

The Use of Liquid Isopropyl Alcohol and Hydrogen Peroxide Gas Plasma to Biologically Decontaminate Spacecraft Electronics

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Abstract

Legitimate concern exists regarding sending spacecraft and their associated hardware to solar system bodies where they could possibly contaminate the body's surface with terrestrial microorganisms. The NASA approved guidelines for sterilization as set forth in NPG 8020.12C, which is consistent with the biological contamination control objectives of the Committee on Space Research (COSPAR), recommends subjecting the spacecraft and its associated hardware to dry heat—a dry heat regimen that could potentially employ a temperature of 110°C for up to 200 hours. Such a temperature exposure could prove detrimental to the spacecraft electronics. The stimulated growth of intermetallic compounds (IMCs) in metallic interconnects and/or thermal degradation of organic materials composing much of the hardware could take place over a prolonged temperature regimen. Such detrimental phenomena would almost certainly compromise the integrity and reliability of the electronics. Investigation of sterilization procedures in the medical field suggests that hydrogen peroxide (H₂O₂) gas plasma (HPGP) technology can effectively function as an alternative to heat sterilization, especially for heat-sensitive items. Treatment with isopropyl alcohol (IPA) in liquid form prior to exposure of the hardware to HPGP should also prove beneficial. Although IPA is not a sterilant, it is frequently used as a disinfectant because of its bactericidal properties. The use of IPA in electronics cleaning is widely recognized and has been utilized for many years with no adverse affects reported. In addition, IPA is the principal ingredient of the test fluid used in ionic contamination testers to assess the amount of ionic contamination found on the surfaces of printed wiring assemblies. This paper will set forth experimental data confirming the feasibility of the IPA/H₂O₂ approach to reach acceptable microbial reduction (MR) levels of spacecraft electronic hardware. In addition, a proposed process flow in which both IPA liquid and HPGP are utilized will be presented in Section 7.0 **Future Work**. A list of acronyms and chemical symbols used throughout this paper is given in Section 9.0 **Acronyms and Chemical Symbols**.

1.0 Background

Legitimate concern exists regarding sending spacecraft and its associated hardware to a planet where the spacecraft and/or its associated hardware could possibly contaminate the planetary surface with terrestrial microorganisms, thus vitiating the search for extraterrestrial life forms. This has resulted in increasing attention to ensure an acceptable level of microbial reduction (MR) of the entire spacecraft and its attendant hardware prior to leaving Earth to ensure that they do not inadvertently contaminate any other planetary surface. All future missions to promising cosmic destinations, such as Mars and Europa, will need an acceptable level of microbial reduction (MR) of the entire spacecraft, including the electronics, prior to leaving Earth.

The NASA approved guidelines for sterilization as set forth in NPG 8020.12C [1], which is consistent with the biological contamination control objectives of the Committee on Space Research (COSPAR), recommends subjecting the spacecraft and its associated hardware to dry heat. To achieve bulk spacecraft Dry Heat Microbial Reduction (DHMR), the dry heat process contemplated for sterilizing a spacecraft and its associated hardware could employ a temperature of 110°C for up to 200 hours. Such a temperature regimen is likely to prove detrimental to the spacecraft electronics. If such a bake-out is performed, it is anticipated that the growth of intermetallic compounds (IMCs) and/or thermal degradation of organic materials composing much of the hardware will take place. Potential interactions could occur from a dry heat treatment because of the complex material combinations of each electronic component, including the printed wiring board, board plating, solder or adhesive, and the metallization finish of the components. A 1967 preliminary study investigated the effect of thermal sterilization on microelectronics for the Voyager program.

3.0 Objectives

The main objectives of this feasibility investigation are to determine the following:

- Bioburden of the control test vehicle
- Effect of the IPA on bioburden reduction
- Effect of HPGP on sterilization efficacy
- Effect of HPGP on the functionality and material compatibility of the electronic components

4.0 Methodology

4.1 Description of test vehicles (TVs) and testing performed

The following test vehicles (TVs) were used in this investigation:

- Populated electronic boards (PWAs) with Parylene C® conformal coating
- Bare printed wiring boards (PWBs) without conformal coating and with immersion silver plating over copper
- Unpackaged, silicon (Si) die with strain gauge and gold (Au) backside metallization
- Populated printed wiring boards, a.k.a. printed wiring assemblies (PWAs), were utilized after having been thermal cycled from -120°C to 85°C in another investigation

Table 1 shows the description of the test vehicles (TVs) and the testing performed in this investigation.

Table 1: Description of test vehicles (TVs) and testing performed

TV Description	Testing and number of TVs per test
1) Populated boards (PWAs) with Parylene C conformal coating	<ul style="list-style-type: none"> ▪ Bioburden estimation (4 TVs) ▪ Bioburden estimation after IPA cleaning (2 TVs) ▪ Sterilization efficacy and material compatibility in HPGP (2 TVs)
2) Bare (without conformal coating) PWBs with immersion silver plating	<ul style="list-style-type: none"> ▪ Bioburden estimation (4 TVs) ▪ Bioburden estimation after IPA cleaning (2 TVs) ▪ Sterilization efficacy in HPGP (2 TVs)
3) Silicon (Si) die with strain gauge and Au backside metallization (without conformal coating)	<ul style="list-style-type: none"> ▪ Bioburden estimation (2 TVs) ▪ Bioburden estimation after IPA cleaning (1 TV) ▪ Sterilization efficacy (2 TVs)
4) Aluminum boat (board holder)	<ul style="list-style-type: none"> ▪ Bioburden estimation (1 TV)

4.2 Bioburden estimation

The term "bioburden" is commonly used to describe the population of viable microorganisms present on a material or product. It is not possible to determine the exact bioburden; therefore, in practice a viable count is determined using a defined technique [10]. An appropriate swabbing method was chosen for the electronics to facilitate removal of microorganisms from the irregularly shaped areas. The entire surface of each test vehicle was wiped with the swab moistened with United States Pharmacopeia (USP) Fluid D [11]. The swab head was then transferred to a tube containing 25 milliliter (mL) of Fluid D and vortexed for three minutes. The resulting Fluid D was filtered through a 0.45 micrometer (µm) membrane filter and rinsed with 100 mL of Fluid D. The filters were subsequently placed on tryptic soy agar (TSA) plates. The plates were incubated at 30-35°C for three days and at 20-25°C for five additional days. To determine the recovery efficiency of this method, a repetitive recovery method was performed as shown in Figure 1. The correction factor was calculated for each test vehicle type using the data from repetitive recovery method to compensate for the incomplete removal of microorganisms from the test vehicles. Gram stain was performed to determine the predominant colony types.

primary habitat of the majority of *Bacillus* species is the soil. From soil, aerobic sporeformers can contaminate everything by dust or other means [14]. The percent recovery was calculated for the recovery efficiency after the first swabbing procedure, recommended for the routine bioburden estimation. The correction factor was calculated using the lowest percent recovery observed for each TV type to take the conservative approach for the bioburden estimation. The calculated correction factors are summarized in Table 3.

Table 2: Bioburden data of the control test vehicles (TVs)

TV type	Replicate TV #	Recovered counts Colony Forming Units (CFUs)			Total counts (CFUs)	% Recovery (after 1st recovery)
		After 1st recovery	After 2nd recovery	After 3rd recovery		
1) Populated boards (PWAs) with Parylene C conformal coating	1	8	2	5	15	53
	2	8	4	0	12	67
	3	7	10	2	19	37
	4	3	2	0	5	60
2) Bare (without conformal coating) PWBs with immersion silver plating	1	6	3	0	9	67
	2	9	6	4	19	47
	3	7	3	0	10	70
	4	77	6	0	83	93
3) Silicon (Si) die with strain gauge and Au backside metallization (without conformal coating)	1	0	0	0	0	NA
	2	0	0	0	0	NA
4) Aluminum boat (board holder)	1	121	6	1	128	95

Table 3: Calculation of correction factor

TV type	Average % recovery	Range of % recovery	Correction factor
1) Populated boards (PWAs) with Parylene C conformal coating	54%	37% - 67%	2.7 (=100/37)
2) Bare (without conformal coating) PWBs with immersion silver plating	69%	47% - 93%	2.1 (=100/47)
3) Silicon (Si) die with strain gauge and Au backside metallization (without conformal coating)	NA	NA	NA
4) Aluminum boat (board holder)	NA	NA	1.3 (=100/95)

5.2 Bioburden estimation after IPA cleaning

The data in Table 4 show a significant reduction on the bioburden level after IPA cleaning. As expected—only GPR and mold without any GPC—were recovered after IPA cleaning. It is well known that IPA possesses general antimicrobial properties but without sporicidal effect. The extent of the bioburden reduction of three types of electronics after IPA cleaning are shown in Figure 2.

Table 5: BI results after HPGP treatment

TV type	BI results (# nonsterile/ # tested)
1) Populated boards (PWAs) with Parylene C conformal coating	0/2
2) Bare (without conformal coating) PWBs with immersion silver plating	0/2
3) Silicon (Si) die with strain gauge and Au backside metallization (without conformal coating)	0/2

5.4 Impact of using Hydrogen Peroxide Gas Plasma (HPGP) on the material compatibility of the TVs

The functionality of selected electronic parts on the PWAs—see photo in Figure 3—was taken before and after HPGP treatment. The continuity measurements shown in Table 6 did not significantly change or result in a value greater than a 10% tolerance or indicate open circuits and failures. These initial results strongly suggest that HPGP is not detrimental to the functionality of the parts by causing electrical opens or shorts.

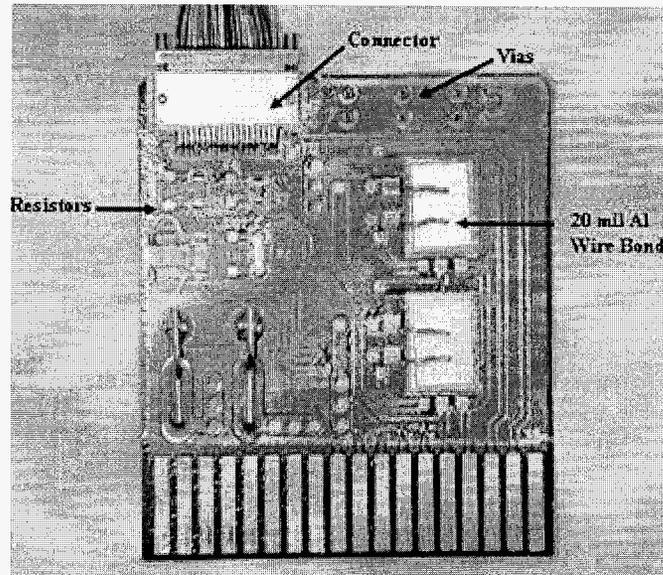


Figure 3: PWA TV

Table 6: Functionality results of PWAs before and after HPGP treatment

TV S/N	Time	Continuity/ Resistance Measurements (Ohms)					
		Via	Resistor 1	Resistor 2	Resistor 3	Resistor 4	Connector
PWA with Parylene C #1	Before HPGP	0.3	1,000	100.4	100.1	100	1.3
	After HPGP	0.3	1,001	101.2	100.1	100	1.3
PWA with Parylene C #2	Before HPGP	0.4	1,001	100.1	100.1	99.9	1.2
	After HPGP	0.3	1,000	100.4	100.1	99.9	1.2

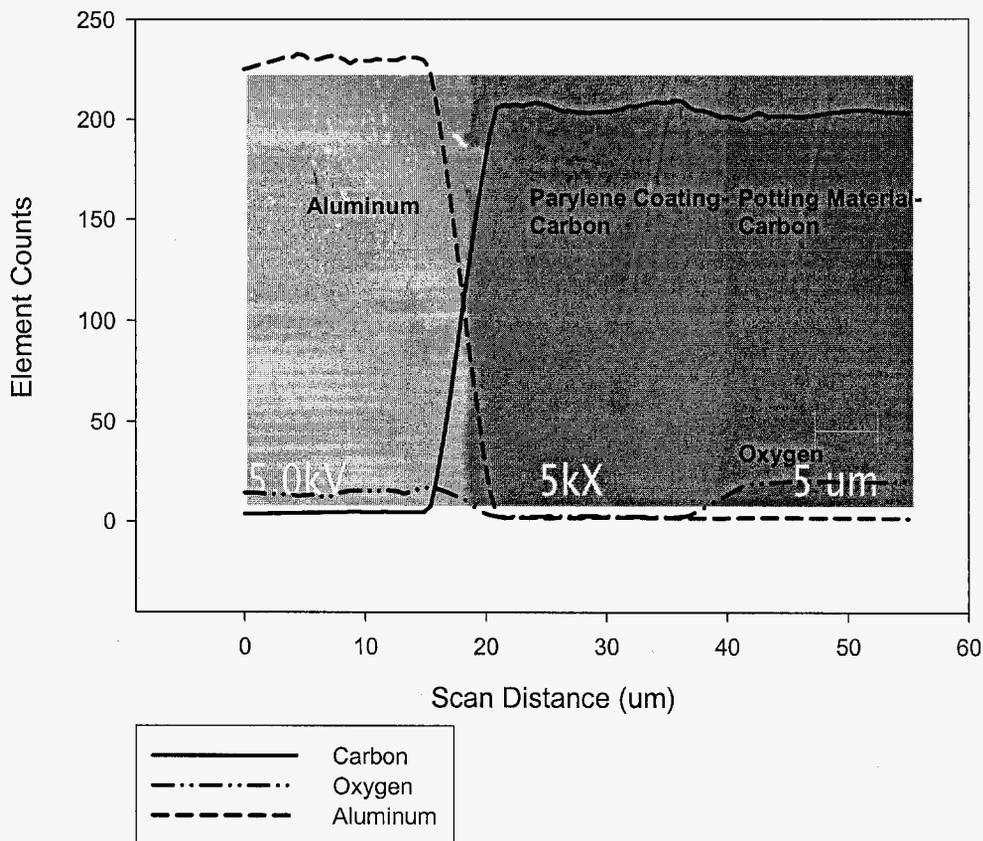


Figure 6: 20 mil aluminum wire bond with Parylene C coating with HPGP treatment at 5kX/5keV

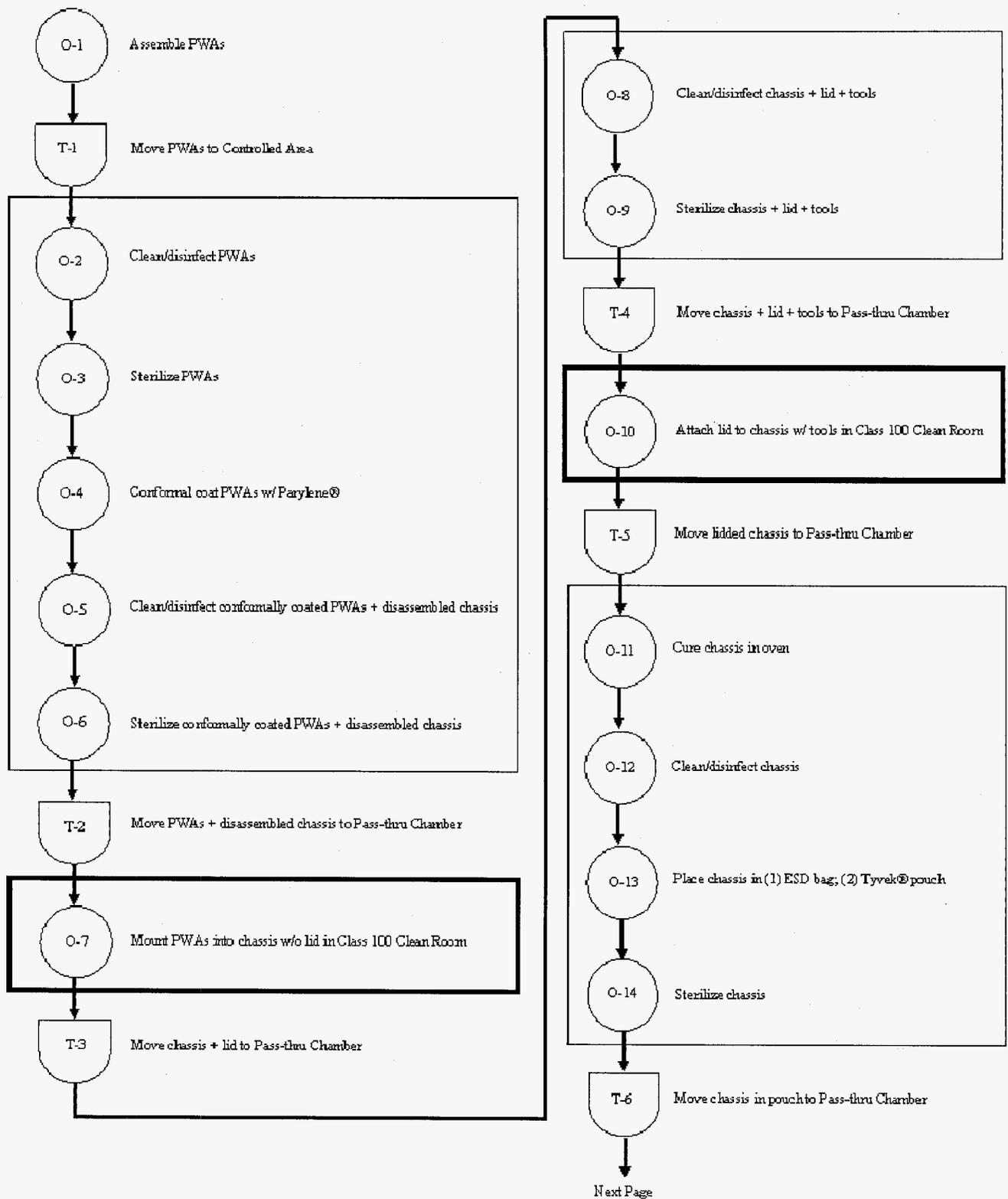
6.0 Conclusions

The following results of this feasibility investigation demonstrate that using IPA and HPGP can be a very advantageous, alternative planetary protection (PP) treatment. These results are:

- The average bioburden recovery of each type of TV was a function of handling (resulting in a higher bioburden) or environmental testing (resulting in a lower bioburden).
- IPA aids in the microbial reduction process of mechanically removing spores and killing nonspores on the PWAs, the bare PWBs with immersion silver plating, and silicon die with strain gauge and Au backside metallization.
- Hydrogen peroxide gas plasma (HPGP) successfully killed all spores using two sterilization injections or 16 minutes of vapor exposure at 50°C on all PWAs, bare PWBs with immersion silver plating, and silicon die with strain gauges and Au backside metallization. Therefore, it is feasible to obtain a SAL of 10^{-6} for the packaged electronics under the full cycle conditions (with four injections or 32 minutes of exposure time) in the industrial HPGP Sterilizer.
- The PWAs subjected to 10 sterilization injections or 80 minutes (to include margin) of vapor exposure at 53°C for the material compatibility analysis did not reveal any change in resistance or failures after treatment.
- The SEM analysis revealed no change in oxidation thickness on the Al wire through the Parylene C coating, which was subjected to ten injections or 80 minutes of exposure to the HPGP at 53°C. There also does not appear to be any corrosion of the Al wire or degradation of the polymer conformal coating.

7.0 Future Work

New missions may have electronics stored outside of a warm box or exposed to the ambient because of design and/or power restrictions/specifications. For example, rovers with environmentally exposed electronics sent to specifically selected Martian regions or having a perennial heat source may undergo IPA/HPGP planetary protection treatment and thermal cycling from -120°C to 85°C . Experiments investigating the survivability of the electronics through IPA/HPGP and low temperature fatigue conditions are also planned. Actual assembly conditions using IPA/HPGP treatment before



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