BATTERY CERTIFICATION FOR SPACE PROTOTYPE APPLICATIONS

Ittalo Pezzotti[1,4], Juan Bernardo Cano[2,4], Gianni Pezzotti[3,4,5]

[1]Institute for Biomedical Technology, Department of Bioinformatics, CNR Segrate Milan – Italy.
[2] Universidad de Antioquia, Department of Electrical Engineering, Medellin-Colombia.
[3]Institute for Crystallography, AdR1 Department of Agrofood, CNR Monterotondo Scalo- Rome - Italy.
[4]Department of Electronic Engineering, University of Rome "Tor Vergata", 00133 Rome- Italy.
[5]Biosensor srl, Via degli Olmetti 44, 00060 Formello - Rome - Italy.
Corresponding author: e-mail: Ittalo.pezzotti@itb.cnr.it

ABSTRACT

Night Vision experiment, on Endeavour's STS-134 mission, consisted on exposing micro-algae, with cellular organelles similar to human retina, to space conditions. The experiment required the development of a non-rechargeable battery-powered instrument for biological material life support. Crew and ship safety is vital in space flight; thus, the experiment's use of batteries must be certified through a series of technical tests required by NASA. This article describes the certification process, including: the protection of circuits, and the electrical, vibration and vacuum tests. Finally, test results, that allowed the use of the instrument in space, are shown.

Keywords: *ShuttleMissionSTS134, Endeavour Shuttle, DAMA, Batteries, Spaceflight, Vacuum test, Vibration test*.

Recibido: 23 de Abril de 2014. Aceptado: 30 de Junio de 2014.
Received: April 23rd, 2014. Accepted: June 30th, 2014.

CERTIFICACIÓN DE BATERÍAS PARA APLICACIONES EN PROTOTIPOS ESPACIALES

RESUMEN

El experimento Night Vision, realizado en la misión STS-134 del transbordador Endeavour, consistió en la exposición a las condiciones espaciales de microalgas con organelos celulares similares a la retina humana. Para el experimento, se construyó un instrumento capaz de mantener en vida el material biológico y dotado de una alimentación autónoma utilizando baterías no recargables. La seguridad de la tripulación y la nave es vital en los vuelos espaciales, por lo que los experimentos que utilizan baterías deben ser certificados a través de una serie de pruebas técnicas exigidas por la NASA. Este artículo presenta el proceso de certificación de baterías para permitir su uso en el vuelo espacial: se describen las protecciones eléctricas implementadas en el circuito, las pruebas eléctricas, de vacío y de vibraciones, y finalmente se ilustran los resultados de dichas pruebas que permitieron la utilización del instrumento en el espacio.

Palabras clave: *Misión STS 134,* Transbordador espacial Endeavour, *DAMA*, Baterías, Vuelo espacial, Pruebas de vacío, Pruebas de vibración.

1. INTRODUCTION

Since the beginning, space exploration has been a very important part of scientific development. Experimentation in non-gravity conditions through the use of different instruments in spaceships [1],[2] has had a big impact on many applications [3],[4]. Many of these are concerned with the possibility of human permanence in space for long periods.

The DAMA (DArkMAtter) Project [5], of the Italian Space Agency (ASI) and the Italian Military Aeronautics, made it possible to send scientific experiments to the International Space Station (ISS) with Mission STS-134 of the Endeavour Space Shuttle. The mission was launched from Cape Cañaveral on May 16th, 2011. One of its main objectives was the installation of the AMS (Alpha Magnetic Spectrometer) in the ISS.

The DAMA Project was made up of 12 experiments: DAMA: APE, FOAM, IENOS, VIABLE ISS, NIGHT VISION, BIOKIS with 7 experiments (BioS-PORE, Photo-Evolution, HiDOSE, TARDIKISS, 3DISS, nDOSE, Arabidops-ISS). The DAMA project was conceived to allow the participation of different institutions: scientific, industrial, social, both Italian and international, with the intention to allow them to use the space station and distribute the costs.

The Night-Vision Experiment was developed by the Institute of Crystallography (IC) of the Italian National Research Board in collaboration with a private company (Biosensor SRL). Its objective is to evaluate substances that diminish the impact of cosmic radiation on astronauts' visual capacity, so that these substances may be incorporated into their food supplies in the future. Specifically, some natural compounds of the Xanthophyll family were evaluated for their ability to block intense radiation.

The substratum was administered to microalgae characterized by having ocular stains similar to the human eye. The microalgae were exposed to the conditions of the space station for the 16 days the mission lasted, and were later analyzed in the lab to verify their level of damage.

An instrument (Figure 1) was developed to contain and keep alive the biological material during the stages of pre-flight, flight, and post-flight of the mission. The design requisites demand an independent source of energy, which, taking into account prices and weight, was made up of non-rechargeable lithium batteries ($LiMnO_2$).

Figure 1–Photograph of the Night Vision Instrument

To be allowed on the shuttle, a series of certifications are necessary, with the intention to guarantee that there are no risks for the crewmembers of the ship. One of the main sources of risk in electronic equipment is the batteries. If the batteries were mechanically or electronically handled in an inadequate manner, there could be an explosion, gas or dangerous chemical substance emissions.

This article illustrates the process for the certification of the batteries that were used in the Night Vision space instrument.

The first section describes the Night Vision Instrument, its structure and function, emphasizing the power supply and the necessary circuits for the protection of the batteries.

The second section describes the technical qualification tests (electric, vacuum and vibration). The materials and methods used are described for each test.

Subsequently, the obtained results are showcased. Finally, there is a conclusion about the process of certification that was carried out and the usability or non-usability of the batteries.

2. MATERIALS AND METHODS

2.1 NIGHT VISION INSTRUMENT

The main objective of the Instrument is to keep microalgae alive during the extension of the mission. Thus, enough luminous energy must be administered to maintain the algae's photosynthesis process.

This is achieved with the use of high-intensity, low consumption white LEDs. For biological and energy consumption reasons, a night/day cycle is simulated, during which the algae are stimulated with light for 7 hours and kept in the dark for the remainder of the 24 hour day [7].

The Night Vision instrument, presented in Figure 2, is composed of:

- 36 measuring cells made of delrin (a biocompatible material), divided in 3 blocks (floors) of 12 cells each. The object of these cells is to contain the biological material, allowing the light in through a polycarbonate (Lexan) window.

Figure 2 -Night Vision Instrument, prepared for flight, 24 hours before the launch.

- A source of light (LED) per measuring cell, with the purpose of keeping the biological material alive [7].

- Control circuits to power on the light sources. Each of the three cell blocks has its own independent control circuit. The control circuits were designed using special chips of modular sequential logic (counters), certified for space applications [8][9].

- Nomex covering, a fireproof material that NASA requires as a safety measure.

2.1.1 Power Supply

Due to the costs and the availability of electrical power in the space environment, it was necessary to dote the instrument with an autonomous power supply that would be able to keep it running during the entire mission (pre, flight and post-flight periods).

The Night Vision Instrument requires a 6 VDC power supply with a maximum current of 3 mA (peak). Lithium Manganese Oxide (Li/MnO_2) non-rechargeable, CR2477 type batteries were chosen. These have a nominal voltage of 3v and a capacity of 950 mAh; plus, their low profile, weight and cost made them ideal [10][11]. The batteries were grouped forming series of two elements. Each series must feed one of the three blocks (floors) of cells in the Instrument, which are electrically isolated. Space limitations made it necessary for all 6 batteries to be located on top of the instrument.

2.1.2 Autonomy Verification

Before proceeding with the certification process, it was necessary to confirm that the selected batteries would give the necessary autonomy to keep the instrument running during the entire mission.

For this purpose, the following test was conducted, the results of which are illustrated in Section 3.1:

- To run the equipment for the estimated duration of the mission (16 days). To continually sample the current consumption of the system and the voltage level of the batteries.

- At the end of this time, to calculate the total capacity consumed by the battery (Ah) and the final voltage.

- Verify that the battery's nominal capacity be superior to the capacity that was consumed, and that the final voltage be superior to the minimum voltage to keep the instrument running.

2.1.3 Electrical Protection

To be accepted on a NASA space flight, every instrument that uses batteries must take into account the following considerations and electrical circuit protections [12].

- Protection against short circuits: A short circuit would produce an excessive dissipation on the battery, causing it to heat up and possibly be destroyed because of gas accumulation. To avoid this risk situation, special fuses were used that are suitable for operation with few milliamperes.

- Protection against an accidental overcharge: The non-rechargeable batteries can explode if they receive an inverse current. This could occur during transitions due to the operation of inductive or capacitive elements (parasites) in the circuit. As a means of protection, a low forward voltage diode is used in series with the battery.

- Protection against inverse overcharge: On some occasions, when a battery is totally run down, the polarity becomes inverted. In these conditions, the battery can become heated or explode. As a protection, anti-parallel diodes are used with each of the batteries.

Figure 3 illustrates the implemented protection circuit. The two batteries (BAT1 and BAT2) in series to produce the required voltage can be observed.

Each battery is accompanied by its corresponding fuse. The D1 and D2 diodes act as a protection against the overcharge of the BAT1 battery. Two diodes are used because NASA requires two levels of protection, and if one diode fails, the second is there as a backup. This is also true for diodes D3 and D4 with the BAT2 battery.

The D5 through D7 diodes are the protection against accidental recharge. Again, repeated diodes are placed parallel (as a second level of protection against the diode that may fail and remains open) and in series (protection against the diodes that may fail and short-circuit).

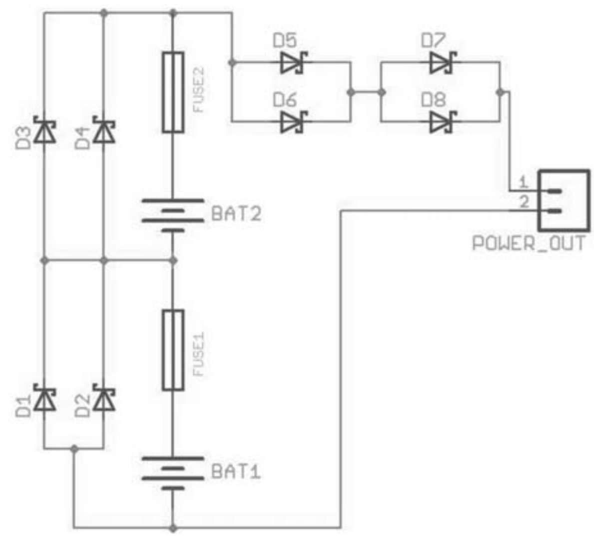

Figure 3: Battery protection circuit.

2.2 BATTERY CERTIFICATION

This section details the tests that were performed on the batteries to receive the approval for space flight.

2.2.1 Certification Process:

- Initially, an electronic circuit is designed and implemented to measure electric variables (open circuit voltage and charged voltage) of the batteries. This circuit is connected to a computer software that acquires and manages data. (Section 2.2.2).

- Using said circuit, an initial set of batteries is measured to determine their initial conditions (electric testing) and other physical variables that may be of interest. (Section 2.3).

- Some batteries from this set are selected and they are submitted to vibration tests. Then they are again submitted to electrical testing.

- These selected batteries mentioned above are submitted to a vacuum test and then to electrical testing once more.

- The data is analyzed to see if there are any variations in the electric parameters of the batteries. This data will be the foundation to complete the technical sheets required by

NASA and to select the best batteries to use in the qualification and flight prototypes.

2.2.2 Selected Circuits and Software

To carry out the tests, it is necessary to measure the voltage of the battery in an open circuit, and under similar charge conditions than the ones used in the application [13]. Figure 4 shows the acquisition circuit.

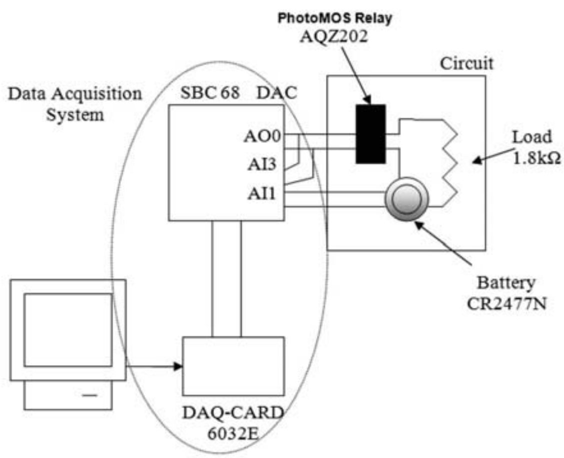

Figure 4 – Electronic Diagram for the Acquisition

The measurements are used in an automated way, using a Data Acquisition Card (National Instruments DAQ-6032E, coupled with theSBC-68 terminal block card) [14], including an electronic circuit that controls the connection/disconnection from a charge resistance (AQZ202 solid state relay) and a control software installed on a computer for data management.

The measurement of the battery's tension is carried out through the analog input of the acquisition card, configured in a differential way with the purpose of reducing noise coupling. The measurement procedure of the acquisition card is as follows:

- The solid state relay is opened and the data corresponding to the open circuit voltage (OCV) is captured.

- When 500ms have elapsed, the solid state relay is switched. The data for the closed circuit battery voltage (CCV) are captured.

Acquisition Software.

The software was developed on a Microsoft Platform, using Visual Basic language [15], making use of National Instruments' libraries for acquisition cards [14].

The software allows the team to manage the OCV CCV data acquisition for each battery, to analyze them in reference to the description of each test, identification code, date, photo and observation. It is also possible to control process parameters such as sampling rate, acquisition times and measuring cycles.

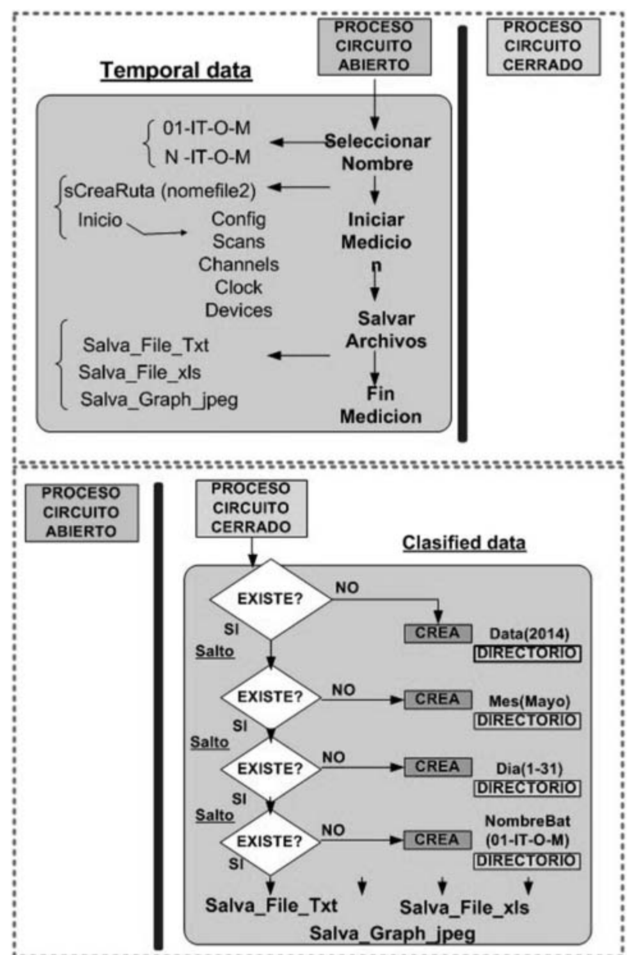

Figure 5– Diagram of the data structure

The software's objective is to facilitate the handling of information, taking into account the great number of tests that have to be conducted, and with the intention of avoiding unnecessary data loss or repetition.

The software allows the creation of a directory structure according to the sequential names comprised of the country, battery name, date and the time when it was first used.

The diagram in Figure 5 shows the open circuit and closed circuit processes carried out by the software, and the file creation process.

The process organizes measurement in a sequential way according to the established parameters. It proceeds to create the file and the directory with the system's configuration, then it stores the file in a text and csv format, and finally, it automatically takes photos of the system.

The software was conceived to allow future expansions, like the use of neuronal nets [16][17] to provide a characterization of the battery, for example.

2.3 Initial Tests

Out of the initial set composed of 120 batteries, a visual inspection was conducted and 100 batteries were selected; they were tagged (with a unique code) and packed for the execution of the tests (Figure 6).

Figure 6 – Lithium battery disposition for certification tests.

The initial tests consisted in the verification of the diameter, weight and vacuum voltage of each of the 100 batteries. This was the record of the initial conditions, before the experiments they were subjected to. Figure 7 shows a collage of images concerning these measurements.

Figure 7 – Physical control measurements.

The batteries were then evaluated using the system described previously (open circuit and closed circuit tests). Table 1 shows the type of data that was obtained.

ACCEPTANCE BEFORE VIBRATION TEST		
NAME BAT.	OPEN CIRCUIT	CLOSE CIRCUIT
MEASURE	AVG	AVG
28-IT-O-M	3,20922002	3,194711112
29-IT-O-M	3,219101987	3,180571242
34-IT-O-M	3,230378163	3,208668421
35-IT-O-M	3,225453508	3,207765883
36-IT-O-M	3,220602668	3,204625779
37-IT-O-M	3,20894377	3,194115096
39-IT-O-M	3,21977526	3,203278566
40-IT-O-M	3,225779853	3,209758913
42-IT-O-M	3,224742478	3,207162145
49-IT-O-M	3,226936074	3,206206041

QUALIFICATION BEFORE VIBRATION TEST		
NAME BAT.	OPEN CIRCUIT	CLOSE CIRCUIT
MEASURE	AVG	AVG
43-IT-O-M	3,226874282	3,211091925
44-IT-O-M	3,219285913	3,199532674
45-IT-O-M	3,24728057	3,229238985
46-IT-O-M	3,226478479	3,208904123
47-IT-O-M	3,234838314	3,218649136
48-IT-O-M	3,230984129	3,214277013

Table 1 – Examples of the data obtained in the preliminary open circuit/closed circuit tests.

2.4 Vibration Tests

The vibration tests were conducted to confirm the resistance of the batteries to the strong accelerations experienced during the launch of the mission. Said vibrations can cause the battery's electrochemical cells to rupture, implying internal short circuits, loss of the material and/or the collapse of the structure [18].

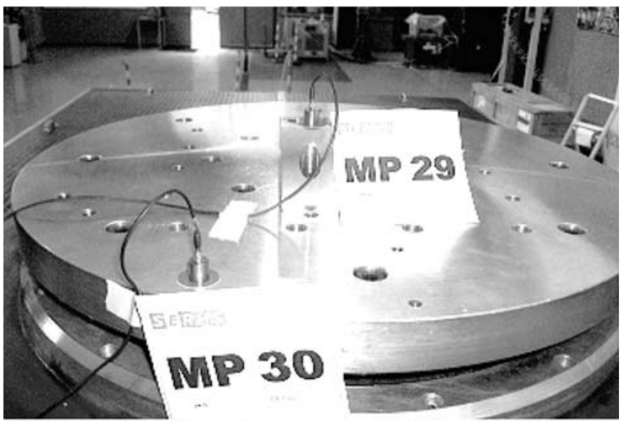

Figure 8 – Vibration system for battery testing (courtesy of SERMS)

The tests were conducted in the SERMS Laboratory (Terni-Italia), which has all the process and equipment calibration requirements to certify the results to NASA.

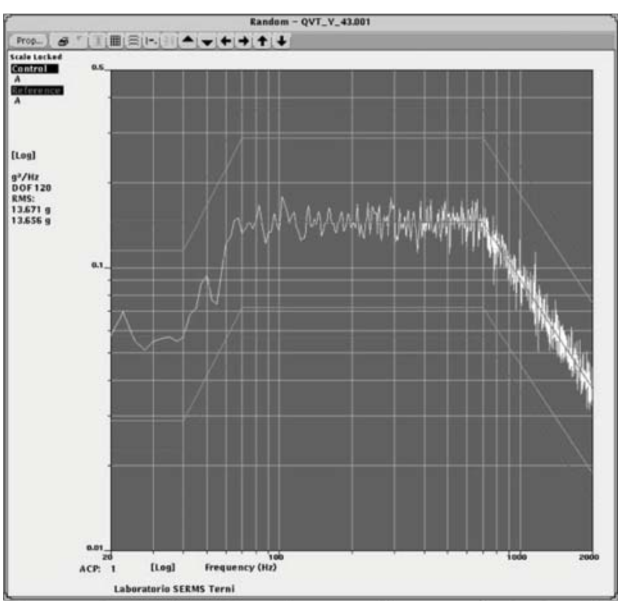

Figure 9 – Acceleration profile applied to the batteries during the tests (Y axis).

The batteries must be exposed to vibrations in their X, Y and Z axes. This is accomplished with mechanical systems powered by sensors that control acceleration in a precise manner. Figure 8 shows part of the vibration system.

The acceleration applied to the batteries is not constant and has to follow a profile clearly specified by NASA that simulates the shuttle launch process. This graphic profile is illustrated in Figure 9.

Each battery in the qualification and acceptance groups suffer these tests, where each space axis (XYZ) experiences changes in acceleration, on different positions for a period of 20 minutes[19].

Once exposed to the vibration, the batteries were inspected once more, using the same procedure that was described for the preliminary tests. A change (decrease) in the CCV or OCV voltages of the batteries indicates internal damage.

2.5 Vacuum Tests

These tests consist of exposing the batteries to low pressure (0.288 mbar) conditions for a period of 6 hours and then verifying their integrity.

To do this, the vacuum system presented in the instrumentation diagram of Figure 10 was used (Certification carried out in the laboratories of the Crystallography Institute, CNR Rome).

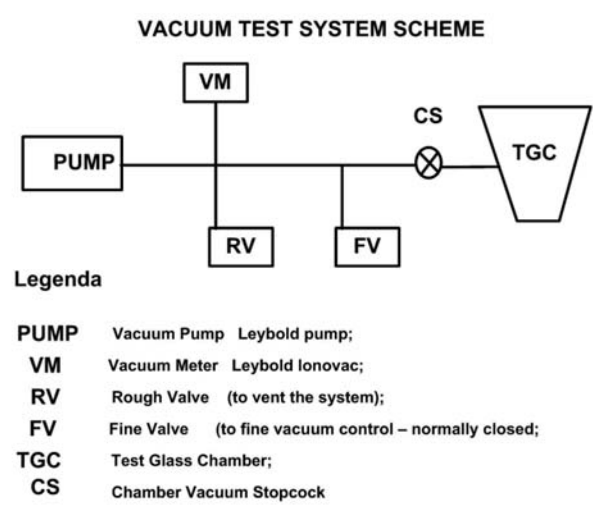

Figure 10–Vacuum tests measurement system.

The materials used in this test were the following:

- Vacuum pump: with two DIVAC 0.8 LT Leybold(GE) diaphragms, certified by the producer according to DIN 28.426, part 1 regulations. Vacuums of 0.5 mbar(a) and pumping capacity of 0.60 m3 h-1(p.atm) and 0.15 m3h-1(p=5.0 mbar).
- Vacuum meter: A Leybold (GE) IONIVAC ITR 90(S/N 120-91) type meter was used. The measuring range goes from 1000 to 5*10(-10) mbar, the measurements can have a 15% uncertainty rate over the measured value, and can reproduce the measured value up to 5%.
- Glass testing chamber: The testing chamber is made in clean metallic glass (boron silicate I-330) for high pressure, according to the DIN 12491, of ACE inc. (GB), with a total volume of 5 liters.

After the exposure to vacuum, the open and closed electrical circuit measurements were conducted once more.

3. RESULTS AND DISCUSSION

3.1 Autonomy Verification

Figure 11 illustrates the data for the current consumption of the instrument. For the article's clarity, they correspond only to a period of 3 days (out of the total 16 days of the test). The consumption corresponds to only one of the three blocks in the instrument (12 cells).

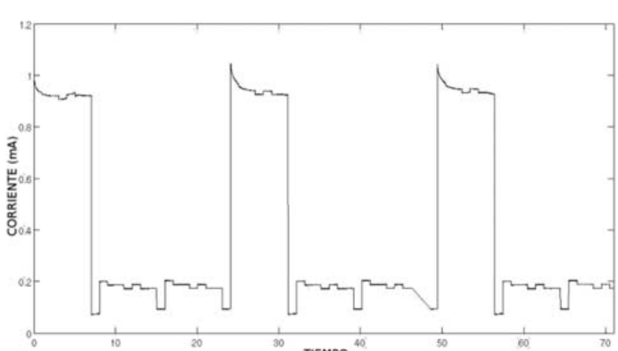

Figure 11: Current consumed by the Instrument against time (hours).

The instrument's generation of the photo-period is evident. When the LEDs are on, the current values are close to 1mA for 7 hours, and with the LEDs off, the current levels are close to 0.2mA for the rest of the 24 hour period.

By calculating the area under the curve for the time between 0-16 days, a total consumption of 192.87mAh is obtained. Compared to the total capacity of the batteries (950mAh), the safety requirements are satisfied with a high safety factor. This high safety factor is necessary in case there are any unforeseen incidents in the mission (launch or landing delays) and taking into account the effects of the space environment on the batteries.

The data obtained validated the battery selection and allowed the continuity of the certification process.

3.2 Vibration Test

As it was previously mentioned, two groups of batteries were selected to be used in the prototype: a qualification group, and an acceptance group. To preserve the article's clarity, only the results for these two groups are showcased.

Once exposed to the vibration tests, the batteries were inspected once more following the same procedure described for the preliminary tests.

Visual inspection after vibration test: The visual inspection detected mechanical damage on only one of the batteries. This damage can be attributed to a faulty placement on the support during the tests. The rest of the set showed no damage.

Electrical measurements after vibration test: Figures 12a and 12b illustrate the data obtained in the CCV and OCV tests after the vibration test. (For visual clarity, the data concerning some batteries is not shown).

In these charts, the open circuit voltage for time < 500ms, and closed circuit voltage for time > 500ms can be observed.. These values were compared to the data from the preliminary tests.

In the acceptance battery group, there was an average decrease of tension of 0.42% (taking into account CCV and OCV values). In the qualification battery group, the decrease was 0.49%.

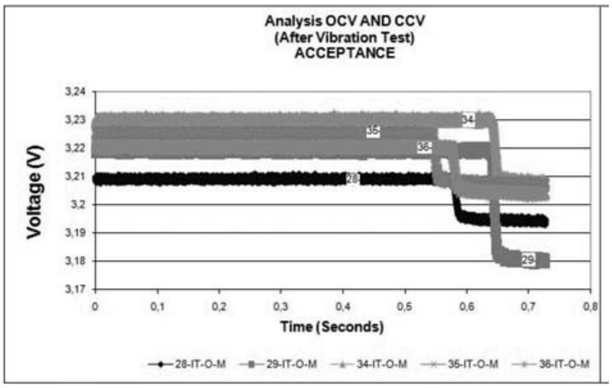

Figure 12a – Tension measurements after vibration test (batteries in acceptance group).

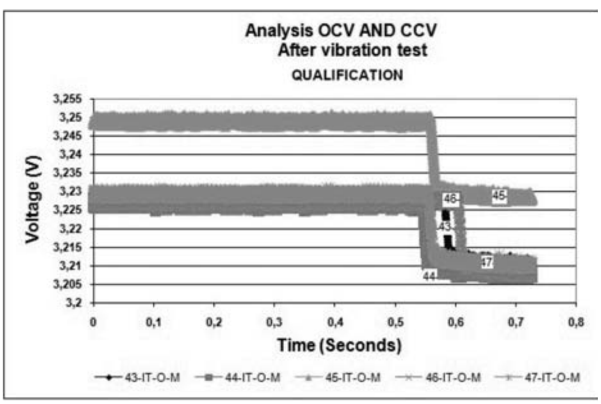

Figure 12b - Tension measurements after vibration test (batteries in qualification group).

The measurements for all the 100 batteries in the set where similar with these measurements, except for one of the batteries, which was discarded for showing major differences in the CCV and OCV measurements.

3.3 Vacuum Test

Visual inspection after vacuum test: No mechanical damage was detected in any of the batteries after vacuum exposure.

Electrical measurements after vacuum test: After the exposure to vacuum conditions, the open and close circuit electrical tests were conducted once more. Figures 13 and 14 illustrate the results (for qualification and acceptance groups).

For the acceptance group, there was an average tension reduction of 0.31% compared to the preliminary tests. For the qualification group, the changes were between 0.35% and 0.41% (Figure 14).

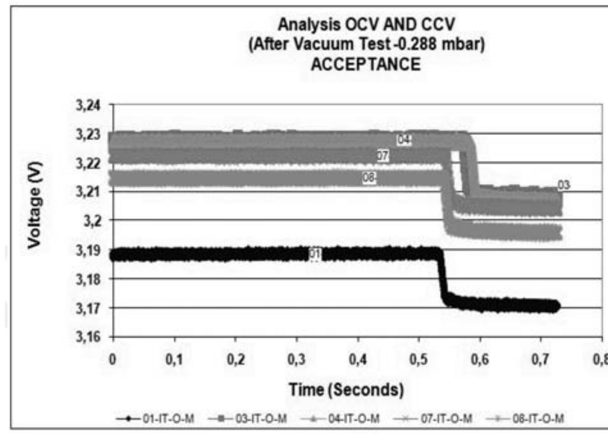

Figure 13 –Vacuum test for acceptance group

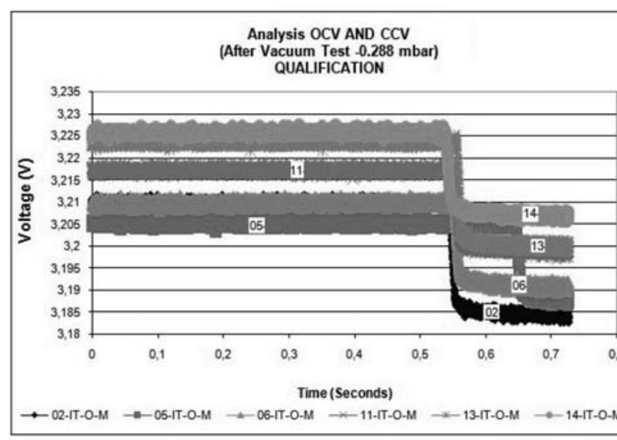

Figure 14 –Vacuum test for qualification group

3.4 Authorization for use in space flight

The results that were obtained both for the acceptance and the qualification groups, as well as the total set, were submitted for evaluation from a group of Battery Experts from NASA [12]. They were responsible for the certification or disproval of the batteries in the experiment.

Apart from the previous results, a design sheet and a battery evaluation form Battery Design Evaluation

Form –EP5) [12] were elaborated, in which the following relevant information was accounted for:

- The entity using the battery.
- The working environment for the battery: Temperature (ranges from -30 y 70°C, with operational point at 25°C)Type of Activity: Intra Vehicular Activity (IVA).
- Battery Characteristics: Composition (Li/MnO_2), size (CR2477), maximum charge conditions (1.2mA). Total capacity of the battery, self-discharge (1%), lifetime of the battery (8 years). Most of this data was obtained from the manufacturer's datasheets [11][10].
- Finally, certifications of the different entities that conducted the tests were annexed. The datasheets for the circuits and the components used in the protection of the batteries were also annexed.

When this documentation was turned in, the evaluation process was successfully concluded, and the approval for the use of these batteries in flight in the Night Vision Instrument was obtained.

3.5 In-flight behavior:

The Night Vision Instrument was launched on May 16th, 2011, after an attempt on April 29th that was aborted due to problems with the heating device in the power units of the shuttle [6].

The mission landed on June 1st, 2011, after 16 days. Following the post-flight operations, the Instrument was delivered and it was confirmed that it was still functioning properly (the LEDs were on at the moment). The batteries showed no visible mechanical damage and the voltage was still enough to maintain the system operation.

4. CONCLUSIONS

- Space instrumentation for missions in the shuttle or the Space Station must be constructed in a way that minimizes all risks for the ship and the crew. In a space context, batteries are potentially dangerous elements. This is why their use is strongly regulated and must be submitted to the necessary certification and electrical protection system implementation.
- NASA's certification process for the use of batteries implies a series of tests to guarantee the resistance of said batteries to the vibrations and low-pressure conditions of space.
- Through the process described in this article, it was possible to obtain the authorization for the use of Renata CR2477 batteries in a space flight. This certification is exclusively for the Night Vision Instrument, but thanks to the similar case criteria, they may be used in other space projects with only a few further tests.
- The design criteria used for the selection of the batteries, which implied a high safety factor, were appropriated for the application. The capacity of the batteries kept the instrument running appropriately for the entire duration of the mission.

5. ACKNOWLEDGEMENTS

- To the Italian Space Agency (ASI), funding entity and active coordinator in the DAMA Project's concerns with space flight.
- To the researcher Doctor Andrea Margonelli from the Italian National Research Council (CNR) of the Crystallography Institute (IC),for their help with vacuum testing.
- Judith Jeevarajan, NASA expert in the Johnson Space Center JSC, as the final evaluator to certify the batteries for the mission
- Schneider Hansjoerg of Renata Batteries, for the information he provided concerning the batteries.

6. REFERENCES

1. G.Pezzotti, A.Tibuzzi, V.Scognamiglio, J.B.Cano, I.Pezzotti, "Portable Biosensor Prototype for Fluorescence Experiments in Space", IV National Congress: "Un mondosenzagravità", (ISSBB), 31 March – 2 April 2009, Santa MargheritaLigure, Italy.
2. A.Tibuzzi, G.Pezzotti, T.Lavecchia, V.Scognamiglio, I.Pezzotti, "Ito-Based

biosensor prototype to monitor electroactivity of cell cultures in space", IV National Congress: “Un mondosenzagravità”, (ISSBB), 31 March – 2 April 2009, SantaMargheritaLigure, Italy.

3. G.Pezzotti, A.Tibuzzi, T.Lavecchia, G.Rea, A.Serafini, M.T.Giardi, “Portable instruments based in multiband fluorescence transducers for biosensing applications”, Revista Politecnica, Year 3, n° 5, pag 123- 128 Medellin, December 2007 ISSN 1900-2351.
4. G. Pezzotti, J.B. Cano, K. Buonasera, “Biosensing technologies for space applications”, revistaPolitecnica, Medellin, año 7, 13, 2011, ISSN 1900-2562.
5. Houston i sei payload italiani per la missione DAMA-STS 134, Agencia especial italiana, http://www.asi.it/files/breve%20esperimenti%20VUS%20con%20intro%20e%20foto.pdf.
6. NASA, ISS misión Shuttle STS 134, ttp://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts134/main/index.html”.
7. J.B. Cano, D. Giannini, G. Pezzotti, G. Rea, M.T. Giardi, “Space impact and technological transfer of a biosensor facility to earth application for environmental monitoring”, Recent Patents on Space Technology, 2011, Volume 1, No. 1, March 15, 2011; ISSN 2210-6871; Bentham Science Publishers Ltd.
8. Scarpulla J, Yarbrough A. What Could Go Wrong?, The Effects of Ionizing Radiation on Space Electronics. The Aerospace Corporation: Crosslink, Summer 2003; 15–9.
9. Mazur JE. An Overview of the Space Radiation Environment. The Aerospace Corporation Magazine of advances in aerospace technology summer, Crosslink, 2003; 1: 10-14.
10. Renata Batteries. CR2477N 3V Lithium Battery Swiss Made. Technical Data Sheet. Rev. CR2477N.03 10/01 www.renata.de.
11. Renata Batteries. 3V Lithium Batteries. General Technical Information on Lithium Batteries. Rev. 10/02 www.renata.de.
12. Crewed Space Vehicle Battery Safety Requirements, JSC-20793 Rev. B. National Aeronautics and Space Administration. 2006.
13. Ricardo Saba Rabié Durán, diseño e implementación de un sistema de adquisición de datos para pruebas de carga y descarga de baterías de ion-litio, Santiago de chile julio 2013.
14. Claudia Lorente, Ken Reindel, National Instruments, characterize batteries and power consumption using the NI PXI-4071 7 ½-digit digital multimeter, apr 10, 2012.
15. Erich R. Buhler, Visual Basic, net guía de migración, McGraw-Hill 2002, interamericana de España, ISBN84-481-3271-8.
16. G. Pezzotti, J. Valencia, N. Londoño, “Discrete deadbeat control of a plant pressure through identification by neural networks”, ISSN : 1548-0992, Latinoamérica Transactions IEEE , Volume 10, Issue 4, Pages 1967 – 1972, June 2012.
17. G. Campi, G. Pezzotti, M. Fratini, A. Ricci, M. Burghammer, R. Cancedda, M. Mastrogiacomo, I. Bukreeva, A. Cedola, “Imaging regenerating bone tissue based on neural networks applied to high resolution micro-diffraction measurements”, Applied Physics DOI:10.1063/1.4852056.
18. Judith Jeevarajan, Ph.D., NASA-JSC 2nd, certification process for commercial batteries for Payloads, IAASS Conference Chicago, May, 2007.
19. Barbara McKissock, Patricia Loyselle, Elisa Vogel, “Guidelines on lithium-ion battery use in space applications”, NASA/TM-2009-215751 NESC-RP-08-75/06-069-I, May 2009.