MANAGING THE TRANSITION ON A GLOBAL SCALE -- CHANGING THE CLEANING AGENT MEANS CHANGES TO EQUIPMENT, PROCESSES, PROCESS CONTROL SPECIFICATIONS AND STANDARDS

by

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I. INTRODUCTION

The production of electronics began with hand soldering, followed by manual cleaning, which reached its peak during the NASA program. Each step in the process tended to be considered on a stand alone basis, without thought being given to the preceding and following steps. Since each step had its own set of specifications, this led to a "patchwork" approach to overall quality. Recognized as a serious problem in the late '70s, when excessive solder defect rates were traced to a mis-match in printed wiring board solderability and permissible flux strength requirements, industry and DoD personnel started work on a unified soldering requirement. The crash drive to remove ozone layer depleting substances from electronics accelerated the trend to fully integrated process and material requirements and documents.

II. OVERVIEW

Several separate but related efforts were *running in parallel throughout the* late '70s into the '90s. The first track consisted of proper alignment of the solderability and soldering materials requirements for both boards and components to ease the assembly process. The second, driven by surface mount technology, centered on using more aggressive cleaning processes. In this case the process could include a more aggressive solvent, a more aggressive process (ultrasonics) or a combination of both. The third track consists of the CFC and Alternatives Benchmark, Phase 2 and Phase 3 programs, carried out by an industry (IPC), environmental (EPA) and military (DoD) cooperative team.

III. CHANGES

Track 1: Solderability and Soldering Materials

Printed Wiring Board Fabrication: The "October Project", a team of fabricators, assemblers and suppliers drawn from the IPC membership, has an ambitious charter to minimize waste, reduce costs and enhance competitiveness of team members. Waste minimization will be driven by use of additive processes and very tight dimensional stability requirements of the incoming laminate and outgoing product. Topology control will help the assembler meet Six Sigma requirements during the placement and subsequent assembly processes. New technologies are needed to generate processes with the robustness needed to achieve high yields with minimal environmental impact. These advances will take place in PWB fabrication, with the fabricator applying the solder to the PWB in a controlled manner, tailoring the pads for minimal defects in the placement, reflow and optionally, cleaning, operations, which will comprise the assembly process floor of the future. The processes the PWB fabricator will be using to facilitate UFP are described below. The first involves electroplating, with its environmental concerns, while the others provide "Photo-Defined Solder Deposits (PDSD's) (Freidrich, Weinhold, Maiwald). These latter technologies have been incorporated in the new IEC TC91 (Surface Mount) Assembly Process documents (Solberg).

Plated Solder Bumps: Since plating with solder is a well-known technique used in the PWB industry, some companies are using this technology to apply "solder bumps" with a thickness of 100 um or more. This technology produces a flat land pattern ideal for surface mounting, but requires the use of a second dry film resist, with a thickness in excess of 60 um, to prevent overplating. Since the time spent in the Sn/Pb plating baths to obtain the solder bumps can be as long as 90 minutes, and since two layers of dry film resist must be processed and stripped, manufacturing times are longer, chemicals consumption is higher, resulting in higher PWB manufacturing costs.

These plated deposits do not melt at the same eutectic point as Sn/Pb, so a reflow solder process is needed. However, this would destroy the flat surface profile of the surface mount land pattern solder pad. This means that the solderability of plated solder deposits is not as good as that of reflowed Sn/Pb. Thus a more highly activated flux is required during component soldering which then requires a more intensive assembly cleaning process. The additional fabrication costs for the plated solder bump are relatively high, but these additional costs can be offset by reduced assembly costs, since the process of stencil printing solder paste onto the board is eliminated. Where only a few assemblies are involved, costs can even be reduced, since there are no stencil set-up costs and the inconvenience of having stencils in the assembly area plus a cleaner for them is avoided.

In some cases, plated solder bumps are the only possible solution for applying a well-defined amount of solder onto fine-pitch surface mount PWBs, provided that Sn/Pb plating will be suitable, since not all solder alloys can be electroplated in this fashion.

OPTIPAD*: A temporary polymer mold is used to define the SMD land pattern area. Molten solder is then deposited on the land pattern to form the solder deposit.

Process description: After the finished PWB panel is solder masked and HASL'd, but before profiling, a temporary solder mask is applied to the manufacturing panel and then processed in the usual manner to provide a polymer "mold" for the SMD lands. After the temporary solder mask has been cured, molten solder is applied to the total panel using patented OPTIPAD solder coating equipment. This equipment forces the solder under pressure into the polymer molds of the SMD land pattern. A membrane then seals the molten solder in the mold until it has cooled and the solder is "frozen" into a solid metal deposit with a flat surface. Next, the temporary solder mask is stripped off. The manufacturing panels are then profiled to either assembly panel or final board size, are cleaned, dried, tested and shipped to the assembler.

In this process, the thickness of the solder deposit is determined by the thickness of the temporary solder mask which is used. Since this mask is a photo-definable polymer, the resolution and line definition is pre-determined by the photo-polymer which is used. With a 125 um (5 mil) thick solder mask, it is possible to manufacture pitch sizes of 300 um (12 mils). Although the solder coating equipment is not yet available on the market, prototype boards can be manufactured to demonstrate the capability of the process for mass production as well as for faster manufacturing through-put at the PCB assembler. Micrographs of lands on a PWB which have been manufactured using this process clearly show that the thickness of the lands are greater than the solder mask which surrounds the pads. In general, the thickness of the solder is between 120 and 130 um (about 5 mils). This technology has been designed to provide a solid, even metal deposit on the SMD land pattern. The composition of the deposited metal alloy depends on the type of solder which is used in the OPTIPAD solder coating machine, and can be changed according to the requirements of the user. Since the stencil printing of solder paste is no longer necessary, the process speeds up and simplifies the soldering process in the assembly area. Also, it is not dependent on being able to electroplate the desired soldering alloy.

SIPAD: The third process which will enable the PWB fabricator to supply to the assembler circuits with a solid, flat solder deposit is the SIPAD process developed and patented by Siemens AG, in Germany.

Process description: The SIPAD process is used on the finished printed circuit board after solder masking. The solder mask used in this application should have a thickness of 100 um, this thickness being important since it is this which determines the amount of solder applied to the surface of the circuit.

The surface of the printed circuit board is first of all activated, after which the solder paste is stencil printed onto the SMD solder land areas. It is necessary to use a stencil to ensure that the deep well formed by the solder mask is filled with the right amount of solder paste. An activated solder paste can be used which may give a more homogeneous solder deposit after reflow. After the solder paste has been re-flowed, the meniscus of the molten solder is flattened using a hot metal plate. The metal plate is cooled down to a temperature below the melting point of the solder, so that the solder freezes inside the solder mask well. The pressure imposed by the metal plate produces a flat surface which is virtually level with the surface of the solder mask. The surface is cleaned after the panel has reached room temperature. Since no components are attached to the surface, cleaning can be undertaken very effectively in standard cleaning equipment used in the PWB fabrication or assembly processes. The viability of this technology has been demonstrated for circuits with a centre-to-centre pad distance of down to 400 um. However, as stencil printing and solder pastes are used in this process, the limitations inherent in stencil printing technology need to be taken into consideration. On the other hand, since the application of the solder paste is undertaken in the PWB production environment, on a highly activated copper surface, solder wetting of the land pattern for the fine-pitch components can be achieved more easily than if the lands are wetted after the PWBs have been shipped, stored and even baked before the application of the solder paste. The solder paste, which has been forced by this process into a clearly defined three-dimensional well, will have longer guaranteed storage times than if the HASL process had been used.

Printed wiring boards must have much tighter dimensional tolerances to minimize the compensation that is generally built into the remainder of the process equipment, as proposed by the October Project members. While the use of additive plating will minimize waste in fabrication, the process is slower and will require the development of an aqueous processable resist that can withstand the exposure to the harsh additive chemistry and conditions. Surface Insulation Resistance (SIR) 3-4 decades above the values presently available could be easily obtained by simply implementing the commercially available SA fusing fluid/HCS semi-aqueous cleaning technology developed in the mid-'80's (Zachariah, Kenyon) for PWB's requiring a fused tin/lead electroplated surface. Development stage HASL fluids based on the SA technology also provide dramatic improvements in SIR values, compared to current processes. Both processes need to be phased in as rapidly as possible to enhance PWB electrical parameters and overall quality. Meanwhile, processes are becoming available that provide flat pads (Plated Solder Bumps, OPTIPAD*, SIPAD) and solder mask to maximize alignment in placement, provide the controlled volume of solder needed for joint formation and eliminate solder balls. The joining can be accomplished with either the special SA flux described above, followed by semi-aqueous cleaning; or by the use of a fugitive flux whose residues vanish during the reflow process, thus not requiring any cleaning. These technologies should work well on bare copper PWB's currently favored by certain users for cost and environmental reasons, although some of the less forgiving formulations may require an inert atmosphere for minimum solder defects.

The first comprehensive computer controlled electronic assembly process was demonstrated by Westinghouse (Davy), who showed that it was possible to automate the entire fluxing, soldering and cleaning process to maximize yields while reducing the impact of chemical usage. Flux was applied by an airless spray system, which both tailored the amount of flux needed while using fresh flux each time eliminated the typical contamination and changes that occurred in fluxers. Minimal flux meant that the preheaters could be eliminated, reducing energy costs and indirectly, production of greenhouse gases. Automatic adjustment of the conveyor speed according to bar codes on the PWB ensured correct soldering parameters for each part number. The cleaning operation was similarly automated and optimized to ensure minimum chemical usage. While developed to automate the process, this work was the seed for all the environmentally responsive process work that followed.

The advent of Surface Mount brought about step changes in wave soldering, as well as introducing the concept of reflow soldering. To understand the changes in wave soldering, we first have to examine reflow soldering, particularly the use of solder paste. For the first time we saw precise control of the amounts of materials needed to accomplish mass soldering. Exactly the right amount of joining metal (solder) and fluxing formulation were applied to the point where the metallurgical and electrical junction (solder joint) was required. Components were added by high speed automated equipment, followed by mass reflow by contact with a hot gas (air, nitrogen, fluorocarbon) and/or infrared emitting panels or lamps. Cleaning within 15 minutes of reflow was preferred to completely remove all flux residues and solder balls prior to changes in the residue that tended to make it significantly difficult to remove (Lermond). The concept of materials conservation/minimization was extended to the wave solder step that typically followed reflow, in combination with either a turbulent "chip" wave followed by a smooth wave or a single smooth wave containing a variable power oscillating plate to produce micro ripples in the wave surface (Electrovert, Omega wave). Both concepts were aimed at providing pathways for any residual flux volatiles to escape quickly without blocking solder contact with the pad and component terminations that needed to be joined. Preheating was controlled and optimized to prevent chip cracking during wave and reflow soldering, plus eliminating the "drawbridging" or "tombstoning" defects seen with early surface mount processes (Prasad). A new family of fluxes with minimal non-volatile residue appeared in the mid '80s, based on the earlier work of Rubin and the German DIN FSW-32 classification. Typically consisting of 2-4% solids, with 75-80% of the solids being dibasic organic acid activators, they became known as AT or "Activated Thinner" fluxes (Bernier). Designed to have almost quantitative consumption of the solids (activators) during the soldering process, the need for cleaning was generally eliminated. Cleaning was still found necessary in the case of RF circuits or if excessive solder balling was present. Realization of the full potential of these materials did not occur until the development of the ultrasonic spray fluxer by an AT&T team (Guth). Guth's team realized that the high loadings of additives required to promote foaming resulted in unacceptable residue levels and degraded the surface insulation resistance. The new fluxer permits precise control of the flux application process, resulting in SIR levels that are both predictable and in compliance with the exacting Bellcore requirements (Balmer, Culver).

The most recent step in chemical waste elimination and defect reduction took place with the introduction of controlled atmosphere soldering in Germany (Seho). This process used a nitrogen blanket doped with ca. 600 ppm of formic acid as an oxygen "getter" in the soldering machine to allow traditional flux to be eliminated, however a 10% solution of adipic acid in 2-propanol was often substituted to ensure complete oxide removal. Next generation equipment was soon able to maintain the nitrogen blanket oxygen level at < 10 ppm, which eliminated the need for formic acid. Some users are now eliminating the adipic acid in favor of highly controlled application of AT flux. Faced with ever accelerating CFC-113 and 1,1,1-trichloroethane (methyl chloroform) phase-out schedules, industry realized that the days of standard, off the shelf cleaning processes were over. For the first time, many did a thoughtful assessment on the need for cleaning for their product, its end-use environment and the consequences of failure. Many found that instituting a highly controlled low solids (AT) flux plus solderability testing would permit the elimination of the cleaning step with only minimal risk. Process control is crucial for

success, some users reported the need to titrate the AT flux for acid content every 15 min. for complex and critical circuits prior to the implementation of the ultrasonic spray fluxers (Klugman).

Pastes: The genesis of defect free ultra-fine pitch soldering and cleaning occurred in the mid '80's at Westinghouse where first 500 um and later 400 um pitch high lead count VHSIC devices were attached and mass vapor phase soldered without the use of solder paste, adhesives or fixturing. Instead, heavily plated solder pads were coated with a special synthetic activated (SA) flux, the components were placed with a vision placement system, followed by soldering using a computer controlled, heat seeking elevator vapor phase system. The resulting assemblies, which were solder ball free, were easily cleaned in a mild CFC solvent (Keen, Kenyon). While this process produced the most reliable solder joints seen in the VHSIC program (DeVore, Wild), the use of a non-MIL-F-14256 compliant flux prevented its adoption, even when Martin Marietta demonstrated that the same success could not be accomplished with rosin flux that complied with the specification (Love). The Westinghouse work, which also demonstrated the concept of dry film solder mask "frames" around the solder pads to eliminate bridging, lay dormant for many years, as the industry worked from 2500 um pitch to 1250 um to 800 um to 625 um and presently to 500 um and below.

The technology roadmaps developed by many industry leaders are aimed at using 250 um pitch devices in production within three years. Meeting this goal by further modification of traditional solder paste flux formulations to achieve the required printing will probably have a negative impact on the drive to lower post-reflow residue levels. Also, current powder production methods are straining to meet the yields of Type 3 powder needed, thus Types 4-6 will be limited in quantity and pastes made with them will command prices of 3-4 times the present levels. Stencils must be thinner and will be more fragile, especially if the trend to stainless steel squeegee blades continues.

Solder paste today is classified according to the activity of the flux portion, before and after reflow (ANSI/J-STD 004-006) and by the post-reflow residue level as determined by TGA (Beikmohamadi). While all users would like to use a L0 (no halide, non corrosive) Class D (<20% residue), air reflowable solder paste, this is not always possible unless the PWB's and components have been properly manufactured and stored. Solder paste for ultra fine pitch will require new processes to make oxide free powder in high yield in the extremely fine Classes 4-6. In tandem with powder development, solder paste manufacturing processes that provide exactly the same material from lot to lot must be implemented. No Clean extremely low residue formulations that provide sufficient activation to cope with reflow of solder onto bare copper PWB's in air without solder balling will be favored, allowing users to standardize processes world-wide with less concern over costs.

Specifications: Soldering materials specifications, formerly distributed among various military, industry, company, national and international documents have been harmonized into a set of three documents for use world wide, using the U.S. Federal Specification QQ-S-571 as a "shell." (Kenyon, Russell). The three documents, ANSI/J-STD-004, ANSI/J-STD-005 and ANSI/J-STD-006, cover Soldering Fluxes, Solder Pastes and Solder Alloys and Forms, respectively. Incorporating the best thinking from experts world wide, the documents are being formatted for submission to ISO for international acceptance.

Track 2: Cleaning Processes

Cleaning Agents: Initially the advent of SMT drove users from aqueous processes to solvent cleaning, based on the superior Wetting Indices (Kenyon) of the various solvents. However the post reflow paste residues proved more difficult to remove than wave solder residues. Suppliers and users alike attempted to increase the solvency power of their solvent formulations, only to find compatibility problems with materials of construction and marking inks. After some initial problems with attack on the laminate caused by long term exposure to boiling methyl chloroform (solved by implementing tetrafunctional resin systems), it became recognized that boiling ultrasonics combined with a mild solvent offered a preferred route to the desired level of cleanliness.

Ultrasonics: Although well known for its ability to augment the mild solvents preferred for compatibility reasons, early component packages, especially the TO-5 family of metal cased packages, tended to transmit ultrasonic energy to the actual gold or aluminum wires that connected the die to the lead frame. Some evidence was gathered (Martin-Marietta) that showed that ultrasonic cleaning could cause damage to components of the late '60s designs, although it was not clear if this was the more powerful 20-25 kHz units normally used in aqueous cleaning applications, or the gentler 40 kHz that became the standard for use with solvents for electronics cleaning until the advent of today's variable frequency (sweeping) ultrasonics. Once these early metal or metal cased packages were supplanted by the plastic packages, which tended to absorb and attenuate the ultrasonic energy transmitted to the die bond wires, the commercial world embraced ultrasonics as a path to better cleaning in a shorter cycle time. Even the medical world found that ultrasonics provided two advantages over conventional solvent immersion or spray cleaning. First, pacemaker design required "piggy backed" integrated circuits to get the needed packaging density, which created a problem with very small stand-offs between the components mounted in this fashion. Second, "infant mortality" of the components required rework and re-testing, which extended delivery schedules. Ultrasonic cleaning solved both problems by cleaning the tightly packed components while transmitting sufficient energy to weed out the components that would have failed during the "burn in" cycle (Stach and Alexonis, NEPCON East). The "show stopper" to general adoption of ultrasonics was the prohibition found in many military documents. With the advent of surface mount technology, introduced in the U.S. with LCCCs for the military, there was a resurgence of interest in ultrasonics to clean under these packages, once it was clearly shown by the glass slide studies of Hale & Steinacker comparing time to achieve visual cleanliness vs spacing that ultrasonics was the only viable cleaning method that maintained productivity. After reviewing the data, the U.S. Navy EMPF laboratory at China Lake drew up a 3 year test program to re-assess the viability of DoD use of ultrasonics for cleaning the new surface mount designs coming into production using the CFC solvents found in the relevant Mil Specs plus some aqueous materials. Meanwhile, a UK government funded ultrasonic cleaning study commenced at GEC's Hirst Reseach Centre, which included some of the newer cleaning agents, such as the hydrocarbon/surfactant (HCS or Semi-Aqueous) materials being qualified under the EPA/DoD/IPC-Industry Phase 2 program. Presented at the EMPF Soldering Seminar ('MM), the GEC studies showed that ultrasonics was a viable method for cleaning today's surface mount packages, especially with the new non-ozone depleting cleaning agents. The EMPF and GEC teams joined forces to develop a Component Screening & Qualification Protocol, which will be administered through the IPC Ultrasonic Cleaning Task Group. The Task Group will also maintain a list of components that have been tested and qualified. The latest version of the mil specs now allow the use of ultrasonics for cleaning of printed wiring assemblies, provided the contractor has carried out the required screening tests on the components.

Track 3: Alternative Cleaning Agents & Processes

To address the need for a Montreal Protocol driven environmentally preferred material that would "drop into" existing cleaning equipment, a chlorocarbon diluted version of the nitromethane stabilized CFC-113/methanol azeotrope accepted as the industry standard was described in a Tech Brief at the EMPF/NWC Seminar in 1988 (Kenyon). EPA leadership present at the program, recognizing the potential for reduced ozone depletion if such materials were adopted, were surprised to learn that the military specs precluded implementation, however this could be overcome by a test program that demonstrated that the new materials cleaned as well or better than the CFCs currently in use (Andersen, Kenyon). The following morning a core group from EPA, DoD and Industry met to set up the basis of such a test program (Andersen, Kenyon, Steinacker, Johnson, Peacock). This program grew into the CFC Benchmark Ad Hoc Solvents Working Group. The team generated a test board/assembly, wrote a test plan, ran two duplicate sets of tests at two Navy facilities and presented the results at a major IPC meeting, requiring only 14 months to accomplish the entire task. Once the Benchmark for the present standard cleaning agent was set, Phase 2 -- testing of candidate new cleaning materials against this benchmark could commence. This effort, monitored by a TMVT or Test Monitoring and Validation Team, ensures that an oversight group is present for each test, in addition to reviewing the test plan before the test date is set and then reviews the data when the test is complete. The TMVT must decide, based on the data, if the candidate material is better than/equivalent to/not as good as the benchmark solvent. All results are published and available from the material sponsor upon request. Phase 3 of the program allows changes to other parts of the test protocol. Sub-sets of Phase 3 include studies of Water Soluble Fluxes/Pastes, No Clean Fluxes/Pastes and Controlled Atmosphere Soldering. (Turbini, Hymes, Lichtenberg)

While many users converted to "no clean" processes (which often required increased vigilance and testing for solderability) many more found that they could not eliminate the "safety net" provided by a cleaning step in their production line. The choice of cleaning agent for the future fragmented into four general families of materials:

Saponification: an established process for rosin flux removal by chemical conversion of the residue; the conversion process is the rate limiting step in the process, large volumes of aqueous waste to drain.

Aqueous: tap or deionized water, used for water soluble flux removal, large volumes of aqueous waste to drain, concern over heavy metals in effluent.

Semi-aqueous: (also called Hydrocarbon Surfactant, UNEP), a new technology characterized by a hydrocarbon wash step, followed by a water rinse, decanting of the resulting emulsion after it breaks to allow recycle of the hydrocarbon and water. In a recent development, the water is further purified by passage through a membrane cartridge prior to recycle to rinse, thus minimizing the volume going to drain. Semi-aqueous processes can be used to remove rosin, synthetic activated (SA), water soluble and certain low solids (AT) fluxes; thus have become very popular with contract assemblers or users reluctant to change their flux/solder, paste/reflow processes.

Flammable: this class includes volatile materials, such as alcohols, with (Baxter) or without the use of a fluorocarbon inerting vapor blanket, Stoddard solvent, mineral spirits, etc. Alcohol is used successfully in certain in-line applications in Germany, however it has been used traditionally in pan and brush cleaning for small runs or prototype cleaning.

Cleaning Equipment & Waste Management

The change in cleaning materials meant that a change is equipment was mandated. Many users had little experience with water-based processes, since so many of the mil specs were built around solvent cleaning. Thus the membrane systems that allowed users to recycle the rinse waste and "close loop" semi-aqueous systems were quickly accepted, since no water disposal permits were needed. Waste streams containing soluble organics and heavy metals require more elaborate treatment for compliance with existing or future regulations.

Specs & Stds.

The first target for change was the body of Military Specifications that had embodied the use of CFC-113 and MCF over the years. Many of these specs involved the use of these solvents as test solvents to determine the resistance of the various marking inks, solder masks, wire insulation, adhesives, plastics, elastomers and encapsulants used to produce high rel assemblies.

MIL-STD-202, Method 215 and the corresponding method in MIL-STD-883.

MIL-F-14256, the classic liquid rosin flux spec., was first incorporated in the ANSI/J-004, then modified to permit the use of two classes of water soluble fluxes, those with polyglycols and those without.

MIL-STD-2000 & MIL-STD-2000A replaced most of the mil soldering documents. While these specs do allow the use of non-rosin fluxes, they must be part on an integrated flux, solder, clean and test protocol.

Test Methods

Initially, all the test methods used for cleanliness assessment were based on a solvent cleaned rosin flux residue. The integrated test methods required above are just now being developed through the IPC Cleanliness Assessment Sub-Committee (Johnson, Sellers). Eventually there will be an appropriate ionic conductivity, surface insulation resistance, electrochemical migration resistance and residual organics method for each flux/solder/deflux process.

Hand Soldering & Cleaning: Traditionally, the hand soldering process was followed by either a simple cleaning in a batch vapor defluxer or by a localized solvent application combined with brushing. The former was preferred, since the latter merely accomplished the spreading of the residues over a larger area but did not remove them from the surface of the assembly. Recent thinking, driven by the equipment shortfall and lack of equipment as simple and inexpensive as the two-sump vapor defluxer, has given rise to a new concept for post-hand solder cleaning, which is applicable to touch-up, re-work and repair operations. In this process, the contaminated area is wetted with a high viscosity liquid cleaner, so it stays in place during the time required to dissolve the residues from the surface of the board. When all the residues are in solution, the cleaner is removed via vacuum through a water scrubber, so only water vapor is discharged. The cleaned area may be rinsed with 2-propanol to remove any traces of the cleaner and quickly dry the surface of the assembly to prepare it for a subsequent conformal coating step.

IV. CHANGE ON A GLOBAL SCALE

The changes cited above have been carried forward on a global basis; first with the contributions of the GEC personnel ultrasonic studies, the UK and Nordic Community versions of the Benchmark program, and the cooperative work on the soldering materials documents. Since the vast majority of the countries have signed the Montreal Protocol, global companies are standardizing processes world wide in compliance with the new cleaning processes.

Bill Kenyon, Senior Scientist, DuPont Electronics, has been involved in product, process, and test development for the past 18 years. He has focused on cleaning-process studies, flux/solder/deflux evaluations, and has pioneered the work responsible for modern synthetic activated (SA) flux technology. He co-founded the CFC Benchmark & Alternatives Ad Hoc Task Group and pressed for an industry semi-aqueous alternative cleaning process offering.

These contributions have led to his being awarded the 1990 Stratospheric Ozone Protection and Marketing Excellence Awards by the EPA and DuPont, respectively, who also nominated him to serve on the United Nations Environmental Program (UNEP) Technical Assessment Panel.

Bill is active in trade, professional, and industry association leadership activities, and chairs or is a member of several national and international committees.

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