volume which is then analyzed for methane. They use a vacuum pump and wheatstone bridge for analysis. The problems, as reported by the maintenance personnel, are as follows:

- a. Cases will become dislodged if dropped from heights estimated at 10 feet.
- b. Meter calibration is affected with a drop.
- c. Units are occasionally dropped in acidic water, which destroys the circuit boards.

The mine is just beginning to purchase and use portable methane monitors from:

Bacharach Instrument Co.
Division of Ambac
Pittsburgh, PA
Model 2307660 (yellow canary)

Therefore, no performance data has been accumulated to date.

Cannelton Industries, Cannelton, West Virginia (Underground Coal)

Drift Mine, low coal – 36–38 inches roof to floor

Mine #105, 2 miles in, 800 feet deep

Persons contacted: Jim Harmon – Safety Supervisor

Harold Clendenin – Training and Environmental Instructor

Charles Turner – Maintenance Supervisor

The mine uses MSA portable methane detectors, part number 457126. This system has a membrane across which the methane will naturally diffuse, and it does not require a vacuum pump. The unit is housed in a plastic case. Also in use are CSE Mine Service Model 102 detectors produced by:

CSE Mine Service
600 Seco Road
Monroeville, PA 17146

The instrument is housed in a metal case and has a digital readout. In discussions with Mr. Turner, it was discovered that MSA machine-mounted methane detectors were used, but due to maintenance problems Cannelton Industries has switched to General or Appalachia Electric Model 102A. Most of the problems with either unit stem from the clogging of the sensor head with dust. Cannelton finds it cheaper to replace the sensor head than to effect repairs when the cost of production downtime and sensor repair time is considered. Service life for a sensor head is reported to be approximately 1 year. It is also reported that normal voltage at the units is 510-520 volts but can drop as low as 460 volts.

The mine uses a National Mine Service phone system and in general does not have many problems with the system. Most of the problems that do occur are with the cables, which become damaged due to handling. At the present time, standard Romex 12-2 cable is used but they are in the process of switching to armored cable.

Environmental conditions were as follows:

Dry bulb 47°F
Wet bulb 44°F
Relative Humidity 79%

Island Creek Coal, Oakwood, Virginia (Underground Coal)

Persons Contacted: John Turyn – Division President
Garland Osborne – Mine Manager
Vernon Reynolds – Pocahontas #5 Mine Superintendent
Burt Whitt – Electrical Engineer

The coal in the mine has a high salt content, which is very corrosive to the machinery. Mine operators are required to wash equipment down with fresh water at least once per shift. As a result, failure of the methane monitor sensor head occurs due to water spray. The monitors are manufactured by Bacharach Instrument Company. Maintenance personnel report that they replace sensor heads every few weeks. As with other mines, it is cheaper to replace than repair. Cable shorts, due to wash water, are also a problem.

Coal was mined by a Joy 12CM continuous miner. The coal was very soft; very little rock was taken. As a result, neither the 10-g nor 5-g impactograph tripped. Environmental readings were as follows:

Dry bulb 57°F
Wet bulb 51°F
Relative Humidity 66%

Originally, instrumentation was installed in a carbon steel enclosure; however, due to the corrosive action of the salt, most enclosures are being replaced with stainless steel or fiberglass.

Ecolozier 4000 CO detectors are used on the belt head. The systems have only been recently installed, but the enclosures are carbon steel.

Florence Mining Co., Seward, Pennsylvania (Underground Coal)

Persons Contacted: Rodger Luther – Manager of Industrial Engineering
Ray Weaver – Production Engineer, Robinson Mine

The mine is a shaft mine, approximately 800 feet deep, using Joy 12CM continuous miners and a longwall miner. The methane detector systems used throughout the mine are MSA Model VI systems operating at 4 Vdc. These units are checked on a daily basis and calibrated on a weekly basis. The maintenance records for 1979 show 3 power units, 17 indicator units, and 7 sensor heads replaced. This is the total amount for nine operating continuous miners. All power units and indicators are sent out for repair while the sensors are replaced. The maintenance personnel feel that most of the problems are as a result of cable shorts and vibration. The sensor is located on the side of the cutter head boom where our impactographs showed shock values between 5 and 10 g's (the 5-g units tripped while the 10-g units did not). Minimal rock was present in the seam. Ambient dust conditions appeared no worse than in previously visited mines.

Communications equipment is manufactured by MSA and has operated satisfactorily. A fire suppression system, manufactured by MSA, is installed and has been in operation for 3 years.

A methane monitoring system is installed on the longwall miner. The indicator unit and power supply are located at the head control console. The sensor head is located on the belt line at the 10th chock from the tail. It is subjected to water spray from the shuttle as it passes during the mining operation. Both 5-g and 10-g impactographs did not trip during operation. Communications equipment suffers from cable shorts as a result of the water spray condition. Environmental conditions were as follows:

Dry bulb 60°F
Wet bulb 58°F
Relative Humidity 89%

Erie Mining Co., Hoyt Lake, Minnesota (Surface Metal)

Persons Contacted: Mike Healy – Industrial Hygienist
Frank Wercinski – Electrical Foreman
Robert Giuliana – Safety Supervisor

Instrumentation used throughout the mine consists of General Electric radios and remote control units for the locomotive of the train haulage system. The remote control units consist of a receiver and a relay box in the locomotive and a "belly box" and transmitter worn by the engineer. The "belly box" is worn on the belt and controls all the train's functions while the transmitter is worn as a backpack. Both units are subject to shock from bumping and occasional dropping. The maintenance personnel report that the major failure area is the switch. When the units are operating 24 hours per day, the switch cycle life of 250,000 is quickly exceeded.

The truck shovel and drill radios are all manufactured by General Electric. The equipment cabs are air conditioned and heated, but are occasionally shut down for days at a time during the year. Ambient temperatures range from -40° to 95° F, while relative humidity varies from 10% during the winter to 100% in the late summer. The radios were reported to function properly in this environment.

One shovel (number 7111) had a closed circuit television camera, roof-mounted, to provide blind side viewing. The shovel operator reported that the system was not useful since dust constantly built up on the lens and obscured vision. Another shovel had a camera mounted on its boom to view the bucket. It was reported that the system response time to changes in the lighting was not fast enough. When the boom was slanted upward or was horizontal, it faced the sun, but when swung back down for additional digging, it was shaded. As a result, the camera system was removed.

The haulage trucks (Lectric 85 ton) were equipped with a fire suppression system assembled by Ansul. This system uses an Agastat time delay relay to automatically shut the engine off, set the brakes, and discharge the fire suppressant in a timed sequence. Alarm and indicator lights were also sounded. High shock loads to the truck occurred at two points. The first shock occurred when the first bucket of ore from the shovel fell into the truck box. The second occurred when the truck box was lowered back onto the truck frame after dumping. Neither of these was sufficient to trip the 5-g impactographs.

Hand-held instruments used by the mine include (1) B & K Type 204 Precision Sound Level Meter, (2) B & K Type 1613 Octave Filter Set, (3) E. I. Dupont Audio Docimeters, (4) GCA Technology RDM 101 Respirable Dust Monitor, and (5) Bendix Micronair II Permissible Air Sampling Pump. All these instruments are used by mine personnel on a test basis and are reported to be used carefully.

U.S. Steel, Mintac Operation, Mount Iron, Minnesota (Surface Metal)

Persons Contacted: Bay Reiley – Mine Superintendent
Tim Lerick – Production Engineer
Chester Lewondouski – Electrical Engineer
Frank Sterle – Electrical Maintenance Foreman
Tony Gregorich – Environmental Technician

All ore is hauled by radio-controlled trains. The radio controls are manufactured by General Radio Signal Company. The units are functionally the same as the ones used by Eire Mining Co. The internal electronic PC boards in the receiver were mounted on four Lord vibration isolators, two on top, two on bottom. During train movement, 5-g impactographs mounted on the enclosure did not trip. The enclosure was equipped with sealed locking covers to prevent dust or operator admittance. The units are cleaned and checked one per month (approximately 840 hours of operation). Radios are the only other instrumentation used and are manufactured by General Electric.

Kemmerer Coal Company, Frontier, Wyoming (Surface Coal)

Persons Contacted: Jim Brophy – Mine Superintendent
Lou Engstrom – Reclamation Engineer
Mike Rampman – Master Mechanic
John Pfister – Morrison-Knudsen, Electrical Supervisor

The Kemmerer Coal Company acts as an intermediary between the Morrison-Knudsen Co. and the Utah Power and Light Co. In the mine site, the Kemmerer Coal Company supplies the manpower while the Morrison-Knudsen Co. supplies the equipment. Overburden and coal removal in the 1-U-D pit are by truck and shovel method. Other pits utilize draglines and scrapers for coal

recovery. The electrical instrumentation used, as found with other surface mines, consisted of communication radios. It was reported that they experienced about a 20% failure rate but did not attribute the failures to one specific mode of operation. The foremen use Motorola radios in their pickups and experience only minor problems.

The only other piece of electronic equipment used on site is a belt-mounted metal detector which is used to locate broken shovel bucket teeth before they get to the ore crusher. The system is manufactured by RCA and has been installed since April 1971 with only minor failures. The detector is housed in its own rain-resistant box. Temperatures reportedly range from -30° to 95° F with humidity rarely above 70%. The metal coil sensing loop is enclosed in 4-inch PVC pipe and has never experienced a failure.

3.0 GENERAL FORMULATION OF INSTRUMENTATION REQUIREMENTS AND GENERAL DISCUSSION OF TEST RESULTS

From the background information generated during the mine visits, general categories of types of mines and instruments used in them were developed. There are five general classifications of mines: underground coal, underground metal, surface metal, surface non-metal, and surface coal. The instrumentation contained in the mines was initially divided into four categories: machine-mounted, wall mounted, personal, and portable. These four categories and five mine types were combined to form a matrix in which various tests would be specified for each piece of equipment. The categories were left general to allow flexibility of specification development both now and in the future, permitting the addition of any new equipment developed for the mines to be covered by the specification.

Machine-mounted equipment includes any equipment mounted on continuous or longwall miners and excavating and haulage vehicles. Specifically, this category encompassed instruments such as machine-mounted methane monitors, CO fire suppressant systems, and video systems. Wall-mounted equipment includes any equipment fixed to a stationary object such as a wall or building and could include a telephone communication system and wall-mounted gas monitor. Personal equipment refers to items specifically worn and operated while on one's person, such as belt-mounted CO monitors and respirators. Portable equipment could be any equipment used that is not permanently mounted in a mine and could be either battery operated or plug-in type.

From the field survey information and all the data gathered during the information search, a set of general design requirements and types of environmental tests to verify conformance to these requirements was determined for each instrumentation category. This included deciding what environmental type tests would be suited for each type of instrument (temperature, humidity, etc.) and then defining environmental limits that the instrument would be subjected to. These requirements were formulated not only with consideration for the critical nature of the instrumentation, but also with consideration for maximizing instrument availability and reducing life cycle costs.

As the environmental test matrix was developed, it became obvious that certain general categories and instrumentation categories could be combined due to their having the same requirements and limits. All the tests and limits specified for surface coal, surface metal, and surface non-metal mines were the same. All the instrumentation used at each type is similar, and environmental surface limits for the various types change only due to geographical location and not because of mine type. Therefore, worst case data was used for generation of one set of surface conditions.

In addition, personal and portable types of equipment are subjected to the same types of environmental conditions during their use; except for input power requirements (personal being always battery operated, while portable may not), the limits are identical. Therefore, this equipment was combined into one grouping. Table 1 was generated and contains the matrix of all general equipment and mine types and lists, in sequential order, the tests used to verify conformance to design operating parameters. This sequence is preferred but not mandatory and has been based on the following testing philosophy:

- a. Ideally, the test item should be mechanically and thermally stressed prior to being subjected to moisture resistance type tests such as salt spray or humidity. This will give a worst case situation with seals, enclosures, and electronic components.
- b. Tests are applied in a sequence which simplifies and improves the effectiveness of the testing program, with consideration for test program cost. Less costly tests are put first to provide the most information with the least amount of financial input.

Once the general requirements and types of tests were formulated, specific procedures had to be developed for each test. As a result, the test levels and procedures of some thirty military specifications and standards and various federal and commercial standards and regulations were reviewed. It was evident that the limits of most MIL standards are more stringent than is needed for mine instrumentation based on the application of the instrument in the environment encountered. However the procedures for testing are considered ones that are most useful for conducting the test. These are standardized procedures that employ proven accelerated test techniques for evaluating electronic instrumentation. In this type of test, the probability of increasing test confidence is balanced by the risk of inducing failure mechanisms which would never occur in actual service. In light of these facts, standardized procedures were chosen using our developed test levels that had been formulated by actual research and accumulated field data.

Section 4 contains a listing of the tests specified with the purpose, rationale, and determination of test levels and procedures explained. This illustrates in detail how procedures were developed, why certain tests are recommended, and from where the levels were derived.

Even though the rationale established a strong basis for developing the criteria, testing of instrumentation to the criteria provided the first basis for evaluating them. If all items were "failing" a certain test, it would certainly become obvious that it could be considered an "overtest". A complete test program, selecting sample instruments covering all categories, would provide a basis for evaluating and modifying the criteria and providing some information about the performance of the items. Since the criteria are based on the best available information to date, and since most specifications go through an evolutionary period of growth as additional information is gained, changes to the criteria may occur in the future. But the present criteria, once tested and modified, would certainly provide the best possible means of evaluating new or presently used instrumentation in the mines.

The evaluation of the criteria began with selecting, in concert with the Bureau of Mines, four pieces of instrumentation and subjecting them to the environmental testing that had been developed. Samples were selected to cover all classifications of instrumentation, these being: (1) portable/personal type, (2) wall-mounted type, and (3) machine-mounted type, for underground and surface coal and metal mines.

The following instruments were subjected to environmental testing:

<u>Type</u>	<u>Classification</u>
Methane Monitor	Machine-Mounted Underground Coal
CO Detector	Personal/Portable Underground Coal/Metal
Deluge System	Wall-Mounted Underground Coal/Metal
Time Domain Reflectometer (TDR)	Personal/Portable Surface, Underground Coal/Metal

The environmental testing, where applicable, consisted of low temperature, high temperature, electric power variation, low pressure, high pressure, thermal shock, sand and dust, moisture, temperature-humidity, sunshine, shock, vibration, acidified salt-spray, and electromagnetic compatibility. The types of tests each instrument received depended upon its intended application. The following chart summarizes the results.

<u>Test</u>	<u>Instrument</u>
Low Temperature	All
High Temperature	Methane Monitor
Electric Power Variation	Deluge System, Methane Monitor
Low Pressure	All
Thermal Shock	TDR CO Monitor
Sand and Dust	All
Moisture	All
Temperature-Humidity	All
Sunshine	TDR
High Pressure	All
Vibration	All
Shock	All
Salt-Spray	All
Electromagnetic Compatibility	All

The following tests showed satisfactory results for the following instruments that were tested: High Temperature, Electric Power Variation, Thermal Shock, Sand and Dust, Sunshine, and High Pressure. Since all of the instruments performed well and these tests employed extreme limits during testing, no modification to these procedures would be necessary. The rest of the testing showed some forms of discrepancies. After low temperature testing, the methane monitor and CO detector showed calibration readings that were out of tolerance. This is considered minor for the instruments and therefore the procedures need not be modified. The TDR did not function after low pressure, moisture, and the vibration tests were performed. Considering the fact that all the other instruments passed these tests but the TDR had showed many other test failures, it was felt that the procedures need not be modified but that the instrument's design needed to be upgraded. After the temperature humidity test was performed, the TDR functioned intermittently and the methane monitor's calibration readings were out of tolerance. Again, since the methane monitor's adjustment is minor and the other two instruments passed the test, the procedures need not be modified. The TDR's design (no effective sealing from moisture) prevented it from passing the temperature-humidity test; hence, the design must be upgraded. After the salt-spray test, the TDR and CO monitor did not function. However, it is felt that this equipment, since it is portable or personal, would be used only temporarily in this kind of atmosphere. In addition, since the corrosion test serves more as a comparative test to indicate only corrosion problems and these would be picked up by the temperature humidity test, it is recommended that the corrosion test be deleted for portable/personal equipment. After the shock test, the TDR would not function due to broken components and integrated "pop in" type circuit cards which were out of their sockets. The "pop in" type design, without soldering, could not be expected to pass a shock test; therefore, the design rather than the procedure should be modified. During the electromagnetic compatibility test, the methane monitor and TDR did not operate properly at certain frequencies of the electric field compatibility portion of the test. Since these types of discrepancies are occurring in the field, it is felt that the test is valid, but the instruments need shielding to solve this specific problem.

The general interpretation of the test results shows that the specification is indeed a realistic one, with the deletion of corrosion testing for portable/personal equipment being the only modification. In addition, the TDR showed numerous test problems most traceable to design deficiencies, while all other instruments had some minor problems which could certainly be removed with little effort.

Section 5, therefore, gives the modified procedures that are recommended for testing and evaluating mine instrumentation.

Table 1. Test Methods and Sequence for Mine Instrumentation

TEST	UNDERGROUND COAL			UNDERGROUND METAL			SURFACE		
	PORT/PERS	WALL	MACHINE	PORT/PERS	WALL	MACHINE	PORT/PERS	WALL	MACHINE
Visual & Dimensional	1	1	1	1	1	1	1	1	1
Design & Construction	2	2	2	2	2	2	2	2	2
Maintainability	3	3	3	3	3	3	3	3	3
Electric Power Variation	4	4	4	4	4	4	4	4	4
High Temperature (Storage)	5	5	5	5	5	5	5+	5+	5+
Low Temperature (Storage/Operating)	6	6	6	6	6	6	6	6	6
Solar Radiation									
High Pressure	7	7	7	7	7	7	7	7	7
Low Pressure	8	8	8	8	8	8	8	8	8
Thermal Shock	9	9	9	9	9	9	9	9	9
Shock (Procedure I, Drop)	10	10	10	10	10	10	10	10	10
Shock (Procedure II, Impulse)									
Vibration									
Transportation	11	11	11	11	11	11	11	11	11
Continuous			10			9			
Haulage			11			10			9
Sand and Dust	12	11	12	11	10	11	10	10	10
Moisture Procedure I								11	11
Moisture Procedure II	13	12	13	12	11	12	11	12	12
Temperature Humidity	14	13	14	13	12	13	12	12	12
Corrosion		14	15		13	14			
Electromagnetic Compatibility	15	15	16	14	14	15	13	13	13
Reliability			17						
Operational Lifetime	16			15			14		14

+Low temperature storage and operating limits are identical.

4.0 ENVIRONMENTAL TEST METHODS BACKGROUND

EXAMINATION

1.0 PURPOSE

The examination is conducted to ensure that the item has been manufactured and functions per specification before any testing commences.

2.0 RATIONALE

Operational and design characteristics should be verified before testing to avoid any failures caused by manufacturing defects. Such failures would necessitate retests after rework or repairs, adding to the cost of the test program.

3.0 DETERMINATION OF TEST LEVELS

Not applicable.

4.0 DETERMINATION OF TEST PROCEDURES

Not applicable.

DESIGN AND CONSTRUCTION

1.0 PURPOSE

The purpose of this section is to identify common requirements for design and construction that all instrumentation should meet when used in a critical application in order to prevent expensive downtime through design faults.

2.0 RATIONALE

At present there is no single set of common standards for design. Each manufacturer uses what is thought to be needed. It is the intent here to standardize common requirements, leaving instrument specific requirements for each individual equipment specification. When different peculiar requirements can no longer be justified, it is the intent that they be incorporated also.

3.0 DETERMINATION OF TEST LEVELS

Not applicable.

4.0 DETERMINATION OF TEST PROCEDURES

Due to the standardization effort that has been made in the military, unified procedures for common design requirements for electronic instrumentation exist in MIL-STD-454 [62]. Based on instrument application, it was felt that these guidelines do apply to mine instrumentation.

MAINTAINABILITY

1.0 PURPOSE

The purpose of the maintainability requirements is to ensure that general maintenance time has been minimized by optimizing maintenance features in design.

2.0 RATIONALE

The need for minimum maintenance time for equipment used in a production situation is of prime importance to mine operators. Less time spent repairing means more hours spent in production. As a result, it is necessary to standardize maintenance features as much as possible and incorporate certain features that will minimize the effort to repair items.

3.0 DETERMINATION OF TEST LEVELS

Not applicable.

4.0 DETERMINATION OF TEST PROCEDURES

Some standard maintenance design has been derived from MIL-STD-1472^[71], but this has been supplemented with specific features that have been determined from mine visits.

ELECTRIC POWER VARIATION

1.0 PURPOSE

The electric power variation test is conducted to ensure that instrumentation will operate during the steady state variations that are normally encountered in mine power systems and will not be damaged during the maximum expected voltage and frequency transients.

2.0 RATIONALE

Electric power in a mine is subject to large voltage fluctuations from nominal values due to the many heavy time varying loads. Trailing cables also contribute to voltage variations at the machine due to comparatively high resistance that is a result of keeping the cable size at a minimum for handling.

3.0 DETERMINATION OF TEST LEVEL

The steady state limits which have been invoked are derived from a USBM Report^[1]. This defines a maximum steady state voltage fluctuation of $\pm 25\%$ of nominal to which underground coal continuous mining equipment must function. All other equipment should be operated under $\pm 10\%$ of the nominal voltage since it would not be subjected to the heavy time varying loads caused by continuous miners. Frequency variation used is derived from minimum standards set for power equipment.

4.0 DETERMINATION OF TEST PROCEDURES

The test procedures have been derived from MIL-E-16400^[65], which describes standardized procedures for testing of shipboard electronic equipment.

HIGH TEMPERATURE (Storage)

1.0 PURPOSE

The high temperature test is conducted to determine the resistance of equipment to elevated temperatures that may be encountered during service life in storage.

2.0 RATIONALE

High temperature effects which occur during exposure in mines include problems caused by differential expansion of dissimilar materials, increased electrical resistance, breakdown of insulative materials, permanent set of packing and gaskets, or breakdown of sealing compounds.

We would normally recommend a high temperature storage and operating test for all equipment. However, as will be explained in the next section, the temperature that underground metal and surface equipment may be exposed to during storage has been determined to be equal to that maximum encountered during service. Therefore, the operating and storage test would be the same. The instrumentation will be tested at this upper limit during the temperature humidity test, so a separate high temperature test is considered redundant and unnecessary. For underground coal equipment the high temperature limit used during the temperature humidity test is the operating limit, so an operating high temperature test is unnecessary. Since the high temperature storage limit is higher than the operating limit, a separate high temperature storage test is necessary and is recommended here.

3.0 DETERMINATION OF TEST LEVELS

The highest temperature equalled or hotter 1 percent of the time during the hottest month of the year for the continental United States has been determined to be 140°F^[3]. This temperature includes coastal areas, as well as inland areas which may be encountered during shipment. In addition the Naval Weapons Center in China Lake has determined that the maximum outdoor temperature that ordnance will be subjected to is 150°F with the top temperature for white-painted containers being 130°F^[2]. Arthur D. Little has determined for the USBM that the seasonal outdoor high temperature limit should be 140°F^[1]. As a result, 140°F was selected for a storage limit for surface equipment. FMC listed a 100°F operating limit for underground coal mines^[31]. Measurements made in mines and discussions held with mine personnel by Dayton T. Brown, Inc. have indicated that 100°F would be a maximum limit for operating temperature of an underground coal mine while 140°F would be an appropriate limit for underground metal mines. Underground metal mines are deep mines which require large volume (up to 250,000 cfm) ventilation systems. These "pump" the air down into the mine and heat the air due to the compression that must take place to reach deep levels (up to 10,000 feet). As a result, the deep mine conditions cause a higher operating limit (140°F) than coal mines (100°F).

4.0 DETERMINATION OF TEST PROCEDURES

The procedure for temperature testing consists basically of placing the item in a test chamber, slowly increasing the temperature to storage conditions, and stabilizing, then slowly returning to normal. The actual test method follows the guidelines of MIL-STD-810C^[59], which contains a proven standardized method for high temperature testing. In order to improve the efficiency of the testing, the test duration specified is dependent on the mass of the item. This permits reduced testing time for the majority of small test items because the temperature stabilization of small mass items is faster than that of large mass items.

LOW TEMPERATURE (Operating and Storage)

1.0 PURPOSE

The low temperature test is conducted to determine the effects of low temperature on equipment during operating and storage conditions.

2.0 RATIONALE

Low Temperature Extreme

The test contained herein is intended to evaluate the susceptibility of instrumentation to the detrimental effects of low temperature, such as those caused by the differential contraction of dissimilar materials in components and assemblies. Other low temperature effects may include: congealing of lubricants, which would bind moving parts; cracking and delamination of finishes; or the opening of seams or seals.

It is also noted that the low temperature storage limit for surface equipment is equal to its operating limit. This is due to the fact that the instrumentation is subjected to outdoor exposure conditions during operation. This eliminates an extra step during the low temperature test.

3.0 DETERMINATION OF TEST LEVELS

The lowest temperature equalled or colder 1% of the time during the coldest months of the year for the continental United States has been determined to be -40°F [3]. This temperature includes coastal areas, as well as inland areas which may be encountered during shipment. This was then used as the lowest storage temperature for all mining instrumentation.

Arthur D. Little has determined for the USBM that the seasonal outdoor temperature range that should be used for mining equipment is -40°F to $+140^{\circ}\text{F}$ [1]. During mine visits, Dayton T. Brown, Inc. has determined through discussions with mine personnel that the lowest temperature encountered in an underground mine is 40°F . The lowest temperature measured in underground mines by Dayton T. Brown, Inc. was 46°F . Therefore, -40°F was used as the lowest operating temperature for surface mining equipment, while 40°F was used as the lowest operating temperature for all underground instrumentation.

4.0 DETERMINATION OF TEST PROCEDURE

The procedure for low temperature testing consists basically of placing the item in the test chamber, slowly reducing the temperature to storage conditions, and stabilizing the temperature a specified period of time. Then the temperature is raised (when specified) to the operating limit for the equipment and the test item is functionally checked, after which the item is slowly raised to ambient conditions. Since the temperature stabilization of most instrumentation cannot be determined readily by direct measurement (internal parts are not accessible), a test duration of sufficient length to ensure stabilization is specified. In order to improve efficiency of testing, the test duration specified is dependent on the mass of the test item. This permits reduced testing time for the majority of small test items.

The actual test method follows the guideline of the MIL-STD-810C [59] for low temperature testing with the changes previously discussed.

SOLAR RADIATION

1.0 PURPOSE

The solar radiation test is conducted to determine the photochemical and heating effects of radiant energy on instrumentation which is used during surface mining.

2.0 RATIONALE

The test serves to identify the susceptibility of exposed instrumentation to the following effects: photochemical effects of sunshine, causing the fading of color and chemical breakdown of paints, fabrics, and natural rubber; heating effects, resulting in internal temperatures of instrumentation substantially above the ambient temperature; softening or melting of plastic components; bubbling of paints and coatings; and damage from the differential expansion of materials. The test also serves to evaluate the compounding of these effects. For example, photochemical reactions may darken a material resulting in greater radiant energy absorption and higher temperatures.

3.0 DETERMINATION OF TEST LEVELS

The maximum radiant energy level (94 watts/ft²) is approximately the maximum instantaneous insolation value that may be expected during the month of August at a latitude location of the southernmost part of Florida (i.e., 24° North)^[57]. The spectral distribution of the radiant energy levels represents percentage ranges equivalent to those invoked by MIL-STD-810^[59]. The following table includes the spectral distribution of MIL-STD-810^[59] levels, as well as the levels which duplicate average North American sunlight.

Light Band	MIL-STD-810 Spectrum-Percentage	North American Spectrum-Percentage
Ultraviolet	4-7	3
Visible	24-28	44
Infrared	48-69	53

It should be noted that the MIL-STD-810 spectrum range encompasses the percentage equivalent to North American sunlight. The MIL-STD-810 levels, however, allow a greater percentage of heat generating, infrared energy. Although this range may result in more severe levels than in actual environments, any effort to exactly match the energy levels at all wavebands would be very costly^[5].

The high temperature level of 35°C (95°F) is equal to the temperature equalled or exceeded 1% of the time during the warmest month of the year for coastal United States^[4]. The lower temperature limit of the specified cycle was adjusted to provide a realistic daily temperature variation.

4.0 DETERMINATION OF TEST PROCEDURES

The peak temperature reached by exposed instrumentation during the day is dependent on factors such as the mass, thermal conductivity, and color of the item. Due to thermal inertia of the item, the peak temperature attained will probably be less than the peak ambient temperature. Therefore, a cyclic test designed to simulate a daily cycle is preferable to a steady state test in which the test item will stabilize at a temperature at least as high as the ambient.

Several sources describe similar profiles with minor variations in temperature extremes^[59, 70]. Since MIL-STD-810C^[59] contains a test procedure for a cyclic temperature insolation test, the general procedure of this document was used.

HIGH PRESSURE

1.0 PURPOSE

The high pressure test is conducted to determine the effects of pressure, greater than atmospheric, on instrumentation used in deep mines.

2.0 RATIONALE

The test determines the ability of sealed parts or containers to withstand static or dynamic pressures (like those encountered during operation in deep mines) without resulting in rupture, damage, or leakage. The test is performed in two ways. For wall-mounted equipment, it is only necessary to test the effect of a single high pressure application since the equipment is brought down into a mine and is mounted permanently there. For personal/portable equipment, however, it is not uncommon for the equipment to be brought in and out of the mine once per day. Therefore, a cycling test from atmospheric to the specified pressure level for 400 cycles (approximately 1 year's service) is more appropriate.

3.0 DETERMINATION OF TEST LEVEL

The increased pressure level for the high pressure test is equivalent to a depth level of approximately 10,000 feet. Discussion with both USBM personnel and mine operators has indicated that this depth would be the maximum mine depth at present. Also Rodgers has indicated that depths of 10,000 feet occur in deep metal mines^[39].

4.0 DETERMINATION OF TEST PROCEDURE

The test procedure consists basically of either exposing the test item to a single increased pressure for a suitable time (wall mounted instrumentation) or cycling between a minimum and maximum pressure for 400 cycles (personal/portable instrumentation).

LOW PRESSURE

1.0 PURPOSE

The low pressure test is conducted to evaluate the susceptibility of instrumentation to reduced pressures which may be encountered in high elevation mines.

2.0 RATIONALE

Damaging effects from low pressure include: leakage into or out of gasket sealed enclosures; low density air, increasing the chance of corona and arcing; decreased efficiency of convection and conduction methods of heat transfer; and low density materials changing their physical and chemical properties. Instrumentation can be subjected to high altitudes in the mines of the Midwest.

3.0 DETERMINATION OF TEST LEVEL

The reduced pressure level for the low pressure test is equivalent to an altitude of 10,000 feet. This altitude would encompass any mine in operation today.

4.0 DETERMINATION OF TEST PROCEDURE

The test procedure consists basically of exposing the test item to the reduced pressure for a specified period of time and operating it.

THERMAL SHOCK

1.0 PURPOSE

The thermal shock test is intended for personal/portable type instrumentation to determine the adverse effects of sudden temperature change on the surrounding environment due primarily to the transfer of instrumentation from a heated environment to low outdoor temperatures or from an above ground condition to a low temperature underground.

2.0 RATIONALE

The test serves to identify the susceptibility of instrumentation to low temperatures and sudden temperature changes, which may result in the cracking or rupture of seals or seams due to rapid differential contraction of dissimilar materials. Some of the specific effects include: congealing of lubricants; cracking of packing or gaskets due to a loss in resiliency and increased brittleness; freezing of entrapped moisture; cracking and delamination of finishes; opening of hermetic seals and case seams; and changes in electrical characteristics, due to mechanical displacement or rupture of conductors or of insulating materials.

3.0 DETERMINATION OF TEST LEVELS

The test temperatures are based on the operating limits set up in the low and high temperature tests.

4.0 DETERMINATION OF TEST PROCEDURE

The procedure for the test consists basically of exposing the test item to three thermal shock cycles and follows the guidelines of MIL-STD-810^[59].

SHOCK

1.0 PURPOSE

The shock test is conducted to determine if equipment is constructed to withstand expected dynamic shock stress and to ascertain that performance degradations or malfunctions will not be produced by the service shock environments expected in handling, transportation, and service use.

2.0 RATIONALE

The service and transportation environment consists of a great variety of mechanical shocks, many of which can be severe enough to damage equipment. For portable, personal, and wall equipment shocks would be encountered during transportation, transit, and normal “dropping” during use or installation. For machine-mounted equipment, shocks are encountered during equipment collision (such as a railcar running into a continuous miner) during loading of ore or coal into a haulage vehicle, or during the continuous mining operation itself. As a result of the use of the items in service, a “drop” test is appropriate for personal/portable/wall equipment while a standard impulse shock test is appropriate for machine-mounted equipment.

3.0 DETERMINATION OF TEST LEVELS

Procedure I

The free fall drop heights have been derived from a study used to develop a proposed ASTM standard for performance testing of shipping containers^[58]. This study presented information, both U.S. and foreign, which defined the probability of occurrence data for drop heights during handling and shipment. Although these drop heights occur during normal loading, unloading, and transference of the items during shipping, it has been determined by Dayton T. Brown, Inc. that they would also cover most severe incidents of shock during rough handling in the mine environment. The study summarizes the following points (which also apply to mine instrumentation):

- a. The probability of a package being dropped from a high height is minimal.
- b. Most packages receive many drops at low heights, while relatively few receive more than one drop from the higher heights.
- c. The heavier or larger the package, the lower the drop height.

A worst case sample of data indicates that there is an 8% probability that a package weighing 0–40 lbs would be dropped from a height above 36 inches, for a 40–80 lb package a height above 30 inches, and for a package over 80 lbs a height above 24 inches.

Since the probability of dropping packages above these heights is low, they have been selected as the test limits for each specific package weight.

Procedure II

The design of shock test levels for machine-mounted equipment should include acceleration levels incurred during normal usage.

During mine visits, Dayton T. Brown, Inc. has measured shocks during normal mining operations. For normal conditions, shock values fall between 5 and 10 g's. However, impactographs registered greater than 10 g's during railcar collisions with the continuous miners. The railcar collisions are a normal occurrence in the mines and must be taken into account in development of a test level. A report that describes environmental conditions incident to the transportation of materials describes and quantifies the shock that occur during railcar coupling^[8]. The railcar coupling can be directly correlated to railcar/miner collision. The study showed that for 98% of all coupling operations the shock spectra translated to approximately a 43-g peak with a 20-millisecond duration.

In addition, Bolt, Beranak, and Newman recently completed an analysis of shock data for 30 different mining machines encompassing 8 basic designs operating in 5 different mines^[7]. Their analysis concluded that there is approximately a 95% probability that shocks will be 40 g's or less.

As a result of this data, a level of 40 g's is used as an upper limit in the shock testing. Also, since the natural frequencies of all elements and components are not usually known, it is desirable that the shock test induce equal acceleration responses throughout the range of probable natural frequencies of the equipment. A study of the shock spectra of various unsymmetrical pulses shows that the spectrum can be met by a large number of unsymmetrical pulses. Symmetrical pulses have acceleration values of zero at repetitive intervals throughout the negative spectrum and cannot meet the requirement. This would tend to rule out half sine pulses. The ideal sawtooth pulse does meet this requirement and has the additional advantages of having a more nearly constant acceleration throughout the frequency range and having a negative spectrum which is the mirror image of the positive spectrum. In a practical sawtooth, the acceleration cannot drop abruptly to zero due to elastic rebound which cannot be completely eliminated in any realistic test. Therefore, the shock shape to be used for testing will be sawtooth in lieu of a half sine.

4.0 DETERMINATION OF TEST PROCEDURES

Both procedures were derived from MIL-STD-810^[59]. Procedure II uses a shock pulse with a sawtooth waveshape and an amplitude equal to the design value for ground equipment (40 g's).

VIBRATION

1.0 PURPOSE

The vibration test is conducted to determine if the equipment is constructed to withstand expected dynamic vibrational stresses and to ensure that performance degradations or malfunctions will not be produced by vibrational environments encountered during transportation or service use.

2.0 RATIONALE

Instrumentation is exposed to various vibrational stresses throughout its life cycle, from shipment from the factory to actual service. Portable/personal equipment does not normally encounter service vibration during its operation; however, in a non-operating condition this equipment is subjected to transportation vibration during shipping. Equipment mounted on continuous miners "sees" operating miner vibrations, while equipment mounted on haulage vehicles experiences vibrations due to riding on rough terrain.

The vibration test is designed to ensure satisfactory performance during exposure to these stresses and to evaluate the resistance to the failure modes generally induced by vibration. Some of these failure modes are:

- a. Overstress failure of major and minor parts during exposure to the resonant frequencies and amplitudes that may be encountered during field use;
- b. Fatigue failures;
- c. Failure resulting from the wearing of interfacing parts, the loosening of fasteners, or the displacement or distortion of parts causing shorts or arcing.

3.0 DETERMINATION OF TEST LEVELS

Procedure I – Transportation

From a report entitled "A Survey of Shock and Vibration Environments in the Four Major Modes of Transportation", it has been determined that 1.5 g's up to 200 Hz would be the worst case environment for transportation by truck^[9]. This report compiled data from over 300 reports and 55 agencies active in the transportation field. This report collected data that is applicable for use in the general transportation field and does not contain data generated during military vehicle use which is considered unrepresentative of the common shipping carrier environment.

Procedure II – Continuous Miner

In order to provide assurance of satisfactory performance for critical underground equipment, the following considerations in the test standard design were made:

- a. The vibration levels represent all types of miners and designs operating in different mines.
- b. The vibration levels represent conditions occurring during various coal cutting conditions with different types of coal (hard, soft).

- c. The test environment must address all locations on the miner where equipment may be mounted if these levels greatly differ.
- d. The test standard must provide a high level of confidence that the equipment will not fail due to the critical nature of the underground mine atmosphere.

A final report by Shaker Research Corp. described vibration testing that had been performed on one operating longwall continuous miner^[11]. Data from the report showed 1 g maximum acceleration on the frame and 4.3 g's maximum on the ranging arm up to 500 Hz for sine vibration levels. Battelle also performed measurements on one continuous miner and reported random vibration levels of approximately 1 g on the machine frame up to 2000 Hz^[10]. In a report by Arthur D. Little, environmental and functional design requirements for supervisory control equipment used in underground coal mining were given^[1]. Their study used data from a 1976 Bolt, Beranek, and Newman study to define spectrum levels that were believed to be the worst-case vibration to be encountered on continuous mining machines. The results show random spectral level densities that were approximately 5 g's on the cutter arm and less than 1 g on the frame. In almost all cases vibration levels measured were less than these. Finally in the latest study (1979) Bolt, Beranek, and Newman were retained by the USBM to recommend shock and vibration qualification tests that would assure the survivability of instrumentation when mounted on underground coal mining equipment^[7]. The source of their data for developing the recommendations was a Bolt, Beranek, and Newman report (#4033) prepared in January 1979 which presented vibration data taken on 30 mining machines encompassing 8 basic designs and operating in 5 different mines. A statistical analysis was used to envelope all data and to develop a curve for frequency versus displacement. This curve was then compared to various military specifications in order to evaluate the vibration test specification of each MIL-STD against the measured and predicted vibration level of underground mining equipment. The report concluded a good match was obtained between measured levels and MIL-STD-810B^[59] for track vehicles and encompassed a sample that assured 99% probability that the levels used would not be exceeded. Therefore, it was recommended that MIL-STD-810B^[59], which is equivalent to approximately 4 g's from 9 to 500 Hz be used.

As can be seen, most sources are speaking of similar acceleration levels, approximately 4 g's on the cutter arm and 1 g on the frame. However, the question arises whether to conduct a random or sine test. From viewing the operation of both longwall and continuous mining machines, it appears that the longwall machine is sine in nature while the continuous miner appears more random. Dayton T. Brown, Inc. has found that sine is a more severe test than random; other authorities in the vibration field concur. Since our equipment (methane monitors, etc.) must operate on both machines and since it would be impractical to recommend two tests for the same equipment, it seems logical to recommend the worst case, i.e., sine. Therefore, a sine test of approximately 4 g's up to 2000 Hz for the cutter arm and 1 g up to 2000 Hz for the frame has been used.

Procedure III – Haulage Vehicles

Haulage vehicles present a completely different environment than a standard cargo transportation test and have no relation to the actual mining machines. Haulage vehicles would incur vibration similar to construction or military vehicles used on rough roads. In a final report to the Department

of Transportation Ostrem describes vibrations for trucks that would compare to this environment^[8]. Ostrem presents worst case data which encompasses military vehicles and the most severe conditions. The report gives an average of about 3.5 g's above 40 Hz and about 2.5 g's below 40 Hz. Again reviewing military specifications, this compares very closely with MIL-STD-810C^[59] for ground wheeled vehicles (using curve Y).

4.0 DETERMINATION OF TEST PROCEDURES

As discussed in the previous section, Procedure I was derived from MIL-STD-810C^[59], Procedure X, curve AW for transportation of cargo; Procedure II was derived from MIL-STD-810B^[59] category F for ground vehicles but extended to 2000 Hz; and Procedure III was derived from MIL-STD-810C^[59] for wheeled ground vehicles, curve Y.

SAND AND DUST

1.0 PURPOSE

The sand and dust test is conducted to ascertain the ability of equipment to resist the effect of a dust atmosphere normally encountered in underground or surface mining.

2.0 RATIONALE

This test simulates a dust atmosphere which may penetrate into cracks, crevices, bearings, and joints. The penetration of dust can cause a wide variety of effects, including: fouling moving parts; making relays inoperative; forming electrically conductive bridges with resulting shorts; and acting as a nucleus for the collection of water vapor, hence providing a source of possible corrosion and malfunction of equipment.

3.0 DETERMINATION OF TEST LEVELS

Three areas must be addressed to completely define the limits of a sand and dust test: velocity, concentration, and size of particles.

From the Seventh Annual Institute on Coal Mining Health, Safety and Research, the maximum average dust concentration for a shift is given as 10 mg/m^3 . Many surveys on respirable dust show particle size to be up to 10 microns; however respirable dust is kept to less than 2 mg/m^3 by ventilation and will not normally settle on equipment and produce problems. We should then be concerned with particle size greater than 10 microns. Dayton T. Brown, Inc. took samples of settled dust from five different mines and subjected the dust to a particle size analysis. In addition, samples from standard available dust mixture were analyzed to determine applicability. It was found that AC Fine Dust classified from Arizona Road Dust compared very closely to the mine samples. Results show the following:

Sample	SIZE (MICRON)				
	10-20	20-30	30-40	40-50	>50
Average from five mines	73.5%	14.8%	5.1%	2.1%	4.3%
AC Fine Dust	81.1%	12.7%	3.4%	.9%	1.1%

AC Fine Dust would then be used for our standard.

For velocity we must consider a worst case ventilation system. For a maximum capacity of 200,000 cfm and an average face area of 100 square feet an air velocity of 2000 fpm would result. This velocity could go down to a few hundred fpm in a smaller ventilation system. Testing should be done at alternate high and low levels to test worst case of forcing at high velocity settled dust that has occurred at low velocity. MIL-STD-810C^[59] happens to meet these criteria with a maximum velocity of 1750 ± 250 fpm and minimum of 300 ± 200 fpm.

4.0 DETERMINATION OF TEST PROCEDURE

The procedure is derived from MIL-STD-810C^[59] Procedure I, using AC Fine Dust at concentrations of 10 mg/m^3 .

MOISTURE

1.0 PURPOSE

The moisture test is conducted to determine the effectiveness of instrumentation enclosures, cases, cover plates, and gasketing to protect equipment from water intrusion in normal service. This moisture can occur as rain in surface mining or as the water spray used to keep dust down in underground mines.

2.0 RATIONALE

The moisture test evaluates the resistance of exposed instrumentation to water penetration and faulty operation during exposure to water spray and a wind rain condition. It also serves to verify the proper operation of sheltered instrumentation when exposed to drops of liquid falling on the instrumentation while it is mounted in its normal position (or drops of liquid falling vertically, with instrumentation inclined at angles up to 45 degrees from its normal mounting position). Moisture may result from condensation on overheads or in lighting or telephone systems. The test will evaluate the resistance of equipment to water intrusion and will evaluate proper design for drainage, preventing water accumulation and corrosion. The susceptibility of instrumentation to the presence of water and moisture-laden atmospheres may be evaluated by "out of tolerance" operation due possibly to short circuits or grounds.

3.0 DETERMINATION OF TEST LEVELS

Procedure I

This procedure is intended for the evaluation of equipment used outdoors under blowing rain conditions (surface mining).

Procedure II

This procedure is intended for simulation of steady state rainfall, which would compare to a water spray condition for underground mining.

4.0 DETERMINATION OF TEST PROCEDURE

Procedure I was derived from MIL-STD-810^[59] Procedure I (wind and rain); Procedure II was derived from MIL-STD-810^[59] Procedure II (steady state rainfall).

TEMPERATURE-HUMIDITY

1.0 PURPOSE

The temperature-humidity test is intended to evaluate in an accelerated manner the resistance of equipment to the effects of a warm, moist atmosphere typically found in surface mines and underground mines in the United States. The test utilizes actually occurring extremes for both temperature and humidity.

2.0 RATIONALE

The test serves to identify the susceptibility of instrumentation to corrosion and moisture absorption, resulting in a loss in material strength and in electrical characteristics, such as dielectric strength. Most degradation results directly or indirectly from the surface wetting of metals or insulation from condensation or from the absorption of water vapor by hygroscopic insulating materials. The forms of deterioration specifically include the corrosion of metals and the physical distortion and decomposition of organic materials, possibly resulting in arcing or shorting of electrical circuits.

This test differs from the steady-state humidity test and derives its added effectiveness in its employment of temperature cycling, which provides alternate periods of condensation and drying essential to the development of corrosion processes and, in addition, produces a "breathing" action of moisture into partially sealed containers^[5]. Increased effectiveness is also obtained by use of a higher temperature, which intensifies the effects of humidity. As a result, the deterioration can be detected by the measurement of electrical characteristics (including such tests as dielectric withstanding voltage and insulation resistance) or by performance of a test for sealing. Results obtained with this test are reproducible and have been confirmed by investigations of field failures. This test has proved reliable for indicating those parts which are unsuited for field use.

The temperature-humidity test is generally a severe test for sensitive equipment, frequently resulting in "out of tolerance" operation during high humidity conditions. In some cases, "out of tolerance" operations during high humidity conditions may be permissible for certain types of state of the art instrumentation. However, the instrumentation should not suffer permanent damage as a result of the test.

3.0 DETERMINATION OF TEST LEVELS

During mine visits and discussions with mine personnel it was noted that during the hot, humid summer months essentially 100% humidity was normal. Andros, in developing a methane monitor for use in face equipment in underground mines, reported a maximum of 100% humidity level that the monitor would "see"^[35]. It was also reported by Casula and Cherchi in a report entitled "Systematic Monitoring of Dust Concentration and the Physical and Mineralogical Composition in the Coal Mines of Sulcis" that maximum measured humidity was 96.8%^[32]. Rodgers, in a report entitled "Analysis of Non-Coal Mine Atmospheres" (underground metal) reported humidity conditions he had measured in many mines to be essentially 100%. These conditions occur in conjunction with maximum operating temperatures in the mines. MIL-STD-210^[70] lists 100% humidity as the extreme "seen" for surface conditions in the United States^[69], this being combined with a maximum temperature of 100°F.

It was therefore decided that a condition of 100°F and 100% humidity would be the worst case upper limit for temperature humidity for all equipment. However, the high temperature “drying” cycle would go up to the maximum operating temperature of 140°F for underground metal and surface equipment but would remain at 100°F for underground coal equipment. (These maximum operating temperatures were discussed previously during the high temperature test.)

4.0 DETERMINATION OF TEST PROCEDURE

The test procedure follows the guidelines of MIL-STD-202^[65] and MIL-STD-810^[59], but the actual humidity cycle has been developed from mine conditions.

CORROSION

1.0 PURPOSE

The corrosion test is conducted to evaluate the relative corrosion merit of the materials, coatings, or system when subjected to an acidified salt-spray atmosphere. The test will enable relative materials selection performance prediction.

2.0 RATIONALE

Damage to instrumentation which is operated or stored in an acidified salt laden atmosphere results primarily from the corrosion of metals. Depending on the configuration of a specific type of instrumentation, corrosion may be attributable to oxidation (rust) or to the electrolytic action between two dissimilar metals in close proximity to each other, or to both. The atmosphere may affect the proper mechanical operation of the instrumentation due to the incrustation of moving parts by salt particles, or it may impair electrical operation by causing surface electrical leakage, arcing, and short circuits. Other effects may include the obscuring of windows, photoelectric sensors, or markings due to salt deposits.

This type test has its greatest utility when evaluating the uniformity (i.e., thickness and degree of priority) of protective coatings, both metallic and nonmetallic, of the same product. It may be used to judge proper design of instrumentation to exclude the atmosphere by using seals, gaskets, or water traps or to ensure proper drainage. It must be noted, however, that the test conditions do not totally simulate a mine environment; nor does the test indicate whether a design will be suitable throughout its intended service life. It will reveal some potential problem areas that will occur in actual service. The corrosion problem is vastly more complex because the causative agents of corrosion and their effects are neither completely identified nor well understood.

3.0 DETERMINATION OF TEST LEVELS

There has been no known research which has attempted to correlate the corrosion effects of actual mine environments with laboratory testing. This is due primarily to the extreme variations found in mine environments and the complexity of the corrosion process.

Some mines contain acidified water; some contain salt as well. The acid conditions are caused by a number of different chemical agents. Dayton T. Brown, Inc. has verified through mine visits the presence of salt and pH values as low as 3.

The test temperature of 35°C (95°F) represents a probable mine environment. It provides an accelerated corrosion rate needed to compensate for a test period which is less than the average exposure expected during the instrumentation life.

4.0 DETERMINATION OF TEST PROCEDURES

The test procedure used is derived from ASTM B287^[72] which is a standard method for an acidified salt-spray test. This simulates a mine acid condition, a salt atmosphere, and a high temperature of 95°F, all found within one or a combination of mine atmospheres.

ELECTROMAGNETIC COMPATIBILITY

1.0 PURPOSE

The electromagnetic compatibility test is performed to determine the effects of conducted and radiated electromagnetic fields on the operation of mine instrumentation. It will ensure that “off the shelf” instrumentation, which is designed and manufactured to good commercial practice, will operate satisfactorily in a mine environment.

2.0 RATIONALE

Electromagnetic interference and compatibility testing serves to ensure the compatible operation of a total instrumentation package which is employed in a complex electromagnetic environment. The proper operation in a particular environment will be dependent on its susceptibility to free space radiation, as well as interference conducted along power lines. Since instrumentation is of commercial design, the objective of testing is primarily twofold: to identify items exhibiting unusually high susceptibility, indicating the need for extraordinary precautions (i.e., isolation or improved shielding design); and to obtain relative sensitivity for the many instrumentation types, rather than pass/fail judgements. These levels may then be utilized to configure or locate the instrumentation in such a relationship that interference is minimized. In the event that the minimum interference levels are not satisfactory, the addition of shielding or filters may be necessary or equipment may be operated on a time sharing schedule.

In general the mine environment is a severe one due to the presence of many types of high power associated with a total mine power system. Mine power systems are subject to substantial fluctuations in nominal voltage due to the many heavy time varying loads. Trailing cables also contribute to voltage variations at the machines because of changing in the mining demand. It is necessary to keep the cable sizes at a minimum so they can be handled, but this causes them to have a comparatively high resistance which causes large voltage drops^[1]. Transients are also very common in mines. Sources of overvoltages include: (1) switching surges, (2) line to ground faults, (3) restriking ground faults, and (4) resonant conditions^[16].

3.0 DETERMINATION OF TEST LEVELS

Studies have been performed by the National Bureau of Standards to determine spectral densities occurring in mines^[11]. A suggested magnetic field susceptibility bound was put together for 100 Hz to 100 MHz under USBM contract H0122005. These are the limits used. Below 10 kHz the magnetic noise is dominated by 60 Hz and 400 Hz harmonics from the power system. These were not included in the study; but individual tests at these frequencies, which have been suggested by Factory Mutual Research Corp.^[4], are included. In addition, the communications frequencies were not covered (above 100 MHz), but these will be tested individually using tests recommended by FMC^[4].

Many transient studies have been performed to define bounds for voltage spikes. Resonant conditions can result in transients 10 times nominal line voltage, but they rarely if ever occur^[16]. Switching operations account for most of the transients occurring and are considered the most destructive. These can be either transformer or circuit breaker switching. Mine measurements

show transients of five times nominal to be a “normal” occurrence^{[16][1]}. For 300 and 440 volt system this would mean the generation of transients up to 2200 volts. Present commercial equipment capability limits the generation of spikes that are less than approximately 500 volts. Therefore only low voltage dc system will be considered. Components of total systems would be checked this way as long as they operate on low voltage dc (less than 50 volts). For devices that operate off low voltage system (<24 Vdc) it has been recommended that a twice nominal voltage or 100 volts test (whichever is less) be performed.

4.0 DETERMINATION OF TEST PROCEDURES

The test procedures have been derived from MIL-STD-462^[61] and MIL-STD-461^[60].

RELIABILITY

1.0 PURPOSE

The reliability test methods include the procedures and testing profiles which may be implemented for the following purposes:

- a. Reliability Qualification (Demonstration) Test—A qualification test is generally conducted prior to production and serves to provide the procuring activity with information which indicates whether a certain design can demonstrate a specified level of reliability under specified environmental conditions.
- b. Reliability Production Acceptance Test—A production acceptance test serves to ascertain that instrumentation made using production methods will meet the specified reliability requirements. This may be conducted periodically throughout the production run to ensure continuous conformance to these requirements.

2.0 RATIONALE

Reliability testing provides a means by which the probability of survival of a piece of equipment can be determined. Since the purpose of reliability testing is to prove that the instrument can provide a specified level of reliability in the field, the test conditions should be designed to simulate the mission profile of the instrument (i.e., events, conditions, or environmental stress levels associated with the anticipated environment of instrument usage). Considerable evidence has been accumulated that shows that the failure rate of deployed equipment is many times worse than would have been anticipated based on the results of existing reliability tests. This is primarily due to the laboratory tests not being representative of real life conditions. Reliability tests can only approximate the actual mission profile in a general way due to the high cost of providing the combined environment test conditions and due to the inavailability of these type test facilities. As a result, the use of reliability testing as a design tool or indicator of satisfactory design can best be obtained by correlating test-demonstrated reliability with actual field reliability. To date the correlation has been accomplished only for avionic equipment used by the military.

The level of reliability that each instrumentation type must demonstrate must be specified by the procuring activity. Assuming that there is a one to one relationship between test failure rate and field failure rate, the level of reliability would be a function of the operational requirements (e.g., percentage of time the instrument must be capable of measuring a parameter—"availability"). In some cases, however, the operational requirement must be compromised with consideration for the state-of-the-art in the design and the cost of the design.

3.0 DETERMINATION OF TEST LEVELS

The reliability profile has been developed using the guidelines of MIL-STD-781^[64] for vehicle-mounted mobile ground equipment and has been based on probable environmental stresses, in lieu of rarely occurring extremes. The sequences of stress application are considered likely occurrences. Both the stresses and their sequence have been derived from actual mining conditions. All environmental stresses have been justified in previous tests (e.g., temperature, humidity, vibration, etc.).

The cycle starts with a low temperature soak T_1 with items non-operational. This would simulate a downtime overnight condition. Next, in early morning the temperature rises to a value T_2 just before operation begins. When operation begins, the instrumentation is turned on and we have combinations of vibration and voltage variation. The temperature and humidity begin to rise simulating daytime operation until they reach a maximum T_3 with 95% relative humidity. On every 5th cycle a high temperature, T_4 , is experienced; this high temperature corresponds to the maximum temperature the item can see in a non-operating condition without maximum humidity. The rest of the cycle constitutes a change back to maximum operating conditions descending to a non-operating cold storage overnight condition.

T_1 and T_4 represent the maximum operating low and high temperatures derived during the low and high temperature tests. T_3 is the maximum temperature during which maximum humidity would be experienced. This temperature humidity condition was derived during the temperature humidity test.

The humidity conditions are the same as those derived during the humidity test. Likewise, the vibration requirements are the realistic levels derived from field data and are the levels given in the individual vibration test. The percentage of 25% vibration for a continuous miner is realistic since a continuous miner operates during approximately 25% of the time of a shift [55].

The input voltage varies between the steady state upper and lower limits of either $\pm 25\%$ or $\pm 10\%$ of nominal voltage depending upon the type of equipment, as specified in the shipboard interface standard MIL-STD-1399. The maximum voltage has been applied during the high temperature dwell, the minimum voltage during the low temperature dwell, and nominal voltage for the balance of the cycle.

4.0 DETERMINATION OF TEST PROCEDURE

The general test procedure has been based on MIL-STD-781C [4], issued in October, 1977. The standard has well developed the statistical basis for the various test plans and encourages the tailoring of test levels and profiles to more accurately duplicate the field environment. The procedure implements the fixed length test plans of MIL-STD-781C [64] in lieu of the probability ratio sequential tests (PRST) since these plans will allow an estimate of the actual instrumentation reliability (MTBF) and will allow the determination of the exact length and, therefore, cost of the test prior to testing. This makes the fixed length test plans especially suitable for qualification tests. The PRST plans would be used when it is only necessary to accept/reject predetermined MTBF values and when uncertainty with regard to test time is relatively unimportant.

5.0 DETAILED ENVIRONMENTAL TEST PROCEDURES

5.1 General Section (Test Conditions)

5.2 Test Conditions. Unless otherwise specified, the test conditions of all test methods shall conform to the requirements in the following paragraphs.

5.2.1 Definition of Standard Conditions. Unless otherwise specified herein or in the procurement specification, measurements and tests shall be conducted at standard ambient conditions. Standard ambient conditions are defined to be at temperatures of 15°C to 35°C (59°F to 95°F) at atmospheric pressures of 650 to 800 millimeters of mercury, and at relative humidity of 45% to 75%. Whenever standard conditions must be more closely controlled to obtain reproducible results, the conditions shall be maintained at temperatures of 25°C±1° (77°F±1.8°), at atmospheric pressures of 650 to 800 millimeters of mercury, and at a relative humidity of 50±5%.

5.2.2 Tolerances of Test Conditions. The tolerances of the test facility or chamber conditions, unless otherwise specified, shall be as follows:

- a. *Temperature:* The controls for the chamber shall be capable of maintaining the air or water temperature at the control sensor within ±2°C (3.6°F). Chambers shall be constructed so that the temperature gradient across the cross-sectional area occupied by the test item shall not exceed 0.3°C (0.5°F) per foot in any direction, but never more than 2.2°C (4°F) total. This temperature gradient, however, may be exceeded in the vicinity of operating equipment which generates heat.
- b. *Pressure:* Pressures shall be maintained within ±5% of the value specified.
- c. *Relative Humidity:* The relative humidity at the control sensor shall be maintained within an accuracy of ±5% of the value specified.
- d. *Vibration:* Vibration amplitude shall be within ±10% of that specified; frequency within ±5%, or ±1 Hz below 25 Hz.
- e. *Acceleration:* Unless otherwise specified, acceleration shall be within ±10% of that specified.
- f. *Power Supply:* Power requirements for operating instrumentation should be such that the maximum voltage and frequency ratings of the instrumentation are not exceeded. The steady state voltage and frequency tolerance requirements shall be within ±5% of the instrumentation rating.

5.2.3 Accuracy of Measurement. Instrumentation and test equipment used to control or monitor the test parameters shall have an accuracy of at least one-third the tolerance for the variable to be measured, unless otherwise specified.

5.2.4 Stabilization of Test Conditions. Unless otherwise specified, temperature stabilization will have been attained when the following occur:

- a. For operating instrumentation, temperature stabilization will have been attained when the temperature of the part of the test item considered to have the longest thermal lag is changing no more than 2.0°C (3.6°F) per hour.

- b. For non-operating instrumentation, temperature stabilization will have been attained when the temperature of the part of the test item considered to have the longest thermal lag reaches a temperature within 2.0°C (3.6°F) of the required temperature. When changing temperatures, the temperature of the chamber air may be adjusted up to 5°C (9°F) beyond the desired end point for a period of time of up to 1 hour to reduce stabilization time, provided that the stabilization requirements of this paragraph are ultimately attained relative to the specified end point temperature, and provided that the extended chamber temperatures will not cause damage to the test item.

Note: In both cases exceptions may occur for large test items.

5.3 Test Facility Requirements

5.3.1 Test Chamber Design. Unless otherwise specified, the volume and capacity of the test chamber shall be suitable to achieve the required test conditions and uniform air flow in the area of the test item(s). If more than one test item is tested simultaneously, they shall be suitably spaced to provide uniform conditions and free circulation for each item. Except where the application of radiant heat is one of the test conditions, the heat source of the test facility shall be so located that radiant heat from the source will not fall directly on the test item.

5.3.2 Measurement of Test Parameters. Unless otherwise specified, thermocouples or equivalent temperature sensors utilized to determine or control the specified chamber temperature shall be located centrally within the chamber, in the supply airstream, or in the return airstream, whichever provides the specified test conditions at the bulk under test and shall be baffled or otherwise protected against radiation effects.

5.3.3 Calibration of Test Equipment. The accuracy of instruments and test equipment used to control or monitor the test parameters shall be verified and shall satisfy the requirements of MIL-C-45662^[73]. All instruments and test equipment used in conducting the tests specified herein shall be calibrated to laboratory standards whose calibration is traceable to the National Bureau of Standards. All test instruments and systems must be calibrated upon receipt, following major repair or parts replacement, or at specified intervals, not exceeding 12 months. Temperature measurement devices should be checked at both the upper and lower limits of the temperature range. Accelerometers shall be dynamically calibrated with the equipment systems to be used with them in testing.

5.4 Test Performance Requirements

5.4.1 Pretest Performance Record. Prior to proceeding with any of the environmental or reliability tests, the test item shall be operated under the closely controlled standard ambient conditions specified in paragraph 5.2.1 to obtain detailed performance and operational data for determining satisfactory operation of the item and to demonstrate an acceptable performance baseline. After completion of these detailed performance measurements, selected performance test criteria shall then be used during the test to monitor and ensure proper instrumentation operation. The test item may be adjusted or aligned at the point in order to conform to the instrumentation specification. The data obtained during the pretest performance record may include parameters such as accuracy, linearity, warmup time, signal response time, and power requirements. The physical condition of the instrumentation shall be examined to evaluate its overall condition, including

finish (minor corrosion or inadequate coating), shape, color, screws for tightness, and workmanship. A record of specific pretest data shall be made to determine degradation in instrumentation performance beyond the permissible limits, both during and after environmental testing. During the pretest performance record, test item characteristics should be noted which would require special tests or test sequences.

5.4.2 Test Item Installation and Orientation. Unless otherwise specified, the test item orientation in the test facility shall be such as to simulate the actual service installation. Plugs, covers, and inspection plates not used in servicing shall remain in place. When mechanical or electrical connections are not used, the connections normally protected in service shall be adequately covered. The installation shall provide for the safety of the equipment, the test facility and the personnel. In temperature controlled chambers the test items shall be spaced to prevent interference in the thermal response of each item.

5.4.3 Pretest Performance Measurements, Functional Checks, and Inspections. Prior to each environmental test, conduct a visual examination of the test item in order to evaluate its general condition and note any defects (e.g., minor corrosion, cracked finishes, or poor workmanship). Also, prior to each test (and generally after installation of the test item in the chamber or on the test fixture) the test item shall be operated to determine that no malfunction or damage was caused due to faulty installation or handling. Performance checks shall be conducted to ensure that operation of the instrumentation is in conformance with the data taken during the pretest performance record (see paragraph 5.4.1). Adjustment or alignment of the instrumentation at this time is permissible. However, no further adjustment or alignment shall be permitted during or following the test, except by accessible controls, external to the test item, which are employed during normal operation of the test item.

5.4.4 Test and Post Test Performance Measurements. When operation of the test item is required during the test exposure, suitable tests or measurements shall be performed to determine whether induced stresses have produced changes in performance or physical characteristics. These measurements may be just sufficient to evaluate satisfactory operation. The inability of the test item to conform to the specified performance parameters within the tolerance limits shall constitute failure of the item. At the completion of each test method, the test item shall again be checked for variations in performance and physical characteristics. If any repairs, replacement of parts, or adjustment or alignment by other than the external accessible controls (intended for use during normal operation) are made during the test, the entire test shall be repeated.

Real time or near real time analysis of test data is highly desirable to verify abnormal response and should be implemented, when practical. Repeat tests to verify the statistical characteristics of the test item and monitoring of test equipment should be included where applicable. Some random test points to isolate trends and influences in the test should be considered.

5.5 Test Result Interpretation

5.5.1 Performance Monitoring. Performance and operational parameters shall be measured during the testing period in order to determine deviation beyond the limits established in the pretest performance record. The instrumentation shall be operated using all mode, settings, and ranges

of its controls and input signals necessary to determine conformance with the specified performance requirements. Input signals typical of those which would be received in service shall be supplied and shall include enough variety to exercise all specified instrumentation functions. Some of the parameters measured during operation of the instrumentation may include the following:

- a. Transfer Function – The transfer function is the ratio of the equipment output signal to input signal. For example, the gain of an amplifier is considered the transfer function of the amplifier. This characteristic may be measured at a single point or throughout the operating range to detect any deviation beyond the specified limits (accuracy) which would constitute a failure.
- b. Power Consumption – The sensing of power consumption may provide indications of shorts, arcing or other conditions which may effect the operation and life of the equipment or the life of the power supply.
- c. Warmup Time – During test conditions which include cycling of the instrumentation, the warmup time may be noted during monitor of the transfer to ensure conformance with the specified performance requirement.

5.5.2 Failure Criteria. The test item shall have failed the test when any of the following occur:

- a. Performance and operational parameters measured before, after or between tests deviate beyond the limits established in the pretest performance record. Data such as accuracy, linearity, warmup time, signal response time or power requirements may be measured after tests, especially when the equipment is not operational during testing.
- b. Intermittent type indications of the monitored performance and operational parameters, unless otherwise specified (intermittent type failures during shock testing or electrical power variations testing may be permissible).
- c. Structural failures, including mechanical binding or loose parts, such as screws, clamps, bolts, and nuts, which may result in a hazard to personnel safety or which may interfere with the ability of the instrumentation to perform its intended mission.
- d. Deterioration, corrosion, or change in physical tolerance limits of any internal or external parts which could in any manner prevent the test item from meeting operational service or maintenance requirements.
- e. Any other type of instrumentation malfunction.

Due to the numerous types of instrumentation, the evaluation of failure may in many cases be left up to the judgement of the test engineer.

5.5.3 Test Data. The test data shall include as a minimum the following information:

- a. Test item description, dimensions, and serial number;
- b. Test methods conducted and sequence;

- c. Ambient test conditions recorded periodically during the test period, as well as any other data required by the particular test method;
- d. Results of all performance, operational and physical characteristics inspections conducted prior to, during and after the tests;
- e. A description of all failure modes and times of occurrence;
- f. A signature and data block for certification of the test data by the test engineer.

5.5.4 Test Reports. The test data may be recorded on the data sheets by the procuring activity.

EXAMINATION

1.0 TEST PROCEDURE

1.1 Each item shall be inspected to ensure proper assembly and adjustment and to ensure that electrical connections are secure and that workmanship is as specified by the manufacturer or individual equipment specification.

1.2 Each item shall be functionally checked to ensure operation per manufacturer's or individual equipment specifications.

DESIGN AND CONSTRUCTION

1.0 GENERAL GUIDELINES

1.1 The following are general guidelines that should be used in design and construction of mine instrumentation. It is noted that the Code of Federal Regulations (30 CFR) must be satisfied first, especially in the areas of permissibility and intrinsic safety and take precedence in the event of a conflict with the information contained herein.

1.2 Requirements

1.2.1 The following requirements of MIL-STD-454^[62] apply.

- Requirement 1: Safety
- Requirement 5: Soldering
- Requirement 7: Interchangeability (within a particular manufacturer only)
- Requirement 9: Workmanship
- Requirement 10: Electrical Connections
- Requirement 16: Dissimilar Metals
- Requirement 31: Moisture Pockets
- Requirement 36: Accessibility
- Requirement 62: Human Engineering

MAINTAINABILITY

1.0 GENERAL GUIDELINES

1.1 The following are general guidelines that should be used to ensure optimum maintainability.

1.2 The general requirements of paragraph 5.9 of MIL-STD-1472^[71] shall apply with specific attention given to:

a. Personal/Portable

- (1) Batteries shall be easily removed and replaced
- (2) Shall incorporate a battery level indicator
- (3) Shall contain self test circuits for functional checkout

b. All Equipment

- (1) Shall have easy replacement of expendable parts
- (2) Shall use mounting and interwiring techniques to minimize replacement time
- (3) Cable entries shall be such as to allow damaged cables to be quickly replaced
- (4) If instrument packages consist of main controller housing and one or more distribution boxes, use of separate branch circuit cable assemblies is required to provide for replacement of individual units.
- (5) Housings shall be so constructed to facilitate replacement of inside sub-assemblies

ELECTRIC POWER VARIATION

1.0 TEST FACILITY

1.1 The test items may be bench tested utilizing a variable voltage/frequency source and a means of measuring voltage and frequency within an accuracy of $\pm 1\%$.

2.0 TEST PROCEDURE

2.1 Test Conditions. The test item shall be subjected to the following ranges of voltage and frequency variation for each of the following tests:

- Voltage: $\pm 25\%$ of nominal voltage for machine-mounted underground coal equipment
 $\pm 10\%$ of nominal voltage for all other equipment
- Frequency: $\pm 5\%$ of nominal frequency

2.2 Test Item Preparation

2.2.1 Performance Measurements. Conduct preliminary performance measurements and functional checks in accordance with paragraph 5.4.3 of the beginning section.

2.3 Test Performance

2.3.1 Voltage and Frequency Variation Test

- a. Connect the power cable of the instrumentation to a variable voltage and frequency source which is set for nominal voltage and frequency.
- b. Maintain the voltage and frequency for a period of at least 15 minutes.
- c. Vary voltage and frequency one at a time while maintaining the other at nominal value to the limits in paragraph 2.1.
- d. Conduct and record performance measurements in accordance with paragraph 5.4.4 of the General Section.

2.4 Test Results

2.4.1 Failure Criteria. The occurrence of any of the criteria delineated in paragraph 5.5.2 of the General Section shall constitute failure.

2.4.2 Test Data. The test data shall include the information specified in paragraph 5.5.3 of the General Section.

HIGH TEMPERATURE (Storage)

1.0 TEST FACILITY

1.1 Test Chamber. The chamber shall be capable of maintaining a high temperature extreme of 60°C (140°F) for the specified test duration.

2.0 TEST PROCEDURE

2.1 Test Item Preparation

2.1.1 Mounting. The test item shall be positioned in a normal usage attitude with the main air-stream of the chamber. Preparation and installation requirements shall be in accordance with paragraph 5.4.2 of the General Section.

2.1.2 Performance Measurements. Conduct preliminary performance measurements and functional check of the instrumentation in accordance with paragraph 5.4.3 of the General Section.

2.2 Test Performance

- a. With the chamber at standard conditions, install the test item.
- b. Raise the internal chamber temperature to 60°C (140°F) at a rate of 0.6°C/minute to 1.1°C/minute (1°F/minute to 2°F/minute).
- c. While ensuring that the relative humidity is not in excess of 15%, maintain the internal chamber temperature for the period of time specified below:

Test Item Weight—kg (lbs.)	Test Duration-hrs.
0–22 (0–10)	12
22–220 (10–100)	24
above 220 (above 100)	48

- d. Return the test item to standard ambient conditions and stabilize.
- e. Operate the test item. Conduct and record performance measurements in accordance with paragraph 5.4.3 of the General Section.

2.3 Test Results

2.3.2 Failure Criteria. Test item failure shall be determined by the criteria delineated in paragraph 5.5.2 of the General Section.

2.3.2 Test Data. The tabulation of test results shall include the data specified in paragraph 5.5.3 of the General Section.

LOW TEMPERATURE (Operating and Storage)

1.0 TEST FACILITY

1.1 Test Chamber. The chamber shall be capable of maintaining a low temperature extreme of -40°C (-40°F) for the specified test duration. The air flow within the chamber shall be sufficient to minimize temperature gradients.

2.0 TEST PROCEDURE

2.1 Test Conditions. The test item shall be exposed to a low temperature extreme of -40°C (-40°F) for the specified durations. The relative humidity during the test need not be controlled. The instrumentation shall be inoperative during the low temperature phase of the test, but may be operated at the low design temperature specified in the instrumentation specification to ensure proper performance.

2.2 Test Item Preparation

2.2.2 Mounting. The test item shall be positioned in a normal usage attitude within the main airstream of the chamber. Preparation and installation requirements shall be in accordance with paragraph 5.4.2 of the General Section.

2.2.3 Performance Measurements. After the preconditioning period, conduct preliminary performance measurements and functional checks of the instrumentation in accordance with paragraph 5.4.3 of the General Section.

2.3 Test Performance

- a. With the chamber at standard conditions, install the test item.
- b. Reduce the chamber temperature at a rate of $0.6^{\circ}\text{C}/\text{minute}$ to $1.1^{\circ}\text{C}/\text{minute}$ (1°F to $2^{\circ}\text{F}/\text{minute}$) to a chamber temperature of -40°C (-40°F).
- c. Maintain the test item temperature at the low temperature extreme for a period of time specified below:

Test Item Weight—kg (lbs.)	Test Duration—hrs.
0–22 (0–10)	12
22–220 (0–100)	24
220 and above (100 and above)	48

- d. Record the temperature of the chamber at least every 2 hours.

- e. Raise the internal temperature to one of the following temperatures depending on the type of mine the instrumentation is being used in. If used in more than one type of mine, select the worst case temperature.

- Underground coal: 4.4°C (40°F)
- Underground metal: 4.4°C (40°F)
- Surface coal: -40°C (-40°F)

Maintain temperature until temperature stabilization is reached.

- f. Operate the test item. Conduct and record performance measurements and functional checks in accordance with paragraph 5.4.4 of the General Section.
- g. At the completion of the low temperature exposure and performance measurements, allow the chamber temperature to return to standard conditions and stabilize.
- h. Operate the test item. Conduct and record performance measurements in accordance with paragraph 5.4.4 of the General Section.
- i. Visually examine the test item for evidence of failure.

2.4 Test Results

2.4.1 Failure Criteria. Test item failure shall be determined by the criteria delineated in paragraph 5.5.2 of the General Section and the following.

- a. Unless otherwise specified, the test item shall have failed when the performance parameters exceed the permissible tolerances at the minimum design temperature. In some cases, “out of tolerance” conditions of certain parameters may be acceptable (i.e., instrumentation warm-up time).
- b. Binding or seizing of switches, controls, etc.

2.4.2 Test Data. The tabulation of test results shall include the data specified in paragraph 5.5.3 of the General Section.

SOLAR RADIATION

1.0 TEST FACILITY

1.1 Test Chamber. The test chamber volume shall be a minimum of 10 times that of the envelope of the test item. The chamber's simulated solar radiation source shall be a minimum of 125% of the horizontal area projection of the test item and shall be located at least .76 meters (30 inches) away from any outer surface of the test item.

1.2 Auxiliary Equipment. The radiation source shall be capable of providing radiant energy levels in the following increments: 24, 47, 71, and 94 watts/ft². At the maximum energy level (94 watts/ft²) the spectral distribution shall consist of 45 to 65 watts/ft² of infrared (wavelengths above 7,800 Angstrom), 4 to 7 watts/ft² of ultraviolet (wavelengths below 3,800 Angstrom), and the balance in the visible wavelengths. The tolerance for control of radiation shall be ± 5 watts/ft².

1.3 Monitoring Equipment

1.3.1 Radiation. A pyranometer should be used to measure radiation.

1.3.2 Temperature. The sensor for monitoring and controlling the chamber temperature shall be located in the airstream where the air enters the chamber workspace. Precautions shall be taken to ensure that the temperature sensor is shielded from the radiant energy source.

1.3.3 Air Velocity. The air velocity may be measured with a hot wire anemometer or pitot tube type device.

2.0 TEST PROCEDURE

2.1 Test Conditions. The test item shall be exposed to three consecutive 24 hour cycles of controlled simulated solar radiation and dry bulb temperature as shown in figure 1. The relative humidity during the cycles shall be uncontrolled. The air velocity within the exposure zone of the test item shall be maintained at 3 to 6 knots (5.5–11.0 kilometers/hr, 300–600 ft/min). The test conditions shall be obtained within 5 minutes of the time periods specified.

2.2 Test Item Preparation

2.2.1 Mounting. The test item shall be positioned in a normal usage attitude and prepared in accordance with paragraph 5.4.2 of the General Section. When testing more than one specimen, the test items shall be positioned such that they do not contact each other and no test item casts a shadow on another test item.

2.2.2 Performance Measurements. Immediately preceding the start of the first cycle, preliminary performance measurements and functional checks shall be performed in accordance with paragraph 5.4.3 of the General Section.

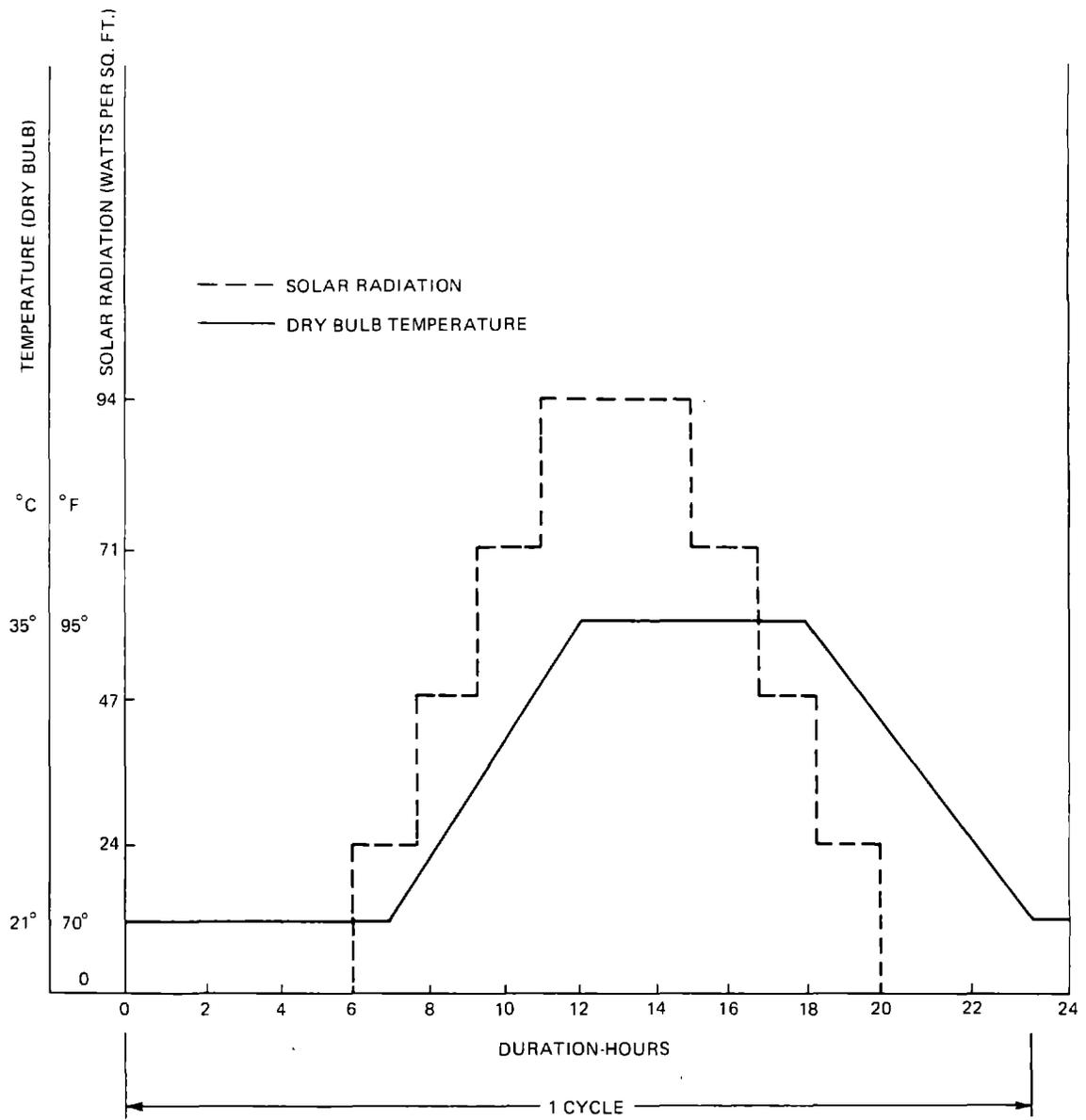


Figure 1. Solar Radiation Cycle

2.3 Test Performance

- a. The chamber air temperature shall be adjusted to 22°C (71°F).
- b. The test item shall be subjected to three consecutive 24-hour cycles of controlled simulated solar radiation and dry bulb temperature as indicated in figure 1.
- c. At the approximate point of peak test item temperature during the third cycle (approximately 16 hours after start), the test item shall be operated and results obtained in accordance with paragraph 5.4.4 of the General Section.
- d. At the conclusion of the third cycle, the test item shall be returned to room ambient conditions.
- e. The test item shall be operated and performance measurements obtained in accordance with paragraph 5.4.4 of the General Section.
- f. Visually examine the test item for evidence of damage.

2.4 Test Results

2.4.1 Failure Criteria. Failures shall be determined by the occurrence of any of the criteria delineated in paragraph 5.5.2 of the General Section and the following:

- a. Chemical breakdown and deterioration of protective coatings.
- b. Drying out of natural rubber and melting of plastic components.
- c. Discoloration of markings, loss of transparency of clear plastics, or any condition which makes proper operation difficult.
- d. Damage to sensitive sensor membranes. If sensors are designed with protective covers for protection of sensitive components, these covers shall be in place during testing.

2.4.2 Test Data. The tabulation of test results shall include the data specified in paragraph 5.5.3 of the General Section.

HIGH PRESSURE

1.0 TEST FACILITY

1.1 Test Chamber. The test chamber shall be suitable for providing the specified increased pressure condition.

2.0 TEST PROCEDURE

2.1 Test Item Preparation

2.1.1 Performance Measurements. Prior to the high pressure cycle, conduct preliminary performance measurements and functional checks of the instrumentation in accordance with paragraph 5.4.3 of the General Section.

2.2 Test Performance

- a. Install instrumentation in the chamber, allowing for test item operation, and maintain standard ambient conditions during the entire test.
- b. Increase the chamber pressure to 19.7 pounds per square inch (equivalent to approximately 10,000 feet below sea level) and stabilize.
- c. For wall- and machine-mounted equipment, maintain this pressure for 2 hours during which performance measurements in accordance with paragraph 5.4.4 of the General Section shall be taken.
- d. For portable and personal equipment, chamber pressure shall be cycled from test pressure (19.7 psi) to atmospheric (14.7 psi) for a total of 365 times. During the last cycle, at high pressure, performance measurements shall be taken in accordance with 5.4.4 of the General Section.
- e. In either case, return chamber to ambient pressure.
- f. Once at ambient conditions, conduct and record performance measurements and functional check in accordance with paragraph 5.4.4 of the General Section. Visually examine the test item for damage.

2.3 Test Results

2.3.1 Failure Criteria. The occurrence of any of the criteria delineated in paragraph 5.5.2 of the General Section shall constitute failure.

2.3.2 Test Data. The test data shall include the information specified in paragraph 5.5.3 of the General Section.

LOW PRESSURE

1.0 TEST FACILITY

1.1 Test Chamber. The test chamber shall be suitable for providing the specified reduced pressure conditions. Precautions should be taken to prevent any possible vibration generated by the vacuum pump from being transmitted to the test chamber.

1.2 Auxiliary and Monitoring Equipment. Other testing equipment required includes a vacuum pump and a pressure indicator to measure the chamber pressure.

2.0 TEST PROCEDURE

2.1 Test Conditions. The test item shall be exposed to a single reduced pressure cycle at 10,000 feet above sea level, during which the chamber is maintained at standard ambient temperature.

2.2 Test Item Preparation

2.2.1 Performance Measurements. Prior to the low pressure cycle, conduct preliminary performance measurements and functional checks of the instrumentation in accordance with paragraph 5.4.3 of the General Section.

2.3 Test Performance

- a. Subject the test item to a reduced pressure of 523 millimeters of mercury (20.6 inches of mercury, equivalent to an altitude of 10,000 feet above sea level) at a rate not to exceed 2,000 feet per minute. The chamber shall be maintained at a standard ambient temperature throughout the test.
- b. Maintain the test item at this pressure for a period of at least 2 hours.
- c. Operate the test item. Conduct and record performance measurements and functional checks in accordance with paragraph 5.4.4 of the General Section.
- d. Return the chamber to standard ambient conditions at a rate not to exceed 2,000 feet per minute.
- e. Operate the test item. Conduct and record performance measurements and functional checks in accordance with paragraph 5.4.4 of the General Section. Visually examine the test item for damage.

2.4 Test Results

2.4.1 Failure Criteria. The occurrence of any of the criteria delineated in paragraph 5.5.2 of the General Section shall constitute failure.

2.4.2 Test Data. The test data shall include the information specified in paragraph 5.5.3 of the General Section.

THERMAL SHOCK

1.0 TEST FACILITY

1.0 Test Chamber. The chambers shall be of sufficient design to minimize temperature gradients within the chamber and should be suitable for the temperature extreme indicated.

2.0 TEST PROCEDURE

2.1 Test Item Preparation

2.1.1 Mounting. The test item shall be positioned in a normal usage attitude within the main airstream. Preparation and installation requirements shall be in accordance with paragraph 5.4.2 of the General Section.

2.1.2 Performance Measurements. Conduct preliminary performance measurements and functional checks of the instrumentation in accordance with paragraph 5.4.3 of the General Section.

2.2 Test Performance

- a. Raise the internal temperature of the chamber to one of the following temperatures and stabilize:

Underground Coal Instrumentation 37.8°C (100°F)

Underground Metal and Surface Mine Instrumentation 60°C (140°F)

- b. Maintain the temperature for a period of not less than 4 hours.

- c. At the conclusion of this time period, transfer the test item, within 5 minutes, to a cold chamber with an internal stabilized chamber temperature of one of the following:

Underground Coal and Underground Metal Instrumentation 4.4°C (40°F)

Surface Mine Instrumentation -40°C (-40°F)

- d. The test item shall be exposed to this temperature for a period of not less than 4 hours.

- e. At the conclusion of this time period, the test item shall, within 5 minutes, be returned to the high temperature chamber maintained at one of the following temperatures:

Underground Coal Instrumentation 37.8°C (100°F)

Underground Metal and Surface Mine Instrumentation 60°C (140°F)

- f. The test item shall be exposed to this temperature for a period of not less than 4 hours.

- g. Return the test item to standard ambient conditions and stabilize.

- h. Conduct and perform performance measurement in accordance with paragraph 5.4.4 of the General Section.
- i. Visually examine the test item for evidence of failure.

2.3 Test Results

2.3.1 Failure Criteria. Test item failure shall be determined by the criteria delineated in paragraph 5.5.2 of the General Section and the following:

- a. Unless otherwise specified, the test item shall have failed when the performance parameters exceed the permissible tolerances at the minimum design temperature. In some cases, “out of tolerance” conditions of certain parameters may be acceptable (i.e., instrumentation warm-up time).
- b. Binding or seizing of switches, control, etc.

2.3.2. Test Data. The tabulation of test results shall include the data specified in paragraph 5.5.3 of the General Section.

SHOCK

1.0 TEST FACILITY

1.1 Shock Machine and Fixtures

1.1.1 Procedure I. The transit drop shall be conducted on a floor of 0.05m (2 in.) thick plywood backed by concrete. The drops shall be made using a quick release hook or drop tester which does not impart rotational or sidewise forces to the test item.

1.1.2 Procedure II. The shock machine shall be suitable for the test item size and weight. It shall be capable of producing the input shock pulse specified in figure 2 (P = peak shock of 40 g's) and shall provide reliable and repeatable results. Each shock mounting fixture shall be as rigid as practicable in order to ensure that the same pulse parameters imparted to the fixture are transmitted to the test item without any change. The design should minimize handling of the test item when changing from one axis to another.

1.2 Monitoring Devices. The system for measuring acceleration shall be suitable for the specified levels and shall provide the accuracy specified in paragraph 5.2.3 of the General Section. The accuracy of the system shall extend through the frequency range of 4 Hz to 500 Hz.

2.0 TEST PROCEDURES

2.1 Selection of Test Procedure

2.1.1 Procedure I. Procedure I is intended for all personal, portable, and wall-mounted equipment used in any type mine considered and simulates a free fall drop.

2.1.2 Procedure II. Procedure II is intended for all machine-mounted equipment and serves to evaluate minimum design requirements.

2.2 Test Conditions. Procedure I consists of 26 drops from various attitudes from the free fall heights specified. Procedure II specifies a sawtooth impulse shock at 40 g's peak acceleration (P) and 11 milliseconds duration (D) for a total of 18 shocks. The test item shall be inoperative during all shock tests. Each shock test procedure shall be applied to a single test item.

2.3 Test Item Preparation

2.3.1 The test item shall be fully assembled, including mounting pads or vibration isolators which are furnished with the unit and used in normal service.

2.3.2 Installation and Mounting. The test item preparation shall be in accordance with paragraph 5.4.2 of the General Section. For Procedure I the test shall be conducted with the instrument in its transit case, if the test item is intended for normal usage while installed in its case. For Procedure II the test item shall be removed from its case for testing. Portable instrumentation shall be secured to the testing machine by means of suitable straps. The mounting arrangement

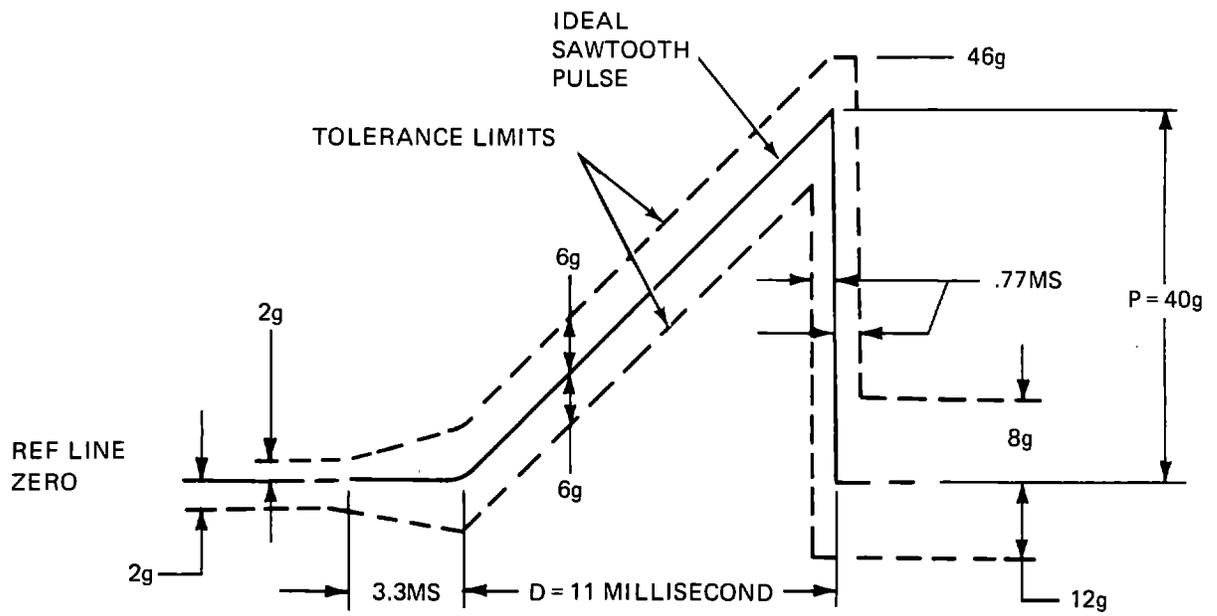


Figure 2. Shock Pulse and Tolerance Limits

shall ensure that the test item does not “bottom out” with the mounting fixture during delivery of the shock pulse. The transducer used to monitor the input shock to the item shall be mounted on the test fixture as close as possible to the test item mounting point. Unless otherwise specified or practicable, the transducer shall not be mounted on the test item to monitor input.

2.3.3 Orientation. For Procedure II the installation shall be such that the direction of shock impulse will be along each of three orthogonal axes of the instrument as it would be installed on the machine. The test item/fixture assembly shall be located with the center of gravity as near as possible to the geometrical center of the shock table.

2.3.4 Performance Measurements. Prior to testing, conduct preliminary performance measurements and functional checks on all test items in accordance with paragraph 5.4.3 of the General Section.

2.4 Test Performance

2.4.1 Procedure I

- a. The test item shall be exposed to the specified free fall drop conditions from the vertical free fall distance specified below using a drop tester or quick release hook.

Test Item Weight—Kg (lbs)	Drop Height—in.
0–18.1 (0–40)	36
18.1–36.3 (40–80)	30
36.3 and over (80 and over)	24

- b. Subject the test item to one drop each on each corner (8), each face (6), and each edge (12) for a total of 26 drops.
- c. Conduct and record performance measurements and functional checks in accordance with paragraph 5.4.4 of the General Section.
- d. Visually examine the test item for evidence of failure.

2.4.2 Procedure II

- a. Prior to the actual test the shock machine shall be calibrated for conformance with the wave shape specified in figure 2. The actual test item, a rejected item, or a rigid dummy mass shall be used for the calibration, except that a rigid dummy mass shall have the same center of gravity and the same mass and shall be installed in the same manner as the actual test item. Two consecutive calibration runs shall be conducted to ensure conformance to the specified waveform.
- b. Remove the calibration load and install the test item.
- c. Subject the test item to three shocks in the selected direction. The shock pulse oscillogram shall be recorded during each run. The oscillogram shall include a time about 33 milliseconds long with a pulse located approximately in the center. The shock values are P = 40 g (Peak value) and D = 11 milliseconds (Duration).

- d. Rotate the item 180 degrees. Subject the item to three shock pulses. (If the test item is of an asymmetrical shape, the machine may require recalibration.) The oscillograms shall be checked after each run to ensure conformance to the specified waveform. In the event the shock pulse exceeds the permissible limits, the shock machine shall be recalibrated.
- e. Repeat paragraphs c and d for each of the other two orthogonal axes for a total of 18 tests.
- f. Conduct and record performance measurements and functional checks in accordance with paragraph 5.4.4 of the General Section.
- g. Visually examine the test item for evidence of failure.

2.5 Test Results

2.5.1 Failure Criteria. Test item failure shall be determined by the criteria delineated in paragraph 5.5.2 of the General Section, except that minor structural damage or distortion is permissible, provided such damage or distortion does not in any way impair the ability of the instrument to perform its principal functions.

2.5.2 Test Data. The tabulation of test results shall include the data specified in paragraph 5.5.3 of the General Section. For Procedure II shock tests, the following additional information shall be provided:

- a. A description or sketch of the test item and the axes and directions of shock input.
- b. A photograph of the oscillogram for each shock pulse. The length of the oscillogram shall be 33 milliseconds long with the pulse located approximately in the center.

VIBRATION

1.0 TEST FACILITY

1.1 Vibration Machine. Vibration testing may be conducted using either electrodynamic or electrohydraulic systems suitable for sine vibration to the specified limits. The vibration machine must be capable of providing a low frequency of 5 Hz. The system should provide sinusoidal acceleration waveforms with less than 10% acceleration distortion from 20 Hz to the upper frequency limit at full system rating. Transverse motion (crosstalk), perpendicular to the input motion, shall be minimized and limited to 100% of the input motion at the input monitoring point.

1.2 Monitoring Equipment. The instrumentation and control system components shall be suitable for the test amplitudes and frequency range, and shall meet the accuracy requirement specified in the General Section. The input control sensing transducer shall be rigidly attached to the vibration table (or mounting fixture) as near as possible to the attachment points of the test item. If input vibration is monitored at more than one control point on large items, the control signal shall be the average of all the accelerometers. Additional transducers shall be located in or on the test item to determine resonant frequencies.

2.0 TEST PROCEDURE

2.1 Selection of Test Procedure. The procedure for each instrumentation type shall be as indicated in the following table, table 2.

Table 2. Vibration Procedure and Profile Chart

Type of Usage	Profile	Procedure	Test Conditions	
			Frequency Range	Accelerations
Personal/Portable/Wall (All types of mines)	Figure 3	I	5-200-5	1.5
Underground Mining Machines (Longwall, Continuous)				
Cutter Arm	Figure 4	II	5-2000-5	4
Frame	Figure 4	II	5-2000-5	1.5
Underground and Surface Haulage	Figure 5	III	5-92	2.5
			92-500	3.5

2.2 Test Conditions. With the exception of Procedure I, the specific vibration profile for each type of instrumentation is a function of the equipment it is used on. Procedure I is a transportation vibration used for all personal/portable/wall-mounted equipment normally not exposed to vibration during operation. Test item operation shall be accomplished only during Procedures II and III. The test item shall not be operated during Procedure I. During Procedures II and III, the test item shall be operated during application of vibration (resonance search, resonance dwell, cycling, and random vibration) so that functional effects caused by these tests may be evaluated. The test item shall meet the performance requirements as specified in paragraph 5.4.4 of the General Section.

2.3 Test Item Preparation

2.3.1 Preconditioning. No special conditioning of the test item is required. The test item shall be fully assembled, including mounting pads or vibration isolators which are furnished with the unit and used in normal service.

2.3.2 Mounting and Installation. The instrumentation shall be secured to the mounting bracket of the testing machine in the same manner that it will be secured in the field. Portable instrumentation shall be secured to the testing machine by means of suitable straps. Mounting brackets shall be sufficiently rigid to ensure that its motion will be essentially the same as the motion of the platform of the testing machine. Precautions shall be taken in securing the test item to the mounting brackets and table such as to minimize the introduction of extraneous responses in the test setup. Instrumentation which is normally furnished with integral resilient mounts (except for portable instrumentation) or in permanent cases or cabinets shall be tested with the mounts or in the cases. The test load shall be distributed as uniformly as possible on the vibration exciter table in order to minimize the effect of unbalanced loads. The transducers used to monitor the input vibration to the item shall be mounted on the test fixture as close as possible to the test item mounting point. Unless otherwise specified, the transducer shall not be mounted on the test item. Additional vibration sensors shall be located in or on the test item to determine resonant frequencies and amplification factors. Locations to be selected should include main structure, printed circuit boards, large components, and modules, where practicable. The sensor sizes and weights shall be limited so that their effect on the dynamic responses being measured is minimal. For sinusoidal vibration, when necessary for obtaining uniform results, a tracking filter should be used in the vibration exciter control feedback loop prior to the servo input.

2.3.3 Orientation. Instrumentation shall be installed on the vibration testing machine in such a manner that the directions of vibration will be along each of three orthogonal axes of the instrumentation as it is installed in the field. To the extent possible, the center of gravity of the test item shall be located in line with the input vibration or the center of the machine in order to minimize transverse vibration. For horizontal vibration, the test item may be turned 90 degrees in the horizontal plane in order to vibrate in each of the two horizontal orientations. At no time shall the instrumentation be installed in anyway other than its normal position.

2.3.4 Performance Measurements. Prior to testing, conduct preliminary performance measurements and functional checks on all the test items in accordance with paragraph 5.4.3 of the General Section.

2.4 Test Performance

2.4.1 Sinusoidal vibration tests – The vibration shall be applied along each of the three mutually perpendicular axes of the test item. The vibratory acceleration levels or double amplitudes of the specified test curve shall be maintained at the item mounting points. When the input vibration is measured at more than one control point, the control signal shall be the average of all the accelerometers unless otherwise specified. For massive test items, fixtures, and large force exciters, it is recommended that the input control level be an average of at least three or more inputs.

2.4.1.1 Resonance search – Resonant frequencies of the equipment shall be determined by varying the frequency of applied vibration slowly through the specified range at reduced test levels but with sufficient amplitude to excite the item. Sinusoidal resonance search may be performed using the test level and cycling time specified for sinusoidal cycling test, provided the resonance search time is included in the required cycling test time of 2.4.1.3.

2.4.1.2 Resonance dwell – The test item shall be vibrated along each axis at the most severe resonant frequencies determined in 2.4.1.1. Test levels, frequency ranges and test times shall be in accordance with the applicable conditions from table 3 and figures 3 through 5 for each equipment category. If more than four significant resonant frequencies are found for any one axis, the four most severe resonant frequencies shall be chosen for the dwell test. If a change in the resonant frequency occurs during the test, its time of occurrence shall be recorded and immediately the frequency shall be adjusted to maintain the peak resonance condition. The final resonant frequency shall be recorded.

2.4.1.3 Cycling – The test item shall be vibrated along each axis in accordance with the applicable test levels, frequency range, and times from table 1 and figures 3 through 5. The frequency of applied vibration shall be swept over the specified range logarithmically in accordance with figure 6. The specified sweep time is that of an ascending plus a descending sweep and is twice the ascending sweep time shown on figure 6 for the specified range.

Table 3. Vibration Test Procedure and Time Schedule

Type of Usage	Procedure	Applicable Test			Test Time Per Axis			Profile
		Resonance Search	Resonance Dwell	Resonance Cycling	Dwell Time at each Resonance	Sinusoidal Cycling Time	Sweep Time	
Personal/Portable/Wall All Mines	I	–	–	X	–	84 min	12 min 5-200-5Hz	Figure 3
Underground Mining Machines	II	X	X	X	30 min	3 hrs less dwell time	20 min 5-2000-5Hz	Figure 4 Curve 1
Cutter Arm								
Frame	II	X	X	X	30 min	3 hrs less dwell time		Figure 4 Curve 2
Underground and Surface Haulage Vehicles	III	–	–	X	–	3 hours	15 min 5-500-5Hz	Figure 5

2.4.2 Test Procedures

Procedure I

Vibration cycling shall be performed in accordance with paragraph 2.4.1.3 using table 3 and figure 3 for test parameters.

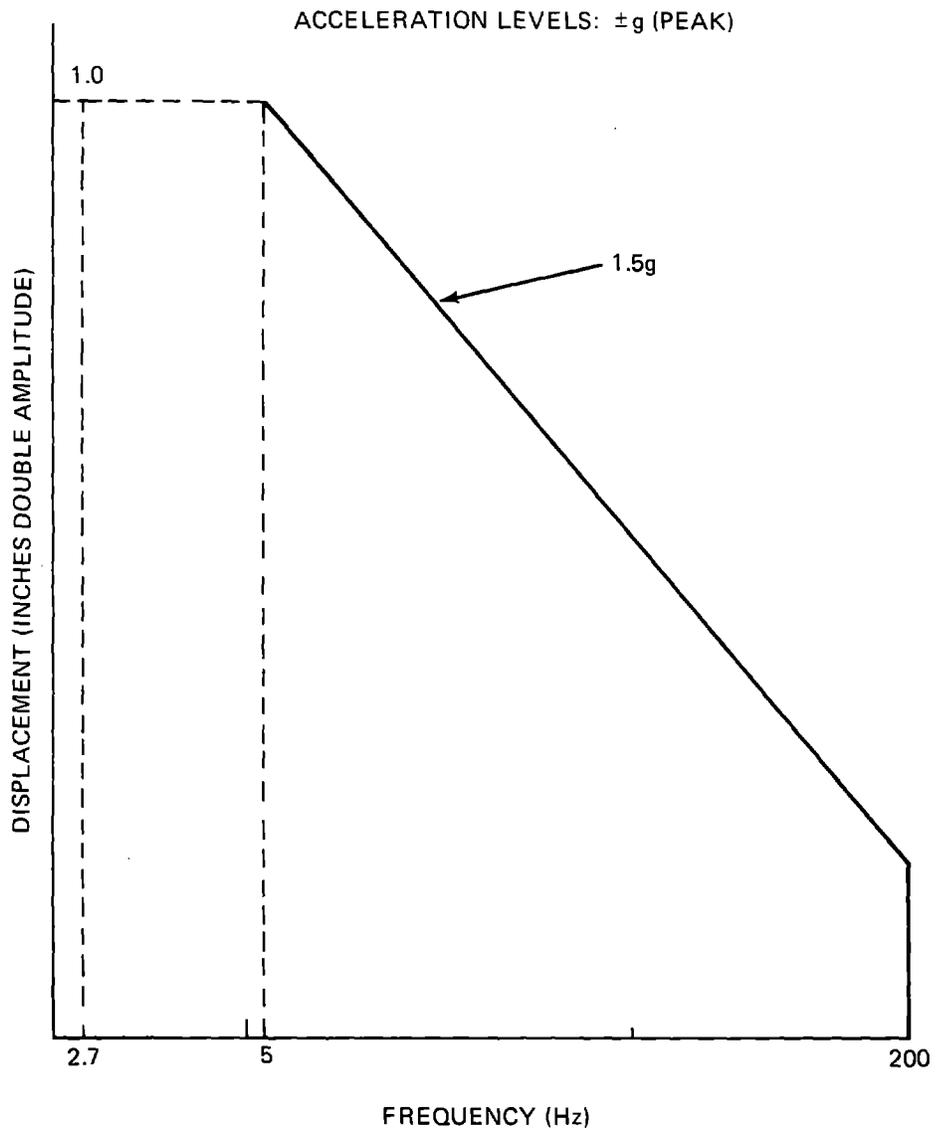


Figure 3. Vibration Profile for Portable/Personal/Wall Equipment

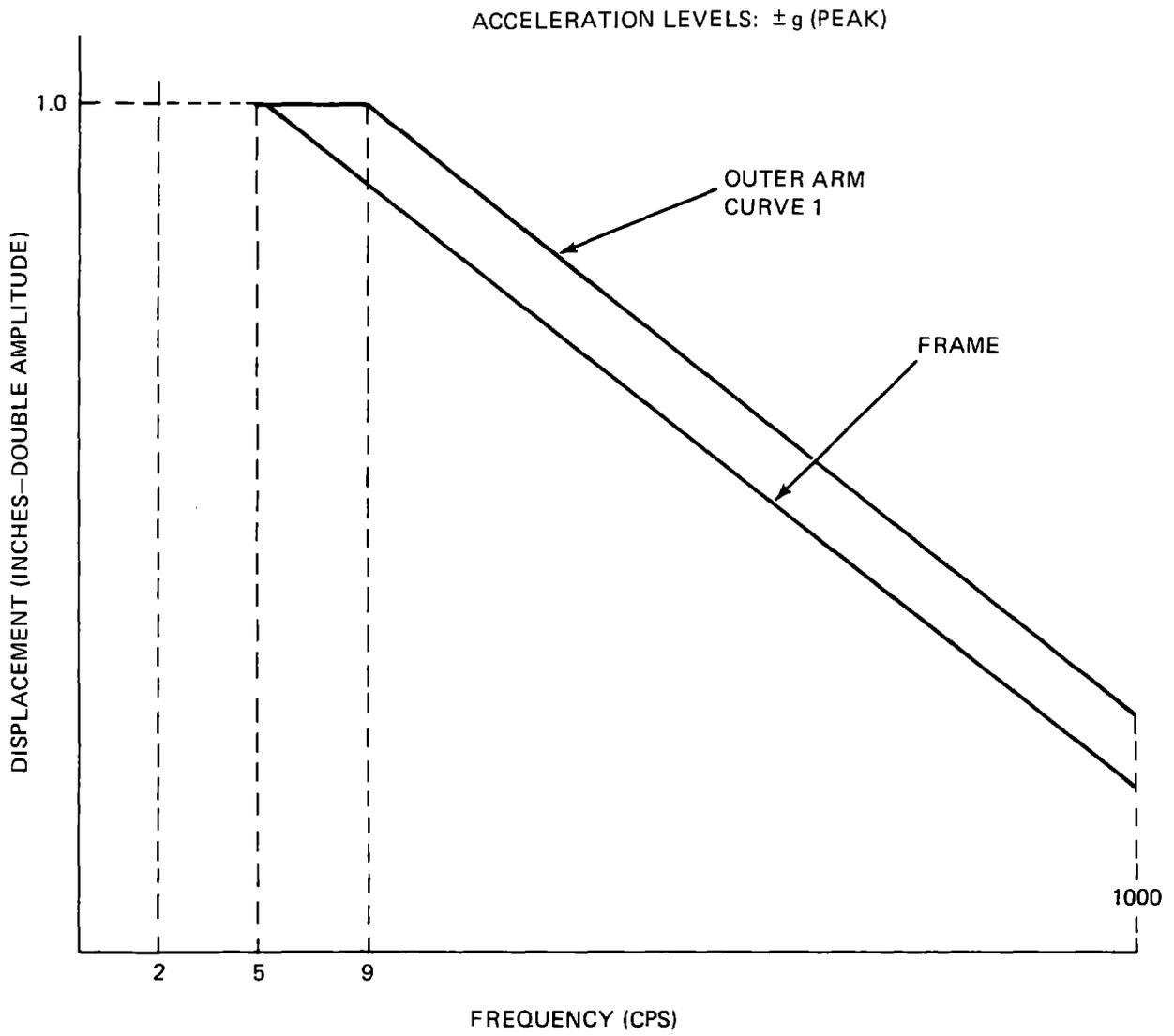


Figure 4. Vibration Profile for Equipment Mounted on Underground Mining Machines

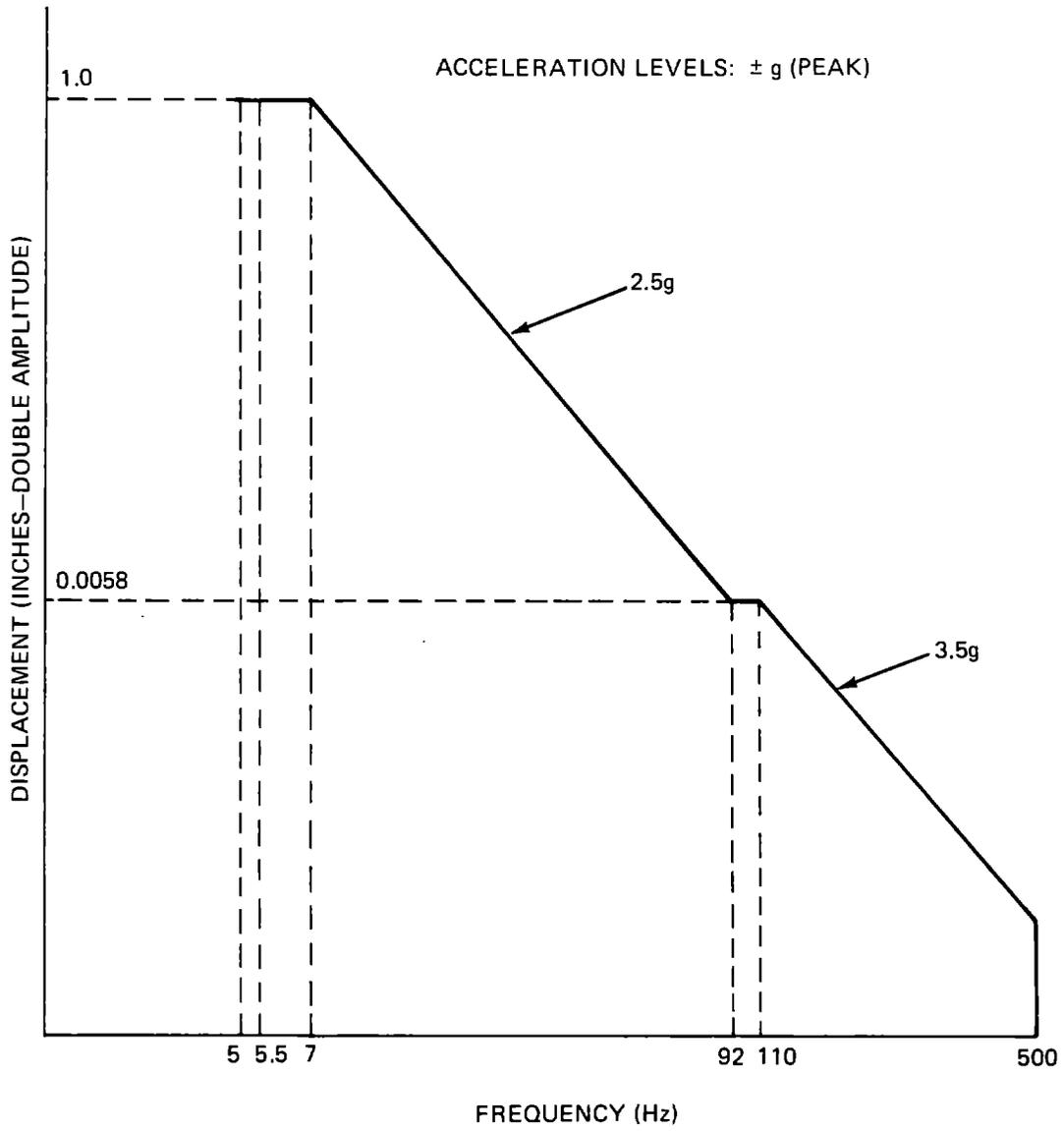


Figure 5. Vibration Profile for Equipment Mounted on Underground and Surface Haulage Vehicles

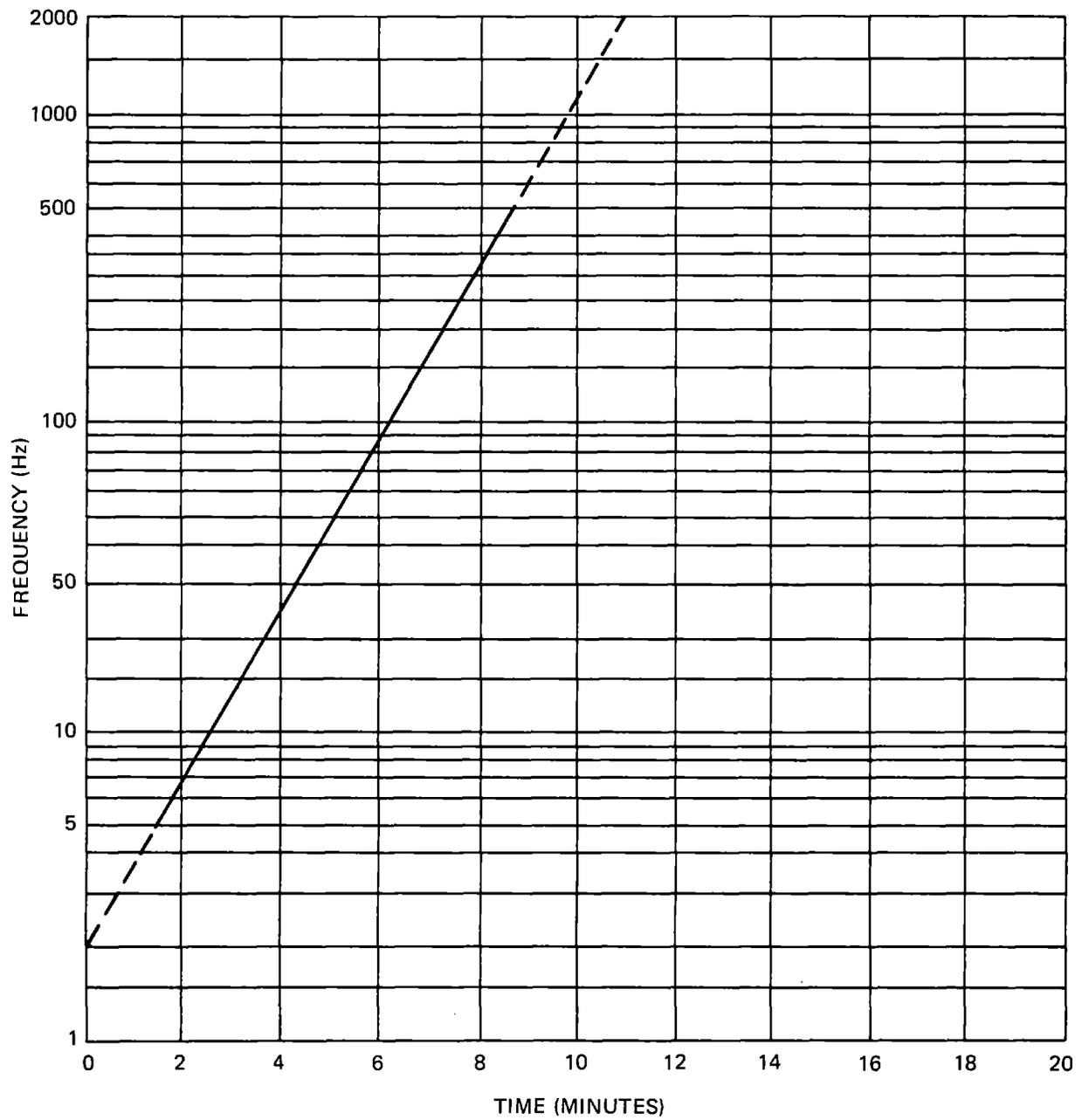


Figure 6. Vibration Logarithmic Sweep Rate

Procedure II

Vibration resonance search, resonance dwells, and vibration cycling shall be performed in accordance with paragraphs 2.4.1.1, 2.4.1.2, and 2.4.1.3, respectively. Test parameters shall be in accordance with table 3 and figure 4 and are dependent on whether the equipment is mounted on the frame or on the cutter arm.

Procedure III

Vibration cycling shall be performed in accordance with paragraph 2.4.1.3, using table 3 and figure 5 for test parameters.

2.5 Test Results

2.5.1 Failure Criteria. Failure occurrences shall be as specified in paragraph 5.5.2 of the General Section and as indicated herein. Acceptability will be contingent upon the ability of the instrumentation to perform its function during testing (if operation during vibration is specified) and after testing. Minor damage or distortion will be permissible provided such damage or distortion does not in any way impair the ability of the instrumentation to perform its principal functions.

2.5.2 Failure Actions. If major damage occurs, the test shall be discontinued and the entire test repeated following repairs or correction of deficiencies. The evaluation of major or minor damage shall be conducted by the test engineer.

2.5.3 Test Data and Final Reports. The test data shall be as indicated in paragraph 5.5.3 of the General Section and shall also include the following:

- a. Actual test profiles implemented;
- b. Accelerometer placement locations;
- c. Test item operating modes;
- d. Any corrective actions taken.

SAND AND DUST

1.0 TEST FACILITY

1.1 Test Chamber. The test facility shall consist of a chamber and accessories to control dust concentration, velocity, temperature, and humidity of dust-laden air. In order to provide adequate circulation of the dust-laden air, not more than 50% of the cross-sectional area (normal to air flow) and 30% of the volume of the chamber shall be occupied by the test item(s). The chamber shall be provided with a suitable means of maintaining and verifying the dust concentration in circulation. A minimum acceptable means for doing this is by use of a properly calibrated smoke meter and standard light source. The dust-laden air shall be introduced into the test space in such a manner as to allow it to become approximately laminar in flow before it strikes the test item.

1.2 Dust Requirements. AC Fine Dust classified from Arizona Road Dust shall be used for this test.

2.0 TEST PROCEDURE

2.1 Test Conditions. The test item will be exposed to a dust concentration of $10\text{mg}/\text{m}^3$ using air velocities of 1750 and 300 fpm. Test temperatures to be used are ambient (23°C , 73°F) and maximum operating temperatures (underground coal -37.8°C , 100°F ; all other equipment -60°C , 140°F).

2.2 Test Item Preparation

2.2.1 Mounting. Position the test item as near the center of the chamber as practicable. If more than one item is being tested, there shall be a minimum clearance of 4 inches between surfaces of test items or any other material or object capable of furnishing protection. Also, no surface of the test item shall be closer than 4 inches from any wall of the test chamber. Orient the item so as to expose the most critical or vulnerable parts to the dust stream. The test item orientation may be changed during the test if so required by the equipment specification.

2.2.2 Performance Measurements. Conduct preliminary performance measurements and functional checks in accordance with paragraph 5.4.3 of the General Section.

2.3 Test Performance

- a. Set the chamber control to maintain an internal chamber temperature of 23°C (73°F) and a relative humidity of less than 22%. Adjust the air velocity to $1,750\pm 250$ feet per minute. Adjust the dust feeder to control the dust concentration at 10 ± 2 milligrams per cubic meter. With the test item nonoperating, maintain these conditions for 6 hours.
- b. Stop the dust feed and reduce the air velocity to 300 ± 200 feet per minute. Raise the internal chamber air temperature to one of the following temperatures:

Underground Coal Equipment: 37.8°C (100°F)
All Other Type Equipment: 60°C (140°F)

If the equipment is used in both applications, use the higher of the two temperatures. Maintain these conditions for 16 hours.

- c. While holding chamber temperature at one of the above adjust the air velocity to 1,750 \pm 250 fpm. Adjust the dust feeder to control the dust concentration at 10 \pm 2 milligrams per cubic meter. Unless otherwise specified, with the test item non-operating, maintain these conditions for 6 hours.
- d. Turn off all chamber controls and allow the test item to return to standard ambient conditions. Remove accumulated dust from the test item by brushing, wiping, or shaking, care being taken to avoid introduction of additional dust into the test item. Dust shall not be removed by either air blast or vacuum cleaning.
- e. Conduct and record performance measurements and functional checks in accordance with paragraph 5.4.4 of the General Section.
- f. Visually examine the test item for evidence of damage or deterioration. In the performance of this inspection, test items containing bearings, grease seals, lubricants, etc. shall be carefully examined for the presence of dust deposits.

2.4 Test Results

2.4.1 Failure Criteria. Failure shall be determined by the occurrence of any of the criteria delineated in paragraph 5.5.2 of the General Section and the following:

- a. Mechanical binding that clearly results in malfunction, component failure, or hazard to personnel;
- b. Deviation from acceptable conditions that may affect the performance of the device.

2.4.2 Test Data. The tabulation of test results shall include the data specified in paragraph 5.5.3 of the General Section.

MOISTURE

1.0 TEST FACILITY

1.1 Test Chamber. The rain chamber shall have the capability of producing falling rain and for Procedure I a facility for producing wind blowing at the rates specified herein. The chamber temperature shall be uncontrolled, except as regulated by water introduced as rain, throughout the test period. The rain shall be produced by a water distribution device of such design that the water is emitted in the form of droplets having a diameter range between 0.5 and 4.5 millimeters. The temperature of the water shall be between 11° and 35°C (52° and 95°F). The water distribution shall be such that, with the wind source turned off, the rain is dispersed completely over the test item and an additional test area to accomplish the wind blown rain effects on the equipment. The wind source shall be so positioned with respect to the test item that it will cause the rain to beat directly, with variations up to 45 degrees from the horizontal, and uniformly against one side of the test item. The wind source shall be capable of producing horizontal wind velocities up to 40 miles per hour. The wind velocity shall be measured at the position of the test item, prior to placement of the item in the chamber. No rust or corrosive contaminants shall be imposed on the test item by the test facility.

2.0 TEST PROCEDURE

2.1 Selection of Test Procedure. Procedure I is a wind-rain test intended for evaluating equipment used in surface mining conditions. Procedure II is a steady state rainfall test, which is used to simulate water spray conditions in underground mining.

2.2 Test Conditions. Procedure II shall subject the test item to a uniform dripping or sprinkling environment at a rate of 2 inches per hour, while in a normal orientation and inclined at an angle of 45 degrees from its normal orientation. Procedure I shall subject the item to a vertical uniform dripping environment and to a wind and water spray condition from various horizontal directions. The air and water temperature during testing shall be between 11° and 35°C (52° and 95°F).

2.3 Test Item Preparation

2.3.1 Installation. The test item shall be prepared in accordance with paragraph 5.4.2 of the General Section. Provision shall be made to allow orientation in the normal attitude and at inclinations of 45 degrees from the vertical.

2.3.2 Performance Measurements. Prior to testing conduct performance measurements and functional checks in accordance with paragraph 5.4.3 of the General Section.

2.4 Test Performance

2.4.1 Procedure I

- a. Prior to the installation of the test item in the test facility, adjust the wind source to produce a velocity of 40 ± 5 miles per hour in the horizontal direction at the location of the test item. Record the wind speed.

- b. Calibrate the spray rate from the vertical distribution system to provide 2 ± 0.5 inches per hour at the location of the top surface of the test item, by adjusting the nozzle size, pressure, and distance of the nozzle from the test item. Then adjust the parameters of the horizontal distribution system (i.e., water pressure, nozzle size, and distance to the test item) equal to the vertical system. Record the rain rate for the vertical system.
- c. Install the test item in the facility in its normal orientation.
- d. Subject the test item to water spray for a period of 10 minutes from the vertical distribution system, immediately followed by wind and spray from the horizontal distribution system for a period of 20 minutes. Unless otherwise specified, the test item shall be operated during the last 15 minutes of the wind and spray exposure. Conduct and record performance measurements and functional checks in accordance with paragraph 5.4.4 of the General Section.

Note: Precaution shall be taken to ensure that the test item is uniformly sprayed over the entire surface during the wind exposure, since the spray cone diameter may be reduced during the wind condition.

- e. Repeat paragraph d with the test item tipped forward at an angle of 45 degrees and again with the item tipped backwards at an angle of 45 degrees.
- f. Repeat paragraphs d and e for the other three sides of the test item.
- g. Remove the accumulated moisture from the exterior surfaces, open the case or protective covers, if possible, and visually examine the interior for the presence of moisture.

2.4.2 Procedure II

- a. Orient the test item in the test chamber in such a manner as to allow impingement of the spray on the item normal (90 degrees) to its horizontal plane. The rate of impingement shall be 2 ± 0.5 inches per hour.
- b. Direct the spray on the top of the test item for at least 8 minutes. Turn off spray for 4 minutes.
- c. Repeat paragraph b for four inclined positions: at a maximum angle of 45 degrees forward, backward, and to each side.
- d. At the conclusion of the testing period, return the item to the horizontal. Conduct and record performance measurements in accordance with paragraph 5.4.4 of the General Section.
- e. Remove the accumulated moisture from the exterior surfaces, open its case or protective covers, if possible, and visually examine the interior for the presence of moisture.

2.5 Test Results

2.5.1 Failure Criteria. Failures shall be determined by the occurrence of any of the criteria delineated in paragraph 5.5.2 of the General Section and the following:

Procedures I and II. Unless otherwise specified, the presence of water within the instrumentation shall be cause for rejection. In some cases, the presence of water may be permissible if it does not affect the proper operation of the item and if the design allows for proper drainage, precluding water accumulation and probable corrosion and malfunction.

2.5.2 Test Data. The tabulation of test results shall include the data specified in paragraph 5.5.3 of the General Section.

TEMPERATURE-HUMIDITY

1.0 TEST FACILITY

1.1 Test Chamber. A test chamber shall be used which can meet the temperature and humidity cycling specified in figure 7. The materials of construction for the chamber, baffles, test item mounts, and supports shall be of non-absorbent materials (e.g., wood) and shall be non-reactive in high humidity. The chamber shall be designed to prevent condensed moisture from dripping on the test item. Provisions shall be made for maintaining the flow of air in the test chamber space below 150 feet per minute, but sufficient to minimize temperature gradients within the chamber. The space shall be vented to the atmosphere to prevent the buildup of total pressure.

1.2 Auxiliary Equipment. The humidity shall be generated from stream or distilled, demineralized, or deionized water having a pH value between 6.0 and 7.2 at 23°C (73°F). No corrosive contaminants or rust shall be imposed on the test item by the test facility. The pH limits of the distilled water shall be carefully controlled to ensure uniform test results.

1.3 Monitoring Equipment

1.3.1 Humidity. Relative humidity shall be determined from the dry bulb/wet bulb thermometer comparison method or a more accurate method. When the wet bulb control method is used, the wet bulb should be located as close to the dry bulb sensor as possible to insure that both sense air at the same temperature. The wet bulb wick must be kept thoroughly wet with the wet bulb and tank cleaned and a new wick installed at least every 30 days. The air velocity flowing across the wet bulb shall not be less than 900 feet per minute. When wet bulb/dry bulb charts are used, they shall be capable of being read with a resolution within 0.6°C (1°F).

1.3.2 Temperature. Unless otherwise specified, the sensors for controlling the chamber temperature shall be located in the air stream where the conditioned air enters the chamber workspace.

2.0 TEST PROCEDURE

2.1 Test Conditions. The test item shall be exposed to 10 complete cycles of the temperature and humidity limits, durations, rates of change, and operational requirements specified in figure 7. The relative humidity during temperature transition periods need not be controlled. Instrumentation shall be operated during testing. The test conditions shall be achieved within the time periods specified ± 5 minutes.

2.2 Test Item Preparation

2.2.1 Mounting. The test item shall be positioned in a normal usage attitude and prepared in accordance with paragraph 5.4.2 of the General Section. When testing more than one specimen, the test items shall be positioned so that they do not contact each other.

2.2.2 Performance Measurements. Immediately after preconditioning, conduct preliminary performance measurements and functional checks in accordance with paragraph 5.4.3 of the General Section.

2.3 Test Performance

- a. Subject the test item to ten, 24 hour cycles in accordance with figure 7.
- b. Monitor chamber dry bulb and wet bulb temperatures within the exposure zone of the test item at least every 2 hours. The wet bulb temperature may be recorded at other chamber locations provided that uniform humidity conditions throughout the chamber are verified. Humidity measurements shall be made throughout the chamber space approximately 2 hours after the start of phase II of the first cycle in order to ascertain uniform conditions.
- c. The on-off duty cycle of the test item shall be as specified in figure 7. Conduct and record performance measurements during phase II of each cycle in accordance with paragraph 5.4.4 of the General Section.
- d. After completion of the test, allow the test item to dry for a minimum of 8 hours.
- e. Conduct and record final performance measurements and functional checks in accordance with paragraph 5.4.4 of the General Section.
- f. Visually examine the test item for evidence of damage, deterioration, or corrosion.

2.4 Test Results

2.4.1 Failure Criteria. Unless otherwise specified, any “out of tolerance” condition during the high temperature, high humidity phase of testing shall constitute failure. Also, the occurrence of any of the criteria delineated in paragraph 5.5.2 of the General Section shall result in failure.

2.4.2 Test Data. The tabulation of test results shall include the data specified in paragraph 5.5.3 of the General Section.

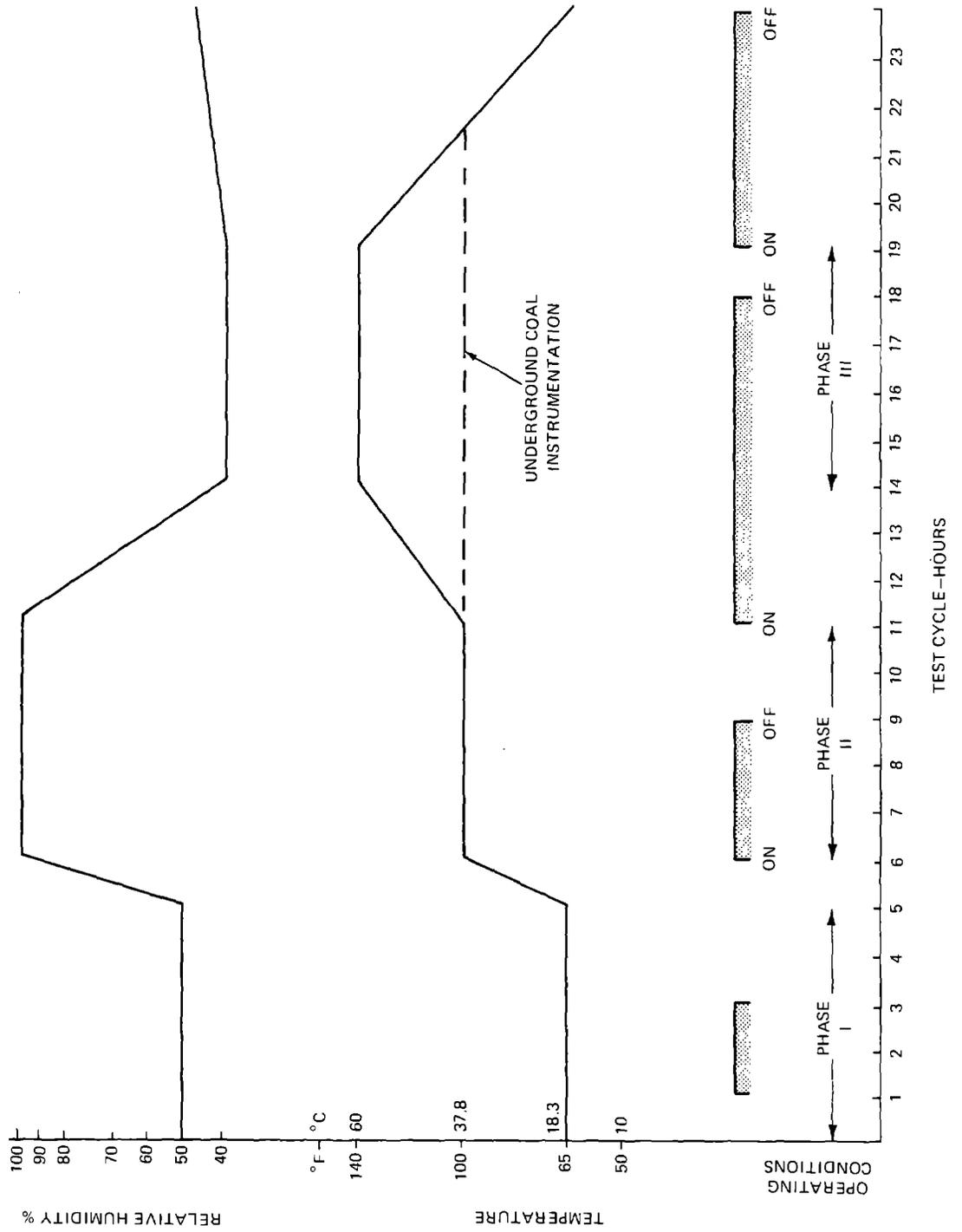


Figure 7. Temperature-Humidity Cycle

CORROSION

1.0 TEST FACILITY

1.1 Test Chamber. The chamber required for acetic acid salt fog testing and all accessories shall be made of material such as glass, hard rubber, plastic, or suitably coated wood which will not affect the corrosiveness of the fog. In addition, all parts that come in contact with test specimens shall be made of materials that will not cause galvanic or electrolytic corrosion. The chamber and accessories shall be constructed and arranged as follows:

- a. There shall be no direct impinging of the spray or dripping of the condensate on the test items.
- b. The spray shall circulate freely about all specimens to the same degree.
- c. No liquid which has entered the exposure chamber and has come into contact with the test items shall return to the salt-solution reservoir.
- d. The chamber shall be properly vented.
- e. The use of immersion heaters within the chamber for the purpose of maintaining the temperature within the exposure zone is not acceptable.

1.2 Auxiliary Equipment and System

- a. Atomizers. The atomizer(s) used shall be of such design and construction as to produce a finely divided, wet, dense fog. Atomizing nozzles shall be made of materials which do not react with the salt solution.
- b. Air Supply. The compressed air supply to the nozzle(s) for atomizing the salt solution shall be free of oil and dirt and maintained between 10 and 25 psi. The air supply may be freed from oil and dirt by passing it through a water scrubber or at least a foot of suitable cleaning material, such as asbestos, sheep's wool, excelsior, or slag wool. Atomizing nozzles may have a "critical pressure" at which an abnormal increase in the corrosiveness of the salt fog occurs. If the "critical pressure" of a nozzle has not been established with certainty, control of fluctuation in the air pressure within ± 0.1 psi (0.7 kN/m^2), by installation of a suitable pressure-regulator valve, minimizes the possibility that the nozzle will be operated at its "critical pressure".

1.3 Salt Water Solution

1.3.1 Salt Concentration. The salt solution shall be prepared by dissolving 5 ± 1 parts by weight of salt in 95 parts of distilled water or water containing not more than 200 ppm of total solids. A solution having a specific gravity of 1.0255 to 1.0400 at 25°C (77°F) will meet the concentration requirement. It is suggested that a daily check be made.

1.3.2 PH Level. The salt used shall be sodium chloride substantially free of nickel and copper and containing on the dry basis not more than 0.1% of sodium iodide and not more than 0.3% of total impurities. The pH of the solution shall be adjusted to the range 3.1 to 3.3,

as measured on a sample of the collected spray, by the addition of acetic acid. The initial solution may be adjusted to a pH of 3.0 to 3.1 with the expectation that the pH of the collected fog will be within the specified limits. Adjustment of the initial pH for make-up solution shall be based upon the requirements to maintain the required pH of the collected samples. If less than 0.1 or more than 0.3% of the glacial acetic acid is required to attain the specified pH, the purity of the water or salt or both may not be satisfactory.

1.3.3 Purity. Before the solution is atomized, it shall be free of suspended solids. The freshly prepared salt solution may be filtered or decanted before it is placed in the reservoir, or the end of the tube leading from the solution to the atomizer may be covered with a double layer of cheesecloth to prevent plugging of the nozzle.

1.4 Monitoring Devices

1.4.1 Temperature. The temperature measuring device shall be located in the exposure zone of the chamber. A suitable method to record the temperature is by a continuous recording device or by a thermometer which can be read from outside the closed cabinet. The recorded temperature must be obtained with the salt-spray chamber closed to avoid a false low reading because of wet bulb effect when the chamber is open.

1.4.2 Salt Concentration. A laboratory type hydrometer may be used to measure the concentration of sodium chloride.

1.4.3 PH Level. The pH measurement shall be made electrometrically, using a glass electrode with a saturated potassium chloride bridge, or by a colorimetric method, such as bromothymol blue, provided the results are equivalent to those obtained with the electrometric method. The pH shall be measured when preparing each new batch of solution and as specified in 1.3.2.

1.4.4 Atomization and Quantity of Fog. At least two clean fog collectors shall be so placed within the exposure zone that no drops of solution from the test specimens or any other source shall be collected. The collectors shall be placed in the proximity of the test specimens, one nearest to any nozzle and the other farthest from all nozzles. The fog shall be such that for each 80 cm² of horizontal collecting area there will be collected in each collector from 0.75 to 2.0 ml of solution per hour based on an average run of at least 16 h. Suitable collecting devices are glass funnels with the stems inserted through stoppers into graduated cylinders, or crystallizing dishes. Funnels and dishes with a diameter of 10 cm have an area of about 80 cm². The sodium chloride concentration of the collected solution shall be 5±1 weight percent.

2.0 TEST PROCEDURES

2.1 Test Conditions. The test item shall be exposed to an acidified (pH 3.1–3.3) salt fog atmosphere maintained at 35±1.1, -1.7°C (95±2, -3°F) for a period of 120 hours.

2.2 Test Item Preparation

2.2.1 Preconditioning. The test item shall be given a minimum of handling, particularly on the significant surfaces, and shall be prepared for test immediately before exposure. Unless otherwise specified, uncoated metallic or metallic coated devices shall be thoroughly cleaned of oil, dirt, and grease as necessary until the surface is free from water break. The cleaning methods

shall not include the use of corrosive solvents, solvents which deposit either corrosive or protective films, or abrasives other than a paste of pure magnesium oxide. Test items having an organic coating shall not be solvent-cleaned. Those portions of test items which come in contact with the support and, unless otherwise specified in the case of coated devices or samples, cut edges, and surfaces not required to be coated, shall be protected with a suitable coating of wax or similar substance impervious to moisture.

2.2.2 Installation and Mounting. The test item shall be prepared in accordance with the requirements of paragraph 5.4.2 of the General Section. The position of the specimens in the acetic acid-salt spray (fog) chamber during the test shall be such that the following conditions are met:

- a. Unless otherwise specified, the specimens shall be supported or suspended between 15 and 30 degrees from the vertical and preferably parallel to the principal direction of horizontal flow of fog through the chamber, based upon the dominant surface being tested.
- b. The specimens shall not contact each other, any metallic material, or any material capable of acting as a wick.
- c. Each specimen shall be so placed as to permit free settling of fog on all specimens.
- d. Suitable materials for the construction or coating of racks and supports are glass, rubber, plastic, or suitably coated wood. Bare metal shall not be used. Specimens shall preferably be supported from the bottom or the side. Slotted wooden strips are suitable for the support of flat panels. Suspension from glass hooks or waxed string may be used as long as the specified position of the specimen is obtained if necessary by means of secondary support at the bottom of the specimens.
- e. Salt solution from one specimen shall not drip on any other specimen.

2.2.3 Performance Measurements. Prior to testing, conduct preliminary performance measurements and functional checks on all test items in accordance with paragraph 5.4.3 of the General Section.

2.3 Test Performance

- a. Prior to installation of the test item, the chamber shall be operated for a period of time sufficient to ensure that the following conditions are provided:
 - (1) The temperature in the exposure zone shall be maintained at 35°C (95°F).
 - (2) The salt solution collected in the receptacles shall have a concentration as specified in paragraph 1.3.1 when measured at a temperature of 35°C (95°F) and a pH as specified in paragraph 1.3.2.
- b. The test item shall be exposed to the acidified salt fog for a period of 120 hours. The test shall be continuous for the duration of the entire test period. Continuous operation implies that the chamber be closed and the fog operating continuously except for short interruptions required to ensure proper chamber conditions and to inspect the test item. These interruptions shall be held to a maximum of 1 hour total in any 48-hour period.

- c. The chamber temperature may be monitored continuously, but at least every 2 hours. Proper salt fog generation shall be verified at least twice per day at least 7 hours apart. This shall include the volume of salt solution collected in the fog collecting devices, concentration (or specific gravity and pH).
- d. At the completion of the exposure period, remove the test item from the chamber and allow it to set at the standard conditions for a period of 1 hour.
- e. Conduct and record performance measurements and functional checks in accordance with paragraph 5.4.4 of the General Section.
- f. Allow the test item to dry at a temperature of 35°C (95°F) for a period of 24 hours. While at standard conditions, repeat the performance measurement and functional checks performed in paragraph e.
- g. Conduct a visual examination of the test item for evidence of corrosion. If necessary, the salt deposits on the test item may be removed using clean water not warmer than 35°C (95°F).

2.4 Test Results

2.4.1 Failure Criteria. Failures shall be determined by the occurrence of any of the criteria delineated in paragraph 5.5.2 of the General Section and the following:

- a. Any evidence of corrosion;
- b. Indications of arcing or short circuits;
- c. Incrustation and binding of moving parts by salt particles.

2.4.2 Test Data. The tabulation of test results shall include the data specified in paragraph 5.5.3 of the General Selection, as well as the following:

- a. Temperature within the exposure zone of the chamber.
- b. Measurements of the salt concentration (ml per hr per 80 cm²) and the pH level of the salt solution reservoir taken prior to the installation of the test item in the chamber and during the exposure period.
- c. Method of cleaning test item prior to and after testing.
- d. Interruptions in test, cause and length of time.
- e. Results of all inspections, performance measurements, and functional checks.
- f. Type of salt, water, and acetic acid used in preparing the solution.
- g. Method of supporting or suspending the item in the chamber.
- h. Type of specimen and its dimensions, or number or description of part.

ELECTROMAGNETIC COMPATIBILITY

1.0 TEST FACILITY

1.1 Test Equipment. The apparatus and monitoring or measuring equipment required for the test setup shall be as prescribed in MIL-STD-461^[60] and MIL-STD-462^[61].

2.0 TEST PROCEDURE

2.1 Selection of Test Procedure. Applicable tests for the various types of instruments shall be selected from the following outline:

EMC Tests for Various Instrument Application

Underground Coal	Underground Metal	Surface
a. Radiation Susceptibility Procedure I Procedure II Procedure III	Radiation Susceptibility Procedure I Procedure II Procedure III	Radiation Susceptibility Procedure II
b. Conducted Susceptibility Procedure IV	Conducted Susceptibility Procedure IV	Conducted Susceptibility Procedure IV

2.2 Test Set-Up

2.2.1 Radiation Susceptibility

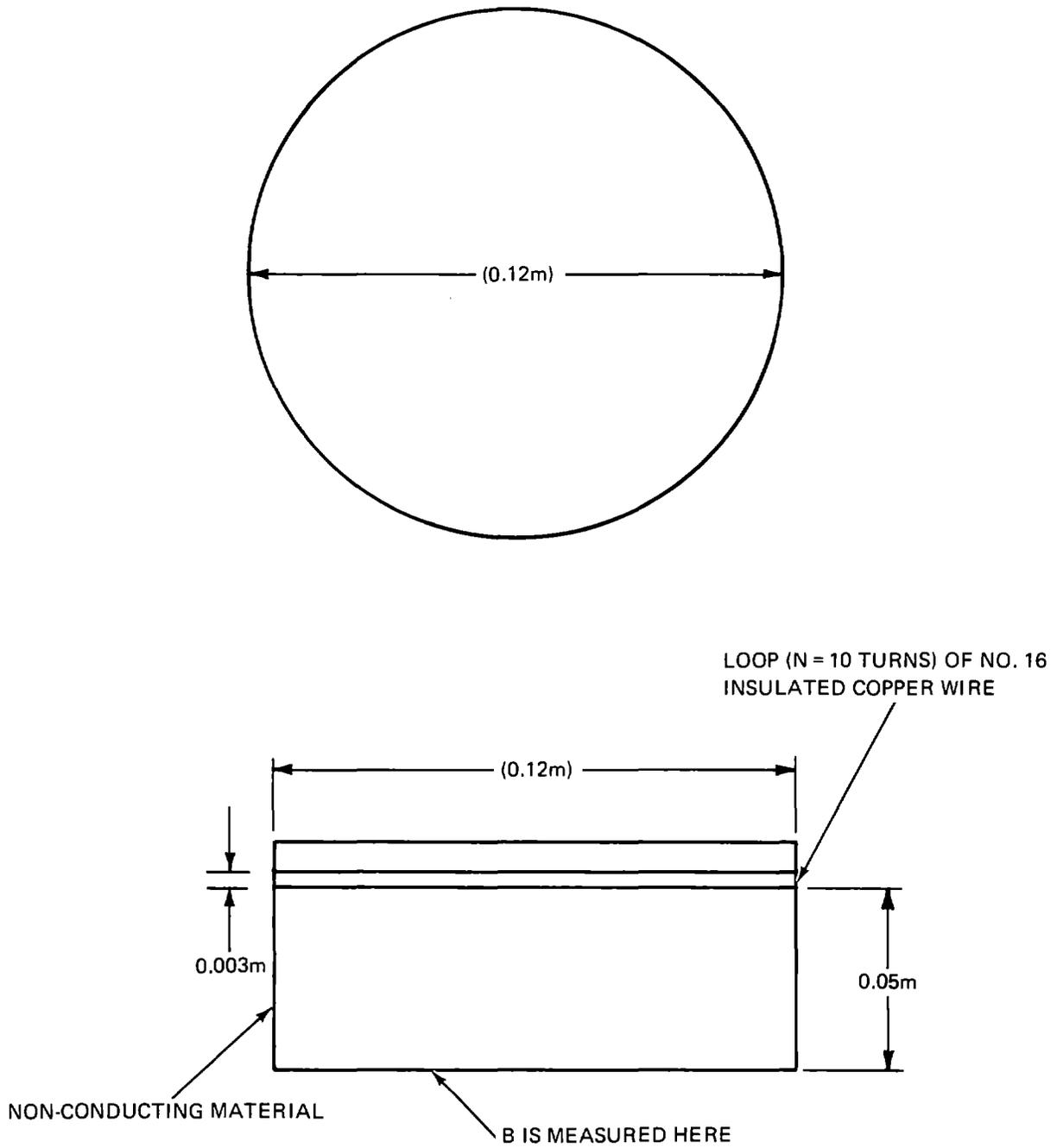
Procedure I

The following apparatus is required to perform Procedure I:

- Radiating Loop.** The radiating loop is shown in figure 8. The loop shall be capable of producing a magnetic flux density of 5×10^{-5} Tesla/Ampere at a point approximately 0.05 m from the face of the loop. It shall be supported on a wooden form or similar non-conducting material.
- Signal Source.** The signal source is shown in figure 9. The loop shall be supplied with sufficient current capable of producing magnetic flux densities 20 to 30 db greater than the applicable limit at the test frequency.
- EMI Meter or Narrow Band VTVM.** The EMI Meter or Narrow band VTVM must be capable of reading levels as low as $30 \mu\text{v}$ in the 30-Hz to 30-kHz frequency range. The equipment shall have a 10-Hz or narrower bandwidth at the 3-db points.

Procedure II

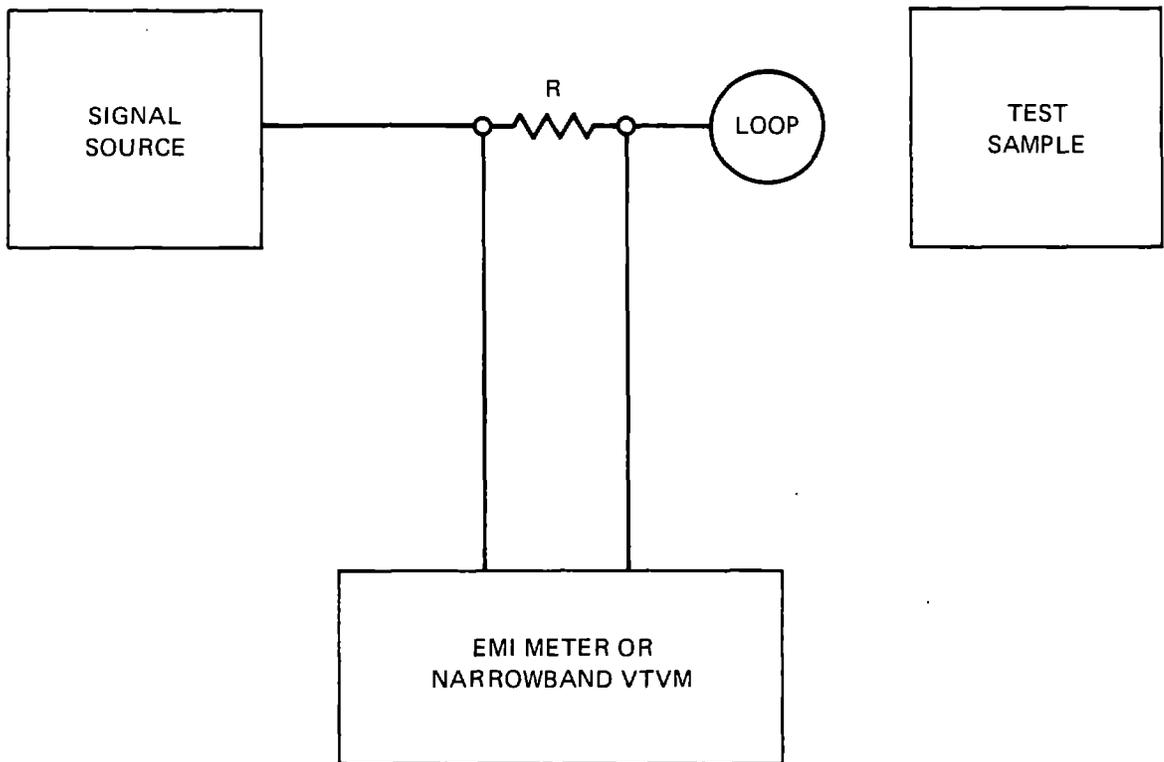
The apparatus required to perform Procedure II is the same as that used for Procedure I.



NOTE 1: $B = 5 \times 10^{-5} \frac{\text{TESLA}}{\text{AMP}}$ AT .05m FROM WIRE TURNS

NOTE 2: LOOP SELF RESONANT FREQUENCY SHALL BE GREATER THAN 100 kHz.

Figure 8. Radiation Susceptibility, Procedures I and II, Loop Antenna



R = RESISTOR OF 1 OHM (a 1-VOLT OUTPUT TO THE VOLTMETER YIELDS a 1-AMP INPUT TO THE LOOP.)

Figure 9. Radiation Susceptibility, Procedures I and II, Signal Source

Procedure III

The following apparatus is required to perform procedure III:

- a. Signal Source. The signal source must be capable of producing sinusoidal signals in the frequency range of 10 to 500 MHz and compatible with the input requirements of the RF Amplifier.
- b. RF Amplifier. The RF amplifier must be capable of delivering 5 watts of power to the antenna over the required test frequency range.
- c. RF Antenna. The apparatus configuration for Procedure III is shown in figure 10.

2.2.2 Conduction Susceptibility

Procedure IV

The apparatus configuration shown in figure 11 (a) or (b) may be used as required to perform Procedure IV. The signal generator must be calibrated to produce the impulse described in figure 12 by using the configuration shown in figure 13. The apparatus required to perform Procedure IV is as follows:

- a. Spike Generator with characteristics as follows:
 - (1) Pulse Width = 10 microseconds.
 - (2) Pulse Repetition Rate = 3 to 10 pps.
 - (3) Voltage Output = not less than 200-volt peak.
 - (4) Output Control = adjustable from 0 to 200-volt peak.
 - (5) Phase Positioning = 0 to 360 degrees.
 - (6) Source Impedance (with injection transformer) = 0.5 ohms.
 - (7) Transformer Current Capacity (commensurate with line being tested).
 - (8) External Synch Capability.
 - (9) External Trigger Capability.
- b. Capacitor. The 10-microfarad feedthrough capacitor as shown in figure 10.
- c. Oscilloscope. Any oscilloscope with 10-MHz bandwidth and adequate sweep rates is acceptable.

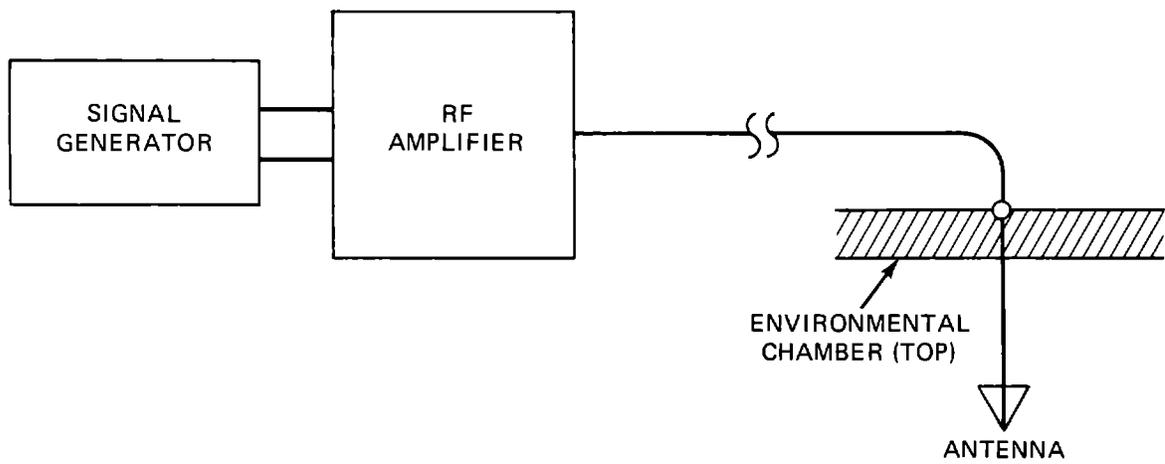
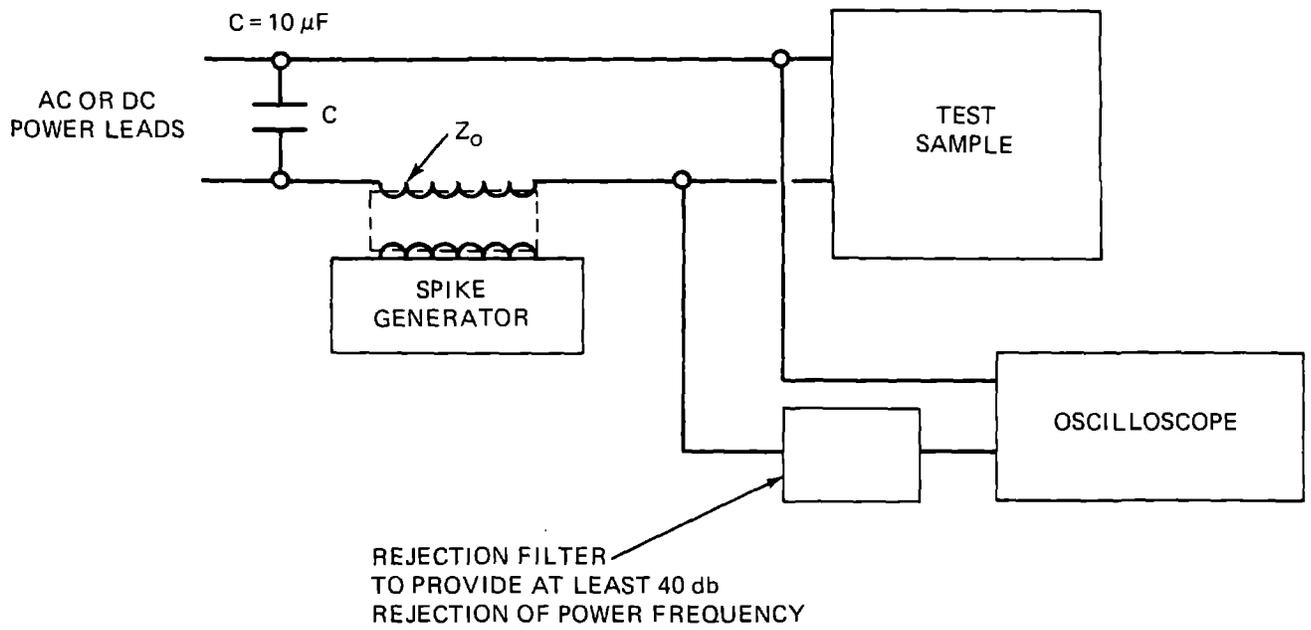
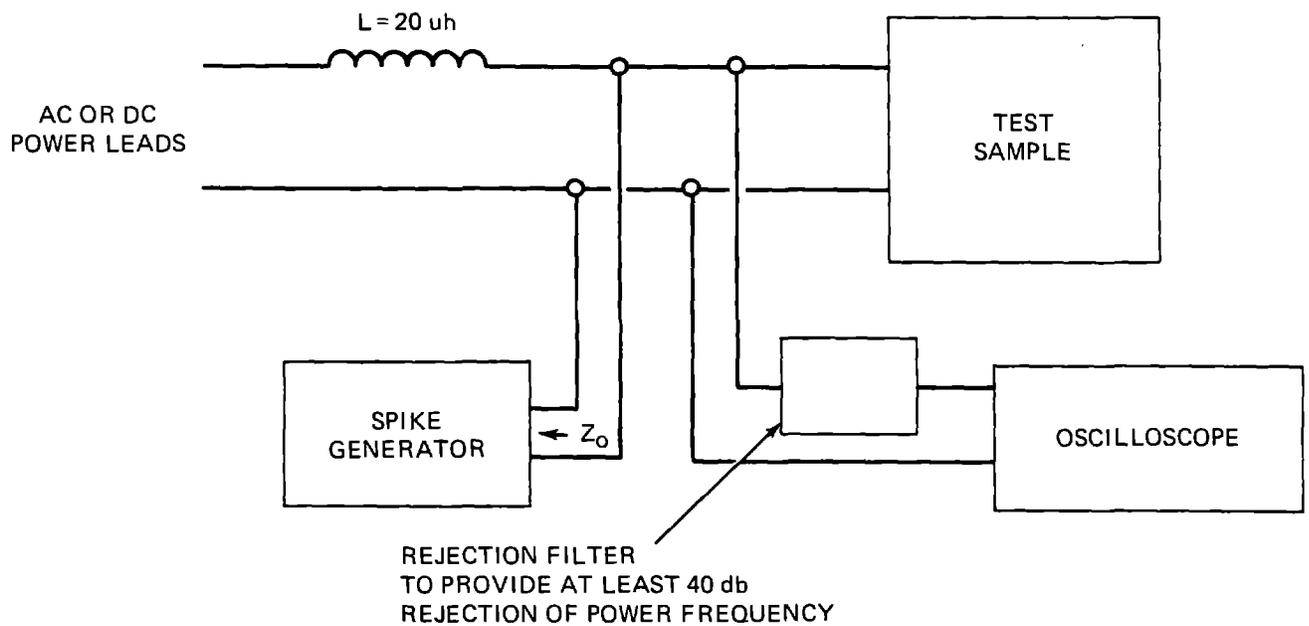


Figure 10. Radiation Susceptibility, Procedure III, Apparatus Configuration

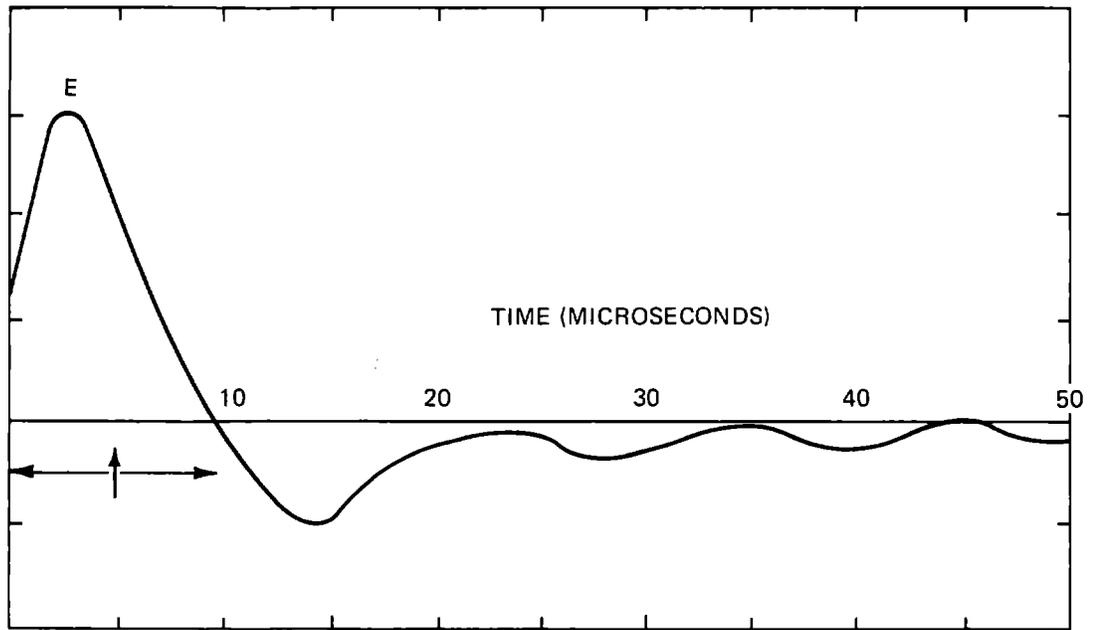


(a) SERIES INJECTION



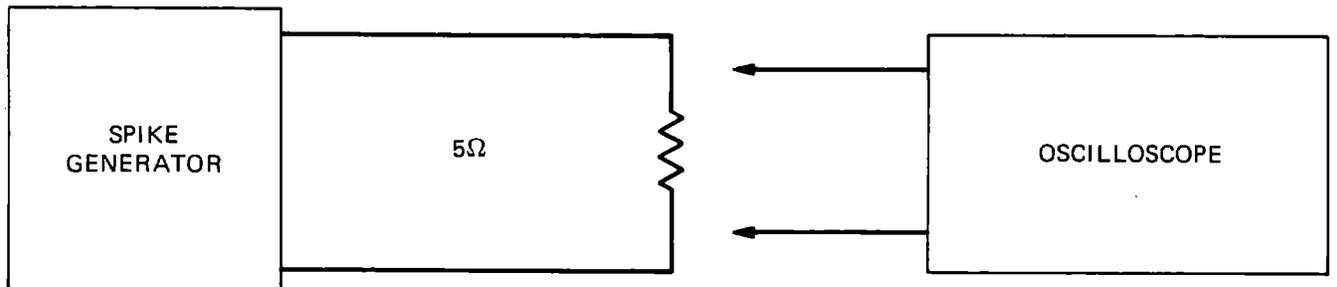
(b) PARALLEL INJECTION

Figure 11. Conduction Susceptibility, Procedure IV, Apparatus Configuration



$E = 2$ TIMES LINE VOLTAGE OR 100 VOLTS, WHICHEVER IS LESS
 $t = 10$ MICROSECONDS

Figure 12. Spike Characteristics for Conduction Susceptibility Test



CONNECT A CALIBRATED 5 OHM NON-INDUCTIVE LOAD RESISTOR
 TO GENERATOR TO VERIFY SPIKE CHARACTERISTICS

Figure 13. Calibration of Spike Characteristics

2.3 Test Item Preparation

2.3.1 Before performing any procedure, preliminary performance measurements and functional checks shall be performed in accordance with paragraph 5.4.3 of the General Section.

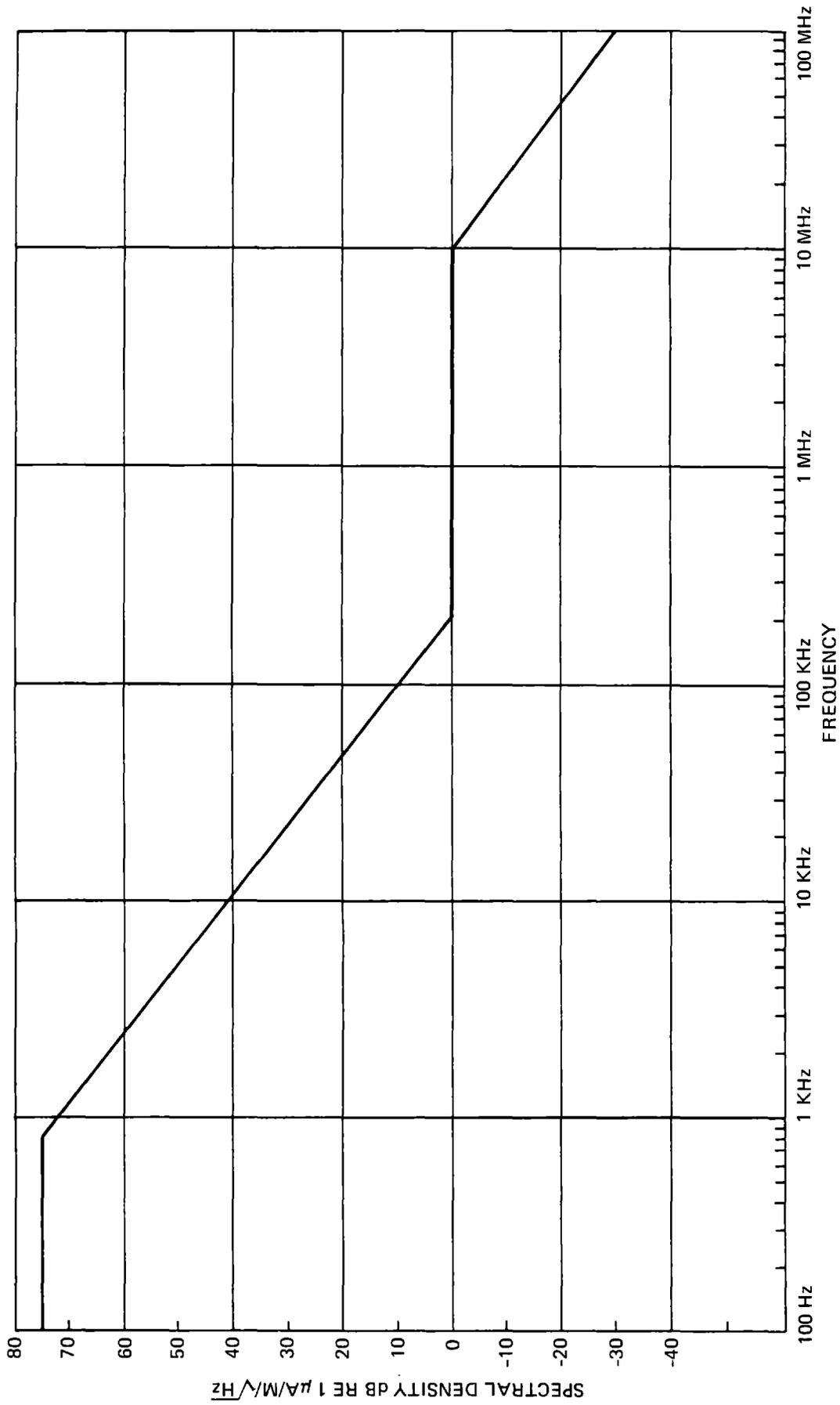
2.4 Test Performance

Procedure I

- a. Install the devices to be tested in the environmental chamber in accordance with paragraph 5.4.2 of the General Section.
- b. Position the 0.12-m (4.7-in.) diameter radiating loop of the RFI/EMI apparatus 0.05 m (2.0 in.) from the surface of one of the devices being tested. The plane of the loop shall be parallel to the plane of the surface of the device being tested.
- c. Establish the appropriate magnetic flux density in the loop to simulate the spectral density shown in figure 14.
- d. Move the loop over the surface of the device including the signal input and output cables and connectors (if applicable) to determine the point at which the applied field produces maximum susceptibility. This can be ascertained by the variation produced in the device readout.
- e. With the loop still in place, operate and inspect the device and obtain the results in accordance with paragraph 5.4.4 of the General Section.

Procedure II

- a. Install the devices to be tested in the environmental chamber in accordance with paragraph 5.4.2 of the General Section.
- b. Position the 0.12-m (4.7-in.) diameter radiating loop of the RFI/EMI apparatus 0.05 m (2.0 in.) from the surface of one of the devices being tested. The plane of the loop shall be parallel to the plane of the surface of the device being tested.
- c. Establish the appropriate magnetic flux density in the loop by applying current to the loop sufficient to establish 110-120 db μ V across the 1-ohm series resistor at a frequency of 60 Hz.
- d. Move the loop over the surface of the device including the signal input and output cables and connectors (if applicable) to determine the point at which the applied field produces maximum susceptibility. This can be ascertained by the variation produced in the device readout.
- e. With the loop still in place, operate and inspect the device and obtain the results in accordance with paragraph 5.4.4 of the General Section.
- f. Repeat steps a–f (inclusive) for each of the devices to be tested.
- g. Repeat steps a–g (inclusive) for a test frequency of 400 Hz by applying sufficient current to the loop to establish 80–90 db μ V across the 1-ohm series resistor (see step c).



SOURCE: DATA FROM NBS CONTRACT H0133005.

Figure 14. Magnetic Field Susceptibility Bound for Underground Mines

- h. Inspect all the devices in accordance with paragraph 5.4.4 of the General Section.
- i. Turn off all power and return the devices to standard ambient conditions.

Procedure III

- a. Install the devices to be tested in the environmental chamber in accordance with paragraph 5.4.2 of the General Section.
- b. Position the devices to be tested such that they are located 0.3 m (1 foot) from the radiating antenna of the RFI/EMI apparatus.
- c. Turn on the power amplifier such that 5 watts of power are delivered to the antenna.
- d. While slowly sweeping the signal generator through the 25–28 MHz frequency range, operate and inspect the device and obtain the results in accordance with paragraph 5.4.4 of the General Section.
- e. Repeat step d for the frequency range of 150–170 MHz.
- f. Repeat step d for the frequency range of 450–470 MHz.
- g. Inspect all the devices in accordance with paragraph 5.4.4 of the General Section.
- h. Turn off all power and return the devices to standard ambient conditions.

Procedure IV

- a. Install the devices to be tested in the environmental chamber in accordance with paragraph 5.4.2 of the General Section.
- b. Turn on the spike generator and apply alternately positive and negative pulses, single and repetitive (6 to 10 pulses per second) spikes to the ungrounded input lines of one of the devices to be tested. Spikes shall be positioned at each of the 90 degree phase shift positions. The characteristic of the spike shall be as illustrated in figure 12.
- c. Operate and inspect the device and obtain results in accordance with paragraph 5.4.4 of the General Section.
- d. Repeat steps c and d until all devices have been tested.
- e. Inspect all the devices in accordance with paragraph 5.4.4 of the General Section.
- f. Turn off all power, and return the devices to standard ambient conditions.

3.0 TEST RESULTS

3.1 Test Result Reporting

Conducted or Radiated Susceptibility. Record only instrumentation malfunction or degradation in performance when exposed to the specified levels.

3.2 Test Result Interpretation. The results of EMI testing are not intended to provide pass/fail conclusions for each instrumentation type. Rather the testing will serve to evaluate the compatibility of instrumentation types with each other or with other types of equipment, and it will assist in prescribing proper precautions taken during installation or usage.

RELIABILITY

1.0 TEST FACILITY

1.1 Test Chamber. The test chamber shall be capable of maintaining the environmental conditions and cycling requirements specified in figure 15 with the tolerances of these conditions being maintained within the limits specified in paragraph 5.2.2 of the General Section. The temperature change rates for both heating and cooling cycles shall not be less than 2.2°C (4°F)/minute and not greater than 5.6°C (10°F)/minute. The materials of construction for the chamber, baffles, test item mounts and supports shall be non-absorbent materials and non-reactive in high humidity. The chamber shall be designed to prevent condensed moisture from dripping on the test item. The air flow should be sufficient to minimize temperature gradients within the chamber, but shall be maintained below 150 feet per minute. The space should be vented to atmosphere to prevent the build-up of chamber pressure.

1.2 Auxiliary Equipment

1.2.1 Humidity Generator. The humidity shall be generated by steam or distilled, demineralized, or deionized water having a pH value between 6.0 and 7.2 at 23°C (73°F). The pH limits of the distilled water must be carefully controlled to ensure uniform test results. No corrosive contaminants or rust shall be imposed on the test item by the test facility.

1.2.2 Vibration Machine. The vibration machine and monitoring system shall be in accordance with the requirements given in the vibration section of this document.

1.2.3 Automatic Controls. The testing cycle may be controlled automatically. Means shall be provided to interrupt the programming used in the automatic control of temperature cycling until maximum and minimum air temperatures are satisfied. Safety devices shall be installed to shut off both the test item and temperature control in the event of temperature overruns.

1.3 Monitoring Equipment

1.3.1 Temperature. Unless otherwise specified, the sensors for controlling the chamber temperature shall be located in the air stream where the conditioned air enters the chamber workspace.

1.3.2 Humidity. Relative humidity shall be determined from the dry bulb/wet bulb thermometer comparison method or a more accurate method. When the wet bulb control method is used, the wet bulb should be located as close to the dry bulb sensor as possible to ensure that both sense air at the same temperature. The wet bulb wick must be kept thoroughly wet with the wet bulb and tank inspected and a new wick installed at least every 30 days. The air velocity flowing across the wet bulb shall not be less than 900 feet per minute. When wet bulb/dry bulb charts are used, they shall be capable of being read with a resolution within 0.6°C (1°F).

1.3.3 Vibration. Vibration parameters may be measured by velocity or accelerometer transducers. The vibration equipment should be checked for proper operation every 24 hours of operation.

1.3.4 On-Off Timing Device. Each test item shall be equipped with a time meter which records the total test item ON time.

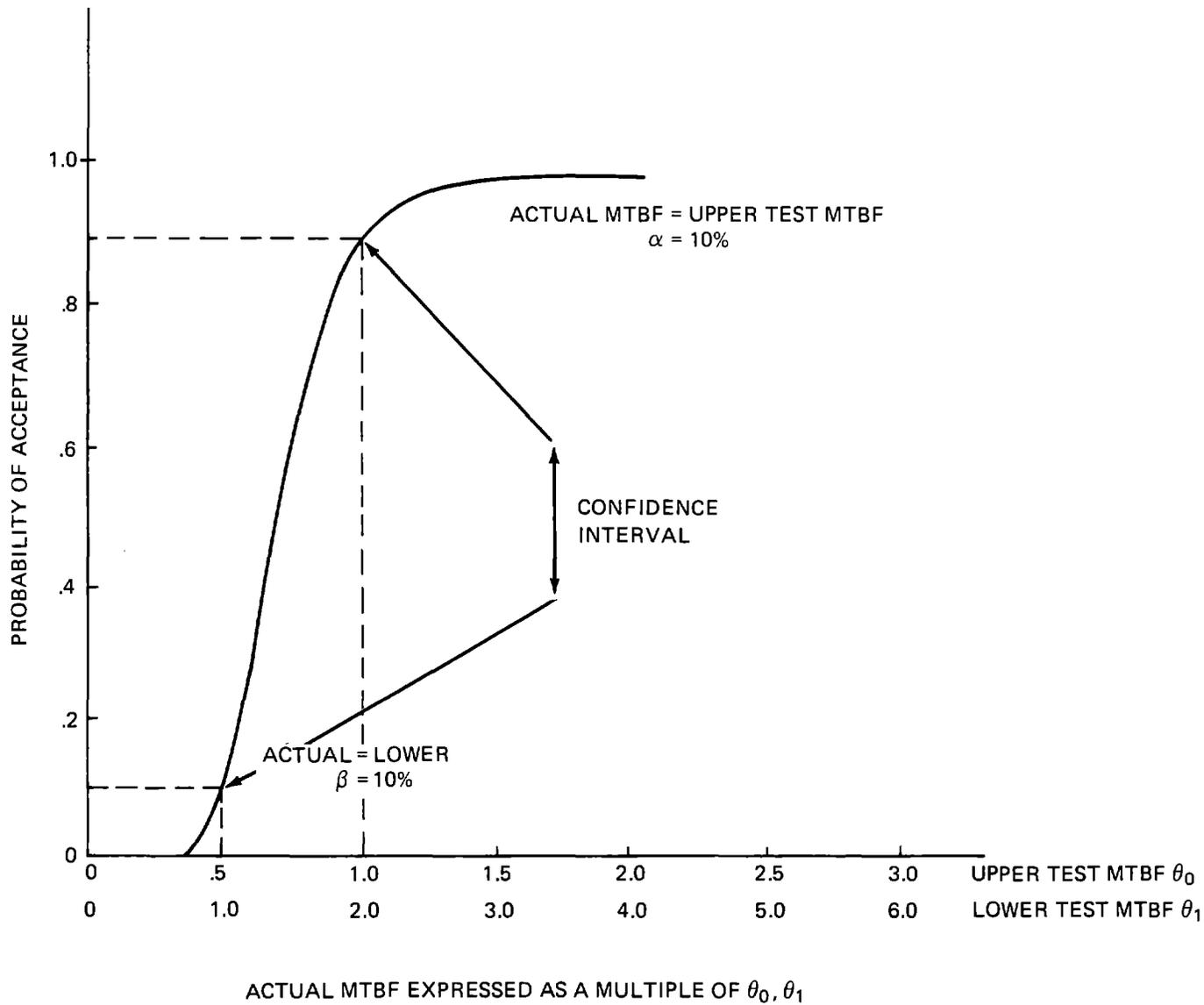


Figure 15. Reliability Sample Test Plan ($\alpha = 10\%$, $\beta = 10\%$)

2.0 TEST PLAN SELECTION

2.1 Identification of Test Parameters. In order to select a suitable test plan, the value of certain test parameters must be chosen. These parameters indicate the level of confidence in the test results, the probability that the test item will pass the test and the test duration (affecting overall testing cost):

Lower Test MTBF (θ_1) – The lower test MTBF (Mean Time Between Failure) is that value of the instrumentation reliability which is unacceptable. The selected test plan will reject with a high probability instrumentation which has an actual reliability that approaches the lower test MTBF.

Upper Test MTBF (θ_0) – The upper test MTBF is an acceptable reliability value. The selected test plan will accept with a high probability instrumentation with an actual reliability close to the upper test MTBF. The upper test MTBF is also the design goal of the manufacturer.

Predicted MTBF – The predicted MTBF is the value of instrumentation reliability which the manufacturer must prove by accepted methods prior to testing. The predicted MTBF shall be at least equal to the upper test MTBF. This will ensure that with high probability the test item will be accepted by the selected test plan.

Consumer's Risk (β) – This is the probability of accepting instrumentation which has an actual reliability equal to the lower test MTBF. The probability of accepting instrumentation which has an actual reliability less than the lower test MTBF will be less than the consumer's risk. An example of a test plan with $\beta = 10\%$ is shown in figure 15.

Producer's Risk (α) – This is the probability of rejecting instrumentation with an actual reliability equal to the upper test MTBF. The probability of rejecting a test item with an actual MTBF greater than the upper test MTBF will be less than the producer's risk. A graphical representation of a test plan with $\alpha = 10\%$ is shown in figure 15.

Discrimination Ratio (d) – The discrimination ratio is the ratio of the upper test MTBF (θ_0) to the lower test MTBF (θ_1).

2.1.1 Decision Risks. The producer's and consumer's risks provide a means for controlling the level of confidence of the test results. The lower the decision risks, the higher the level of confidence in the reliability demonstrated by the instrumentation. However, low decision risks generally require testing for a greater number of hours (higher cost).

2.1.2 Discrimination Ratio. In general, the higher the discrimination ratio, the shorter the test. However, the ratio must not be too high since this will cause the upper test MTBF, which is the design goal of the manufacturer, to become unattainable.

2.1.3 Specified Confidence Intervals. When it is desired that the MTBF value demonstrated by the test must be within some confidence interval, the following process is suggested: select the confidence interval such that its lower limit is equal to $(100 - (\text{consumer's} + \text{producer's risk}))\%$. For example, an 80% confidence level in the demonstrated MTBF would be selected with a 10% consumer's risk, 60% confidence interval with a 20% consumer's risk, or 40% confidence interval with a 30% consumer's risk.

2.2 Types of Test Plans. Table 4 provides a list of test plans designed to varying combinations of decision risks and discrimination ratios.

Table 4. Reliability Test Plans

Test Plan	True decision risks		Discrimination Ratio θ_0/θ_1	Test duration (multiples) of θ_1	Accept-reject failures	
					Reject (equal or more)	Accept (equal or less)
	α	β				
A	12.0%	9.9%	1.5	45.0	37	36
B	10.9%	21.4%	1.5	29.9	26	25
C	17.8%	22.1%	1.5	21.1	18	17
D	9.6%	10.6%	2.0	18.8	14	13
E	9.8%	20.9%	2.0	12.4	10	9
F	19.9%	21.0%	2.0	7.8	6	5
G	9.4%	9.9%	3.0	9.3	6	5
H	10.9%	21.3%	3.0	5.4	4	3
I	17.5%	19.7%	3.0	4.3	3	2
High Risk Test Plans						
J	28.8%	31.3%	1.5	8.0	7	6
K	28.8%	28.5%	2.0	3.7	3	2
L	30.7%	33.3%	3.0	1.1	1	0

2.2.1 Test Duration. The test length shall be as indicated in table 4 for a particular test plan, or when the number of failures which constitutes a reject decision is accumulated. Test item ON time (i.e., actual operating time) shall be used in determining test length and compliance with the accept/reject criteria. Each test sample shall operate at least one-half of the average operating time of all items on test.

2.2.2 Accept-Reject Criteria. When an accept decision has been reached, the instrumentation design has been qualified for production with respect to reliability. If an accept decision is reached on a sampling basis, all items in the lot are accepted.

3.0 PRETEST REQUIREMENTS

3.1 Reliability Prediction. Prior to reliability testing, the instrumentation manufacturer should provide a reliability prediction report which indicates that the instrumentation reliability predicted is at least equal to the upper test MTBF (θ_0). The primary purpose of this prediction is to avoid costly testing of designs which are not capable of providing the minimum specified reliability. In the event that the design proposed for testing displays an undue risk (predicted MTBF is low compared to the upper test MTBF), the design is not ready for test. The reliability prediction may be based upon the following in their order of precedence:

- a. MIL-HDBK-217^[74]
- b. Past Test Results
- c. Actual Field Data

3.2 Pretest Burn-In/Preconditioning. Burn-in and screening tests or preconditioning procedures should be implemented as a matter of course for all test units and units delivered for a procurement contract. These procedures serve to reduce infant mortality (high failure rate at early stages in the instrumentation life cycle) due to workmanship defects or quality control deficiencies. Instrumentation selected for the reliability test shall be representative of all the units furnished for a procurement contract. The test items shall receive no special preconditioning other than that used for all production units. This applies to preconditioning at all levels of assembly. No changes to these procedures shall be permitted, unless otherwise approved by the procuring activity.

3.3 Pretest Performance Record. Prior to proceeding with the reliability testing, a pretest performance record shall be formulated in accordance with paragraph 5.4.1 of the General Section.

3.4 Sample Size. The quantity of items to be tested (either in sequence or simultaneously) shall be as specified by the procuring activity. If not specified, the quantity shall be as follows:

- a. Reliability Qualification (Demonstration) Test. At least two test items representative of the production design configuration shall be used.
- b. Reliability Production Acceptance Test. The minimum number of samples to be tested per lot is three units. The recommended sample size is 10% of the lot size, up to a maximum of 20 units per lot.

4.0 TEST PROCEDURE

4.1 Reliability Profile. The reliability profile in figure 16 shall be used for all instrumentation specified in table 1.

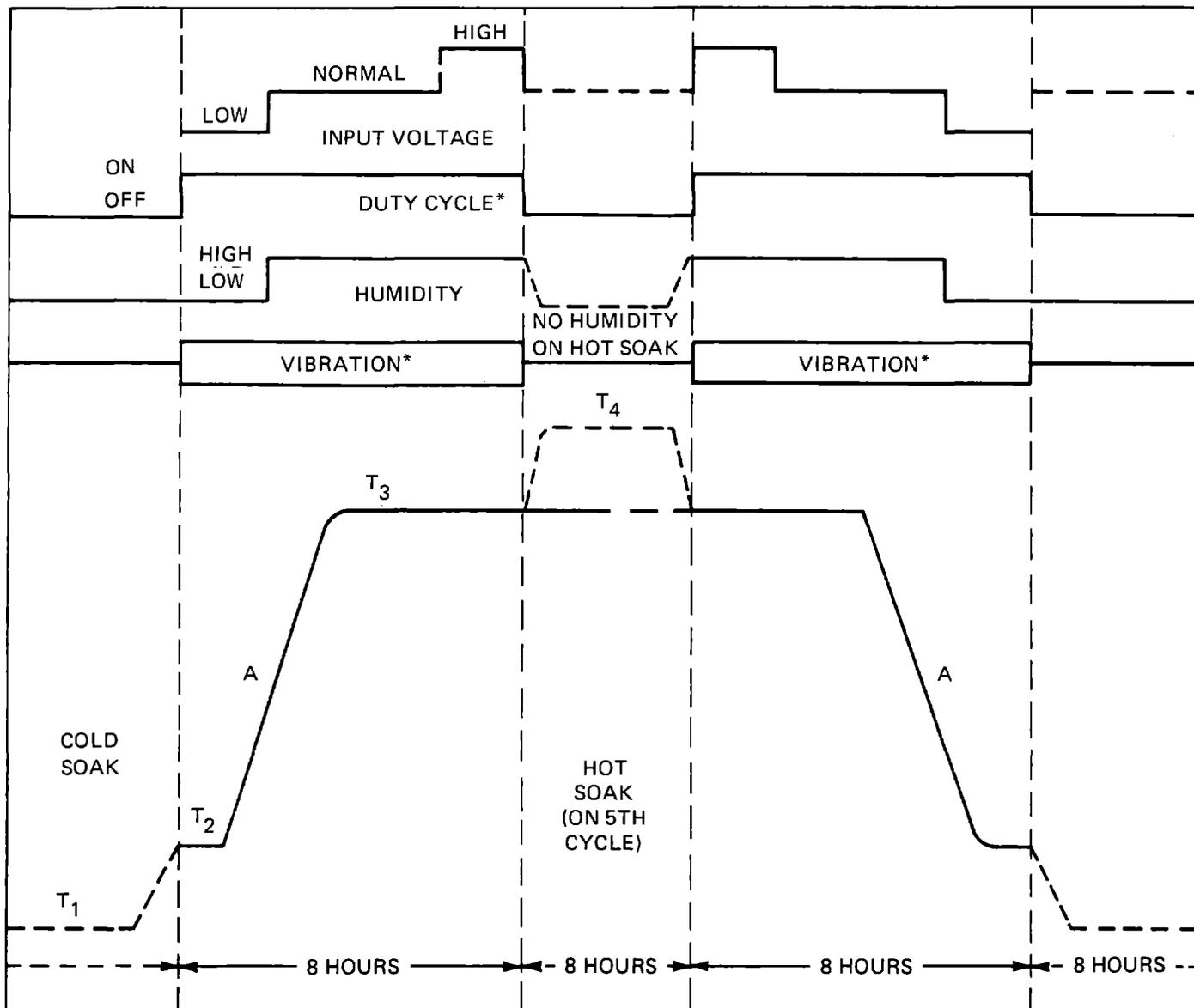
4.2 Test Conditions. The test item(s) shall be exposed to the number of test cycles specified in the plan to provide the total operating (instrumentation ON) time specified or until the number of failures constituting a reject decision is obtained. The sequence and duration of the environmental stresses shall be as indicated in figure 15. The test cycle shall be conducted in $24 \pm 1/2$ hours and shall consist of the following stress levels:

Temperature:

Underground Coal (machine mounted)	– maximum 37.8°C (100°F) minimum 4.4°C (40°F)
Underground Metal (machine mounted)	– maximum 60°C (140°F) minimum 4.4°C (40°F)
Surface (haulage)	– maximum 60°C (140°F) minimum -40°C (-40°F)

Relative Humidity:

90–100% concurrent with the 37.8°C (100°F) maximum operating temperature, as specified in Humidity Test of this document.



A—RATE OF TEMPERATURE CHANGE SHALL AVERAGE 5°C/MINUTE

--- NON-OPERATING

— OPERATING

*VIBRATION IS APPLIED ON A PERCENTAGE OF AN HOUR

ENVIRONMENT	TEMPERATURE °F				VIBRATION		
	T ₁	T ₂	T ₃	T ₄	LEVEL (g)	FREQUENCY (Hz)	% EXPOSED/HR
UNDERGROUND COAL CONTINUOUS MINOR HAULAGE	40	60	100	100	4.0	0-2000	25%
	40	60	100	100	1.5	0-500	50%
UNDERGROUND METAL CONTINUOUS MINOR HAULAGE	40	60	100	140	4.0	0-2000	25%
	40	60	100	140	1.5	0-500	50%
SURFACE HAULAGE VEHICLE	-40	20	100	140	1.5	0-500	50%

Figure 16. Reliability Test Profile

Vibration:

Only the cycling portion of the vibration test shall be used. (See Section 2.4.1.3 of the vibration test.) Cycling shall be performed for the percentage of each hour specified as shown in figure 15. Vibration profiles and sweep rates are detailed in table 3 and figures 4, 5, and 6 of the vibration section.

Input Voltage and Duty Cycle:

Input voltage shall be $\pm 25\%$ of the nominal voltage for machine-mounted underground coal equipment and $\pm 10\%$ of the nominal specified for all other equipment. Instruments shall remain on at all times during conditions except for the low and high temperature soaks.

4.4 Test Item Preparation and Mounting. The test item shall be prepared in accordance with paragraph 5.4.2 of the General Section. The test item shall be mounted to the vibration fixture such that the vibration is applied in its most susceptible direction. For example, when the instrumentation being tested contains circuit boards or cards, vibration shall be normal to the plane of the majority of the cards. Unless otherwise specified, the test item shall be vibrated in only one axis. When vibration in three orthogonal axes is deemed necessary, three items must be tested simultaneously, each mounted in a different axis. The mounting arrangement shall be sufficiently rigid to ensure that the test item motion at the interface will be the same as the testing machine platform. Unless otherwise specified, the instrument shall be tested without resilient mounts.

4.5 Preventive Maintenance. Preventive maintenance procedures implemented during normal service shall be performed during the reliability test. These procedures shall be itemized and submitted to the procuring activity prior to the test in order to distinguish between normal maintenance and corrective actions to failure occurrences. No additional preventive maintenance procedures shall be allowed during testing or during equipment repair unless specifically authorized by the procuring activity.

4.6 Test Performance

- a. After installation of the test item in the facility, conduct performance measurements and functional checks in accordance with paragraph 5.4.3 of the General Section.
- b. Subject the test item to the test cycle indicated in figure 16. The cycle shall be repeated until a failure occurs or until the total test time is attained. The test time includes only the time that the test item is ON.
- c. If a failure occurs, the test item shall be repaired and testing resumed, preferably in that part of the cycle where the failure occurred. The procedure for failures shall be as defined in paragraph 5.3 of this section.
- d. Record the chamber ambient, dry bulb and wet bulb temperatures on an hourly schedule in the Test Log and Data Record (a test log and data record shall be maintained for each item on test). Any notable occurrence or test condition shall be recorded. The humidity conditions may be uncontrolled during the period of temperature change.

- e. Conduct and record performance measurements in accordance with paragraph 5.4.4 of the General Section for the following periods within each cycle:
 - (1) High temperature dwell (37.8°C (100°F) or 60°C (140°F)).
 - (2) High temperature/high humidity dwell (37.8°C (100°F) and 90–100% R.H.).
 - (3) Low temperature dwell (4.4°C (40°F) or -40°C (-40°F)).
 - (4) One hour prior to the end of the 24 hour cycle.
- f. The test shall be terminated at either of the following events:
 - (1) The number of complete test cycles provides sufficient test item ON time required by the selected test plan.
 - (2) The total number of failures equals a reject decision as required by the selected test plan.

5.0 Test Results

5.1 Accept/Reject Criteria. An accept decision has been reached when the total instrumentation ON time accumulated is equal to that required by the selected test plan and the number of relevant failures is less than that which constitutes a chargeable reject decision. When an accept decision has been reached, the instrument design has been qualified for production with respect to reliability. If an accept decision is reached on a lot sampling basis, all items in the lot are accepted. A reject decision has been reached when the number of relevant, chargeable failures accumulated equals the maximum permissible specified by the test plan.

5.2 Failure Criteria. Failure occurrences shall be identified by the criteria provided in paragraph 5.5.2 of the General Section. All failures shall be classified as nonrelevant or relevant, with relevant failures being further classified as chargeable or nonchargeable.

- a. Non-relevant failures. Non-relevant failures are those resulting from installation damage, improper handling, overstress condition in excess of specified test conditions, test facility or test instrumentation failure, or adjustments normally required in service.
- b. Relevant failures. Relevant failures include the following types:
 - (1) Chargeable. These failures include intermittent failures, failures which cannot be duplicated or for which no cause can be determined (unverified), and failures not caused by a prior failure (independent).
 - (2) Nonchargeable. These failures include those caused by a preceding failure (dependent) of another component and are included as part of that failure or failures resulting from operation beyond the specified life expectancy of the component or test item.

5.3 Failure Actions. On the occasion of failure the following sequence of events should be conducted:

- a. The failed test item shall be removed from test and repaired with minimum interruption to any other item(s) being tested simultaneously.
- b. The incident shall be recorded on the following logs:
 - (1) Test Log and Data Record. Indicate time of failure and the test conditions at time of failure. If the exact time of failure cannot be determined, the failure shall be presumed to have occurred at the last recorded observation or accurate measurement of the test conditions. Any interruption of conditions due to servicing or removal of the failed item shall be noted.
 - (2) Test Item Failure Record. The test item failure record is maintained for each test item to provide a time history of all failures. The failure record serves to indicate widely divergent behavior between each test item.
 - (3) Failure Summary Record. The failure summary record contains all the information needed to reach an accept/reject decision on the test sample. It shall include a tabulation of all failures which are relevant and chargeable, serial number of failed item, total hours of operating time, calculated MTBF at failure, and time of occurrence (correlated to the Test Log and Data Record).
 - (4) Failure Tag. Prior to shipment to the repair facility, a tag should be affixed to the test item and should contain the following information: test item serial number, failure description, failure report number, correlation with the Test Log and Data Record and the Test Item Failure Record, and a description of the repair performed by the repair activity. The tag should be removed upon return of the item to the test, retained for documentation of the Failure Report, and affixed to the removed, faulty parts when possible.
- c. All failed parts shall be replaced; any part which has deteriorated, but does not exceed tolerance limits shall not be replaced unless that part is known to have been overstressed beyond its rated capacity due to another part failure. Complete modules or subassemblies shall not be permanently replaced unless they have been designated as disposable at failure or unless approved by the procuring activity.
- d. After a failed and repaired test item has been verified as being operable, it shall be returned to the test with appropriate entries in the Test Log and Data Record and with a minimum interruption to any other items continuing on test. The absence of one or more items for the purpose of failure repair should not affect the ability to make test decisions from log data.

5.4 Failure Analysis. Each failure shall be investigated to ensure that the failure was not caused by the test equipment or any interfacing equipment, or that the test equipment was not damaged by the test item. The analysis of the failure may include visual examination, radiographic analysis, or other troubleshooting procedures as necessary to determine the extent and cause of failure.

5.5 Failure Report. The results of the failure analysis and corrective action shall be documented in the failure report. A failure report shall be provided each time a failure occurs and shall include the following:

- a. Time of failure, identification of failed item (serial number), and total operating time at failure occurrence.
- b. Symptom of failure and test conditions at time of failure.
- c. Extent of confirmation of failure symptoms.
- d. Description of repair action or adjustment.
- e. Identification of failed components, assembly, or subassembly.
- f. Cause of failure.
- g. Identification of failure classification and type (i.e., relevant versus nonrelevant, dependent versus independent). Supporting data for non-relevant and nonchargeable failures (such as test equipment malfunction) shall be provided.

5.6 Corrective Action Plan. In the event of a reject decision or when a pattern failure occurs (two or more failures of the same part in identical or equivalent applications which are caused by the same basic failure mechanism), a corrective action plan for the test item must be submitted to the procuring activity. For reject decisions, this plan must address all of the failures that have occurred during testing.

6.0 POST TEST REQUIREMENTS

6.1 Restoration of Test Items. Upon completion of the reliability tests, and unless otherwise directed by the procuring activity, instrumentation shall be refurbished by the contractor as necessary to return the item to satisfactory operating condition. All failed or deteriorated parts shall be replaced.

6.2 Final Report. The final report should include the requirements of paragraph 5.5.3 of the General Section and the following:

- a. Description of the Test Setup. Test facilities and test equipment.
- b. Test Procedure. Including Vibration Survey (if required), deviations from approved procedures or specified test conditions, etc.
- c. Failure Report Summary. A summary of each failure, derived from the individual failure reports.
- d. Reliability Analysis. For an accept decision, the reliability analysis shall include the calculation of the estimated instrumentation MTBF and the confidence interval. Any conclusions or inferences as to the effects of the test environments should be provided.

6.3 MTBF Estimation From Observed Test Data. When the procuring activity must not only have a statistical basis for determining contractual compliance; and it must also have a basis for estimating the MTBF values to be expected in field service, a fixed length test plan must be used. All agencies conducting reliability tests under the provisions of this standard shall provide the procuring activity with current values of demonstrated MTBF (θ) as part of each required test report, when required.

6.3.1 Exclusion of hypothesis test values. Since they are assumptions rather than test results, neither the upper test value (θ_0) nor the lower test value (θ_1) of any hypothesis test plan shall be used in estimation of demonstrated MTBF; rather the demonstrated MTBF (θ) must be calculated from demonstrated test results. Producer's risk (α) and consumer's risk (β) are excluded from these calculations since they refer to the probability of passing or failing the test rather than to the probable range of true MTBF demonstrated during the test. However, the test parameters values (θ_0 , θ_1 , α , β) should be provided to assist in the understanding of how and why the data was gathered.

6.3.1.1 Specified confidence interval. In order to obtain an interval estimate of the demonstrated MTBF, the procuring activity must specify the confidence interval to be used. It is suggested that a confidence interval be selected such that its lower limit is equal to $(100 - (\text{producer's} + \text{consumer's risk}))\%$ – that is: 10% consumer's risk, 80% confidence interval; 20% consumer's risk, 60% confidence interval, 30% consumer's risk, 40% confidence interval.

6.3.2 MTBF Estimation. An interval estimate of the demonstrated MTBF of the test item shall be provided within the specified confidence interval. The estimate may be conducted at two occurrences:

- a. Upon a failure occurrence during a test or terminating the test in a reject decision.
- b. At test termination with an accept decision.

6.3.2.1 MTBF estimation at failure occurrence. This calculation shall be made when a test is in process or has terminated in a reject decision.

- a. Calculate the observed MTBF ($\hat{\theta}$) by dividing the total operating time of the equipment(s) at the occurrence of the most recent relevant failure by the number of relevant failures.
- b. Enter table 5 or figure 17 with total failures and the specified confidence interval. Read out the lower and upper confidence multiplier for that number of failures.
- c. Multiply observed MTBF ($\hat{\theta}$) (calculated by step a. above) by both the upper and lower confidence limit multipliers to obtain the lower and upper demonstrated MTBF values.
- d. Record demonstrated MTBF as the specified percentage of confidence, followed by the lower and upper MTBF value in parenthesis: $\theta = xx$ percent (lower limit MTBF, upper limit MTBF). MTBF values will be rounded off to the nearest whole number.

- e. If the values are not available in figure 17 or table 5, then the correct values can be obtained by computation as follows.

$$\begin{aligned} \text{MTBF multiplier} &= \frac{2r}{X^2 \left(\frac{1+c}{2}, 2r \right)}, \text{ upper limits} \\ &= \frac{2r}{X^2 \left(\frac{1-c}{2}, 2r \right)}, \text{ lower limits} \end{aligned}$$

where r = number of failures
 X^2 = Chi-square statistical distribution
 c = confidence

For example: using 90% confidence interval, $c = .9$
 Then $\frac{1+c}{2} = .95$ and $\frac{1-c}{2} = .05$

6.3.2.2 MTBF Estimation at Acceptance. This calculation shall be made when the test is terminated in an accept decision.

- a. Calculate the observed MTBF (θ) by dividing the total operating time of the equipment(s) by the number of relevant failures.
- b. Enter table 6 or figure 18 with total failures and the specified confidence interval. Read out the lower and upper confidence multiplier for that number of failures.
- c. Multiply observed MTBF ($\hat{\theta}$) (calculated by step a. above) by both the upper and lower confidence multipliers to obtain the lower and upper demonstrated MTBF values.
- d. Record demonstrated MTBF as the specified percentage of confidence followed by the lower and upper MTBF values in parenthesis: $\theta = xx$ percent (lower limit MTBF, upper limit MTBF). MTBF values will be rounded off to the nearest whole number.
- e. If the values are not available in figure 18 or table 6, then the correct values can be obtained by computation as follows:

$$\begin{aligned} \text{MTBF multiplier} &= \frac{2r}{X^2 \left(\frac{1+c}{2}, 2r+2 \right)}, \text{ upper limits} \\ &= \frac{2r}{X^2 \left(\frac{1-c}{2}, 2r \right)}, \text{ lower limits} \end{aligned}$$

where r = number of failures
 X^2 = Chi-square statistical distribution
 c = confidence

6.3.3 Projection of Expected Field MTBF. The contractor (or test agency, if other than the contractor) is responsible for providing demonstrated MTBF under test conditions. The procuring activity is responsible for projecting expected MTBF under field service conditions. However, this responsibility may be delegated to the contractor or test agency when so specified in the contract.

Table 5. Demonstrated MTBF Confidence Limit Multipliers (for failure calculation)

Total Number of Failures	Confidence Intervals					
	40%		60%		80%	
	70% Lower Limit	70% Upper Limit	80% Lower Limit	80% Upper Limit	90% Lower Limit	90% Upper Limit
1	.801	2.804	.621	4.481	.434	9.491
2	.820	1.823	.668	2.426	.515	3.761
3	.830	1.568	.701	1.954	.564	2.722
4	.840	1.447	.725	1.742	.599	2.293
5	.849	1.376	.744	1.618	.626	2.055
6	.856	1.328	.759	1.537	.647	1.904
7	.863	1.294	.771	1.479	.665	1.797
8	.869	1.267	.782	1.435	.680	1.718
9	.874	1.247	.796	1.400	.693	1.657
10	.878	1.230	.799	1.372	.704	1.607
11	.882	1.215	.806	1.349	.714	1.567
12	.886	1.203	.812	1.329	.723	1.533
13	.889	1.193	.818	1.312	.731	1.504
14	.892	1.184	.823	1.297	.738	1.478
15	.895	1.176	.828	1.284	.745	1.456
16	.897	1.169	.832	1.272	.751	1.437
17	.900	1.163	.836	1.262	.757	1.419
18	.902	1.157	.840	1.253	.763	1.404
19	.904	1.152	.843	1.244	.767	1.390
20	.906	1.147	.846	1.237	.772	1.377
30	.920	1.115	.870	1.185	.806	1.291

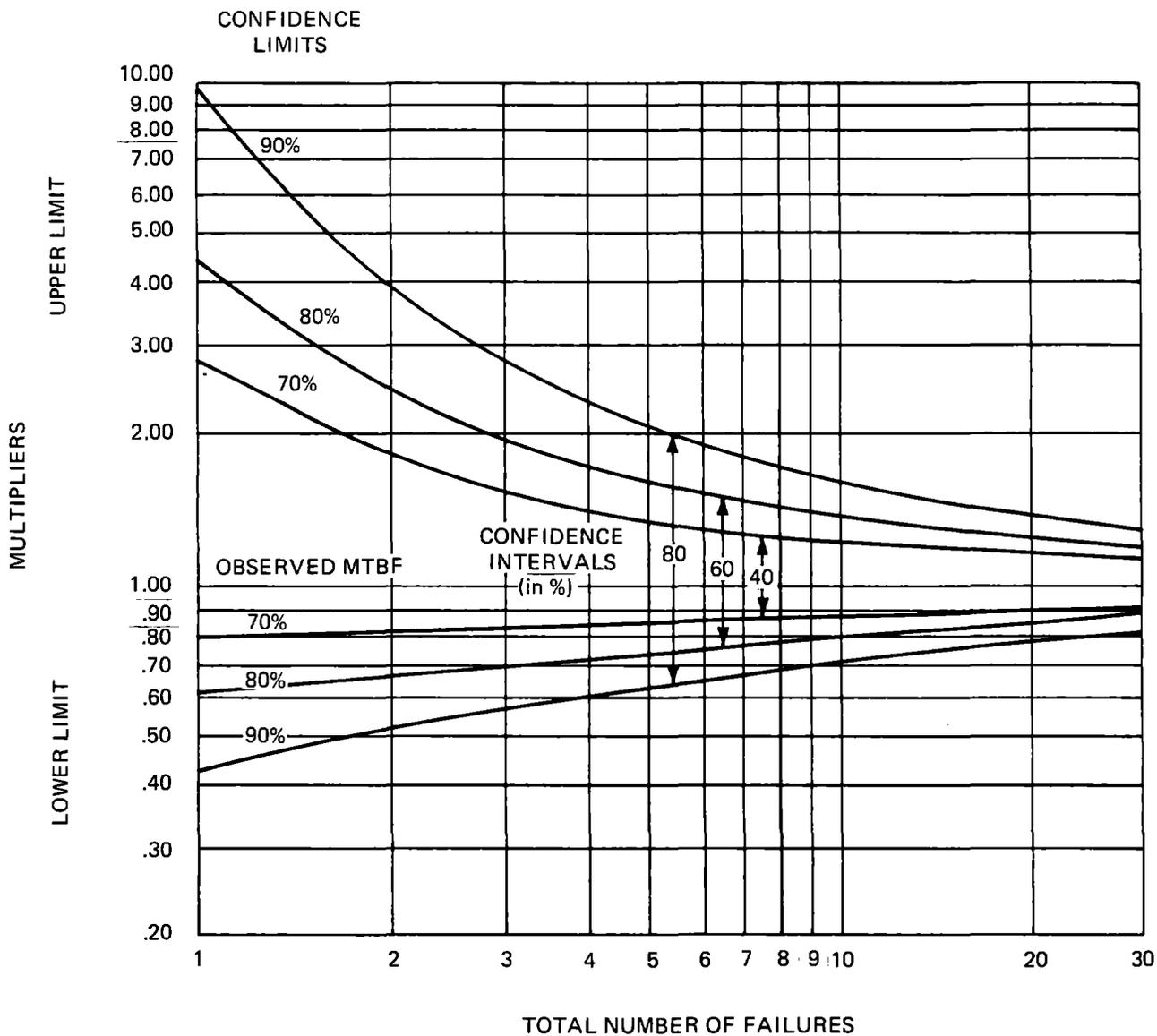


Figure 17. Demonstrated MTBF Confidence Limit Multipliers (for failure calculation)

Table 6. Demonstrated MTBF Confidence Limit Multipliers (for time calculation)

Total Number of Failures	Confidence Intervals					
	40%		60%		80%	
	70% Lower Limit	70% Upper Limit	80% Lower Limit	80% Upper Limit	90% Lower Limit	90% Upper Limit
1	0.410	2.804	0.334	4.481	0.257	9.491
2	0.553	1.823	0.467	2.426	0.376	3.761
3	0.630	1.568	0.544	1.954	0.499	2.722
4	0.679	1.447	0.595	1.742	0.500	2.293
5	0.714	1.376	0.632	1.618	0.534	2.055
6	0.740	1.328	0.661	1.537	0.570	1.904
7	0.760	1.294	0.684	1.479	0.595	1.797
8	0.777	1.267	0.703	1.435	0.616	1.718
9	0.790	1.247	0.719	1.400	0.634	1.657
10	0.802	1.230	0.733	1.372	0.649	1.607
11	0.812	1.215	0.744	1.349	0.663	1.567
12	0.821	1.203	0.755	1.329	0.675	1.533
13	0.828	1.193	0.764	1.312	0.686	1.504
14	0.835	1.184	0.772	1.297	0.696	1.478
15	0.841	1.176	0.780	1.284	0.705	1.456
16	0.847	1.169	0.787	1.272	0.713	1.437
17	0.852	1.163	0.793	1.262	0.720	1.419
18	0.856	1.157	0.799	1.253	0.727	1.404
19	0.861	1.152	0.804	1.244	0.734	1.390
20	0.864	1.147	0.809	1.237	0.740	1.377
30	0.891	1.115	0.844	1.185	0.783	1.291

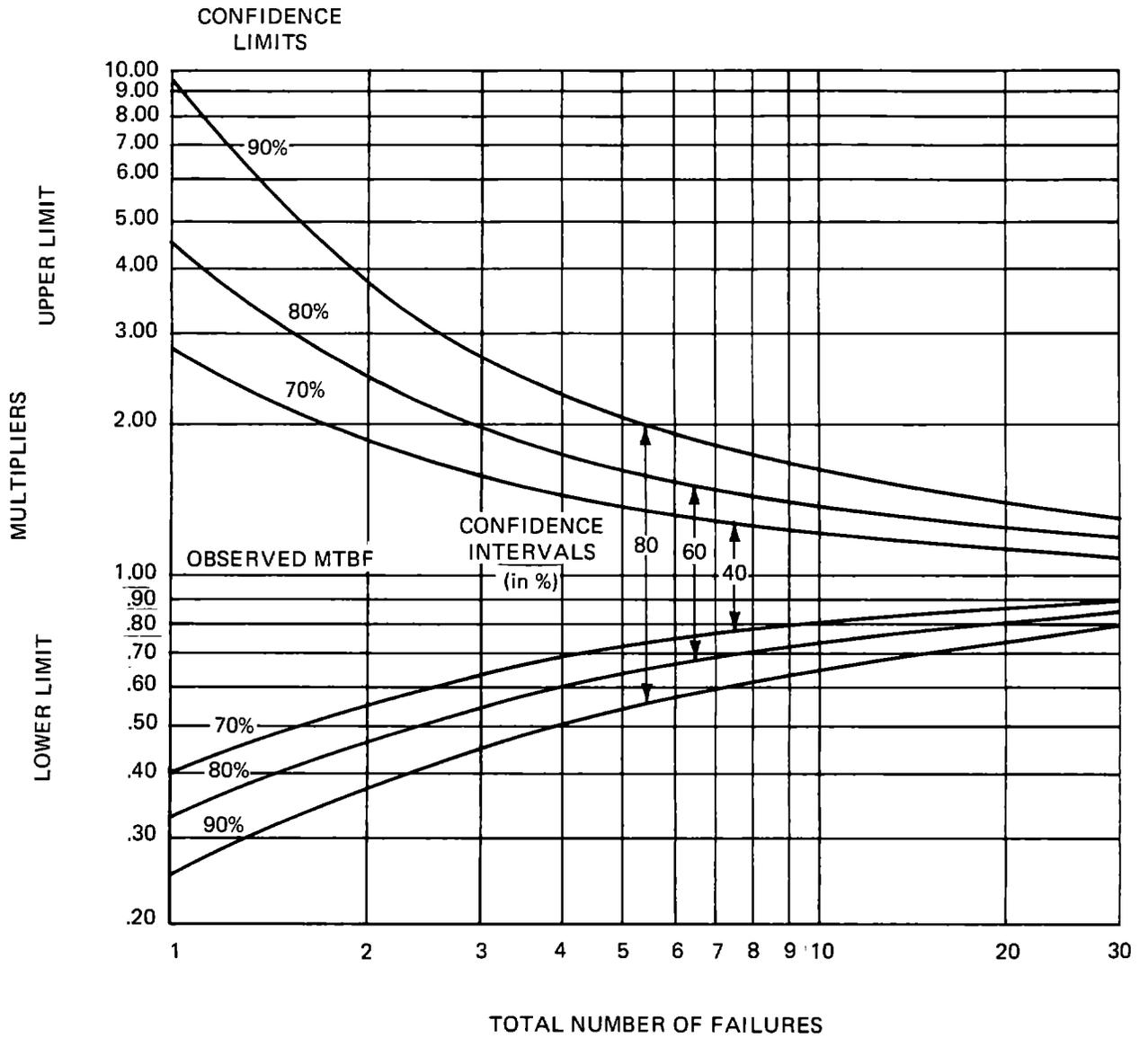


Figure 18. Demonstrated MTBF Confidence Limit Multipliers (for time calculation)

OPERATIONAL LIFETIME

1.0 TEST FACILITY

1.1 **Test Chamber.** No special test facility is required.

2.0 TEST PROCEDURE

2.1 Test Item Preparation

2.1.1 Calibrate each device in accordance with the item specification or manufacturer's procedures. Make sure batteries are fully charged, if rechargeable, or replace batteries with new cells.

2.1.2 Performance Measurements. Conduct preliminary performance measurements and functional checks on all tests in accordance with paragraph 5.4.3 of the General Section.

2.2 Test Performance

- a. Turn on devices for the operational lifetime requirements for power provided by the individual item specification or manufacturer's procedures.
- b. Shortly before reaching the lifetime requirements, conduct performance measurements and functional checks in accordance with paragraph 5.4.4 of the General Section.

2.3 Test Results

2.3.1 Failure Criteria. If the item fails to operate for the specified lifetime or does not meet performance requirements at the end of the lifetime requirements, it shall be considered a failure.

2.3.2 Test Data. The test data shall include the information specified in paragraph 5.5.3 of the General Section.

6.0 CONCLUSIONS AND RECOMMENDATIONS



Conclusions

- a. It is felt that the specification overall is a realistic document for the testing of mine instrumentation, with the deletion of the corrosion test for portable/personal equipment being the only change. No difficulties were encountered in performing any of the tests.
- b. The performance of the CO detector, methane monitor, and deluge system was very good. However, there are some problems that should be addressed.
 - (1) The methane monitor is susceptible to electric EMI fields in certain frequencies which can cause incorrect readings and possible shutdown of a continuous miner in operation.
 - (2) Readjustments of the calibration readings of the CO detector and methane monitor after certain tests means that the equipment calibrations should be checked on a daily basis.
 - (3) The deluge system would require some additional changes or protection of the switches and batteries to successfully pass the shock test.
- c. The performance and reliability of the TDRs was poor. Numerous design defects exist and it requires much change to be a reliable instrument in the field.
- d. As with all specifications, as additional testing is performed and correlated with field information, certain requirements may be added, altered, or changed. This will constantly update the specification to include the "latest thinking" state of the art environmental test facilities and to provide the best possible evaluation of any newly developed equipment intended for use in mines.
- e. The detailed tests methods specified in this document are intended for use as an environmental testing document. Performance and operational criteria for each specific type of instrument should be specified by the manufacturer or in an individual equipment specification.

Recommendations

Due to the fact that only one instrument per type could be procured, no reliability testing could be performed (requires multiple instruments of the same type). It is therefore recommended that a follow-up program be initiated to procure multiple instruments of one type and perform reliability testing to evaluate the testing.

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GLOSSARY

Abrasion	The wear or erosion of the surfaces of submerged instrumentation by suspended solids, sand, or silt.
Accuracy	The extent to which the readings of an instrument approach the true values of the measured quantity.
Conducted Emissions	Electromagnetic emissions propagated along a conductor.
Conducted Susceptibility	A measure of the interference signal current or voltage required on power, control, and signal leads to cause an undesirable response or degradation of performance.
Confidence Interval	An interval which has a specified probability of containing a given parameter or characteristic.
Confidence Level	The probability that a value will be within a given confidence interval.
Crosstalk	The motion of a vibration table perpendicular to the intended motion.
Demonstrated MTBF	The probable range of true MTBF under test conditions, observed MTBF within a stated confidence interval.
Dry bulb temperature	The actual air temperature, not dependent on atmospheric humidity.
Duty Cycle	The on-off power condition of a test item during a reliability test.
Electromagnetic Compatibility (EMC)	The condition which prevails when electronic equipment is performing its individually designed function in a common electromagnetic environment without causing or suffering unacceptable degradation due to unintentional electromagnetic interference to or from other equipment in the same environment.
Electromagnetic Interference (EMI)	Any electromagnetic energy which interrupts, obstructs, or otherwise degrades or limits the effective performance of electronic equipment.
Exposed	In an outdoor ambient environment and, therefore, subjected to the natural elements.
Filter	A device for separating signals on the basis of their frequency.
Frequency Response	The system gain for a constant input amplitude as a function of frequency.

Induced Stress	An environmental stress generated as a result of the operation of a structure or equipment.
Linearity	A measure of the linear characteristics of a system; that is, the extent that the output or response is proportional to the input or excitation.
Machine-Mounted Equipment	Any equipment mounted on a non-stationary machine, such as that contained on a continuous miner or haulage vehicle.
MTBF	Mean Time Between Failures – The basic unit of reliability which is determined by dividing the cumulative operating time by the cumulative number of relevant, chargeable failures. (Equal to observed MTBF.)
Natural Stress	Stresses generated by the forces of nature, such as climatic conditions.
Operational Requirements	Instrumentation design requirements which serve to facilitate usage, such as ease of adjustment.
Performance Requirements	Instrumentation design requirements that indicate the level or manner in which an item accomplishes its purpose, such as accuracy, resolution, linearity, warmup time, or signal response time.
Portable	Normally transported in the course of accomplishing its mission and, therefore, susceptible to handling type stresses.
Predicted MTBF	Predicted MTBF (θ_p) is the value that is determined by reliability prediction methods based on equipment design and the use environment. (θ_p should approach θ_o , Upper MTBF, to ensure that with high probability the equipment will be accepted during the reliability qualification test.
Psychrometric Chart	A graphical representation of the thermodynamic properties of air.
Radiated Emissions	Desired and undesired electromagnetic energy which is propagated through space. If undesirable, such an emission is called radiated interference.
Radiated Susceptibility	A measure of the radiated interference field required to cause equipment degradation.
Reliability	A measure of the probability of instrumentation “survival” in a specified environment.

Resonance	In vibration, the frequency where the response to excitation ratios is greater than unity. The response may be either from the item or a component of the item.
Sensor	Probe; component of a total instrumentation system used to sense a parameter. A sensor is frequently considered a portable item and subjected to handling type stresses.
Stress	An environmental condition, either natural or induced.
Tolerance	The permissible variations from a given value.
Transient	A pulse or temporary condition (e.g., voltage, frequency) occurring prior to or after a steady state condition.
Transfer Function	Ratio of the output signal to the input signal for a specific equipment.
Wall-Mounted Equipment	Any equipment fixed to a stationary object, such as a building.
Warmup Time	Time required for an instrumentation output to attain (and maintain) a performance level within a specified error band after being energized.
Wet Bulb Temperature	The temperatures of a volume of air if cooled adiabatically to saturation at constant pressure by evaporation of water into it, all latent heat being supplied that volume.

