The Value of Workmanship Standards:

What we want
What we ask for
What we get

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CQSDI Conference, March 2013

What do we want?

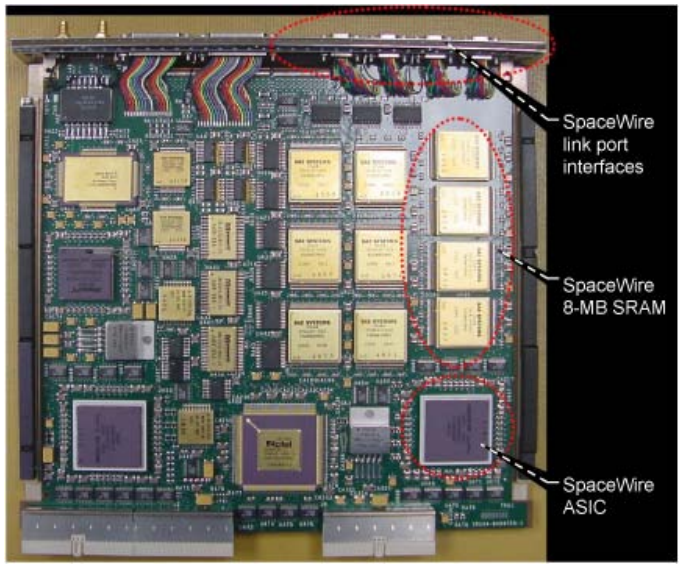
What is the value of the Workmanship Standards?

[Workmanship] Quality Assurance:

- Reduces occurrences of defects

  Defects that prevent achieving:
  - intended design
  - "durability" goals *(reliability)*

Lunar Reconnaissance Orbiter (LRO)



LRO Processor Board

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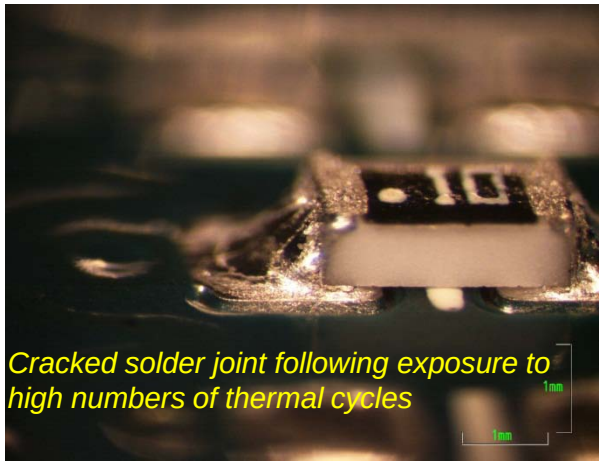
[Workmanship] Quality Assurance:

- Quality Baseline: "Best we know how" to <u>build quality in</u> at low level of assembly
  - Screening for observable artifacts shown in the past to cause failure early in life *(infant mortality)* or when exposed to vibration, shock, and thermal cycling *("qualification")*.
  - Guides (requires) manufacturers to processes known:
    - to produce highly repeatable interconnects which haven't failed
    - to reduce un-screenable defects *(latent defects)*

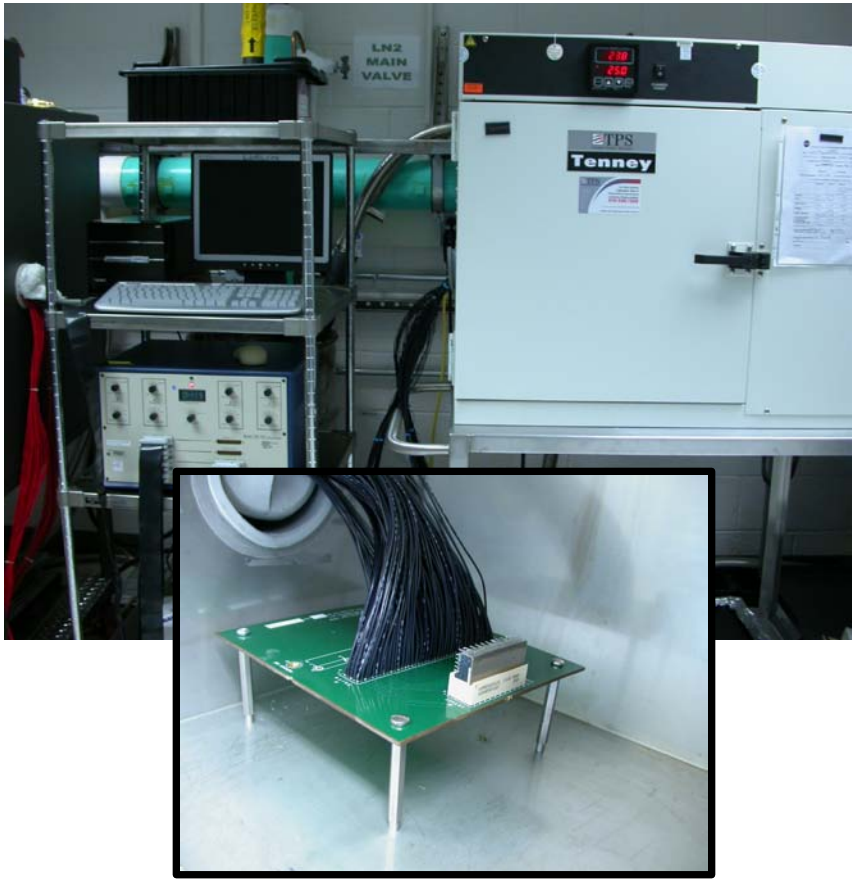


Cracked solder joint following exposure to high numbers of thermal cycles

Corrosion product on cables from flux residue

[Workmanship] Quality Assurance:

- Ensures applied item is as good as qualified item
  - Process repeatability provides traceability to qualification



Thermal cycling of partially-filled solder joints

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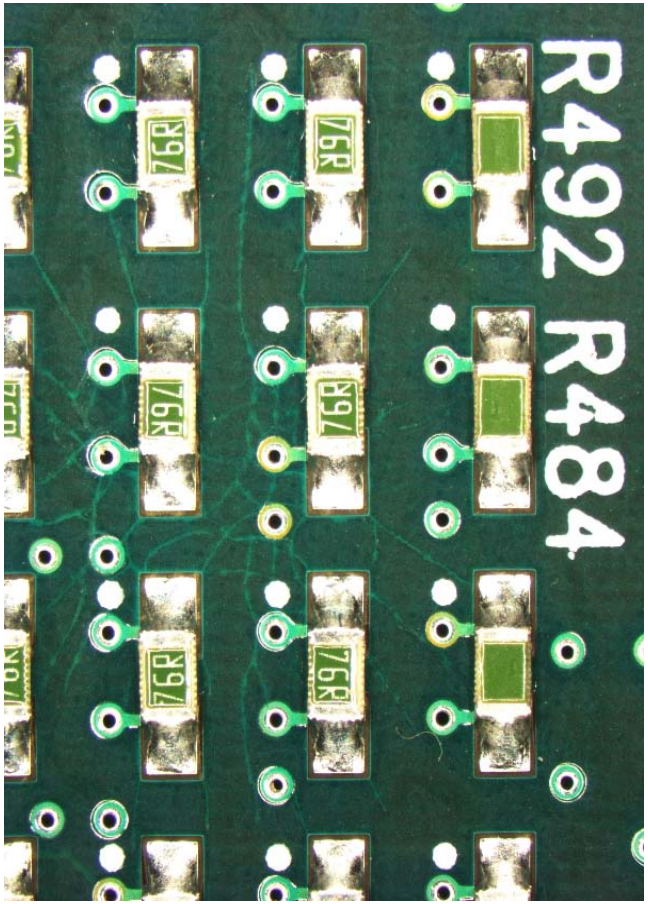
Where do Workmanship defects come from?

- Unsuccessful design
- Low manufacturability
- Low-quality building blocks (parts and materials)
- Under-developed or uncontrolled processes
- Untrained personnel
- Screening escapes



Cracks ion surface of printed circuit board (PCB)

How do we ask for absence of defects due to poor engineering design?

From J-STD-001ES, 1.13.2

The development [of acceptance criteria for nonstandard configurations] should include user involvement. The acceptance criteria **shall** have user agreement. Mounting and soldering requirements for specialized processes and/or technologies not specified herein **shall** be performed in accordance with documented procedures which are available for review.

Excessive heat rise created in non-standard interconnect

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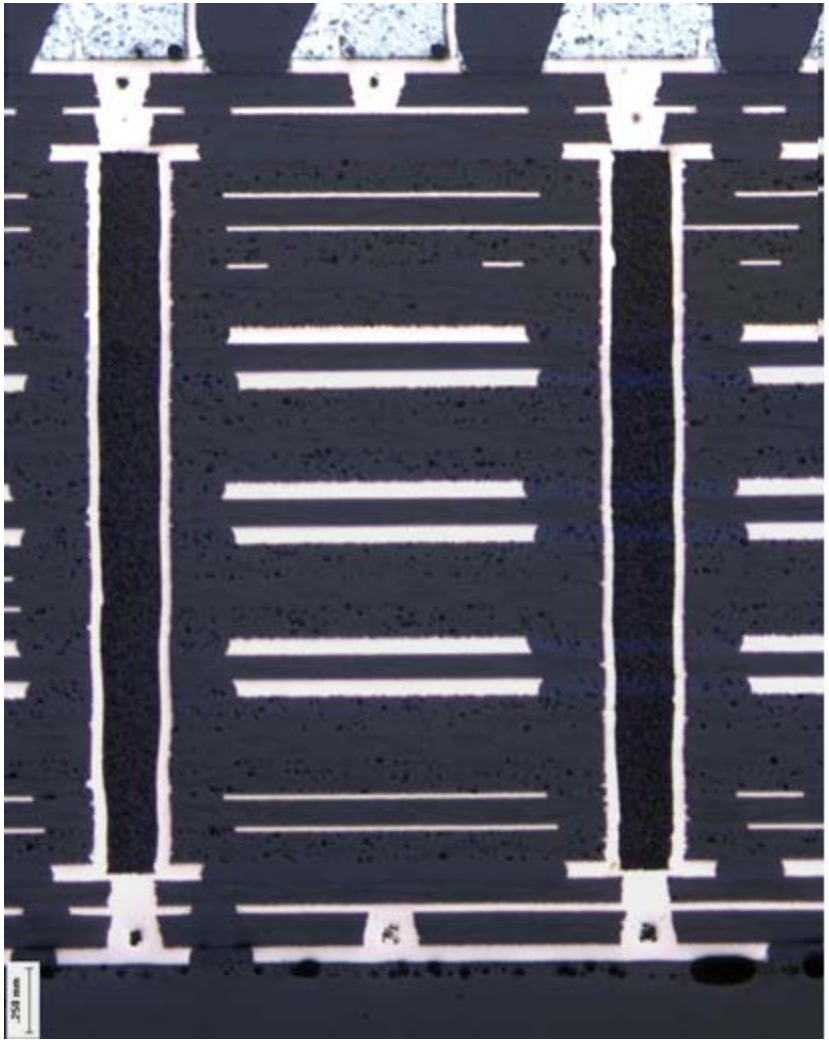
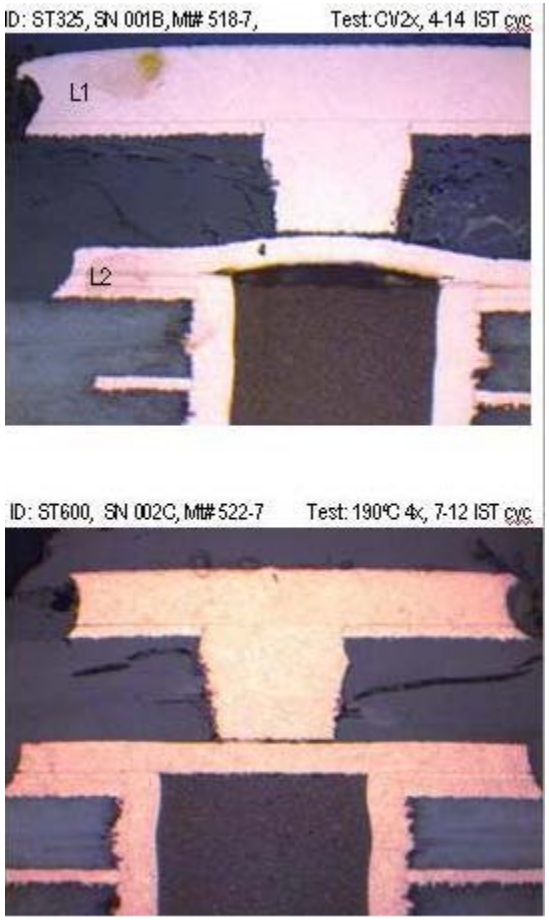
Printed Circuit Board coupon analysis + respinning non-compliant lots revealed this design to have very low manufacturability





How do we ask for absence of defects due to poor engineering design?

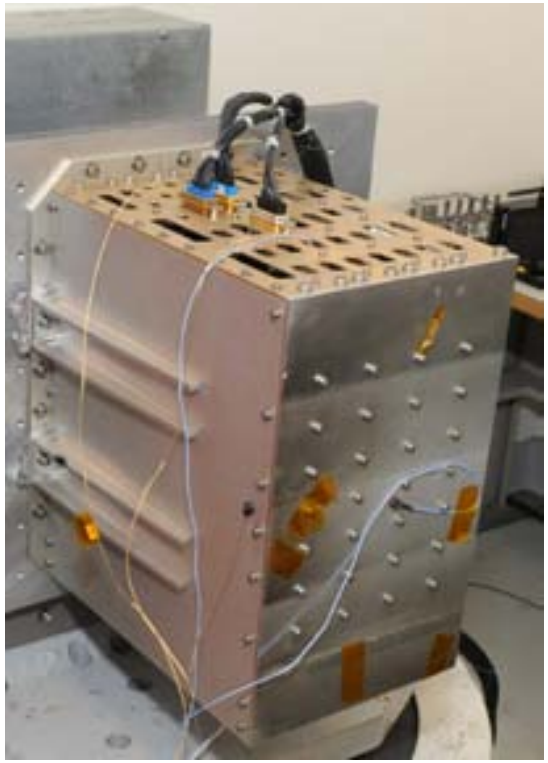
From NASA-STD-8739.4, para 7.1

Precautions shall be taken to prevent the mismating of connectors, caused by interchanging or by reversing, through one of the following techniques:

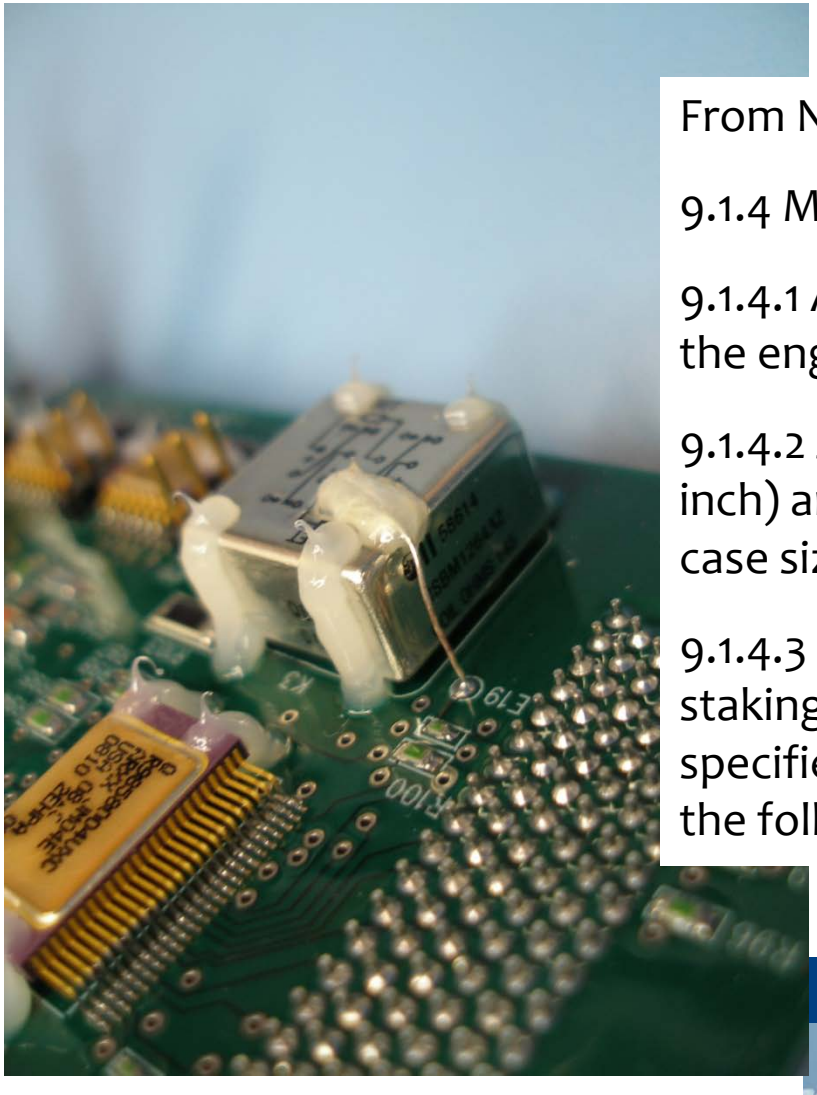
7.1.1 Use of constraints that locate similar connectors built into interconnecting cables and harnesses so they cannot be interchanged (Requirement).

7.1.2 Selection of different sizes for connectors to be located adjacent to each other (Requirement).

7.1.3 Polarization or dissimilar keying of adjacent, similar connectors (Requirement).



How do we ask for absence of defects due to poor engineering design?



From NASA-STD-8739.1A

9.1.4 Mandatory Staking.

9.1.4.1 All required staking shall be detailed on the engineering documentation (*Requirement*).

9.1.4.2 Jumper wires in excess of 2.54 cm (1 inch) and axial leaded tantalum capacitors of all case sizes shall be staked.

9.1.4.3 If parts are identified to be staked but staking location or staking dimensions are not specified on the engineering documentation, the following shall be used as default criteria…

How do we ask for absence of defects due to low quality parts, materials and processes?

From J-STD-001ES, 3.1
Materials The materials and processes used to assemble/manufacture electronic assemblies **shall** be selected such that their use, in combination, produce products acceptable to this standard.

- Solder and flux defined, shelf life
- Prep required: cleaning, baking, tinning, gold removal
- Fixturing
- Tool calibration
- ESD Control
- Thermal shock protection
- Storage and handling

How do we ask for absence of defects due to uncontrolled processes?

From J-STD-001ES, 4.17

The Manufacturer **shall develop and maintain operating procedures** describing the reflow soldering process and the proper operation of the equipment. These procedures **shall** include, as a minimum, **a reproducible** time/temperature **envelope** including the flux and solder paste application procedures and coverage, drying/degassing operation (when required), preheating operation, controlled atmosphere (if used), solder reflow operation, and a cooling operation (see 4.15.2). These steps may be part of an integral or in-line system or may be accomplished through a series of separate operations. When PCAs are required to be subjected to additional mass reflows in excess of the documented manufacturing process plan, the reason for the additional processing **shall** be documented, and notification **shall** be provided to the User within 24 hours.

From J-STD-001ES, 3.1

When major elements of the **proven processes are changed** (e.g., flux, solder paste, cleaning media or system, solder alloy or soldering system), **validation of the acceptability of the change(s) shall be performed and documented** in accordance with approved tests agreed upon between the Manufacturer and User. The change **shall** be approved by the User prior to use. Major elements may also pertain to a change in bare boards (including supplier), solder resist, or metallization.

How do we ask for absence of defects due to uncontrolled processes?

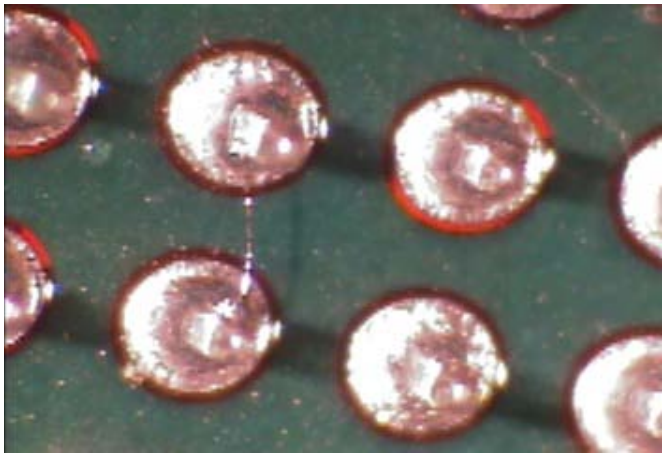
From NASA-STD-8739.4, para. 5.1.2

The supplier **shall assure that the design personnel are familiar** with the requirements of this Standard, crimping, cabling, and harnessing techniques, and other pertinent requirements of the contract (Requirement). The **supplier shall implement and document a training program** which provides the necessary training of **fabrication and inspection personnel** in crimping, cabling, and harnessing requirements and techniques (Requirement). Use of equipment and procedures pertinent to their responsibilities in performance of the contract requirements shall also be documented (Requirement). The supplier is responsible for certifying and maintaining the certification of each individual who fabricates, inspects, or instructs.

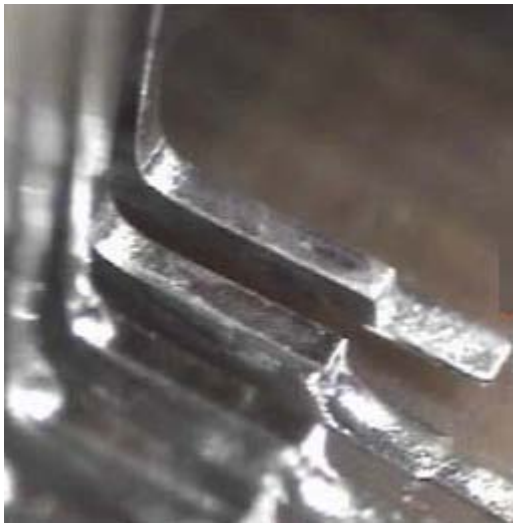
Commitment to using known good designs, materials, parts, processes, and trained personnel also streamlines failure root cause analysis and continuous improvement.

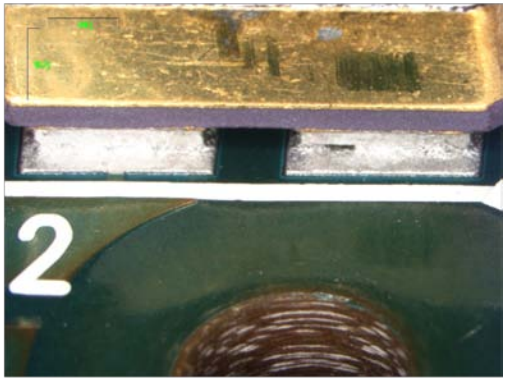
How do we ask for defect screening?

- Inspection conditions defined
- Accept/reject criteria defined
- Operators and inspectors trained



Most well known and understood parts of the Workmanship quality approach.





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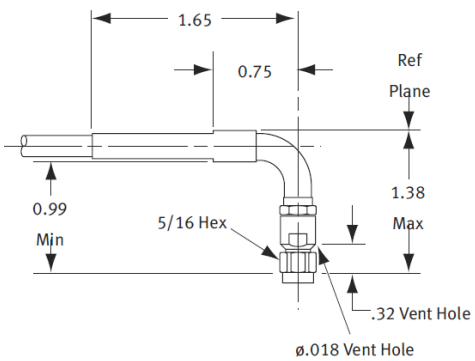
Commercial-off-the-shelf (COTS)

NASA-STD-8739.6, para. 1.2.3, "The workmanship requirements of [NASA's Workmanship Standards] do not apply to suppliers of commercial-off-the-shelf (COTS) items. Projects which use COTS hardware for applications described in 1.2.2 above are responsible for identifying and managing risk associated with hardware that was built without material controls, production methods, and/or quality inspections defined by the workmanship standards."



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We know what we want.

We have a way to ask for it.

Do we always get it?

No.

Why don't we always get compliance to Workmanship requirements?

Failure to flow down requirements. The requirements are there but they do not get applied or they are not flown down to subcontracts. WHY?

- Hardware is "off-the-shelf"
  - From 'heritage' NASA procurements which pre-date assurance requirements like Workmanship (includes subcontractors)
  - Leveraging off of DoD, aeronautics, automobile, or commercial market where Workmanship requirements may not be uniformly applied.

- Supplier does not have the sophistication or volume to establish standard, qualified manufacturing processes
  - University or other R&D interest
  - Niche manufacturer; single source supplying item with unique performance

Increasing absence of process engineering and packaging qualification testing.

- Dependence on design + fabrication using old or existing techniques.
- Destruct units are too expensive.

Do our contract technical representatives, designers, and quality engineers understand the difference between Performance and Assurance?

Grounding through a dissipative surface for ESD control shall provide connection resistance between $10^6\Omega$ and $10^9\Omega$

How will it work?

Ground connections used for ESD Control shall be verified through monthly measurements and recorded.

How do you know it will work?

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Do we mistake craft for engineered solutions?

"We always use rosin type flux because it works well."

"Only rosin flux of category type ROL0 or ROL1, as defined by IPC-STD-004, is permitted."

If everyone knows "the best way", their understanding of it is identical, materials and tools remain unchanged, and the approach is always used, then performance is achieved. (Luck vs. Assurance)

Demands "the best way" using a specific, quantitative, and repeatable interpretation of it (performance and assurance).

Note: Training is an assurance method.

Path to Success: Luck or Quality Assurance

Experienced Operators

Process Used Before

Process is Documented

Process Parameters Controlled

Product is Qualified

Operators are Trained

Defect Screening

Luck avoids:

Design requires different or new manufac-turing techniques

Process may not be repeatable or known by everyone

Process is operator-dependent and that operator is not available

Produced items are not identical creating opportunity for false positive in reliability testing

No evidence that design is reliable

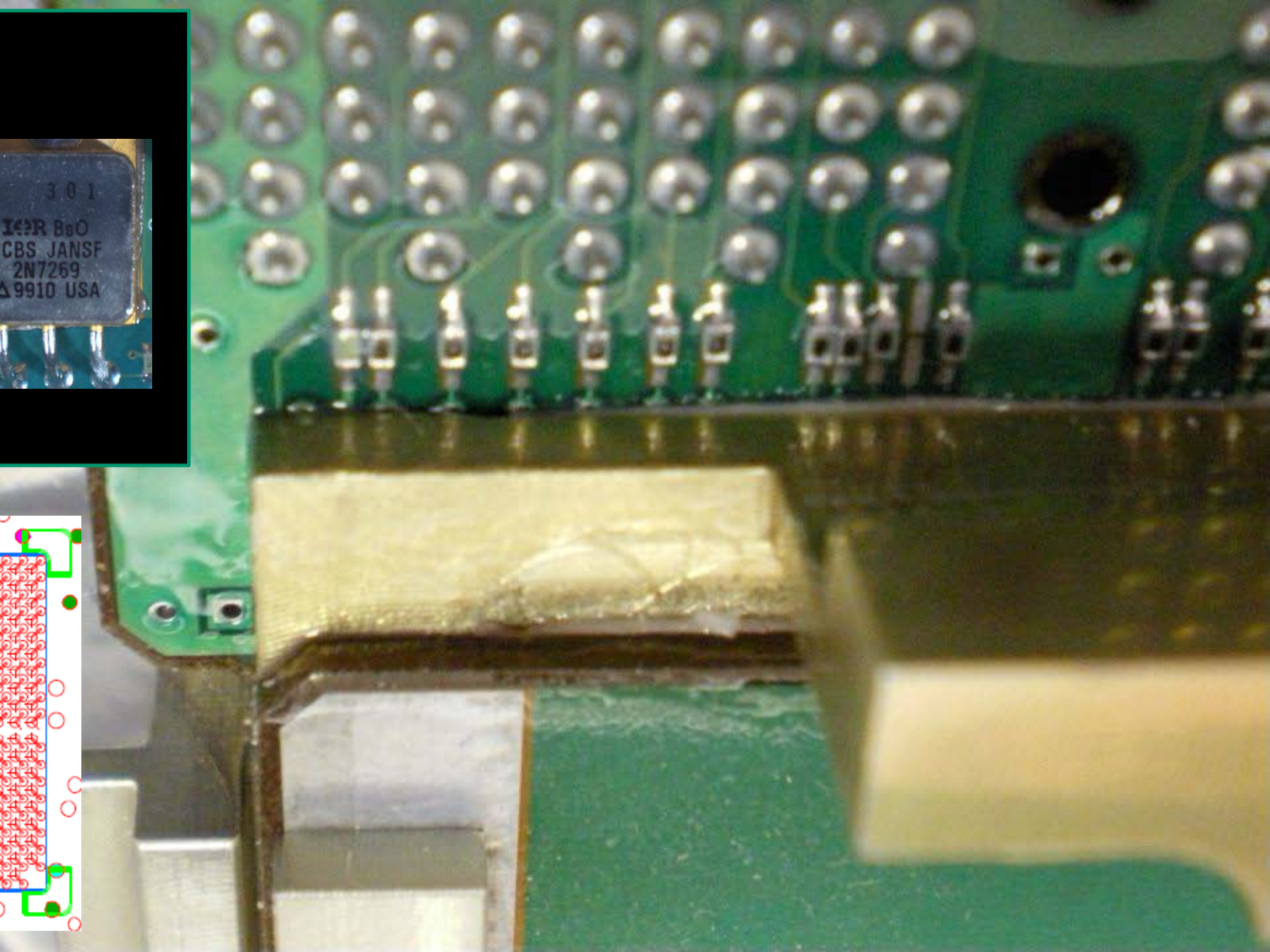
Untrained operators = uncontrolled variable

Begin to see repeatable predictable outcomes

Representative Item is proven to be capable of application

Defective items removed from population to be used in mission

Assurance ensures >>>>>>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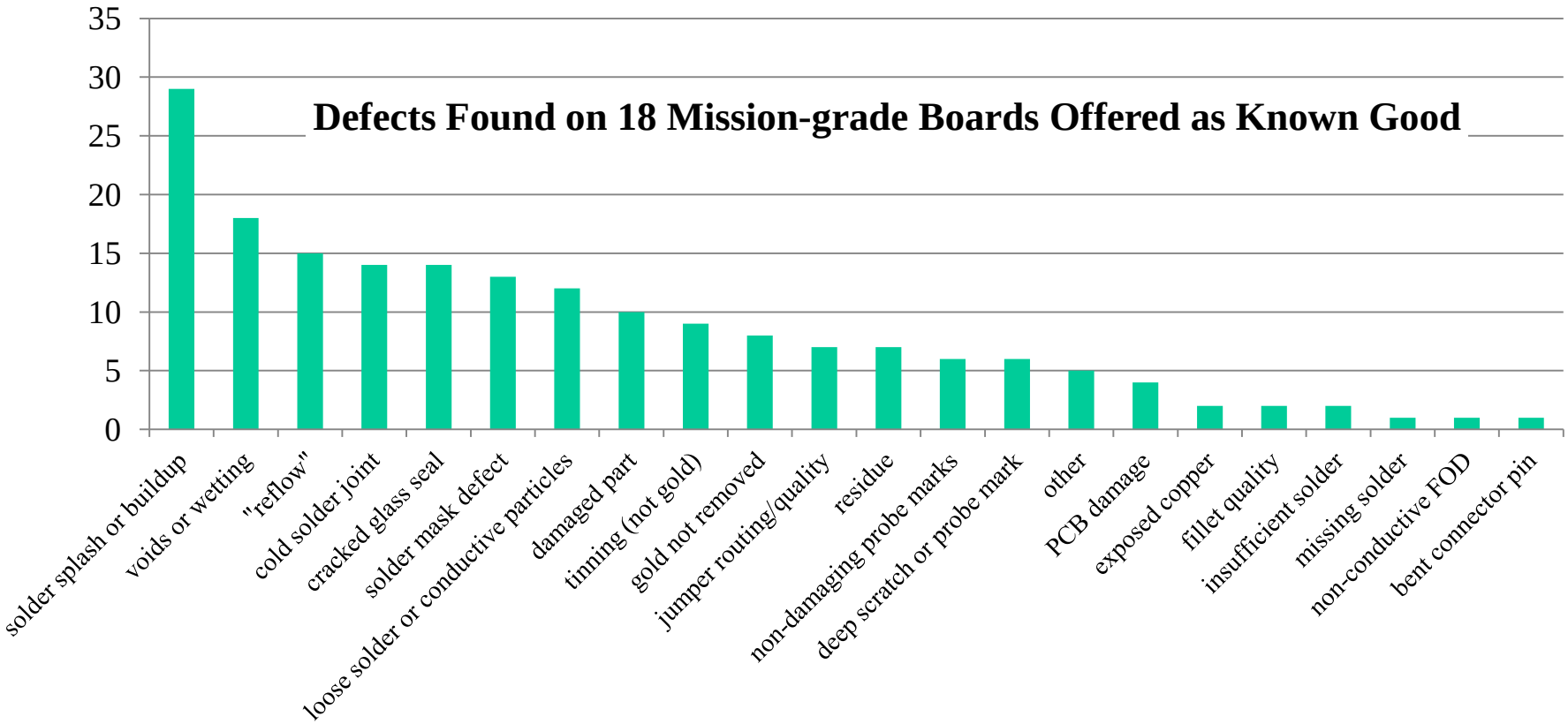
We want to use this particular item but the supplier doesn't train their operators to the Workmanship standards. What's the risk?



180 Defect Total

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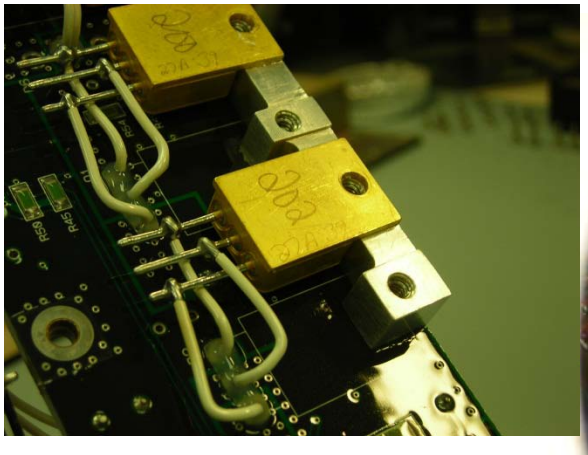
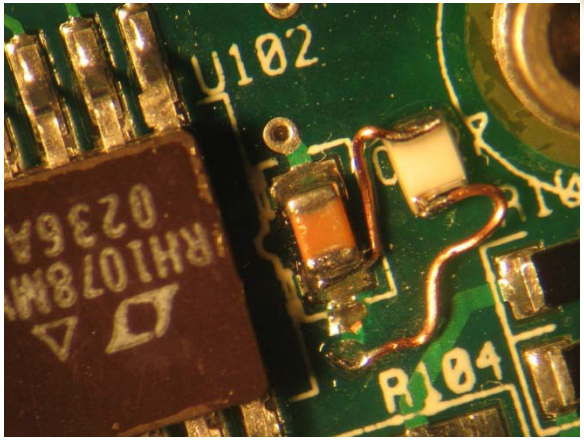
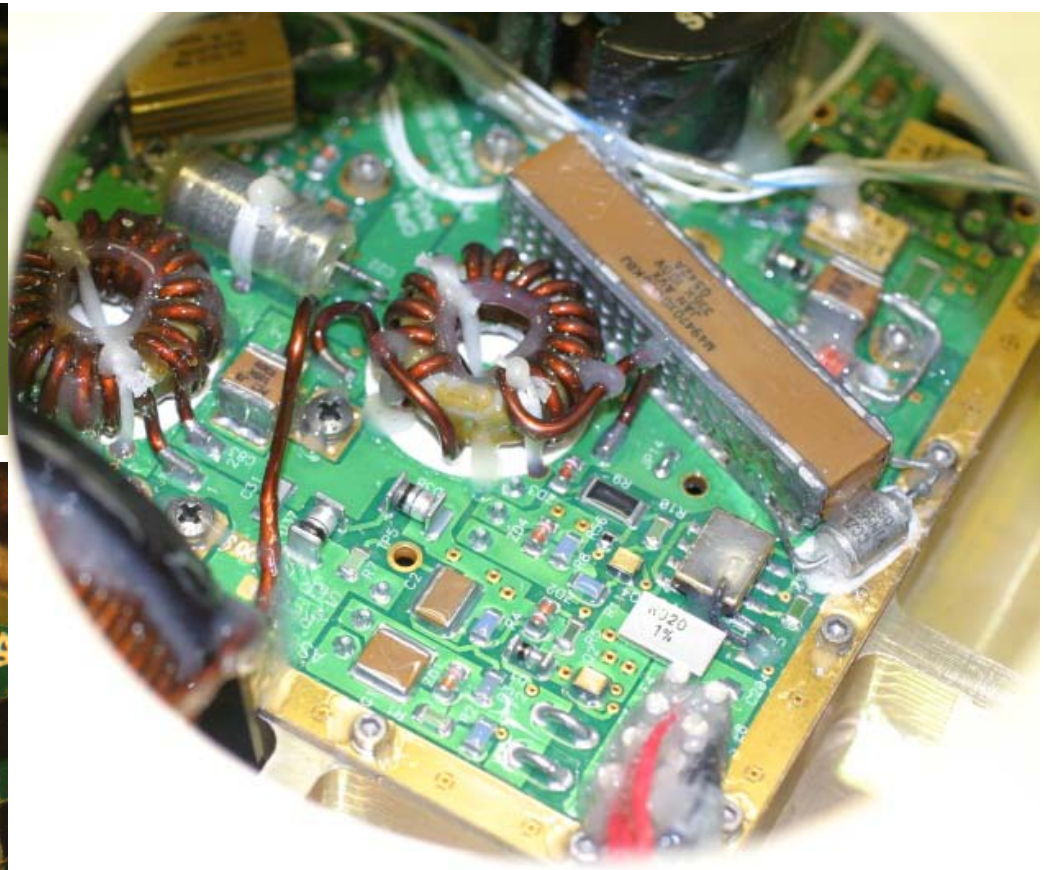
This is non-standard. Can you inspect this for Workmanship and see if it is OK?







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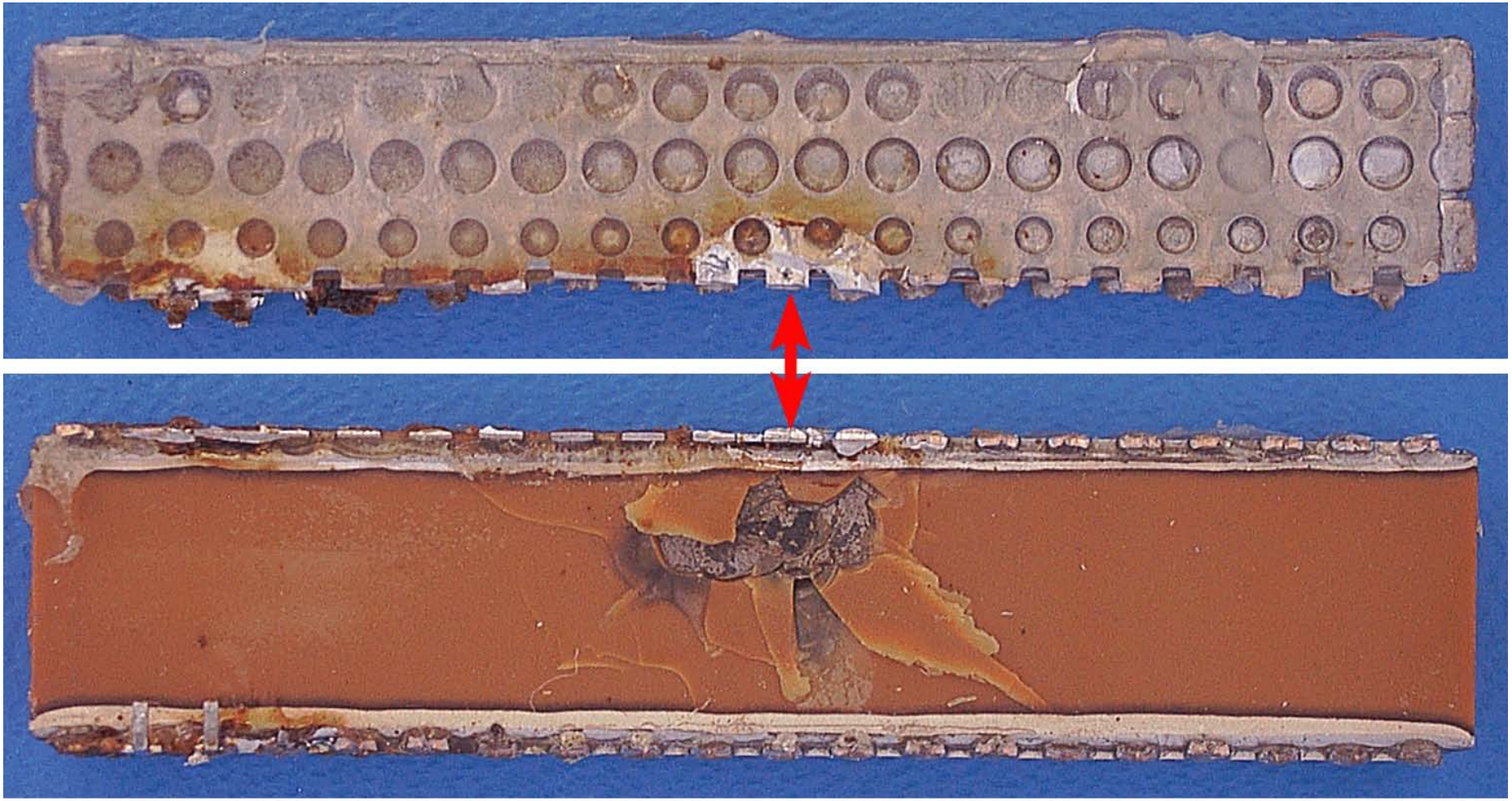
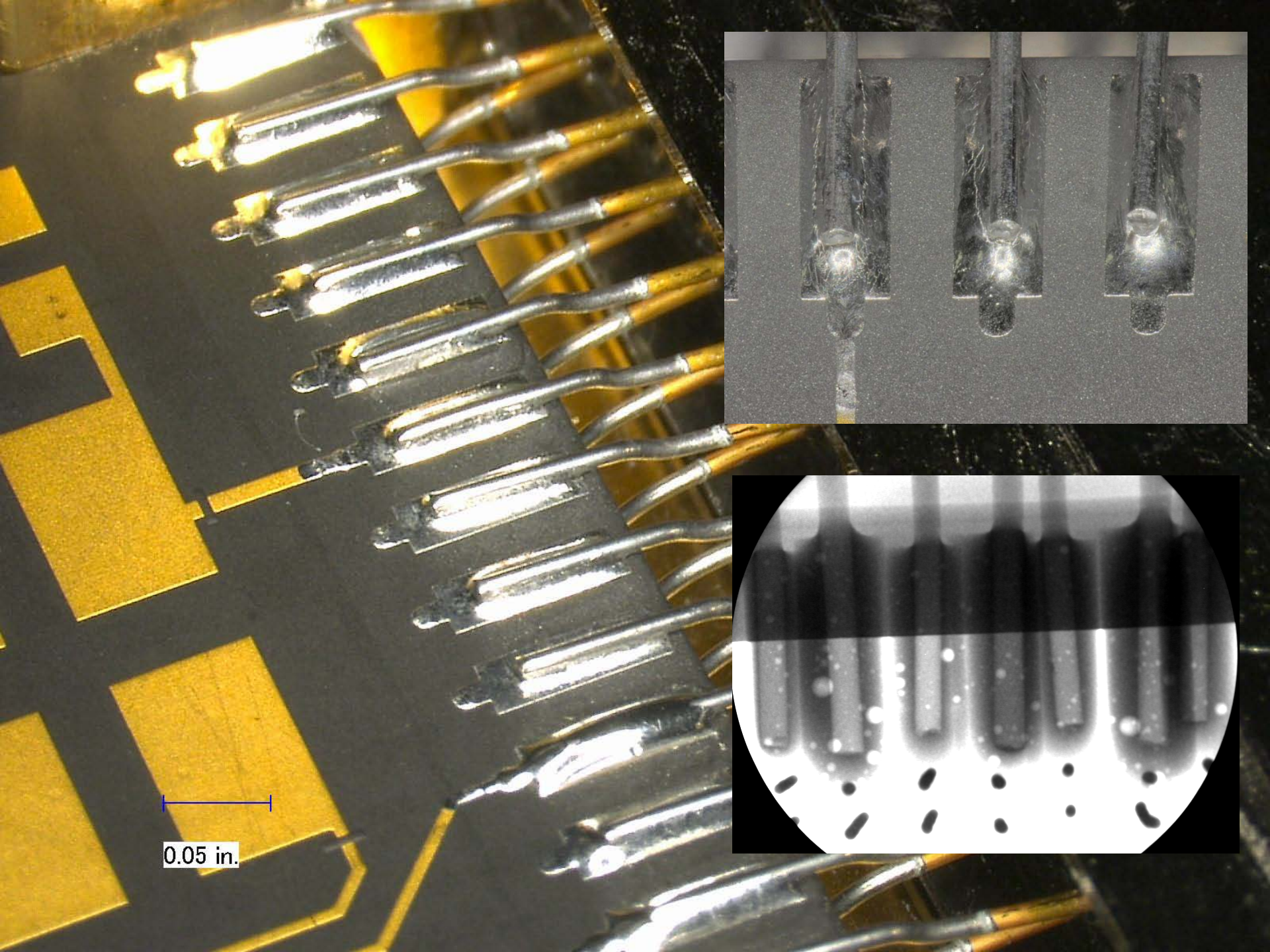
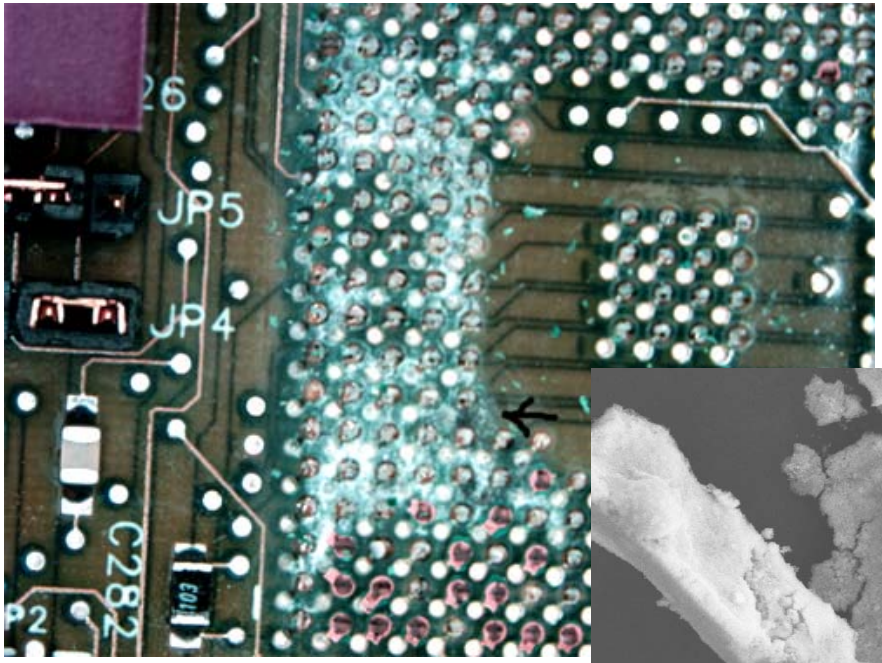
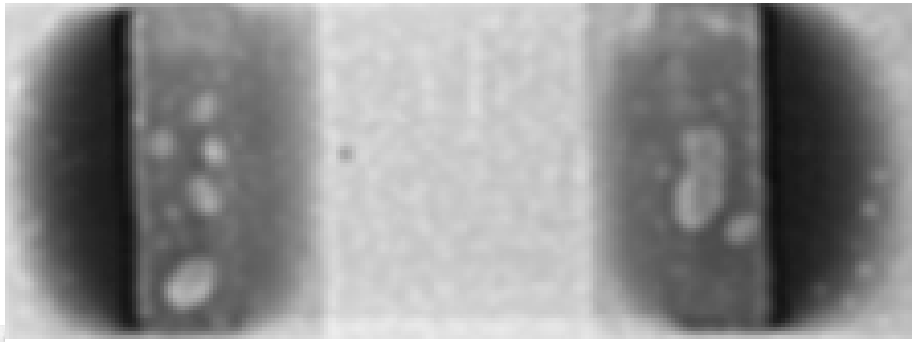
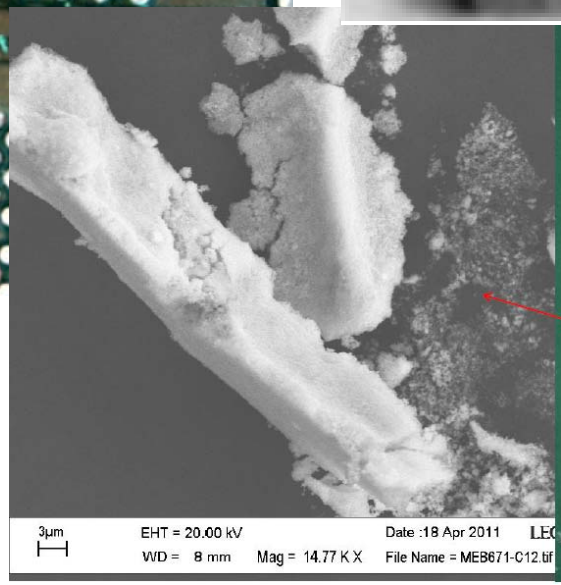


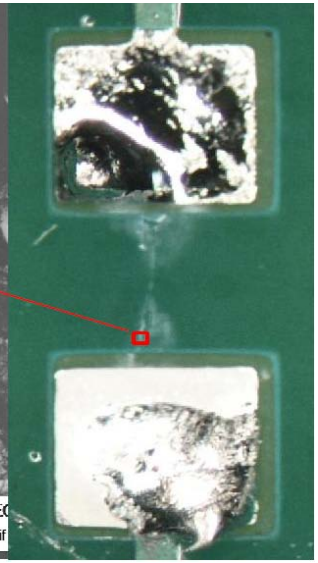

0.05 in.

Our supplier doesn't use rosin flux. Is that OK?









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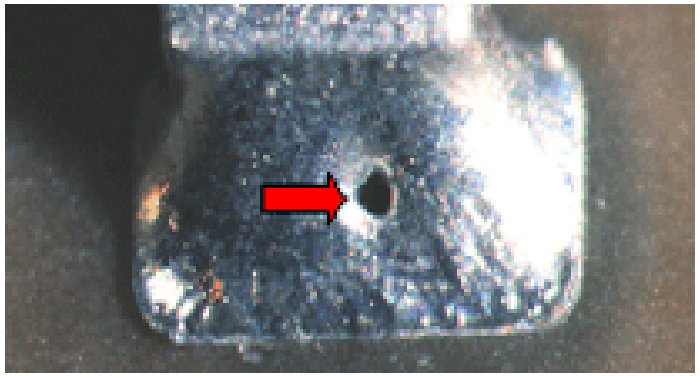
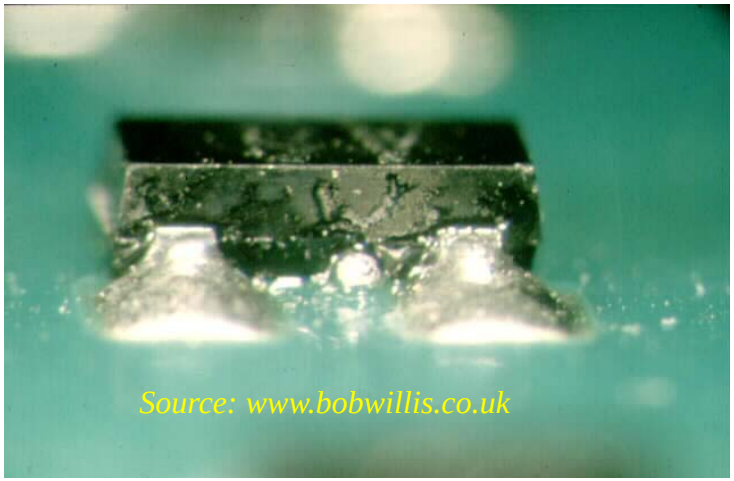
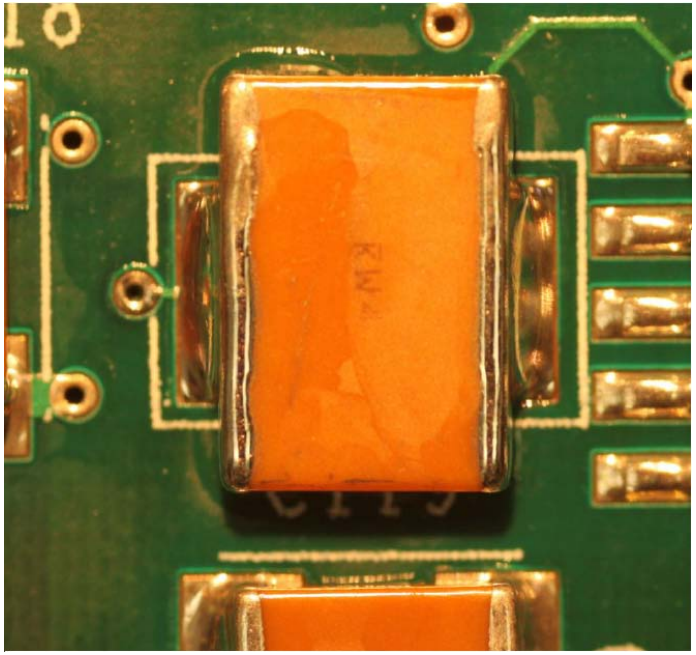
What is the risk associated with "use as is" when an interconnect is found with a Workmanship defect? What is sufficient evidence of risk mitigation?



"Blow hole" in solder joint



Solder Ball



Significant part overhang

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Closing thoughts….

The Workmanship Standards serve to force positive outcomes rather than to depend only on finding and repairing defects.

The Workmanship requirements address all avenues that can introduce defects or allow them to exist at the next level of integration: design, materials, processes, process control, screening.

Though we value screening assemblies for defects, we prefer that defects are prevented. Repair is becoming less tolerable.

Closing thoughts….

Defect prevention is highly dependent on Process Engineering though this role is not named in the Workmanship standards nor is training required.

NASA's business model draws them to *some* suppliers who are not positioned to comply with Workmanship requirements partially or in total.

Attention to assurance vs. performance can help clarify risks associated with production lines which do not align with Workmanship requirements *(What quality techniques are in place to keep defect rates very low?)*

Opportunities for requirements relief may exist when reliability engineering sorts through definitions of defects by relevant environment.