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Lithium Sulfur Dioxide Batteries Used in Aircraft; Technical Standard Order Authorization; Airworthiness Directive

FS-78-129-T

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Part 37

[Docket No. 18889; Amendment 37-44]

Lithium Sulfur Dioxide Batteries TSO-C97; Technical Standard Order Authorization

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Final rule.

SUMMARY: This amendment adopts a new Technical Standard Order (TSO) that sets forth standards for Lithium Sulfur Dioxide ($LiSO_2$) batteries used in aircraft. The new standards are established to reduce or eliminate failures of equipment incorporating the batteries due to corrosion, venting violently, and explosion of the batteries and the leakage of harmful gases into occupied areas of aircraft.

EFFECTIVE DATE: September 26, 1979.

FOR FURTHER INFORMATION CONTACT: Mr. Adolfo O. Astorga, Systems Branch, Aircraft Engineering Division, Office of Airworthiness, Federal Aviation Administration, 800 Independence Avenue, S.W., Washington, D.C. 20591; Telephone (202) 426-8395.

SUPPLEMENTARY INFORMATION:

Background

$LiSO_2$ batteries have been used primarily in general aviation Emergency Locator Transmitters (ELT's) and to a limited degree in various air carrier aircraft safety equipment. The use of this type of battery has been promoted because it has a longer shelf life and can be used at lower operating temperatures than other batteries. However, $LiSO_2$ batteries have vented violently, exploded and leaked harmful gases which have incapacitated pilots and corroded other equipment and airframe structures.

To provide information to the public on this subject, the FAA issued Advisory Circular AC No. 20-91 on April 11, 1975, "Lithium Batteries Used in Emergency Locator Transmitters," which warned of the possible hazards associated with the use of $LiSO_2$ batteries. Also, four Airworthiness Directives (AD's) numbers 74-20-10 (Amendment 39-1976, 39 FR 34513), as amended, 74-02-07 (Amendment 39-2021, 39 FR 40919), as amended 79-05-02 (Amendment 39-3422, 44 FR 10980), and 79-18-05 (Amendment 39-3549, published in this issue of the **Federal Register**) have been issued relating the use of $LiSO_2$ batteries. Amendments 39-1976 and 39-20-21 required design changes and periodic inspections of certain $LiSO_2$ batteries. Amendment 39-3422 required removal of all $LiSO_2$ batteries and ELT's powered by $LiSO_2$ batteries from U.S.-registered civil aircraft. Amendment 39-3549 requires either reinstallation of ELT's powered by $LiSO_2$ batteries which meet new standards or installation of another ELT powered by another source. The last AD continues to require the removal from aircraft of any $LiSO_2$ batteries which do not meet the new standards and any ELT's powered by such batteries, and it extends the period of time in which aircraft, from which an ELT has been removed to comply with the AD's, may be operated without the required ELT. It also allows the use of $LiSO_2$ batteries which meet the new standard in other equipment.

At this time, if no further action were to be taken, the public would be deprived of the benefit of using $LiSO_2$ batteries which provide for operation of ELT's to temperatures below $-40°C$. Over 95 percent of the $LiSO_2$ battery usage in aircraft is in ELT's. Other batteries do not operate effectively below $-20°C$, and their use would have a detrimental effect on search and rescue (SAR) operations for downed aircraft. While the ELT is only one of the devices and techniques available to SAR forces, it continues to provide a unique and valuable means of locating crash sites. Thus, SAR forces and the National Transportation Safety Board are strongly encouraging the use of $LiSO_2$ batteries. Their main rationale for this position is the existence of large portions of the U.S. which experience temperatures below $-20°C$. Below $-20°C$, $LiSO_2$ batteries continue to operate where many other batteries cease to function.

To provide for the availability of safe $LiSO_2$ batteries, the FAA has determined it necessary to issue performance and environmental standards for such batteries. The standards adopted herein are based on Notice No. 79-8, published in the **Federal Register** on March 26, 1979 (44 FR 18038).

Interested persons have been afforded an opportunity to participate in the making of this amendment and due consideration has been given to all matter presented. A number of substantive changes and changes of an editorial and clarifying nature have been made to the proposed rules based upon relevant comments received and upon further review within the FAA. Except for minor editorial and clarifying changes and the substantive changes discussed below, this amendment and the reasons for it are the same as those contained in Notice No. 79-8.

Discussion of General Comments

Seventeen individual sets of comments were received in response to Notice No. 79-8. All of these were in general agreement with the overall scope and intent of the notice. Three commenters supported the proposal without specific comments. The other commenters suggested various changes and clarifications.

One commenter recommended that the use of nonlithium batteries be required in all aircraft applications. The FAA disagrees. $LiSO_2$ batteries have performance capabilities superior to other electrochemical power sources. The final decision whether to use a $LiSO_2$ battery must be left to the consumer as long as safe cells can be made available.

One commenter recommended that the requirement that Emergency Locator Transmitters (ELT's) be carried on aircraft should be eliminated. The FAA disagrees. According to data collected by the U.S. Air Force, ELT's perform a useful function in saving many lives each year, and they significantly reduce search and rescue time. It should be noted that the ELT requirement is mandated by public law, and the FAA does not have the legal authority to repeal this requirement.

Numerous commenters suggested editorial changes to clarify requirements or to remove perceived inconsistencies in the proposed standard. Based on these comments and after further review, the FAA has made a number of editorial changes of non-substantive nature. In response to several other suggestions that guidance material be provided, an Appendix B is added to provide the detailed test procedures for conduct of tests required by this standard. In addition, in light of the comments received, the FAA has reconsidered the usage of the terms "cell" and "battery" in the standard and has made changes to assure that these terms are consistent with the intent of the test requirements.

Discussion of Specific Comments to § 37.209

§ 37.209(a)

One commenter objected to the term "minimum performance standards" in proposed § 37.209(a) and recommended that the term be replaced with "minimum safety standards." However, the term "performance" in connection with technical standard orders is intended to be broader than "safety".

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Safety is not the only consideration in the use of $LiSO_2$ batteries. The majority of $LiSO_2$ battery applications is in ELT's where performance under extreme environmental conditions is also important. In this context, the performance standards are necessarily safety standards. Accordingly, § 37.209(a) is adopted without substantive change.

§ 37.209(b)

One commenter objected to the requirements in proposed § 37.209(b), to mark each battery with the date it will reach 50 percent of its useful life. It was indicated that this requirement, in combination with § 37.200(g)(2) for ELT's, would put an unfair restriction on the use of $LiSO_2$ batteries by limiting the useful life to 25 percent of the shelf life. The FAA agrees and § 37.209(b) has been changed to require that each battery be marked with the date on which it must be replaced.

In response to another comment, the date marking requirements of § 37.209(b) apply only to batteries and not to cells. The marking requirement is clearly stated in this regard.

Two commenters recommended in effect that the caution statement be broadened to allow other wording. However, while FAA recognizes that there may be other ways to word the caution statement, the standardized statement covering essential specifics is retained. Discussions held during a meeting of the Lithium Battery Safety Working Group of the Joint Logisitics Chiefs Sub-Panel for Batteries and Fuel Cells indicated prolonged temperatures above 70°C will lead to significantly shorter life and possible chemical destabilization of $LiSO_2$ batteries. To clarify the caution statement, the words "high temperature" have been replaced with the words "temperatures above 70°C (158°F)."

§ 37.209(c)

One commenter requested clarification of the term "battery limitations" as used in proposed § 37.209(c)(1). Specific examples are maximum current, special shipping requirements, and maximum exposure temperature; however, since it is not possible to identify all such limitations they are not listed in the rule.

One commenter questioned whether proposed § 37.209(c)(2) should be directed toward the end equipment manufacturer rather than the battery supplier. However, it is the responsibility of the battery manufacturer to determine how its product is to be used. One way to do this is by carefully controlling the battery configuration. This requirement merely requires that the battery manufacturer supply basic data to the equipment manufacturer. Accordingly, § 37.209(c)(2) is adopted without substantive change.

No comments were received on proposed § 37.209(c)(3), and the section is adopted as proposed.

Several commenters questioned the need for the process specifications that must be furnished to the FAA in proposed § 37.209(c)(4). This requirement is needed to verify that the battery on the drawings is the one tested and the one produced. However, it should be noted that the FAA may allow the data to be maintained at the manufacturer's facility. Another commentor requested clarification of what the FAA would require as process specifications. Section 37.209(c)(4), as adopted, has been clarified by including more details on the data requirements.

One commenter requested verification that cell life and battery life data would not form part of data required under proposed § 37.209(c)(5). That understanding is correct. However, the manufacturer may wish to include such data since battery capacity under differing environmental conditions and loads is important data if equipment manufacturers are to properly employ these batteries. Section 37.209(c)(5) is adopted without substantive change.

§ 37.209(d)

One commenter stated that the data and information specified in § 37.209(c)(5), as required in proposed § 37.209(d), is superfluous and should be deleted. The FAA does not agree. Another commenter recommended that this data be made available upon request of the user. The required data must be supplied to the person receiving for use one or more cells manufactured under this TSO to ensure proper utilization of $LiSO_2$ batteries.

In light of the comments received, and upon further consideration, the FAA has concluded that cells that vent during any of the conditions specified in tests required by the Federal Aviation Administration Standard, Lithium Sulfur Dioxide Batteries, except those of § 3.7, may be allowed to be used, provided that data on these cells are furnished to the equipment manufacturer for designing for containment in the event of an explosion and for venting of gaseous products. Section 37.209(d) has been changed accordingly.

Comments to the Federal Aviation Administration Standard, Lithium Sulfur Dioxide Batteries

§ 1.0—General

No comments were received on proposed § 1.0, and this section is adopted as proposed.

§ 2.1—Cell Isolation

One commenter suggested that a sentence be added to proposed § 2.1 to require battery protection against shorting due to rubbing and chafing. The FAA does not agree that such a provision is necessary since the vibration and shock tests required by the TSO would show up mechanical faults in the battery design.

One commenter suggested that if it were demonstrated that charging currents did not lead to a hazardous condition, charging currents should be allowed. The FAA does not agree. This condition is virtually impossible to demonstrate. Factors such as age of cell, vibration, and temperature may have played a role in the recent failures of $LiSO_2$ cells. Furthermore, information in a National Aeronautics and Space Administration (NASA) Report on a workshop held at Goddard Space Flight Center, November 15–17, 1977, (NASA Conference Publication 2041) shows that reverse charging of cells can lead to explosions.

Two commenters suggested that the requirements for cell isolation be revised to make it clear that each cell must be protected. In addition, one commenter suggested that cells that have charging voltages less than one cell's nominal open circuit voltage are harmless. Another commenter suggested revising the cell isolation requirement to allow cells to be used in series. The FAA agrees with all these coments and FAA has determined that when four or less cells are connected in series, there is insufficient energy to cause one cell to go into reversal and that a shunt diode is required when five or more cells are connected in series. Section 2.1 has been revised to incorporate these provisions.

§ 2.2—Cell Connection

One commenter recommended that the type of cell connection in a multicell battery should be left to the manufacturer citing, as an example, the satisfactory performance of pressure contacts in a flashlight. The FAA does not agree. The majority of $LiSO_2$ batteries are used in ELT's, and they are normally located in areas of the aircraft that are not easily accessible; therefore, the condition of these batteries is not checked before each flight. In addition, the aircraft operates in an environment

more severe than that to which most flashlights are exposed. Furthermore, pressure contacts are more prone to increase resistance as a result of corrosion. Accordingly, § 2.2 is adopted without substantive change.

§ *2.3—Safety Relief*

One commenter pointed out that any venting of a $LiSO_2$ cell would release SO_2 and acetonitrile, though not in toxic concentrations. It was stated that concentrations of SO_2 would only be unpleasant. The FAA does not agree. Threshold toxicity of SO_2 is 5 ppm. Six to 12 ppm of SO_2 causes immediate irritation to the eyes, nose, throat, and lungs. Fifty to 100 ppm of SO_2 is the maximum permissible concentration for exposures of 30 to 60 minutes. This concentration may cause respiratory paralysis. Four hundred to 500 ppm of SO_2 is an immediate danger to life. The data in Garrett Manufacturing Limited Report No. 75C3053, Revision A indicates that in a small general aviation aircraft, 13 to 14 minute concentrations of over 50 ppm would be encountered if one "C" cell vented. Peak concentrations of over 170 ppm of SO_2 would be experienced. In addition, laboratory evaluation of products formed during a venting uncovered the presence of hydrogen cyanide. This is highly toxic in small concentrations. While the SO_2 may not reach fatal levels, it can and has reached levels where a pilot has been incapacitated.

One commenter suggested that the safety relief should operate well below the melting point of lithium (186°C). The FAA agrees and based on the performance of existing designs, the maximum temperature for safety relief operation has been changed to 130°C.

One commenter recommended that button cells be exempted from the requirement to have a safety relief, since button cells do not have sufficient energy to rupture the cell case. The FAA does not agree. Since no supporting data was submitted, the FAA has no basis on which to exempt button cells at the present time.

One commenter recommended that proposed § 2.3 be divided into two parts; one would cover operation of the safety relief, the other discharge of toxic substances. The commenter also recommended that if a cell vented during any of the tests prescribed, then overboard venting should be allowed. The FAA agrees and § 2.3 has been revised consistent with the recommendations.

§ *2.4—Encapsulation*

Several commenters questioned the prohibition of encapsulating the battery. It was recommended that encapsulation should be allowed if it did not prevent proper functioning of the safety relief. The FAA agrees, provided that the encapsulation material does not cause the battery to overheat. Accordingly, § 2.4 is adopted with these changes. In this connection, test requirements, § § T-2 and T-3, have been added to new Appendix B to test for any effects encapsulation may have on the battery.

§ *2.5—Seal*

Several commenters recommended that a test procedure be provided to verify the performance of a hermetic seal. The FAA agrees. Section T-4 has been added to Appendix B of this standard for that purpose. As suggested by another commenter, a definition of hermetic seal has been added to Appendix A of this standard. To further clarify the definition, a specific weight loss limit has been added to § 2.5 to account for moisture losses due to the high temperatures of this test.

§ *2.6—Fuse-Protection*

Several commenters recommended that the fuse location relative to the battery case be more clearly defined. The FAA agrees. The intent was that the fuse, for a battery of one or more cells, would be within the battery container, but external to the cell.

Several other commenters suggested that fuse protection was not necessary for some batteries. The FAA does not agree. Service Difficulty Reports indicate that the venting violently and explosion associated with $LiSO_2$ batteries are time related, and fusing is one way to protect batteries over long time periods.

A number of commenters suggested that the proposed current limiting device of 150 milliamperes for the battery discharge was not appropriate for all batteries. The commenters also suggested that the rating of the device should be related to the ampere rate at which the batteries are tested in other sections of the standard. Finally, one commenter recommended changing the section title to "Current Limiting Protection". The FAA agrees. Section 2.6 as adopted, incorporates the recommended changes.

§ *2.7—Voltage-Life*

Several commenters stated that the proposed voltage life characteristics requirements in § 2.7 should be eliminated because the requirement is not meaningful without specifying the rate of discharge which is dependent on the battery application. The FAA agrees and proposed § 2.7 is withdrawn.

§ *2.8—Useful Life*

Two commenters stated that the 60°C proposed in § 2.8 for storage is an unrealistic environmental condition, while another commenter suggested a temperature of 24°C. The objective of this requirement is to model actual average environmental conditions. Ideally, the temperature would vary with time of day and throughout the year. As this is not practical, a compromise temperature between the extremes is sought. Therefore, 40°C is adopted as a more realistic environmental condition. To compensate for this higher than the suggested 24°C temperature, the useful life is increased to 4 years. Another commenter suggested that proposed § 2.8 be made a storage survivability test. However, to change the requirement and make it a storage survivability test misses the intent of the requirement. The problems associated with $LiSO_2$ batteries may be time related, and thus it is the FAA's intent to limit the life of $LiSO_2$ batteries until the batteries can be proven to be safe beyond the useful life.

In answer to the question of one commenter, the useful life of the battery begins on the date of manufacture. Several commenters requested a definition of useful life. To clarify the term "useful life," § T-5 of Appendix B has been added to provide a method to determine the useful life of batteries.

One commenter believed that there is a conflict between the useful life of the battery as defined in proposed § 2.8 and as defined in FAR § 37.200(g)(2) concerning ELT's. The FAA sees no conflict since the data furnished by the ELT transmitter manufacturer must be based on the data furnished by the battery manufacturer. With the changes discussed, § 2.8 is adopted and redesignated as § 2.7

§ *2.9—Transient Response*

Several commenters stated that the proposed transient response requirement in § 2.9 should be eliminated because the requirement is unattainable or not practicable to meet. The FAA agrees, and proposed § 2.9 is withdrawn.

§ *2.10—Examination of Product*

No comments were received on the proposed § 2.10. Accordingly, this section is adopted without substantive change and redesignated as § 2.8.

§ *2.11.1—Open Circuit Voltage*

One commenter suggested that a minimum standard of 2.9 volts per cell be utilized as the specified minimum

open circuit voltage in proposed § 2.11.1. The FAA does not agree. The objective of this test is to determine variations in cell voltage that cause charging currents. Several commenters recommended that ±5 or ±10 percent be used instead of the proposed ±2.5 percent for open circuit voltage. The FAA agrees. The value ±5 percent is more readily obtainable without compromising the objective of the test. One commenter suggested that a definition for the term "nominal" be provided in the proposed requirement. The term "nominal" as used in the proposed requirement is not needed because the tolerance in the requirement allows for an approximation. Accordingly, § 2.11.1 is adopted with the changes noted, and redesignated as § 2.9.

§ *2.11.2—Voltage Under Constant Load*

Two commenters stated that the proposed voltage under constant load requirements in § 2.11.2 are not meaningful and the intent of the requirements is not clear. Other commenters recommended that proposed § 2.11.2 be deleted because the requirements are dependent on the battery application. The FAA agrees, and proposed § 2.11.2 is withdrawn.

§ *2.12—Capacity*

Two commenters recommended that minimum capacity be established for each battery application. The FAA does not agree since it cannot be predicted what future applications will be made and variation in cell capacity can affect the safety of $LiSO_2$ batteries. Several commenters stated that the proposed "±2.5 percent" variation in cell capacity is not realistic and is too restrictive, and some recommended that "±10 percent" be used. The FAA agrees. Another commenter recommended that cell capacity be measured only down to a cell voltage of 2.0 volts. However, there are certain battery applications, as for example in ELT's, where the battery may be required to be completely discharged. One commenter suggested that capacity be clarified. This is accomplished by the addition of § T-6 to Appendix B of this standard. Accordingly, proposed § 2.12 is adopted with the changes discussed, and redesignated as § 2.10.

§ *3.1—Effects of Test*

One commenter suggested that exceptions, §§ 3.6, 3.9, 3.11, and 3.12 be added to those already listed. Based on these comments and upon further review the FAA has determined that only tests which may involve destruction of the cell should be listed as exceptions. Therefore, this section is revised to include as exceptions §§ 3.6, 3.7, 3.8, 3.9, and 3.10. Another commenter recommended that the tests should be performed in a specific sequence in order to reduce the time and expense in demonstrating compliance to the standard. The FAA has determined that specifying a testing sequence would reduce time and expense in demonstrating compliance to the standard. Accordingly, proposed § 3.1 is adopted with the changes discussed above and retitled "General".

§ *3.2—Shock Test*

One commenter recommended the use of a military standard procedure instead of the procedure proposed in § 3.2 for the shock test. Several commentators believe that the test conditions are too severe and unrealistic and should be changed. The FAA does not agree. Batteries that meet this standard will primarily be used to power ELT's and the shock test requirements for the batteries should be compatible with the shock test requirement for ELT's. Two commenters recommended that the shock test be performed on the battery rather than individual cells since this would simultaneously evaluate the cell, intercell connections, insulation, fuse, and battery configuration to shock conditions. The FAA agrees. Furthermore, the FAA has determined that it is not necessary for the cell to meet the examination of product requirements (proposed § 2.10), voltage requirements (proposed § 2.11), and capacity requirements (proposed § 2.12) following application of the shocks as proposed. Deletion of these 3 requirements from § 3.2 will reduce the time and expense in demonstrating compliance to the standard. The same considerations apply with respect to the vibration test of § 3.3, the temperature cycle test of § 3.4, and the altitude test of § 3.5 and the post-test requirements are deleted also from these sections. Proposed § 3.2 is adopted with the changes discussed above.

§ *3.3—Vibration Test*

Two commenters recommended the use of a military test procedure instead of the test procedure proposed in § 3.3. One of the commenters suggested increasing the acceleration requirement from "7G" to "40G". The FAA does not agree. The proposed test ensures compatability with the test procedure for ELT's which is the equipment that will primarily use batteries meeting this standard. Several commenters recommended that the proposed test be performed on assembled batteries rather than on each cell as proposed. The FAA agrees. One commenter stated that if this applied to a battery, then the battery should only be tested as part of the equipment that it is used in. However, this does not follow since the battery test demonstrates the integrity of the battery, while the equipment test demonstrates the integrity of the combination of the two items. One commenter stated that the shock and vibration tests are not compatible because the methods for securing the batteries during the tests are not the same. However, no reason has been given for requiring that the means for securing the batteries during the shock and vibration tests need to be the same. Accordingly, proposed § 3.3 is adopted with the change to make it applicable to assembled batteries and to delete the post test requirements as discussed under § 3.2.

§ *3.4—Temperature Cycle Test*

One commenter recommended that U.S. Military Standard 810C Method 503.1 be used for the test in place of the requirements proposed in § 3.4. The FAA does not agree. The proposed temperature test is more severe and it is considered essential for the intended application of $LiSO_2$ batteries. One commenter questioned how the battery would be tested for leakage after completion of the test proposed in § 3.4. A test procedure is added to Appendix B under § T-4 to test for leakage. One commenter recommended that multiple temperature cycling be required to determine the effectiveness of the seal. The FAA agrees. Temperature cycling more closely models actual environmental conditions. One commenter suggested specifying how the battery would be returned from the high temperature to room temperature, and that proposed § 3.4 should be made consistent with other sections in the standard. The FAA agrees. The proposed temperature cycle test as adopted specifies that information. For a discussion of the deletion of §§ 2.10, 2.11, and 2.12 referenced in § 3.4, see the discussion on § 3.2. Accordingly, proposed § 3.4 is adopted with the changes discussed above.

§ *3.5—Altitude Test*

One commenter suggested that U.S. Military Standard 810C Method 504.1 be used for the test, instead of the requirement proposed in § 3.5. The FAA does not agree. The suggested requirement is not appropriate. One commenter recommended, for clarity, replacing the term "exhibit leakage" with the term "examined and tested for leakage." The FAA agrees; however, the requirement to test for leakage is relocated to § 3.6 in the standard. One

commenter stated that the temperature, altitude, and time requirements proposed are not realistic. However, the purpose of the test is to evaluate the integrity of the hermetic seal in low atmospheric pressure under accelerated conditions. For a discussion of the deletion of §§ 2.10, 2.11, and 2.12 referenced in §3.5, see the discussion on § 3.2. Accordingly, proposed §3.5 is adopted with the change discussed above.

§ 3.6.1—Verification of Vent Operation

One commenter stated that since SO_2 gas is toxic, no $LiSO_2$ battery could meet the requirement proposed in §3.6.1. The intent of this requirement is not to eliminate the use of $LiSO_2$ batteries, but to require verification of vent operation performance. One commenter recommended that the proposed requirements not be applied to button cells. The FAA does not agree. As previously discussed, all cells are required to have a vent. One commenter recommended that this test be performed only on a cell and not on the battery. The FAA agrees that the requirements are more appropriate for the cell.

The substance of proposed § 3.6.1 with clarifying changes and with the change discussed above are incorporated in § T-1 of Appendix B of this standard. Therefore, proposed § 3.6.1 is withdrawn. The requirement for a hotplate in proposed § 3.6.1 has been replaced in § T-1 of Appendix B of this standard with electric heating tape.

§ 3.6.2—Open Flame Test

Several commenters stated that the proposed open flame test in § 3.6.2 could not be met because the flash point of acetonitrile (one of the electrolite components of $LiSO_2$ batteries) is below the proposed flame test temperature. Upon further review, the FAA is withdrawing proposed § 3.6.2.

§ 3.7—Cell Deformation Test

One commenter stated that the proposed cell deformation test in § 3.7 should be eliminated because it does not simulate an internal short circuit which is the intent of the test. The FAA agrees, and proposed § 3.7 is withdrawn.

§ 3.8—Accelerated Life Test

One commenter suggested deleting the accelerated life test because it pertained to performance rather than safety standards. Another commenter suggested deleting this requirement because it seems to be of little significance to the assessment of cell usage. The FAA does not agree on deleting proposed §3.8. From a safety viewpoint, it is important that long-term storage not adversely affect the cell capacity. Variation in cell capacity may at some time cause charging currents to be generated, thus leading to a potentially hazardous situation. The adopted test requirements will indicate how storage affects cell capacity. Two commenters recommended that the proposed "± 2.5 percent" variation in cell capacity requirement be replaced with "± 10 percent." They stated that larger variance is more typical of battery capacity. The FAA agrees. Accordingly, proposed §3.8 is redesignated as §3.7, and adopted with change for percent variation, and retitled "High Temperature Cell Capacity Test" to more accurately describe its purpose. In addition, the section requires that the test be performed in accordance with § T-6 of Appendix B which identifies the test equipment required and test procedure to use.

§ 3.9—Reverse Discharge Test

Several commenters stated that the fuse would blow during this test, since the specified current exceeded the maximum current value of the fuse. One commenter recommended that the rate at which the cell is discharged be equal to the rating of the fuse. The FAA agrees. Another commenter suggested that the test be performed at high temperature (55°C). However, the intent of the requirement is to have the test performed at room temperature. Therefore, for clarity, a test temperature value of 24° ± 3°C is prescribed. In addition, for clarity, the duration for observing the condition of the cell after the test should be defined, and a period of 24 hours is specified. Proposed § 3.9 is adopted with the changes discussed above and redesignated as § 3.8.

§ 3.10—Immersion Test-Salt Water

One commenter suggested deleting the reference requirements of §§ 2.11 and 2.12 in proposed § 3.10, stating that they pertain to performance rather than safety standards. Another commenter suggested that the entire section be deleted. The FAA does not agree. The adverse effects of humidity on the battery voltage and capacity are safety related and must be determined. One commenter questioned whether the test would apply to batteries or cells, or both. The test applies only to batteries. For clarification, the test requirement is revised to require compliance with § T-4 of Appendix B which identifies the test equipment and the test procedure to use. As revised, proposed § 3.10 is adopted and redesignated § 3.6.

§ 3.11—Short Circuit Test

Several commenters made recommendations to the proposed short circuit test in § 3.11 that would negate the intent of the requirement. Other commenters suggested editorial changes. In light of the comments received and upon further review, proposed § 3.11 is withdrawn.

§ 3.12—Forced Discharge Test

One commenter suggested deleting proposed § 3.12 because it was redundant. The FAA does not agree. While the forced discharge test is similar to the reverse discharge test, this test may provide different results. One commenter suggested that the term "not greater than −20°C" in proposed § 3.12 should be clarified. This is standard terminology for temperatures higher than a reference temperature and is thus retained. One commenter recommended that this test also be applied to the batteries that have completed the accelerated life test of § 3.8. Considering $LiSO_2$ battery service experience, the FAA agrees. One commenter suggested that this test be performed on time-expired cells (cells that have reached their useful life). The FAA does not agree. This would add an unacceptable time to qualify the batteries. Several commenters suggested that proposed § 3.12 was either unclear or had inconsistencies for fuse ampere rate vs. test ampere rate. Another commenter stated that the test was apparently aimed at one size battery and suggested that it be made applicable to all size batteries. The forced discharge test is intended to have general applicability to all size batteries and as adopted, the discharge current is revised to equal that of the rating of the fuse used in the battery for a period corresponding to the rated capacity of the battery. In addition, for clarity, the duration for monitoring the cells after the test is added. As revised, proposed § 3.12 is adopted and redesignated as § 3.9.

§ 3.13—Total Discharge Test

One commenter recommended deleting the term "vent violently". The FAA does not agree. A battery should not vent when discharged. One commenter recommended defining a time for observing the battery after the short is applied to determine if venting occurs. The FAA agrees. Twenty-four hours is believed to be a reasonable observation period. Several commenters recommended that the battery testing current levels be made consistent with the fuse value and battery capacity. The FAA agrees. The change would make these requirements consistent with the

other discharge requirement. Accordingly, proposed § 3.13 is revised and as adopted, redesignated § 3.10.

Appendix A

Several commenters requested that additional terms be defined, or suggested revision to the definitions proposed in Appendix A. Appendix A is adopted with clarifying changes and with additional definitions as discussed under the discussion of comments to this standard.

Adoption of the Amendment

Accordingly, Part 37 of the Federal Aviation Regulations (14 CFR Part 37) is amended by adding a new § 37.209 effective Sept. 26, 1979 to read as follows:

§ 37.209 Lithium sulfur dioxide batteries TSO-C97.

(a) *Applicability.* This technical standard order prescribes the minimum performance standards that lithium sulfur dioxide ($LiSO_2$) batteries must meet to be identified with the applicable TSO marking. Batteries that are to be so identified must meet the requirements of the "Federal Aviation Administration Standard, Lithium Sulfur Dioxide Batteries" set forth at the end of this section.

(b) *Marking.* Each battery must be marked in accordance with § 37.7 and must be marked with the month and year of manufacture and the date on which it must be replaced. In addition, each cell and battery must be marked with the phrase, "$LiSO_2$ BATTERY CAUTION: PRESSURIZED CONTENTS; NEVER RECHARGE, SHORT CIRCUIT, OR EXPOSE TO TEMPERATURES ABOVE 70°C (158°F)".

(c) *Data requirements.* In accordance with § 37.5, the manufacturer must furnish to the Chief, Aircraft Engineering Division, Office of Airworthiness, Federal Aviation Administration (or in the case of the Western Region, the Chief, Aircraft Engineering Division) in the region in which the manufacturer is located, the following technical data:

(1) One copy of the battery limitations and operating characteristics.

(2) One copy of the installation procedures and installation limitations with applicable drawings and specifications indicating all limitations, restrictions, and conditions pertinent to the installation.

(3) One copy of the manufacturer's test report.

(4) One copy of the Master Drawing List of the battery, including identification of all drawings and applicable revision status and all process specifications and revision status.

(5) Battery data sheets specifying, within the prescribed range of environmental conditions, the actual performance of batteries of that type with respect to each performance factor prescribed in the applicable standard.

(d) *Data to be furnished with manufactured units.* (1) One copy of the data and information specified in paragraphs (c)(1), (c)(2), and (c)(5) of this section must be furnished to each person receiving for use one or more articles manufactured under this TSO.

(2) If a cell vents from any of the tests required by the Federal Aviation Administration Standard, Lithium Sulfur Dioxide Batteries, except those of §§ T-1 and T-2 of Appendix B of the standard, one copy of the data must be furnished to each person receiving for use one or more cells manufactured under this TSO which will allow that person to design—

(i) A receptacle to contain the simultaneous violent venting or explosion of all cells within the battery; and

(ii) Provisions for venting overboard the gaseous products of the explosion.

Federal Aviation Administration Standard

Lithium Sulfur Dioxide Batteries

1.0 *General.*

1.1 This standard applies to cells and batteries of a nonaqueous $LiSO_2$ type. Batteries may consist of a single cell, cells connected in series or in parallel, or both, to obtain the necessary output for the intended application. Definitions for terms used in this standard are set forth in Appendix A of this standard.

2.0 *Minimum Performance Standards Under Standard Conditions.*

2.1 *Cell Isolation.* Cells in a multi-cell battery or packs of more than one battery may not be connected in parallel unless provisions are made to prevent individual cells from being exposed to charging voltages greater that the cell's nominal open circuit voltage. When five or more cells are reconnected in series, each cell must be protected by a shunt diode.

2.2 *Cell connection.* All electrical connections between cells in a battery must be soldered, welded, or brazed in accordance with an approved process specification.

2.3 *Safety Relief.*

2.3.1 *Safety Relief Mechanism.* Each cell used in the battery must incorporate a safety relief mechanism that will relieve internal pressure at a value and rate which will preclude venting violently, or explosion. The safety relief must operate at a temperature below 130°C in accordance with § T-1 of Appendix B of this standard.

2.3.2 *Discharged Materials.* If a cell vents during any of the tests required by §§ 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, and 3.10, the data requirements of § 37.209(d)(2) must be met.

2.4 *Encapsulation.* Encapsulation of the battery may not be used unless it is demonstrated, in accordance with §§ T-2 and T-3 of Appendix B of this standard, that encapsulation does not inhibit the functioning of the safety release mechanism or cause the battery to overheat.

2.5 *Seal.* Each cell must be hermetically sealed. The seal must be tested in accordance with § T-4 of Appendix B of this standard. The difference in the weight of the cell before and after this test must be less than 50 milligrams.

2.6 *Current Limiting Protection.* The battery must have a current limiting device. This device must limit the current that can be drawn from the battery to a value lower than that which it was subjected to in §§ 3.8, 3.9, and 3.10 of this standard, and must be an integral part of the battery and not susceptible to shorting or any failure causing the device to be bypassed.

2.7 *Useful life.* The useful life of the battery may not exceed 4 years unless demonstrated. The useful life must be demonstrated at a minimum temperature of 40°C. When tested at periods in excess of 4 years, the battery must retain 80 percent of its ampere-hour capacity as demonstrated in accordance with § T-5 of Appendix B of this standard, and meet the requirements of §§ 2.9, 2.10, and all sections under § 3.0 of this standard.

2.8 *Examination of Product.* When required, subsequent to a test required by § 3.0 of this standard, each of the cells must be visually examined. Special emphasis must be placed on observing signs of leakage and overall appearance of the safety relief feature.

2.9 *Open Circuit Voltage.* Open circuit voltage of the battery must be measured and be within ±5 percent of its specified value, and the polarity must be correct.

2.10 *Capacity.* The variation in battery capacity may not vary more than ±10 percent when compared with the capacity as demonstrated in accordance with § T-6 of Appendix B of this standard.

3.0 *Minimum Performance Standards Under Environmental Conditions.*

3.1 *General.* Except as provided in §§ 3.6, 3.7, 3.8, 3.9, and 3.10 of this

standard, the design of the battery must be such that subsequent to the application of the specified tests, no condition may exist that would be detrimental to the continued performance of the battery. The same battery must be used for the following tests and these tests must be performed in this order: §§ 3.2, 3.3, 3.4, 3.5, and 3.6.

3.2 *Shock Test.* The battery must be secured to a shock table by a mechanically secure device. The shock test machine must be capable of imparting to the battery a series of calibrated shock impulses. The shock impulse waveform must be a half sine pulse whose distoration at any point on the waveform may not be greater than 15 percent of the peak value of the shock pulse. For the purposes of this section, duration of the shock impulse is specified with reference to the zero points of the half sine wave, and shock forces are specified in terms of peak amplitude G values. The shock impulse must be measured using a calibrated accelerometer and associated instrumentation having a 3dB response over a range of at least 5 to 250 Hertz. The shock test must be conducted as follows:

(a) Mount the battery on the shock test machine in such a manner that it can be subjected to shock impulses in each direction successively along the three mutually orthogonal axes of the battery.

(b) Apply a 100G shock impulse of duration 23±2 milliseconds to the battery in a direction coincident with the first orthogonal axis.

(c) Reset the activation mechanism.

(d) Repeat the procedures specified in §§ 3.2(b) and (c) applying an impulse shock in the remaining 5 axial directions.

3.3 *Vibration Test.* The battery must be secured to a vibration table so that sinusoidal vibratory motion can be exerted parallel to one of the three major orthogonal axes of the battery. The battery must be affixed to the vibration table by the means specified by the equipment manufacturer for service installations. The vibration frequency must be varied at a rate not to exceed 1.0 octave per minute. The vibration must exhibit a constant total excursion of 2.5mm from 5 Hertz to the frequency at which an acceleration of 7G (zero-to-peak) is reached and from that frequency to 2,000 Hertz at a constant acceleration of 7G. Continue the vibration for a minimum of 1 hour. The tests described in this section must be repeated with the vibratory motion being applied along each of the other major axes of the cell.

3.4 *Temperature Cycle Test.* The battery must be subjected to a temperature not greater than −65°C for a period of 20 hours. The test chamber temperature must then be raised at a rate of 5°±2°C per minute to a temperature of at least +71°C, and this temperature maintained for a period of 4 hours. After the 4-hour period, the test chamber temperature must be returned, at a rate of 5°±2°C per minute, to a temperature not greater than −65°C, and this temperature must be maintained for 20 hours. The temperature cycle must be repeated 5 times. After completion of the temperature cycle, the battery must be returned to room temperature.

3.5 *Altitude Test.* The battery must be stored for 6 hours at an atmospheric pressure corresponding to an altitude of 15,000 meters at 24°±4°C. The pressure must then be increased to sea level pressure.

3.6 *Immersion Test—Salt Water.* After being immersed in salt water (3.5±0.1 percent sodium chloride), with terminals insulated, for a period of at least 15 hours, the battery must be tested for leakage in accordance with § T–4 of Appendix B of this standard, and meet the requirements of §§ 2.8, 2.9, and 2.10 of this standard.

3.7 *High Temperature Battery Capacity Test.* After 30 days of storage at a temperature of 71°±2°C, the battery must be returned to room temperature and must be capable of delivering 90 percent of its rated capacity with no more than ±10 percent variation in cell capacity. The test must be performed in accordance with § T–6 of Appendix B of this standard.

3.8 *Reverse Discharge Test.* The cell must not be fuse protected. The cell must be discharged in series with an external power supply at a current equal to that of the rating of the fuse used in the battery at a temperature of 24°±3°C. The discharge must be maintained for a time corresponding to the rated capacity of the battery that the cell will be used in or until the cell has vented. The cell condition must be monitored for 24 hours after termination of reverse discharge.

3.9 *Forced Discharge Test.* The battery must be operative and have the fuse removed for purposes of this test. The test must be conducted on (1) a battery that has not been discharged, and (2) a battery that has completed the high temperature battery capacity test of § 3.7. a battery must be forced discharged at a current load equal to that of the rating of the fuse used in the battery at a temperature not greater than −20°C isothermally for a period corresponding to the rated capacity of the battery. The battery condition must be monitored for 24 hours after the rated capacity of the battery has been reached.

3.10 *Total Discharge Test.* The battery must be operative and have the fuse removed for purposes of this test. The battery must be discharged at a temperature of 24°±3°C at a current level equal to that of the rating of the fuse used in the battery for a period corresponding to the rated capacity of the battery. Immediately thereafter, a direct short must be placed and left across the battery terminals. The battery condition must be monitored for 24 hours after the direct short has been applied.

Appendix A

The following definitions of terms are applicable to the Lithium Sulfur Dioxide Batteries Standard.

1.0 *Definitions.* For purposes of this standard, the following definitions apply:

"Battery" means an electrical energy source made up of one or more cells, arranged in electrical series or parallel or in a series-parallel combination.

"Capacity" means the total amount of electrical energy, measure in ampere hours, that a cell can generate.

"Cell" means an individual electrochemical unit.

"Hermetic sealed cells" means that each cell is sealed in such a manner that over the useful life of the cell there is no loss of gaseous or solid material from the cell.

"Venting" means the controlled release of the electrolyte or any chemical reactant products, or both, from a cell.

"Venting violently" means the rapid uncontrolled discharge of either harmful gases or liquid, or both, from a cell accompanied by the generation of heat

Appendix B

The following test procedures give details for demonstrating that the requirements of the Lithium Sulfur Dioxide Batteries Standard are met.

T–1 *Verification of Safety Relief Mechanism (§ 2.3.1)*

Equipment Required: Calibrated iron constantan thermocouple, accurate to within ±1°C. Electric heating tape. Recording potentiometer.

Test Procedure: a. Attach a thermocouple to the surface of the metal cell case under test and attach the thermocouple to the recording potentiometer.

b. Wrap the circumference of the cell, not covering the ends, with the electric heating tape.

c. Increase the temperature of the cell at a linear rate of 10°±3°C per minute.

d. Continuously monitor the temperature of the cell case and record the temperature at which the cell(s) vent.

T–2 *Operation of Safety Relief in Encapsulating Material (§ 2.4)*

a. Expose the battery to environmental conditions which will cause the battery to

vent (e.g., high temperature or direct short with the current limiting device inoperative).

b. The operation of the safety relief mechanisms and the encapsulation should be observed.

c. Determine that the encapsulation material does not cause the battery to vent in a manner different than that of the cell tested in § T-1.

T-3 *Heat Transfer Properties of the Encapulation Material (§ 2.4)*

Equipment Required: Two calibrated thermocouples accurate to ±1°C. Two recording potentiometers.

Test Procedure: a. Attach a load to an encapsulated battery with the fuse removed which will draw a current equal to the ampere rating of the fuse used in the battery.

b. Attach a load to an identical battery without encapsulation and with the fuse removed which will draw a current equal to the ampere rating of the fuse used in the battery.

c. Continuously monitor the temperature of both batteries. The room ambient temperature should by 24° ±3°C.

d. Continue the test until the ampere hour rating of the cell is reached.

T-4 *Hermetic Seal Test (§ 2.5)*

Equipment Required: Temperature-controlled oven. Scale (accurate to 1 milligram).

Test Procedure: a. Weigh each cell under test.

b. Place each cell in the temperature-controlled oven.

c. Raise the temperature to 71°C.

d. Maintain this temperature for 30 days.

e. Lower the temperature to ambient.

f. Remove the cells and weigh each cell.

g. Compare the weight of each cell with the weight before the test.

T-5 *Useful Life (§ 2.7)*

Equipment Required: Temperature-controlled oven.

Test Procedure: a. Place each battery in the temperature-controlled oven, seals pointed down so that the seal is covered by the electrolyte.

b. Raise the temperature to at least 40°C.

c. Maintain this temperature for 4 years plus the additional time for which useful life is desired to be demonstrated.

d. Lower the temperature and remove each battery.

e. Measure the remaining capacity of the cell in accordance with § T-6 of this Appendix.

T-6 *Battery Capacity (§ 2.10).*

Equipment Required: Resistive load. Data recorder. Digital printer. Digital voltmeter.

Test Procedure: a. Attach a resistive load to the battery under test which will initially draw a current equivalent to the value of the fuse used in the battery in which the cell under test is to be used.

b. Monitor the voltage time until the end-voltage of the battery reaches 0.5 volt.

c. Calculate the cell capacity using the timed averaged voltage method. The formula for this method is

$$\bar{V} = \frac{1}{tco} \sum_{i=1}^{n-1} \frac{(V_i + V_i + 1)}{2} (t_i + 1 - t_i)$$

$$AH = \bar{V} \frac{tco}{R_L}$$

where:

V = Time averaged voltage

tco = Elapsed discharge time to cutoff in hours

V_i = Voltage at time t_i

V_{i+1} = Voltage at time t_{i+1}

t_i = Time in hours at which V_i was measured

t_{i+1} = Time in hours at which V_{i+1} was measured

AH = Discharged capacity

R_L = Load resistance in ohms.

(Secs. 313(a), 601, and 603, Federal Aviation Act of 1958, as amended (49 U.S.C. 1354(a), 1421, and 1423); sec. 6(c), Department of Transportation Act (49 U.S.C. 1655(c)).

Note.—The FAA has determined that this document involves a regulation which is not considered to be significant under the procedures and criteria prescribed by Executive Order 12044 and as implemented by the Department of Transportation Regulatory Policies and Procedures (44 FR 11034, February 26, 1979). A copy of the final evaluation prepared for this action is contained in the regulatory docket. A copy of it may be obtained by contacting the person identified under the caption "FOR FURTHER INFORMATION CONTACT".

Issued in Washington, D.C., on August 23, 1979.

James O. Robinson,

Acting Director, Office of Airworthiness.

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