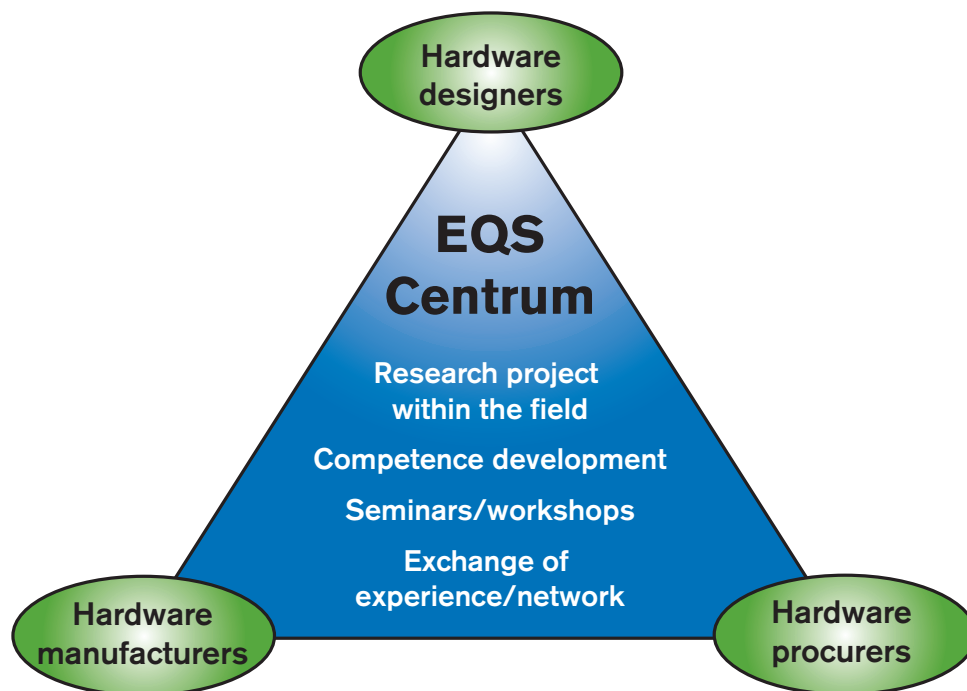


# EQS Centrum

Quality of Electronics through Collaboration  
and Lean Product Development



Swerea IVF and Swerea KIMAB are together starting a research centre under the name of EQS Centrum. The objective of the centre is to develop working methods, tools and knowledge to enable more efficient product development of electronic hardware. This is achieved by ensuring manufacturability and reliability early in the development process to avoid delays in the product launch, thus facilitating the implementation of new technology to improve functionality, lower manufacturing costs or in response to new legal requirements. Focus is placed not only on ensuring quality during the product development phase but also during the procurement process of electronic components and subcomponents from suppliers. The target group is companies designing and manufacturing electronic hardware, their suppliers as well as companies that buy in completed electronic components for integration in their own products.

## The Challenge:

### To Ensure Short Development Times when Utilising New Technology

The rapid pace of developments in new materials, components and manufacturing methods for the production of electronic hardware offers great opportunities to improve functionality and reduce production costs. As a result, competence in selecting the correct design solution has become ever more important in competitive industries. At the same time the implementation of new technology brings as always the associated risk of increased level of early failures and other new failure mechanisms. Late discovery of reliability issues can cause long delays in the product launch or substantial warranty costs.

The challenge is to find a method of working for product development that will facilitate the implementation of new technology. Further, it is necessary to find methods to ensure robustness and reliability as early as possible in the design phase. At EQS Centrum we focus on both of these areas.

### Implementation of New Technology

Over the last few years, Toyota's concept for lean product development has received ever more attention here in Sweden, mostly from industries other than the electronics industry. Set-based Concurrent Engineering within lean product development is a modus operandi for quickly and efficiently finding the best design solution. This is accomplished by evaluating different design solutions in parallel. A better name might be the multi-solution technique.

The cornerstone of this working methodology is to go through and verify alternative technical solutions at an early stage in the development process to later select, without bias, one design solution. (See diagram 1). In parallel with more and less innovative solutions it is advisable to have at least one alternative based on tried and tested technology to minimise the risk for delays in the product launch if the more innovative solutions should prove impossible to realise. At the same time retaining the opportunity that one of these solutions could result in a product with much improved functionality and/or a lower production cost.

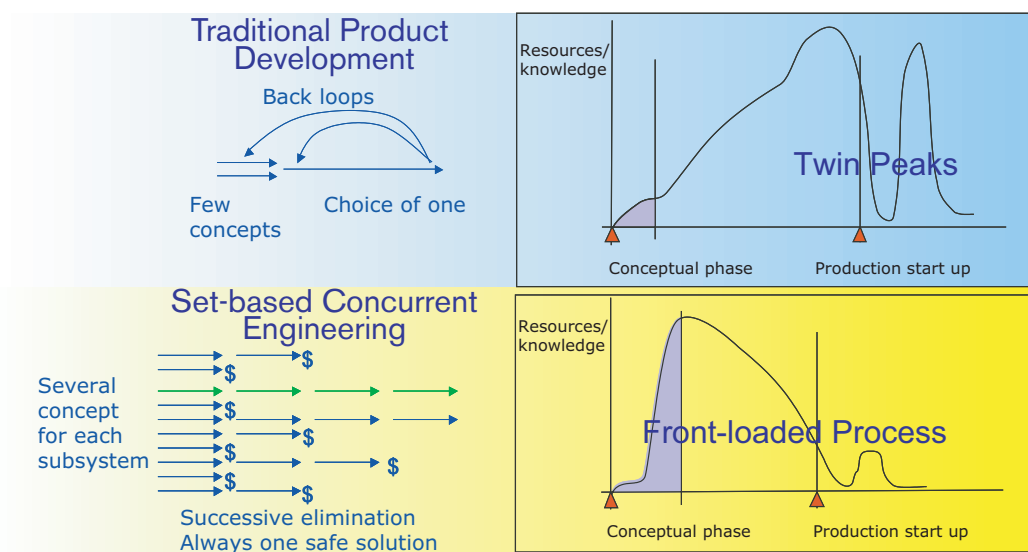


Figure 1: Comparison between traditional product development and Set-based Concurrent Engineering.

The method of working entails early evaluation in the product development process as to how the different design solutions affect functionality, manufacturability, reliability, cost of manufacture etc. The aim is to achieve a knowledge-based decision making by gathering sufficient information to determine which design results in the best solution before the final selection is made. This requires great effort at the beginning of the product development process but in return minimises the risk of late discovery of problems and the need to redesign. The process results in the final decision regarding design taking place much later than in traditional product development yet still often leads to an earlier product launch due to the absence of design changes. This also results in significantly fewer quality problems discovered after the production start.

Perhaps the greatest benefit from this methodology is all the knowledge gained during the evaluation of the alternative designs. Good management of this knowledge builds a good base for choosing better design alternatives for the next product and, as a portion of the basic evaluation of the alternative designs has then already been conducted, it becomes faster to determine the possibility of realising these.

To achieve this will require large changes to the traditional product development method. Firstly the manufacturers and/or subcontractors need to be more integrated in the product development process to ensure high manufacturability as this will affect both the manufacturing cost and product reliability. Secondly, the robustness and reliability of different designs must be evaluated early in the product development phase; this requires completely different methods to traditional product development where verification of robustness and reliability normally occurs late in the product development phase if it occurs at all.

## Robustness and Reliability

The reliability of printed boards and printed board assemblies is traditionally ensured by manufacturing these according to standards based on best manufacturing practises. True reliability testing of these is seldom carried out; rather quality is ensured primarily by inspection requirements. When reliability testing is carried out in product development, it tends to occur when the product is fully developed. This in combination with the extensive use of outsourcing within the electronics industry has led to ever more people experiencing lack of reliability from electronic hardware. The risk of reliability issues is even greater when utilising new technology. A more detailed description of the underlying causes of this drop in reliability is available in appendix 2.

To ensure the reliability of electronic hardware during product development, the design must be proved to have acceptable reliability (for a fault free product). Further, the product must be possible to manufacture with a high yield and with few production-related defects.

To verify that the design's reliability is acceptable requires the determination of the loads that the product will be subjected to during its life and how these loads will affect the risk of faults. Therefore, the company that will be responsible for the product's reliability in the field must be part of this process.

Thereafter comes the identification of the failure mechanisms that these loads can cause due to the chosen packaging concept and which of these failure mechanisms could critically affect the product's reliability. It could be failure mechanisms caused by temporary overloads or failure mechanisms caused by aging and wear out. Only after this is it possible to determine how to form reliability tests to ensure their relevance. As a general rule, each failure mechanism requires a unique reliability test.

The design not only affects reliability but also the manufacturability. A design that is on the borderline of what the production process can handle, or one that contains new technology, entails a greater risk of production related defects in the product. For most products it is the variables in the production process that lie at the root of reliability issues, it is therefore crucial to determine how a design affects manufacturability early in the design phase.

When utilising new technology it is also important to evaluate the level of qualification and process checking that is required to ensure consistently high quality in the production. This entails the involvement of the manufacturers in the design process. They must be able to give input to the design and also have the opportunity in time to ensure quality in production if new technology is to be used.

HALT- and HASS-testing are two relatively new test methods that have been developed to improve the robustness of the product and to find production related defects during the product development phase. The HALT-test is used early in the design phase to identify weaknesses in the design and choice of materials (design defects). The testing should be conducted as soon as functioning prototypes have been produced. By exposing these to increasing loads until faults occur it is possible to identify the product's weakest points. Thereafter a judgement is made as to the ability of design changes to improve the robustness of the product. Testing occurs using rising loads in the form of thermal testing (down to -100 °C and up to 200 °C), temperature cycling (60 °C/min on the test object), vibration (6-axis vibration up to ca 65 g's) and combined temperature cycling and vibration exposure.

The HASS test is an advanced form of Environmental Stress Screening (ESS) and is used to find production related defects in products. The results of an earlier HALT test form the basis for selecting as high load levels as possible to increase the chances of finding defects. Through analysis of the fault report from the HASS test it is possible to gather information regarding the type of defects than can occur. Thereafter, it is possible to determine if the occurrence of such defects can be reduced by design changes or better process control in the production line. HASS testing can be performed on start-up of production and/or as random testing of samples during production.

Another important source of information for improved reliability is field returns. Fault analysis of these provides valuable information regarding reliability problems related to both design and production.

## Competence and Knowledge Building through Collaboration

The method of working based on Set-based Concurrent Engineering requires the competence to be able to determine how choice of materials and packaging concept will affect failure mechanisms that can affect reliability. Another prerequisite is the competence to determine how the verification of reliability and production processes with relevant tests during different stages of the product development should be conducted.

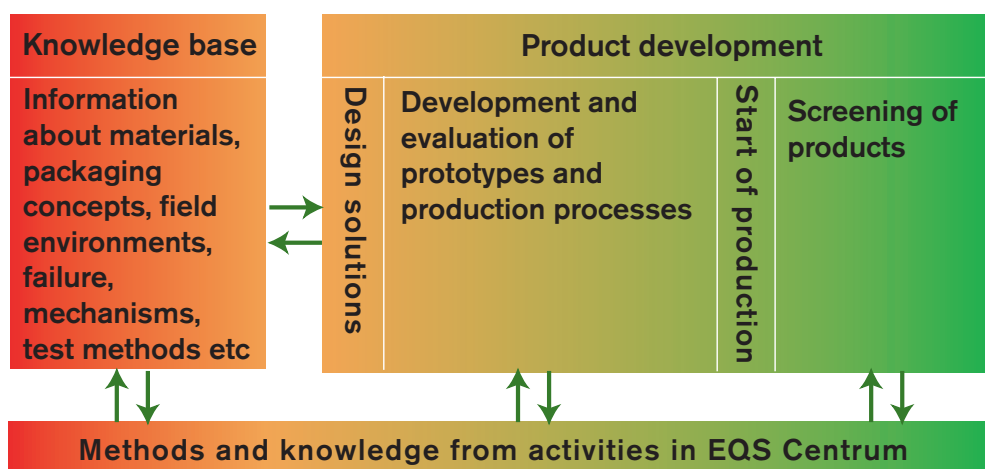


Figure 2

*A knowledge base is built through collaboration between EQS Centrum and participating companies to quickly and efficiently commence working with lean product development.*

It is difficult for individual companies to build up the knowledge required for this method of working. Therefore, the aim of the EQS Centrum is to utilise collaboration between electronic companies to build a common knowledge base (see diagram 2). In the initial year, an important part will be how we apply Set-based Concurrent Engineering in practise to develop the best design. Another important part of our activities will be our research into new reliability risks when utilising new technology and into how best to ensure robustness and reliability when developing new hardware products. This also applies to the procurement of electronic components from subcontractors.

Working teams will be created, for example for the characterization of operating environments and/or test strategies to verify reliability and robustness during the production process. The target group is designers and manufacturers of electronic hardware and their suppliers; it will also include companies that buy in completed electronic products for inclusion in their own products.

EQS Centrum is run jointly by Swerea IVF and Swerea KIMAB. Research will be financed by membership fees as well as, at least initially, with funds reserved for the institute's build up of competence. The direction of activities at EQS Centrum will be decided by a steering group with representatives from the member companies. The conditions for participating in EQS Centrum are laid out in the document "Description of EQS Centrum and the Terms and Conditions of Membership".

The aim is to commence operations in the first quarter of 2008. IVF and KIMAB have suggested as research projects for the coming year "New reliability risks with lead free soldering" (see appendix 1). Swerea IVF and Swerea KIMAB have conducted prestudies during 2005 and 2006 of these three failure mechanisms.

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Further information about EQS Centrum is available from <http://extra.swereaivf.se/eqs>

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## Appendix 1

### New Reliability Risks with Lead Free Soldering

There are three main failure mechanisms with lead free products that have come to notice. These are brittle fractures in solder joints, the formation of tin whiskers and the formation of Conductive Anodic Filaments (CAF) in printed board laminates. During 2005 and 2006, Swerea IVF and Swerea KIMAB have conducted prestudies on these three failure mechanisms. The proposals for continuation of these works are set out below.

The failure mechanisms are not unique to lead free soldering but are most commonly occurring in lead free products. For two of them, brittle fractures in solder joints and the formation of CAF, the repair and reworking of solder joints entails an extra large risk that this will result in failures in the field. How the repair and reworking of solder joints affect reliability will therefore be an important constituent of the projects.

#### Brittle Fractures in Solder Joints

Brittle fractures can occur in solder joints when exposed to sudden mechanical loads, the bending of a printed board assembly when being handled or a product being dropped to the floor can be enough for a brittle fracture to occur. The greater rigidity of lead free solder based on tin, silver and copper when compared to tin-lead solder lies at the root of the greater risk that occurs when using lead free solder. First and foremost it is solder joints to nickel surfaces (i.e. solder lands coated with nickel/gold) that are sensitive to this type of fracture. The properties of the solder as well as the thickness and composition of the intermetallic layer that is formed between the solder and the soldered surface also affect the risk of brittle fractures. Thicker intermetallic layers tend to increase the risk of brittle fractures and especially so when double layers with two intermetallic phases are formed. The thickness of the intermetallic layer increases with the number of soldering cycles but growth also occur when solder joints are exposed to temperatures exceeding 60 °C. As the replacement of a BGA component generally requires three soldering cycles this can cause a significant growth in the intermetallic layer on the printed board's solder lands.

The risk for brittle fractures decreases if one uses non-solder mask defined (NSMD) solder lands but this in turn increases the risk for that solder lands are ripped off from the laminate (pad cratering).

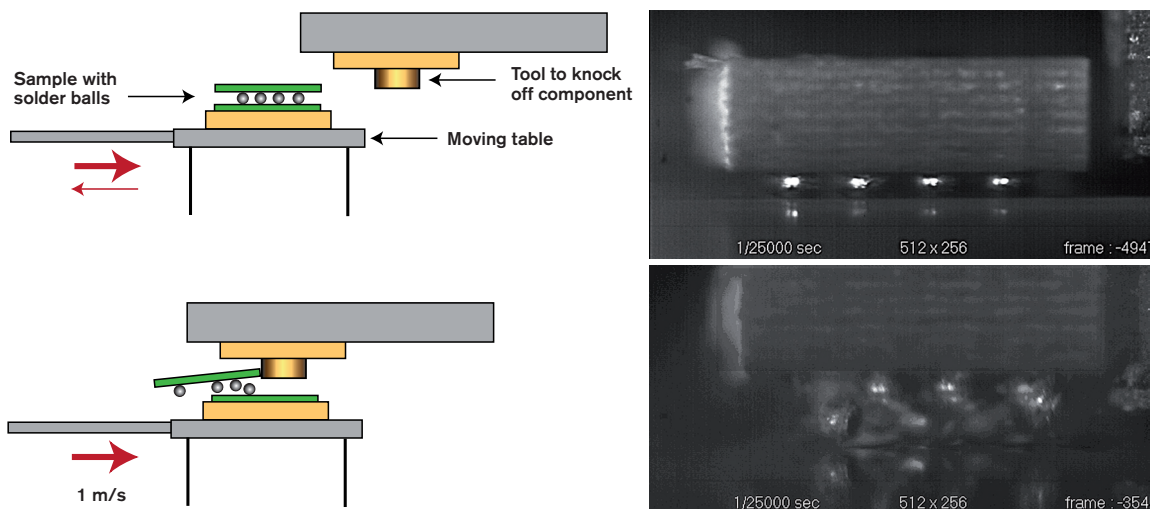


Figure 3 Shearing of components with a unique test method developed to test the risk of brittle fractures in solder joints.

Solder joints to copper surfaces have long been deemed risk free as regards brittle fractures but these can occur even with solder joints to copper. Under certain conditions Kirkendall voids are formed in the intermetallic layer which increases the risk of brittle fractures. New research shows that in 5–10% of solder joints to copper enough voids can occur to cause faults in applications where the solder joints are subjected to mechanical loads. The risk is greatest with applications exposed to high temperatures for a long period of time, but there are also examples of extensive formation of voids at low temperatures. There are even examples of this after storage for one year at room temperature. The reason for this is as yet unknown, but it appears to be connected to impurities in the copper. It is often possible to see great variations between different batches of printed boards from the same manufacturer and sometimes even between different solder lands on the same printed board.

A continuation of this project will see us evaluate how different combinations of solder and metallisation of printed boards and components as well as the number of soldering cycles and ageing at different temperatures affect the risk of brittle fractures. Swerea KIMAB has developed a unique method for testing the risk of brittle fractures in solder joints to assembled components through shearing with a high shearing speed (see diagram 3).

### Formation of Tin Whiskers

The formation of tin whiskers is a well-known problem that can occur when plating with pure tin. Tin whiskers are hair like growths consisting of pure tin (see diagram 4). These can cause short-circuits. The cure to prevent the formation of whiskers has been to use tin coatings containing about 15 % lead. Due to the phasing out of lead, especially with components and in some cases even with printed boards, many have returned to plating with pure tin. There are metallisation manufacturers who state that their coatings are whisker free; unfortunately several studies have found whiskers present even with these metallisations. There is no basic understanding regarding the formation and growth of whiskers today.

It is not however on this issue that an EQS study will focus, rather it will focus on developing methods to predict the risk of whiskers in a metallisation, this includes production methods and combinations of materials that minimise the risk of whiskers. Previous

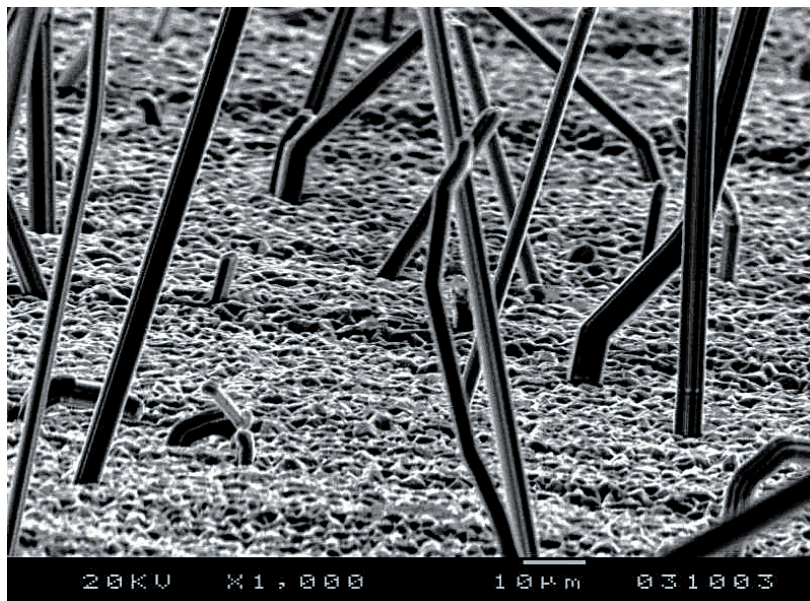


Figure 4 Photograph of whiskers taken with a scanning electron microscope.

studies have indicated opportunities to steer the processes to enable the avoidance of whiskers. Examples of important factors include checking the cleanliness of the coating process, the alloy and the evenness of the underlying layer, storage, heat treatment and handling.

### **The Formation of Conductive Anodic Filaments (CAF) in Printed Boards**

The higher soldering temperature used in lead free soldering entails greater stress of printed boards that can result in delamination between the glass fibres and the epoxy in the laminate. If there are glass fibres connecting two via hole platings then leakage current can be caused along the strands of glass fibres. Via hole platings that have positive potential will see the build up of copper ions and these will diffuse along the glass fibres. With time the concentration of copper ions will build up until a short circuit occurs. This failure mechanism is known as CAF which is an abbreviation of Conductive Anodic Filament.

Traditional FR4 laminate is prone to this failure mechanism, the more layers and solder cycles the greater the risk for formation of CAF. Absorption of moisture by the printed board before soldering also heightens the risk of CAF. There is therefore a very great risk that repair and reworking of solder joints can give rise to CAF. The longer it has been since the printed board's manufacture to its repair and reworking, the greater the risk of CAF as there has been more time for moisture to be absorbed. New laminates that tolerate higher soldering temperatures have been developed but these can have poorer qualities from other aspects such as a greater degree of brittleness, which results in poorer qualities when being drilled.

The prestudy conducted showed that the absorption of moisture by the printed board before soldering greatly raised the risk of CAF. In the continuation of this project, different laminates, that have been produced to offer greater resistance to CAF, will be tested. The project will also include testing of how repairs and reworking affect the risks of CAF forming.

## Appendix 2

### Underlying Causes Behind the Poorer Reliability of Electronic Hardware

More and more alarms are coming regarding the lack of reliability of electronic hardware. The causes of the reduction in reliability can most often be found in the working methods for ensuring quality. This is traditionally ensured by manufacturing and/or testing components, printed boards and printed board assemblies in accordance with established standards.

The quality of the components is mainly ensured by testing these in accordance with JEDEC-JESD47, Stress-Test-Driven Qualification of Integrated Circuits. This standard contains a large number of different stress-tests for detecting defective components. Faults caused by ageing and wear out are not normally detected by these tests.

The quality of printed boards and printed board assemblies is generally ensured by being manufactured in accordance with the requirements stipulated in IPC standards (e.g. 6012 for printed boards and J-STD-001 for printed board assemblies). These standards principally contain inspection requirements and IPC points out that the fulfilment of these requirements is no guarantee that the product will be reliable; rather the requirements should be seen as minimum requirements. For products with high requirements for reliability or when new technology is being used, supplementary reliability test should be conducted.

The comprehensive outsourcing within the electronics industry, which has resulted in ever more parties becoming involved in the product design chain, has also strongly contributed to the increasing levels of quality problems. Perhaps the most serious consequence of outsourcing has been the focus by each and every one on the optimisation of their own business. To increase their own profitability, they utilise the cheapest materials and/or manufacturing methods possible. At the same time there are strong driving forces for implementing new technology, for example to improve performance or as a response to legal requirements. Manufacturing and testing according to traditional standards suits as it minimises costs. It does however entail a great risk that the requirements and tests are not relevant for the new technology.

The consequence of everyone in the product development chain relying on there being relevant standards and reliability tests has often been the lack of anyone in the product development chain with a sufficiently overall view. There lacks defined responsibility for ensuring that both subcomponents and the finished product fulfil stipulated (or expected) quality requirements. Whilst packaging concepts are developed ever faster and become more and more advanced and complex the working methods and knowledge for ensuring reliability have not been able to keep pace with this development. Rather they have taken a step backward due to outsourcing. An illustrative and instructive example of just how wrong it can go is the implementation of red phosphorus as a flame retardant material in components.

#### Lessons from Using Red Phosphorus as a Flame Retardant Material

A good example of the importance of a well thought through strategy for how to ensure the reliability of electronic components is the reliability problem caused by the use of red phosphorus as a flame retardant material in plastic components. At least 13 component manufacturers have used red phosphorus in the manufacture of more than one billion components in the beginning of the 21st century. One of the companies hardest hit was Fujitsu, who used components with red phosphorus in hard disk drivers. This has cost them over SEK 1 billion in damages to their customers. From a purely technical point of view the reliability problems were caused by the slow transformation of red phosphorus into phosphoric acid in the presence of oxygen and water. This leads to corrosion of metals in the components which results in current leakage and in the worst cases short circuits.

A more interesting issue is how these components could be released into the market. An analysis of this has been conducted by the Japan Science and Technology Agency (<http://shippai.jst.go.jp/en/Detail?fn=0&id=CA1000624&>). Their conclusion was that the

principal reason for the failure in judgement was the extent of outsourcing and the great pressure this lead to on prices. Each part of the product development chain focussed on their own processes and no-one took responsibility for the whole. To reduce the time to market and lower costs, reliability testing was reduced and companies have dispensed with staff with reliability competence.

The reliability testing that was conducted has been less than sufficient due to the use of outdated evaluation technology. Most component manufacturers test and qualify their components in accordance with JEDEC JESD47, which consists of a number of standard tests. These tests were used when qualifying red phosphorus as a flame retardant material. It is clearly stated in the standard that if there is risk of new failure mechanisms occurring, then the tests themselves are not sufficient for assuring reliability. Then tests are to be conducted in accordance with JESD34, which requires the identification of critical failure mechanisms and then the design of relevant reliability tests based on these. None of the 13 component manufacturers who used red phosphorus did this despite the failure mechanism was in fact well know and clearly described in the patents for the use of red phosphorus as a flame retardant material in electronic components.

The conclusions drawn by Japan Science and Technology Agency concern the effects of outsourcing on component manufacture. The conclusions are even more relevant as regards printed board and printed board assembly manufacture as often no reliability testing is conducted at all of these.