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Comments to MSHA

**Comments of the National Institute for Occupational Safety and Health on the
Mine Safety and Health Administration**

**Request for information on Proximity Detection Systems
for Underground Mines**

RIN 1219—AB65

**Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
Cincinnati, Ohio**

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AB65-COMM-6

NIOSH Responses to MSHA RFI on Proximity Detection

Information Request 1

Please provide information on the most effective protection to miners that you believe proximity detection systems could provide, e.g., warning, stopping the equipment, or other protection. Include your rationale.

The collision-avoidance function (machine/worker or machine/machine) is the most effective protection that proximity-detection systems provide. Collision avoidance ranges from automatically controlling the machine (e.g., shutdown or disabling certain dangerous movements) to allowing the operator to take action in avoiding an accident by increasing situational awareness (e.g., visual, audible, or tactile alarms). The action taken after detection differs depending on the type of equipment and how it is controlled. Totally different collision-avoidance functionality is needed for remote-controlled mining equipment with Operators Adjacent to Mobile Machinery (OAMM) compared with equipment that has an Operator On-Board (OOB) [3]. OAMM equipment, such as remote-controlled continuous miners and roof-bolting machined, provides the most challenging design requirements for effective proximity-detection systems.

The potential victim and his potential injury vary depending on the type of machine. With OAMM, a preoccupied operator is exposed to pinning or struck-by hazards by the machine being operated [4]. In addition, injury could result from a malfunctioning controller or engaging the wrong control lever, causing the machine to move in an unexpected and undesirable direction [4]. For example, a roof-bolter operator is susceptible to being struck by the machine's boom, and a continuous-miner operator is vulnerable to pinning between the machine frame and mine rib [4].

Non-operators are also exposed to pinning and crushing hazards with OAMM. If a worker enters within a predefined distance of a remote-controlled continuous miner (RCCM), the operator could be simply warned of the worker's presence or a shut-down may be appropriate depending on his location. This protection is not suitable for an RCCM operator given the required close proximity necessary during some mining operations.

Since an OOB operator is not situated in a vulnerable or high-risk location, a lower level of complexity in the detection and collision-avoidance functions may be possible. Increasing an operator's situational awareness through proximity-warning alarms or visibility aids may reduce collisions [3] with mine personnel in the machine's path.

Collision-avoidance proximity-detection systems must be specific to each type of mobile equipment. Possible modes of injury associated with a machine should be used to guide the development and decision methods used in the collision-avoidance functions. This approach reduces nuisance alarms because the levels of protection are dictated by the perceived risks of

various worker/machine interactions. Reducing nuisance alarms has also been shown to greatly affect user acceptance [1, 2].

References for Request 1

1. Bliss J, Dunn M [2000]. Behavioral implications of alarm mistrust as a function of task workload. *Ergonomics* 43(9):1283–1300.
2. Breznitz S [1984]. *Cry wolf: The psychology of false alarms*. Hillsdale, NJ: Lawrence Erlbaum Associates.
3. Ruff T [2007]. Recommendations for evaluating and implementing proximity warning systems on surface mining equipment. Report of Investigations 9672 (DHHS(NIOSH) Publication No. 2007–146). Spokane, WA: National Institute for Occupational Safety and Health [<http://www.cdc.gov/niosh/mining/pubs/pdfs/2007-146.pdf>].
4. Bartels JR, Ambrose DH, Gallagher S [2009]. Analyzing Factors Influencing Struck-By Accidents Of A Moving Mining Machine By Using Motion Capture And DHM Simulations. SAE International Journal of Passenger Cars, Electronics and Electrical Systems, Society of Automotive Engineers [<http://www.cdc.gov/niosh/mining/pubs/pubreference/outputid3322.htm>].
5. Bartels JR, Gallagher S, Ambrose DH [2009]. A Pilot Study of the Role of Visual Attention Locations and Work Position in Underground Coal Mines. *Professional Safety* 54(8):28–35. <http://www.cdc.gov/niosh/mining/pubs/pubreference/outputid2739.htm>

Information Request 2

Other than electromagnetic field based systems, please address other methods for effectively achieving MSHA's goal for reducing pinning, crushing, and striking hazards in underground mines.

Given the precision requirements associated with the Operator Adjacent to Mobile Machinery (OAMM), the only practical detection technique is the electromagnetic-field based approach [1]. (Since the application of new technology always exists, any future rulemaking should be performance based and not specify a particular type of technology.) The electromagnetic-field approach is currently being used by the manufacturers of the MSHA-approved systems that use automatic-decision logic to de-energize a machine if a predefined safe area is violated. NIOSH has been conducting research in alternative collision-avoidance techniques, such as slowing the motion or restricting specific movements of a machine for explicit operator/machine interactions, as described in the following publications:

- Ambrose-DH, Bartels-JR, Kwitowski-AJ, Helinski-RF, Gallagher-S, McWilliams-LJ, Battenhouse-TR; "Mining Roof Bolting Machine Safety: A Study of the Drill Boom Vertical Velocity," NIOSH IC 9477, DHHS/CDC/NIOSH, May 2005
<http://www.cdc.gov/niosh/mining/pubs/pdfs/2005-128.pdf>
- Ducarme-JP, Kwitowski-AJ, Bartels-JR; "Operating speed assessments of underground mining equipment," Mining Engineering Magazine, est. Mar 2010
- Bartels-JR, Ambrose-DH, Gallagher-S; "Analyzing Factors Influencing Struck-By Accidents Of A Moving Mining Machine By Using Motion Capture And DHM Simulations," SAE International Journal of Passenger Cars, Electronics and Electrical Systems, Society of Automotive Engineers, May 2008 Pending publication in March
<http://www.cdc.gov/niosh/mining/pubs/pubreference/outputid3322.htm>
- Bartels-JR, Ambrose-DH, Gallagher-S; "Effect of Operator Position on the Incidence of Continuous Mining Machine/Worker Collisions," Proceedings of the Human Factors Ergonomic Society 51st Annual Meeting, Baltimore, MD, Human Factors and Ergonomics Society, Oct 2007 <http://www.cdc.gov/niosh/mining/pubs/pubreference/outputid2567.htm>
- Mowrey, GL, Schiffbauer, WH [2009] "Engineering Considerations and Selection Criteria for Proximity Warning Systems for Mining Operations," Web document
<http://www.cdc.gov/niosh/mining/topics/electrical/pwsselection.htm>.

NIOSH is in the process of developing a prototype system that pinpoints the location of an operator, or other workers, in the proximity of a remote-controlled continuous miner (RCCM). By doing so, the system is permitted to make intelligent decisions, such as disabling specific

movements of the machine, while allowing the machine to continue to operate. While encouraging results have occurred, this system is only in the early prototype stage.

For the category of Operator On-Board (OOB) machines, where the interest is in protecting personnel other than the operator, a possible detection technique could utilize a tag-based system that exploits the same tags used by the tracking systems required under the MINER Act. These systems include reader-based, radio-frequency identification (RFID), and node-based radio systems as described in the *NIOSH Tutorial on Wireless Communications and Electronic Tracking Draft, 2009*. These systems could be adapted to provide proximity detection for use with OOB machines. An advantage of this approach is that a mineworker does not have to wear an additional tag or radio thus eliminating the need for additional power and weight, which is becoming a critical consideration as new technologies are introduced into the mine. This approach may also offer a cost advantage since less new equipment would be needed. It should be noted that the current tracking technologies would not likely provide the level of precision required for OAMM machines.

References for Request 2

1. Mowrey GL, Schiffbauer WH [2009]. Engineering Considerations and Selection Criteria for Proximity Warning Systems for Mining Operations [<http://www.cdc.gov/niosh/mining/topics/electrical/pwsselection.htm>].

Information Request 5

Please describe procedures that might be appropriate for testing and evaluating whether a proximity detection system is functioning properly. Include details such as the frequency of tests and the qualifications of person performing tests; include specific rationale for your suggestions.

Two types of testing are applicable to this request – acceptance testing and routine testing to verify correct functioning of the system. Acceptance testing pertains to the development of a protocol that would evaluate a system to ensure that the system is in full compliance with predetermined specifications. A completed test protocol for acceptance testing can only be developed after clearly defining system specifications. The specifications provided would be dependent on the type of technology being used (e.g. magnetic field systems), the type of control/response anticipated (e.g. machine shut-down, warning, and prohibiting dangerous machine movements based upon workers' positions), decision methodology (e.g. automated or operator decision/action required), and protection philosophy (e.g. safe zones or an intelligent system that allows safe operation while disabling machine movements that might place a worker at risk).

The following items should be considered during protocol development for acceptance testing:

- The desired accuracy of the position of the sensor with respect to a reference point on the machine should be defined as it will dictate parameters such as the type of measurement equipment utilized and the number and location of measurement points.
- The sensor location on the body of a mine worker should be defined, and the impact of this location should be evaluated. Sensor location does not directly represent body location (e.g. a sensor on the chest may still allow the lower body to be in a dangerous location while the sensor itself is in an acceptable location).
- The nature of the technology and the desired type of protection must be fully understood in order to ascertain the location and number of measurement points as the system may be affected by factors such as the mining environment (e.g. proximity of large metal masses or interference incurred by other equipment).
- The number of sensors being tracked and the desired response of the system for each sensor should be defined such that the protocol may be designed to test that the system responds appropriately when combinations of these sensors are introduced into the system's detection area.
- The desired response time of the proximity-detection system, the machine operator, and a worker entering into an unsafe area should be defined.

The West Virginia Mine Safety Technology Task Force [7] asked for NIOSH's assistance in the development of a protocol to make general assessments of safe zones, defined by proximity-detector manufacturers. For this request, the Task Force requested the protocol requirements be

developed for magnetic-field technology, a control response to de-energize the machine, and a safety-zone protection methodology.

Developing such a protocol is complex, requiring consultations with many sources in its preparation. In the following reference section, a limited list of sources is presented for consideration before developing a protocol [1,2,3,4,5]. The NIOSH developed test protocol for the Task Force did not represent a full and complete evaluation, but instead was limited to assessing manufacturers' claims relative to the general size and shape of safety zones around the periphery of the machine [6].

Regarding routine testing to verify correct functioning, each system should perform self-diagnostics to identify hardware or software problems. Also, the machine operator should have a set of procedures to briefly assess the system at the start of each shift.

References for Request 5

1. "Developing a Protocol: A Guide for CDC Investigators"
<http://intranet.cdc.gov/od/ocso/osrs/hrpo/worksheets/protocol.pdf>
2. Hand DJ [2004]. Measurement theory and practice: The world through quantification. Oxford University Press Inc., New York.
3. Rabinovich S [2005]. Measurement Errors and Uncertainties: Theory and Practice. Springer Science+Business Media, Inc., New York.
4. DOD [1996]. Department of Defense Test Method Standard: DOD Preferred Methods for Acceptance of Product. MIL-STD-1916.
5. DOD [2005]. Department of Defense Standard Practice: Failure Rate Sampling Plans and Procedures. MIL-STD-690D.
6. West Virginia Mine Safety Technology Task Force [2009]. WV Mine Safety & Technology Task Force Proposed Plan to Evaluate Proximity Detection Systems (PDS). West Virginia Mine Safety Technology Task Force, 1615 Washington St. East, Charleston WV 25311-2126.
7. West Virginia Mine Safety Technology Task Force
<http://www.wvminesafety.org/default.htm>

Information Request 7

How should the size and shape of the area around equipment that a proximity detection system monitors be determined? What specific criteria should be used to identify this area, e.g., width of entry, seam height, section type, size of equipment, procedures for moving equipment, speed of equipment, and related information? Please provide any additional criteria that you believe would be useful in identifying the area to be protected.

The goal of a proximity-detection system should be to prevent machine actions or situations that could injure workers while not placing undue restrictions on how the workers perform their jobs. The total time required for performing proximity-detection functions, plus a safety factor, should be used to define the minimum detection range (i.e. the size and shape of detection zones around the equipment) [2]. The total time required includes these components:

- Detection of a potential victim,
- Decision processing to determine if a collision-avoidance function is needed,
- Initiation of the collision-avoidance function, and
- Implementation of the collision-avoidance function.

The sum of the times required to perform these functions defines the reaction time of the system. With Operator on Board (OOB) equipment, the proximity-detection/collision-avoidance system should perform several functions sequentially for the machine to avoid injuring a worker [2]. For the system to be effective, the system-reaction time must be less than the time it takes the machine to strike the worker considering the velocities of the machine and the worker. A system that involves a man-in-the-loop approach (i.e. the equipment operator receives a warning and decides how to react) requires a longer decision-processing time, and therefore a larger detection range, than a system which is fully automated.

Minimum ranges can be calculated for different points around the machine which then can be used to define a minimum detection zone. If a potential error distribution is known and a confidence interval is selected, a corresponding safety margin can be included to arrive at the minimum detection range.

The OAMM category of equipment presents a more challenging situation because the operator could be closer than the minimum detection range during normal operations. This issue can be addressed by the following options:

- The operator must modify his behavior to be outside of the detection zone;
- The detection zone can be shaped so that areas are identified where the operator is allowed to be located, but not be protected; or

- The collision-avoidance system is intelligent enough to restrict explicit machine motions (e.g. not allowing the left track of a RCCM from operating in reverse) to protect the operator when in a specific location, while allowing the machine to continue to operate.

Proximity-detector manufacturers use the second option to deal with the RCCM challenge by using discrete antennas to create a unique field shape [4, 5]. NIOSH is attempting to address this problem by developing a system that meets the requirements of the third option by locating the position and orientation of an operator and other workers in relation to the continuous-mining machine. Knowing this information, the system intercepts any remote-control commands to the continuous-mining machine that may cause injury to an operator, without disabling other machine functions. This development is only in the early prototype stage.

References for Request 7

1. Bartels JR, Ambrose DH, Gallagher S [2009]. Analyzing Factors Influencing Struck-By Accidents. SAE Int J Passenger Cars, Electron Electr Syst 1(1):599-604 [<http://www.cdc.gov/niosh/mining/pubs/pubreference/outputid3322.htm>].
2. Bartels JR, Gallagher S, Ambrose DH [2009]. A Pilot Study of the Role of Visual Attention Locations and Work Position in Underground Coal Mines. Professional Safety 54(8):28-35 [<http://www.cdc.gov/niosh/mining/pubs/pubreference/outputid2739.htm>].
3. Jobses CC, Bartels JR, Ducarme J, Lutz T [2009]. Visual Needs Evaluation of Continuous Miner Operators. Mining Engineering. Pending printing in March.
4. Schiffbauer WH [2001]. An Active Proximity Warning System for Surface and Underground Mining Applications. SME Annual Meeting, Preprint No. 01-117, SME, Inc., pp. 1-8 [<http://www.cdc.gov/niosh/mining/pubs/pubreference/outputid112.htm>].
5. Mowrey GL, Schiffbauer WH [2009]. Engineering Considerations and Selection Criteria for Proximity Warning Systems for Mining Operations [<http://www.cdc.gov/niosh/mining/topics/electrical/pwsselection.htm>].

Information Request 8

Proximity detection systems can be programmed and installed to provide different zones of protection depending on equipment function. For example, a proximity detection system could monitor a larger area around the RCCM when it is being moved and a smaller area when the machine operator is performing a specific task, such as cutting and loading material. How should a proximity detection system be programmed and installed for each equipment function?

Please see answer to Request 7 as it defines techniques to address this issue. By considering the relative speed, reaction times, and other parameters, a minimum required detection distance can be calculated for each situation and each area around the machine. This information can be used to program the system to implement the appropriate collision-avoidance function. For example, if the machine's tram rate is fast, the system needs to implement the collision-avoidance function earlier than if the machine movement is slow. If the detection technique involves a high degree of uncertainty (low accuracy), the detection zone needs to be larger than a detection zone specified by a highly accurate detection technique. The system ultimately will need to be programmed to ensure worker protection while minimizing false alarms. The actual size of the optimal zone will vary depending on the application and the technology used.

References for Request 8

1. Bartels-JR, Ambrose-DH, Gallagher-S, "Analyzing Factors Influencing Struck-By Accidents," SAE Int J Passenger Cars, Electron Electr Syst 1(1):599-604.
<http://www.cdc.gov/niosh/mining/pubs/pubreference/outputid3322.htm>
2. Bartels-JR, Gallagher-S, Ambrose-DH, "A Pilot Study of the Role of Visual Attention Locations and Work Position in Underground Coal Mines," Professional Safety 2009 Aug; 54(8):28-35.
<http://www.cdc.gov/niosh/mining/pubs/pubreference/outputid2739.htm>
3. C. C. Jobes, Bartels-JR, Ducarme J, Lutz T, "Visual Needs Evaluation of Continuous Miner Operators," Mining Engineering 2009 March. Pending printing in March
4. Schiffbauer-WH, "An Active Proximity Warning System for Surface and Underground Mining Applications," SME Annual Meeting (Denver, CO; Feb 26-28, 2001), Preprint No. 01-117, SME, Inc., 2001 Feb:1-8.
<http://www.cdc.gov/niosh/mining/pubs/pubreference/outputid112.htm>
5. Mowrey, GL, Schiffbauer, WH [2009] "Engineering Considerations and Selection Criteria for Proximity Warning Systems for Mining Operations," Web document.
<http://www.cdc.gov/niosh/mining/topics/electrical/pwsselection.htm>.

NOT MEASUREMENT
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Part 21
1 April 1996

DEPARTMENT OF DEFENSE TEST METHOD STANDARD

DOD PREFERRED METHODS FOR ACCEPTANCE OF PRODUCT



AMSC N/A

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Attachment 1

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FOREWORD

1. This Military Standard is approved for use by all Departments and Agencies of the Department of Defense (DoD).

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commander, U.S. Army Armament Research, Development and Engineering Center, ATTN: AMSTA-AR-EDE-S, Picatinny Arsenal, NJ 07806-5000, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

3. DoD procurement practices encourage industry innovation and provide flexibility to achieve the benefits of continuous improvement.

4. There is an evolving industrial product quality philosophy that recognizes the need for quality policy changes that will provide defense contractors with opportunities and incentives toward improvement of product quality and cooperative relationships between the contractor and the Government.

5. Process controls and statistical control methods are the preferable means of preventing nonconformances, controlling quality, and generating information for improvement. An effective process control system may also be used to provide information to assess the quality of deliverables submitted for acceptance. Suppliers are encouraged to use process control and statistical control procedures for their internal control and to submit effective process control procedures in lieu of prescribed sampling requirements to the Government for approval.

6. Sampling inspection by itself is an inefficient industrial practice for demonstrating conformance to the requirements of a contract and its technical data package. The application of sampling plans for acceptance involves both consumer and producer risks; and increased sampling is one way of reducing these risks, but it also increases costs. Suppliers can reduce risks by employing efficient processes with appropriate process controls. To the extent that such practices are employed and are effective, risk is controlled and, consequently, inspection and testing can be reduced.

7. The following points provide the basis for this standard:

- a. Contractors are required to submit deliverables that conform to requirements and to generate and maintain sufficient evidence of conformance.
- b. Contractors are responsible for establishing their own manufacturing and process controls to produce results in accordance with requirements.
- c. Contractors are expected to use recognized prevention practices such as process controls and statistical techniques.

8. This standard also provides a set of sampling plans and procedures for planning and conducting inspections to assess quality and conformance to contract requirements. This standard complies with the DoD policy of eliminating acceptable quality levels (AQL's) and associated practices within specifications.

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1. SCOPE

1.1 Scope. The purpose of this standard is to encourage defense contractors and other commercial organizations supplying goods and services to the U.S. Government to submit efficient and effective process control (prevention) procedures in place of prescribed sampling requirements. The goal is to support the movement away from an AQL-based inspection (detection) strategy to implementation of an effective prevention-based strategy including a comprehensive quality system, continuous improvement and a partnership with the Government. The underlying theme is a partnership between DoD and the defense supplier, with the requisite competence of both parties, and a clear mutual benefit from processes capable of consistently high quality products and services. The objective is to create an atmosphere where every noncompliance is an opportunity for corrective action and improvement rather than one where acceptable quality levels are the contractually sufficient goals.

1.2 Applicability. This standard, when referenced in the contract, specification, or purchase order, is applicable to the prime contractor, and should be extended to subcontractors or vendor facilities. The quality plans are to be applied as specified in the contract documents, and deliverables may be submitted for acceptance if the requirements of this standard have been met.

1.3 Applications. Quality plans and procedures in this standard may be used when appropriate to assess conformance to requirements of the following:

- a. End items
- b. Components or basic materials
- c. Operations or services
- d. Materials in process
- e. Supplies in storage
- f. Maintenance operations
- g. Data or records
- h. Administrative procedures

Note, use of the word "product" throughout this standard also refers to services and other deliverables.

1.4 Product requirements. The contractor is required to submit product that meets all contract and specification requirements. The application of the quality plans or procedures of this standard does not relieve the contractor of responsibility for meeting all contract product requirements. The contractor's quality system, including manufacturing processes and quality control measures, will be established and operated to consistently produce products that meet all requirements. Absence of any inspection or process control requirement in the contract does not

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relieve the contractor of responsibility for assuring that all products or supplies submitted to the Government for acceptance conform to all requirements of the contract.

1.5 Limitations. The sampling plans and procedures of this standard are not intended for use with destructive tests or where product screening is not feasible or desirable. In such cases, the sampling plans to be used will be specified in the contract or product specifications.

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2. APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section are specified in sections 3, 4, and 5 of this standard. This section does not include documents cited in other sections of this standard or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements documents cited in sections 3, 4, and 5 of this standard, whether or not they are listed.

2.2 Non-Government publications. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted are those listed in the issue of the DoDISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DoDISS are the issues of the documents cited in the solicitation (see 6.2).

AMERICAN NATIONAL STANDARDS INSTITUTE/AMERICAN SOCIETY FOR QUALITY CONTROL (ANSI/ASQC)

- ANSI Z1.1/ASQC B1 - Guide for Quality Control Charts.
- ANSI Z1.2/ASQC B2 - Control Chart Methods of Analyzing Data.
- ANSI Z1.3/ASQC B3 - Control Chart Method of Controlling Quality During Production.
- ANSI/ASQC Q9000 - Quality Management and Quality Assurance Standards Guidelines for Selection and Use.
- ANSI/ASQC Q9004 - Quality Management and Quality System Elements Guidelines.

INTERNATIONAL ORGANIZATION OF STANDARDS (ISO)

- ISO 8402 - Quality - Vocabulary.
- ISO 9000 - Quality Management and Quality Assurance Standards - Guidelines for Selection and Use.
- ISO 9004 - Quality Management and Quality System Elements - Guidelines.

(Copies of DoD adopted non-Government Standards are available to Military activities through the DoD Single Stock Point, Standardization Documents Order Desk, Bldg. 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094. Military activities may obtain copies of non-DoD adopted documents from the sponsoring Industry Association. Non-military activities may obtain copies of non-Government standards and publications from the American Society for Quality Control, PO Box 3066, Milwaukee, WI 53201-3066 and the American National Standards Institute, 1430 Broadway, New York, NY 10018, as appropriate.)

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2.3 Order of precedence. In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

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3. DEFINITIONS

3.1 Acronyms used in this standard. The acronyms used in this standard are defined as follows

- a. ACO - Administrative Contracting Officer.
- b. ANSI - American National Standards Institute.
- c. AQL - Acceptable Quality Level.
- d. ASQC - American Society for Quality Control.
- e. CL - Code Letter.
- f. DFARS - DoD Federal Acquisitions Regulation Supplement.
- g. DoD - Department of Defense.
- h. DoDISS - DoD Index of Specifications and Standards.
- i. DoDSSP - DoD Single Stock Point.
- j. FAR - Federal Acquisitions Regulation.
- k. FMEA - Failure Modes and Effects Analysis.
- l. ISO - International Organization for Standardization.
- m. PCO - Procurement Contracting Officer.
- n. PDCA - Plan-Do-Check-Act.
- o. QAR - Quality Assurance Representative.
- p. SPC - Statistical Process Control.
- q. VL - Verification Level.

3.2 Acceptance. The act of an authorized representative of the Government by which the Government, for itself or as agent of another, assumes ownership of existing identified supplies tendered or approves specific services rendered as partial or complete performance of the contract. (FAR 46.101)

3.3 Contract quality requirements. The technical requirements in the contract relating to the quality of the product or service and those contract clauses prescribing inspection, and other quality controls incumbent on the contractor, to assure that the product or service conforms to the contractual requirements. (FAR 46.101)

3.4 Critical characteristic. A characteristic that judgment and experience indicate must be met to avoid hazardous or unsafe conditions for individuals using, maintaining, or depending upon the product; or that judgment and experience indicate must be met to assure performance of the tactical function of a major item such as a ship, aircraft, tank, missile, or space vehicle.

3.5 Critical nonconforming unit. A unit of product that fails to conform to specified requirements for one or more critical characteristics.

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3.6 Government contract quality assurance. The various functions, including inspection, performed by the Government to determine whether a contractor has fulfilled the contract obligations pertaining to quality and quantity. (FAR 46.101)

3.7 Inspection. Examining and testing supplies or services (including, when appropriate, raw materials, components, and intermediate assemblies) to determine whether they conform to contract requirements. (FAR 46.101)

3.8 Major characteristic. A characteristic, other than critical, that must be met to avoid failure or material reduction of usability of the unit of product for intended purpose.

3.9 Major nonconforming unit. A unit of product that fails to conform to specified requirements for one or more major characteristics, but conforms to all critical characteristics.

3.10 Minor characteristic. A characteristic, other than critical or major, whose departure from its specification requirement is not likely to reduce materially the usability of the unit of product for its intended purpose or whose departure from established standards has little bearing on the effective use or operation of the unit.

3.11 Minor nonconforming unit. A unit of product that fails to conform to specified requirements of one or more minor characteristics, but conforms to all critical and major characteristics.

3.12 Nonconformance. A departure from a specified requirement for any characteristic.

3.13 Nonconforming unit. A unit of product that has one or more nonconformances.

3.14 Production interval. A period of production under continuous sampling assumed to consist of essentially homogeneous quality. It is normally a single shift. It can be a day if it is reasonably certain that shift changes do not affect quality of product, but shall not be longer than a day.

3.15 Quality. The composite of material attributes including performance features and characteristics of a product or service to satisfy a given need. (DFARS 46.101)

3.16 Quality assurance. A planned and systematic pattern of all actions necessary to provide adequate confidence that adequate technical requirements are established; products and services conform to established technical requirements; and satisfactory performance is achieved. (DFARS 46.101)

3.17 Quality audit. A systematic examination of the acts and decisions with respect to quality in order to independently verify or evaluate the operational requirements of the quality program or the specification or contract requirements of the product or service. (DFARS 46.101)

3.18 Quality program. A program which is developed, planned, and managed to carry out cost effectively all efforts to effect the quality of materials and services from concept

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through validation, full-scale development, production, deployment, and disposal. (DFARS 46.101)

3.19 Screening inspection. An inspection process whereby every unit is checked and all nonconforming units are removed; also referred to as 100 percent inspection.

3.20 Traceability. The ability to trace the history, application or location of an item or activity, or similar items or activities, by means of recorded identification. (ISO 8402)

3.21 Verification level (VL). Prescribes the level of significance or utility of a characteristic to the user. The amount of effort to assure conformance can be allocated on the basis of importance to the user. (Major characteristics will require more verification effort than minor characteristics.) VL-VII requires the highest level of effort, and the effort decreases as the VL decreases to the lowest level, VL-I.

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4. GENERAL REQUIREMENTS

4.1 Acceptance by contractor-proposed provisions.

4.1.1 General.

- a. This standard, when referenced in the contract or product specifications, requires the contractor to perform sampling inspection in accordance with paragraph 4.2 and the product specification. However, it is recognized that sampling inspection alone does not control or improve quality. Product quality comes from proper product and process design and process control activities. When such activities are effective, sampling inspection is a redundant effort and an unnecessary cost. Contractors that have an acceptable quality system and proven process controls on specific processes are encouraged to consider submitting alternate acceptance methods for one or more contractually specified characteristics. In addition, contractors that have a successful quality system and a history of successful process controls relevant to the products/services being procured in this contract, are encouraged to consider submitting a systemic alternate acceptance method for all the contractual sampling inspection requirements associated with paragraph 4.2.
- b. Submissions shall describe the alternate acceptance methods, the sampling inspection provision to be replaced, and an evaluation of the protection provided by the alternate methods as compared with the inspection requirement to be replaced. The alternate acceptance method shall include evidence of process control and capability during production together with adequate criteria, measurement, and evaluation procedures to maintain control of the process. The acceptability of the alternate acceptance methods is dependent upon the existence of a quality system, the demonstration of its process focus, and the availability of objective evidence of effectiveness.

4.1.2 Requirements and procedures.

- a. Contractors currently operating quality systems in accordance with such models as MIL-Q-9858 enhanced with Statistical Process Controls (SPC), ANSI/ASQC Q9004, or others that are deemed satisfactory to the Government representative are qualified to apply for alternate acceptance methods if demonstration of process focus and objective evidence of effectiveness exists.
- b. The contractor shall include in his request for approval of an alternate acceptance method an assessment plan to periodically verify process stability, capability, and other conditions under which the alternate acceptance method was developed. The current minimum values of process capability are equivalent to a C_{pk} of 2.00 for critical characteristics, 1.33 for major characteristics, and 1.00 for minor

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characteristics. Upon approval of the assessment plan, the contractor may reduce or eliminate inspection sampling when the plan criteria are met or exceeded.

4.1.3 Submission and incorporation.

4.1.3.1 Submission. There are two ways of submitting alternate acceptance methods:

- a. Submission of individual alternate acceptance methods for one or more contractually specified sampling inspection requirements through the Government quality assurance representative (QAR) to the procuring contracting officer (PCO) for approval at any time during the contract period of performance.
- b. Submission of a systemic alternate acceptance method to the PCO prior to contract being awarded. This pre-approval allows the contractor to adopt alternate acceptance methods throughout the length of the contract. After contract award, submissions of a systemic alternate acceptance method should be made through the administrative contracting officer (ACO) to the PCO.

4.1.3.2 Incorporation. All approved alternate acceptance methods shall be incorporated into the contractor's manufacturing and quality program plans or other vehicles acceptable to the contracting agency, as applicable.

4.1.4 Withdrawal of approval of alternates. The Government reserves the right to withdraw approval of alternate acceptance methods that are determined to provide less assurance of quality than the inspection requirements originally specified or when the inability to maintain process stability and capability over time becomes apparent.

4.2 Acceptance by tables.

4.2.1 Preferred sampling plans. This standard establishes three sets of matched sampling plans for the sampling inspection of product submitted to the Government for acceptance. These sampling plans provide for inspecting the samples from lots or batches by attributes or variables measurement and for continuous sampling by attributes measurement. The three sets of matched sampling plans are indexed by seven specified verification levels (VL) and five code letters (CL), which are determined by the lot or production interval size. The sampling plans are matched between corresponding VL and CL combinations to result in essentially similar protection. The contractor has the option to utilize the type of plan, at the same verification level, that best complements the production process.

4.2.2 Formation and identification of lots or batches. The product shall be assembled into identifiable lots, sublots, or batches, or in such other manner as may be prescribed. Each lot or batch shall, as far as practicable, consist of units of product of a single type, grade, class, size, and composition, manufactured under essentially the same conditions, and at essentially the same time. The lots or batches shall be identified by the contractor and shall be kept intact in

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adequate and suitable storage space. Although lot or batch size is not used to select a continuous sampling plan, the formation of lots or batches may remain desirable for reasons of homogeneity, shipping convenience, and facilitation of payment.

4.2.3 Determination of sampling plan. A sampling plan is determined by:

- a. Verification level (VL) as specified.
- b. Type of sampling (attributes, variables, or continuous).
- c. Lot or production interval size code letter (CL) from Table I.
- d. Switching procedure (normal, tightened, reduced).

For lot acceptance situations (attributes or variables), the occurrence of one or more nonconformances shall result in withholding acceptance of the product submitted and initiation of corrective action. When continuous sampling is in effect, the occurrence of a nonconforming unit while in a sampling phase results in withholding acceptance of that unit, a return to screening, and initiation of corrective action. If a nonconforming unit is found while in a screening phase, acceptance is withheld for that unit and screening is continued until the requirements of paragraph 5.2.2.3.2 are satisfied.

4.2.4 Sampling of lots or batches.

4.2.4.1 Selection of units. Units of product drawn from a lot for a sample shall be selected at random from the lot without regard to their quality. Random sampling requires that each unit in the lot, batch, or production interval has the same probability of being selected for the sample.

4.2.4.2 Representative (stratified) sampling. When appropriate, the number of units in the sample shall be selected in proportion to the size of sublots or subbatches, or parts of the lot or batch, identified by some rational criterion. When representative sampling is used, the units from each subplot, subbatch, or part shall be selected at random.

4.2.4.3 Process of sampling. A sample may be drawn after all units comprising the lot or batch have been assembled, or sample units may be drawn during assembly of the lot or batch, in which case the size of the lot or batch shall be determined before samples are drawn. When the lot or batch passes the sampling plan, such lots or batches are acceptable and may be submitted to the Government.

4.2.4.4 Non-conforming product. When sample units are drawn during lot or batch assembly and nonconforming units are found, the contractor shall withhold from acceptance that portion of the lot completed and all additional production occurring prior to the initiation and verification of corrective action. For lots or batches withheld from acceptance, the contractor shall take the following actions:

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- a. Screen the lots or batches and dispose of all nonconforming units in accordance with paragraph 4.3.
- b. Determine the cause of the nonconformances and implement appropriate process changes.
- c. Initiate the switching requirements of paragraph 5.2.1.3.
- d. Advise the Government representative of actions taken and resubmit the screened lot or batches to the Government for evaluation/consideration.

4.3 Disposition of nonconforming product. All units of product found to be nonconforming by the contractor shall be removed and kept apart from the flow of production or otherwise identified or segregated to preclude submission to the Government. The contractor may rework or repair these units unless the contract excludes such activities. Corrected product shall be screened by the contractor and resubmitted to the Government apart from the regular flow of the product.

4.4 Critical characteristics. Unless otherwise specified in the contract or product specifications, the contractor is required for each critical characteristic to implement an automated screening or a fail safe manufacturing operation and apply sampling plan VL-VII to verify the performance of the screening operation. The occurrence of one or more critical nonconformances requires corrective action as specified in paragraph 4.5.

4.5 Special reservations for critical nonconformance. When a critical nonconformance is discovered at any phase of production or during any inspection, the following immediate actions are required:

- a. Prevent delivery of critical nonconforming units to the Government.
- b. Notify the Government representative.
- c. Identify the cause.
- d. Take corrective action.
- e. Screen all available units

Records of corrective actions shall be maintained and made available to the Government representative.

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5. DETAILED REQUIREMENTS

5.1 Acceptance by contractor-proposed provisions. In order for an alternate acceptance method to be considered, the contractor shall establish and implement an internal prevention-based quality system as a means of ensuring that all products conform to requirements specified by the contract and associated specifications and standards. The acceptability of the quality system as part of the request for alternate acceptance method(s) is dependent on its compliance with an industry-accepted quality system model, demonstration of its process focus, and the availability of objective evidence of its implementation and effectiveness.

5.1.1 Quality system plan. The quality system shall be documented and shall be subject to on-site Government review throughout the contract. It shall include, at a minimum, a description of the organizational structure, responsibilities, procedures, processes, and resources. Such documentation is hereinafter called the quality system plan. The contractor shall maintain, disseminate, update, and improve the quality system plan in order to ensure its continued use and accuracy. The design and documentation of the quality system plan shall allow for ease of use, review, and audit by internal as well as Government personnel.

5.1.2 Prevention-based quality system. The quality system shall be prevention-based. Common quality system models that reflect this philosophy include the ISO 9000 series, MIL-Q-9858 enhanced with SPC, and many industry specific total quality standards and programs. The quality system shall also reflect additional needs in accordance with the requirements of this standard. Regardless of the model chosen, the quality system shall demonstrate its prevention-based outlook by meeting the following objectives throughout all areas of contract performance:

- a. The quality system is understood and executed by all personnel having any influence on product or process quality.
- b. Products and services meet or exceed customer requirements.
- c. Quality is deliberately and economically controlled.
- d. Emphasis is on the prevention of process discrepancies and product nonconformances.
- e. Discrepancies and nonconformances that do occur are readily detected, and root cause corrective actions are taken and verified.
- f. Sound problem solving and statistical methods are employed to continuously reduce process variability and, in turn, improve process capability and product quality.
- g. Records are maintained and indicate implementation of the quality plan and effectiveness of the control procedures.

5.1.3 Process focus of quality system. To demonstrate a process focus, the contractor shall demonstrate that the manufacturing process and its related processes have been studied and are understood, controlled, and documented to show that they are:

- a. Consistently producing conforming product.

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- b. Controlled as far upstream as possible.
- c. Robust to variation in equipment, raw materials, and other process inputs, and designed to yield a quality product.
- d. Operated with the intent to constantly strive to reduce process/product variability.
- e. Designed to utilize manufacturing equipment with objectives of minimum variability around targeted values.
- f. Managed for continuous improvement.
- g. Designed and controlled using a combination of manufacturing practices and statistical methods in order to ensure defect prevention and process improvement.

5.1.4 Objective evidence of quality system implementation and effectiveness.

5.1.4.1 Examples of evidence regarding process improvement.

- a. Process flow charts showing the key control points where action is taken to prevent the production of defective product.
- b. Identification of process improvement techniques and tools used, e.g., Plan-Do-Check-Act (PDCA) cycle, Failure Modes and Effects Analysis (FMEA), Pareto Analysis, and Cause and Effect Analysis.
- c. Identification of the measures used, e.g., trend analysis, cost of quality, cycle time reduction, defect rates, 6-sigma capability.
- d. Results of the improvements from the use of these process improvement tools.
- e. Results of properly planned experiments that led to reduced common cause variability of a process and improved productivity

5.1.4.2 Examples of evidence regarding process control.

- a. Identification of the scope of use of process control techniques, e.g., SPC, automation, gages, set-up verification, preventative maintenance, visual inspection.
- b. Process control plans, including the improvement goals and statements of management commitment to SPC.
- c. Approaches and supporting data used to determine if suppliers have adequate controls to assure defective product is not produced and delivered.
- d. Descriptions of the required training in SPC and/or continuous improvement, i.e., the number of courses and their content, courses required for personnel at each organizational level and function associated with the quality plan, the qualifications of the instructors or trainers for SPC classes, support by management to attend such courses, and information demonstrating the effectiveness of the training.

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- e. Identification and definition of the interrelations of all departments (e.g., production, engineering, purchasing, marketing, administration, etc.) involved in SPC and quality improvement, their responsibilities, and the use of teams.
- f. When applying control charts, the reasoning behind establishing rational subgroups and sampling frequency; the procedures for determining and updating control limits; and the criteria for determining out-of-control conditions.
- g. Identification of key parameters used in lieu of one or more specified characteristics, verification of the correlation of such parameters to those characteristics, and description of the manufacturing process steps responsible for these parameters.
- h. Identification of personnel responsible for process-related corrective action.
- i. Proper gage measurement studies showing measurement variations relative to the total variation.
- j. Traceability of the product and process corrective action(s) taken when the process went out of statistical control, showing how the root cause was identified and eliminated.

5.1.4.3 Examples of evidence regarding product conformance.

- a. Control charts showing the process in statistical control in accordance with the criteria asked for in paragraph 5.1.4.2.f.
- b. Records of product and process corrective action(s) taken when nonconformances occur.
- c. Process capability studies consisting of the correct calculation and interpretation of indices, such as C_p and C_{pk} .
- d. History of product inspection results reinforced by statistical data and analysis.
- e. Results from in-process control methods, such as 100 percent automated assembly and/or inspection.

5.2 Acceptance by tables:

5.2.1 Sampling inspection. When acceptance is to be accomplished using the sampling tables provided in this document, the following considerations apply.

5.2.1.1 Verification level specification. The VL's are specified in the contract or product specifications. A VL may be specified for individual characteristics, for a group of characteristics, or for subgroups of characteristics within the group. The VL and code letter (CL) from Table I determine the sampling plan required to assess product compliance to contract and specification requirements. Contractors are expected to produce and submit product in full conformance to all requirements. Lots, batches, or production intervals of product that consistently meet or exceed all requirements will be accepted by the sampling plans of this standard and will result in qualifying for reduced sampling levels.

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TABLE I. Code letters (CL) for entry into the sampling tables

Lot or production interval size	Verification levels						
	VII	VI	V	IV	III	II	I
2-170	A	A	A	A	A	A	A
171-288	A	A	A	A	A	A	B
289-544	A	A	A	A	A	B	C
545-960	A	A	A	A	B	C	D
961-1632	A	A	A	B	C	D	E
1633-3072	A	A	B	C	D	E	E
3073-5440	A	B	C	D	E	E	E
5441-9216	B	C	D	E	E	E	E
9217-17408	C	D	E	E	E	E	E
17409-30720	D	E	E	E	E	E	E
30721 and larger	E	E	E	E	E	E	E

5.2.1.2 Sampling procedures. Sampling is performed at one of three stages called normal, tightened, and reduced. Unless otherwise specified, the VL stated in the contract shall be considered the normal stage of inspection and shall be used at the start of inspection. The tightened and the reduced stages are then defined as the stages to the immediate left and right, respectively, of the initial stage. The sampling inspection stage in effect shall continue unchanged for each group of characteristics or individual characteristic except where the switching procedures given in paragraph 5.2.1.3 require change. The switching procedures shall be applied to each group of characteristics or to individual characteristics.

5.2.1.3 Switching procedures. The procedures for switching among normal, tightened, and reduced inspection are given as Note (2) in Tables II, III, and IV.

The switching procedures are independent of the results of any remedial action, such as screening, additional samples, etc., resulting from the occurrence of sample nonconformances and withholding of acceptance.

Some Table IV switching criteria depend upon a corresponding Table II entry. These entries have been denoted by $n_a(N)$ and $n_a(T)$ in the descriptions that follow. $n_a(N)$ represents the Table II sample size used for normal sampling at the VL and CL currently in effect. Likewise, $n_a(T)$ represents the tightened sample size.

5.2.1.3.1 Normal to tightened. When normal inspection is in effect, tightened inspection shall be instituted when one of the following conditions occurs, depending on the type of sampling plan being used:

Lot or batch sampling (Tables II and III):

2 lots or batches have been withheld from acceptance within the last 5 or fewer lots or batches.

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Continuous sampling (Table IV):

2 nonconforming units are found within a period of inspections (whether on sampling or screening) totaling no more than 5 times $n_a(N)$.

5.2.1.3.2 Tightened to normal. When tightened inspection is in effect, normal inspection may be instituted when the following conditions are both satisfied:

- a. The cause for producing the nonconformances is corrected.
- b. Lot or batch sampling (Tables II and III):

5 consecutive lots/batches are accepted.

Continuous sampling (Table IV):

No nonconforming units have been found within a period of inspections (whether on sampling or screening) totaling at least 5 times $n_a(T)$ units.

5.2.1.3.3 Normal to reduced. When normal inspection is in effect, reduced inspection may be instituted when the following conditions are all satisfied:

- a. Lot or batch sampling (Tables II and III):

10 consecutive lots/batches are accepted while on normal inspection.

Continuous sampling (Table IV):

No nonconforming units have been found within a period of inspections (whether on sampling or screening) totaling at least 10 times $n_a(N)$ units.

- b. Production is at a steady rate.
- c. The contractor's quality system is considered satisfactory by the Government.
- d. Reduced inspection is considered desirable by the Government.

5.2.1.3.4 Reduced to normal. When reduced inspection is in effect, normal inspection shall be instituted when one of the following conditions occur.

- a. Lot or batch sampling (Tables II and III):

A lot/batch is withheld from acceptance.

Continuous sampling (Table IV):

A nonconforming unit is found.

- b. Production becomes irregular or delayed.
- c. The contractor's quality system is unsatisfactory.
- d. Other conditions warrant that normal inspection be re-instituted.

5.2.1.4 Discontinuation of acceptance. If sampling inspection of lots or batches remains in tightened inspection due to discovery of nonconformances or when, on continuous sampling

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plans, there are long periods of screening due to discovery of nonconformances, the Government reserves the right to discontinue acceptance of the product until the causes of nonconformances are eliminated or other means acceptable to the procuring agency have been instituted. When sampling inspection is restarted after discontinuation of acceptance, it shall be at the tightened inspection stage.

5.2.2 Preferred sampling inspection tables. See the Appendix for methods of computing sampling results, using switching rules, and determining compliance with requirements using the attributes, variables, and continuous sampling plans contained in this section.

5.2.2.1 Attributes sampling plans for lot or batch inspection. The preferred attributes sampling plans for lots or batches are described in Table II for normal, tightened, and reduced inspection.

5.2.2.1.1 Acceptability criterion. The lot or batch shall be considered acceptable only if no nonconforming units are found upon inspection of the random sample of the size listed in Table II.

TABLE II. Attributes sampling plans

Code letter	Verification levels								
	T	VII	VI	V	IV	III	II	I	R
	Sample size (n _a)								
A	3072	1280	512	192	80	32	12	5	3
B	4096	1536	640	256	96	40	16	6	3
C	5120	2048	768	320	128	48	20	8	3
D	6144	2560	1024	384	160	64	24	10	4
E	8192	3072	1280	512	192	80	32	12	5

NOTES:

- (1) When the lot size is less than or equal to the sample size, 100 percent attributes inspection is required.
- (2) One verification level (VL) to the left/right of the specified normal VL is the respective tightened/reduced plan. Tightened inspection of VL-VII is T, reduced inspection of VL-I is R.

5.2.2.2 Variables sampling plans for lot or batch inspection. The preferred variables sampling plans for lots or batches are described in Table III for normal, tightened, and reduced inspection.

5.2.2.2.1 Limitations on use. Variables sampling is not to be used indiscriminately. Its use shall depend upon evidence, provided by graphical or statistical analyses, that the assumptions of independence and normality are being met. Attribute sampling shall be used whenever the evidence fails to warrant use of variables sampling.

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5.2.2.2.2 Nonconforming unit. For the purposes of variables sampling, a unit of product shall be considered nonconforming if its variables measurement is outside the specified tolerance.

5.2.2.2.3 Acceptability criteria. The lot or batch shall be considered acceptable if its sample contains no nonconforming units and the applicable "k" and "F" criteria (see Table III) are met. If the sample contains any nonconforming unit, or if the sample does not meet the "k" criterion, or if the sample does not meet the "F" criterion (when applicable), the lot does not meet the acceptability criteria.

- a. k criterion, single-sided specification. For a single-sided specification the quantity $\frac{|\bar{x} - \text{spec limit}|}{s}$ shall be greater than or equal to the k value specified in Table III in order to meet the "k" criterion.
- b. k criterion, double-sided specification. For a double-sided specification, each of the quantities $\frac{(\bar{x} - L)}{s}$ and $\frac{(U - \bar{x})}{s}$ must be greater than or equal to the k value specified in Table III in order to meet the "k" criterion.
- c. F criterion (only applicable in double-sided specifications). For a double-sided specification the quantity $\frac{s}{(U - L)}$ must be less than or equal to the specified F value in Table III in order to meet the "F" criterion.

Note: \bar{x} = sample mean, s = sample standard deviation,
 U = upper specification limit, L = lower specification limit.

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TABLE III. Variables sampling plans

Code letter	Verification levels								R
	T	VII	VI	V	IV	III	II	I	
Sample size (n_V)									
A	113	87	64	44	29	18	9	4	2
B	122	92	69	49	32	20	11	5	2
C	129	100	74	54	37	23	13	7	2
D	136	107	81	58	41	26	15	8	3
E	145	113	87	64	44	29	18	9	4
k values (one- or two-sided)									
A	3.51	3.27	3.00	2.69	2.40	2.05	1.64	1.21	1.20
B	3.58	3.32	3.07	2.79	2.46	2.14	1.77	1.33	1.20
C	3.64	3.40	3.12	2.86	2.56	2.21	1.86	1.45	1.20
D	3.69	3.46	3.21	2.91	2.63	2.32	1.93	1.56	1.20
E	3.76	3.51	3.27	3.00	2.69	2.40	2.05	1.64	1.21
F values (two-sided)									
A	.136	.145	.157	.174	.193	.222	.271	.370	.707
B	.134	.143	.154	.168	.188	.214	.253	.333	.707
C	.132	.140	.152	.165	.182	.208	.242	.301	.707
D	.130	.138	.148	.162	.177	.199	.233	.283	.435
E	.128	.136	.145	.157	.174	.193	.222	.271	.370

NOTES:

- (1) When the lot size is less than or equal to the sample size, 100 percent attributes inspection is required.
- (2) One verification level (VL) to the left/right of the specified normal VL is the respective tightened/reduced plan. Tightened inspection of VL-VII is T, reduced inspection of VL-I is R.

5.2.2.3 Continuous attributes sampling inspection plans. The preferred continuous sampling plans for inspection by attributes are described in Table IV for normal, tightened, and reduced inspection.

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TABLE IV. Continuous sampling plans

Code letter	T	Verification levels							R
		VII	VI	V	IV	III	II	I	
Screening phase: clearance numbers (i)									
A	3867	2207	1134	527	264	125	55	27	NA
B	7061	3402	1754	842	372	180	83	36	NA
C	11337	5609	2524	1237	572	246	116	53	NA
D	16827	8411	3957	1714	815	368	155	73	NA
E	26912	11868	5709	2605	1101	513	228	96	NA
Sampling phase: frequencies (f)									
A	1/3	4/17	1/6	2/17	1/12	1/17	1/24	1/34	1/48
B	4/17	1/6	2/17	1/12	1/17	1/24	1/34	1/48	1/68
C	1/6	2/17	1/12	1/17	1/24	1/34	1/48	1/68	1/96
D	2/17	1/12	1/17	1/24	1/34	1/48	1/68	1/96	1/136
E	1/12	1/17	1/24	1/34	1/48	1/68	1/96	1/136	1/192

NOTES:

(1) Use of other i and f combinations are permitted provided they are computed in accordance with Appendix, paragraph 30.5.

(2) During the screening phase, one verification level (VL) to the left of the specified normal VL is the tightened plan. Tightened inspection of VL VII is T. There is no reduced plan while in the screening phase.
During the sampling phase, one verification level (VL) to the left/right of the specified normal VL is the respective tightened/reduced plan. Tightened inspection of VL-VII is T, reduced inspection of VL-I is R.

(3) Sample units shall be chosen with frequency (f) so as to give each unit of product an equal chance of being inspected. The inspector should allow the interval between sample units to vary somewhat rather than draw sample units according to a rigid pattern.

5.2.2.3.1 Conditions for continuous sampling procedures. The following conditions must exist before the continuous attributes sampling procedures of this section may be used for inspection.

- a. Moving product.
- b. Ample space, equipment, and manpower at or near the inspection station to permit 100 percent inspection when required.
- c. A process that is producing or is capable of producing material whose quality is stable.

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5.2.2.3.2 Continuous sampling inspection procedure. At the start of production, all units are inspected. Sampling inspection may be initiated at frequency "f" when the following conditions are satisfied:

- a. All units of product are of the same configuration and produced under stable conditions.
- b. At least "i" consecutive units inspected are free of nonconformances.

Sampling inspection shall be terminated and 100 percent inspection resumed if either of the following conditions occur:

- a. The production process is interrupted for more than three operating days.
- b. The requirement that all units of product are of the same configuration and produced under stable conditions is not satisfied.
- c. A unit having any nonconformance is found during sampling.

5.2.2.3.3 Acceptability criterion. In continuous sampling, units of product are determined to be acceptable or not on essentially an individual basis. While 100 percent inspection is being performed, each unit is individually inspected and categorized as a conforming or a nonconforming unit and accepted or not accepted accordingly. While inspection is being performed on a sampling basis, each unit that is inspected is categorized as acceptable or not acceptable depending on whether it is found to be conforming or nonconforming and each unit not inspected is considered to be conforming and hence accepted. (See "Special reservation for critical nonconforming unit", paragraph 5.2.2.3.3.1.)

5.2.2.3.3.1 Special reservation for critical nonconforming unit. In addition to the provisions of paragraph 4.5, if a critical nonconforming unit is found while on sample inspection, all product since the last conforming unit was found shall be inspected.

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6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory).

6.1 Intended use. This document is intended for use in contracts in place of AQL-based sampling documents.

6.2 Issue of DoDISS. When this standard is used in acquisition, the applicable issue of the DoDISS must be cited in the solicitation (see 2.2).

6.3 Supersession data. The following military standards are planned to be canceled when this standard is approved:

a. MIL-STD-414 - Sampling Procedures and Tables for Inspection by Variables for Percent Defective

b. MIL-STD-1235 - Single-and Multi-Level Continuous Sampling Procedures and Tables for Inspection by Attributes

6.4 Subject term (keyword listing).

Attributes
Continuous
Control
Process
Sampling
Statistical
Variables
Verification

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EXAMPLES OF SAMPLING PLAN USE

10. SCOPE

10.1 General. This Appendix is not a mandatory part of the standard. The information contained herein is intended for guidance only.

10.2 Purpose. This Appendix illustrates how to implement the three types of sampling plans described in paragraphs 4 and 5 of this standard. The examples explain how to use the four tables, how to apply the switching rules, and how to do some of the requisite calculations. In addition, this Appendix explains how the contractor can modify Table IV to some extent by calculating and using other "i" and "f" values.

20. APPLICABLE DOCUMENTS. This section is not applicable to this Appendix.

30. EXAMPLES

30.1 Attributes sampling. Wing nuts are to be inspected for missing thread. A verification level IV (VL-IV) has been specified. The producer chooses to use attributes

Lot #	Lot Size	Code Letter	Sample Size	Non-conformances	Lot Disposition	Stage T/N/R	Action
1	5000	D	160	2	Withhold Acceptance	N	Begin with normal sampling, VL-IV.
2	900	A	80	0	Accept	N	
3	3000	C	128	1	Withhold Acceptance	N	2 lots out of 5 fail to pass. Switch to tightened VL-IV. Check process.
4	1000	B	256	0	Accept	T	
5	1000	B	256	0	Accept	T	
6	900	A	192	0	Accept	T	
7	2000	C	320	0	Accept	T	
8	2500	C	320	0	Accept	T	Process corrected and 5 consecutive lots accepted. Switch to normal VL-IV.
9	3000	C	128	0	Accept	N	
10	5000	D	160	0	Accept	N	

FIGURE 1. Attributes sampling inspection log.

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sampling plans from Table II. Lot sizes may vary as a result of production decisions. A segment of the producer's experience is shown in figure 1.

30.2 Variables sampling (single-sided specification limit case). The maximum temperature of operation for a certain device is specified as 209 (measured in degrees F). Verification level I (VL-I) has been specified. A lot of 40 items is submitted for inspection in accordance with variables sampling. Table III requires a sample size of $n_v = 4$ for code letter A. Suppose the measurements obtained are as follows: 197, 188, 184, and 205; and compliance

Line	Information Needed	Symbol	Formula	Result	Explanation
1	Sample size	n_v		4	See Table III
2	Sum of measurements		$\sum x$	774	
3	Sum of squared measurements		$\sum x^2$	150034	
4	Correction factor	CF	$(\sum x)^2 / n_v$	149769	$(774)^2 / 4$
5	Corrected sum of squares	SS	$\sum x^2 - CF$	265	150034-149769
6	Sample variance	V	$SS / (n_v - 1)$	88.333	265/3
7	Sample standard deviation	s	\sqrt{V}	9.399	$\sqrt{88.333}$
8	Sample mean	\bar{x}	$\sum x / n_v$	193.500	774/4
9	Lower specification limit Upper specification limit	L U		Not applicable 209	
10	Lower quality index Upper quality index Quality Index	Q_L Q_U Q	$(\bar{x} - L) / s$ $(U - \bar{x}) / s$ $\min(Q_L, Q_U)$	Not applicable 1.649 1.649	 $(209 - 193.5) / 9.399$
11	Sample F value	\hat{F}	$s / (U - L)$	Not applicable	
12	Number of nonconformances k value F value	C k F		0 1.210 Not applicable	See Table III See Table III
13	C acceptability criterion k acceptability criterion F acceptability criterion		$C = 0 ?$ $Q \geq k ?$ $\hat{F} \leq F ?$	Yes Yes Not applicable	 1.649 \geq 1.21
NOTES: The k value is the minimum allowable value for the quality index, Q . The F value is the maximum allowable value for the sample F value, \hat{F} .					

FIGURE 2. Computations for single specification limit case.

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with the acceptability criteria is to be determined. Computations are shown in figure 2. The lot is accepted since it meets all applicable acceptability criteria.

30.3 Variables sampling (double-sided specification limit case). The minimum temperature of operation for a certain device is specified as 180 (measured in degrees F). The maximum is 209. Verification level I (VL-I) has been specified. A lot of 40 items is submitted for inspection in accordance with variables sampling. Table III requires a sample of size $n_v = 4$ for code letter A (CL-A). Suppose the measurements obtained are as follows: 197, 188, 184 and 205; and compliance with the acceptability criteria is to be determined. Computations are shown in figure 3. The lot is accepted since it meets all applicable acceptability criteria.

Line	Information Needed	Symbol	Formula	Result	Explanation
1	Sample size	n_v		4	See Table III
2	Sum of measurements		$\sum x$	774	
3	Sum of squared measurements		$\sum x^2$	150034	
4	Correction factor	CF	$(\sum x)^2 / n_v$	149769	$(774)^2 / 4$
5	Corrected sum of squares	SS	$\sum x^2 - CF$	265	150034-149769
6	Sample variance	V	$SS / (n_v - 1)$	88.333	265/3
7	Sample standard deviation	s	\sqrt{V}	9.399	$\sqrt{88.333}$
8	Sample mean	\bar{x}	$\sum x / n_v$	193.500	774/4
9	Lower specification limit Upper specification limit	L U		180 209	
10	Lower quality index Upper quality index Quality Index	Q_L Q_U Q	$(\bar{x} - L) / s$ $(U - \bar{x}) / s$ $\min(Q_L, Q_U)$	1.436 1.649 1.436	$(193.5-180)/9.399$ $(209-193.5)/9.399$
11	Sample F value	\hat{F}	$s / (U - L)$	0.324	$9.399 / (209-180)$
12	Number of nonconformances k value F value	C k F		0 1.210 0.370	See Table III See Table III
13	C acceptability criterion k acceptability criterion F acceptability criterion		$C = 0?$ $Q \geq k?$ $\hat{F} \leq F?$	Yes Yes Yes	$1.436 \geq 1.210$ $0.324 \leq 0.370$
NOTES: The k value is the minimum allowable value for the quality index, Q . The F value is the maximum allowable value for the sample F value, \hat{F} .					

FIGURE 3. Computations for double specification limit case.

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30.4 Continuous sampling. A visual inspection of stamped metal parts for the presence of a spot weld will be performed immediately after units pass through a spot welding station. Verification level II (VL-II) has been specified. The product will be submitted for continuous attributes sampling inspection. The production interval size is an 8-hour shift, which initially will consist of between 700 to 800 welded parts. With VL-II and code letter C (CL-C) from Table I, the "i" and "f" values (Table IV) are found to be 116 and 1/48, respectively. A segment of sampling experience is shown in figure 4.

Product Item Number	Code Letter	Frequency or 100%	Stage T/N/R	Event/Action
1	C	100%	N	Start production: Begin screening phase with $i = 116$.
8	C	100%	N	Find a defective unit: Reset counter.
124	C	100%	N	$i = 116$ consecutive conforming units cleared: Begin sampling phase with $f = 1/48$.
170	C	1/48	N	First random sample selected: Found it to conform.
9697	C	1/48	N	200 consecutive conforming sampled units observed: Switch to reduced inspection with $f = 1/68$. Here, 200 equals 10 times the Table II sample size entry for CL-C and VL-II.
9769	C	1/68	R	Next sample randomly selected with $f = 1/68$.
13982	C	1/68	R	Production interval size tripled (2100 to 2400 units): End CL-C and begin CL-E sampling phase, $f = 1/136$, since VL-II and reduced sampling inspection are in effect.
14121	E	1/136	R	First random sample taken with new $f = 1/136$: Found it to conform. Continue random sampling.
16290	E	1/136	R	A nonconforming unit observed: Switch to normal inspection. Initiate screening phase with $i = 228$, since CL-E and VL-II are in effect.
16518	E	100%	N	$i = 228$ consecutive conforming units cleared: Begin sampling phase with $f = 1/96$.

FIGURE 4. Continuous sampling inspection log.

30.5 Continuous sampling - plan tailoring. The producer may opt to use another continuous sampling plan instead of the one specified in Table IV. The only restrictions are that such a change is not allowed while inside a screening sequence and that the new plan be derived in accordance with the procedure described below.

Certain circumstances make such choices desirable. Sometimes the selection of a clearance number or frequency is application dependent, e.g., if it matters that i or $1/f$ be a

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multiple of pallet size. Availability and capability of screening and sampling crews are yet further considerations.

The plan cited in Table IV consists of the largest i number and the smallest f number combination. Plans whose i is larger than the tabulated i , or whose f is smaller than the tabulated f , are not permitted. Producers willing to sample at rates larger than f can reduce i substantially.

The procedure that allows choice is presented by way of the preceding continuous sampling example situation as initially described, subject to one modification: the producer prefers to start with a plan having an i of 50 instead of the 116 specified. The procedure to determine a valid f is as shown in figure 5.

Line	Information Needed	Symbol	Formula	Result	Explanation
1	Clearance number	i		116	Table IV
2	Target i number	i_t	$i_t < i?$	Yes	$50 < 116$
3	Attribute sample size	n_a		20	Table II, same VL, CL
4	Compute f_0 :				
	Step 1	S_1	$(n_a + 1)(1 + 1/n_a)^{n_a}$	55.7193	
	Step 2	S_2	$(i_t + 1)(1 + 1/i_t)^{i_t}$	137.2710	
	Step 3	S_3	$[S_1 / (S_1 - 1)]^{i_t}$	2.4732	
	Step 4	f_0	$(S_1 - 1) / [(S_2)(S_3)]$	0.1612	
5	Valid f		$Any f > f_0$	1/6	$1/6 > 0.1612$

FIGURE 5. Procedure to determine a valid f .

Therefore, an i of 50 may be used in lieu of 116 if f is increased from 1/48 to 1/6.

If it is f that is preselected, the corresponding i may be found by trial and error, that is, by iterative implementation of the procedure described.

The printed numerical results have been rounded to 4-decimal accuracy. However, use of the procedure requires that all calculations be performed with at least 6-digit precision. Evidence supporting the validity of numerical results shall be maintained and be available for review upon request. Proper execution of the procedure ensures Tables IV and II are comparable with respect to the average fraction inspected and the average outgoing quality limit.

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CONCLUDING MATERIAL

Custodians:

Army - AR
Navy - OS
Air Force - 05
DLA - DH

Preparing activity:

Army - AR

Review activities:

Army - AT, AV, CR, EA, GL, ME, MI, MR
Navy - AP, AS, CH, EC, NM, NW, SA, SH, YD-1
Air Force - 10, 11, 13, 17, 19, 70, 71, 80, 82, 84
DLA - ES

(Project QCIC -0146)

NOT MEASUREMENT
SENSITIVE

2010 MAR 31

MIL-STD-690D
10 June 2005
SUPERSEDING
MIL-STD-690C
26 March 1993

DEPARTMENT OF DEFENSE

STANDARD PRACTICE

FAILURE RATE SAMPLING PLANS
AND PROCEDURES



AMSC N/A

AREA SESS

Attachment 2

MIL-STD-690D

FOREWORD

1. This Department of Defense standard is approved for use by all Departments and Agencies of the Department of Defense.

2. Comments, suggestions, or questions on this document should be addressed to: Defense Supply Center, Columbus, ATTN: DSCC-VAT, Post Office Box 3990, Columbus, Ohio 43218-3990 or by email resistor@dla.mil. Since contact information can change, you may want to verify the currency of this address information using the ASSIST Online database at <http://assist.daps.dla.mil>.

3. Much of the basic procedure outlined herein is based upon the efforts of the Quality Assurance Practices Committee of the Electronic Industries Association. Their assistance, as well as those of other industry and military services activities, is herewith acknowledged.

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1. SCOPE

1.1 Purpose. This standard provides procedures for failure rate (FR) qualification, sampling plans for establishing and maintaining FR levels at selected confidence levels, and lot conformance inspection procedures associated with FR testing for the purpose of direct reference in appropriate military electronic parts established reliability (ER) specifications. Figures and tables throughout this standard are based on exponential distribution. Weibull distribution will be acceptable in certain components such as capacitors. Use of Weibull distribution for any component must be approved by the qualifying activity. This standard also provides guidance to specification writers in the use of this standard (see appendix A) and references material for users of ER parts.

1.2 Application. This standard is applicable for reference in electronic parts ER specifications when the following conditions exist:

- a. Electronic parts are essentially the same design and are manufactured under essentially continuous production; the production process is established and controlled in accordance with MIL-STD-790.
- b. The part design and manufacturing processes produce a product whose failure rate can reasonably be assumed to be constant with time over its intended life (i.e., an exponential distribution of failures per unit time).
- c. The qualifying activity administers this standard to provide the consumer with assurance that the qualified FR level is being maintained by a given manufacturer, since these procedures in themselves are not sufficient to assure the qualified FR level.

1.3 Method of reference. This standard can be referenced in ER specifications by specifying the following procedures:

- a. Procedure I, "Qualification at the initial FR level" (see 5.1).
- b. Procedure II, "Extension of qualification to lower FR levels" (see 5.2).
- c. Procedure III, "Maintenance of FR level qualification" (see 5.3).
- d. Procedure IV, "Lot conformance FR inspection" (when specified) (see 5.4).

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2. APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section are specified in section 3, 4, and 5 of this standard. This section does not include documents cited in other sections of this standard or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements documents cited in section 3, 4, and 5 of this standard, whether or not they are listed.

2.2 Government documents.

2.2.1. Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are cited in the solicitation or contract.

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-790 - Established Reliability and High Reliability Qualified Products List (QPL) Systems for Electrical, Electronic, and Fiber Optic Parts Specifications.

(Copies of these documents are available online at <http://assist.daps.dla.mil/quicksearch/> or <http://assist.daps.dla.mil> or from the Standardization Documents Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.)

2.3 Order of precedence. In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

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3. DEFINITIONS

3.1 Reliability terms. The definitions of all reliability terms used herein are as follows:

- a. Burn-in (pre-conditioning). The operation of an item under stress to stabilize its characteristics.
- b. Confidence level. This term denotes the probability of disqualifying a product when the true failure rate of the product is at the failure rate specified for qualification.
- c. Corrective action. A documented design, process, procedure, or materials change implemented and validated to correct the cause of failure or design deficiency.
- d. Derating. (1) Using an item in such a way that applied stresses are below rated values.
(2) The lowering of the rating of an item in one stress field to allow an increase in another stress field.
- e. Established reliability. A quantitative maximum failure rate demonstrated under controlled conditions specified in a Department of Defense specification and usually expressed as percent failures per thousand hours of test.
- f. Failure. The event or inoperable state, in which any item, or part of an item does not, or would not, perform as previously specified.
- g. Failure analysis. Subsequent to a failure, the logical systematic examination of an item, its construction, application, and documentation to identify the failure made and determine the failure mechanism and its basic course.
- h. Failure rate (FR) level. This term denotes the maximum percentage of failures (per 1,000 unit hours) based on a specified confidence level.
- i. Failure rate (FR) test. This term denotes the test required to accumulate data from which a failure rate is calculated and is used synonymously with the standard specification term "life test".
- j. Higher FR level. This term is a relative description of a FR level associated with a higher number of failures per unit time.
- k. Inspection lot. A group of electronic parts offered for inspection at one time and in combinations authorized by the applicable ER specifications.
- l. Lower FR level. This term is a relative description of a FR level associated with a fewer number of failures per unit time.
- m. Mean time to failure (MTTF). A basic measure of reliability for non-repairable items: the total number of life units of an item divided by the total number of failures within that population, during a particular measurement interval under stated conditions.
- n. Predicted. That which is expected at some future time, postulated on analysis of past experience and tests.
- o. Qualifying activity. The military activity or its agent delegated to administer the qualification program.
- p. Reliability. (1) The duration or probability of failure free performance under stated conditions.
(2) The probability that an item can perform its intended function for a specified interval under stated conditions. (For non-redundant items this is equivalent to definition (1). For redundant items this is equivalent to definition of mission reliability).

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- q. Screening. A process for inspecting items to be removed, that are unsatisfactory, or those likely to exhibit early failure. Inspection included visual examination, physical dimension measurement and functional performance measurement under specified environmental conditions.
- r. Test, acceptance. A test conducted under specified conditions by, or on behalf of, the Government, using delivered or deliverable items, in order to determine the item's compliance with specified requirements. (includes acceptance of first production units).
- s. Test measurement and diagnostic equipment (TMDE). Any system or device used to evaluate the condition of an item to identify or isolate any actual or potential failures.
- t. Test qualification (design approval). A test conducted under specified conditions, by or on behalf of the Government, using items representative of the production configuration, in order to determine compliance with item design requirements as a basis for production approval. (also known as a "Demonstration.")
- u. True failure rate. This term describes the failure rate that would be measured if all units of a controlled process were, in fact, tested. A "controlled process" is one in which FR variation about its mean is due to chance causes.
- v. Truncation. Truncation is a "cutoff" point for life test data, that establishes a precise point in time in which the manufacturer can choose the elimination of previous extended life test data when:
 - (1) A life test failures has occurred and the manufacturer has determined the cause and implemented corrective action acceptable to the qualifying activity.
 - (2) The manufacturer seeks an extension of failure rate on the basis of new design improvements, occurring after a life test failure or failures.

The truncation point is not a random event. There must exist a clear distinction between the "old" less reliable and the "new" improved design (see 5.5).

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4. GENERAL REQUIREMENTS

4.1 FR levels.

- a. FR levels are related to operation of the part at the stress level specified by the applicable ER specification.
- b. Provisions are made for FR levels ranging from 1.0 to 0.001 percent per 1,000 component part hours. In the event the existing FR level of a current product is higher than 1.0 percent, an additional level (level "L") shall be added which will represent the state-of-the-art for the part.
- c. Although the failure is expressed in percent per 1,000 hours (%/1,000 hr) throughout this standard, sampling plans and statistical tables may be used for FR levels expressed either in terms of percent per 1,000 cycles, operations, or in terms of duty cycle and stress level.
- d. Where a FR level is required for periods other than 1,000 hours, an appropriate conversion factor may be applied.

Example: 1%/10,000 hours is equivalent to 0.1%/1,000 hours, or when specifying %/10,000 hours, the unit-hour requirement is to be multiplied by 10.

- e. Tables are provided to show the relationship between true failure rates and selected confidence levels.

4.1.1 FR level determination. Determination of FR levels shall be based upon data from all FR tests. Data shall be accumulated from:

- a. The qualification FR sample. The specification designates the number of sample units to be inspected, number of permissible failures, duration of FR test, and other criteria that may apply.
- b. Inspection lots which have been submitted for FR conformance inspection during any qualification period or interval. Data accumulated shall meet the specification requirement referenced in 4.1.1a.
- c. Samples subjected to extended FR tests. The data shall be added at the specified time of measurement and not at the end of the FR test.

4.1.2 Qualification approval for higher FR levels. Qualification approval granted on one of the lower FR levels shall include approval for all of the higher established FR levels. For example: Qualification approval for level "R" shall include approval for levels "P", "M", and "L" (if "L" is designated in the ER specification).

4.1.3 Supplying to higher ER levels. Parts qualified and marked (color coded or part numbered) to lower failure rate levels are substitutable for higher failure rate level parts with acquiring activity approval. A manufacturer may supply to all higher FR levels than that to which they are qualified, and may elect to use the sample size associated with the FR level to be supplied on orders or contracts. Election by the manufacturer to apply this option does not negate the requirement to maintain qualification in accordance with procedure III (see 5.3).

4.1.4 FR marking. All parts shall be marked with the FR level to which they are qualified, except when the contract or purchase order specifies higher FR marking under the substitution criteria of 4.1.3.

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4.1.4.1 FR marking upgrading. Where parts have been produced for part manufacturer's stock to a specific failure rate level and qualification has been subsequently extended to a lower failure rate level, the existing stock may be remarked to the latest qualified failure rate level provided:

- a. The lower failure rate shall have been achieved solely through the accumulation of FR test data with no change in materials, process controls, process limits, except as accepted by the qualifying activity in accordance with the corrective plan of action requirements of MIL-STD-790.
- b. The manufacturer provides a written detail procedure of the remarking process and test data to substantiate that the remarking procedures do not affect the part reliability or performance and the procedure is accepted by the qualifying activity.
- c. Parts shall have passed the ER specification conformance inspection and shall have been in stock for no more than 3 months, except where the manufacturer provides test data substantiating longer storage periods.
- d. If parts are remarked, date and lot code shall not be changed.

4.2 Failure criteria. Deviation of one or more specified parameters beyond the specified limits shall constitute a failure. If more than one parameter is to apply to the FR test, failure of more than one parameter on a single sample constitutes one failure in determining conformance to the acceptance criteria.

4.3 FR test records. Test records shall be maintained for the period required to substantiate the FR level qualification and shall include the data derived from the FR tests. The format is suggested on figure 1. Any measurement that indicates failed parts shall be clearly marked and identified as such in the test record (for exemption of data see 4.4). A sample unit which fails any given time interval shall be recorded as a failure immediately following the previous measurement and for all subsequent measurements. The manufacturer may remove failed sample units from the test. If the "C" number predicted for the maintenance period is exceeded or the failure is attributed to an unusual occurrence, the manufacturer shall immediately notify the qualifying activity (see 5.3.3.). If a failed sample unit is not removed, the test hours accumulated subsequent to its failure shall not be recorded with the cumulative component hours. All failures occurring during any FR test shall be reported to the qualifying activity at the time of failure. All FR data recorded shall be variables type data; attributes type data is not acceptable, except as permitted in the applicable ER specification. Figure 1 type data shall be made available when requested by the Government. A cumulative type record as shown on figure 2 shall be submitted to the qualifying activity at the end of each applicable maintenance period (see 5.3), or when requested by the qualifying activity.

4.4 Exception of data. Where FR test is known to be faulty as a result of test equipment failure, the test data obtained shall be entered in the test record along with a complete explanation and submitted to the qualifying activity. The qualifying activity shall determine whether the failure will be used in the computation of the FR level. There shall be ample technical and statistical evidence that the cause of equipment failure has been removed and will not recur in future production. No FR sample lots can be removed from test without the approval of the qualifying activity.

4.5 FR qualification procedures. FR qualification is an integral phase of the total qualification requirements in ER specifications. The procedures specified herein pertain only to the reliability requirements of these specifications. Qualification at any FR level shall be specified at either a 60 percent or a 90 percent confidence level. FR qualification procedures are as follows:

- a. Procedure I, "Qualification at the initial FR level" (see 5.1).
- b. Procedure II, "Extension of qualification to lower FR levels" (see 5.2).
- c. Procedure III, "Maintenance of FR level qualification" (see 5.3).

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Lot number <u> 1 </u>		Lot size <u> 1,000 </u>		Record no. <u> </u>															
Dates of production <u> </u>		Sample size <u> 110 </u>		Test temperature <u> </u>															
<u>Type designation in lot</u>		<u>Quantity in lot</u>		<u>Quantity in sample</u>															
CLR25BD600UGM		500		55															
CLR25BE400UGM		500		55															
Sample No.	Rating (μf-V dc)	Designated test time ^{1/}	Date of measurement <u> </u>			Date of measurement <u> </u>			Date of measurement <u> </u>										
			Hours since last measurement <u> </u>			Hours since last measurement <u> </u>			Hours since last measurement <u> </u>										
			Capacitance		pF	DCL	Capacitance		pF	DCL	Capacitance		pF	DCL					
			μF	% change				μF	% change										
			Total failed units ^{2/} <u> </u>			Total failed units ^{2/} <u> </u>			Total failed units ^{2/} <u> </u>										
			Total unit hours since last measurement <u> </u>			Total unit hours since last measurement <u> </u>			Total unit hours since last measurement <u> </u>										

1/ Designated test time shall be entered before life test is initiated.

2/ Only one failure shall be charged per unit regardless of number of parameters failed. NOTE: All measurements which exceed requirements shall be significantly marked as failures by underlining or circling the measurement.

FIGURE 1. Examples of FR test records.

4.6 Lot conformance FR inspection procedure (when specified). A lot conformance FR inspection (procedure IV, see 5.4) may be specified when reliability assurance beyond that guaranteed by procedure III (see 5.3) is required. The lot conformance FR inspection provides the manufacturer with a high assurance of acceptance of product at the specified FR level, and at the same time provides the consumer with reasonable protection against acceptance of products worse than the specified FR level.

4.7 Disposition of sample units. Sample units subjected to extended FR tests shall not be shipped. When the ER specification requires compliance with procedure IV (see 5.4) and allows the shipment of the lot conformance FR inspection samples, these units may be delivered on the contract or order provided:

- a. The lot has passed the FR tests.
- b. The part terminals were not soldered.
- c. The part meets initial tolerance requirements.

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RELAY LIFE TEST RECORD												
Lot date code:						Lot record no.						
Lot size:						Sample size:						
Part numbers in lot				Quantity in lot				Quantity in sample				
Sample serial numbers												
Designated test operations 1/												
Test measurements	Pre-life	Post-life	Pre-life	Post-life	Pre-life	Post-life	Pre-life	Post-life	Pre-life	Post-life		
Dielectric												
Insulation resistance												
Coil current												
Coil Resistance												
Contact resistance = 1												
Contact resistance = 2												
Contact resistance = 3												
Contact resistance = 4												
Pickup voltage												
Dropout voltage												
Operate time												
Release time												
Contact pounce												
Failure to operate												
Contact miss												
Contact sticking-welding												
Case fuse blown												
Unit operators												
Failure												
Total number of unit operations:						Total number of failures:						

1/ To be designated prior to start of test.

FIGURE 1. Examples of FR test records - Continued.

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Lot date code:		Lot record number:								
Lot size:		Sample size:								
Part numbers in lot:		Quantity in lot:								
		Quantity in sample:								
Sample serial numbers										
	Initial		100		500		1,000		2,000	
	Before	After	Before	After	Before	After	Before	After	Before	After
Contact resistance										
Insulation resistance										
Unit operating hours										
Total operating hours										
Failures										

FIGURE 1. Examples of FR test records – Continued.

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Lot record number	Number of parts on test	Total number of hours on test	Total number of unit hours without failures since last measurement	Number of failures observed	Cumulative unit hours	Cumulative unit failures

NOTE: A failure is assumed to have occurred immediately after the previous reading. The failure shall be charged but the component hours accumulated on the failed unit since the last measurement shall not be entered.

FIGURE 2. Example of maintenance of FR level record.

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5. DETAILED REQUIREMENTS

5.1 Procedure I, "Qualification at the initial FR level". Qualification at the initial FR level shall be predicated upon accumulation of valid data meeting the requirements of 5.1.2a or 5.1.2b, as applicable. FR tests shall be conducted for the specified duration and single sample size. The qualifying activity may grant qualification at a FR level lower than that specified provided the manufacturer performs all tests required for initial qualification and submits valid data from current production which substantiates lower failure rates.

5.1.1 Applicable data. Data shall be accumulated from sample units selected from a production run and produced with equipment and procedures normally used in production. One of the prerequisites for valid data is that all lots produced during the production period are represented. The data shall be from the same product in current production; i.e., data from products of preceding designs shall not be acceptable.

5.1.2 FR sampling plans (FRSP).

- a. Single sampling plans based on a 60 percent confidence level are provided in table I (see table A-I of appendix A).
- b. Single sampling plans based on a 90 percent confidence level are provided in table II (see table A-I of appendix A).

TABLE I. FRSP-60.

FR level symbol	Qualified FR level 1/	Cumulative unit hours in millions (c = number of failures permitted)										
		c=0	c=1	c=2	c=3	c=4	c=5	c=6	c=7	c=8	c=9	c=10
	%/1,000 hr											
L	2/			("M" row divided by "L")								
M	1.0	.0916	.202	.311	.418	.524	.629	.735	.839	.943	1.048	1.152
P	0.1	.916	2.02	3.11	4.18	5.24	6.29	7.35	8.39	9.43	10.48	11.52
R	0.01	9.16	20.2	31.1	41.8	52.4	62.9	73.5	83.9	94.3	104.8	115.2
S	0.001	91.6	202	311	418	524	629	735	839	943	1048	1152

1/ For FR level expressed in terms other than %/1,000 hour, see 4.1c and 4.1d.

2/ Where a FR level greater than 1.0 percent is required, level "L" shall be specified and the cumulative unit hours computed as shown.

TABLE II. FRSP-90.

FR level symbol	Qualified FR level 1/	Cumulative unit hours in millions (c = number of failures permitted)										
		c=0	c=1	c=2	c=3	c=4	c=5	c=6	c=7	c=8	c=9	c=10
	%/1,000 hr											
L	2/			("M" row divided by "L")								
M	1.0	.230	.389	.532	.668	.799	.927	1.054	1.171	1.300	1.421	1.544
P	0.1	2.30	3.89	5.32	6.68	7.99	9.27	10.54	11.71	13.00	14.21	15.44
R	0.01	23.0	38.9	53.2	66.8	79.9	92.7	105.4	117.1	130.0	142.1	154.4
S	0.001	230	389	532	668	799	927	1054	1171	1300	1421	1544

1/ For FR level expressed in terms other than %/1,000 hour, see 4.1c and 4.1d.

2/ Where a FR level greater than 1.0 percent is required, level "L" shall be specified and the cumulative unit hours computed as shown.

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5.1.2.1 True failure rates for FRSP-60 and FRSP-90. Table III gives two points on each of the operating characteristic curves for FRSP-60 and FRSP-90, as follows:

- a. The true failures rates required of the product so that process will qualify 19 times out of 20; and
- b. The true failure rates of a product whose process will fail to qualify 9 times out of 10.

TABLE III. True failure rates for FRSP-60 and FRSP-90
(prepared for 1%/1,000 hr FR level).

Number of failures permitted (c)	True product failure rate required to qualify a process 19 times out of 20 (%/1,000 hour)		True product failure rate which would fail to qualify a process 9 times out of 10 (%/1,000 hours)	
	FRSP-60	FRSP-90	FRSP-60	FRSP-90
0	0.06	0.02	2.51	1.0
1	0.18	0.09	1.92	1.0
2	0.26	0.15	1.71	1.0
3	0.33	0.20	1.60	1.0
4	0.38	0.25	1.53	1.0
5	0.42	0.28	1.47	1.0
6	0.45	0.31	1.43	1.0
7	0.47	0.34	1.41	1.0
8	0.50	0.36	1.38	1.0
9	0.52	0.38	1.36	1.0
10	0.54	0.40	1.34	1.0

NOTE: For other than "M" (1%) FR level; divide above FR values by 10 for "P" (0.1%) level; by 100 for other than "R" (0.01%) level; by 1,000 for "S" (0.001%) level.

5.1.3 Failure FR test. All sample units subjected to the specified qualification test shall be maintained on test for the total time specified for the extended FR test.

5.1.4 Failure to qualify. When the number of failures permitted is exceeded; the manufacturer shall discontinue the FR test and shall notify the qualifying activity. The manufacturer may request approval to reinstitute qualification testing on a new set of sample units provided the failures have been analyzed and the cause of failure has been corrected as specified in MIL-STD-790.

5.1.5 Details to be specified. The following details are to be specified in the ER specification:

- a. Initial FR level symbol and FRSP-60 or FRSP-90, as applicable (see 5.1.2).
- b. Duration of ER test (specify rated, and where applicable, accelerated conditions) (see 5.1).
- c. Number of sample units to be inspected and number of failures permitted for FR test (see 5.1).
- d. Duration of extended ER test (specify rated and, where applicable, accelerated conditions) (see 5.1.3).
- e. Number of samples to be continued on FR test (specify rated and, where applicable, accelerated conditions (see 5.1.3).
- f. Failure criteria (see 4.2).

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5.2 Procedure II, "Extension of qualification to lower FR levels". The manufacturer may extend the qualification granted under Procedure I to a lower FR level. Approval by the qualifying activity of such an extension shall be based on the same sampling plan, test duration, and failure criteria of Procedure I and the additional criteria prescribed in the procedure.

5.2.1 Applicable data.

- a. Data shall be accumulated from ER tests performed during qualification at the initial FR level maintenance of qualification, and extended FR tests, and when specified, from lot conformance FR inspection.
- b. Any data used to extend qualification shall include the results of all FR tests performed during the production period represented by the data. Data shall represent successive inspection tests starting with current production to the date of the oldest data submitted.
- c. Unless approved by the qualifying activity in accordance with MIL-STD-790, the data shall represent a product which has not changed significantly (in terms of process, material, design, or construction) during the production period.
- d. Extension of qualification to levels "P", "R", or "S" shall not be granted based upon data which are wholly from incomplete FR tests. As a minimum, data from completed FR tests on the same sample size as that required for initial qualification shall be included in the total data submitted. Where the ER specification contains specified life acceleration factors and associated accelerated life tests, data from completed accelerated life test shall be considered as equivalent to data from completed extended FR tests.
- e. Data from FR tests conducted to specifications other than ER specification for which qualification is desired may be submitted for consideration to the qualifying activity. Complete information concerning the specification tested to the test procedures or requirements, should be provided to support the validity of the data. Only data generated under conditions equal to or more stringent than those specified in the applicable ER specification shall be considered as valid.

5.2.2 Extent and limitation of coverage. Extension of the initially qualified FR level to the next lower level shall be within the same limits of qualification coverage as the initial qualification submission.

Example: When initial qualification is limited to the individual style submitted, the next lower FR level qualification shall be on the same basis. When extension of a qualified level to lower levels (such as "P" (0.1%/1,000 hr) to "R" (0.01%/1,000 hr) or "R" (0.01%/1,000 hr) to "S" (0.001%/1,000 hr)) is involved, consideration may be given to the combining of data from two or more styles of similar construction. In these cases, when permitted by the ER specification, permission to combine the data shall be obtained from the qualifying activity and shall be based on the similarity of design, construction, materials, and requirements of the styles involved. When data from two or more styles are combined, the data shall also be separately recorded for each style. Extension of qualification shall cover only the styles represented by the data.

5.2.3 Details to be specified. The extent and limitation of coverage (see 5.2) is to be specified in the ER specification.

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5.2.4 Extension of failure rate (optional). Manufacturers may designate, at their option, specific samples to load on life test for the sole purpose of accumulating hours to extend a failure rate. These samples must be randomly selected from the manufacturer's production and cover the full range of values that, upon successful completion, will provide for failure rate extension. The test hours accumulated for this test cannot be used by manufacturers as part of their failure rate maintenance testing (see 5.2.2). If this option is chosen, the manufacturer shall notify the qualifying activity:

- a. That this option is being used prior to loading samples.
- b. Details of the sample parts that will be used in the upload (date codes, values, and styles).
- c. Prior to discontinuing the test for any reason. NOTE: The qualifying activity has the option of requiring the manufacturer to do a complete failure analysis on failed test samples and require the manufacturer to notify customers of affected products.

5.3 Procedure III, "Maintenance of FR level qualification":

- a. Maintenance of qualification at the qualified FR level shall be predicted upon compliance with the requirements of 5.3.2. The qualification maintenance period shall be specified in the ER specification, and is not an option to be selected by the manufacturer. At the beginning of each qualification maintenance period, the manufacturer shall elect and record the unit-hour requirements ("C" number) that will be met within the qualification maintenance period specified and notify the qualifying activity. If a manufacturer selects a different unit-hour "C" requirement than used during the previous qualification maintenance period, the manufacturer is required to notify the qualifying activity of this change at the beginning of, or prior to, the new maintenance period.
- b. The maintenance period in effect shall not be changed, regardless of the unit-hours accumulated. Unit-hours that exceed those required for the maintenance period shall be at the manufacturer's risk (within the original "C" number). However, these unit-hours may be used for failure rate extension.
- c. Qualification shall be maintained periodically, in accordance with 5.3.2, as long as the product remains qualified at any given FR level.
- d. The same combination of data permitted in establishing lower FR levels (see 5.2) may be used in maintaining these FR levels. However, the FR level established in accordance with Procedure I shall be maintained separately for each style qualified, unless otherwise specified. If qualification has been granted at the "R" or "S" level and production is not sufficient on each style to maintain the unit hours required by table IV, the minimum number of unit hours required for any one style would be the unit hours required to maintain that style at the "P" FR level. These unit hours may be obtained from units which are on extended FR tests or from parts manufactured for test. Data may be combined from all similar styles for the remaining unit hours required for the "R" or "S" FR level. In instances where qualification by similarity is not detailed in the applicable specifications, determination of similarity and information regarding consolidation of data is to be obtained from the applicable military specification and the qualifying activity. The qualifying activity has the option of style groupings if excessive failures occur in one particular style.
- e. Where the manufacturer determines that they will not meet the minimum unit hours required during the maintenance period, the qualifying activity shall be notified immediately.

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5.3.1 Applicable data:

- a. Data from all FR tests underway or combined during the applicable qualification maintenance period (see 5.3.2) shall be applicable. Only that portion of the data generated during the maintenance period shall be applicable. Specifically the sources of these data are:
 - (1) Data from initial qualification samples that were maintained on test for extended FR testing (see 5.1.3).
 - (2) Data accumulated from samples subjected to the FR tests specified for lot conformance FR inspection when this procedure is specified (see 5.4). This includes both data from the relatively short time lot conformance FR test as well as the data generated from those samples continued on the extended FR test.
 - (3) Data accumulated from samples subjected to extended FR test in those specifications where lot conformance FR inspection is not specified. In these specifications, test samples shall be selected from each inspection lot. These samples shall be accumulated and placed on the specified extended FR test at least once a month or on a lot by basis. A minimum sample size from each lot shall be specified, however, the manufacturer may increase this sample size so that the unit hours generated within the specified qualification maintenance period meet the applicable requirements of table IV.
- b. During the FR tests, parameter measurements shall be made periodically as specified. The data so accumulated since previous measurements shall be recorded and added to the total unit hours accumulated from the beginning of the qualification maintenance period. Data shall be recorded from all samples on test during the maintenance period whether or not they are from inspection lots formed during this period.
- c. The data shall be representative of the styles and ranges of values produced over the production period covered by the applicable maintenance period.
- d. Data from FR tests completed during previous qualification maintenance periods shall not be used (this data may be used for extension of qualification to a lower FR level).

5.3.2 FR sampling plans. Single sampling plans based on a 10-percent confidence level are provided in FRSP-10 table IV. Table V gives two points on each of the operating characteristic curves for FRSP-10, as follows:

- a. The true failure rates required to maintain qualification 19 times out of 20.
- b. The true failure rates which would cause disqualification 9 times out of 10.

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TABLE IV. FRSP-10.

FR level symbol	Qualified FR level ^{1/}	Qualification maintenance period (in months)			Cumulative unit hours in millions (c = number of failures permitted)										
		A	B	C	c=0	c=1	c=2	c=3	c=4	c=5	c=6	c=7	c=8	c=9	c=10
L	^{2/}	3	6	^{3/}											
M	1.0	3	6	^{3/}		.0532	(^{4/} "M" row divided by "L")	.175	.243	.315	.389	.467	.544	.623	.701
P	0.1	6	9	6		.532	1.10	1.75	2.43	3.15	3.89	4.67	5.44	6.23	7.01
R	0.01	9	12	24		5.32	11.0	17.5	24.3	31.5	38.9	46.7	54.4	62.3	70.1
S	0.001	12	15		10.5 ^{4/}	53.2	110	175	243	315	389	467	544	623	701

- ^{1/} Expressed in %/1,000 hours. For FR level expressed in terms other than %/1,000 hour, see 4.1c and 4.1d.
- ^{2/} Where a FR level greater than 1.0 percent is required, level "L" shall be specified and the cumulative unit hours computed as shown.
- ^{3/} Each lot.
- ^{4/} Applicable to FR level "S" only.

TABLE V. True failure rates for FRSP-10 (prepared for 1 percent per 1,000 hours FR level).

Number of failures permitted	True failure rate required to maintain qualification 19 times out of 20	True failure rate which would cause disqualification 9 times out of 10
(c)	(%/1,000 hrs)	(%/1,000 hrs)
0	0.49	21.8
1	0.67	7.3
2	0.74	4.8
3	0.78	3.8
4	0.81	3.3
5	0.83	2.9
6	0.84	2.7
7	0.85	2.5
8	0.86	2.4
9	0.87	2.3
10	0.88	2.2

NOTE: For other than M (1 percent) FR level, divide above FR values by 10 for P (0.1 percent) level; by 100 for R (0.01 percent); or by 1,000 for S (0.001 percent) level.

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5.3.3 Failure to maintain FR level qualification (see 4.3). Failure to maintain a qualified FR level in accordance with 5.3 shall result in loss of qualification at that FR level. Loss of qualification to a FR shall take place at any time during the qualification maintenance period when the number of failures recorded exceeds the number of failure permitted. The extent of the product affected by the loss of failure rate will be determined by the qualifying activity and may include all product represented by the unit hours on test during the maintenance period in question. If, however, the number of failures recorded exceeds the number of failures permitted (i.e., "c number") by one, the qualifying activity may permit the manufacturer to modify the test plan in an effort to maintain the original failure rate level. This modification to the test plan shall only be allowed with qualifying activity approval following evaluation of the nature and cause of the failure. FR data shall be reviewed by the qualifying activity to justify reestablishment of qualification at a higher FR level. Reestablishment under these circumstances shall be to FRSP-60 or FRSP-90 (see 5.1.5a). All data generated over the production period (corresponding to the qualification maintenance period in FRSP-10) shall be reviewed in reestablishing qualification. FR data shall include the data which caused disqualification. To extend qualification from the reestablished FR level to the lowest level held, the manufacturer shall be required to meet the same requirements specified for Procedure II (see 5.2). Removal of life test samples that have failed during performance of the life test shall be in accordance with the following:

- a. When the failure of a sample is within the "C" number predicted for the maintenance period, the manufacturer is permitted to remove the failed sample unit from the life test. Prior notification and approval by the qualifying activity is not required as long as the "C" number is not exceeded. Life test data associated with the failure as well as the failure itself shall be counted toward meeting the number of unit hours and selected "C" number for the maintenance period. Manufacturers are not permitted to discard any sample(s), life test data, or failures without notification and approval by the qualifying activity.
- b. When the failure of a sample results in exceeding the specified "C" number for the maintenance period, the manufacturer is permitted to remove the sample(s) from the life test at the manufacturer's risk and shall notify the qualifying activity immediately. Manufacturers are not permitted to discard any sample(s), life test data, or failures without prior notification and approval by the qualifying activity.
- c. When life test failures are attributed to an unusual occurrence (test equipment malfunction or failure) the manufacturer is permitted to remove the sample(s) from the life test at the manufacturer's risk and shall notify the qualifying activity immediately. Manufacturers are not permitted to discard any sample(s), life test data, or failures without prior notification and approval by the qualifying activity.

5.3.4 Sublotting failure rate maintenance procedure, failure rates R and S only (optional). The manufacturer may select the sublotting procedure at his option with qualifying activity approval. When selecting the sublotting option, the manufacturer shall submit a sublot procedure plan to the qualifying activity prior to the initiation of the maintenance period. The sublot procedure is used to demonstrate/validate failure rate levels for each sublot in addition to the overall failure rate (see 5.3). the procedure plan shall include:

- a. The overall "C" number and unit hours selected for the overall plan.
- b. The definition and description of individual sublots (styles, combination of styles, values, and value ranges).
- c. The "C" number subplot and unit hours for the individual subplot (see 5.3a).

NOTE: The individual subplot unit hours shall meet or exceed the unit hours required by the individual "C" number for the failure rate level (see table IV).

- d. The sum of individual subplot unit hours shall meet or exceed the unit hours required by the overall "C" number for the failure rate level (see table IV).
- e. The combination of sublots and ranges selected shall meet the requirements of 5.3.1c, except as required to meet the minimum unit-hours requirement.
- f. All changes to the previously accepted plan shall be submitted for review and approval of the qualifying activity. The submission and approval shall occur prior to subsequent initiation of a maintenance period.

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5.3.4.1 Failure to meet overall "C" number. The following criteria, only applies where the overall "C" number has been exceeded: Where the combined lot submission exceeds the selected "C" = number, the sublotting plan is reviewed to determine if the submission exceeds the select "C" = number, the sublotting plan is reviewed to determine if the sublot numbers were exceeded. If failures have occurred in only one style above and beyond the stated limit in the sublotting table, those styles that did not exceed the sublot "C" = number can be released with the qualifying activity's approval. Where a "C" number has been exceeded for more than one sublot, the manufacturer has failed to maintain FR and shall notify the qualifying activity and proceed as stated in 5.4.4.

5.3.4.2 Overall "C" number not exceeded. Where the overall "C" number is not exceeded, evaluation of the individual sublot is not required, even though the individual sublot "C" number is exceeded.

5.3.4.3 Example of sublot calculation. The following example provides guidance for use of the sublot maintenance option (see table VI):

- a. Five styles are combined for "S" failure rate level under period A.
- b. A C = 2 failure rate maintenance plan is established for a 12 month period.
- c. This requires 110 million unit hours for the 12 month period.

TABLE VI. Example of sublot calculation plan.

Unit hours	C = #	Failures occurring				
		A	B	C	D	E
Sublot 1 > or = 10.5 million	0	1	0	2	0	1
Sublot 2 > or = 53.2 million	1	1	2	1	0	0
Sublot 3 > or = 10.5 million	0	1	0	0	0	1
Sublot 4 > or = 10.5 million	0	0	1	0	0	0
Sublot 5 > or = 10.5 million	0	0	0	0	3	0
Total > or = 110.0 million	C = 2					

- A. All sublots affected by reduction of failure rate.
- B. All sublots affected by reduction of failure rate.
- C. Only sublot "1" affected by reduction of failure rate.
- D. Only sublot "5" affected by reduction of failure rate.
- E. Overall "C" number not exceeded; all lots acceptable.

5.3.5 Details to be specified. The following details are to be specified in the ER specification:

- a. Applicable qualification maintenance period (see 5.3.2). For those ER specifications where Procedure IV is specified, the maintenance period letter shall correspond to the lot sampling plan letter of Procedure IV, e.g., period "A", when plan "A" is specified.
- b. Data combinations permitted (see 5.3d).

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5.4 Procedure IV, "Lot conformance FR inspection". Where Procedure IV is specified (see 4.6), sample units shall be selected at random from each inspection lot. As far as practicable each style, value, class, and grade allowed in lot formation, which are in the lot formed, shall be represented in the sample in approximately the same proportion as in the inspection lot. Permissible combinations of styles and values represented in the inspection lot shall be the same combinations permitted for Procedures I and II.

- a. The minimum number of sample units to be subjected to lot conformance FR inspection shall be as specified in 5.4.1. Manufacturers may test larger sample sizes than indicated herein; the number of failures permitted shall be 1.
- b. When the volume of production or the frequency of orders, are such that, temporarily, compliance with this procedure presents an economic problem, the qualifying activity shall be contacted. At the discretion of the qualifying activity, alternate sample sizes and maintenance periods shall be provided.

5.4.1 Sampling plans. Unless otherwise specified in the ER specification, the lot conformance FR sampling plans shall be as specified in table VII.

TABLE VII. Lot conformance FR plan.

FR levels	Sample size for lot conformance plan			Number of failures permitted
	A	B	C	
All levels				
L, M, P, R, S	110	36	21	1

5.4.2 Extended FR tests. A minimum number of sample units as specified shall be selected at random from each inspection lot and subjected to the specified extended FR test. The manufacturer may increase this sample size from lot to lot, if desired, in order to develop the necessary number of unit hours of data required for Procedure III or IV; however, each sample shall be tested for the full length of time specified for Procedure I (see 5.1.5d). The units selected for the extended FR test may be either:

- a. From those subjected to lot conformance FR inspection tests of Procedure IV, or
- b. From remaining units in the inspection lot. In any case, the units to be subjected to the extended FR test shall be predetermined before any FR tests are initiated. The extended FR test may be either initiated periodically with units accumulated from each inspection lot, or may be initiated on a lot by lot basis. The units selected for extended FR tests from each lot, shall be representative of the styles and values included in the lot to the maximum extent possible.

5.4.3 Action in case of failure:

- a. Where the lot conformance FR inspection enables early shipment of an inspection lot, a failure, to the lot conformance failure definition, should result only in disallowing early shipment of the inspection lot. If continuation of the full qualification period does not result in an unacceptable number of failures, to the failure definition, the inspection lot may then be shipped.
- b. Those units in a rejected lot which were predestinated for extended FR testing shall either remain or be placed on test for the full length of time.
- c. Failures in excess of those permitted during extended FR testing shall be reported to the qualifying activity, and to all known recipients of the parts from the inspection lots represented by the sample.

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5.4.4 Details to be specified. The following details are to be specified in the ER specification when Procedure IV is utilized:

- a. Lot conformance plan (the plan letter shall correspond to the qualification maintenance period letter of FRSP-10) (see 5.4.1 and 5.3.2).
- b. Duration of lot conformance test.
- c. Failure criteria (see 4.2).
- d. Permissible combination of styles and values that may be represented in an inspection lot (see 5.4).
- e. Disposition of samples and inspection lot (ship samples with the lot, ship lot at specified test period, keep samples on test, etc.,) (see 4.7).

5.5 Procedure for truncation of life test data. Truncation shall not be used to avoid a change in the FR level. The truncation point shall occur, with the qualifying activity's approval, either:

- a. After life test failure(s) has occurred and an assignable cause has been found and corrective action acceptable to the qualifying activity has been successfully implemented.
- b. Following implementation of a new design or process improvement and a failure rate extension is being sought.

An improved FR shall not be granted by the qualifying activity until the first test samples after the truncation point have completed the test. If the truncation procedure is used, no device shall be taken off test even if the data generated by the device on test is not to be used for determination of the "new" FR. FR shall be maintained for the current maintenance period. Random failures are not cause for truncation, and truncation shall not be used to avoid a change in the FR level. Also, truncation shall not be used if the cause of the failure(s) cannot be determined.

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6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1 FR level conversion. FR levels may be converted to mean time to failure (MTTF) as follows:

$$\text{MTTF} = 100,000 \div \% / 1,000 \text{ hours.}$$

Example: Where FR level P = .1 percent per 1,000 hours.

$$\text{MTTF} = 100,000 \div .1 = 1 \text{ failure per } 10^6 \text{ hours.}$$

6.2 Computation of the unit hour requirement. Table VIII is a complete Poisson distribution table that is suitable for computing unit hours. To calculate unit hours with a "C" number of 0 (for table I, table II, or table IV), determine the probability of acceptance (Pa) by subtracting the FRSP value (.60, .90, or .10) from 1.

Example: $P_a = 1 - .60 = .40$

From the Poisson table, find .40 under the C = 0 column. This value of "m" is found, by interpolation, to be .916 for level M qualification and "m" in the table is the total of failure rate λ (lambda) multiplied by the time (test hours).

$$m = \lambda \times t$$

$$\text{unit hours} = m \div \lambda \text{ (1\%/1,000 hours).}$$

$$\text{unit hours} = m \div \lambda = .916 \div .00001 = .0916 \text{ million hours.}$$

Values for P, R, and S levels are found by multiplying the previous level by 10.

6.3 Computation of the true failure rate. Table VIII is used again to compute the true failure rates for qualifying 19 of 20 times and for rejecting 9 of 10 times. To calculate the true failure rate to accept 19 out of 20 times (= .95), look up .95 in the C = 0 column (interpolation is needed). The value of "m" is found to be .051. Referring to 6.2, λ (true failure rate) is found by dividing "m" by the time for FRSP-60.

Example: $\lambda = m \div t = .051 \div .0916 \text{ million hours} = .06 \text{ percent per 1,000 hours.}$

Repeat the process to determine the true failure rate for FRSP-90.

To calculate the true failure rate to reject 9 out of 10 times ($P_a = 1 - .90$) look up .10 in the C = 0 column (interpolation is needed). The value of "m" is found to be 2.30. Referring to 6.2, λ (true failure rate) is found by dividing "m" by time for FRSP-60.

Example: $\lambda = m \div t = 2.30 \div .0916 \text{ million hours} = 2.51 \text{ percent per 1,000 hours.}$

Repeat the process to calculate the values in table V.

6.4 Subject term (key word) listing.

Confidence levels
Cumulative unit hours
Established Reliability
Extension of qualification
Failure rate (FR)

Failure rate sampling plan (FRSP)
Maintenance of qualification
Qualification
Qualifying activity
Truncation of data

6.5 Changes from previous issue. Marginal notations are not used in this revision to identify changes with respect to the previous issue due to the extensiveness of the changes.

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TABLE VIII. Cumulative poisson probabilities.

C \ M	0	1	2	3	4	5
0.01	.990	1.000				
0.02	.980	1.000				
0.03	.970	1.000				
0.04	.961	.999	1.000			
0.05	.951	.999	1.000			
0.06	.942	.998	1.000			
0.07	.932	.998	1.000			
0.08	.923	.997	1.000			
0.09	.914	.996	1.000			
0.10	.905	.995	1.000			
0.12	.887	.993	1.000			
0.14	.869	.991	1.000			
0.16	.852	.988	.999	1.000		
0.18	.835	.986	.999	1.000		
0.20	.819	.982	.999	1.000		
0.22	.803	.979	.998	1.000		
0.24	.787	.975	.998	1.000		
0.26	.771	.972	.998	1.000		
0.28	.756	.967	.997	1.000		
0.30	.741	.963	.996	1.000		
0.32	.726	.959	.996	1.000		
0.34	.712	.954	.995	1.000		
0.36	.698	.949	.994	.999	1.000	
0.38	.684	.944	.993	.999	1.000	
0.40	.670	.938	.992	.999	1.000	
0.42	.657	.933	.991	.999	1.000	
0.44	.644	.927	.990	.999	1.000	
0.46	.631	.922	.988	.999	1.000	
0.48	.619	.916	.987	.998	1.000	
0.50	.607	.910	.986	.998	1.000	
0.52	.595	.904	.984	.998	1.000	
0.54	.583	.897	.982	.998	1.000	
0.56	.571	.891	.981	.997	1.000	
0.58	.560	.885	.979	.997	1.000	
0.60	.549	.878	.977	.997	1.000	
0.62	.538	.871	.975	.996	1.000	
0.64	.527	.865	.973	.996	.999	
0.66	.517	.858	.971	.995	.999	1.000
0.68	.507	.851	.968	.995	.999	1.000
0.70	.497	.844	.966	.994	.999	1.000
0.72	.487	.837	.963	.994	.999	1.000
0.74	.477	.830	.961	.993	.999	1.000
0.76	.468	.823	.958	.992	.999	1.000
0.78	.458	.816	.955	.992	.999	1.000
0.80	.449	.809	.953	.991	.999	1.000

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TABLE VIII. Cumulative poisson probabilities - Continued.

C \ M	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
8.2	.000	.003	.012	.037	.089	.174	.290	.425	.565	.692	.796	.873	.926	.960	.979
8.4	.000	.002	.010	.032	.079	.157	.267	.399	.537	.666	.774	.857	.915	.952	.975
8.6	.000	.002	.009	.028	.070	.142	.246	.373	.509	.640	.752	.840	.903	.945	.970
8.8	.000	.001	.007	.024	.062	.128	.228	.348	.482	.614	.729	.822	.890	.936	.965
9.0	.000	.001	.006	.021	.055	.116	.207	.324	.456	.587	.706	.803	.876	.926	.959
9.2	.000	.001	.005	.018	.049	.104	.189	.301	.430	.561	.682	.783	.861	.916	.952
9.4	.000	.001	.005	.016	.043	.093	.173	.279	.404	.535	.658	.763	.845	.904	.944
9.6	.000	.001	.004	.014	.038	.084	.157	.258	.380	.509	.633	.741	.828	.892	.936
9.8	.000	.001	.003	.012	.033	.075	.143	.239	.356	.483	.608	.719	.810	.879	.927
10.0	.000	.000	.003	.010	.029	.067	.130	.220	.333	.458	.583	.697	.792	.864	.917
10.5		.000	.002	.007	.021	.050	.102	.179	.279	.397	.521	.639	.742	.825	.888
11.0		.000	.001	.005	.015	.038	.079	.143	.232	.341	.460	.579	.689	.781	.854
11.5		.000	.001	.003	.011	.028	.060	.114	.191	.289	.402	.520	.633	.733	.815
12.0		.000	.001	.002	.008	.020	.046	.090	.155	.242	.347	.462	.576	.682	.772
12.5			.000	.002	.005	.015	.035	.070	.125	.201	.297	.406	.519	.628	.725
13.0			.000	.001	.004	.011	.026	.054	.100	.166	.252	.353	.463	.573	.675
13.5			.000	.001	.003	.008	.019	.041	.079	.135	.211	.304	.409	.518	.623
14.0				.000	.002	.006	.014	.032	.062	.109	.176	.260	.358	.464	.570
14.5				.000	.001	.004	.010	.024	.048	.088	.145	.220	.311	.413	.518
15.0				.000	.001	.003	.008	.018	.037	.070	.118	.185	.268	.363	.466
16.0					.000	.001	.004	.010	.022	.043	.077	.127	.193	.275	.368
17.0					.000	.001	.002	.005	.013	.026	.049	.085	.135	.201	.281
18.0						.000	.001	.003	.007	.015	.030	.055	.092	.143	.208
19.0						.000	.001	.002	.004	.009	.018	.035	.061	.098	.150

C \ M	15	16	17	18	19	20	21
8.2	.990	.995	.998	.999	1.000		
8.4	.987	.994	.997	.999	1.000		
8.6	.985	.993	.997	.999	.999	1.000	
8.8	.982	.991	.996	.998	.999	1.000	
9.0	.978	.989	.995	.998	.999	1.000	
9.2	.974	.987	.993	.997	.999	.999	1.000
9.4	.969	.984	.992	.996	.998	.999	1.000
9.6	.964	.981	.990	.995	.998	.999	1.000
9.8	.958	.977	.980	.994	.997	.999	.999
10.0	.951	.973	.986	.993	.997	.998	.999
10.5	.932	.960	.978	.988	.994	.997	.999
11.0	.907	.944	.968	.982	.991	.995	.998
11.5	.878	.924	.954	.974	.986	.992	.996
12.0	.844	.899	.937	.963	.979	.988	.994
12.5	.806	.869	.916	.948	.969	.983	.991
13.0	.764	.835	.890	.930	.957	.975	.986
13.5	.718	.798	.861	.908	.942	.965	.980
14.0	.669	.756	.827	.883	.923	.952	.971
14.5	.619	.711	.790	.853	.901	.936	.960
15.0	.568	.664	.749	.819	.875	.917	.947
16.0	.467	.566	.659	.742	.812	.868	.911
17.0	.371	.468	.564	.655	.736	.805	.861
18.0	.287	.375	.469	.562	.651	.731	.799
19.0	.215	.292	.378	.469	.561	.647	.725

C \ M	30	31	32	33	34	35
16.0	.999	1.000				
17.0	.999	.999	1.000			
18.0	.997	.998	.999	1.000		
19.0	.993	.996	.998	.999	.999	1.000

C \ M	22	23	24	25	26	27	28	29
10.0	1.000							
10.5		1.000						
11.0			1.000					
11.5				1.000				
12.0					1.000			
12.5						1.000		
13.0							1.000	
13.5								1.000
14.0								
14.5								
15.0								
16.0								
17.0								
18.0								
19.0								

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TABLE VIII. Cumulative poisson probabilities - Continued.

C \ M	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
20.0	.000	.001	.002	.005	.011	.021	.039	.066	.105	.157	.221	.297	.381	.470	.559
21.0	.000	.001	.002	.003	.006	.013	.025	.043	.072	.111	.163	.227	.302	.384	.471
22.0	.000	.001	.002	.004	.008	.015	.028	.048	.077	.117	.169	.232	.306	.387	.471
23.0	.000	.001	.002	.004	.008	.015	.028	.048	.077	.117	.169	.232	.306	.387	.471
24.0	.000	.001	.002	.004	.008	.015	.028	.048	.077	.117	.169	.232	.306	.387	.471
25.0	.000	.001	.002	.004	.008	.015	.028	.048	.077	.117	.169	.232	.306	.387	.471
26.0	.000	.001	.002	.004	.008	.015	.028	.048	.077	.117	.169	.232	.306	.387	.471
27.0	.000	.001	.002	.004	.008	.015	.028	.048	.077	.117	.169	.232	.306	.387	.471
28.0	.000	.001	.002	.004	.008	.015	.028	.048	.077	.117	.169	.232	.306	.387	.471
29.0	.000	.001	.002	.004	.008	.015	.028	.048	.077	.117	.169	.232	.306	.387	.471
30.0	.000	.001	.002	.004	.008	.015	.028	.048	.077	.117	.169	.232	.306	.387	.471
31.0	.000	.001	.002	.004	.008	.015	.028	.048	.077	.117	.169	.232	.306	.387	.471
32.0	.000	.001	.002	.004	.008	.015	.028	.048	.077	.117	.169	.232	.306	.387	.471
33.0	.000	.001	.002	.004	.008	.015	.028	.048	.077	.117	.169	.232	.306	.387	.471
34.0	.000	.001	.002	.004	.008	.015	.028	.048	.077	.117	.169	.232	.306	.387	.471

C \ M	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
20.0	.644	.721	.787	.843	.888	.922	.948	.966	.978	.987	.992	.995	.997	.999	.999
21.0	.558	.640	.716	.782	.838	.883	.917	.944	.963	.976	.985	.991	.994	.997	.998
22.0	.472	.556	.637	.712	.777	.832	.877	.913	.940	.959	.973	.983	.989	.994	.996
23.0	.389	.472	.555	.635	.708	.772	.827	.873	.908	.936	.956	.971	.981	.988	.993
24.0	.314	.392	.473	.554	.632	.704	.768	.823	.868	.904	.932	.953	.969	.979	.987
25.0	.247	.318	.394	.473	.553	.629	.700	.763	.818	.863	.900	.929	.950	.966	.978
26.0	.190	.252	.321	.396	.474	.552	.627	.697	.759	.813	.859	.896	.925	.947	.964
27.0	.144	.195	.256	.324	.398	.474	.551	.625	.693	.755	.809	.855	.892	.921	.944
28.0	.106	.148	.200	.260	.327	.400	.475	.550	.623	.690	.752	.805	.850	.888	.918
29.0	.077	.110	.153	.204	.264	.330	.401	.475	.549	.621	.687	.748	.801	.846	.884
30.0	.054	.081	.115	.157	.208	.267	.333	.403	.476	.548	.619	.685	.744	.797	.843
31.0	.038	.058	.084	.119	.161	.212	.271	.335	.405	.476	.548	.617	.682	.741	.794
32.0	.026	.041	.061	.088	.123	.166	.216	.274	.338	.406	.476	.547	.615	.679	.738
33.0	.018	.028	.043	.064	.092	.127	.170	.220	.277	.340	.408	.477	.546	.613	.677
34.0	.012	.019	.030	.046	.067	.095	.131	.173	.224	.280	.343	.409	.477	.545	.612

C \ M	36	37	38	39	40	41	42	43
20.0	1.000	.999	1.000					
21.0	.999	.999	1.000					
22.0	.998	.999	.999	1.000				
23.0	.996	.997	.999	.999	1.000			
24.0	.992	.995	.997	.998	.999	.999	1.000	
25.0	.985	.991	.994	.997	.998	.999	.999	1.000
26.0	.976	.984	.990	.994	.996	.998	.999	.999
27.0	.961	.974	.983	.989	.993	.996	.997	.998
28.0	.941	.959	.972	.981	.988	.992	.995	.997
29.0	.914	.938	.956	.970	.979	.986	.991	.994
30.0	.880	.911	.935	.954	.968	.978	.985	.990
31.0	.839	.877	.908	.932	.951	.966	.976	.984
32.0	.790	.835	.873	.904	.929	.949	.964	.975
33.0	.735	.787	.832	.870	.901	.926	.946	.962
34.0	.674	.732	.783	.828	.866	.898	.924	.944

C \ M	51	52	53	54	55
31.0	1.000				
32.0	.999	1.000			
33.0	.998	.999	1.000		
34.0	.996	.998	.999	.999	1.000

C \ M	44	45	46	47	48	49	50
31.0	1.000						
32.0	.999	.999	1.000				
33.0	.998	.999	.999	1.000			
34.0	.996	.998	.999	.999	1.000		
35.0	.994	.996	.998	.999	.999	.999	1.000
36.0	.989	.993	.996	.997	.998	.999	.999
37.0	.983	.988	.992	.995	.997	.998	.999
38.0	.973	.981	.987	.992	.995	.997	.998
39.0	.960	.971	.980	.986	.991	.994	.996

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TABLE VIII. Cumulative poisson probabilities - Continued.

C \ M	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
35.0	.000	.001	.001	.002	.004	.008	.013	.021	.032	.049	.070	.099	.134	.177	.227
36.0		.000	.001	.001	.003	.005	.008	.014	.022	.035	.051	.074	.102	.138	.181
37.0			.000	.001	.002	.003	.006	.009	.015	.024	.037	.054	.077	.106	.141
38.0			.000	.001	.001	.002	.004	.006	.010	.017	.026	.039	.057	.080	.109
39.0				.000	.001	.001	.002	.004	.007	.011	.018	.028	.041	.059	.083
40.0					.000	.001	.001	.003	.004	.008	.012	.019	.029	.043	.062
41.0						.000	.001	.002	.003	.005	.008	.013	.021	.031	.045
42.0						.000	.001	.001	.002	.003	.006	.009	.014	.022	.033
43.0							.000	.001	.001	.002	.004	.006	.010	.016	.024
44.0								.000	.001	.001	.002	.004	.007	.011	.017
45.0									.000	.001	.002	.003	.004	.007	.012
46.0									.000	.001	.001	.002	.003	.005	.008
47.0										.000	.001	.001	.002	.003	.005
48.0											.000	.001	.001	.002	.004
49.0												.000	.001	.001	.002

C \ M	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
35.0	.283	.345	.410	.478	.545	.610	.672	.729	.780	.825	.863	.895	.921	.941	.958
36.0	.230	.286	.347	.411	.478	.544	.609	.670	.726	.777	.822	.860	.892	.918	.939
37.0	.184	.233	.289	.349	.413	.478	.544	.607	.668	.724	.774	.819	.857	.889	.915
38.0	.145	.187	.237	.291	.351	.414	.478	.543	.606	.666	.721	.771	.816	.854	.886
39.0	.112	.148	.191	.240	.294	.353	.415	.479	.542	.605	.664	.719	.768	.813	.851
40.0	.086	.115	.151	.194	.242	.296	.355	.416	.479	.542	.603	.662	.716	.766	.810
41.0	.064	.088	.118	.155	.197	.245	.299	.356	.417	.479	.541	.602	.660	.714	.763
42.0	.048	.067	.091	.121	.158	.200	.248	.301	.358	.418	.479	.541	.601	.658	.712
43.0	.035	.050	.069	.094	.124	.161	.203	.251	.303	.360	.419	.480	.540	.600	.656
44.0	.025	.037	.052	.072	.097	.127	.164	.206	.253	.305	.361	.420	.480	.540	.599
45.0	.018	.026	.038	.054	.074	.099	.130	.166	.208	.256	.307	.363	.421	.480	.540
46.0	.012	.019	.028	.040	.056	.077	.102	.133	.169	.211	.258	.309	.364	.422	.480
47.0	.009	.013	.020	.029	.042	.058	.079	.105	.136	.172	.214	.260	.311	.366	.423
48.0	.006	.009	.014	.021	.031	.044	.060	.081	.107	.138	.175	.216	.263	.313	.367
49.0	.004	.006	.010	.015	.023	.032	.046	.062	.084	.110	.141	.177	.219	.265	.315

C \ M	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
35.0	.970	.979	.985	.990	.993	.996	.997	.998	.999	.999	1.000				
36.0	.955	.968	.977	.984	.989	.993	.995	.997	.998	.999	.999	1.000			
37.0	.937	.953	.966	.976	.983	.989	.992	.995	.997	.998	.999	.999	.999	1.000	
38.0	.913	.934	.951	.965	.975	.982	.988	.992	.994	.996	.998	.998	.999	.999	1.000
39.0	.883	.910	.932	.949	.963	.973	.981	.987	.991	.994	.996	.997	.998	.999	.999
40.0	.848	.880	.908	.930	.947	.961	.972	.980	.986	.990	.993	.996	.997	.998	.999
41.0	.807	.845	.878	.905	.927	.945	.960	.971	.979	.985	.990	.993	.995	.997	.998
42.0	.760	.804	.842	.875	.902	.925	.943	.958	.969	.978	.984	.989	.992	.995	.997
43.0	.709	.758	.801	.840	.872	.900	.923	.941	.956	.968	.977	.983	.988	.992	.994
44.0	.655	.707	.756	.799	.837	.870	.898	.921	.939	.954	.966	.975	.982	.987	.991
45.0	.598	.653	.705	.753	.796	.834	.867	.895	.918	.937	.953	.965	.974	.981	.987
46.0	.539	.597	.652	.703	.751	.794	.832	.865	.893	.916	.935	.951	.963	.973	.980
47.0	.481	.539	.596	.650	.701	.749	.791	.829	.862	.890	.914	.934	.949	.962	.972
48.0	.423	.481	.538	.595	.649	.700	.746	.789	.827	.860	.888	.912	.932	.948	.960
49.0	.368	.424	.481	.538	.594	.647	.698	.744	.787	.824	.857	.886	.910	.930	.946

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TABLE VIII. Cumulative poisson probabilities - Continued.

C \ M	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
39.0	1.000														
40.0	.999	1.000													
41.0	.999	.999	.999	1.000											
42.0	.998	.999	.999	.999	1.000										
43.0	.996	.997	.998	.999	.999	1.000									
44.0	.994	.996	.997	.998	.999	.999	1.000								
45.0	.991	.994	.996	.997	.998	.999	.999	.999	1.000						
46.0	.986	.990	.993	.995	.997	.998	.999	.999	.999	1.000					
47.0	.979	.985	.989	.993	.995	.997	.998	.998	.999	.999	1.000				
48.0	.971	.978	.984	.989	.992	.995	.996	.997	.998	.999	.999	1.000			
49.0	.959	.969	.977	.984	.988	.992	.994	.996	.997	.998	.999	.999	.999	1.000	

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APPENDIX A

GUIDANCE FOR SPECIFICATION WRITERS

A.1. SCOPE

A.1.1 Scope. This appendix provides an outline and description of requirements which are to be included in ER specifications. Their use will insure uniform requirements and procedures in all ER specifications. This appendix is a mandatory part of the standard. The information contained herein is intended for compliance.

A.2. APPLICABLE DOCUMENTS.

A.2.1 General. The documents listed in this section are specified in this appendix of this standard. This section does not include documents cited in other sections of this standard or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements documents cited in appendix of this standard, whether or not they are listed.

A.2.2 Government documents.

A.2.2.1. Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are cited in the solicitation or contract.

DEPARTMENT OF DEFENSE HANDBOOKS

MIL-HDBK-217 - Reliability Prediction of Electronic Equipment.

(Copies of these documents are available online at <http://assist.daps.dla.mil/quicksearch/> or <http://assist.daps.dla.mil> or from the Standardization Documents Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.)

A.2.3 Order of precedence. In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

A.3. QUALIFICATION

A.3.1 Qualification at the initial FR level. Qualification shall be granted at the FR level representing the state-of-the-art. Unless valid data from current production substantiates other FR levels, qualification shall be granted at the "M" (1.0%) level. Qualification at the "M" (1.0%) level shall be based on results of qualification FR tests on a single sample size. A sampling plan in which the maximum number of failures permitted is greater than zero shall be used. In those ER specifications in which the initial qualification ER test is shorter in time than the extended ER test, all units subject to the qualification FR test shall be maintained on test for the time specified for the extended FR test. It is preferred that qualification be granted at initial failure rate through testing of a specified sample size and that qualification to lower failure rate levels be accomplished by accumulation of data from successive inspection lots. In this manner the failure rate will be more representative of production capability and history.

A.3.2 Extension of qualification to FR levels. Extension of qualification to lower FR level shall be accomplished by accumulating data from FR tests performed on sample selected from successive inspection lots. Qualification at lower failure rates is thus based upon data taken over a long period of production and not a single sample produced at one time. Extension of qualification is granted at the same confidence level (60 percent or 90 percent) as was used for the initial FR qualification.

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A.3.3 Maintenance of FR level qualification. Maintenance of FR level qualification shall be monitored by means of a sampling plan based on a 10 percent confidence level. The sampling plan should provide the necessary number of cumulative unit hours (excluding permitted failures) required over a specified time period to maintain the qualified FR level.

A.3.4 Verification of qualification. Every 6 months the manufacturer shall compile a summary of the results of conformance inspection and extended FR test data, in the form of a verification of qualification report, and forward it to the qualifying activity within 30 days after the end of the reporting period as the basis of continued qualification approval. In addition, the manufacturer shall immediately notify the qualifying activity whenever the FR data indicates that the manufacturer has failed to maintain the qualified FR level or the periodic inspection data indicates failure of the qualified product to meet the requirements of the specification. Continuation of qualification approval shall be based on evidence that over the 6 month period, the following has been met:

- a. The manufacturer meets the requirements of MIL-STD-790.
- b. The manufacturer has not modified the design of the item.
- c. The specification requirements for the item have not been amended so as to affect the character of the item.
- d. Lot rejection under the applicable inspection groups does not exceed the specified percentage or one lot, whichever is greater (see 5.3).
- e. Requirements for periodic tests are met, if applicable.
- f. The records of FR tests substantiate that the "L" (specified percentage), "M" (1.0%), or "P" (0.1%) FR level has been maintained or that the manufacturer continues to meet the "R" (0.01%) or "S" (0.001%) FR level for which qualified although the total component of hours of testing does not as yet meet the requirements of 5.3.

When periodic requirements were not met and the manufacturer has taken corrective action satisfactory to the Government, periodic retesting shall be instituted. A summary of the retesting shall be forwarded to the qualifying activity within 30 days after completion of the retest.

A.4. LOT CONFORMANCE FR INSPECTIONS (WHEN SPECIFIED)

A.4.1 Sampling plan. When lot conformance FR inspection is considered necessary, the sampling plans of table VI, provided herein, should be used. They provide reasonable assurance of lot quality and that the lot under inspection is not significantly different from previously accepted lots. In view of the fact that in most ER specifications, 100 percent of the product will have been subjected to burn-in/screening tests which are designed to eliminate early life failures, the need for lot conformance FR tests should be carefully considered. The effect of these lot-by lot tests on the price and delay in delivery of ER parts should be evaluated against the additional verification information to be granted.

A.5. GENERAL

A.5.1 Failure criteria. The failure criteria for the relatively "short-time" FR test used for lot conformance inspection may differ from the failure criteria established for the extended FR test. The data resulting from the lot conformance FR inspection test, therefore should be analyzed in two ways for the two different purposes it will be used. First, for purposes of lot conformance FR inspection, the failure criteria established for the "short-time" FR test would be applied. Secondly, for purposes of adding to the FR test data being accumulated for FR determinations, the failure criteria established for the extended FR test would be applied to determine whether a failure occurred with, this criteria. Therefore, a failure in the lot conformance FR inspection test may not necessarily constitute a failure when the unit hours are recorded for the FR determinations. This is necessary since, for FR determination, the failure criteria should be the same for all data used. For FR determination a single failure criteria should be specified for all measurements.

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A.5.2 Duration of FR test. The ER specification shall indicate the duration for the lot conformance FR inspection test and the extended FR test.

A.5.3 Screening tests. In order to provide the consumer with further assurance of the reliability of the products shipped, ER specifications should include, where applicable, screening tests performed on a 100 percent inspection basis. However, before a screening test is included in an ER specification, there should be sound technical basis for its inclusion and sufficient data to support its effectiveness on all types of product included in the specification. These tests should be specified as a prerequisite for conformance inspection and should include a requirement providing for lot rejection when a specified percentage of the lot exceeds the screening requirements. A burn-in test under conditions of accelerated voltage and temperature or other suitable stresses may be specified as part of the screening tests. Screening tests should be performed only once and preferably in conjunction with the Government inspector since it should not be repeated for the purpose of reinspection.

A.5.4 Accelerated FR tests and acceleration factors. If engineering considerations permit the use of valid accelerated test procedures and associated acceleration factors, the acceleration factor should be applied primarily to reduce the duration of the FR test and not to reduce sample size. Caution must be exercised where large acceleration factors are involved in reducing the duration of the FR test. The test time should not be reduced below some reasonable period applicable to the individual ER specification. In any case, it is recommended that a portion of the FR test data be developed from unaccelerated test conditions. Depending on the acceleration factor, the type of electronic parts and the type of FR test, a requirement that 25 percent of the samples subjected to FR test be tested at unaccelerated (rated) conditions is considered reasonable. The data generated on testing at rated conditions should be evaluated periodically by the qualifying activity to revalidate the acceleration factors used.

A.6. FR QUALIFICATION DATA

A.6.1 Expanding FR sampling plan. Table A-I provides the number of cumulative unit hours for determining the probability of qualification when the true failure rate is 1%/1,000 hours. This table may be used to expand the FR sampling plans specified in section 5 of this standard or to develop additional FR sampling plans.

A.7. APPLICATION INFORMATION

A.7.1 Reliability data. ER specifications or associated military standards should contain as much valid application and use information as is available to the preparing activity. Reference to MIL-HDBK-217, "Reliability Prediction of Electronic Equipment", should be made when appropriate.

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TABLE A-1. FR qualification data in unit hours (based on exponential Distribution and computed at 1%/1,000 hr).

Confidence level	Cumulative unit hours C = Number of failures permitted						Probability of qualification 1/
	C = 0	C = 1	C = 2	C = 3	C = 4	C = 5	
.01	1,000	14,844	43,750	82,500	128,125	178,750	.99
.05	5,125	35,547	81,719	136,563	197,031	281,250	.95
.10	10,547	53,203	110,000	174,531	243,281	315,156	.90
.20	22,305	82,422	153,516	229,688	308,906	390,313	.80
.30	35,664	109,727	191,406	276,406	363,359	451,719	.70
.40	51,094	137,656	228,516	321,094	414,766	509,063	.60
.50	69,297	167,813	267,422	367,188	467,109	567,031	.50
.60	91,641	202,266	310,547	417,500	523,672	629,219	.40
.70	120,391	243,906	361,563	476,250	589,063	700,625	.30
.80	160,938	299,375	427,969	551,563	672,188	790,625	.20
.90	230,313	389,063	532,188	668,125	799,375	927,344	.10
.95	299,375	474,375	629,375	775,625	915,625	1,050,000	.05
.99	460,000	660,000	840,625	1,000,000	1,159,375	1,309,375	.01
	C = 6	C = 7	C = 8	C = 9	C = 10		
.01	233,125	290,625	351,250	412,500	477,500		.99
.05	328,438	398,125	469,375	542,500	616,875		.95
.10	389,531	465,625	543,281	622,188	702,188		.90
.20	473,438	557,656	642,813	728,906	815,625		.80
.30	541,094	631,250	722,031	813,281	905,078		.70
.40	603,906	699,141	794,688	890,430	986,426		.60
.50	666,953	766,875	866,895	966,797	1,066,797		.50
.60	734,219	838,965	946,359	1,047,559	1,151,563		.40
.70	811,133	920,898	1,030,078	1,138,672	1,246,875		.30
.80	907,617	1,023,242	1,137,891	1,251,953	1,365,039		.20
.90	1,053,125	1,176,953	1,299,609	1,420,703	1,540,625		.10
.95	1,184,375	1,314,844	1,443,750	1,570,313	1,696,191		.05
.99	1,450,000	1,600,000	1,740,625	1,877,344	2,014,063		.01

1/ Computed with a tolerance of ± 0.001 .

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TABLE A-II. True failure rates for C = 0 (level M).

Probability of qualification	True failure rates at confidence level:											
	99%	95%	90%	80%	70%	60%	50%	40%	30%	20%	10%	5%
.99	.002	.003	.004	.006	.008	.011	.014	.020	.028	.045	.095	.195
.95	.011	.017	.022	.032	.043	.056	.074	.100	.144	.230	.486	1.000
.90	.023	.035	.046	.066	.088	.115	.152	.206	.296	.473	1.000	2.058
.80	.048	.074	.097	.139	.185	.243	.322	.437	.625	1.000	2.115	4.352
.70	.078	.119	.155	.222	.296	.389	.515	.698	1.000	1.599	3.381	6.959
.60	.111	.171	.222	.317	.424	.558	.737	1.000	1.433	2.291	4.844	9.970
.50	.151	.231	.301	.431	.576	.756	1.000	1.356	1.043	3.107	6.570	13.521
.40	.199	.306	.398	.569	.761	1.000	1.322	1.794	2.570	4.109	8.689	17.881
.30	.262	.402	.523	.748	1.000	1.314	1.737	2.356	3.376	5.398	11.415	23.491
.20	.350	.538	.699	1.000	1.337	1.756	2.322	3.150	4.513	7.215	15.259	31.402
.10	.501	.769	1.000	1.431	1.913	2.513	3.324	4.508	6.458	10.326	21.837	44.939
.05	.651	1.000	1.300	1.860	2.487	3.267	4.320	5.859	8.394	13.422	28.385	58.415
.01	1.000	1.537	1.997	2.858	3.821	5.020	6.638	9.003	12.898	20.623	43.615	89.756

NOTE: For other than M (1.0%) failure rate level, divide above values by 10 for P (0.1%) level, by 100 for R (0.01%) level, by 1,000 for S (0.001%) level, or by 10,000 for T (0.0001%) level.

TABLE A-III. True failure rates for C = 1 (level M).

Probability of qualification	True failure rates at confidence level:											
	99%	95%	90%	80%	70%	60%	50%	40%	30%	20%	10%	5%
.99	.022	.031	.038	.050	.061	.073	.088	.108	.135	.180	.279	.418
.95	.054	.075	.091	.119	.146	.176	.212	.258	.324	.431	.668	1.000
.90	.081	.112	.137	.178	.218	.263	.317	.386	.485	.646	1.000	1.497
.80	.125	.174	.212	.275	.338	.407	.491	.599	.751	1.000	1.549	2.319
.70	.166	.231	.282	.367	.450	.542	.654	.797	1.000	1.331	2.062	3.087
.60	.209	.290	.354	.450	.564	.681	.820	1.000	1.255	1.670	2.587	3.873
.50	.254	.354	.431	.561	.688	.830	1.000	1.219	1.529	2.036	3.154	4.721
.40	.306	.426	.520	.676	.829	1.000	1.205	1.469	1.843	2.454	3.802	5.690
.30	.370	.514	.627	.815	1.000	1.206	1.453	1.772	2.223	2.959	4.584	6.862
.20	.454	.631	.769	1.000	1.227	1.480	1.784	2.175	2.728	3.632	5.627	8.422
.10	.589	.820	1.000	1.300	1.595	1.924	2.318	2.826	3.546	4.720	7.313	10.946
.05	.719	1.000	1.219	1.585	1.945	2.345	2.827	3.446	4.323	5.755	8.916	13.345
.01	1.000	1.391	1.696	2.205	2.706	3.263	3.933	4.795	6.015	8.008	12.405	18.567

NOTE: For other than M (1.0%) failure rate level, divide above values by 10 for P (0.1%) level, by 100 for R (0.01%) level, by 1,000 for S (0.001%) level, or by 10,000 for T (0.0001%) level.

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TABLE A-IV. True failure rates for C = 2 (level M).

Probability of qualification	True failure rates at confidence level:											
	99%	95%	90%	80%	70%	60%	50%	40%	30%	20%	10%	5%
.99	.052	.070	.082	.102	.121	.141	.164	.191	.229	.285	.398	.535
.95	.097	.130	.154	.191	.226	.263	.306	.358	.427	.532	.743	1.000
.90	.131	.175	.207	.257	.304	.354	.411	.481	.575	.717	1.000	1.346
.80	.183	.244	.288	.359	.425	.494	.574	.672	.802	1.000	1.396	1.879
.70	.228	.304	.360	.447	.529	.616	.716	.838	1.000	1.247	1.740	2.342
.60	.272	.363	.429	.534	.632	.736	.855	1.000	1.194	1.489	2.077	2.796
.50	.318	.425	.502	.625	.740	.861	1.000	1.170	1.397	1.742	2.431	3.272
.40	.369	.493	.584	.726	.859	1.000	1.161	1.359	1.622	2.023	2.823	3.800
.30	.430	.574	.679	.845	1.000	1.164	1.352	1.582	1.889	2.355	3.287	4.424
.20	.509	.680	.804	1.000	1.184	1.378	1.600	1.873	2.236	2.788	3.891	5.237
.10	.633	.846	1.000	1.244	1.472	1.713	1.990	2.329	2.780	3.467	4.838	6.512
.05	.749	1.000	1.183	1.471	1.741	2.027	2.353	2.754	3.288	4.100	5.722	7.702
.01	1.000	1.336	1.680	1.964	2.325	2.707	3.143	3.679	4.392	5.476	7.642	10.287

NOTE: For other than M (1.0%) failure rate level, divide above values by 10 for P (0.1%) level, by 100 for R (0.01%) level, by 1,000 for S (0.001%) level, or by 10,000 for T (0.0001%) level.

TABLE A-V. True failure rates for C = 3 (level M).

Probability of qualification	True failure rates at confidence level:											
	99%	95%	90%	80%	70%	60%	50%	40%	30%	20%	10%	5%
.99	.082	.106	.123	.150	.173	.198	.225	.257	.298	.359	.473	.604
.95	.137	.176	.204	.248	.287	.327	.372	.425	.494	.595	.782	1.000
.90	.175	.225	.261	.316	.366	.418	.475	.544	.631	.760	1.000	1.278
.80	.230	.296	.344	.416	.482	.550	.626	.715	.831	1.000	1.316	1.682
.70	.276	.356	.414	.501	.580	.662	.753	.861	1.000	1.203	1.584	2.024
.60	.321	.414	.481	.582	.674	.769	.874	1.000	1.162	1.398	1.840	2.351
.50	.367	.473	.550	.666	.771	.879	1.000	1.144	1.328	1.599	2.104	2.689
.40	.418	.538	.625	.757	.877	1.000	1.137	1.300	1.510	1.818	2.392	3.057
.30	.476	.614	.713	.863	1.000	1.141	1.297	1.483	1.723	2.073	2.729	3.487
.20	.552	.711	.826	1.000	1.158	1.321	1.502	1.718	1.996	2.401	3.160	4.039
.10	.668	.861	1.000	1.211	1.403	1.600	1.820	2.081	2.417	2.909	3.828	4.892
.05	.776	1.000	1.161	1.408	1.629	1.858	2.112	2.416	2.806	3.377	4.444	5.680
.01	1.000	1.289	1.497	1.813	2.100	2.395	2.723	3.114	3.618	4.354	5.730	7.323

NOTE: For other than M (1.0%) failure rate level, divide above values by 10 for P (0.1%) level, by 100 for R (0.01%) level, by 1,000 for S (0.001%) level, or by 10,000 for T (0.0001%) level.

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TABLE A-VI. True failure rates for C = 4 (level M).

Probability of qualification	True failure rates at confidence level:											
	99%	95%	90%	80%	70%	60%	50%	40%	30%	20%	10%	5%
.99	.111	.140	.160	.191	.218	.245	.274	.309	.353	.415	.527	.650
.95	.170	.215	.246	.293	.334	.376	.422	.475	.542	.638	.810	1.000
.90	.210	.266	.304	.362	.413	.465	.521	.587	.670	.788	1.000	1.235
.80	.266	.337	.386	.460	.524	.590	.661	.745	.850	1.000	1.270	1.568
.70	.313	.397	.455	.541	.617	.694	.778	.876	1.000	1.176	1.494	1.844
.60	.358	.453	.519	.617	.704	.792	.888	1.000	1.141	1.343	1.705	2.105
.50	.403	.510	.584	.695	.793	.892	1.000	1.126	1.286	1.512	1.920	2.371
.40	.452	.572	.655	.779	.889	1.000	1.121	1.263	1.441	1.695	2.153	2.658
.30	.508	.643	.737	.876	1.000	1.125	1.261	1.420	1.621	1.907	2.421	2.990
.20	.580	.734	.841	1.000	1.141	1.284	1.439	1.621	1.850	2.176	2.763	3.412
.10	.689	.873	1.000	1.182	1.357	1.526	1.711	1.927	2.200	2.588	3.286	4.057
.05	.790	1.000	1.145	1.362	1.554	1.748	1.960	2.208	2.520	2.964	3.764	4.647
.01	1.000	1.266	1.450	1.725	1.968	2.214	2.482	2.795	3.191	3.753	4.766	5.884

NOTE: For other than M (1.0%) failure rate level, divide above values by 10 for P (0.1%) level, by 100 for R (0.01%) level, by 1,000 for S (0.001%) level, or by 10,000 for T (0.0001%) level.

TABLE A-VII. True failure rates for C = 5 (level M).

Probability of qualification	True failure rates at confidence level:											
	99%	95%	90%	80%	70%	60%	50%	40%	30%	20%	10%	5%
.99	.137	.170	.193	.226	.255	.284	.315	.351	.396	.458	.567	.684
.95	.200	.249	.282	.330	.373	.415	.461	.513	.578	.669	.829	1.000
.90	.241	.300	.340	.399	.450	.501	.556	.619	.698	.807	1.000	1.206
.80	.298	.372	.421	.494	.557	.620	.688	.767	.864	1.000	1.238	1.494
.70	.345	.430	.487	.571	.645	.718	.797	.887	1.000	1.157	1.433	1.729
.60	.389	.485	.549	.644	.727	.809	.898	1.000	1.127	1.304	1.615	1.949
.50	.433	.540	.611	.717	.809	.901	1.000	1.114	1.255	1.453	1.799	2.170
.40	.481	.599	.679	.796	.898	1.000	1.110	1.236	1.393	1.612	1.997	2.408
.30	.535	.667	.756	.886	1.000	1.113	1.236	1.376	1.551	1.795	2.223	2.682
.20	.604	.753	.853	1.000	1.128	1.257	1.394	1.553	1.750	2.026	2.509	3.026
.10	.708	.883	1.000	1.173	1.324	1.474	1.635	1.822	2.053	2.376	2.942	3.550
.05	.802	1.000	1.132	1.328	1.499	1.669	1.852	2.063	2.324	2.690	3.332	4.019
.01	1.000	1.247	1.412	1.656	1.869	2.081	2.309	2.572	2.899	3.355	4.155	5.012

NOTE: For other than M (1.0%) failure rate level, divide above values by 10 for P (0.1%) level, by 100 for R (0.01%) level, by 1,000 for S (0.001%) level, or by 10,000 for T (0.0001%) level.

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TABLE A-VIII. True failure rates for C = 6 (level M).

Probability of qualification	True failure rates at confidence level:											
	99%	95%	90%	80%	70%	60%	50%	40%	30%	20%	10%	5%
.99	.161	.197	.221	.257	.287	.318	.350	.386	.431	.492	.598	.710
.95	.227	.277	.312	.362	.405	.447	.492	.544	.607	.694	.843	1.000
.90	.269	.329	.370	.429	.480	.531	.584	.645	.720	.823	1.000	1.186
.80	.327	.400	.450	.522	.584	.645	.710	.784	.875	1.000	1.215	1.442
.70	.373	.457	.514	.596	.667	.737	.811	.895	1.000	1.143	1.389	1.647
.60	.416	.510	.573	.665	.745	.823	.905	1.000	1.116	1.276	1.550	1.839
.50	.460	.563	.633	.734	.822	.908	1.000	1.104	1.233	1.409	1.712	2.031
.40	.506	.620	.697	.809	.905	1.000	1.101	1.216	1.357	1.551	1.885	2.235
.30	.559	.685	.770	.894	1.000	1.105	1.216	1.343	1.499	1.713	2.082	2.470
.20	.626	.766	.862	1.000	1.119	1.236	1.361	1.503	1.677	1.917	2.330	2.763
.10	.726	.889	1.000	1.160	1.298	1.434	1.579	1.744	1.946	2.224	2.704	3.206
.05	.817	1.000	1.125	1.305	1.460	1.613	1.776	1.961	2.189	2.502	3.041	3.606
.01	1.000	1.224	1.377	1.598	1.788	1.975	2.174	2.401	2.680	3.063	3.722	4.415

NOTE: For other than M (1.0%) failure rate level, divide above values by 10 for P (0.1%) level, by 100 for R (0.01%) level, by 1,000 for S (0.001%) level, or by 10,000 for T (0.0001%) level.

TABLE A-IX. True failure rates for C = 7 (level M).

Probability of qualification	True failure rates at confidence level:											
	99%	95%	90%	80%	70%	60%	50%	40%	30%	20%	10%	5%
.99	.182	.221	.247	.284	.316	.346	.379	.416	.460	.521	.624	.730
.95	.249	.303	.338	.389	.432	.475	.519	.569	.631	.714	.855	1.000
.90	.291	.354	.396	.455	.506	.555	.607	.666	.738	.835	1.000	1.170
.80	.349	.424	.474	.545	.606	.665	.727	.798	.883	1.000	1.198	1.401
.70	.395	.480	.536	.617	.685	.752	.823	.903	1.000	1.132	1.356	1.586
.60	.437	.532	.594	.683	.759	.833	.912	1.000	1.108	1.254	1.502	1.756
.50	.479	.583	.652	.749	.833	.914	1.000	1.097	1.215	1.375	1.647	1.926
.40	.524	.638	.713	.820	.911	1.000	1.094	1.200	1.329	1.504	1.802	2.107
.30	.576	.700	.782	.900	1.000	1.098	1.201	1.317	1.459	1.651	1.978	2.313
.20	.640	.778	.869	1.000	1.111	1.220	1.334	1.464	1.621	1.835	2.198	2.570
.10	.736	.895	1.000	1.150	1.278	1.403	1.535	1.683	1.864	2.111	2.528	2.956
.05	.822	1.000	1.117	1.285	1.428	1.567	1.715	1.881	2.083	2.358	2.824	3.303
.01	1.000	1.217	1.359	1.564	1.737	1.907	2.086	2.289	2.535	2.869	3.436	4.019

NOTE: For other than M (1.0%) failure rate level, divide above values by 10 for P (0.1%) level, by 100 for R (0.01%) level, by 1,000 for S (0.001%) level, or by 10,000 for T (0.0001%) level.

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TABLE A-X. True failure rates for C = 8 (level M).

Probability of qualification	True failure rates at confidence level:											
	99%	95%	90%	80%	70%	60%	50%	40%	30%	20%	10%	5%
.99	.202	.243	.270	.309	.341	.373	.405	.442	.486	.546	.647	.748
.95	.270	.325	.361	.412	.456	.498	.541	.591	.650	.730	.864	1.000
.90	.312	.376	.418	.477	.527	.576	.627	.684	.752	.845	1.000	1.157
.80	.369	.445	.495	.565	.624	.681	.742	.809	.890	1.000	1.183	1.370
.70	.415	.500	.556	.635	.701	.765	.833	.909	1.000	1.123	1.329	1.538
.60	.457	.550	.611	.698	.771	.842	.917	1.000	1.101	1.236	1.463	1.693
.50	.498	.600	.667	.761	.842	.919	1.000	1.091	1.201	1.349	1.596	1.847
.40	.542	.653	.726	.826	.916	1.000	1.088	1.187	1.307	1.468	1.736	2.010
.30	.592	.713	.793	.905	1.000	1.902	1.188	1.296	1.427	1.602	1.896	2.195
.20	.654	.788	.876	1.000	1.105	1.206	1.313	1.432	1.576	1.770	2.094	2.424
.10	.747	.900	1.000	1.142	1.262	1.378	1.499	1.635	1.800	2.022	2.392	2.769
.05	.829	1.000	1.111	1.269	1.402	1.530	1.665	1.817	2.000	2.246	2.657	3.076
.01	1.000	1.206	1.339	1.530	1.690	1.845	2.008	2.190	2.411	2.708	3.204	3.708

NOTE: For other than M (1.0%) failure rate level, divide above values by 10 for P (0.1%) level, by 100 for R (0.01%) level, by 1,000 for S (0.001%) level, or by 10,000 for T (0.0001%) level.

TABLE A-XI. True failure rates for C = 9 (level M).

Probability of qualification	True failure rates at confidence level:											
	99%	95%	90%	80%	70%	60%	50%	40%	30%	20%	10%	5%
.99	.220	.263	.290	.329	.362	.394	.427	.463	.507	.566	.663	.760
.95	.289	.345	.382	.433	.476	.518	.561	.609	.667	.744	.872	1.000
.90	.331	.396	.438	.497	.546	.594	.644	.699	.765	.854	1.000	1.169
.80	.388	.464	.513	.582	.640	.696	.754	.819	.896	1.000	1.172	1.344
.70	.433	.518	.572	.650	.714	.776	.841	.913	1.000	1.116	1.307	1.499
.60	.474	.567	.627	.711	.782	.850	.921	1.000	1.095	1.222	1.431	1.641
.50	.515	.616	.681	.772	.849	.923	1.000	1.086	1.189	1.326	1.554	1.782
.40	.558	.667	.737	.837	.920	1.000	1.084	1.176	1.288	1.437	1.684	1.931
.30	.607	.725	.801	.910	1.000	1.087	1.178	1.279	1.400	1.562	1.830	2.099
.20	.667	.797	.881	1.000	1.099	1.195	1.295	1.406	1.539	1.718	2.012	2.308
.10	.757	.905	1.000	1.135	1.248	1.356	1.469	1.596	1.747	1.949	2.283	2.619
.05	.836	1.000	1.105	1.254	1.380	1.499	1.624	1.764	1.831	2.154	2.524	2.895
.01	1.000	1.196	1.321	1.500	1.649	1.792	1.942	2.108	2.308	2.576	3.017	3.461

NOTE: For other than M (1.0%) failure rate level, divide above values by 10 for P (0.1%) level, by 100 for R (0.01%) level, by 1,000 for S (0.001%) level, or by 10,000 for T (0.0001%) level.

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TABLE XII. True failure rates for C = 10 (level M).

Probability of qualification	True failure rates at confidence level:											
	99%	95%	90%	80%	70%	60%	50%	40%	30%	20%	10%	5%
.99	.237	.282	.310	.350	.382	.415	.448	.484	.528	.585	.680	.774
.95	.306	.364	.400	.452	.495	.536	.578	.625	.682	.756	.879	1.000
.90	.349	.414	.456	.514	.563	.610	.658	.712	.776	.861	1.000	1.138
.80	.405	.481	.529	.598	.654	.708	.764	.827	.901	1.000	1.162	1.322
.70	.449	.534	.587	.663	.726	.786	.848	.918	1.000	1.110	1.289	1.467
.60	.490	.582	.640	.723	.791	.857	.925	1.000	1.090	1.209	1.405	1.599
.50	.530	.629	.692	.782	.856	.926	1.000	1.081	1.179	1.308	1.519	1.729
.40	.572	.679	.747	.844	.924	1.000	1.079	1.167	1.272	1.412	1.640	1.867
.30	.619	.735	.809	.913	1.000	1.083	1.169	1.264	1.378	1.529	1.776	2.021
.20	.678	.805	.886	1.000	1.095	1.185	1.280	1.384	1.508	1.674	1.944	2.213
.10	.765	.908	1.000	1.129	1.236	1.338	1.444	1.562	1.702	1.889	2.194	2.497
.05	.842	1.000	1.101	1.243	1.360	1.473	1.590	1.720	1.874	2.080	2.416	2.750
.01	1.000	1.187	1.307	1.475	1.615	1.749	1.888	2.042	2.225	2.469	2.868	3.265

NOTE: For other than M (1.0%) failure rate level, divide above values by 10 for P (0.1%) level, by 100 for R (0.01%) level, by 1,000 for S (0.001%) level, or by 10,000 for T (0.0001%) level.

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Measurement theory and practice

The world through quantification

David J. Hand



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Attachment 3

Measurement Theory and Practice

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CRY WOLF:

The Psychology of False Alarms

Shlomo Breznitz
University of Haifa



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attachment 4

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Behavioural implications of alarm mistrust as a function of task workload

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The research was conducted to investigate the effect of increasing primary task and alarm workload on alarm mistrust as reflected by alarm and primary task performances. A total of 126 undergraduate students performed a complex psychomotor task battery three times, with the number of concurrent tasks increasing each time. During their performance, the students were required to react to an alarm system (including visual and auditory components) of questionable reliability. Depending on the group to which participants were assigned, the alarm presentation rate constituted a low-, medium- or high-workload condition. Alarm response data (times, frequencies, accuracies) and primary task data (tracking error) were analyzed to assess performance differences as a function of primary and secondary task workload levels. Results generally supported the hypotheses: increasing primary task and alarm task workload degraded alarm response performance. Also, response frequencies supported earlier research suggesting that participants 'probability match' their response rates to alarm system reliability. The results are discussed with regard to the cry-wolf effect, attention theory and alarm system design.

1. Introduction

The use of automated systems has increased in contemporary life (Parasuraman and Mouloua 1987). Such systems place human operators into a monitoring role, dependent upon status displays and emergency signals for information about system functioning. The emergency signal represents an increasingly important focus of research attention (Lees 1974). Two recent works have addressed emergency signal design and implementation (Stanton 1994, Edworthy and Adams 1996). Also, volume 38, number 11 of this journal was specifically devoted to emergency signals.

Most emergency signal research to date has involved a common element: alarms and warnings as true signals that convey correct information about authentic danger. However, the occurrence of false signals is common in complex-task environments such as civilian and military aviation (Loomis and Porter 1982,

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Tyler *et al.* 1995), underground mining (Mallett *et al.* 1993), medical care facilities (Kerr 1985) and nuclear power control rooms (Kemény 1979). False alarms have become so commonplace in some environments that there are standards specifying the characteristics of a false alarm (Simpson and Sheppard 1992). Usually these standards focus on the mechanical components of the alarm system, stressing that a false alarm is a fault indicated by monitoring circuitry where no fault exists.

Although false alarms clearly pose serious safety concerns such as diversion of operator attention and reduced reaction time (Seminara *et al.* 1977), only recently have researchers devoted significant effort to the cognitive and behavioural implications of false alarms. Breznitz (1983) showed that false alarms lead to a 'cry-wolf' effect, manifested by decreased heart rate and skin conductance levels. Paté-Cornell (1986) attempted to quantify the cry-wolf effect by developing economic analysis models to predict operator response performance. Her models characterize alarm mistrust as a product of high false alarm rates and short alarm lead times (the time between alarm activation and task-related consequences).

Researchers have recently begun to empirically evaluate Paté-Cornell's models and to support the theories of Breznitz (1983) and others. Bliss *et al.* (1995b) and Getty *et al.* (1995) investigated operator response characteristics at various levels of alarm reliability and urgency, finding that in certain conditions the cry-wolf effect may be manifested by degraded alarm response speed, accuracy and frequency. This finding was a departure from Paté-Cornell's model (1986), which suggested that alarm mistrust would lead to a total lack of responding.

Recently, researchers have attempted to determine factors that mediate the cry-wolf effect. Some of their efforts have focused on addressing the source of the problem, namely alarm mistrust. Other efforts have concentrated on the behavioural responses resulting from alarm mistrust.

To influence the existence of alarm mistrust, Bliss *et al.* (1995a) investigated whether hearsay information affects operator perceptions of alarm system reliability. They measured alarm responses in successive experimental sessions, noting that such responses were more frequent after participants were told by an experimental confederate to expect a more reliable alarm system.

Bliss *et al.* (1996) also manipulated alarm mistrust by providing participants with one of two additional sources of information. In certain cases participants were given access to a gauge from which they could assess alarm validity. In other conditions participants were told the reliability level of the overall alarm system. Bliss *et al.* (1996) found that participants with alarm system reliability information made more frequent responses, but those with individual alarm validity information made more appropriate responses.

In addition to efforts to restore trust in an alarm system, researchers have also tested manipulations aimed not toward improving trust, but simply increasing response rates.

Bliss *et al.* (1995b) determined that increasing the urgency of alarms would cause participants to respond more often, regardless of false alarm rate. In a separate experiment, Bliss *et al.* (1995a) found that manipulation of alarm urgency may also cause participants to respond more quickly. These findings support the efforts of Patterson (1982), Edworthy *et al.* (1991) and Momtahan (1990), who have successfully manipulated the spectral pattern of alarm signals to increase urgency.

Sorkin *et al.* (1988) and others have suggested that alarm responding scenarios resemble a dual-task paradigm where operators must shift attention from a primary task to attend to alarms. Based on this assumption, researchers have examined how changes in the primary task affect alarm responses. Bliss and McAbee (1995) showed that primary tasks considered more critical by operators will be heeded at the expense of alarm responding. This effect is more pronounced if the alarm system has low reliability (frequent false alarms) than if the system is reliable.

The current research addresses a variable that has not been considered in the context of alarm mistrust: mental workload. Over the past 20 years interest in mental workload has exploded with a host of researchers examining workload and related concepts in a variety of situations. One of the primary issues debated is the nature of the concept. Moray *et al.* (1977) went to great lengths to organize ideas about mental workload into a body of formal definitions, descriptions and applications. More recently, Lysaght *et al.* (1989) prepared a comprehensive review of the literature on mental workload in an attempt more clearly to define the concept. One result of their efforts has been the knowledge that the level of workload may alter performance in a complex-task environment. Lysaght *et al.* (1989: 10) depict an inverted-U relationship between workload and performance, where extremely high or low levels of workload may be detrimental to task performance. Proctor and van Zandt (1994) noted that this relationship may be a reflection of the Yerkes-Dodson Law that associates stress and arousal (Yerkes and Dodson 1908).

Wickens' (1992) multiple resource theory has also been used to predict and explain the behavioural implications of mental workload. The multiple-resource view suggests that in multiple-task environments different attentional resources may be used for tasks that are qualitatively different, and the same attentional resources are time-shared among tasks that are qualitatively similar. In operational environments where there is often a limited amount of time available for task processing, this means that similar tasks must compete for processing time. In such cases, operator workload levels are increased and responses are degraded (Hancock 1987).

1.1. Goal of this research

Breznitz (1983) and Bliss (1993) have already established that the mistrust inherent in the cry-wolf phenomenon exists and may be quantified by task performance measures in a research setting. However, neither considered how varying levels of primary or alarm task workload may influence responses to unreliable alarm systems. Because workload and the cry-wolf effect have each been shown to degrade psychomotor task performance, it is plausible that the two influences may interact. If this happens, high workload levels might further degrade response performances to unreliable alarms. The purpose of this research is to investigate the interaction of primary and secondary task mental workload levels in the context of the cry-wolf phenomenon.

To manipulate workload in this research, the present authors followed the recommendations of Lysaght *et al.* (1989). Specifically, the number and types of tasks to be performed were manipulated in an attempt to vary primary and secondary task workload. Using a 3×3 mixed research design, the rate of alarm activation between participants was manipulated to vary the secondary

task workload. Also, the type and number of concurrent primary tasks within participants were manipulated to vary the primary task workload. Alarm response time, frequency and accuracy, and primary task root-mean-square (RMS) tracking error were also measured.

1.2. Hypotheses

Lysaght *et al.* (1989) describe two factors that affect workload: number and type of tasks, and characteristics of the human operator. Meister (1985) supports this with the view of workload as a multidimensional construct represented by both worker characteristics and system characteristics. Based on these conceptualizations, the number of concurrent tasks and increased alarm presentation rates were increased to alter primary and secondary task workloads respectively.

In a discussion of divided attention, Wickens (1984) noted that if a task requires more of a resource, less will be available for allocation to other tasks, and performance of those other tasks will decline. Based on this premise, our first set of hypotheses stated that secondary task (alarm) reactions would be degraded under higher levels of primary task workload. Specifically, alarm response accuracy and frequency are expected to decrease, while alarm response time would increase.

Our second set of hypotheses followed from Lysaght *et al.*'s conceptualization of workload, and it related to the impact of increasing secondary task workload on secondary task performance. Specifically, alarm response parameters (response time, frequency, accuracy) are expected to worsen as secondary task workload increased.

Support for these predictions has been noted by Bliss and McAbee (1995) in a dual-task cry-wolf context where complex task operators allocated attention to primary and secondary tasks in a manner consistent with Wickens' (1984) multiple-resource theory. In that and other research, it has been noted that participants often 'probability match' the alarm response rates so that they respond with a frequency proportional to the true alarm presentation rate. For that reason, it was planned to evaluate the above predictions relative to ambient response rates, which were expected to approximate the true alarm rate.

2. Methods

A 3 × 3 mixed research design was used where alarm workload (alarm activation rate) was manipulated between groups, and primary task workload (number of concurrent tasks) was manipulated within groups. The between-group manipulation of alarm activation rate was designed to ensure a stable conceptualization of alarm system reliability among participants, and to prevent any confusion that might result from presenting multiple activation rates to the same participants. The within-group manipulation of primary task workload was meant to resemble real-world task environments (such as aviation or the military) where workload may increase over the course of a mission.

2.1. Participants

Following methods detailed by Keppel (1982), a power analysis revealed that using 126 participants (14 per condition) would yield an experimental power of 0.80 at $p = 0.05$. Participants were volunteers from undergraduate courses at the University of Alabama at Huntsville who were awarded course credit for participation. Equal numbers of male and female participants were included in each experimental condition.

2.2. Primary task

All participants performed the tracking, monitoring and resource management portions of the Multi-attribute Task (MAT) Battery (Comstock and Arnegard 1992). These tasks were designed to simulate activities performed by aeroplane pilots during flight. Figure 1 depicts the primary task screen.

The tracking task portion of the screen measured 12.5 × 9.5 cm. During the tracking task, participants used a mouse to attempt to keep a floating ball aligned with a set of crosshairs (figure 1). The floating ball fluctuated randomly around the screen so that it was necessary continually to adjust its position to keep it centred.

The monitoring portion of the MAT Battery required the participant to monitor four gauges moving vertically among six notches with a defined centre line (figure 1). The participant watched for fluctuations of two or more notches above or below the centre line. If such a fluctuation occurred for any gauge, the participant depressed the corresponding function key on the computer keyboard. For example, if the first gauge was out of tolerance, the participant would press the function key labelled 'F1'. This would cause the pointer to centre, and then begin to fluctuate again.

The resource management task required each participant to monitor six fuel tanks for their fill level, which was indicated by coloured shading of the tank (figure 1). Two primary tanks were to be maintained at > 2500 gallons by filling them from the four resource tanks. Two of the resource tanks had to be maintained above empty. Eight pumps represented by small numbered squares transferred the liquid among the tanks. The pumps were activated by depressing the corresponding number keys on the computer keyboard, and deactivated by depressing the number key again. Arrows indicated the direction of flow of liquid through each pump. A

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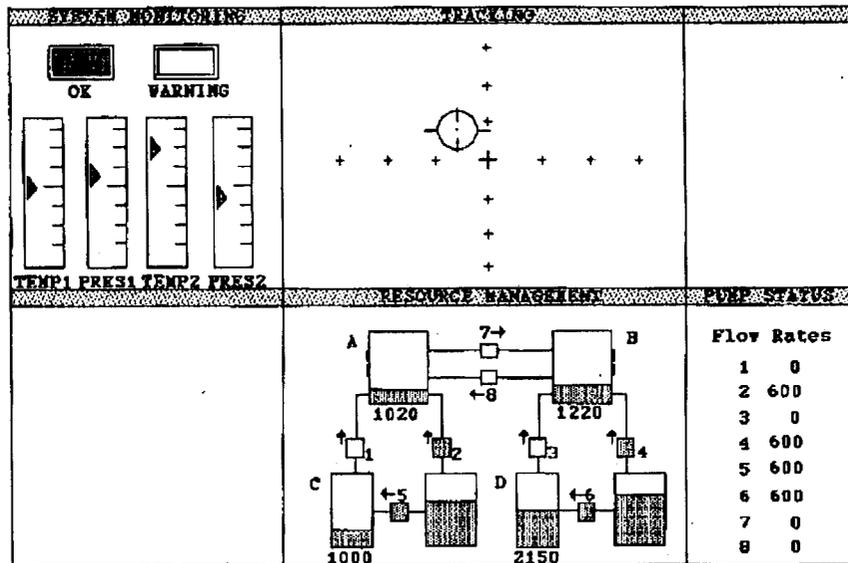


Figure 1. Multi-attribute battery primary task screen.

column in the right of the screen showed the amount of liquid flowing through each pump.

The tracking task was the most continuous of the three primary tasks and was the one task that was consistently used in each experimental session. The dependent variable measured from the primary task was the average of RMS tracking error score sampled every 11 s. It was expected that because the number and type of tasks performed concurrently increased across experimental sessions, the primary task workload would increase from the first to the third sessions. This approach was taken from the recommendations of Lysaght *et al.* (1989) who described varying the number and types of tasks as a means of varying mental workload levels.

2.3. Secondary task

At the same time that the participants were performing the primary task, they were also presented with intermittent alarms as the secondary task, in a manner similar to research by Bliss *et al.* (1995b). The alarms were programmed on a Macintosh computer using Supercard 1.6 software and presented on a Macintosh Quadra 660AV computer with 8 MB RAM and a clock speed of 45 MHz. The alarms were both auditory and visual to institute signal redundancy and increase the probability of detection by the participant (Wogalter and Young 1991).

Regarding auditory and visual structure, the current alarms were identical to the medium-urgency alarm used by Bliss *et al.* (1995b). Each alarm consisted of a 13.97 × 22.86 cm rounded-corner, rectangular yellow panel on a 190.05 × 24.77 cm rectangular white background. Printed on the panel in black capital letters (48-point Helvetica font) was a textual message (WARNING!) indicating a medium-level urgency alarm. Choice of colour and textual message was taken from the work of Wogalter and Silver (1990), ANSI (1991) guidelines and Young (1991), in which these authors detailed aspects of warning effectiveness. This visual signal appeared for 15 s, or until the participant responded (whichever came first).

The auditory portion of the signals was a non-verbal signal recorded from a commercial aircraft simulator (Boeing 757/767). The overspeed siren was used, with each auditory signal sounding once for 2 s and then becoming silent. During the experiment the background noise in the room was 42 dBA. The alarms sounded at 67 dBA (averaged over time).

Participants responded to alarms with their right hand using the Macintosh mouse to click on a 0.635 × 0.635 cm response button appearing below the alarm panel on the screen. (Prior research by Bliss *et al.* 1995a, b established no effect of hand dominance on response speed or accuracy.) When an alarm activated, the Macintosh cursor (arrow) was automatically centred on the screen. Therefore, participants had to move the arrow to the response button to make a response (figure 2). Requiring this type of response allowed the assessment of response patterns by recording response time, frequency and accuracy parameters into a data file. Response time (in 1/60ths of a second) was calculated as the time from alarm activation until the mouse was clicked once.

Response accuracy was determined by calculating the distance in pixels from the cursor arrow to the centre of the response button when the participant pressed the mouse button. Participants were encouraged to aim for the very centre of the response button, indicated by a small circle, measuring 4 pixels in diameter. If no response occurred within 15 s of activation, a lack of response was coded into the data file. If the participant responded to a true alarm or did not respond to a false

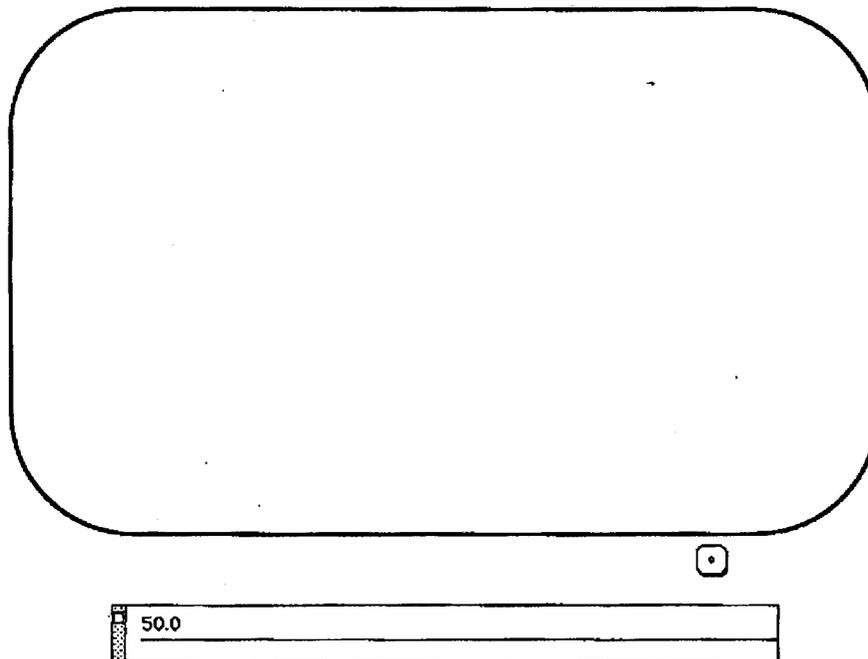


Figure 2: Alarm response secondary task screen.

alarm, a female voice stated 'correct'. If the participant responded to a false alarm or did not respond to a true alarm, the voice stated 'incorrect'. Other than this feedback, there was no auditory or visual difference between true and false alarms (this was done to reflect the characteristics of real-world alarm systems).

Sixty percent of the alarms were true. Figures 3–5 show the temporal composition of the alarms. As shown, workload was manipulated by changing the temporal spacing (activation rate) among the 10 alarms. In the low workload condition, alarms were evenly distributed across the entire session. In the medium and high workload conditions, the alarm activation rate was compressed so that the 10 alarms activated within a shorter period, and participants performed the primary task alone for a portion of the session. This manipulation was meant to increase workload while resembling real-world situations where many alarms activate in a short period.

2.4. Experimental procedure

After completing an informed consent form, participants completed a demographics form assessing background information about age, gender, major, computer experience, vision and hearing. Participants then were randomly assigned to one of three groups differing according to the workload level of the alarm task (low, medium, high). Primary task workload was varied within groups; participants performed only the tracking task in the first session, the tracking and monitoring

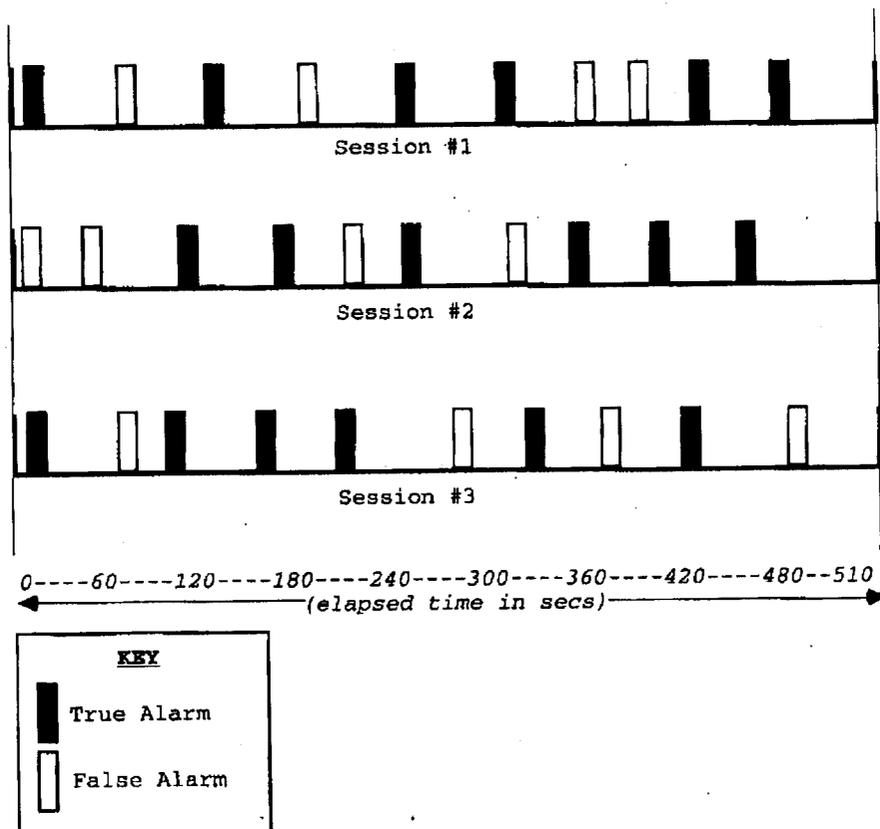


Figure 3. Alarm sequence for each session for participants in the low secondary workload condition.

tasks during the second session, and the tracking, monitoring and resource allocation tasks in the third session.

Next, the participants received primary and secondary task verbal instructions and familiarization. The participants completed a 30-s practice session on each of the MAT Battery tests (30 s for each subtask individually, 30 s for all subtasks in combination). Based on prior research with similar tasks (Kennedy *et al.* 1990) it was suspected that the MAT tasks would stabilize relatively quickly. Participants also received an example of true and false alarms, and an explanation of the contingencies associated with response and non-response.

To help motivate participants, they were given a starting score of 50 points and were told that the number of experimental sessions they would perform would be dependent upon their final score after three experimental sessions (with the agreement that low performers would have to complete a fourth experimental session, although none did). Points were gained for correct reactions to alarms, while they were deducted for incorrect reactions. For each correct alarm reaction one point was added to the cumulative score. One point was deducted from the score for each incorrect alarm reaction. A correct reaction constituted responding to true alarms

and not responding to false alarms. An incorrect reaction occurred if there was a response to a false alarm or if there was no response to a true alarm. If the time to respond to a true alarm was >5 s, or if the response was not within the response panel, participants would receive half the correct response point value (0.5 point). Table 1 depicts the point system. This method has been shown to motivate participants in prior research (Bliss *et al.* 1995a).

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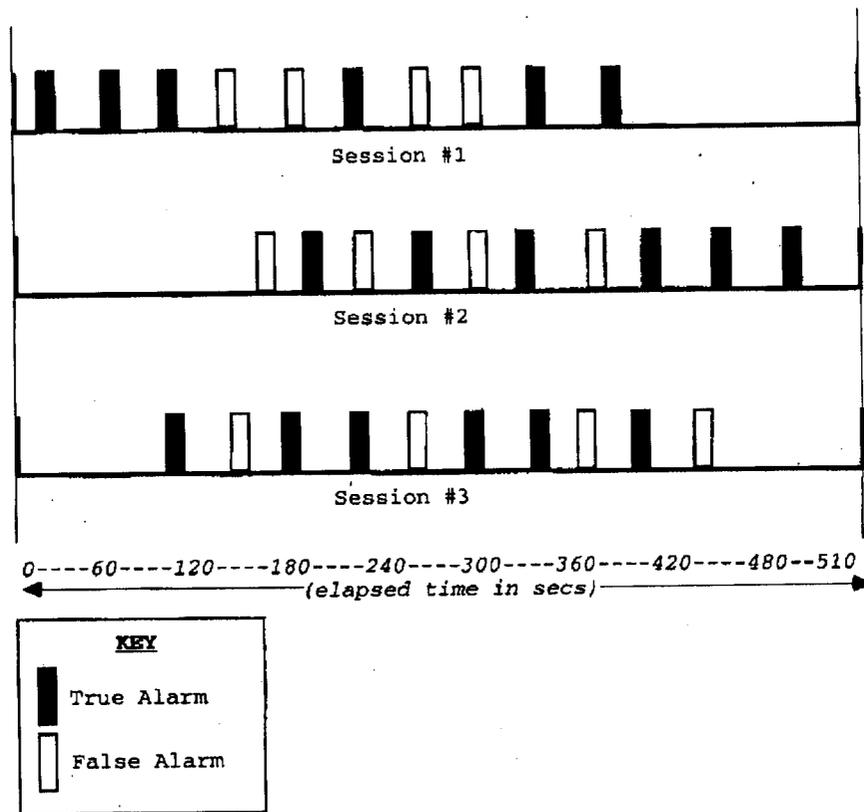


Figure 4. Alarm sequence for each session for participants in the medium secondary workload condition.

Table 1. Point system for alarm reactions.

Responses	Alarms	
	True	False
Response	gain 1 point	lose 1 point
No response	lose 1 point	gain 1 point
Late (> 5 s)	gain 0.5 point	lose 1 point
Inaccurate	gain 0.5 point	lose 1 point

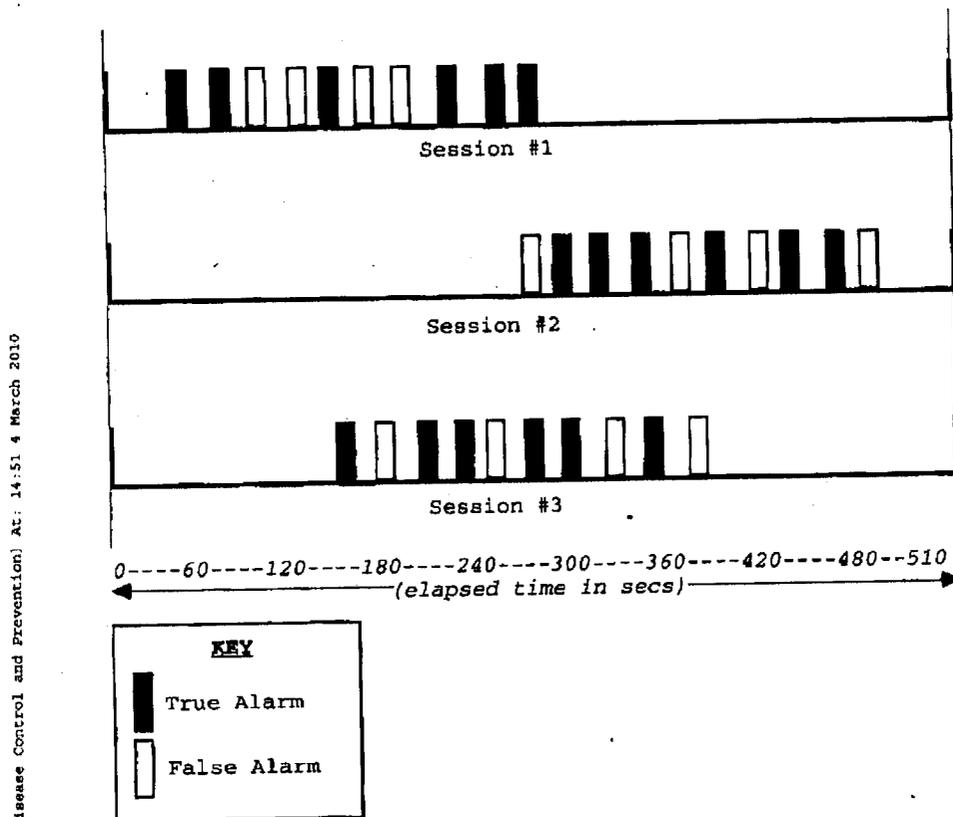


Figure 5. Alarm sequence for each session for participants in the high secondary workload condition.

The duration of each test was 8.5 min with 1-min breaks between sessions. All participants experienced increasing primary task workload from the first to the third experimental session. Primary task workload was manipulated in this way to mirror real-world conditions (such as military or aviation missions) where workload may increase over time, and to strengthen the manipulation (because fatigue may add to workload). There was a total of 10 alarms per block; six true and four false alarms. Before each session participants were told to expect 60% true alarms, but were not told how many alarms to expect in each session. To vary alarm task workload, the activation rate was manipulated between groups by presenting participants with varying times between alarm activation. Alarm workload was kept stable for each group to avoid confounding workload with shifting perceptions of alarm system reliability. Later, participants were debriefed and dismissed.

3. Results

A set of three 3×3 mixed analyses of variance (ANOVA) determined the effects of increasing primary and secondary task workload on alarm response time, frequency and accuracy. Because response parameters were hypothesized to change in a linear

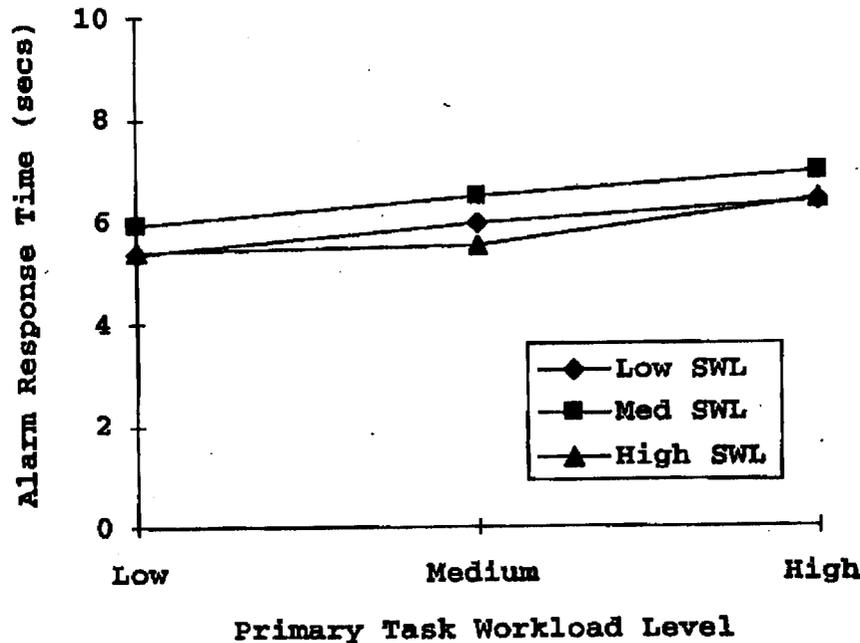


Figure 6. Alarm response time as a function of primary task (MAT Battery) and secondary task (alarm) workload level (SWL).

fashion as a function of increasing levels of primary task workload, a trend analysis evaluated the results.

Figure 6 shows mean alarm response time as a function of primary task workload. The omnibus ANOVA for alarm response time was not significant ($p > 0.05$); however, there was a main effect of primary task workload, $F(2,242) = 30.04$, $p < 0.01$. From figure 6 it is evident that as primary task workload increased, alarm response time increased. The main effect of secondary task workload and the interaction of primary task workload and secondary task workload were not significant ($p > 0.05$).

Trend analyses further explained the significant main effect for primary task workload. The results indicate that alarm response time increased in a linear fashion as primary task workload increased, $F(1,121) = 47.48$, $p < 0.01$.

Next, an ANOVA determined whether response frequency changed as a function of primary task or secondary task workload. These results are shown in figure 7. The ANOVA revealed a significant interaction between primary and secondary task workload, $F(4,246) = 2.98$, $p < 0.05$. This interaction suggests that alarm response frequency decreases as primary task workload increases, but only for particular levels of secondary task workload. From figure 7, the interaction is most evident within the medium secondary workload condition. The main effect of primary task workload was also significant, $F(2,246) = 11.90$, $p < 0.01$, showing that as primary task workload increased response frequency decreased. Finally, the main effect of secondary task workload was significant, $F(2,123) = 3.28$, $p < 0.05$, indicating that as secondary task workload increased the number of alarm responses decreased (figure

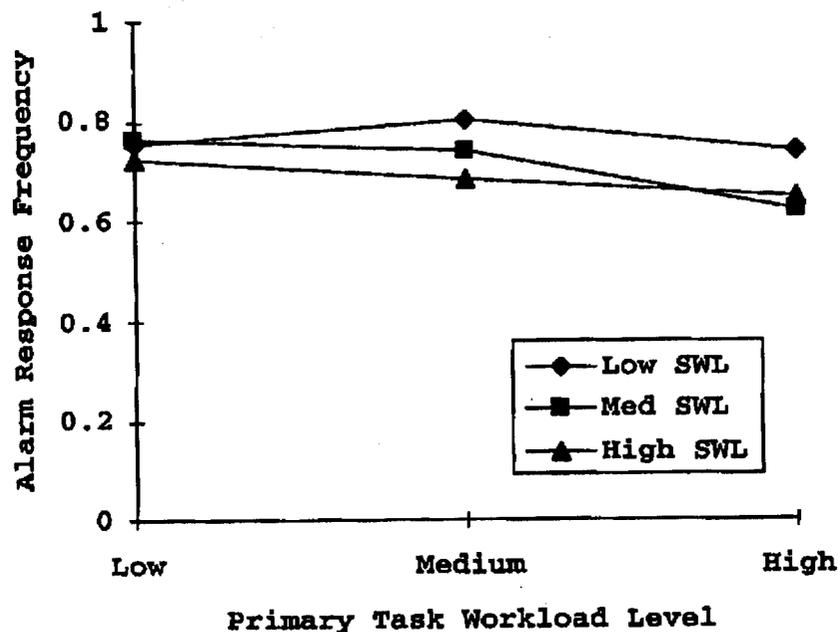


Figure 7. Alarm response frequency as a function of primary task (MAT Battery) and secondary task (alarm) workload level (SWL).

7). Also the frequency with which participants responded to alarms decreased in a linear fashion with increasing levels of primary task workload $F(1,123) = 16.45$, $p < 0.01$. There was also a significant quadratic trend, $F(1,123) = 5.76$, $p < 0.05$, suggesting that high levels of primary task workload were disproportionately taxing to alarm responders.

Next, an ANOVA was conducted using alarm response accuracy as a dependent variable. Neither the omnibus interaction nor the primary or secondary task workload main effects were significant at the $p = 0.05$ level.

Finally, the primary task tracking data were analyzed to investigate the effect of increasing primary task workload on tracking task performance. Figure 8 depicts the RMS tracking error as a function of primary and secondary task workload. While the main effect of primary task workload and the interaction of primary task workload and secondary task workload were not significant ($p > 0.05$), the main effect of secondary task workload was significant, $F(2,121) = 5.42$, $p < .01$. From figure 8 this indicates that tracking error increased as secondary task workload increased.

As noted by Bliss *et al.* (1995b), one useful technique for analyzing alarm response data is to determine the number of participants choosing to respond to either all or none of the alarms presented. In the current research, five participants responded to all alarms, while only one participant responded to none.

4. Discussion

The goal of this research was to investigate the interaction of primary and secondary task workload in a realistic alarm situation. Specifically, a dual-task performance

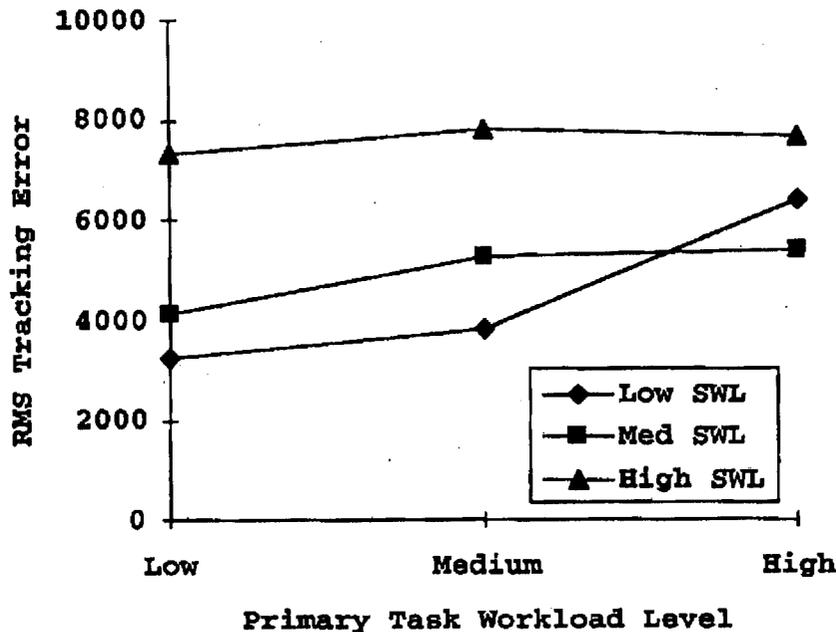


Figure 8. Primary tracking task error (RMS) as a function of primary task (MAT Battery) and secondary task (alarm) workload level (SWL).

situation was created where the secondary task consisted of reacting to alarms of questionable reliability. Empirical studies of the influence of workload are not new; the unique nature of this research is that the present workload investigation was conducted within the context of alarm mistrust. It would be of interest to know how varying levels of task workload might influence the behavioural manifestations of alarm mistrust (the cry-wolf effect).

4.1. Primary task workload and alarm response performance

In general, our hypotheses concerning alarm response performance and primary task workload were supported by the data. As primary task workload increased, alarm task performance became worse.

The lack of significance for alarm response accuracy, being the lone exception, was intriguing. Bliss *et al.* (1995b) used a dichotomous method of scoring accuracy (hit or miss), but the measure lacked sensitivity. Therefore, in the current research, another accuracy measure was developed based on screen pixels that (it was hoped) would prove more sensitive. However, once again accuracy measure was lacking.

Taken as a whole, the research to date suggests that response time and frequency may be more meaningful measures of performance than response accuracy. In addition to the increased sensitivity of response time and frequency, they are also ecologically valid measures of performance. In actual task performance situations, stressful conditions usually dictate that an operator's attention be diverted from the primary task to respond in a timely fashion. Such attention seems to be reflected well by response frequency and speed. The data from the current experiment indicated

that response time was significantly affected by primary task workload. This observation may be predicted by Lysaght *et al.*'s (1989) conceptualization of mental workload. According to them, workload should increase as the number and types of tasks increases. Therefore, as the workload of a primary task increases, performance of other tasks in the system will degrade.

In the present experiment, the workload level of the primary task increased as the number and types of tasks comprising the primary task being performed increased; therefore, attention to the secondary alarm decreased. The significance of the response time variable results from the fact that when primary task workload was high, participants focused on performance of that task so that responding to alarms was slower. With regard to alarm response frequency, our second hypothesis was also supported by the data. Response frequency decreased as a function of increasing primary task workload. The frequency of responding to alarms indicates a trust or mistrust of the alarm validity, which is an important tenet of the cry-wolf phenomenon. As has been noted by Breznitz (1983) and others, certain learning phenomena such as habituation may explain changes in response frequency.

According to Breznitz (1983), in an environment where repeated false alarms occur, the detector becomes habituated to the false alarms (familiar stimuli) so that when true alarms occur (novel stimuli) they are mistrusted. The detector then fails to respond to both true and false alarms.

In the current research participants were instructed that both the primary and secondary task were equally important. This line of instruction may have contributed to the habituation effect by making participants reluctant to divide attention between the two tasks since they also had the knowledge that a disproportionate percentage (40%) of the alarms was false. The reliability percentage coupled with the belief that the primary task performance was as important as alarm response performance may have contributed to a lack of attention to the alarms.

Another possible explanation for the alarm response frequency and reaction time data is that participants chose a performance strategy that included disregarding alarms in conditions of high primary task workload. This behaviour was noted with alarm response frequency in prior research (Bliss 1993). In that research, although many participants chose to match their response rates to the stated reliability rates, ~10% of respondents chose 'all-or-none' strategies where they responded either to all or none of the alarms. When questioned, they explained that the strategy was chosen to alleviate cognitive effort so that they could devote maximal attention to the primary task (Bliss 1993).

Although both explanations (habituation and purposeful strategy selection) make intuitive sense, it is difficult to determine their comparative validity from the available data.

4.2. Secondary task workload and alarm response performance

Although it had been hypothesized that response speed and accuracy would worsen as secondary task workload increased, the data failed to support these hypotheses. Wickens' (1992) multiple-resource theory may offer one explanation for the lack of support.

In this research the primary and secondary tasks required different resources; although both tasks required manual responses, the input and processing resources

for the two tasks differed. Wickens' (1992) theory suggests that the primary and secondary tasks may have been time-shared efficiently because of their different structures. Therefore, response times and accuracies were not affected by increasing workload levels because of the ability of participants to draw from different resource pools. This was especially true because of the redundant coding of alarm signals; participants could have chosen to process either the visual or auditory components of the alarms to minimize conflicts with the primary task stimuli.

Although there was no effect for response time or accuracy, alarm response frequency decreased as secondary task workload increased. This finding echoes prior research where response frequency had been shown to be a particularly sensitive measure of alarm trust (Bliss *et al.* 1995b). Theoretically, components of selective attention theory may effectively explain this outcome, as discussed below.

As Wickens (1992) notes, laboratory studies of optimal sampling involve presenting the participant with two or more channels along which events periodically may occur. Such studies have resulted in three conclusions that are applicable to the results in this research.

The first conclusion is that participants form a 'mental model' of the statistical features of the events in the environment. This model, which essentially is a set of expectancies about how frequently and when events will occur, determines the participant's sampling strategy. One example of this strategy is evident from prior alarm mistrust research (cf. Bliss *et al.* 1995a, b) where participants would match their response rates to the rate of true alarms in an alarm set. This response pattern resembles earlier research by Herrnstein (1961) concerning probability matching. In the current experiment, participant expectation that the alarms were 60% reliable affected the response patterns. Similar to Bliss *et al.*'s (1995a, b) work, participants closely matched the reliability rate given in the instructions (60% true alarms) and frequently overmatched (responded to >60% of alarms presented).

Second, Wickens (1992) noted that people tend to sample channels with high event rates more frequently than those with lower event rates. Therefore, participants should be expected to respond more frequently during high-workload sessions in which alarms activate more frequently. As noted from figure 7, this was true in the current research.

Third, preview information such as stated alarm reliability level may be a factor in the allocation of attention resources. When given preview information about future events, more optimal sampling performance occurs because an 'external model' (set of previewed events) is guiding response behaviour. However, Tulga and Sheridan (1980) found that as the number of channels (sources of stimuli) increased, people were less likely to use this external model because of a load on working memory. Therefore, the preliminary information on the reliability of the alarm system in this experiment may have had a smaller role as primary and secondary workload increased.

4.3. Implications for alarm system design

The objective of this research was to investigate the interaction of mental workload and the cry-wolf phenomenon. In addition to the theoretical conclusions noted above, there are several implications that may be drawn for those involved with alarm system design.

First, it has been shown that increased primary and secondary task workloads may compound the alarm response degradation resulting from low alarm system

reliability. This may be of importance to alarm designers concerned with sensory overload in operational environments (such as aircraft cockpits and nuclear control centres). Our research suggests that in situations where several tasks must be managed in addition to the alarm system, the reliability of the alarm system becomes more crucial. To address this problem, designers may want to limit the number and types of tasks to be performed in conjunction with the alarm response task, and regulate task duties accordingly.

To assist designers in this task, it may be beneficial to employ mental workload assessment techniques such as the modified Cooper-Harper scale (Wierwille and Casali 1983), SWAT (Reid *et al.* 1981), W/INDEX (North and Riley 1989) or NASA-TLX (Hart and Staveland 1988) in the early stages of alarm design testing. Such assessment should be further tempered by theories of human performance such as Wickens' (1992) multiple-resource theory. According to that theory, performance in multi-task environments improves when different resources are required for information exchange and processing. Hence, designers should be mindful of the various modalities for information input and output. Wickens (1992) points out that a system designer can assess the loading of human resources by a design in the early stages of the design process using task analysis techniques. Hart and Wickens (1990) found that the structural and demand characteristics of the multiple-resources model can be applied in determining either relative or absolute predictions of task interference and mental workload in a multiple-task situation.

One design strategy to account for increasing workload or decreasing alarm reliability may be to increase alarm activation leadtime. For example, if it is suspected that a given alarm system may generate alarms while operators are engaged with other tasks, the designer may adjust the activation criterion so that the alarm offers more decision time. Such a strategy may also aid designers to accommodate ongoing tasks of varying criticality levels (Bliss and McAbee 1995).

On a related point, the manipulation of secondary task workload in the present experiment may have implications for situations where multiple alarms increase workload. McDonald *et al.* (1995) noted that when multiple alarms activate, operators may cognitively associate them, even when there is no basis for such association. Also multiple alarm systems may bolster operator impressions of reliability, and may also increase mental workload. This is a fruitful area for continued research.

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