Both sides have valid reasoning. Here's why.

The No-Clean Issue

BY FRANK CALA, PH.D.

The purpose of this paper is to both review the vital role played bv cleaning in the manufacture of electronic assemblies and to show why assembly level cleaning will be alive and well into the foreseeable future. As this article will show, the future direction of electronics is such that cleaning can be expected to become even more prominent in a number of areas. Post assembly cleaning makes parts acquisition, handling and soldering a relatively non-demanding and forgiving process. It takes a considerable amount of hassle out of the process and helps make building a reliable assembly a more certain process. These are key factors in a world where field reliability and volume production at low cost are two unforgiving task masters.

The reason for this reaffirmation of cleaning is that it has become almost fashionable in some quarters to view cleaning at the assembly level as being out-of-date. Low residue soldering is an extremely demanding process, with risks to yields and field reliability. It has definite limitations and there are important unanswered questions.

The Reasons for Cleaning Assemblies

There are numerous important reasons for cleaning at the assembly level [1,2,3]. Benefits range from a relatively uncomplicated and reliable assembly operation to the likelihood that the current process is sufficiently robust to accommodate all current and future assemblies. Because of cleaning, residue-related failures are not a primary concern, as assemblies are shipped out the door. Some of the basic benefits of post assembly cleaning are as follows:

•Ease and Flexibility in the Procurement of Incoming Bare Boards and Components.

Post assembly cleaning permits a realistic operating window for the acceptability of incoming parts. As received, bare (unpopulated) circuit boards can have all manner of ionic (e.g. chlorides, sulfates, bromides, etc.) and nonionic[4] contamination. Boards and components may be received with excessive oxidation or tarnish. Using full strength fluxes can generally compensate for shortcomings in the solderability of incoming materials. Cleaning both allows the use of these more effective fluxes and assures removal of residues of various types. This gives the assembler a degree of flexibility in choosing suppliers. This can, in turn, yield bottom line results for the assembler. Further, reliable assemblies can be manufactured even when the assembler has only limited control over the supply vendors. This could be the situation for a contract manufacturer or a medium volume operation.

A critical requirement of low residue soldering in a no-

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The electronics industry has experienced many changes in process technology during the last few years. One of the most significant changes has been the widespread implementation of low-residue (a.k.a. no-clean) soldering processes. Although many companies worldwide have adopted low-residue processing and have realized substantial cost, cycle time and environmental benefits, some sectors of the industry have been slow to implement low-residue processing technology. The decision to adopt a low-residue process, like any other process change, should be made only after gaining a thorough understanding of the impact and requirements of the change. In an attempt to assist the reader to that end, this article captures the essence of key low-residue technology assessments conducted to date and addresses some misconception about low-residue processing that have surfaced.

Environmental Benefits

Low-residue soldering was conceived as a solution for environmental concerns. The low- residue process produces the following environmental benefits:

- the virtual elimination of lead waste and reduced solder consumption by eliminating solder dross (when soldering in nitrogen);
- reduced volatile organic compound (VOC) emissions from the reduction of flux and associated processing solvents; and
- reduced effluent streams by eliminating the dependence on post-solder cleaning processes.

By definition, low-residue soldering is a green process. For world class organizations, environmental solutions are one component of business solutions, i.e., environmental solutions save money.

Cost Savings

With the inherent environmental benefits of a low-residue process, substantial cost savings are seen. By transitioning to a low-residue process, Texas Instruments' DS&E Business realized a 96 percent reduction in mass soldering process material costs at constant production volumes. [1,2] In addition, Northern Telecom, Plexus, Cummins Electronics and Siemens Stromberg-Carlson all realized a significant reduction in manufacturing cost.[3] The elimination of post-solder cleaning moves product through the factory faster and simplifies the overall build process. With a solid understanding of product performance requirements, low-residue soldering makes good business sense.

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clean operation is that incoming bare boards and components must be both clean and solderable[6,7,8]. This is not an easy task and simply saying we should demand what we paid for will not make it happen (particularly with extremely low per-board profit margins). These requirements can be a problem for contract manufacturers when using components and /or bare boards supplied directly by their customers. Further, due to the weakness of no-clean fluxes and the lack of post assembly cleaning, absolutely no decline or dips can be allowed in these requirements for incoming materials. Ongoing monitoring by the assembler should be a must. The prudent no-clean assembler should not simply rely solely on an initial qualification of a board fabricator. The consequences of so doing could be dire. For example, components. with solderability just slightly below standards are not solderable with no-clean fluxes[5]. Trying to shift total responsibility for quality to the fabricator could be a very costly proposition (e.g. cost of bare boards, cost in rework, returns or future sales if the fabricator slips up).

Experienced people who are doing low residue soldering relate that the assembler has to do a lot of homework with respect to the cleanliness of the incoming circuit boards. It is not sufficient to simply give a specification for maximum total ionic contamination. It is important to know the nature of the contamination (e.g. chlorides). This involves more advanced analytical techniques [e.g. someone has to hire a chemist). Contamination can also be expected to vary by fabricator and even by fabrication site for a given vendor.

Insufficiently clean bare boards will cause failures even on assemblies that generally might not be expected to be high tech. An example of this is a line of office equipment which u utilized the no-clean approach and the PCBs failed before the end of their service life. Failure was traced primarily to contamination coming in on the as-received bare board[8].

Although it is the quality of the bare boards that is most often spoken about in no-clean circles, similar concerns must also be voiced as strongly regarding the components [1]0. Solder dipped components can have chloride flux activators on the surface of the leads. Similarly, those that use a plating process can have contaminants such as fluorides, sulfates and sulfonic acid. The observation has been made that in a no-clean process, the levels of these residues (either by themselves or in combination with those on the board) can be such that corrosion cells are formed and result in corrosion and metal migration [10].

•Absence of Post Solder Cleaning Results in a Significantly More Demanding and Unforgiving Process.

The aim of cleaning assemblies is not simply to deflux, but to also remove residues due to board fabrication, assembly, general handling and even to remove solder balls. The presence of contamination from one source or another can seriously compromise reliability. Importantly, the act of post solder cleaning makes the overall assembly process considerably more user friendly. Because of post solder-cleaning, there is leeway with respect to the quality of incoming materials, the aggressiveness of the flux used and even items such as reflow profiles. This forgiveness greatly helps ensure good solder joints and long term assembly reliability.

It is extremely trying to put into practice a low residue soldering / no-clean operation, both initially and on an ongoing basis. It is much more exacting than most of the

Solderability

Low-residue fluxes contain less activator than rosin-based or water soluble fluxes . In addition, low-residue fluxes use different activators than those found in typical rosin-based or water soluble fluxes. By substantially reducing the amount of flux activator, and using a relatively benign chemistry, the flux-related risk to circuitry in a low-residue processing environment is eliminated, for all practical purposes.[4] As with traditional rosin flux soldering processes, implementation of manufacturing control measures is prudent. Such measures as controlling part stock, partnering with suppliers and maintaining an active and effective part solderability control and handling program, using ANSI/J-STD-O02 and 00 as benchmarks, are a necessity regardless of the flux type used.[5] In addition, the use of nitrogen in the low-residue mass soldering process provides a widening of the process window. Comparable soldering process performance in terms of defect rates) is obtained at Texas Instrument for a low-residue process using the same part solderability control program that was implemented for an RMA flux recess. [1]

Indeed, the need for more stringent control on part solderability would have been cost prohibitive when Texas Instruments was considering conversion to a low-residue process. Nitrogen widens the process window by eliminating the formation of oxides on the to-be-soldered surfaces during the soldering process and by beneficially affecting solder wave dynamics. Capillary action in the plated-through-holes and spread on land patterns is ultimately enhanced.

Reliability

Quality and long-term reliability can be achieved with low-residue/no-clean processes, which follow generally accepted, good practices for assembly. Evaluations by a broad spectrum of industry have documented the long-term performance of electronic circuitry (including high frequency, high voltage, high current and high speed digital) produced using low-residue fluxes and processes, and found their performance to be “equal to or better than” that of electronic assemblies produced using traditional rosin fluxes and industry accepted cleaning processes.[4,6,7,8] Commercial and military electronics manufacturers have been using no-clean processes for years to produce reliable hardware, with no field return attributed to flux residues.[3,9]

Cleaning I

In 1994 the EMPF/Industry Low-residue Soldering Program polled 10 companies that had successfully implemented low-residue/no-clean soldering processes. All these companies stressed the need or specifying an incoming cleanliness requirement for printed wiring boards to be used in assemblies manufactured with low-residue processes. Other manufacturers, who were not assessed in the EMPF survey, also impose incoming cleanliness requirements as part of their low-residue processes. The authors recommend incoming cleanliness requirements as a step to assure quality and reliability of assemblies manufactured with low-residue processing, as well ai reasonable handling and storage practices to prevent excessive contamination. However, companies who successfully implement low-residue processes eliminate non-value-added cleaning, such as post-solder cleaning.

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uninitiated realize. The range of problems run from the soldering process itself, to the ability to obtain solderable materials, to the verification that any resulting higher levels of residue (including solder balls) do not affect the reliability of particular assemblies. Soldered joints are generally duller in appearance and this can be a real problem for many customers. The difficulties and unforgiving aspect of obtaining clean bare boards and components should not be underestimated, particularly when this must be an every day, every hour, every minute exercise.

As increasingly complex and more demanding assemblies come into an operation, the question that has to be asked is whether the low residue/no-clean process in place will still be adequate? Because of the demanding nature of this approach, a rather intensive reverification would certainly be appropriate for each increasing level of assembly complexity or miniaturization.

One basic problem with low residue soldering is the limited activity of the flux. Wave and reflow processes must be tightly controlled. The rate of temperature ramp-up is critical. Too slow a ramp-up will deplete flux activity prematurely. This will result in there not being sufficient flux to prevent reoxidation of surfaces *prior* to actual soldering. Conversely, too quick a ramp up could damage some components. Both nitrogen inerting and spray fluxing are highly recommended. It should be noted that while nitrogen can prevent further oxidation of metals during soldering, it does not remove oxidation or tarnish which is already present [11] (e.g. it does not "fix" poorly solderable metals).

Tight vendor control is a must and extends to all incoming materials. Lapses in solderability and cleanliness have to constantly be guarded against. It should be noted that even slight changes in ultra violet energy during exposure of a photo imaged solder mask will impact circuit board ionic cleanliness levels [1]2. Age and storage conditions of materials are very important. Low residue flux or paste must be of uniform quality from lot to lot and must be carefully monitored.

Low residue pastes must be wcu-keel with much faster than regular pastes. They lose tack in a much shorter period of time (e.g. can be as short as 15 minutes). The time delay between paste application and component placement is crucial.

The no-clean approach also yields a very significant dilemma with solder balls. They are not removed without a post assembly cleaning step and there is not yet a real solution for solder ball formation with no clean. With modern trends in electronics technology, solder balls are more dangerous than ever before[13]. Apparently the situation is even worse when an inert gas is utilized and a series of complex process contols are recommended[13].

Hand soldering is both different and more difficult. Operators have to be retrained and they are slowed down with no clean fluxes [14]. Tip selection and maintenance are very important, as is the feed rate of the solder, Again, the dilemma is the weak flux. Odor can be a problem with no clean and hand soldering Rework is discouraged unless absolutely necessary, basically because it results in more flux residue. Even here in rework, there arc cautions. Generally, the same brand flux that was used in the soldering process should be used in reworking, due to possible incompatibilities between flux from different manufacturers,

Design Requirements

It has been suggested recently that circuit board design rules are different, or more prohibitive than they have traditionally been, for low- residue processing.[10] On the other hand, a body of indusrytq de assessments has found low-residue processed hardware to to behave comparably to hardware processed with traditional rosin-based flux and cleaning. 3,4,6,7,8,11 None these works conclude a need for changing design rules. Printed wiring boards, regardless of the assembly technology be used, require design rules and guidelines, hence docu ments such as IPC-D-275 have been developed for use by industry. The suggestion that new rules are required for low-residue is not supported by a body of objective, industry-wide testing.

Synopses of Major Collaborative Research Efforts

The authors recommend gaining familiarity with the following reports and program, which collectively provide a thorough review of low-residue soldering technology. Contact information is provided for each at the end of its individual synopsis.

Motorola/Sandia National Laboratories/Los Alamos National Laboratory CRADA CR91 -1026, Evaluation of a No-Clean Soldering Process Designed to Eliminate the Use of Ozone Depletina Chemicals, published November 1992.

The purpose of this effort t was to evaluate an environmentally friendly, low- residue soldering technology that could eliminate post-sold leaning, particularly with ozone depleting chemicals (ODCs). The results of this effort gained national attention and resulted in Sandia receiving more than 350 inquiries about implementing low-residue technology. The conclusions drawn from the study include the following:

- ionic cleanliness for no-clean hardware equivalent to, and in some cases better than, that obtained *for the* rosin flux/solvent cleaning pro
- visual solder quality for no-clean hardward equivalent to the existing, optimized rosin flux/solvent cleaning process:
- the no-clean hardware proved electrically and mechanically reliable over a wide range of processing parameters:
- no-clean soldered board with ionic cleanliness in excess of the military specification still proved reliable.

To obtain a copy, contact Dr. Ronald L. Iman at Sandia National Laboratories (505) 844-8834, (505) 844-3321 (fax), or e-mail: rliman@sandia.gov.

IPC-TR-581, IPC Phase 3 Co *3 Controlled Atmosphere Solderinq* Study, *published August 1994. 4*

This effort, sponsored by *the IPC,* evaluated two non-rosin low-residue fluxes in both the cleaned and not cleaned modes, for use on commerc ial and military assemblies. A Test Monitoring and Validat ion Team (TMVT) actively pal--ticipated in the testing and verified testing was conducted to the test plan and evaluat Lion guidelines. Nineteen indi - viduals, representing 14 comp anies or military organizatons, participated in the actual testing. A test series, including ionic cleanliness, ion chromat ography and surface insulation resistance (SIR], was conducted on the IPC-B-24 substrate. Based upon the results of the test series, the group concluded that low-residue flux materials, in a no-clean

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•Cleaning Will Accommodate Current and Future Device Trends and is Not at Odds With the Technology

There are a number of types of devices, such as high voltage-low current and high frequency, which are exceedingly sensitive to residues. The presence of these devices can be expected to increase dramatically and quickly. These are areas where the low residue/no clean approach appears to be at odds with the basic requirements of the circuity[15]. Obviously, post solder cleaning very nicely serves the needs of these systems.

There are new semiconducttors that are very high impedance and therefore draw considerably less current than earlier designs. But even the slightest current change will have a significant impact upon these systems. Thus residues can be expected to become even more of a challenge to reliability. It is important, for example, that memory storage devices not experience excessive current consumption (e.g. as can occur duc to residues].

Even extremely low residues can be expected to be a serious issue with high frequency devices. These types of devices are fairly commonplace today and will certainly experience greatly accelerated growth in the next few years. Telecommunications is one such example and cellular phones are now being operated in the 870 MHz range. With such devices already heavily used in business, reliability is both expected and demanded.

It *is important to* understand that the historical trend is such that high frequencies can be expected to surface in many mode, performed equally as we 1 as, or better than, the rosin fluxed/solvent cleaned controls.

Contact the IPC at (708) 509-9700 or (708] 509-9798 (fax) for information.

IPC-TR-582. Cleaning *and Cleanliness Testing Program-Test results for Phase 3 Low Processed in Ambient Air*, *published November 1994.*

This effort, also sponsored by the IPC, screened three low-residue liquid fluxes and three low-residue solder pastes using the IPC-B-24 test substrate. One paste and one liquid flux were selected from the screen data and further tested on the IPC-B-36 test substrate. A TMVT monitored the actual substrate processing and contributed to the evaluation of the data and generation of the final report. Fifteen individuals, representing a diverse cross-section of the electronics industry, participated. A test series similar to that used in the IPC-TR-581 evaluation was used. Based upon the data generated from this test series, the group concluded that low solids flux technology represented a viable alternative to the use of rosin fluxes followed by CFC cleaning.

Contact the IPC at [708) 509--9700 or (708) 509-9798 (fax) for information,

Evaluation of Low-Residue for Military and Commercial Applications: A Report from the Low-Residue Solder-new areas. For example, while frequencies are currently lower for computers relative to cellular phones, they are headed in the upward direction. Clock frequencies for early computers were 4-10 MHz, whereas the Pentium-based computer is 80-130 MHz. Commercial computer designs will soon have CPUs operating in the 275-300 MHz range[15]. It has been found that the effect of no-clean flux residues on near-end crosstalk is significantly more noticeable at frequencies of 5 to 50 MHz than at lower frequencies of 100 KHz to 1 MHz[16]. Higher frequencies were not studied. Crosstalk is a result of coupling or leakage between circuits and it can induce unintended switching of gates within a digital system,

•Post Assembly Cleaning Significantly Decreases The Unknowns

Post assembly cleaning does not leave the assembler with a lot of unknowns to be troubled with. In addition to the concerns voiced above, there are additional questions regarding no-clean which appear not to have a ready answer at this time. Examples which have been voiced at meetings are:

1. Even though incoming bare boards may be clean, contaminants can effuse out of the board itself during the soldering process. What happens then?
2. What should the detailed standards be for incoming bare boards for use with low residue soldering?
3. How can solder balls be prevented? Does low residue flux generate more solder balls than normal flux?

Proponents of no clean have proposed that the number of solder balls is likely to be the same for both normal and low residue flux, with the only difference being the act of cleaning. In the author's opinion, it is actually more likely that a significantly greater number of solder balls are formed

ing Task Force, published June 1995.

This work is a recipient of both a 1995 EPA Stratospheric Ozone Protection Award and a 1995 Gold President's Quality Award from Sandia National Laboratories. This effort directly involved 10 industry/military organizations and was reviewed by scores of others. The goal of the LRSTF was to evaluate, and qualify low-residue technology for wide scale use in industry. The task force sought to build upon the body of research already in existence and conduct an evaluation that assessed the low-residue flux process (without cleaning) on circuitry and materials of continuing concern to industry. Industry concerns and input were obtained through test plan reviews and two planning meetings which were open to industry and well attended. The evaluation required three different test substrates, including a mixed technology [SMT, PTH) assembly designed specifically for this evaluation. This design incorporated high voltage, high current, high speed digital and high frequency networks, as well as hand soldered stranded wires, among its features. Based upon data obtained from a comprehensive test series, the group concluded the performance oft e low-residue (no-clean) boards was comparable to the controls in all electrical tests even though the low-residue processes were not optimized. Good conformal coat adhesio n was achieved for low-residue processed boards, without cleaning.

To obtain a copy of this report, contact Dr. Ronald L. Iman at Sandia National Laboratories (505) 844-8834, (505) 844-3321 [fax] or E-mail: rliman at sandia.gov.

EMPF/Industry Low-Residue Soldering Program

Representatives from the electronics manufacturing in-with a low residue approach. More solder balls are a definite possibility if only because of the sensitivity of these weak fluxes to preheat temperatures and to the rate of temperature ramp-up during the soldering process [17].

Summary

Post assembly cleaning has many important functions in the successful manufacture of electronic assemblies. It serves the critical function of permitting the assembler to use fluxes that are sufficiently active to virtually always ensure a good solder joint., It allows for variations in the various stages of the overall process. The assembler is not tied to a process whereby a slight slippage in any one of a number of areas will bring failure, For example, a temperature ramp up rate that is slightly too high will prematurely deplete a low residue flux[17] and the result will be a bad solder joint. Cleaning allows the assembler to run the process rather than the opposite being the situation. An assembly line, for example, can be kept running even if a just received lot of circuit boards or components has only marginal solderability. There is considerably less concern about contamination related failures.

Cleaning after assembly is a very well understood technology with a proven track record. It does not carry with it the uncertainties or questions associated with a low residue approach. It is a technique for reliability that will not only be able to keep in lock step with advancing electronics industry, material vendors, equipment vendors, and government agencies have been working together since April 1994 at the Electronics Manufacturing and Productivity Facility (EMPF, the Navy's Center of Excellence for Electronics Manufacturing) to benchmark the status of low-residue soldering technology, perform R&D and demonstrate acceptable materials, processes and tests that reduce the development time required to implement no-clean processes. Among the companies working with the EMPF are **Cummins Electronics, Motorola, Texas Instruments, Northern Telecom, Woven Electronics, Siemens Stromberg-Carlson, Manu-Tronics Inc., Paragon Electric Company, Control Products Corp., Plexus, Boeing, Rockwell,** Delco Electronics, Hexacon Electric, Les Hymes & Associates, Contamination Studies Laboratory, SEHO USA and Metcal (case studies for all bold print companies were documented).[3] These efforts also have participants from the Army, Air Force, Navy and Department of Energy.

Results of this industry/government program include:

- Law-Residue [No-Clean) Soldering Process Implementation Course (Caught either at the EMPF or customized for on-site training). Attendees acquire the knowledge and skills necessary to successfully develop and implement low-residue (no-clean) processes for PTH, SMT and mixed technology including: incoming material requirements; handling; SMT, PTH and hand soldering; rework; cleanliness assessment:

nology, but it will be an absolute requirement in most areas. Field reliability will continue to increase in importance. Importantly, reliability may be becoming more difficult to track because of our throw away society. If a computer from company "A fails after 3-4 years due to dendrite growth, the consumer will probably simply purchase a new one. However, **the purchase will** almost certainly be from a different manufacturer, company "B". To make matters worse, company "A will never know they lost a customer because of reliability and will continue to believe that they have a reliable process and product.

Lastly, cleaning today is not a difficult process, nor does it present environmental problems, Modern cleaning equipment is effective, very user friendly and environmentally responsible. There is a wide variety of proven CFC alternative cleaning agents [18]. Waste treatment and closed looping systems arc readily available from many sources.

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and inspection. Hands-on experience is gained through use of the EMPF's Demonstration Factory. Contact the EMPF Learning Center, (317) 226-5640.

- IPC/EMPF Hand Soldering with Low-Residue Fluxes Video. This video is internded for hand soldering operators and explains how and why low-residue fluxes are used, and what techniques are required for successful low-residue/no-clean hand soldering. Contact the IPC at (708) 509-9700.
- EMPF's Low-Residue (No-Clean) Demonstration Factory with fine-pitch surface mount, plated-through-hole and hand soldering capabilities:6. This facility is available to commercial and military industry for R&D, prototyping and consulting. Contact the EMPF Helpline, (3 17) 226-5607.

Conclusion

Process change should not be accomplished without thoroughly understanding the specifics of the replacement technology and the i pact of the change on traditional operations. This rule of thumb applies to any process change within a manufacturing environment. It has been our experience that problems can and will arise when a change is made without conducting preliminary research and gaining uncle standing first. As can be seen, our industry has already n ted the benefits of low-residue processing and substantial data and other resources are available for manufacturer wishing to make an educated transition.

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