EVALUATION TEST PROGRAMME GUIDELINES FOR COOLED INFRARED DETECTOR ASSEMBLIES

ESCC Basic Specification No. 23204

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DCR No.	CHANGE DESCRIPTION

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1 PURPOSE

The purpose of this guideline document is to recommend an approach and pertinent requirements for the evaluation of cooled Infrared (IR) Detector Assembles for use in space applications.

2 SCOPE

2.1 GENERAL

This Evaluation Test Programme Guideline defines the accelerated testing required to overstress specific characteristics of IR Detector Assemblies that are cooled during operation (i.e. operation < 233K) in order to detect possible failure modes. However, the test program within this guideline has been developed with a particular focus on IR Detector Assemblies operated at cryogenic temperatures (i.e. operation < 200K), which represents the 'worst case' in terms of reliability, and has minimal overlap with other existing guidelines or specifications. The guideline also defines the minimum content of a Constructional Analysis to be performed to detect any design and/or construction defects which may affect reliability and which may support failure analysis activities.

2.2 APPLICABILITY

This Evaluation Test Programme Guideline is applicable to IR Detector Assemblies with hermetic and non-hermetic packages. It is also applicable to any Add-on active and passive components such as an interconnection substrate (e.g. package), resistors, capacitors, temperature sensor(s), a window and window-holder, filters and filter-holders, flexible PCB(s) and electrical connector(s), which form part of the detector's design. When the IR Detector Assembly includes non-evaluated Add-on components, the Evaluation Test Programme shall be complemented with suitable tests based on applicable ESCC basic and ancillary specifications, or ECSS standards.

3 RELATED DOCUMENTS

3.1 APPLICABLE DOCUMENTS

The following ESCC documents form part of, and shall be read in conjunction with, this specification:

- No. 20400, Internal Visual Inspection.
- No. 20500, External Visual Inspection.
- No. 20900, Radiographic Inspection of Electronic Components.
- No. 21300, Terms, Definitions, Abbreviations, Symbols and Units.
- No. 21400, Scanning Electron Microscope (SEM) Inspection of Semiconductor Dice
- No. 22500, Guidelines for Displacement Damage Irradiation Testing.
- No. 22900, Total Dose Steady-State Irradiation Test Method.
- No. 23800, Electrostatic Discharge Sensitivity Test Method.
- No. 25100, Single Event Effects Test Method and Guidelines.
- No. 25200, Application of Scanning Acoustic Microscopy to Plastic Encapsulated Devices

Unless otherwise stated herein, reference within the text of this specification to "the Detail Specification" shall mean the relevant draft procurement Detail Specification (see Para. 6.1.3).

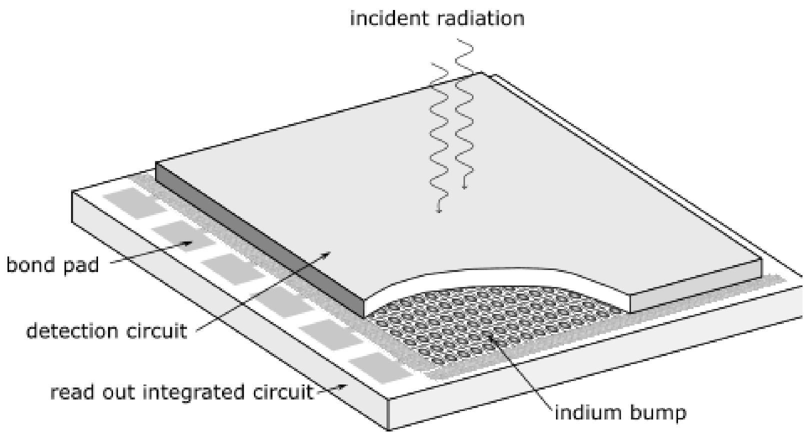
3.2 REFERENCE DOCUMENTS

- ECSS-Q-ST-60-05, Generic Procurement Requirements for Hybrids
- ECSS-Q-ST-70-02, Thermal Vacuum Outgassing Test for the Screening of Space Materials.
- ECSS-Q-ST-70-13, Measurement of the Peel and Pull-Off Strength of Coatings and Finishes Using Pressure-Sensitive Tapes.
- ECSS-Q-ST-70-17, Durability testing of coatings.
- ECSS-Q-ST-70-60, Qualification and Procurement of Printed Circuit Boards.
- ECSS-E-ST-10-03, Testing.
- MIL-STD-750, Test Methods for Semiconductor Devices.
- MIL-STD-883, Test Methods and Procedures for Micro-electronics.
- Ref. 1: Pecht et al., Criteria for the Assessment of Reliability Models, IEEE Transactions on components, packaging and manufacturing technology – Part B, Vol. 20, No. 3, 1997.
- Ref. 2: Dantas de Morais, et al., Low temperature FIB cross section: Application to indium micro bumps, Microelectronics Reliability, 54, p1802, 2014.
- Ref. 3: Hubbell, J. H. and Seltzer, S.M., X-Ray Mass Attenuation Coefficients, NIST Standard Reference Database 126, https://www.nist.gov/pml/x-ray-mass-attenuation-coefficients
- Ref. 4: Goiffon, V. et al., Multilevel RTS in Proton Irradiated CMOS Image Sensors Manufactured in a Deep Submicron Technology, IEEE Trans NUCL Sci, Vol 56, No. 4, 2009.

4 TERMS, DEFINITIONS, ABBREVIATIONS, SYMBOLS AND UNITS

The terms, definitions, abbreviations, symbols and units specified in ESCC Basic Specification No. 21300 shall apply. In addition, the following definitions and abbreviations shall apply:

Detection circuit:	The structure containing the photosensitive substrate material where the conversion of photons to electrical signal takes place. May have one or more pixels, and may also include a mechanical substrate.
Read-out Integrated Circuit (ROIC):	Silicon circuit providing the electrical signals to operate the pixels, as well as the circuitry to provide the output electrical signal. **NOTE:** Unless stated otherwise, ROIC implies as-received from the foundry, i.e. prior to any processing in preparation for further assembly.
Hybridised Array:	The detection circuit hybridised to the ROIC via flip-chip (see figure below). This may include multiple detection circuits bonded on one ROIC. **NOTE:** An IR Detector Assembly that has the detection circuit wire-bonded to the ROIC is not considered a Hybridised Array.



Schematic Example of a Hybridised Array Sub-Assembly

Retina:	Synonymous with Hybridised Array
Add-on:	Each constituent element which is included in the final IR Detector Assembly product. Examples may include one or more: • Submount • Interconnection substrate • Temperature sensor • Window • Window-holder • Filter • Resistor • Capacitor • Flexible PCB • Electrical connector • Cold-shield
Sub-assembly:	Add-ons that have been assembled together. Examples may include: • Hybridised Array • Package • Window integrated with window holder • Filter integrated with filter holder • Wire bonded assembly • All glued assembly
Building block:	Synonymous with Add-on or sub-assembly.

Infrared (IR) Detector Assembly:	The image sensor assembly complete with all electrical, thermal, and mechanical interfaces allowing next-level integration with: front-end-electronics, cooling means, and focal plane.
	For instance, the IR Detector Assembly incorporates:
	• Hybridised Array (or monolithic array)
	• Package providing the mechanical, thermal and electrical connection to the detection circuit
	• Fully assembled package Add-ons or sub-assemblies such as:
	  o Temperature sensors
	  o Window and window-holder
	  o Filter and filter-holder
	• Fully assembled electrical interface, such as a flex cable with terminating connector.

Hermetic package:	A component encapsulation which by design and construction is able to pass a seal test.
Non-hermetic package:	A component encapsulation which by design or construction is unable to pass a seal test.
Homogeneous Lot:	For an active Add-on: a unique lot with respect to diffusion, metallisation and passivation processes (adapted from ECSS-Q-ST-60-05). For a passive Add-on: a unique lot with respect to firing or metallisation (adapted from ECSS-Q-ST-60-05).
Production Lot:	For an IR Detector Assembly or sub-assembly: Parts manufactured on the same production line, using the same production techniques, in one uninterrupted period, according to the same part design and using the same materials and processes (adapted from ECSS-Q-ST-60-05).
Representative Production Lot:	A lot that represents several Production Lots, grouping products from the same family, manufactured on the same production line using the same production techniques, according to the same part design and using the same materials and processes (adapted from ECSS-Q-ST-60-05).

Test Vehicle for Evaluation (TVE):	The item to which the Evaluation Test Programme applies.
Component:	Synonymous with TVE.
Cooled temperature range:	Temperature between 200K and 233K.
Cryogenic temperature range:	Temperature below 200K.
ARC:	Anti-Reflection Coating
EOL:	End of Life
NIEL:	Non-Ionising Energy Loss

5 INTRODUCTION

The tests specified in this Evaluation Test Programme should be based on the sequence shown in Chart I (but see Para. 5.1). All results shall be recorded, and all failed IR Detector Assemblies shall be submitted to failure analysis where probable failure modes and mechanisms shall be determined.

The Evaluation Test Programme shall be approved by the Customer, and the Manufacturer shall report the results to the Customer. The evaluation testing may be performed by either the Manufacturer or a test house, under the supervision and responsibility of the Manufacturer, and as approved by the Customer.

5.1 INITIAL ASSESSMENT

Prior to the creation and performance of the Evaluation Test Programme, an initial assessment is recommended to be performed in order to extensively characterise each building block of the IR Detector Assembly, to address intrinsic and extrinsic failure modes and to determine the margins for these failure mechanisms. This initial assessment should be performed using all available data relevant to the design, manufacture and performance of the detector and, where specific data is not available, complementary testing of suitable test samples, to destruction wherever possible.

The results of this initial assessment should be used to inform the content of the subsequent Evaluation Test Programme.

6 REQUIREMENTS

6.1 GENERAL

6.1.1 Selection of Components for Evaluation Testing

Evaluation testing in accordance with Chart I shall be performed on test vehicles (TVE) representative of the IR Detector Assemblies being evaluated, selected to be the most suitable for highlighting those characteristics and parameters that are pertinent to an investigation on failure modes and weaknesses.

The test vehicles selected for evaluation testing shall be agreed by the Customer/User and the Manufacturer.

The minimum sample size for evaluation testing is indicated in Chart I.

The particular characteristics of the test vehicle selected will depend on which tests are being performed. Where possible, all test vehicles should be compliant to the intended design, performance and inspection criteria. However, devices deviating in some way may be selected for a test sequence if it is agreed with the Customer/User that it will not impact the interpretation of the test results. Add-ons shall be included in the TVE where considered relevant. Unless otherwise agreed with the Customer/User, the test vehicles shall be as follows:

<table>
<tr><th>Test Vehicle Designation</th><th>Applicable Evaluation Tests (see Chart I)</th><th>Description</th></tr>
<tr><td>TVE1</td><td>All testing except as listed below</td><td>IR Detector Assembly (see Note 1)</td></tr>
<tr><td>TVE2</td><td>Radiation Subgroup: Displacement Damage and Total Ionising Dose testing</td><td>Hybridised Array representative of the standard IR Detector Assembly, but may be in a non-representative package, provided it can be operated as per in the intended application (see Note 2)</td></tr>
<tr><td rowspan="3">TVE3</td><td>Radiation Subgroup: Single Event Effects testing</td><td rowspan="3">ROIC representative of the IR Detector Assembly, but may have a non-representative interface, provided all functionality necessary for the relevant evaluation tests is available (see Note 2)</td></tr>
<tr><td>Electrostatic Discharge Sensitivity Subgroup testing</td></tr>
<tr><td>Storage / Endurance Subgroup: Intermittent Operating Life testing</td></tr>
</table>

NOTES:

1. TVE1 shall be IR Detector Assemblies from a single production lot, or a representative production lot. The same applies for the constituent sub-assemblies forming the IR Detector Assembly. Add-ons shall be from fully traceable, homogeneous lots. These components shall not have been submitted to any screening.
2. TVE2 and TVE3 shall be selected from a single production lot, or a representative production lot. The same applies for any sub-assemblies forming the TVE. Add-ons shall be from fully traceable, homogeneous lots. These components shall not have been submitted to any screening.

6.1.2 Materials and Finishes

All non-metallic materials and finishes of the IR Detector Assemblies shall be tested in accordance with ECSS-Q-ST-70-02 to verify their outgassing requirements, unless relevant data is available.

6.1.3 Detail Specification

Should a Detail Specification for the IR Detector Assembly to be evaluated not exist, the Manufacturer shall prepare such a document in draft form and submit it to the Customer/User for provisional approval. This Detail Specification shall contain all the mechanical, electro-optical and other specific test requirements applicable to the components being evaluated, as required herein. This Detail Specification shall then serve as a basis for the testing of the IR Detector Assemblies.

6.1.4 Inspection Rights

The Customer/User and Manufacturer shall agree on points of inspection of the test vehicles being processed for evaluation purposes.

6.1.5 Control During Manufacture

Pre-assembly visual inspections shall be performed on the lot to be evaluated and this requirement shall form part of the Manufacturer's standard procedure.

Progress of the test vehicles' manufacture shall be observed, closely monitored and recorded. The Manufacturer shall trace the quantities in/out and record the cause for rejection of any failures. The record of process controls and inspections shall be available to the Customer/User on request.

6.2 100% INSPECTION (SEE CHART I)

The selected test vehicles shall be inspected on a 100% basis to verify their suitability for the Evaluation Test Programme as specified in Chart I and the following sub-paragraphs.

Defects or deviations from the established requirements may invalidate the evaluation. For each measurement or inspection performed, the results shall be summarised in terms of quantity tested, quantity passed and quantity rejected. If any items are rejected, the reason shall be clearly identified. Any components rejected specifically during the 100% Inspection shall be replaced.

6.2.1 Marking and Serialisation

In order to guarantee traceability, all TVE's shall be permanently marked and serialised in accordance with the Manufacturer's standard procedures. Care shall be taken to ensure the marking process itself will not introduce potential source of degradation due to, for example, corrosion.

6.2.2 Completion of Inspection

The completion of inspection shall result in a batch of test vehicles that have been verified as to their suitability for the Evaluation Test Programme, i.e. each test vehicle has satisfied the requirements of Chart I 100% Inspection.

6.3 ELECTRO-OPTICAL MEASUREMENTS (SEE CHART I)

Measurements shall be made in accordance with Electrical and Optical Measurements in the Detail Specification at high, operating and low temperatures on test vehicles that have successfully completed the 100% Inspection (ref. Para. 6.2). All results shall be recorded against serial numbers. For specific TVEs, the characterisation test sequences may be simplified provided the parameters measured are sufficient and complete for the purpose of the evaluation.

These characterisation results shall be carefully analysed upon completion of the measurement sequence and compared to the results obtained on the set of control components (see Para. 6.4(a)). In the event that any component(s) exhibits an unexplained significant parameter difference to the controls, measurements shall be repeated on the suspect component(s).

Any components which fail one (or more) characteristic requirements during these electro-optical measurements shall be replaced.

6.4 EVALUATION TESTING (SEE CHART I)

Evaluation testing shall be performed in accordance with the requirements specified in Chart I. The tests of Chart I shall be performed on the specified test vehicles that have successfully completed the Electro-Optical Measurements (ref. Para. 6.3). Evaluation testing is divided into subgroups of tests as follows. All test vehicles assigned to a subgroup shall be subjected to all of the tests in that subgroup, in the sequence shown. The applicable test requirements are detailed in the paragraphs referenced in Chart I (see Para. 6.5).

(a) Control subgroup (2 TVE1 components)

The components of this group shall be retained for comparison purposes. Whenever measurements are made on any components under test, these samples shall also be measured. A logbook shall document all measurements and storage conditions for these devices.

(b) Constructional Analysis subgroup (2 TVE1 components).

(c) Electrostatic Discharge Sensitivity subgroup (2 TVE3 components).

(d) Radiation subgroup (6 TVE2 and 3 TVE3 components).

(e) Thermo-Mechanical subgroup (3 TVE1 components).

(f) Storage / Endurance subgroup (3 TVE1 and 3 TVE3 components).

6.4.1 Failures

The following shall be counted as component failures:

- Components which fail during tests for which the pass/fail criteria are inherent in the test method.
- Components which fail one or more of the applicable limits during End-Point Electro-Optical Measurements (see Para. 6.5.22).
- Visual Inspection failure.
- Mechanical failure.
- Handling failure.

All failed components shall be analysed. The depth of analysis shall depend on the circumstances in which failure occurred and upon whether useful information may be gained. As a minimum, the failure mode shall be determined in each case. Failed components shall not be replaced. Samples not failing catastrophically, e.g. those displaying out of tolerance electro-optical characteristics, shall not be removed from the test sequence but monitored to observe degradation trends.

6.5 TEST METHODS AND PROCEDURES

6.5.1 Weight

All test vehicles of type TVE1 shall be weighed to an accuracy of ±0.05% or 0.1g, whichever is greater. Any components which exceed the maximum weight specified in the Detail Specification shall be replaced.

6.5.2 Dimension Check

The basic outline (L x W x H) plus lead/terminal dimensions of all test vehicles of type TVE1 shall be measured along with any other dimensions in the Detail Specification and the results recorded, together with any non-conformances.

Any components rejected specifically during the 100% Inspection shall be replaced.

6.5.3 Functional Electro-Optical Measurements

All test vehicles shall be measured to verify basic functionality (in accordance with the Detail Specification (go-no-go)).

Any components rejected specifically during the 100% Inspection shall be replaced.

6.5.4 External and Internal Visual Inspection

It is recommended that tailored, device-specific External and Internal Visual Inspection requirements be included in the Detail Specification, due to the highly customised nature of IR Detector Assemblies. Otherwise, the following shall apply:

All components shall be externally inspected in accordance with ESCC Basic Specification No. 20500.

For hermetic package components, a full Internal Visual Inspection may be possible through the attached window if the window allows a complete overall view of the cavity and of the component's construction. Relevant specifications that can be applied for Internal Visual Inspection include the following:

- ESCC Basic Specification No. 20400.
- MIL-STD-883 Test Method 2010 (Test Condition A)
- MIL-STD-883 Test Method 2017

If a full Internal Visual Inspection is not possible (or if the window is not transparent), a Partial Internal Visual Inspection shall be performed (or an inspection performed prior to attachment of the window). In such cases the Partial Internal Visual Inspection shall be as specified in the Detail Specification.

Any components rejected specifically during the 100% Inspection shall be replaced.

All findings shall be photo documented. As a minimum, a consistent set of photographs shall be taken and provided as follows (where such photographs are possible for the applicable TVE):

- An overall photograph of the component.
- An overall photograph of the detection circuit and/or hybridised array.
- An overall photograph of each Add-on.
- Any finding during the inspection that could be a reject or cause for concern. Full details of the finding (location, size, picture, root cause, possible reliability impact) shall also be recorded and provided. Criticality of any such findings shall be assessed and agreed between Customer/User and Manufacturer on a case-by-case basis.
- Any finding related to manufacturing capability limitation, even if considered as non-critical, shall be recorded to also enable monitoring for evolution during evaluation testing.

Specific attention shall be given to the following points:

- Cosmetic aspect of any optical coatings applied to surfaces such as the hybridised array, window, filter.
- Lighting, tilt and magnification conditions should be adapted to capture any surface defects that could impact the performance of the IR Detector Assembly.
- The edges of the detection circuit, using a tilt jig to ensure consistent view angle.
- Wire bonds.
- Cracks, chip-outs in die.

6.5.5 Mobile Particle Detection

For hermetic package or closed cavity TVEs only, where such tests are able to be performed.

All components shall be subjected to a mechanical shock/vibration test in accordance with MIL-STD-883 Test Method 2020, Condition A, or MIL-STD-883 Test Method 2002, Condition A. The applicable test method shall be as specified in the Detail Specification.

Particle Mapping shall be performed in accordance with Para. 6.5.5.1 before and after the shock/vibration sequence.

Any components rejected specifically during the 100% Inspection shall be replaced.

6.5.5.1 Particle Mapping

For hermetic package or closed-cavity TVEs only.

Any foreign particle within the package that is large enough to reduce the narrowest spacing between unglassivated operating material to less than 50% (metallisation, bare semiconductor material, mounting material, bonding wire, etc.) or is greater than or equal to the minimum particle size, as specified in the Detail Specification, shall be identified and recorded against serial number, and by its location and size. If such observation of particles through detector window is not possible, alternative means such as photo-response non-uniformity characterisation shall be performed.

If any such particle has moved from its initial location recorded during the 100% Inspection, the component shall be considered as a failure, or allocated to a test stream where such a mobile particle will not have an impact on the evaluation result.

Any TVEs rejected specifically during the 100% Inspection after Mobile Particle Detection shall be replaced.

Any subsequent failures related to Particle Mapping during evaluation shall be processed as failures in accordance with Para. 6.4.1.

6.5.6 Seal Test

For hermetic package components only.

The Manufacturer shall perform an analysis to derive relevant pass/fail criteria for both Fine and Gross Leak tests, in particular demonstrating that the actual package leak rate is sufficiently small to avoid any risk of condensation on the internal surfaces at the operating temperature in vacuum at EOL. This derived pass/fail criteria shall be included in the Detail Specification.

Fine and gross leak tests shall be performed on all components as follows.

Any components rejected specifically during the 100% Inspection shall be replaced.

(a) Fine Leak
MIL-STD-883 Test Method 1014 Condition A1, A2, C5, CH1, CH2 or Z. Pass/fail criteria shall be as specified in the Detail Specification.

(b) Gross Leak
MIL-STD-883 Test Method 1014, Condition C1, C3, C4, CH1, CH2 or Z. Pass/fail criteria shall be as specified in the Detail Specification. For conditions C1 (or C3) based on Perfluorocarbons, if a temperature other than the default (125ºC) for the indicator fluid (or test chamber) is used, this shall be clearly stated.

6.5.7 Internal Gas Analysis

Hermetic package components only.

In accordance with MIL-STD-883 Test Method 1018.

For IR Detector Assemblies operated at cryogenic temperatures, the pass/fail criteria shall be adapted to ensure that constituent gasses inside the package will not condense at the Operating Temperature (e.g. H_2O, CO_2 or N_2).

6.5.8 Scanning Acoustic Microscope Inspection

In accordance with ESCC Basic Specification No. 25200. All findings shall be photo documented.

6.5.9 Radiographic Inspection

In accordance with ESCC Basic Specification No. 20900. All findings shall be photo documented. Sub-assemblies which are stand-alone pieces after de-encapsulation shall also be subject to radiographic inspection (such as window/window-holder assembly).

Specific attention shall be given to the following points:

- Voids
- Wire bonds

6.5.10 De-Encapsulation

Each component shall be de-encapsulated such that there is no resulting damage or contamination to the internal structure, and the ability to observe any defects is not impaired.

6.5.11 Internal Visual Inspection (after de-encapsulation)

In accordance with ESCC Basic Specification No. 20400. All findings shall be photo documented. Sub-assemblies which are stand-alone pieces after de-encapsulation shall also be subject to visual inspection (such as window/window-holder assembly, or filter/filter-holder assembly).

Specific attention shall be given to the following reject criteria:

- Cosmetic aspect of any coatings applied to surfaces
- Wire bonds
- Cracks or chip-outs in detection circuit
- Cracks on the edges of the detection circuit, using a tilt jig to ensure consistent view angle

6.5.12 Coating Peel and Pull-Off Strength

Applicable to the component window and/or any die coating, or any other relevant coating or Add-on component.

Unless otherwise specified, a peel and pull-off test shall be performed on the window and/or the die coating in accordance with ECSS-Q-ST-70-13, ECSS-Q-ST-70-17 (Annex E), and the Detail Specification.

6.5.13 Scanning Electron Microscope (SEM) Inspection

In accordance with ESCC Basic Specification No. 21400. All findings shall be photo documented.

Specific attention shall be given to the following details:

(a) Detailed examination of any anomalies identified by the internal visual inspection.

(b) Low magnification (up to 500x) shall be used to assess:
- Clearance of bond wires at the die edge
- Quality of bonding at the die
- Quality of bonding at the post

(c) High magnification (1000x or greater) shall be used to assess:
- Metallisation coverage at contact windows, bonding pads, etc.

6.5.14 Sub-assembly Bond Strength

Applicable to all bonded interfaces between passive sub-assemblies and the package; for instance, the filter-holder bond to the package, or the window-holder bond to the package.

In accordance with MIL-STD-883 Test Method 2019 or 2027. Since these test methods are defined for active Add-ons, the pass/fail criteria shall be adapted based on a mechanical model of the assemblies.

6.5.15 Bond Strength

Applicable to all internal wires.

In accordance with MIL-STD-883 Test Method 2011. All bonds shall be tested. Individual separation forces and categories shall be recorded.

6.5.16 Die Shear or Substrate Attach Strength

Applicable to all bonded interfaces including any active Add-ons, such as the ROIC attachment to the package, or a temperature sensor attachment to the package.

In accordance with MIL-STD-883 Test Method 2019 or 2027. Individual separation forces and categories shall be recorded.

6.5.17 Flip-Chip Pull-Off

Applicable to flip-chip Add-on components.

In accordance with MIL-STD-883 Test Method 2031.

6.5.18 Microsection

Precautions: There are many toxic substances used in the manufacturing of IR Detector Assemblies, and therefore precautionary measures shall be employed.

Applicable to the component, but also to any individual sub-assemblies which remain as stand-alone pieces following previous tests of the Constructional Analysis subgroup. Notably this shall include the window/window-holder for hermetic package components.

The component shall be potted in a transparent thermosetting resin. This shall have a curing temperature below the maximum storage temperature of the component, or if this is too restrictive, the curing temperature shall be chosen so as not to induce any changes in the aspects of the component being investigated. The resin shall be evacuated after mixing and after the component has been mounted in the uncured resin.

The component shall be ground and polished to achieve a surface finish of at least 0.1μm. To improve definition and detail, chemical etches shall be used to highlight junction definition, metallographic features, etc.

For components with hybridisation, an alternative means to inspect the connection area (indium balls and underfill material) is to remove the upper detection circuit by mechano-chemical means.

Visual and SEM inspection of the microsectioned areas shall be performed, with specific attention given to the following points:

(a) Diffusion and oxide characteristics
(b) Metal/semiconductor interfaces
(c) Metal/metal interfaces
(d) Thickness and consistency of layers; particularly insulating layers in components with multiple layer metallisation
(e) Plating thickness and consistency on posts and pins.

6.5.19 Focused Ion Beam (FIB) Inspection

As an alternative to microsection, FIB can also be used to mill a region of the component and allow viewing of a small region of interest; for instance, within the hybridised array to inspect the connection area (indium bumps and surrounds) and interface metallisation.

In applying a FIB method, it should be noted that there can be artefacts introduced when a Ga ion beam is used, where the Ga ions interact with the indium to form a eutectic compound with low melting point. This compound sublimates quickly in the FIB vacuum chamber leaving voids in the micro-section (see Ref. 2). This issue can be avoided by cooling the sample during the milling, or using an alternative beam (such as Xe plasma).

6.5.20 Materials and Finishes Analysis

Materials analysis shall be performed on all external and internal materials and finishes by energy-dispersive X-ray (EDX). Organic materials analysis shall be performed by Fourier-transform infrared spectroscopy (FTIR). Due to package dimension constraints, some materials of the assembly may not be directly accessible and their nature shall be determined during microsection (see Para. 6.5.18).

All non-metallic materials and finishes shall be tested in accordance with ECSS-Q-ST-70-02 to verify they meet the outgassing requirements, unless relevant data is available.

6.5.21 Electrostatic Discharge Sensitivity
In accordance with ESCC Basic Specification No. 23800 or MIL-STD-883 Test Method 3015.

6.5.22 End-Point Electro-Optical Measurements
Measurements shall be made in accordance with Electrical and Optical Measurements in the Detail Specification. All values obtained shall be recorded against serial numbers and each parameter drift shall be calculated referenced to the value recorded at the previous measurement point during testing.

6.5.23 Displacement Damage Dose (DDD)
In accordance with ESCC Basic Specification No. 22500.

As an option, the Displacement Damage and Total Ionising Dose tests may be implemented on the same components (3 TVE2), if justified by the Manufacturer and agreed by the Customer/User.

NOTES:
Ideally, for mission evaluation, the components under test should be irradiated with particles and energies representative of the operating environment. Full simulation of the environment is not practical; therefore, the irradiations should be undertaken using the dominant particle type and energy so there is less reliance on NIEL scaling. For example, the most common use for space-borne detectors is in moderate to well-shielded applications in low earth orbit. In these cases, the main interest is in protons with energies of several tens of MeV as the shielded spectrum usually has a peak at around 50 or 60 MeV. Hence a good energy for testing is 50 or 60MeV at the hybridised array surface. Furthermore, the beam energy should be calculated to account for propagation through any windows (cryostat, IR detector, filters etc). Some elements in the IR Detector Assembly (e.g. ARC materials) may produce secondary radiation, which should also be considered in deriving the test plan.

Proton irradiations for displacement damage testing are normally performed with fluxes in the range 10^7 to 10^8 p/cm^2/s.

Proton fluence shall reach at least 2xDDDm where DDDm is the mission displacement damage dose. Intermediate characterisation at 1.2xDDDm is recommended.

Irradiation shall be at or near the expected operating temperature with measurements performed without changing the temperature or, at least, following typical changes of temperature expected during the mission. As most of the time the transportable cryostats hosting the components under test do not offer the capability to switch during the radiation test campaign from a “darkness condition” (e.g. component surrounded by a cold shield) to an “under illumination” condition (e.g. component illuminated by an external source via cryostat optical window), and as for most applications the flight IR Detector Assembly is operated with thermal background due to the optical configuration, it is recommended to use at least an “under illumination” condition for the tests performed at a radiation facility before and after the irradiation (including intermediate steps if any), ideally with an optical aperture mimicking the operational background condition. Such a configuration is indeed expected to give access to the largest set of electro-optical parameters. In such a configuration and if useful, a lower background level could be investigated by implementing a Narcissus mirror in front of the cryostat optical window. In case a “darkness condition” needs to be implemented for radiation test completion, supplementary test cryostats should be added accordingly.

The initial defect concentrations produced by displacement damage are usually considered to be independent of applied bias during irradiation. Therefore, displacement damage testing is usually undertaken unbiased (with all terminals of the TVE shorted together). Furthermore, unbiased irradiations tend to lead to a reduction in the effects of total ionising dose and therefore displacement damage effects can be isolated more easily.

Irradiated TVEs shall be re-measured after a period of room temperatures storage (unbiased) of no less than 24 hours, and no more than 1 month.

Prior to and after the test, a Random Telegraph Signal (RTS) detection algorithm shall be implemented to characterise the occurrence of such phenomena, and how it evolves due to displacement damage. An example of an RTS algorithm which has been applied across various designs, technologies, temperatures and irradiation conditions can be found in Ref. 4. The measurement basis for this assessment is a time series in a "darkness condition", with temperature stabilised and duration of > 30 minutes (for initial and final measurement points) or > 5 minutes (for intermediate measurement points).

6.5.24 Single Event Effects (SEE)

In accordance with ESCC Basic Specification No. 25100.

NOTES:

Irradiation shall be at or near the expected operating temperature with measurements performed without changing the temperature or, at least, following typical changes of temperature expected during the mission. It is imperative that the penetration range of the heavy ions is sufficient to activate the SEE, thus ideally the TVE design shall have the ROIC only (i.e. without hybridised detection circuit for the beam to traverse).

A room temperature irradiation is expected to be a worst case for SEL testing and could be used as a preliminary assessment test. For SEU, SEFI and SET it is recommended to realise the tests at operating temperature taking into account that the temperature dependence of these effects remains unclear.

6.5.25 Total Ionising Dose (TID)
In accordance with ESCC Basic Specification No. 22900.

As an option, the Displacement Damage and Total Ionising Dose tests may be implemented on the same components (3 TVE2), if justified by the Manufacturer and agreed by the Customer/User.

NOTES:
Irradiation shall be at or near the expected operating temperature with measurements performed without changing the temperature or, at least, following typical changes of temperature expected during the mission. As most of the time, the transportable cryostats hosting the components under test do not offer the capability to switch during the radiation test campaign from a “darkness condition” (e.g. component surrounded by a cold shield) to an “under illumination” condition (e.g. component illuminated by an external source via cryostat optical window), and as for most applications the flight IR Detector Assembly is operated with thermal background due to the optical configuration, it is recommended to use at least an “under illumination” condition for the tests performed at a radiation facility before and after the irradiation (including intermediate steps if any); ideally with an optical aperture mimicking the operational background condition. Such a configuration is indeed expected to give access to the largest set of electro-optical parameters. In such a configuration and if useful, a lower background level could be investigated by implementing a Narcissus mirror in front of the cryostat optical window. In case a “darkness condition” needs to be implemented for radiation test completion, supplementary test cryostats should be added accordingly.

Low dose-rate irradiations are recommended (< 360rad(Si)/hour).

The dose received shall be determined for all of the functional semiconductor materials in the IR Detector Assembly, e.g. $Hg_{(1-x)}Cd_xTe$, GaAs, Si. Although the ionising dose is commonly stated relative to Si, the equivalent dose for other materials can be approximated using the mass energy absorption coefficient, which can be found from the NIST database of “X-Ray Mass Attenuation Coefficients” (Ref. 3).

The TID deposited during the test shall reach at least 2xTIDm for all relevant constituent materials where TIDm is the mission TID. Intermediate characterisation at 1.2xTIDm is recommended.

The irradiation shall be performed biased and clocked, respecting the ON/OFF timing ratio required during the mission.

Following the irradiation and first set of electro-optic measurements performed without changing the temperature, an annealing sequence should be included. A suggested sequence for the anneal steps is as follows:

- Step 1: 24 hour operating temperature anneal (biased and clocked) with End-Point Electro-Optical Measurements performed in accordance with Para. 6.5.22 after this step
- Step 2: 168 hour room temperature anneal, or at the highest temperature experienced by the IR Detector Assembly during the mission (biased and clocked) with End-Point Electro-Optical Measurements performed in accordance with Para. 6.5.22 after this step.

6.5.26 Mechanical Shock
In accordance with MIL-STD-883 Test Method 2002.

Test Condition shall be selected to meet (or exceed) the mission requirements in terms of Shock Response Spectrum (SRS) over the entire frequency band foreseen for the mission with a test factor of 3dB applied to the maximum expected SRS values.

6.5.27 Random Vibration
In accordance with MIL-STD-883 Test Method 2026

Test Condition shall be selected to meet (or exceed) the random vibration mission requirements in terms of acceleration power spectral density (PSD) over the entire frequency band foreseen for the mission with a safety factor of 3dB applied to the maximum expected PSD values. The test shall be applied in each orientation: X, Y, and Z, for a minimum duration of 3 minutes per axis.

6.5.28 Vibration, Variable Frequency
In accordance with MIL-STD-883 Test Method 2007

Test Condition shall be selected to meet the vibration mission requirements in terms of acceleration over the 20 to 2000Hz frequency range for the mission with a safety factor of 1.25 applied to the maximum expected acceleration. Sine sweep rate shall be no more than 2 octaves/minute.

6.5.29 Moisture Exposure
In accordance with the following:

Test temperature, relative humidity and duration shall be calculated using either an acceleration model proposed and justified by the Manufacturer or an empirical one issued from the literature. A review of various models, including for instance the ‘Hallberg and Peck’ or ‘Sinnadurai’ models can be found in Ref. 1.

The test shall cover at least two times the expected mission storage duration. It is recommended, when applicable, to lower the acceleration and to increase the test duration to avoid the activation of extraneous non-representative failure mechanisms, particularly in the case of non-hermetic package designs where the acceleration models may not capture the relevant failure modes of IR detector technologies.

In any case the duration of the test shall not be less than 500 hours.

In case the TVEs subjected to moisture exposure test will be subsequently subjected to a vacuum thermal cycling, it may be proposed to implement a room-temperature bake out to remove extraneous moisture in the IR Detector Assembly which may otherwise lead to a non-representative failure in the subsequent test.

6.5.30 Thermal Cycling
In accordance with the following:

The temperature cycle profile and the time held at each temperature (low and high) shall be based on the mission profile with appropriate margins (for instance maximum $T_{storage}$ +10°C and minimum $T_{storage}$ -10°C). This test shall include on-ground and in-orbit cycles (decontamination cycles included). The number of cycles shall be at least two times the mission requirement, or 100 in the absence of a mission requirement.

End-Point Electro-Optical Measurements in accordance with Para. 6.5.22 shall be performed as a minimum at: 0.6 x Nc and 1 x Nc, where Nc is the number of cycles to be applied.

For non-hermetic package components, the thermal cycling shall be implemented in a vacuum environment.

6.5.31 Destructive Physical Analysis
In accordance with the following:

(a) External and Internal Visual Inspection: in accordance with Para. 6.5.4.
(b) Radiographic Inspection in accordance with Para. 6.5.9.
(c) Scanning Acoustic Microscope Inspection in accordance with Para. 6.5.8.
(d) Mobile Particle Detection in accordance with Para. 6.5.5 (hermetic package or closed-cavity TVEs only).
(e) Internal Gas Analysis in accordance with Para. 6.5.7 (hermetic package components only).
(f) De-Encapsulation in accordance with Para. 6.5.10.
(g) Hermeticity test of the stand-alone window/window-holder assembly in accordance with the Detail Specification (hermetic package components only
(h) Coating Peel and Pull-Off Strength in accordance with Para. 6.5.12.
(i) SEM Inspection in accordance with Para. 6.5.13.
(j) Bond Strength in accordance with Para. 6.5.14.
(k) Die Shear or Substrate Attach Strength in accordance with Para. 6.5.16.
(l) Flip-chip Pull-Off (as applicable) in accordance with Para. 6.5.17.
(m) Internal Visual Inspection in accordance with Para. 6.5.11.
(n) Microsection in accordance with Para. 6.5.18.

The steps above shall be photo documented.

6.5.32 High Temperature Storage and Operating Life
The aim of these accelerated tests is to demonstrate that components will not run into wear out mode during mission life time. They may also serve as collection of reliability data for random failure rate calculation.

The accelerated tests shall be based on following inputs:

- Mission life
- Failure modes and associated acceleration factors (activation energy)

Accelerated test conditions shall be selected based on available Manufacturer data and/or relevant literature. **Note**: if activation energies are not known, they shall be determined separately as part of the Initial Assessment (see Para. 5.1).

Two kinds of accelerated tests have to be performed:

(a) High Temperature Storage with the purpose of covering the lifetime of the IR Detector Assembly on ground i.e. for AIT and storage periods.
(b) Operating Life with the purpose of covering the operating lifetime of the IR Detector Assembly.

End-Point Electro-Optical Measurements in accordance with Para. 6.5.22 shall be performed as a minimum at: 0.6xTm/AF, 1.2xTm/AF and 2xTm/AF, where Tm is the expected mission duration and AF the acceleration factor.

6.5.32.1 High Temperature Storage

In accordance with the following:

Test temperature and duration shall be calculated using the Arrhenius law with the activation energy proposed by the Manufacturer to cover all the relevant failure modes. The test shall cover at least two times the storage duration expected for the mission. It is recommended, when applicable, to lower the temperature activation and to increase the test duration to avoid the activation of extraneous non-representative failure mechanisms.

In any case:

- the duration of the test shall not be lower than 500 hours,
- the test temperature should not exceed the maximum temperature allowed for the component. This temperature has to be fixed by the Manufacturer taking into account the nature of the materials and their temperature stability range (e.g. absence of phase transition temperature),
- the environmental conditions (e.g. humidity) shall be representative of the storage conditions.

6.5.32.2 Operating Life

In accordance with the following:

For IR Detector Assemblies operated at cryogenic temperatures, the main expected failure mode in operation is related to Hot Carrier Injection (HCI). This failure mechanism could be accelerated using either the detector temperature or the component bias. The Manufacturer shall propose an acceleration condition that actually activates the HCI during the test. The test duration has to be set to demonstrate that the test can cover at least two times the mission requirement.

It is recommended, when applicable, to lower the acceleration and to increase the test duration to avoid the activation of extraneous non-representative failure mechanisms.

In any case:

- the duration of the test shall not be lower than 500 hours,
- the test temperature should not be lower than the minimum temperature allowed for the component. This temperature has to be fixed by the Manufacturer taking into account the nature of the materials and their temperature stability range (e.g. absence of phase transition temperature).

Life test data obtained on circuits specifically designed for the HCI test, and that are representative of the same technology, could also be used to underpin the results obtained on the evaluated IR Detector Assembly. In this case, it is the Manufacturer’s responsibility to demonstrate that the results obtained on specific circuits are relevant regarding the evaluation of the full IR Detector Assembly.

Note that it could be considered to implement this test on TVE3 rather than TVE1 devices.

6.5.33 Intermittent Operating Life

In accordance with MIL-STD-750 Test Method 1036 or 1037, at the expected operating temperature.

NOTES:

The number of cycles and the appropriate test sequence shall be based on the mission profile with appropriate margins (+100%). The number of cycles shall also include extra cycles due to SEL occurrence on-orbit.

7 DATA DOCUMENTATION

7.1 GENERAL REQUIREMENTS

An evaluation test report shall be established. This shall comprise the following:

(a) Cover sheet(s).
(b) List of equipment used (testing and measuring).
(c) List of test references.
(d) The Detail Specification (see Para. 6.1.3).
(e) Manufacturing Data (see Para. 6.1.5).
(f) Test vehicles identification (see Para. 6.1.1).
(g) 100% Inspection results and data (see Para. 6.2).
(h) Electro-Optical Measurements data (see Para. 6.3).
(i) Evaluation Testing results and data (see Para. 6.4).
(j) List of failed components and failure analysis results (see Para. 5).
(k) Summary of results and conclusions.

Items (a) to (k) inclusive shall be grouped, preferably as sub-packages, and for identification purposes each page shall include the following information:

- Manufacturer's/test house's name.
- Lot identification.
- Date of establishment of the document.
- Page number.

7.1.2 Cover Sheet(s)

The cover sheet (or sheets) of the evaluation test report shall include as a minimum:

(a) Reference to this document, including issue and date.
(b) Component type and part number.
(c) Lot identification details including wafer lot number(s), as applicable.
(d) Manufacturer's/Test House's name and address.
(e) Location of the manufacturing plant/Test House.
(f) Signature on behalf of the Manufacturer/Test House.
(g) Total number of pages of the evaluation test report.

7.1.3 List of Equipment Used

A list of equipment used for tests and measurements shall be included in the evaluation test report. Where applicable, this list shall contain the inventory number, Manufacturer's type number, serial number, calibration status data etc. This list shall indicate for which tests such equipment was used.

7.1.4 List of Test References

This list shall include all references or codes which are necessary to correlate the test data provided with the applicable tests.

7.1.5 The Detail Specification (see Para. 6.1.3)

A copy of the draft Detail Specification prepared by the Manufacturer for the components being evaluated.

7.1.6 Test Vehicles Identification (see Para. 6.1.1)

This shall identify the criteria used for the selection of the particular test vehicles used for the Evaluation Test Programme when evaluating a range of components by means of representative samples.

7.1.7 100% Inspection Results and Data (see Para. 6.2)

The quantity of components subjected to each test shall be identified together with the quantity and reason for any rejects. Full details of all tests and test conditions applied shall be provided.

7.1.8 Electro-Optical Measurements Data (see Para. 6.3)

All data shall be recorded against serial numbers. A histogram of characteristics shall be produced. Full details of all tests and test conditions applied shall be provided.

7.1.9 Evaluation Testing Results and Data (see Para. 6.4)

A test result summary shall be compiled showing the components submitted to, and the number rejected after each test in each subgroup of Evaluation Testing in Chart I. Component serial numbers for each subgroup shall be identified.

Full details of all tests and test conditions applied shall be provided.

For each test requiring electro-optical or mechanical measurements, the results shall be recorded against component serial number. Where a drift value is specified during a test, the drift calculation shall be recorded against component serial number.

For the Constructional Analysis and the Destructive Physical Analysis, all the required photographs taken during testing shall be provided.

7.1.10 List of Failed Components and Failure Analysis Results (see Para. 5)

The failed components list and failure analysis report for any failures during the Evaluation Test Programme, shall provide full details of:

(a) The reference and description of the test or measurement performed as defined in this specification and/or the Detail Specification during all stages of the Evaluation Test Programme from manufacturing to Evaluation Testing.

(b) Traceability information including serial number (if applicable) of the failed component.

(c) The failed parameter and the failure mode of the component.

(d) Detailed failure analysis results.

7.1.11 Summary of Results and Conclusions.

All results and reports produced shall be briefly reviewed and the success or otherwise of the Evaluation Test Programme determined. Any production changes that need to be introduced into the PID shall be defined.

8 CHART I - EVALUATION TEST PROGRAMME

100% INSPECTION (Para. 6.2) (10 TVE1, 6 TVE2, 8TVE3 (minimum))	
Para. 6.5.1	Weight
Para. 6.5.2	Dimension Check
Para. 6.5.3	Functional Electro-Optical Measurements (go-no-go)
Para. 6.5.4	External and Internal Visual Inspection
Para. 6.5.5	Mobile Particle Detection
Para. 6.5.6	Seal (Fine and Gross Leak)
Para. 6.2.1	Marking and Serialisation

ELECTRO-OPTICAL MEASUREMENTS (Para. 6.3)
(10 TVE1, 6 TVE2, 8TVE3 (minimum))

EVALUATION TESTING (Para. 6.4)
(10 TVE1, 6 TVE2, 8TVE3)

Control Subgroup Para. 6.4(a))	**Constructional Analysis Subgroup**	**Electrostatic Discharge Sensitivity Subgroup**	**Radiation Subgroup**	**Thermo-Mechanical Subgroup**	**Storage / Endurance Subgroup**
(2 TVE1)	(2 TVE1)	(2 TVE3)	(6 TVE2, 3 TVE3)	(3 TVE1)	(3 TVE1, 3 TVE3)

Continued on next pages.

Constructional Analysis Subgroup (Para. 6.4(b)) (2 TVE1)	
Para. 6.5.7	Internal Gas Analysis
Para. 6.5.8	Scanning Acoustic Microscope Inspection
Para. 6.5.4	External and Internal Visual Inspection
Para. 6.5.9	Radiographic Inspection
Para. 6.5.10	De-encapsulation
Para. 6.5.11	Internal Visual Inspection
Para. 6.5.12	Coating Peel and Pull-Off Strength
Para. 6.5.13	SEM Inspection
Para. 6.5.14	Sub-assembly Bond Strength
Para. 6.5.15	Bond Strength
Para. 6.5.16	Die Shear or Substrate Attach Strength
Para. 6.5.17	Flip-chip Pull-Off
Para. 6.5.18	Microsection
Para. 6.5.19	FIB Inspection
Para. 6.5.20	Materials and Finishes Analysis

Electrostatic Discharge Sensitivity Subgroup (Para. 6.4(c)) (2 TVE3)	
Para. 6.5.21	Electrostatic Discharge Sensitivity
Para. 6.5.4	External and Internal Visual Inspection
Para. 6.5.22	End-Point Electro-Optical Measurements

Radiation Subgroup (Para. 6.4(d))					
3 TVE2		3 TVE3		3 TVE2	
Para. 6.5.23	Displacement Damage	Para. 6.5.24	Single Event Effects	Para. 6.5.25	Total Ionising Dose
Para. 6.5.4	External and Internal Visual Inspection	Para. 6.5.4	External and Internal Visual Inspection	Para. 6.5.4	External and Internal Visual Inspection
Para. 6.5.22	End-Point Electro-Optical Measurements	Para. 6.5.22	End-Point Electro-Optical Measurements	Para. 6.5.22	End-Point Electro-Optical Measurements

Thermo-Mechanical Subgroup (Para. 6.4(e)) (3 TVE1)	
Para. 6.5.26	Mechanical Shock
Para. 6.5.6	Seal (Fine and Gross Leak)
Para. 6.5.4	External and Internal Visual Inspection
Para. 6.5.22	End-Point Electro-Optical Measurements
Para. 6.5.27	Random Vibration
Para. 6.5.6	Seal (Fine and Gross Leak)
Para. 6.5.4	External and Internal Visual Inspection
Para. 6.5.22	End-Point Electro-Optical Measurements
Para. 6.5.28	Vibration, Variable Frequency
Para. 6.5.6	Seal (Fine and Gross Leak)
Para. 6.5.4	External and Internal Visual Inspection
Para. 6.5.22	End-Point Electro-Optical Measurements
Para. 6.5.29	Moisture Exposure
Para. 6.5.4	External and Internal Visual Inspection
Para. 6.5.22	End-Point Electro-Optical Measurements
Para. 6.5.30	Thermal Cycling
Para. 6.5.6	Seal (Fine and Gross Leak)
Para. 6.5.4	External and Internal Visual Inspection
Para. 6.5.22	End-Point Electro-Optical Measurements

2 TVE1	
Para. 6.5.31	Destructive Physical Analysis

Storage / Endurance Subgroup (Para. 6.4(f))

3 TVE1	
Para. 6.5.32.1	High Temperature Storage
Para. 6.5.6	Seal (Fine and Gross Leak)
Para. 6.5.4	External and Internal Visual Inspection
Para. 6.5.22	End-Point Electro-Optical Measurements
Para. 6.5.32.2	Operating Life
Para. 6.5.6	Seal (Fine and Gross Leak)
Para. 6.5.4	External and Internal Visual Inspection
Para. 6.5.22	End-Point Electro-Optical Measurements

2 TVE1	
Para. 6.5.31	Destructive Physical Analysis

3 TVE3	
Para. 6.5.33	Intermittent Operating Life
Para. 6.5.6	Seal (Fine and Gross Leak)
Para. 6.5.4	External and Internal Visual Inspection
Para. 6.5.22	End-Point Electro-Optical Measurements