Evaluation of the effect of Ageing on the Cleanability of Solder Flux Residues for Spacecraft Electronic Assemblies

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ABSTRACT

The cleaning efficiency of flux residues of various ages were assessed by measuring the ionic contamination removed in an Ionograph 500 SMD. The flux residues were removed from bare boards, and boards with through hole and surface mount components. The effect of different temperature ageing was also investigated. The work has shown that there is a maximum time interval following assembly during which cleaning should be carried out. The ionic contamination of aged assemblies with through hole and surface mount components were cleaned with varying efficiencies. The surface mount components were more difficult to clean. The use of brushing and scrubbing proved particularly beneficial for the through hole components. A proprietary cleaner proved more effective than the alternatives considered.

1 INTRODUCTION

The European Space Agency (ESA) specifications for hand soldering (ref 1) and the assembly of surface mount devices and mixed technology components on printed circuit boards (pcb's) by soldering (ref 2) have evolved during the last 25 years and are soon to be revised. These are the main "soldering" specifications which are followed by the 75 or more companies throughout ESA's 14 Member States which have been contracted to assemble electronic hardware for spacecraft such as telecommunications satellites, weather satellites, the International Space Station, the Ariane launch vehicles and scientific satellites and probes.

Several questions have been raised during the updating of the soldering specifications, some of which are of a technical nature and related to practical aspects of component assembly. This paper addresses a short research programme to assess a problem concerning the present requirements for cleaning flux and its residues from the surface of pcb assemblies. Although once permitted, the ozone depleting solvents (ODS) such as trichlorotrifluoroethane, are now forbidden and reference 1 only now permits the use of certain alcohols as well as deionised water.

One part of this work was to assess the effectiveness of certain new cleaning liquids in the removal of common fluxes and their residues and compare their performance against that of permitted present-day cleaning liquids. However, the overall programme addressed a longstanding question: What duration of time, and under what conditions of temperature, can assembled (and repaired/modified) pcb's be left before they are submitted to cleaning processes?

The present specifications state that after the solder has solidified and cooled, flux and residue shall be carefully removed immediately after the soldering operations. Certainly spacecraft electronic circuits must be extremely clean; experience has shown (from ref 3) that residual flux can result in the stress corrosion cracking of component leads, galvanic corrosion and the growth of electrically conductive tin-lead filaments which can result in short circuits between the tracks on pcb's. Also, under vacuum conditions, because up to 48% of the flux mass will outgas into space (with 12% condensing onto adjacent surfaces) it can be appreciated that flux residues may lead to corona discharge and the contamination of other spacecraft surfaces.

In brief, the objectives of this study were to:

- Recommend maximum intervals between cleaning operations
- Recommend cleaning method and solvent (based partly on previous ESA study)
- Recommend method for removal of badly aged/polymerised flux

These objectives were addressed in three phases.

2 THE TEST PROGRAMME

2.1 MATERIALS

A multi-purpose test pcb was selected which comprised a simple FR4 board with provision for through hole and surface mount resistors, as shown in Figure 1.

A pure rosin flux with no activator, (Multicore type SMNA) was used during Phase 1 tests in order to assess the use of the Ionograph contamination test equipment and its use for the removal of a simple non-activated flux that had been applied, then "aged", onto the pcb surface for various times and temperatures.

For assembly tests a flux-cored solder wire (Metallwerk Goslar to reference 1) and solder paste (Multicore type Sn62RM92AGS90) were selected in order to duplicate the materials and processes used by some ESA contractors. Five boards were tested for each of the conditions described in Phase 1, Phase 2 and Phase 3) of this study.

In order to simulate the soldering processes used by ESA contractors both the fluxed bare boards, and the boards with applied solder paste plus surface mount components, were run through an infrared soldering oven set to the predetermined temperature/time profile shown in Figure 2. This process had the effect of activating the various fluxes and creating residues very similar to those found on actual pcb assemblies.

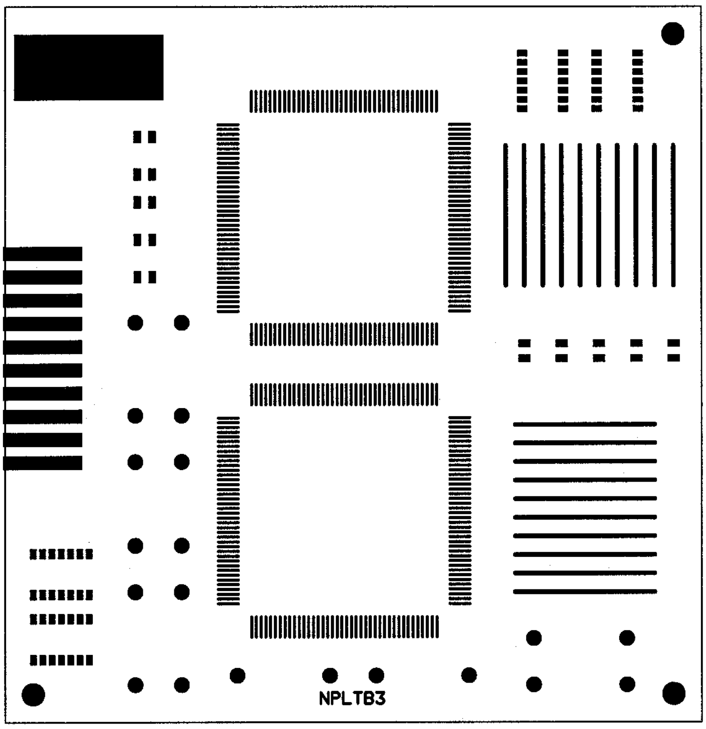

Figure 1: Layout of the test board (Dimensions 95 x 97mm)

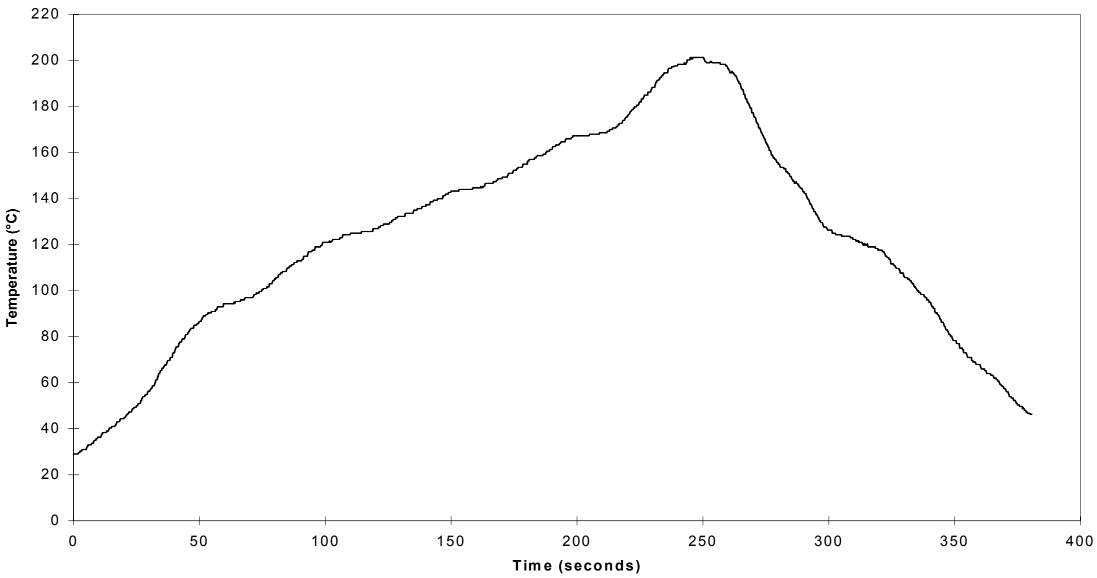

Figure 2: The reflow temperature profile

An Alpha Metals Ionograph 500M with 75% iso-propyl alcohol (IPA) plus 25% de-ionised water extract solution at 45 C was used for all the contamination measurements. This contamination test followed standard procedures (the limits for which are 1.6 μg/cm² eq

NaCl ionisable flux residues as prescribed in reference 1). Simply, the machine dissolves off from the PCB all the soluble material, and passes this solution first through a conductivity cell and then a ion column to clean the solution. This solution is continually recycled around the machine. During a test the machine integrates the current in the conductivity cell to produce the total ionic contamination dissolved from the board.

2.2 THE WORK PLAN

The work was split up into three phases.

Phase 1: Flux residue testing on bare boards

A standard FR4 bare board (without resist) fluxed with pure rosin based flux with no activator, (Multicore SMNA) was used. Boards were taken through the standard reflow profile shown in Figure 2. The boards were then stored at room temperature for 8 ages of 1hour, 2hrs, 8hrs, 2 days, 4days, 7days, 14days and 30 days. Further boards following reflow were baked for 1, 2 and 8 hours at 120°C, and 2, 8 and 24 hours at 80°C. All 14 board conditions were tested for ionic contamination in an Ionograph. These temperatures were selected to represent the drying or baking of pcb assemblies prior to additional soldering processes such as step soldering, or hardware submitted to "rework".

Phase 2: Flux residue testing on assembled boards

Test boards were assembled with through hole components using hand soldering and flux cored solder wire. Surface mount components were assembled using solder paste and reflow soldering. The through hole and surface mount components were tested on separate boards. The assembled boards were stored at room temperature for 7 ages of 2 hrs, 8 hrs, 2 days, 4 days, 7 days, 14 days and 30 days. Further boards following assembly were baked for 1, 2 and 8 hours at 120°C. Following storage the assembled boards were cleaned using the standard procedure of vertically immersing the boards in 99.5% pure IPA for 30 seconds at room temperature with no agitation. All 20 board conditions were tested for ionic contamination in the Ionograph after immersion cleaning.

Phase 3: Assessment of Cleaning Methods and Solvents

PCBs were assembled with components in the manner described for Phase 2, and stored under the worst conditions identified in Phase 2. The boards were cleaned by three methods; immersion, immersion and brushing, and immersion and cotton bud scrubbing, as follows:

a) **Immersion**: The boards were immersed for 1 minute vertically in a beaker containing 1000 ml of liquid cleaner.

b) **Immersion and brushing:** The boards were immersed for 1 minute vertically in a beaker containing 1000 ml liquid cleaner and then brushed using bristle brush. The brush was 9mm diameter with 20mm long nylon bristles. Two cleaning actions were applied, depending on the components:
   Through Hole: The brushing action was 10 strokes along the length axis of the through hole resistors and then 10 strokes on the other axis across the joints. This was repeated for both sides of the board.
   SM Components: For the SM components the board was cleaned by brushing for 1 minute total, in the X and Y direction, across all the joints.

c) **Immersion and cotton bud scrubbing:** The boards were immersed vertically in a beaker containing the liquid cleaner and then scrubbed using cotton bud for 1 minute. The scrubbing action procedure was the same as that used for brushing.

Four solvents were assessed during this phase of the study:

- 100% IPA (iso-propyl alcohol) as presently favoured by ESA contractors
- IPA plus 25% de-ionised water (DI water) as used by some contractors
- Safewash 2000*: Novel water-based solvent composed of
  - 75-85% Demineralised water
  - 0-5% Monoethanolamine
  - 5-10% Methoxy propoxy propanol
  - 0-5% Alcohol ethoxylate
  - 0-5% Eucalyptus oil
  - trace Green dye
  - specific gravity 1.002
  - no flash point

- Fluxclene Cleaning Solvent*. Novel solvent composed of
  - 20-35% Methoxy propanol
  - 20-35% Isopropanol
  - 33-40% Proprietary hydrocarbon solvent.
  - 100% ozone friendly - zero ODP
  - Specific gravity 0.78
  - Inhalation toxicity 300ppm
  - Flash Point » 0°C
  - Residue on evaporation < 1ppm

This last phase of the programme resulted in the assembly and testing of 24 PCBs, all of which were cleanliness tested using the standard Ionograph method.

3 PHASE 1: FLUX RESIDUE TESTING ON BARE BOARDS

3.1 Test Conditions

Seventy FR4 bare boards (size: 50x45 mm) were thoroughly cleaned in the Ionograph and then fluxed with 30 µl of the pure rosin flux. Visual inspection of the area of flux coverage on the boards showed they were all very similar, at approximately 25 mm diameter. The board was held at 100 °C for this operation and then taken through the standard reflow profile shown in Fig 2. Some of the boards were then stored at room temperature for the following times: 1, 2 and 8, hours, 2, 4 , 7, 14 and 30 days. Typically the room storage condition was 23 C / 40 % RH. The remaining boards following reflow were baked for 1, 2 and 8 hours at 120 °C, and 2, 8 and 24 hours at 80 °C. All 70 boards were finally tested for ionic contamination by the Ionograph method.

3.2 Results of Testing on Bare Boards

* Trade Names from Electrolube Ltd., Wargrave, UK. These solvents have NOT been assessed for compatibility with the plastics and marking inks making up electronic components and packages.

The average ionic contamination results and standard deviation from five boards for each of the 8 ages at room temperature are given in Table 1 and Figure 3. Note the values are quite high since a high fraction of the board area is fluxed and even what is described as pure rosin flux does possess a degree of "activity". The results are the total contamination divided by the area of one side of the board. In Figure 3 are shown two inserts, typical of Ionograph traces. They show that the contamination was removed with equal speed, independent of storage time. Three ages at 80 ^{o}C and 3 ages at 120 ^{o}C are given in Table 2 and Figure 4, and in Table 3 and Figure 5, respectively.

Table 1

The average ionic contamination results as a function of storage time at room temperature

Storage Time (h: hour, d: day)	1 h	2 h	8 h	2 d	4 d	7 d	14 d	30 d
Ionic contamination (µg/cm^2 eq. NaCl)	5.85	6.20	6.91	5.72	6.57	5.97	5.20	5.75
Standard deviation σ_{n-1}	0.10	0.10	0.22	0.11	0.36	0.60	0.24	0.22

Table 2

The average ionic contamination results as a function of storage time at 80 ^{o}C

Storage Time (hours)	2	8	24
Ionic contamination (µg/cm^2 eq. NaCl)	6.42	7.86	7.06
Standard deviation σ_{n-1}	0.20	0.24	0.33

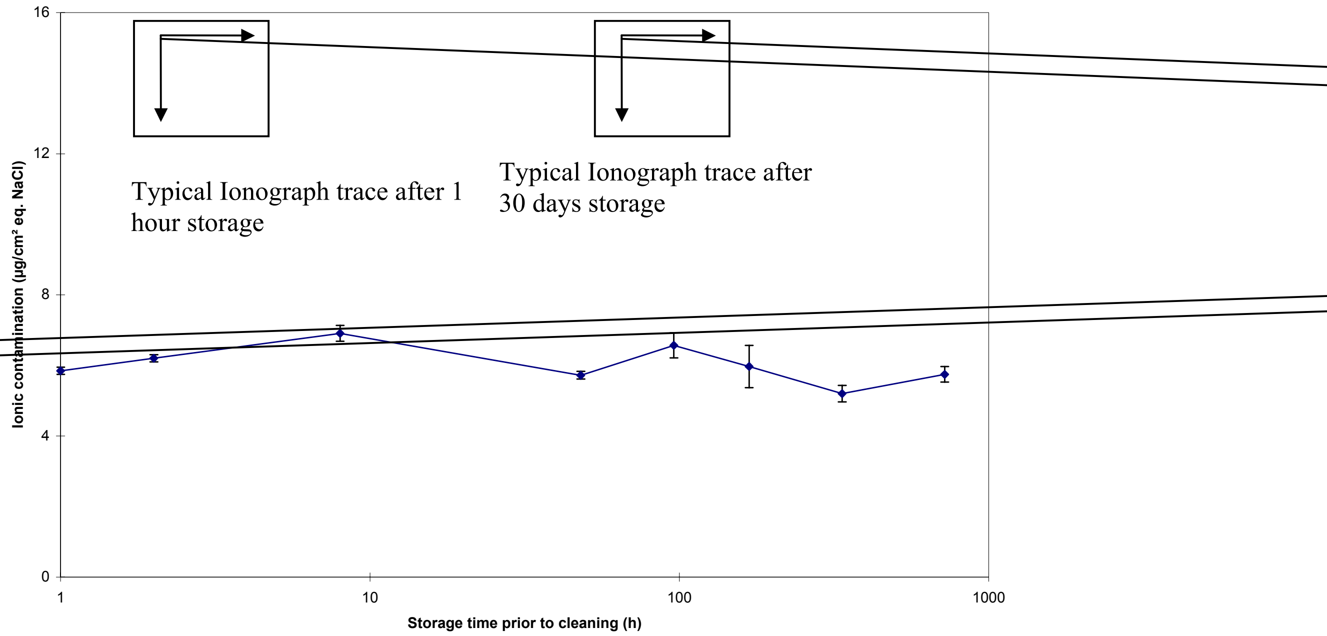

Figure 3: The average ionic contamination results as a function of storage time at room temperature

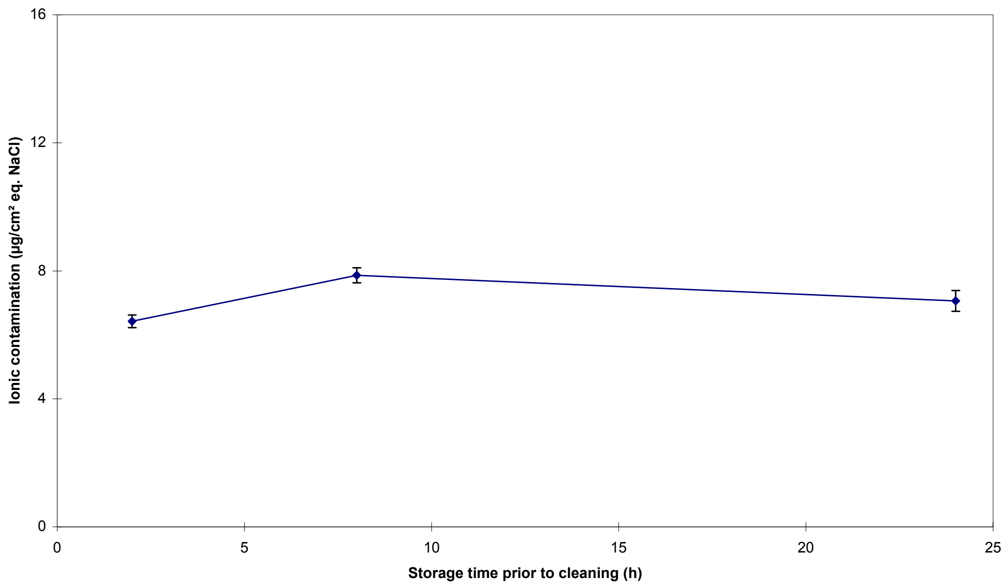

Figure 4: The average ionic contamination results as a function of storage time at 80 °C

Table 3

The average ionic contamination results as a function of storage time at 120 °C

Storage Time (hours)	1	2	8
Ionic contamination ($\mu g/cm^2$ eq. NaCl)	6.50	6.74	7.92
Standard deviation σ_{n-1}	0.28	0.28	0.30

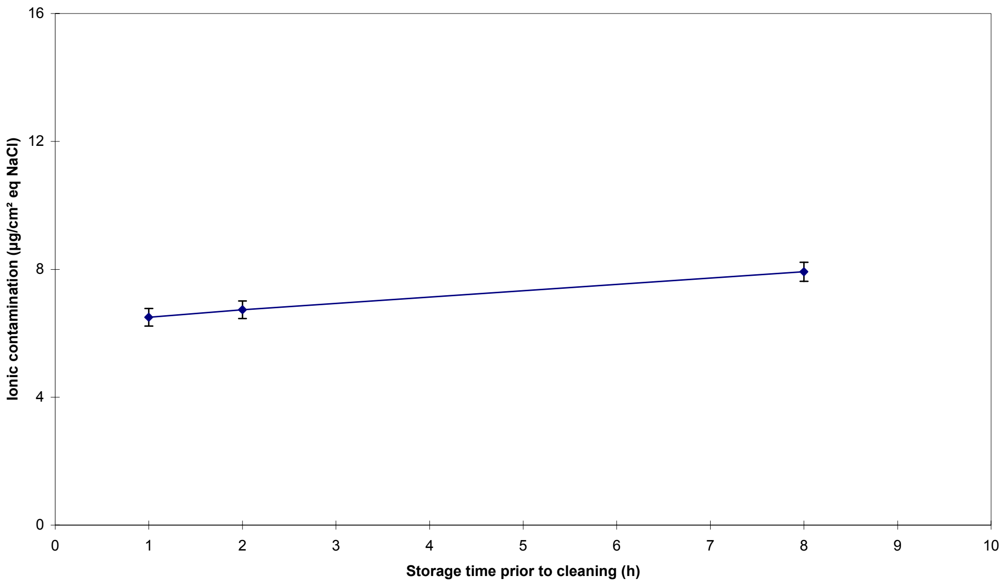

Figure 5: The average ionic contamination results as a function of storage time at 120 °C

3.3 Discussion of Testing on Bare Boards

The results from the three storage conditions all show comparable levels of ionic contamination being removed . There are no dramatic changes in measured contamination levels with storage time. There is a small increase in contamination removed in the first 8 hours for all storage conditions, which then slowly decreases for room temperature and 80 °C. The measured contamination level at 8 hours does show a small increase with temperature: 6.91, 7.86 and 7.92 for respectively room temperature, 80 °C, and 120 °C ageing temperatures. Activated flux residues are known to penetrate into the epoxy top coat of FR4 PCB substrates (ref 3). These results indicate that elevated temperature storage can cause these natural ionic activators to diffuse to the PCB surface at a greater rate than when storage is at room temperature.

3.4 Summary of Testing on Bare Boards

Storage of contaminated bare boards in different environments did not indicate any particular problem, hence the storage temperature is not important in affecting the measured ionic contamination level. There are no dramatic changes in contamination levels with storage time for this particular non-activated rosin flux. Hence, the interval between assembly and the cleaning operation is not an important matter.

4. PHASE 2: FLUX RESIDUE TESTING ON ASSEMBLED BOARD

This work was split into two parts: through hole and surface mount components. 100 boards were used for this part, all the boards being cleaned prior to any assembly.

4.1 Test Conditions

4.1.1 Test boards with through hole components

The cleaned boards were assembled with ten leaded resistors for through hole mounting, using hand soldering and 10 cm of the supplied flux cored solder wire for each board according to reference 1. The boards were stored at room temperature for 7 ages: 2 and 8 hours, and 2, 4 , 7, 14 and 30 days. Further boards were baked for 1, 2 and 8 hours at 120 ^{o}C. Following the storage period and prior to Ionograph testing, the assembled boards were cleaned by immersion in IPA for 30 seconds at room temperature. All 50 boards were tested for ionic contamination in the Ionograph. When calculating the contamination for the through hole components the board area was calculated using both sides of the board, in $\mu g/cm^2$.

If boards were not cleaned, and tested immediately after assembly, the contamination level was approximatley 1.36 $\mu g/cm^2$. Note that the present ESA maximum limit for contamination of "cleaned boards" is 1.6 $\mu g/cm^2$. Although the measured value of 1.36 $\mu g/cm^2$ is acceptable, here we are interested in the trend in contamination level with time and not the absolute value.

4.1.2 Test boards with SMT components

The stencil printing was carried out in two parts. The first part was with a limited number of SM pads printed. The contamination level from these boards was small, so a modified stencil was used that printed all the surface mount (SM) pads on the test board shown in Figure 1:

Part 1

The boards were printed at 22°C/40%RH. The SM foot prints were 10 x SMT resistors 0805 and 4 x SOIC 14 pins. The printed boards were assembled with ten SMT resistors 0805 and four SOIC 14 for each board and then taken through the standard reflow shown in Figure 2. The boards were then stored and tested. The board area for these SM component PCBs was calculated using only one side of the board (since they were single sided), when calculating the contamination in $\mu g/cm^2$.

Part 2

Since the contamination level was low in Part 1 of this Phase, the stencil was modified to print more solder paste, this time on all the SM pads of the test boards. Fifty cleaned test boards were printed using the modified stencil. These printed boards were taken through the standard reflow as before in Part 1 but without any mounted components. The boards were then stored and tested.

4.2 Results of Testing on Assembled Boards

The average ionic contamination results and standard deviation for five boards stored at room temperature for 7 ages with through hole components are given in Table 4 and Figure 6, and the 3 ages at 120 ^{o}C are given in Table 5 and Figure 7. Similarly, the results for surface mount components at room temperature given are given in Table 6 and Figure 8, and for 120 ^{o}C in Table 7 and Figure 9. The results for the surface mount components Part 2 at room temperature are given in Table 8 and Figure 10, and at 120 ^{o}C in Table 9 and Figure 11.

The contamination levels here when using components are typically lower than those seen in Phase 1 where the flux was applied directly to a large area of the board.

Table 4

Ionic contamination results as a function of storage time at room temperature for through hole components

Storage Time (h: hour, d: day)	2 h	8 h	2 d	4 d	7 d	14 d	30 d
Ionic contamination (µg/cm^2 eq. NaCl)	0.86	0.87	0.94	1.14	1.26	1.37	1.36
Standard deviation σ_{n-1}	0.05	0.04	0.04	0.06	0.07	0.04	0.05

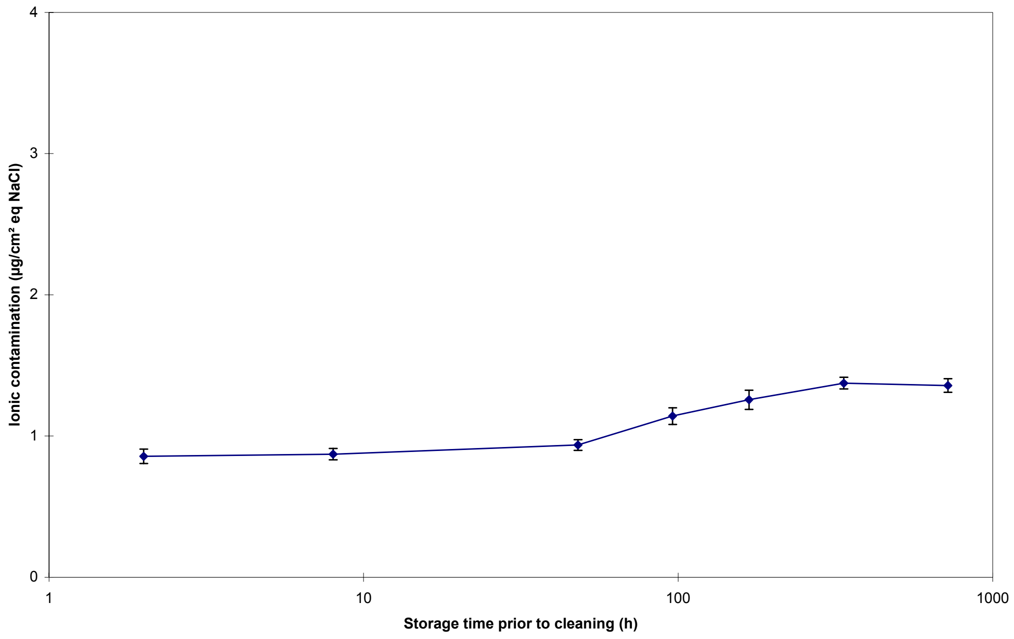

Figure 6: Ionic contamination as a function of storage time at room temperature for through hole components (immersion cleaning only)

Table 5

The average ionic contamination as a function of storage time at 120 ^{o}C for through hole components

Storage Time (hours)	1	2	8
Ionic contamination (µg/cm² eq. NaCl)	0.81	0.84	0.94
Standard deviation σ_{n-1}	0.06	0.02	0.03

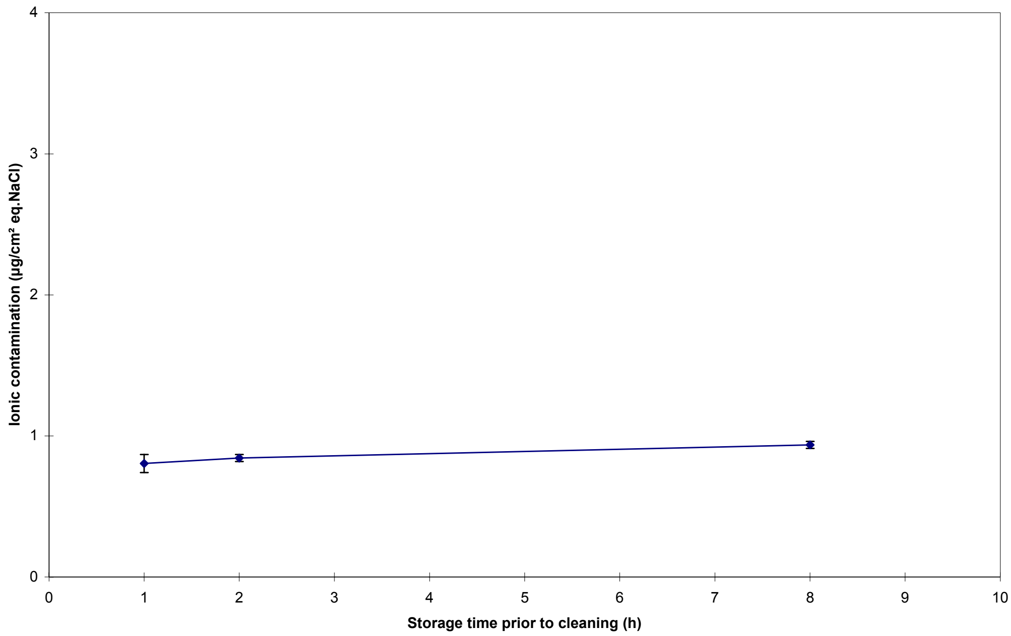

Figure 7 Ionic contamination as a function of storage time at 120 °C
for through hole components (immersion cleaning only)

Table 6

Ionic contamination results as a function of storage time at
room temperature for surface mount components (Part 1)

Storage Time (h: hour, d: day)	2 h	8 h	2 d	4 d	7 d	14 d	30 d
Ionic contamination (µg/cm² eq. NaCl)	0.50	0.51	0.55	0.51	0.57	0.71	0.94
Standard deviation σ_{n-1}	0.08	0.11	0.05	0.05	0.18	0.20	0.18

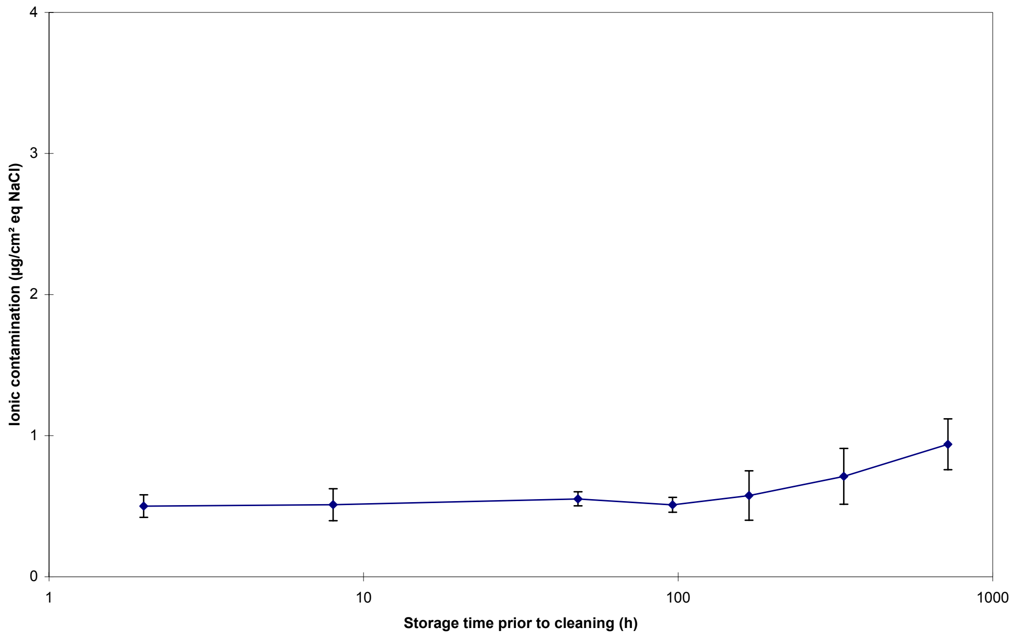

Figure 8 Ionic contamination as a function of storage time at room temperature for surface mount components (Part 1)

Table 7

The average ionic contamination results as a function of storage time at 120°C for surface mount components (Part 1)

Storage Time (hours)	1	2	8
Ionic contamination (µg/cm² eq. NaCl)	0.34	0.44	0.45
Standard deviation σ_{n-1}	0.18	0.12	0.13

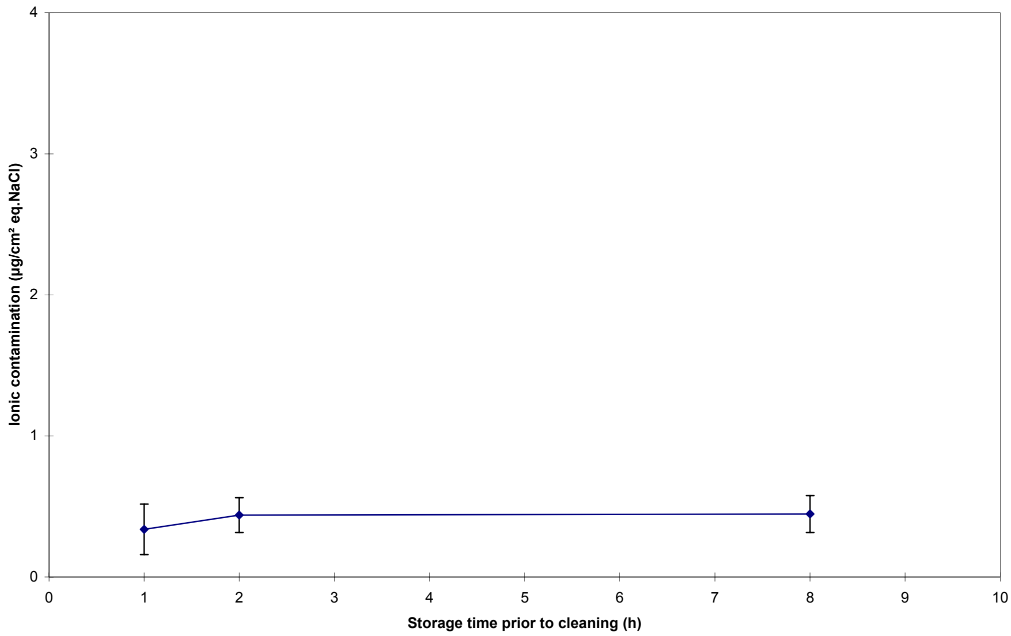

Figure 9 Ionic contamination as a function of storage time at 120 °C
for surface mount components (Part 1)

Table 8

The average ionic contamination results as a function of storage time
at room temperature for surface mount boards (Part 2)

Ages (h: hour, d: day)	2 h	8 h	2 d	4 d	7 d	14 d	30 d
Ionic contamination ($\mu g/cm^2$ eq. NaCl)	1.67	1.67	1.48	1.95	1.64	2.78	2.48
Standard deviation σ_{n-1}	0.16	0.10	0.11	0.15	0.11	0.29	0.43

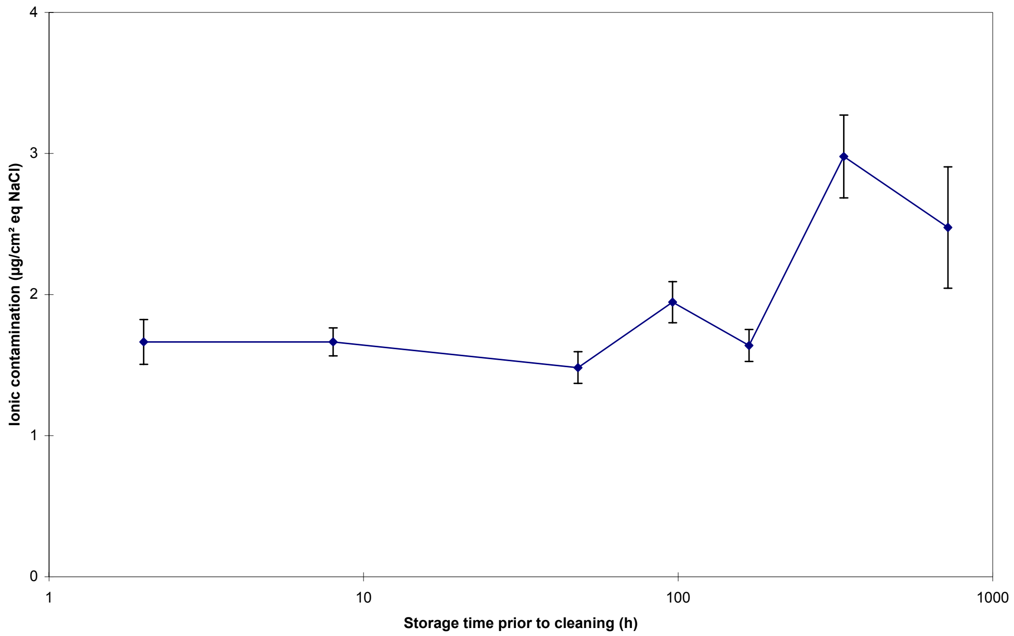

Figure 10 Ionic contamination as a function of storage time at room temperature for surface mount boards (Part 2)

Table 9

The average ionic contamination results as a function of storage time at 120 °C for surface mount components (Part 2)

Storage Time (hours)	1	2	8
Ionic contamination ($\mu g/cm^2$ eq. NaCl)	1.52	1.62	1.77
Standard deviation σ_{n-1}	0.36	0.30	0.15

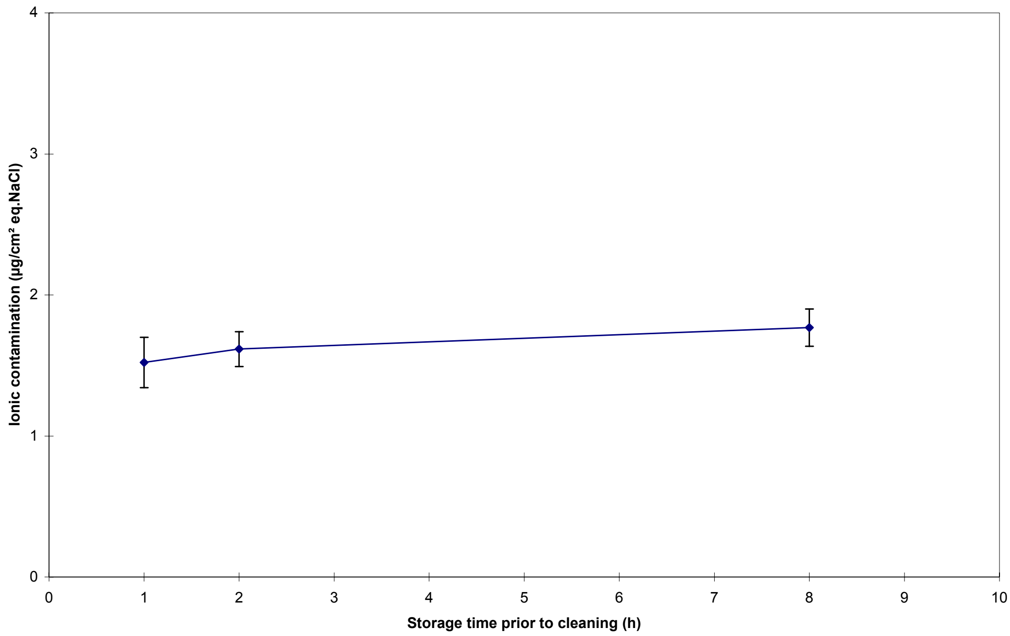

Figure 11 Ionic contamination as a function of storage time at 120 °C for surface mount components (Part 2)

4.3 Discussion of Testing on Assembled Boards

The results for all three tests show very similar trends for the same storage conditions. However, the absolute values do vary between the various components. For both room temperature and 120 °C the measured ionic contamination levels for the first few hours are similar.

The room temperature results for the through hole boards show a significant increase in the measured contamination after 2 days for all three tests. This may be because this type of flux (active flux in the paste) and its residue have became much more difficult to remove by immersion cleaning after this period. The measured contamination level after immersion cleaning became almost constant after two weeks of storage, and is equivalent to the flux residue on the board if it is not cleaned. Hence immersion cleaning is not effective after two weeks storage. This is the case for both the through hole and the surface mount components. So, the allowable storage condition is two days and the highest measured contamination level is achieved after two weeks at room temperature.

There is very little difference between the results of Part 1 and 2 for the surface mount components, except of course the level of contamination.

4.4 Summary of Testing on Assembled Boards

The simple IPA immersion cleaning is only effective for up to 2 days after assembly using the solder paste. The measured contamination level after immersion cleaning increases with storage time for both room temperature and 120°C storage. Any cleaning operation should be performed as soon as possible after the assembly, in order to obtain the best cleaning, certainly the cleaning operations must occur within two days after assembly. The worst storage condition is in excess of two weeks at room temperature.

5 PHASE 3: ASSESSMENT OF CLEANING METHOD AND SOLVENTS

5.1 Test Conditions

One hundred and twenty test boards were assembled, half of them with through hole components and the other half with surface mount components. For the surface mount board all the pads were printed with paste, and SOIC and R0805 components were placed. These assembled PCBs were stored for 30 days at room temperature. Following storage the boards were cleaned by one of three methods: immersion, immersion and brush, and immersion and cotton bud scrubbing for 60 seconds. The four solvents listed in Section 2.2 were used. Three cleaning methods have been detailed in Work Plan, Phase 3. With Safewash 2000 the boards were finally rinsed twice in distilled water as part of the cleaning process, because of the high ionic concentration of the cleaner. The rinsing action was to hold the boards horizontally in the first distilled water container and move them from side to side 10 times, and then to hold them vertically in the second distilled water and pulled up and down 10 times, inside the liquid. The distilled water was changed for every 5 boards

5.2 Results of Different Cleaning Methods

The average ionic contamination results as a function of cleaning method for the boards with the through hole components after different cleaning procedures are given in Table 10 and Figure 12. Similarly, the results for the boards with surface mount components are given in Table 11 and Figure 13. Again the board area used in the calculation was both sides for the through hole components and one side for the SM components. Note that the present acceptance level for assembled pcbs is 1.6 μg/cm^2 eq NaCl as given in Reference 1.

Table 10

Ionic contamination results for boards with through hole components after different cleaning processes (30 day storage prior to cleaning)

Cleaner	Immersion		Immersion and brush		Immersion and scrubbing	
	Ionic contamination (µg/cm² eq. NaCl)	Standard deviation (σ_{n-1})	Ionic contamination (µg/cm² eq. NaCl)	Standard deviation (σ_{n-1})	Ionic contamination (µg/m² eq. NaCl)	Standard deviation (σ_{n-1})
100% IPA	1.07	0.06	0.42	0.05	0.49	0.04
25% DI water	1.05	0.09	0.55	0.04	0.60	0.04
Safe wash 2000	0.88	0.03	0.36	0.03	0.38	0.03
Solvent cleaner	0.37	0.04	0.33	0.04	0.34	0.03

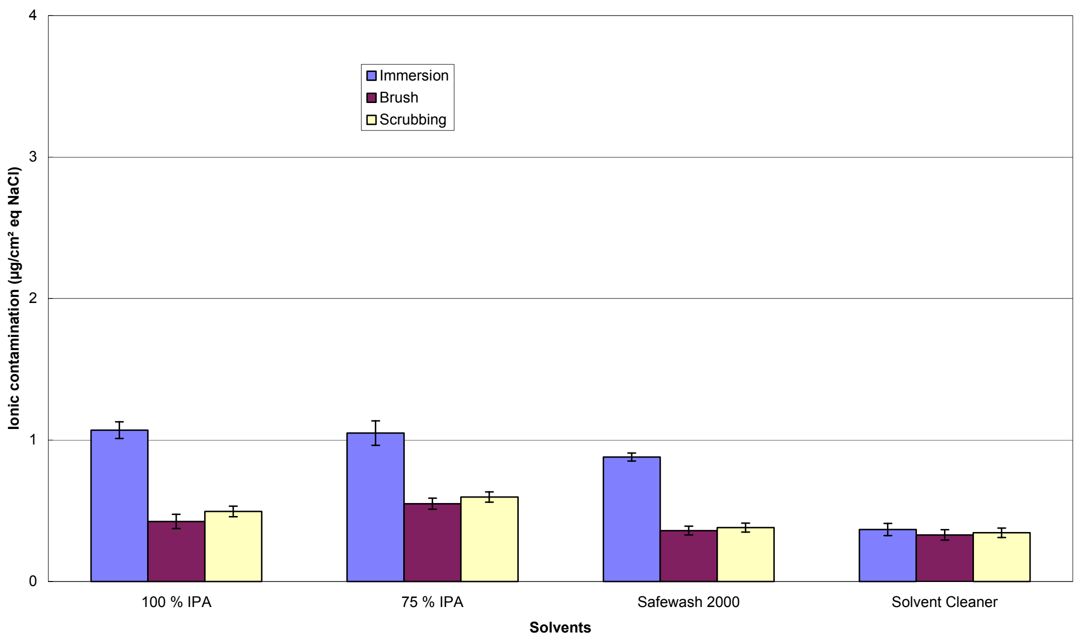

Figure 12 Ionic contamination of through hole boards after different cleaning processes (30 day storage prior to cleaning)

Table 11

The average ionic contamination results for boards with surface mount components after different cleaning processes (30 day storage prior to cleaning)

Cleaner	Immersion		Immersion and brush		Immersion and scrubbing	
	Ionic contamination (µg/cm² eq. NaCl)	Standard deviation (σ_{n-1})	Ionic contamination (µg/m² eq. NaCl)	Standard deviation (σ_{n-1})	Ionic contamination (µg/cm² eq. NaCl)	Standard deviation (σ_{n-1})
100% IPA	3.04	0.28	2.58	0.21	3.06	0.24
25% DI water	2.45	0.14	2.45	0.21	2.50	0.21
Safe wash 2000	2.78	0.36	2.64	0.40	3.44	0.67
Solvent cleaner	1.42	0.31	0.74	0.17	0.71	0.15

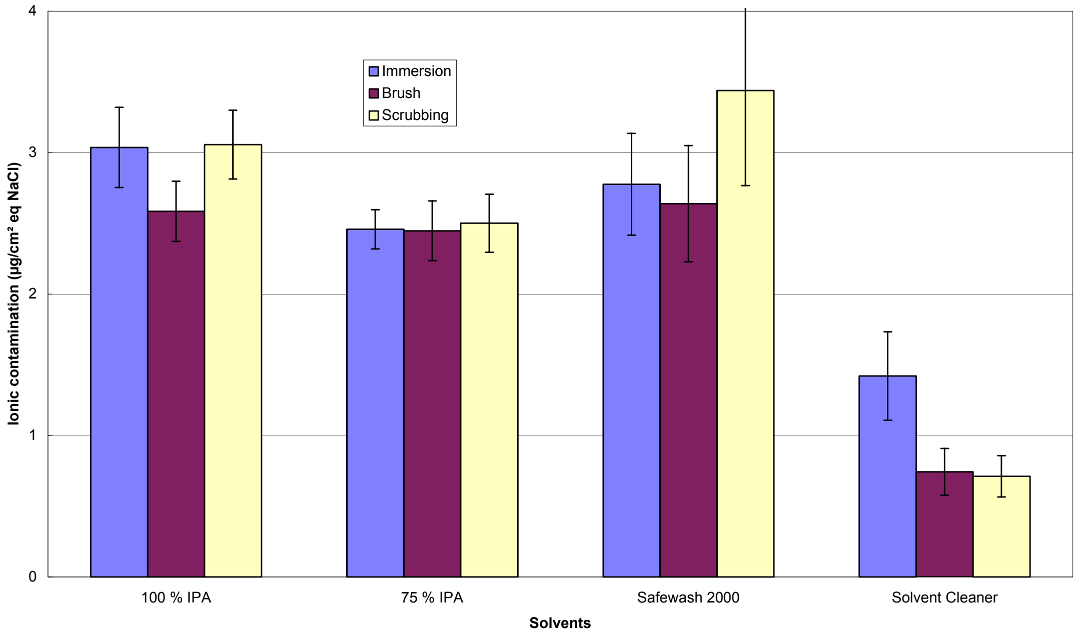

Figure 13 Ionic contamination of surface mount boards after different cleaning processes (30 day storage prior to cleaning)

5.3 Discussion of Different Cleaning Methods

The results show that the aged assemblies can be cleaned to varying degrees by these four solvents and three cleaning methods. The proprietary liquid solvent cleaner gave the best cleaning results for both assembled board types. It can dissolve the flux residue from the board by immersion without the need for any physical brush and scrubbing. For the other solvents brushing and scrubbing have significant advantages for through hole boards.

For surface mount boards the cleaning method is not so significant, reflecting the difficulty in manual cleaning of flux residues from SM components. The contamination level and the variation in level for surface mount boards is also much higher than for through hole boards after the different cleaning regimes. This is probably because it is more difficult to remove flux residues for surface mount components than through hole components.

5.4 Summary of Different Cleaning Methods

The liquid solvent cleaner gives the best clean for all types of assembly. There is little difference between the other three cleaning solutions.

For through hole components brushing appears to be slightly better than scrubbing and is far superior to plain immersion.

Surface mount components are more difficult to clean than through hole components. For the SM components the cleaning method only appeared to be significant with the solvent cleaner. Only this cleaner produced results that were compliant with the present ESA value of 1.6 $\mu g/cm^2$ eq NaCl.

6 CONCLUSIONS

6.1 The ageing properties of the Metallwerk Goslar fluxed cored solder wire and the Multicore solder paste were very similar but different to the pure rosin flux. The Metallwerk Goslar and Multicore residues showed ageing characteristics that made them difficult to clean after 48 hours storage at room temperature by simple immersion in IPA. Hence, it is recommended that cleaning be carried out within 48 hours of assembly. A 24 hour period would offer a level of safety and might be preferable. Heating the boards to 80 and 120°C did not cause any adverse effects for the time intervals investigated, typical of pre-baked boards.

6.2 The choice of cleaning fluid proved to be very interesting. A proprietary Solvent Cleaner outperformed the other solvents by a significant margin, a factor of 2, for simple immersion cleaning. For surface mount (SM) components this is particularly significant since brushing and scrubbing had little influence. The other three solvents did not show any marked difference in performance. Hence there is little advantage of using pure IPA and IPA with distilled water. The aqueous based solvent offered no cleaning benefit over IPA.

6.3 The difference with agitation methods was marked for the through hole components. Brushing and scrubbing were both far more effective than simple immersion. Brushing was slightly more effective than scrubbing. For the SM components brushing and scrubbing had no effect with the IPA solutions and aqueous based solvent, but a similar effect to the through hole components with the solvent cleaner. The through hole components proved far easier to clean than the surface mount components, as might be expected, since the stand off and apertures are far smaller with the SM components. Cleaning efficiency increases with the fourth power of the stand off height increases(ref.4). Further work needs to assess the compatibility of these novel solvents with the various materials and marking inks utilised in the manufacture of spacecraft electronics.

6.4 Overall the work shows that cleaning within 24 hours of assembly should be mandatory. The use of brushing is recommended, (scrubbing with cotton buds may leave small amounts of debris) particularly for through hole components. The cleaning solution can have a big effect and the use of proprietary solvents may offer significant cleaning advantages. The use of SM components present more problems in terms of cleaning than through hole components.

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