



AEROSPACE STANDARD

AS6171™/4

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Techniques for Suspect/Counterfeit EEE Parts Detection by Delid/Decapsulation Physical Analysis Test Methods

RATIONALE

The purpose of this document is to provide guidelines and requirements for the use of decapsulation, delidding or disassembly of EEE parts. The document further states the requirements for physical analysis and inspection in order to document characteristics that are consistent with suspect counterfeit parts.

INTRODUCTION

Inspection of the internal structure of a part, such as microelectronic die surface or metallization traces of a thin-film resistor, is a critical task in assessing whether a part may be considered counterfeit. Attributes that are not normally visible during external optical examination of a production part can be examined after a decapsulation or disassembly process. This helps in determining if the attributes are consistent with a part from the original manufacturer.

DISCLAIMER: The images contained herein are provided to illustrate the application of detection methods identified in the document, and are by no means intended to imply that a manufacturer identified in an image and text is involved with the suspect product.

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1. SCOPE

This method standardizes inspection, test procedures and minimum training and certification requirements to detect Suspect/Counterfeit (SC) Electrical, Electronic, and Electromechanical (EEE) components or parts utilizing Delid/Decapsulation Physical Analysis. The methods described in this document are employed to either delid or remove the cover from a hermetically sealed package or to remove the encapsulation or coating of an EEE part, in order to examine the internal structure and to determine if the part is suspect counterfeit. Information obtained from this inspection and analysis may be used to:

- a. prevent inclusion of counterfeit parts in the assembly
- b. identify defective parts
- c. aid in disposition of parts that exhibit anomalies

This test method should not be confused with Destructive Physical Analysis as defined in MIL-STD-1580. MIL-STD-1580 describes destructive physical analysis procedures for inspection and interpretation of quality issues.

Due to the destructive nature of the test method that allows access to materials, design and layout information, the method may also enable observation of trends in design and material or process changes undertaken by the device manufacturer.

If AS6171/4 is invoked in the contract, the base document, AS6171 General Requirements shall also apply.

1.1 Purpose

The purpose of this document is to provide guidelines and requirements associated with the use of decapsulation, disassembly, and internal inspection as part of the process to verify the identity of the manufacturer of a part, and/or to discern and document characteristics that are consistent with suspect counterfeit parts.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AS6171	Test Method Standard, General Requirements, Suspect/Counterfeit, Electrical, Electronic, and Electromechanical Parts.
AS6171/2	Techniques for Suspect/Counterfeit EEE Parts Detection by External Visual Inspection, Remarking and Resurfacing, and Surface Texture Analysis Test Methods.
AS6171/5	Techniques for Suspect/Counterfeit EEE Parts Detection by Radiological Test Methods.

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Aerospace Technical Report.

- 2.2.1 MIL-STD-1580, Destructive Physical Analysis for Electronic, Electromagnetic, and Electromechanical Parts
- 2.2.2 MIL-STD-883, Test Method Standard, Microcircuits
- 2.2.3 MIL-STD-750, Test Method Standard, Test Methods for Semiconductor Devices
- 2.2.4 Murali, S., N. Srikanth, and Charles J. Vath III. "Effect of wire size on the formation of intermetallics and Kirkendall voids on thermal aging of thermosonic wire bonds." *Materials letters* 58.25 (2004): 3096-3101.
- 2.2.5 Park, Jongwoo, et al., "Interfacial degradation mechanism of Au/Al and alloy/Al bonds under high temperature storage test: Contamination, epoxy molding compound, wire and bonding strength." *Components and Packaging Technologies*, IEEE Transactions on 30.4 (2007): 731-744.
- 2.2.6 C.J. Hang, et al., "Growth behavior of Cu/Al intermetallic compounds and cracks in copper ball bonds during isothermal aging" *Microelectronics Reliability* 48 (3): 416-424 (2008).

2.3 Definitions

See AS6171 General Requirements, Section 2.2.

2.4 Acronyms

See AS6171 General Requirements, Section 2.3.

3. DESCRIPTION OF THE METHODOLOGY/PROCEDURE - MICROCIRCUITS, HYBRIDS, DIODES, AND TRANSISTORS

The steps described in the subsequent sub-sections outline the methodology for conducting decapsulation and delidding. The procedure starts with the least destructive methods such as optical inspection and radiological inspection. Destructive steps such as manual and automated decapsulation, laser ablation and delidding are then described. At the end, a summary of inspection criteria is provided. Appendix A provides a step-by-step photo-documentation of the steps described in sub-sections below.

3.1 External Optical Examination

Examine the part for any anomalous conditions that may affect the decapsulation process (cracks in the case, uneven surfaces, etc.). See AS6171/2 for detailed external visual inspection (EVI) requirements.

3.2 Radiological

- 3.2.1 Radiological images shall be obtained in a top-down and side view orientation.
- 3.2.2 Information shall be obtained regarding the internal structure and alignment in order to minimize the potential damage that can occur from the decapsulation or delidding process. For plastic encapsulated parts, determine the side of the part which needs to be chemically etched in order to expose the die face. Note that while most die face opposite the direction that the leads are mounted, in some instances, the die face may be oriented towards the mounting side of the device (reference Example 2 in Appendix A).
- 3.2.3 Radiological image shall be obtained at the proper magnification which will help in the location of the die within the case, and will also help with the gasket selection when using an automated decapsulator.

3.2.4 For full details on radiological inspection refer to AS6171/5 (Techniques for Suspect/Counterfeit EEE Parts Detection by Radiological Test Methods).

3.3 Decapsulation of Plastic Parts and Delidding of Cavity Devices

3.3.1 Plastic Parts

The case material shall be removed to expose the die through one or more of the following methods. Decapsulation exposes the die circuitry, and interconnections for subsequent inspection using optical and electron microscopy. It also allows for wire pull and ball shear, over etching can cause the die attach material to be removed or the lead fingers to be separated from the wire bonds. Caution should be used when decapsulating devices using laser ablation. Certain laser types, wavelengths and parameters can damage the die surface, the wire bonds or other features within the device. It is advisable to supplant laser ablation with either automated or manual decapsulation.

CAUTION: The decapsulation process involves the use of hazardous chemicals, including nitric acid and sulfuric acid. Hazardous materials should only be handled by personnel trained in the proper usage and disposal of said materials. Use of proper Personal Protection Equipment (PPE) for the chemicals being used should be a requirement.

3.3.1.1 Automated Decapsulation Tool

Follow the automated decapsulator manufacturer's instructions to remove the case material from over the die, using the information obtained from the radiological examination to determine the location of the die, size of the die, mounting orientation, and optimal gasket size. All decapsulation parameters shall be recorded for each device to determine repeatability or aberrations in the process.

Note that this process may require practice and experience with the tool to obtain the expertise required to expose the die without damaging the other internal structures (bond pads, bond wires, lead frame, die attach material, substrate, etc.). If requested, a process guide may be provided by the manufacturer of the decapsulator tool.

3.3.1.2 Manual Decapsulation of a Device

The case material over a die shall be removed by using laboratory equipment that has the ability to safely heat and dispense discrete amounts of acids in a controlled manner.

In the manual decapsulation process, it is advisable to start with milling a shallow well/hole over the center of the die approximately one-third of the package thickness, and away from the loop of the bond wires. (It is advisable not to use a regular drill bit because the conical hole is undesirable, use a milling bit instead.) Place the drilled package on a scrap metal plate and heat it on a hot plate to about 80 °C (for red fuming nitric acid). Start with 80 °C but the temperature may need to be changed depending on the reaction of the molding compound to the acid. Also depending on the size/shape of the device, the method of application and volume of acid may change. Small devices may need a shallower well milled away to preserve the bond wires and other desirable structures. While the package is being heated, prepare a squeeze bottle of acetone and a small amount (approximately 5 ml) of red fuming nitric acid in a small glass beaker. Using a Pasteur pipette, drop 1 to 2 drops of red fuming nitric acid in the hole of the heated package. Rinse away the reacted molding compound material with acetone into a waste glass beaker after the fumes subside. Repeat the acid exposure until the microcircuit die is exposed. Note: a final, neutralizing rinse can be performed in order to neutralize any remaining traces of acid on the part. Common neutralizing agents include a mild solution of sodium bicarbonate. A low pressure air brush can also be used to remove traces of solvents or reaction products from the exposed cavity. Caution should be exercised when directing the air flow towards the cavity so the bond wires and leads are not damaged.

Nitric acid is most commonly used for decapsulating plastic parts, however, depending on the materials used for constructing the part, the amount of inert filler and bond wires, other acid types or mixtures of acids can be used. Common examples are low concentration (approximately 20%) sulfuric acid, low temperature (sub ambient) nitric acid or mixes of nitric and sulfuric acid.

Note that this method can be hazardous, and shall only be attempted by personnel who are experienced with this process. Personnel not familiar with this process should not attempt to remove the case material in this manner.

3.3.1.3 Laser Ablation Decapsulation

Laser ablation is a technique that is used to remove the plastic mold compound. Laser decapsulation equipment and setup parameters should be selected to minimize damage to the wire bonds, die passivation and die. In general practice, laser decapsulation is used in conjunction with chemical decapsulation. The first step in this practice involves using a laser ablation tool to remove a majority of the plastic molding compound. Subsequently, the part is decapsulated using chemical decapsulation processes described earlier. This two-step process can help in minimizing chemical use, enable higher throughput and increases the precision in localizing the decapsulation cavity site.

3.3.2 Manual Delidding of Ceramic Devices

There are commonly two forms of ceramic devices in the supply chain. One has two ceramic plates sandwiched around a glass seal. The other is a ceramic device with a hermetically sealed metal cover that is soldered in place over the die area.

3.3.2.1 The sandwich device could be opened with a specialized tool dedicated to deprocessing lidded ceramic devices. Alternatively, the device can be delidded by placing in a vise and using a chisel or chisel shaped tool to sever the seal.

3.3.2.2 Hermetically sealed devices may be opened with a special delidding tool, mechanically machined off, or use a thin razor blade knife to remove the metal seal. In some cases, application of heat to the seal area can increase the effectiveness of opening the device. However, the use of heat should be minimized to prevent damage to the component. Any of the three previously mentioned processes may be used.

3.3.3 Opening of Cylindrical-Lid “TO Can” Devices

3.3.3.1 TO cans may be opened with a special can opener tool that was designed for this purpose without damage to the die.

3.3.3.2 A laser cutting tool can also be used to cut the “TO Can” open while maintaining the internal structure.

3.3.4 Opening of Metal Lid Package

Metal lid packages require a milling process or routing of the edges in order to remove the top metal lid. Thickness of the metal lid and how the device is sealed shall determine which process is used.

3.4 Inspection and Photo-Documentation

3.4.1 An overall photograph of the decapsulated device shall be obtained, demonstrating the condition of the part after decapsulation. That photograph shall show the die completely exposed, and also show the bond pad and bond wires. The purpose of this photograph is to display that proper decapsulation was performed prior to inspection. The lab should subject the die to an optical examination at medium to high magnification, with a magnification sufficient to read all identifying die markings. Then the lab should take a higher magnification photograph showing only the die, and if markings are present, document those markings with a photograph. If any of the information listed below in items 1 through 9 is not present, document the absence of that information in the report and photo-document the remaining information. If comparing it to an “exemplar,” compare the location of markings with sample test batch. Sufficient magnification shall be used to show die characteristics. Some inspections listed below require the use of additional equipment in order to properly document the die information. Inspections requiring additional equipment are noted below.

1. Manufacturer markings
2. Name
3. Logo
4. Die dimensions/orientation

5. Lead frame
 6. Unique image (iconic image used by the die manufacturer such as a flag, a space shuttle, a cartoon man, a tree, etc.)
 7. Die part numbers
 8. Die mask ID numbers
 9. Year of design or tape-out
 10. Pin 1 bond pad outline
 11. Bond wire diameter
 12. Bond wire material (Energy Dispersive Spectroscopy (EDS) or X-Ray Fluorescence (XRF) and Scanning Electron Microscopy (SEM) required)
 13. Bond types (SEM required)
 - a. Thermosonic
 - b. Crescent with or without safety bonds
 - c. Ultrasonic bonds
 - d. Compound bonds
- 3.4.1.1 Record and photo-document any other markings or features that may help in identifying the origins of the die.
- 3.4.2 In the event a complex package or alternative package material (see 7.2 for listing of complex package types) is being tested, it is recommended that photo-documentation and visual inspection be performed immediately following decapsulation. This is because certain materials such as copper, are highly reactive to chemicals used during decapsulation or to the ambient conditions.
- 3.5 Further analysis to obtain more data about the part should be performed, as required. This includes the deprocessing of the die using, for example focused ion beam (FIB) analysis, or a cross-section analysis of the part to determine characteristics of the die and internal structure. Some types of analysis and part-type characteristics are listed below.
1. Passivation layer thickness and type analysis (silicon nitride, oxide types, polyimide, etc.)
 2. Metallization characterization
 3. Three or five layers per metal line
 4. Etch profile
 5. Lead frame material and characteristics
 6. Die attach
 7. Isolation types (STI, field-ox, deep trench, etc.)
 8. Transistor types (CMOS, bipolar, RF, etc.)

- 3.6 Characteristics of the part in question should be compared to the manufacturer's data. Characteristics such as the manufacturer's logo and name should be easy to discern when compared to known good examples provided from the manufacturer. Other characteristics may require comparison to a known good part or manufacturer's data base. Support from the manufacturer may be required.
- 3.7 Information collected during inspection, post decapsulation shall be compared between each sample within the test lot. Any anomalies found during comparison shall be noted and used for determining authenticity of parts. In the event that a datasheet or known good sample is unavailable, a comparison of data within the test lot should be performed.
- 3.8 Wire Bond Pull

Wire bond pull, if requested, should be performed on a minimum of 2 out of the 3 devices allocated for DDPA as specified in the Test Requirements as part of the SOW. For Large Scale Integrated (LSI) circuits, devices containing less than 50 bond wires should have all bond wires pulled. Devices containing greater than 50 bond wires should have 50 bond wires pulled with an addition of 5% of any remaining bond wires. Wire bond pull shall follow the requirements and procedure specified in MIL-STD-1580 for the specific device type. For Microcircuits, the test procedure shall be as specified in MIL-STD-883, TM 2011, Test Condition D. For Semiconductor Devices, the test procedure shall be as specified in MIL-STD-750, TM 2037, Test Condition D, as applicable.

Impurities often cause a loss of surface bondability and premature bond failure during the operational life of the device. Impurities and inter-diffusion in wire bonds can cause Kirkendall voids. With gold-aluminum bonds, the inter-diffusion front moves through the gold, forming intermetallic alloy phases. Due to the lower solubility of the intermetallic, impurities sweep ahead of the front, precipitate there, and act as sinks for the vacancies produced during the diffusion process (2.2.4), (2.2.5), and (2.2.6). When a wire pull failure occurs at the bond pad to wire interface, the force causing the failure and the failure category shall be recorded and become part of the DDPA report. When this mode of failure occurs and the failure site is at the pad to wire interface, additional cross-section and SEM analysis may be required in order to inspect and document the interface for presence of intermetallic compounds.

3.8.1 Visual Examination

Visual examination using higher magnification (for example 500X), should be performed to verify metallization step coverage in addition to documenting anomalous conditions, as described in earlier sections. The visual examination may include the use of SEM to inspect for the presence of intermetallic compounds. The growth of gold-aluminum or copper-aluminum intermetallic compounds at the ball bond to die pad interface, especially due to high temperature aging, would increase the contact resistance and degrade the bond reliability. This could be an indication of used parts sold as new.

3.9 Die Shear

Die shear shall be performed on a minimum of 2 out of the 3 devices allocated for DDPA, at the Critical Risk Level, or as specified in the Test Requirements as part of the SOW. Die Shear shall follow the requirements and procedures specified in MIL-STD-1580 for the specific device type. For Microcircuits, the test procedure shall be as specified in MIL-STD-883, TM 2019.

For Semiconductor Devices, the test procedure shall be as specified in MIL-STD-750, TM 2017. The shear force at die attach or die fracture, the location of the shear, and the percentage of the die still attached, shall be recorded and the resultant data and images shall become part of the DDPA report. The failure criteria shall be as specified in the TM 2019 for the type of die attach material used. The separating force and the visual appearance of the residual die attach media and substrate/header metallization, and any anomalous conditions shall be documented.

3.10 Storage of the Decapsulated/Delidded Part

After the part has been decapsulated/delidded and inspected as per the guidelines mentioned above, the parts shall be prepared for long- or short-term storage as per the requirements of the User/Requestor.

4. DESCRIPTION OF THE PROCEDURE - RESISTORS, CAPACITORS, INDUCTORS, FILTERS, CONNECTORS, CABLES, FUSES, TRANSFORMERS (PASSIVE DEVICES)

4.1 The statement of work with the associated test requirements and test specifications for EEE parts to be evaluated shall use the guidelines outlined in MIL-STD-1580. Often, there are no distinctive internal markings on the parts listed above that would allow for an easy and perceptive screen to determine the manufacturer of the part (unlike semiconductor devices that often have the name, a logo of the manufacturer, or other distinctive markings visible on the surface of the die). If a destructive analysis is deemed to be required, then the analysis of the internal structures would take the form of a construction analysis. The data collected on the internal structures' characteristics shall be documented in enough detail and resolution to enable a comparison against a known good part from the same lot. If a known good part isn't available, then the data collected from each part shall be compared to each sample within the sample test lot. Any anomalies found during comparison shall be documented and used for determining authenticity of parts. When possible, if a known good part is not available, then arrangements would need to be made to have the original part manufacturer (OCM) assess the data and photos and make a determination (which would require cooperation from the OCM). The following pieces of data of the internal structures would likely be useful in this assessment:

1. Internal dimensions
2. Elemental composition of the part materials
3. Apparent construction and interconnection techniques
4. Internal alignments characteristics

4.2 The analysis would require some of the following analytical techniques and tools:

1. Cross-section analysis
2. Chemical depotting and decapsulation
3. Mechanical disassembly
4. Optical examination and photo-documentation
5. Scanning electron microscope examination
6. Elemental analysis tools such as energy dispersive radiological (EDS), Auger, FTIR, XRF, etc.
7. Focused ion beam (FIB)

4.3 Data shall be recorded and photo-documentation shall be obtained at various magnifications in order to properly capture the following features:

1. Overall photos showing the internal structures and alignment
2. Interconnections and interfaces
3. Plating thicknesses and optical characteristics
4. Photomicrographs with calibrated measuring bars for critical dimensional measurements
5. Data and spectra from elemental analysis

5. TEST EQUIPMENT, TEST SAMPLES, AND CALIBRATION

5.1 Chemical Decapsulation Process

CAUTION: The decapsulation process involves the use of hazardous chemicals, including nitric acid and sulfuric acid. Hazardous materials should only be handled by personnel trained in the proper usage and disposal of said materials.

To perform the chemical decapsulation process, the use of an automated decapsulator may be beneficial as it has the capability of performing the chemical removal of the molded material while confined in a protected chamber. The process may also be performed manually, using a hot plate and laboratory equipment. This manual process involves the dispensing of controlled amounts of acids on the part. In either case, manual or automated, laboratory equipment and facilities shall be suited to safely rinse the part and remove residual chemicals or debris.

The responsible test laboratory should have a standard operating procedure to address the safe storage, use and disposal of the chemicals and consumables used during the chemical decapsulation process. The facility of the responsible test laboratory should be equipped to store and dispose of the acid or solvent rinse solution used in the decapsulation process. The by-products of decapsulation may be liquid, semi-solid or solid. A comprehensive list of recommended safety equipment is available in 6.9. Acid and solvent mixtures, which are liquid can be stored in appropriate bottles for disposal. The disposal bottle should be labeled as per MSDS. Always consult and follow the local, state or national environmental regulations to safely and responsibly dispose of the by-products of chemical decapsulation.

5.2 Mechanical Disassembly Tools

To perform a mechanical disassembly of a part, tools typically found in test laboratories will often be utilized. This includes cross-section tables and associated epoxy mounting material and other supplies, fine-tipped picks, X-acto blades, bladed saws, diamond wire saws, etc. Regardless of the laboratory tools used, internal structure of a part shall remain unchanged after mechanical disassembly.

5.3 Decapsulation using Laser Ablation

Laser ablation is used to remove the plastic mold compound of a part. Suitable laser parameters should be selected to remove the molding compound without damage to the interconnects, die or other features on the part. Laser ablation is typically used as a preliminary step before completing a decapsulation using plasma or chemicals. It is significantly faster than plasma techniques, and does not expose the package to potentially corrosive chemicals. In a large majority of cases, a decapsulation using laser ablation can be finished using an automated or manual chemical decapsulation process.

5.4 Radiographic and/or Radiographic Tools

Radiological images are extremely useful in acquiring information about the internal structures of the device prior to the decapsulation/disassembly procedure. A radiological system should be used for documenting the internal structure. Radiographs or images in various orientations can be acquired to document the internal structure and alignment from multiple angles, providing a better perspective of the internal construction. It is also beneficial if the radiological system can be setup to provide either a 1:1 ratio image, or have the ability to provide a calibrated scale by which dimensions can be obtained. Another technique for determining die size, orientation and location in plastic encapsulated microcircuits is acoustic microscopy.

5.5 Metallurgical Microscopes and Photo-Documentation Equipment

To perform the examination and photo-documentation of the internal structure of a part, to document part markings, anomalies, and manufacturer-specific structures, low- and high-power optical microscopes (for example 500X) should be used. The microscope should be coupled with adequate lighting and lighting manipulation filters. Optical filters allow observation of certain features such as mask definition, markings and logos on the die. The microscope should be coupled with an image capture capability. The images can be captured in either still or video mode. Some of the characteristics observed using metallurgical microscopy can also be observed using scanning electron microscope (SEM).

5.6 Scanning Electron Microscope (SEM), Energy Dispersive Radiological (EDS) Tool

A scanning electron microscope is often required to examine and document features that are too small to be analyzed using optical microscopy. These features may include anomalous growth surrounding wire bonds, die metallization and patterning, staining, passivation damage or bond wire clearance. Many SEM systems are coupled with energy dispersive radiological system or energy dispersive spectroscopy (EDS) tools. The addition of the energy dispersive spectroscopy tool allows for elemental analysis of features observed in the SEM. Some of the characteristics observed using SEM can also be observed using metallurgical microscopes.

5.7 Plasma, Reactive Ion Etching (RIE)

A plasma decapsulation tool uses ionized gases to remove plastic mold compounds in order to expose the internal die and other structures. While the process produces a “cleaner” die surface than other processes, it requires a much longer process time in order to achieve acceptable results. This process time can be reduced by using laser ablation or sanding to remove plastic mold compound prior to plasma and RIE processes.

5.8 Summary of Package Types and Recommended Decapsulation Methods

Table 1 - Recommended decapsulation methods for various package types

Package Types	Decapsulation Methods			
	Chemical	Plasma	Laser	Mechanical
Plastic	YES	YES	YES ¹	YES ²
Ceramic	NO	NO	NO	YES
Metal	NO	NO	YES	YES

NOTE 1: See discussion in 3.3.1.3.

NOTE 2: See discussion of mechanical preparation methods in 3.3.1.2.

6. DETAILED REQUIREMENTS

6.1 Sample Submission Information

6.1.1 When available, User/Requestor submitting samples for testing shall provide device information (i.e., die size, bond wire material, etc.) to contracted test lab to better determine decapsulation parameters.

6.2 Sampling

6.2.1 Sample selection shall be done in accordance with AS6171 General Requirements, Section 3.5.

6.2.2 Reference sample shall be radiologically inspected to confirm die location for proper gasket selection when using automated decapsulation method. Reference sample shall still be radiologically inspected when using manual decapsulation method so as to confirm die location.

6.2.3 Each sample shall be documented with a photo to show markings for comparison after decapsulation. The photo-documentation should include an overview of the sample clearly showing the part markings, manufacturer's logo and other relevant information. Note that in some instances where markings are applied on the top and bottom side of the part, both the surfaces should be photo documented.

6.3 Categories of Testing/Risk Levels

Refer to AS6171 General Requirements for tier level definitions and risks.