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MILITARY STANDARD

NICKEL-CADMIUM BATTERY USAGE PRACTICES FOR SPACE VEHICLES

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DEPARTMENT OF THE AIR FORCE
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Nickel-Cadmium Battery Usage Practices for Space Vehicles

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SECTION 1

SCOPE

1.1 PURPOSE

This standard establishes requirements for the storage, handling, and usage of nickel-cadmium batteries for space vehicle applications. Compliance with this standard is intended to assure proper performance of nickel-cadmium batteries and to provide protection against preflight degradation and premature degradation during operational use on space vehicles.

1.2 APPLICATION

This standard is intended for reference in applicable space vehicle specifications or other documents to incorporate common requirements and practices necessary to assure successful nickel-cadmium battery operation during space missions.

SECTION 2

REFERENCED DOCUMENTS

(Not applicable)

SECTION 3

DEFINITIONS

3.1 BATTERY

A battery for use on space vehicles is an assembly of battery cells electrically connected in series to provide the desired voltage. Generally, the cells are physically integrated into either a single assembly or into several separate assemblies connected in series. The battery may also include one or more attachments such as electrical bypass devices, heaters, strain gauges, temperature sensors, or thermal switches.

3.2 BATTERY CAPACITY (C)

The "nameplate" or "rated" nickel-cadmium battery capacity is denoted by C. It is the minimum number of ampere-hours that a battery, that has been charged at C/10 amperes for 16 $\pm$ 2 hours, is required to provide when discharged at C/2 amperes to an average cell voltage of 1.0 volts, at beginning of life (initial battery acceptance test). Both the C/10 charge and the C/2 discharge are with the battery at a stabilized ambient temperature of 22 $\pm$ 3 degrees C.

3.3 BATTERY CELL

A battery cell is a single unit device that transforms chemical energy into electrical energy at a characteristic voltage when discharged. Battery cells covered by this standard are hermetically sealed, contain nickel and cadmium electrodes, and have passed formal acceptance test requirements.

3.4 BATTERY CONDITIONING MODULE

A battery conditioning module is a ground support apparatus that performs the function of discharging a battery, through the battery main power connectors, or discharging individual battery cells, through a wiring harness connected to each of the battery cell terminals, at specified controlled discharge currents. A number of battery conditioning modules currently in use have the battery discharging as well as the charging function packaged in a single unit.

3.5 BATTERY SET

A battery set is the complete complement of two or more nickel-cadmium batteries installed in the same space vehicle.

3.6 CELL ACTIVATION

The addition of potassium hydroxide (KOH) electrolyte to the nickel cadmium cell during final assembly and test constitutes cell activation.

3.7 C/n CHARGE OR DISCHARGE CURRENT

The charge or discharge current for a battery is defined as C/n amperes where C is the rated battery capacity in ampere-hours and n is any value for elapsed time measured in hours. For example, a discharge current of C/2 for a 16 ampere-hour rated battery is a discharge current of 8 amperes.

3.8 COLD STORAGE

Cold storage for nickel-cadmium batteries that are not in use is long term storage where the temperature environment is controlled between -10 degrees C and +5 degrees C.

3.9 DEPTH OF DISCHARGE

The depth of discharge for a battery that has been charged at least to its rated capacity (C) is the ratio of capacity removed during discharge to the rated battery capacity (C) expressed as a percentage.

3.10 DESTRUCTIVE PHYSICAL ANALYSIS

Destructive physical analysis of a battery cell is a systematic, logical, detailed examination of the cell, including examination and measurement during various stages of physical disassembly, and subsequent chemical, electrochemical, and metallurgical analysis.

3.11 HIGH RATE CHARGE

A high rate charge current is the current sequence used to recharge a battery to its rated capacity.

3.12 INERT STORAGE

Inert storage is the maintenance of items, such as electrodes or unactivated cells, in a sealed chamber containing an inert atmosphere such as dry nitrogen. Usually an inert gas pressurizing system is used to maintain a positive pressure of approximately +125 millimeters vertical water column above ambient conditions. If an adequate purge is not provided, the seal integrity may be the most important feature, since the partial pressure of water vapor, or other contaminants, across the seal is independent of the internal pressure of the inert gas.

3.13 QUIESCENT PERIODS

Quiescent periods are the periods of time during either ground or on-orbit operations that a charged battery is not in active use, that is, it is not being discharged or recharged except for possible trickle charge.

3.14 RECHARGE RATIO

The recharge ratio for a battery is the number of ampere-hours returned to the battery by high rate charging, exclusive of trickle charge, divided by the number of ampere-hours removed from the battery during the preceding discharge.

3.15 RECONDITIONING

Reconditioning of a nickel-cadmium battery is a discharge-charge sequence intended to minimize degradation of the battery electrical performance. The process involves the discharge of the battery at a C/100 rate or less, to an average cell voltage of 1.0 volts or less. The subsequent charging process should be sufficient to restore the rated, or actual measured capacity, whichever is greater, and to compensate for charge inefficiency.

3.16 SHORTING PLUG

A shorting plug is a device that provides a current path across the terminals of each individual cell of a fully discharged nickel-cadmium battery in order to finally discharge all battery cells and maintain a shorted condition at the cell level. Shorting plugs are generally connected to an intermediate mating connector mounted on the battery case, or on the space vehicle structure, where the intermediate connector leads form a wiring harness that is in turn connected to each of the battery cell terminals.

3.17 STATE OF CHARGE

The state of charge of a battery that has been charged at least to its rated capacity, is the ratio of the rated battery capacity (C) minus capacity removed, to the rated battery capacity (C), expressed as a percentage. Thus, the state of charge is 100 percent minus the depth of discharge.

3.18 TRICKLE CHARGE

A trickle charge current is a low rate charging current usually used following a significantly higher charge current to offset open circuit stand losses that would occur in the absence of the lower rate trickle charge current.

SECTION 4

GENERAL REQUIREMENTS

4.1 BATTERY STORAGE AND HANDLING

The requirements set forth in this section and subsequent subsections, apply to the storage, handling, and operation of nickel-cadmium batteries during ground activities preceding launch. The organization of requirements generally follows the chronological order of events normally expected to occur from battery fabrication through launch.

Where practicable, inert storage for electrodes and unactivated cells shall be utilized prior to battery assembly, to minimize degradation. Following completion of assembly, batteries for operational use on a space vehicle shall successfully complete acceptance testing and then either be prepared for installation on the space vehicle or placed in a cold storage facility. Storage, handling, and conditioning shall be in accordance with practices that minimize preflight degradation.

4.1.1 Storage. Nickel-cadmium batteries that are not in use shall be placed in cold storage, whenever practicable, in a fully discharged state and shorted at the battery cell level with shorting plugs. Cold storage temperatures shall be maintained between -10 degrees C and +5 degrees C. In no instance shall a battery that is not in use remain outside of cold storage for a period exceeding 45 days.

Batteries not in use and not in cold storage, shall be stored inside a building under a controlled temperature environment between -10 degrees C and +25 degrees C, and whenever practicable, maintained in a fully discharged state and shorted at the battery cell level with shorting plugs.

Even if properly stored, batteries shall not be used for flight if the time between battery cell activation and launch exceeds three years (1095 days).

4.1.2 Battery Discharge and Shorting. The discharge of nickel-cadmium batteries to accommodate periods of nonuse, shall be accomplished with a battery conditioning module at the rate of C/10 amperes, or less, until 1.0 volt is achieved by any one cell, and then each cell discharged to a state of charge low enough to prevent cell voltage recovery from occurring prior to the installation of shorting plugs. Shorting plugs shall then be used for the purpose of maintaining a shorted condition across the terminals of each battery cell. The battery shall be maintained at 22 ± 3 degrees C during the discharge and shorting process.

4.1.3 Battery Conditioning Module. A battery conditioning module shall be used as specified herein to discharge a battery or individual battery cells at specified control rates. As a safety feature, devices shall be incorporated in the design of battery conditioning modules to accommodate the discharge of any battery charge, up to rated capacity, without causing any damage to the battery or space vehicle, including the prevention of any battery cell voltage reversals.

4.1.4 **Shorting Plugs**. Shorting plugs shall be used as specified herein to maintain a shorted condition across the terminals of each individual nickel-cadmium battery cell. As a safety feature, shorting plugs shall be designed to accommodate an inadvertent connection to a charged battery, up to its rated capacity, without causing any damage to any component of the battery or to the space vehicle. Shorting plugs shall also be designed to prevent any battery cell voltage reversals. To implement these safety features, shorting plugs shall incorporate heat dissipating resistors, fuses, circuit breakers, resistors, fuseable links, combinations of these, or other components. The design shall provide a means for verifying that any fuses or fuseable links have not opened, and that circuit breakers are in their correct positions.

4.1.5 Handling Fixture. A handling plate shall be used after the battery is assembled and prior to installation of the battery on the space vehicle. The handling plate shall protect from damage the battery bottom and any other structural or thermal interface of the battery with the space vehicle. The handling plate shall be removed when the battery is installed on the space vehicle.

4.1.6 Terminal Cover. An easily attachable and removable plastic cover shall protect the battery's terminal side after its assembly until just prior to its installation on the space vehicle. Optionally, the cover may remain in place for some or all of the space vehicle launch preparation, but shall be removed prior to launch.

4.1.7 Connector Saver. A connector saver shall be used during all testing prior to battery installation on the space vehicle to avoid repeated connecting and disconnecting of the flight connector. The connector saver shall interface between the battery flight connectors and any mating test or ground support equipment cables. The connector saver shall be removed just before storage or space vehicle installation.

4.1.8 Shipment to Space Vehicle Fabrication and Assembly Site. Nickel-cadmium batteries shall be transported from the battery manufacturers factory location to the space vehicle fabrication and assembly site in a fully discharged state and shorted at the battery cell level with shorting plugs. Batteries shall be maintained between -10 degrees C and +25 degrees C during handling and transportation.

4.1.9 Conditioning Prior to Installation On Space Vehicle. A battery conditioning module shall be used to initially condition a nickel-cadmium battery after removal from cold storage. The battery shall be charged at the rate of C/20 amperes for 40 ± 4 hours, and then discharged at the rate of C/2 amperes, or less, until 1.0 volt is achieved by any one battery cell. Each battery cell shall then be fully discharged until a specified low level cell voltage is attained (usually a value between 10 and 100 millivolts per cell). The battery temperature shall be maintained at 22 ± 3 degrees C during the initial conditioning process.

Before the installation of a nickel-cadmium battery on a space vehicle is allowed to proceed, the battery must undergo one or more operational charge-discharge cycles to verify the capability of meeting battery specification operating and capacity requirements. With the use of a battery conditioning module, the battery shall be charged at the rate of C/10 amperes, and then discharged at the rate of C/2 amperes, until a specified cell voltage is achieved (generally about 1.0 volt per cell). The battery temperature shall be maintained at 22 ± 3 degrees C during operational charge-discharge cycling.

4.1.10 Acceptance Testing of Space Vehicle. To maximize on-orbit performance, the actual batteries to be used for flight shall not be installed or used for space vehicle level integration or acceptance tests at the space vehicle fabrication and assembly site, except as may be necessary for nonoperational tests such as spin balance. Test batteries that are equivalent in configuration to the flight batteries, and that have passed battery flight level acceptance tests, shall be used for space vehicle level integration and acceptance testing.

4.1.11 Transportation to Launch Site. Flight batteries may be installed in the space vehicle before it is shipped to the launch site or they may be shipped separately and installed at the launch site. In either case, the batteries shall be shipped in a fully discharged state and shorted at the cell level with shorting plugs. Vibration and shock loads during handling, transportation and installation shall not exceed the levels specified in the detailed battery specification. Batteries shall be maintained between -10 degrees C and +25 degrees C, if it is practicable to do so, during handling, transportation and installation. In no case shall the upper temperature limit for a battery exceed +30 degrees C during handling, transportation and installation. The battery temperature environment shall be continually monitored and recorded during transportation.

4.1.12 Quiescent Periods. During ground operation quiescent periods, a nickel-cadmium battery installed on a space vehicle shall be maintained in the trickle charged or the fully discharged and shorted at the cell level condition whenever practicable. The quiescent time period when a charged battery is open circuited shall be minimized in number and duration. In no case shall quiescent periods exceed 96 hours for a charged battery without initiating trickle charging or discharging the battery and shorting each individual cell. Battery temperatures shall be maintained between -10 degrees C and +25 degrees C during quiescent periods.

4.1.13 Installed Battery Discharge and Shorting. The discharge of nickel-cadmium batteries installed on a space vehicle to accommodate quiescent periods during ground operations, shall be accomplished with a battery conditioning module at a specified rate not to exceed C/2 amperes, until any one battery cell reaches 1.0 volt, and then each battery cell discharged to a state of charge low enough to prevent cell voltage recovery from occurring prior to the installation of shorting plugs. Shorting plugs shall then be used for the purpose of maintaining a shorted condition across the terminals of each battery cell. The battery shall be maintained at 22 ± 3 degrees C during the discharge and shorting process.

4.1.14 Cumulative Open Circuit Time. The number and duration of periods when a nickel-cadmium battery is open circuited shall be minimized when the battery is not in use or quiescent. The total open circuit time accumulated on a flight battery during nonuse and quiescent periods shall not exceed 20 days during ground operations.

4.1.15 Reconditioning. Flight batteries that are not in storage shall be reconditioned every 45 ± 3 days. For space vehicles launched by an expendable launch vehicle, the flight batteries shall be reconditioned within the 30 day period immediately preceding the launch. For space vehicles launched by the Space Transportation System, the flight batteries shall be reconditioned within the 30 day period immediately preceding space vehicle placement into the cargo bay.

4.1.16 Records. Records documenting the flight accreditation status of batteries shall be maintained. These records shall provide traceability from production of the battery, through final installation in the space vehicle, and on through to launch. The records shall indicate changes in battery location, status, use, or any conditions that could affect reliability or performance. Time-correlated records shall be maintained indicating battery charge or discharge current, battery voltage, and temperature to a sufficient accuracy to allow an assessment of potential degradation.

4.1.17 Not for Flight Marking. Batteries, the cells of which have been activated over three years (1095 days), or which by intent, by usage, or by material disposition are not suitable for use in flight, and which could be accidentally substituted for flight or flight spare hardware, shall be red tagged or striped with red paint, or both, to prevent such substitution. The red tag shall be conspicuous and marked "NOT FOR FLIGHT." The red paint shall be material compatible and the stripes unmistakable.

4.2. ON-ORBIT OPERATIONS

4.2.1 Charge Control. Normal battery charging and control procedures, and contingency procedures, shall be prepared based upon test data obtained during vehicle and battery development testing (see 4.3) and the requirements stated herein. These documented procedures shall be the basis for battery operations and controls while on orbit.

4.2.2 Amount of Recharge. High rate battery charging shall be controlled so as to return the amount of capacity which has been discharged plus an additional amount to compensate for charge inefficiency. Provisions shall exist for increasing and for decreasing the recharge ratio automatically, by ground command, or both.

4.2.3 Charge Current. Charge current shall be regulated consistent with battery operating temperature, battery charge voltage limits, time available for recharging, and charging source capability. Overcharging at a high rate shall be minimized.

4.2.4 Trickle Charging. When the amount of recharge requirements have been satisfied, battery charging is considered complete and the battery shall be maintained in trickle charge until its next discharge, orbit permitting. The trickle charge current shall be at a rate sufficient to maintain the capacity achieved by the high rate charging.

4.2.5 Reconditioning. Reconditioning shall be performed periodically, orbit permitting, from the onset of the mission. For space vehicles in geosynchronous orbits, reconditioning shall be performed prior to every eclipse season, once the space vehicle is on station. For space vehicles in other orbits, reconditioning shall be performed on a regular basis, depending upon orbit.

4.2.6 Quiescent Periods. During on-orbit quiescent periods, the battery shall be trickle charged, orbit permitting. The trickle charge current shall be at a rate sufficient to maintain the existing battery capacity.

4.2.7 Depth of Discharge and Cycle Limits. Battery depth of discharge and number of cycles during the mission shall be no greater than warranted by available data germane to the battery design and the mission. The number of cycles is defined as the number of charge-discharge sequences predicted for eclipse and other operations during the complete orbital lifetime.

4.2.8 Temperature. Battery temperatures throughout the orbital lifetime shall be maintained in the range 0 degrees C to +10 degrees C, with excursions beyond these limits minimized.

4.2.9 Overtemperature Backup Protection. Backup protection against battery overheating shall be provided in the form of switching that reduces or terminates charging. Charge current to a battery shall be automatically reduced or terminated if the temperature of that battery reaches +32 degrees C.

4.2.10 Battery Monitoring. Battery voltage, including individual cell voltage, current, and temperature shall be monitored periodically during flight, including during battery reconditioning and eclipse operations. These data, together with depth of discharge performance, shall be summarized and evaluated to provide performance predictions for on-orbit operations.

4.2.11 Battery Isolation. If on-orbit conditions warrant, either the battery charge circuits, or the space vehicle load circuits, or both, shall be switched by command to provide electrical isolation from the battery.

4.3. DEVELOPMENT TESTING

Development testing shall be conducted on new battery designs for each application. Development testing shall also be conducted on existing battery designs for each new supplier, for each new application, and when changes are incorporated. The development tests specified herein are not inclusive of all tests that should be conducted during battery and space vehicle development, but the tests that are included in this standard have a close relationship to battery usage practices. The following development tests shall be conducted to evaluate the batteries under the operating conditions that will exist when redundant batteries in the battery set have failed and been removed from the circuit, as well as in the no failure case.

4.3.1 Charge Control Development. Testing of the battery shall be performed to determine the minimum recharge ratio that will provide a full charge under the conditions of intended operational use in the space vehicle. Control parameters to be used, such as battery voltage and battery temperature, shall be characterized for a flight-type battery sufficiently to permit a charge control design that will meet the requirements for vehicle operations including contingencies. Third electrode cells, coulomb meter cells, or a single temperature set point shall not be used as the basis for primary charge control.

4.3.2 Life Tests. Life testing is intended to develop and demonstrate the required charge control procedures to ensure necessary battery orbital lifetime. Real time life tests shall be performed on a sufficient number of battery cells to permit annual removal of at least one cell from the life test group for destructive physical analysis over the duration of the real time life test. The number of cells in the life test group shall be sufficiently large so that all of the cells are not sacrificed to destructive physical analysis during the test period. The destructive physical analysis data shall be used to evaluate battery cell degradation with time and usage and to predict cell degradation as a function of mission duration. Life tests shall also be performed on previously acceptance tested, flight-type batteries operating under the electrical and environmental conditions expected during operational use in the space vehicle. Battery temperatures shall be measured at intervals adequate to characterize the battery thermal profile for the mission. These tests shall demonstrate that flight batteries can meet their on-orbit performance requirements for the required mission life. These tests shall accurately simulate charge and discharge periods and reconditioning shall be included as planned for the mission.

4.3.3 Vehicle Thermal Vacuum Testing. Flight type batteries shall be installed and operated during space vehicle thermal vacuum testing. Temperatures on and around the batteries shall be monitored during the thermal cycling of the vehicle such that analytical simulations of battery heat transfer can be validated. These tests may be conducted as part of the vehicle thermal balance testing or vehicle qualification testing.

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