ESTEC Contract No.8906/90/NL/PM(SC)

QUALITY STANDARDS FOR OPTOELECTRONICS

Final Report

STANDARD TEST METHODS FOR PASSIVE OPTOELECTRONIC COMPONENTS

Issue 1

Prepared by:
OPTOPLAN A/S, A.Hordvik, H.Nakstad
DET NORSKE VERITAS, P.Helstrup
Date 1992-09-15

FOREWORD

The scope of the ESTEC Contract No. 8906/90/NL/PM(SC) has been to establish specific standards for optoelectronic passive components.

The Contract has been divided in 4 Tasks i.e.

- Task 1: Definition of the list of components
- Task 2: Definition of test strategies
- Task 3: Definition of test procedures and methods
- Task 4: Consultancy

This is the Final Report. It consists of a summary and of the reports issued previously under Task 1, 2, 3 and 4, which can be found in the Parts 1, 2, 3 and 4 respectively. Some minor editorial changes have, however, been made in the original Task reports to avoid repetition of the same material in each part. Further, the content has been updated where necessary.

In Part 1 the passive optoelectronic components that are expected to be used in space applications have been identified. A description of the problem areas of particular concern for establishing quality standards for such applications have been given.

Part 2 contains a description of standard test strategies for the components.

In Part 3 a listing of existing test methods and a detailed description of new test methods have been given.

In Part 4 the development trends and the availability of large core optical fibre types suitable for space usage have been described.

Part 5 contains appendices including definitions, abbreviations, symbols, units and other relevant information.

TABLE OF CONTENTS

SUMMARY

1. Project description

The scope of the ESTEC Contract No.8906/90/NL/PM(SC) has been to establish specific standards for optoelectronic passive components. The Contract has been divided in 4 Tasks i.e.

- Task 1: Definition of the list of components
- Task 2: Definition of test strategies
- Task 3: Definition of test procedures and methods
- Task 4: Consultancy

The objective of Task 1 has been to identify the passive optoelectronic components that are expected to be used in space application, and describe the problem areas of particular concern for establishing quality standards for such applications.

The objective of Task 2 has been to prepare standard test strategies for the components, taking as guidelines the existing standards in the ESA Space Components Coordination system (ESA/SCC) for electric cables and electric connectors.

The objective of Task 3 has been to work out a detailed description of new test methods giving a complete description of all environmental, geometrical, mechanical, optical standard test methods for the components, taking as guidelines the existing standards in the ESA/SCC system mentioned above.

The objective of Task 4 has been to investigate the development trends and the availability of large core optical fibre types, single mode and polarization maintaining fibres suitable for space usage.

The work has been performed in accordance with the specific articles listed in the Contract. Besides the work is based on additional documentation received from ESTEC, and other relevant references. All references have been listed in the Task Reports and in the Final Report.

For each of the Tasks a complete Task Report has been issued. The Final Report encompasses all the work performed in the Tasks 1, 2, 3 and 4.

2. Relevant components and existing standards

The project has been concerned with the passive optoelectronics components which are used in fibre optic transmissions systems. The passive components which can be found in these systems are:

- Optical fibres
- Optical fibre cables
- Fibre optic connectors
- Fibre optic splices
- Splice organisers and closures
- Fibre optic attenuators
- Fibre optic branching devices (couplers)
- Fibre optic switches
- Fibre optic wavelength multiplexers/demultiplexers (WDM)
- Fibre optic isolators
- Combined electric/fibre optic cable

3. Environmental parameters

In space applications, and particularly in the pre-orbit and on-station phase, the components will be subjected to environmental loads which are quite different from those normally met in terrestrial applications.

In order to quantify the environmental loads to which the components may be subjected, a survey has been made of the environmental parameters expected in typical space applications. Tables have been set up listing the environmental loads the components may meet during transportation, handling, storage, pre-launch, launch/ascent, transfer to orbit and on-station. The basis for the tables has been the applicable documents submitted by ESTEC. Certain parameters are, however, not available, but in some cases values have been suggested.

The following environmental parameters and conditions were found to be of special concern for the passive optical fibre components used in space applications:

- temperature extremes,
- rapid temperature cycling,
- vibrations,
- mechanical shock,
- rapid depressurisation,
- operation in vacuum,
- ionizing radiation.

4. Problem areas encountered in the establishment of quality standards and the applicability of standard test methods

In the beginning of the project, a survey was made of the problem areas which may be encountered in the development of quality standards for passive fibre optic components suited for space applications. Compared to terrestrial application two general areas were found to require special attention:

- The lack of established test methods for the environmental parameters which are particular to space applications.

- The need for a comprehensive and thorough test strategy for each component due to the strict requirements which must be met by a component to be used in space.

One problem of particular concern is the fact that ionizing radiation will induce losses in the optical fibre. The induced loss is affected by many parameters, and the test procedure and the interpretation of the results must take this into account. The difficulties can be summarised as follows:

- Test parameters such as dose rate, total dose, type of radiation, transmitted optical power, optical wavelength, temperature, fibre length, fibre coil diameter, and past radiation history, can all effect the test results. The test parameters must therefore be specified in detail and be representative of the application in question.

- It is difficult to make good estimates of the effects of long term exposure from short term exposure experiments. Short term experiments can give an upper limit on the expected induced loss, but the use of results from short term experiments without any adjustments will give unnecessary strict acceptance requirement.

The IEC has recently published a test procedure with respect to testing the effects of ionizing radiation on optical fibres. This method has been found pertinent, but for our application we have found it necessary to make some modifications in the the procedure.

Also the other fibre optic components must be tested with regard to possible effects of ionizing radiation. Although space qualified materials should be used in the components, one must ensure that no unexpected problems will occur. For these components it has generally been found sufficient to limit the testing with respect to ionizing radiation to the evaluation phase.

Accepted test procedures with respect to operation of fibre optic components in vacuum are not available. This pertains both to long term operation at various temperatures and rapid pressure fall from atmospheric pressure to high vacuum. New test methods have therefore been proposed.

The existing IEC test procedures for temperature cycling, high and low temperatures and rapid temperature changes all were found applicable with some minor modifications, even though the temperature extremes and temporal variations encountered in space may be larger than those met in typical terrestrial application. For spatial thermal gradients a special test does not appear necessary. But it can for example for cables be incorporated in other thermal tests.

The IEC and EIA tests for vibration and shock are also applicable although the specified shock parameters are significantly lower than those necessary for space applications. The test procedures can, however, be used.

The mechanical lifetime of a fibre is determined by stress corrosion or fatigue. Stress corrosion increases with increasing humidity. Operation in vacuum is thus more favourable than operation under normal atmospheric condition. The requirement on fibre strength may therefore well be determined by the mechanical stresses to which the fibre is subjected before launch rather than when operating in space. Theoretical models exist for predicting lifetime of a fibre subjected to a certain tensile stress using data from short term tensile strength experiments. Such models can be used to estimate necessary proof test levels for the fibre.

For splices enclosures and isolators no generally accepted standards are yet available, but IEC draft documents have been issued for comments. Special procedures for the determination of splice loss may be needed for some cases. Also, since splices often are made on the spot during installation of a system, the opportunity for testing is limited. A special procedure involving dummy splices has therefore been proposed.

5. Test strategies

Detailed test strategies have been worked out for each component. The test programmes include evaluation testing, production testing, qualification testing and lot acceptance testing.

'Burn-in' is a screening method commonly used for solid-state electronic devices. This method entails exposure of components at elevated temperatures for a certain period of time. The method has been found not to be relevant for passive optical components.

For each type of testing a detailed set of tests including the test sequence has been described encompassing geometrical, optical, mechanical and environmental characteristics.

For the evaluation testing the following information is given for each component:

- A brief discussion explaining why the specific properties have been chosen for evaluation testing.
- The recommended test sequence with a brief justification for the proposed sequence.
- The recommended number of samples to test.
- The test method with reference to the list of test methods.
- Brief description of important test parameters and the severity to which each component should be tested.

For most of the components a number of non-destructive optical measurements can be performed. Such tests are prescribed for the final production testing. It can be noted that this is quite standard for fibre optic components. Where appropriate a temperature test is proposed as an additional check.

For the qualification testing and lot acceptance testing the following information is given:

- A brief discussion explaining the purpose of the test, if appropriate.
- The order in which the tests should be done, and the justification for the proposed order.
- The recommended number of samples to test.
- The test method with reference to the list of methods.

Test severities and acceptance values of the various parameters need to be defined in the detail specifications.

The proposed evaluation testing is quite comprehensive. The qualification testing and lot acceptance testing have therefore in general been limited to those properties which are regarded as production dependent.

Some of the issues considered while formulating the test strategies for the various components are summarised in the following.

Optical fibres

The proposed test strategies will in general be applicable to all fibre types, but some properties and the corresponding tests are of relevance only to certain fibre types.

It is assumed that in space applications the fibre will be enclosed in a cable structure. The fibre will thus be protected against some mechanical and environmental loads. The main proposed test programmes are applicable to fibres assumed to be used in a cable. However, for completeness tests applicable to uncabled fibres have also been included.

Optical fibre cables

The cable protects the fibre against mechanical and environmental loads, and the test programme has mainly been set up to investigate the properties of the cable in this respect.

The cable may affect the fibre attenuation and for single mode fibres also the cut-off wavelength. Other optical characteristics such as bandwidth, numerical aperture, mode field diameter and beat length are not affected. These properties are specified for the fibre and have not be treated for the cabled fibre.

Fibre optic connectors

Fibre optic connectors exist in different versions with respect to optical and mechanical design. The optical design differs with respect to coupling method, i.e. lens coupling or butt-butt coupling. The mechanical design differs with respect to means of fibre or ferrule alignment, fastening mechanism, environmental protection and cable retention means. The proposed test programme is applicable to all these designs.

A fibre optic connector as an individual component does not contain any optical fibre and will have to be attached to a fibre or cable before any optical measurements can be performed. Production control and final production testing are thus only possible to perform on the geometrical dimensions of the connector. The evaluation, qualification and lot acceptance testing are performed on connectors attached to a specified fibre/cable according to a specified procedure.

Fibre optic splices

Fibre optic splices can be formed by a fusion process or by mechanical means. The mechanical splices can be either permanent or separable (although not intended to be separated).

The splice is made when it is installed, and only a very limited range of tests can be done on an installed splice. It is therefore recommended that dummy splices be made as part of the installation process, and that the dummy splices be subjected to various environmental and mechanical tests. This test programme replaces the normal lot acceptance testing. The qualification and installation testing have been set up only for fusion splices, which are regarded as the splice type most likely to be used in space applications.

Splice holders, organisers and closures

The splice holder is a device, in which a number of protected fibre splices are stored. A splice organiser is a device which contains and organises splice holder(s) and/or protected fibre splices. The splice organisers are intended for use in a closure.

Some of the tests must here be performed with spliced optical fibres or cables installed while in other cases only unspliced fibres or cables may be installed for the test.

Fibre optic attenuators

Fibre optic attenuators are passive fibre optic components applied in systems where the signal, or parts thereof, for some reason needs to be attenuated. The attenuation can be fixed or variable, wavelength dependent or wavelength independent. In some cases the fibre optic attenuator may be used as a spectral filter.

Fibre optic attenuators without any intended wavelength dependence will not very likely be applied in space applications. These components are most often used in laboratory applications to simulate the loss in a real system. The proposed test programme is, however, applicable to fibre optic attenuators in general.

Fibre optic branching devices (couplers)

Fibre optic branching devices are manufactured using several different technologies, such as fused biconical taper, micro-optics, and waveguides formed on either electro-optical materials or glass substrates (integrated optics).

Devices based on the different technologies will have different characteristics with respect to environmental loads such as temperature and vibration because of the different optical design. The mechanical properties will mainly be determined by the packaging and the mounting of the fibre. The proposed test strategy encompasses all device types.

The sample selection will depend on the technology involved. Fused devices and micro-optic devices are manufactured on a one to one basis while the integrated devices are manufactured in a more automated manner using the same mask and the same wafers for several components.

Fibre optic switches

Fibre optic switches are either based on mechanical alignment of optical components or waveguide technology. In switches based on mechanical alignment, the light beam or the fibre is moved from one position to another. The actuating mechanism can either be mechanical or electrical. Switches with electrical actuating mechanism may apply piezo electric elements or magnets to move mirrors, lenses etc. Mechanical and electrical switches will be dependent on movement of components inside the device. They will therefore be vulnerable to loads such as vibration and shock.

Both electrical and integrated optics switches are dependent on an electric field. They are therefore not strictly passive components. The optical transmission is, however, passive (no amplification or conversion from electrical to optical energy), and they are thus considered to belong to the group of passive fibre optic devices.

Fibre optic wavelength multiplexers/demultiplexers (WDM)

The test strategy for these devices is quite similar to that of fibre optic branching devices. The main difference between the two components is that for the WDM there is a strong and specified wavelength dependence of the transfer coefficients. This must be reflected in the tests.

Fibre optic isolators

Fibre optic isolators are used to avoid backreflections in communication links where these backreflections might deteriorate the performance of certain components, for instance DFB (distributed feedback) lasers. Isolators may also be used with fibre optic amplifiers where multiple reflections may cause lasing instead of amplification.

The fibre optic isolator is based on the Faraday effect. Due to the principle of operation the isolator will be useable only for a specific wavelength range, and there will be inherent temperature dependent effects.

A fibre optic isolator is usually made from miniature versions of bulk optical components. The alignment of the different components will be critical and thus vulnerable to mechanical and environmental loads. The operation of the device is dependent on the magnetic field, and the shielding from external magnetic fields is important.

Combined electric/fibre optic cable

The combined cable must meet the same requirements as an equivalent separate electrical cable as well as the requirements for an equivalent separate optical cable. In addition the optical part must function as specified when the electrical cable is energised. The resistive heating may affect the optical cable and cause losses to be induced in the optical fibres and even damage the fibres and cable unless it is properly designed. The electrical cable will not be influenced by the optical signal. For the combined cable a complete test programme will have to be established for both the electrical and fibre optic part. Only the optical part has been considered, but the tests shall be done on the combined cable. The heating effect of the electrical cable on the optical fibre cable has been taken into account in the test programme.

6. Test procedures and methods

The recommended test strategies specify a range of tests for each component, and a complete set of test methods have been worked out for all the components. Since a fibre optic component used in space will perform the same function, be based on the same physical principles and in general have similar or equal properties as other fibre optic components, many of the test methods developed for terrestrial applications can also be used for space applications. Existing internationally recognised standard test methods for passive fibre optic devices have therefore been evaluated. Relevant test methods have been adopted. In instances when test methods from several standard bodies are considered applicable, IEC Standards have been preferred followed by those from EIA. In some cases the IEC Standards only exist as a draft document at present. Reference has then be given to the draft. It is expected that the drafts will be issued as official standards in the near future.

For each component all geometrical, mechanical, optical and environmental tests have been listed. When existing methods are considered applicable, a complete reference is given to the relevant standard. Where standard methods have not been found applicable or existing, new test methods have been worked out. Where considered necessary, existing standard methods have been modified. Only the new test methods are described in detail.

The test methods for the basic optical and geometrical properties will not depend on the environment. The existing methods are thus applicable. However, a few optical test methods have as of yet not been considered by the standard organisations. New test methods have been proposed for polarization properties and modal effects. It is recommended that as the standard organisations establish new test methods for the optical properties in question, such methods should be adopted by ESTEC.

The test methods for mechanical properties will in general also be the same whether the component is intended for terrestrial or space application. The main difference would be in the severity of the test parameter(s). These tests have been discussed only in case modifications are deemed necessary.

Several new environmental tests have been described. This concerns tests with respect to rapid depressurisation, operation in vacuum, solar radiation and UV radiation. For ionizing radiation the described test method for the various components is based on the IEC tests for fibres and cables. But some changes in dose level and dose rates are specified to suit the radiation levels expected in space.

Table 2 shows the number of test methods described for the passive optoelectronic components in this project.

	Number of tests			
	Geometrical	Optical	Mechanical	Environmental
New or modified tests	2	23	22	74
Total number of tests	35	70	128	168

Table 2 Number of test methods.

In Tables 3 through 6 are listed the geometrical, optical, mechanical and environmental properties for which test methods have been described for each component. In some cases where the space has been left open, the property in question is not applicable or of concern for that particular component.

Geometrical properties	Components										
	Fibre	Cable [1]	Connector	Splice	Closure assembly	Attenuator	Branching device	Switch	WDM	Isolator	Combined cable [1]
Concentricity errors	•										
Diameter of cladding	•										
Diameter of core	•										
Diameter of primary coat.and buffers	•										
Inside diameter of cylindrical object			•								
Inside diameter of rectangular object			•								
Length of cable		•									•
Length of fibre	•										
Mass		•	•	•	•	•	•	•	•	•	•
Non-circularities	•										
Outline/overall dimensions		•		•	•	•	•	•	•	•	•
Outside diameter of cyl.object			•								
Outside diameter of rect.object			•								
Thickness of sheath		•									•

[1] Fibre geometrises for cabled fibres are measured using the same methods as for the uncabled fibres.

Table 3 Geometrical properties for which test methods are described.

Optical properties	Components										
	Fibre	Cable	Connector	Splice	Closure assembly	Attenuator	Branching device	Switch	WDM	Isolator	Combined cable
Attenuation	•	•				•					•
Backward loss										•	
Bandwidth	•										
Beat length	•										
Bending sensitivity (macro/micro)	•										
Change in insertion & backward loss										•	
Change in optical transmission	•	•				•	•	•	•		•
Continuity	•	•									•
Cross talk			•	•				•			
Cut-off wavelength	•	•									•
Insertion loss			•	•	•			•		•	
Maximum input power						•					
Modal distribution			•			•	•	•	•		
Mode field diameter	•										
Monitoring technique				•							
Numerical aperture	•										
Optical branching efficiency							•		•		
Optical power handling capability	•		•	•			•	•	•	•	
Polarization cross-coupling	•		•								
Polarization dependence/sensitivity						•	•	•	•	•	
Return loss			•	•		•		•		•	
Spectral loss			•			•				•	
Spectral dependence of insertion loss				•							
Stability of performance								•			
Susceptibility to ambient light			•	•		•	•	•	•	•	
Switching speeds and chattering								•			

Table 4 Optical properties for which test methods are described.

Mechanical properties	Components										
	Fibre	Cable	Connector	Splice	Closure assembly	Attenuator	Branching device	Switch	WDM	Isolator	Combined cable
Abrasion	•	•									•
Acceleration			•	•	•	•	•	•	•	•	
Actuating mechanism								•			
Axial compression			•	•	•						
Bending	•										
Bending moment			•								
Bend under tension		•									•
Bump			•	•	•	•	•	•	•	•	
Cold bend		•									•
Connector drop			•								
Crush	•	•									•
Crush resistance			•	•	•	•	•	•	•	•	
Drop				•		•	•	•	•	•	
Effectiveness of clamping device				•	•						
Engagement and separation force			•								
Fibre or ferrule retention			•								
Flexing	•	•									•
Gauge retention force			•								
Impact	•	•	•	•	•	•	•	•	•	•	•
Kink	•	•									•
Proof test	•										
Repeated bending		•									•
Shock			•	•	•	•	•	•	•	•	
Snatch	•	•									•
Static load			•								
Strength of attachment of fibre						•	•	•	•	•	
Strength of cable retention and entry			•								
Strength of coupling mechanism			•								
Strippability	•										
Tensile strength	•	•		•							•
Torsion	•	•									•
Vibration		•	•	•	•	•	•	•	•	•	•

Table 5 Mechanical properties for which test methods are described.

Environmental properties	Components										
	Fibre	Cable	Connector	Splice	Closure assembly	Attenuator	Branching device	Switch	WDM	Isolator	Combined cable
Ageing	•	•	•	•	•	•	•	•	•	•	•
Assembly/disassembly of closure					•						
Climatic sequence			•	•	•	•	•	•	•	•	
Condensation			•	•	•	•	•	•	•	•	
Corrosive atmosphere					•						
Dust					•						
Electromagnetic field								•			
Flammability		•	•	•	•	•	•	•	•	•	•
Ionizing radiation	•	•	•	•	•	•	•	•	•	•	•
Intermateability			•								
Mechanical endurance			•		•						
Rapid change of temperature		•	•	•	•	•	•	•	•	•	•
Rapid depressurisation		•	•	•	•	•	•	•	•	•	•
Resistance to solvents/fluids		•	•	•	•	•	•	•	•	•	•
Sealing			•		•	•	•	•	•		
Solar radiation	•	•	•	•	•	•	•	•	•	•	•
Susceptibility to ext.magnetic fields										•	
Temperature cycling	•	•									•
Temperature extremes			•	•	•	•	•	•	•	•	
UV radiation	•	•	•	•	•	•	•	•	•	•	•
Vacuum incl. temp. cycling	•	•	•	•	•	•	•	•	•	•	•

Table 6 Environmental properties for which test methods are described.

7. Trends and availability of optical fibres for space usage

An investigation has been made of the development trends and the availability of large core optical fibres for power transmission, single mode fibres and polarization maintaining fibres suitable for space usage.

Fibres for space usage must in addition to meeting the requirements typical for terrestrial applications, also be able to operate when exposed to high levels of ionizing radiation, at high and low temperatures and in vacuum.

Pure silica core fibres exhibit the lowest radiation induced losses. Large core fibres are usually of this type, and so-called radiation hardened fibres are available from several suppliers. In the most recent development fibres giving only about 2.5 dB/km induced loss (865 nm, room temperature) after exposure to 10^5 rad have been reported. Specified maximum permissible power levels for this type are in the order of 100 kW/m^2 for CW laser and 2-5 GW/cm^2 for pulsed (nanosecond) lasers.

Pure silica single mode fibres are available from one supplier. These fibres exhibit similar low losses at 1300 nm and 1550 nm.

Polarization maintaining (PM) fibres generally have Ge-doped cores and therefore show higher radiation induced losses. Radiation hardened PM fibres are available from one company, but the radiation induced losses are somewhat higher than for the pure silica fibres.

Standard primary fibre coatings are normally specified to operate in the range -55°C to +85°C. For large temperature ranges and vacuum operation special coatings will be needed. Fibres with polyimide coatings have been tested for the US space programme with good results. Several companies will supply fibres with such coatings.

None of the most promising fibres have, however, undergone complete tests with respect to space operation. More detailed investigations of radiation hardness, and operation at high and low temperatures and operation in vacuum are needed to determine that the identified fibres are space qualified.

1. INTRODUCTION

This Part contains Task Report No.1 of the ESTEC Contract No.8906/90/NL/PM(SC).

2. OBJECTIVE OF WORK TASK 1

The objective of this Task has been to identify the passive optoelectronic components that are expected to be used in space application and describe the problem areas of particular concern for establishing quality standards for such applications i.e.:

- Study of input documents to identify relevant components and problem areas.
- Define typical environmental conditions.
- Define components for which test strategies are to be specified.
- Describe essential mechanical/environmental/geometrical/optical characteristics, requiring specific test methods or standards.
- Evaluate how identified problem areas effect the establishment of quality standards.

3. DOCUMENTATION

3.1 General

The work has been performed in accordance with the specific articles listed in the Contract. Besides the work is based on additional documentation received from ESTEC and other relevant references listed below. Literature references have been listed in Chapter 8.3. References used have been given in brackets e.g. [A4].

3.2 Applicable Documents

A1	Characterisation/adaption of new optical fibre devices, Vol 1,2,3,4
A2	Test bed development for FO communication links Doc.7483/87/NL/PB(SC)
A3	Test Bench for Optical Communication Equipment No.XA88/011/RC/ml
A4	Test Equipment Requirement Specification No.XA88/127/RC ESA
A5	Blank
A6	Final Report Development of a Test Bed for FO Com Links Ph.1 No.7483/87/Nl/PB(SC)
A7	MIL STD 202 Test methods for el electronic and electrical comp. parts
A8	MIL STD 750 Test methods for semiconductor devices
A9	MIL STD 883 Test methods and procedures for microelectronics
A10	DOD STD 1678 Fibre optics test methods and instrumentation
A11	ESA PSS-01-60 Comp. selection, procurement and control
A12	PSS-01-20 Quality assurance of ESA
A13	SCC Object and basic rules of the SCC system No.00000
A14	SCC Organisation of the SCC System No.11000
A15	SCC The codification system for SCC documents and specifications No.13006
A16	SCC Approval procedures for SCCG documentation No.13008
A17	SCC ESA/SCC Basic specification No.23100
A18	SCC Connectors, RF Coaxial No.3402
A19	SCC Wires and cables, El. 600V, Low frequency No.3901
A20	SCC Cables, Coaxial, Radio frequency, Flexible No.3902

A21	SCC System for Components Suitability for Space application No.12000
A23	SCC Basic Specification No.20100
A24	SCC List of ESA/SCC Documents and Specifications ESA/SCC REF/001
A25	SCC List of ESA/SCC Documents and Specifications ESA/SCC REF/001 ADD.01
A26	SCC Coaxial Cables, Radio Frequency, Flexible, 50 ohms, Detail Spes. No.3902/001
A27	SCC Detail Specification, Coaxial Cables, RF, Flex., 50ohms,PTFE, No. 3902/001
A28	SCC Detail Specification, Polyimide insulated, LF, 600V 100 to +200C, No. 3901/001
A29	SCC Detail Specification, Extruded cross-linked fluoroplolymer,LF, No. 3901/011
A30	SCC Detail Specification, PTFE insulated wires and cables, LF, No. 3901/013
A31	SCC Basic Specification, Preservation, packing and despatch of SCC el. No.20600
A32	SCC Basic Specification, Requirements for the evaluation of standard el. No. 22600
A33	SCC Basic Specification, Terms, Definitions, Abbre., Symbols and Units No.21300
A34	SCC Basic Specification, Terms, Definitions, Abbre., Symbols and Units No.21334
A35	SCC Basic Specification, Total Dose Steady-state Irradiation No.22900
A36	SCC Basic Specification, Evaluation Test Programme for Connectors, multi. No.24100

3.3 Reference Documents

R1	The European SILEX Project and other advanced space concepts for FO
R2	PAPER, NASA, Natural environment design criteria for the space station program
R3	PAPER, NASA, An analysis of energetic space radiation and dose rates
R4	IEC Publication 693 Dimensions of Optical Fibres
R5	IEC Publication 793-1 Pt.1 Optical fibres, Generic specification
R6	IEC Publication 793-2 Pt.2 Optical fibres, Product specification
R7	IEC Publication 794-1 Pt.1 Optical fibre cable, Generic specification
R8	IEC Publication 794-2 Pt.2 Optical fibre cable, Product specification
R9	IEC Publication 869-1 Pt.1 Fibre optic attenuators, Generic specification
R10	IEC Publication 874-0 Pt.0 Connectors for optical fibres and cables. Guide
R11	IEC Publication 874-1 Pt.1 Connectors for optical fibres and cables. Generic spec.
R12	IEC Publication 874-2 Pt.2 Sectional specification, FO connector type FSAM
R13	IEC Publication 874-3 Pt.3 Sectional specification, FO connector type CF03
R14	IEC Publication 874-4 Pt.4 Sectional specification, FO connector type CF04
R15	IEC Publication 874-5 Pt.5 Sectional specification, FO connector type BAM
R16	IEC Publication 874-6 Pt.6 Sectional specification, FO connector type BACS
R17	IEC Publication 874-7 Pt.7 Sectional specification, FO connector type FC
R18	IEC Publication 874-8 Pt.8 Sectional specification, FO connector type D
R19	IEC Publication 874-9 Pt.9 Sectional specification, FO connector type OF-2
R20	IEC Publication 875-1 Pt.1 FO branching devices, Generic specification
R21	IEC Publication 875-2 Pt.1 Transmission coupler, Sectional specification.
R22	IEC Publication 875-3 Pt.1 WDM, Sectional specification.
R23	IEC Publication 876-1 Pt.1 FO switches, Generic specification.
R24	IEC Publication 721-3-0 Pt.3 Classification of environmental conditions.
R25	Environmental Design Requirements Doc.No. SPE/DRS/0320/SES
R26	Materials evaluation at ESA/ESTEC, G.Gourmelon, M.Froggatt, D.Collins
R27	IEC Publication 1073-1 Pt.1 Generic specification. Splices for optical fibres and cables

4. ENVIRONMENTAL CONDITIONS

4.1 General

In an environment the components are exposed to different influences such as heat, pressure, radiation, humidity and vibrations. These influences control chemical and physical processes affecting the components.

Basically they will be affected by the environmental influences in two ways:

- by the effects of short-term extreme environmental conditions, which may directly cause malfunction or destroy the component;
- by the effect of long-term subjection to non-extreme environmental stresses, which may slowly degrade the product and finally cause malfunction or destruction of the component.

A component may be unaffected by an extreme condition when it is new, but may fail when it is subjected to the same condition after being used for a long period due to the effect of ageing. Extreme conditions may affect the components when in an operating mode, non-operating mode, or both. The components have to be designed to survive and work in the actual environment for a certain period of time. It is important for the component specification to define whether the component is required to be capable of operating or only to survive without permanent damage, when being subjected to the environmental conditions. Furthermore, it is necessary to know whether the function in question always must be available, or whether a certain 'warm-up' period can be accepted before coming into operation.

An optimum should be sought between:

- the environmental resistance of unprotected component
- the protection of the component from environmental influences
- restrictions in transportation, storage, handling and use of the product.

It should be noted that an overdesign of a component, in order to withstand environmental conditions more extreme than necessary, does not necessarily result in higher reliability. An overdesign or unnecessary built-in protection may lead to more complex components with increased number of failure modes. Furthermore, overdesign of components as well as unnecessary requirements on locations in order to ensure environmental conditions less severe than necessary, can become very expensive.

Safety factors for design purposes must be specified. These factors must incorporate the reliability requirements, effectiveness and accuracy of design and production techniques. Safety factors to be considered on thermal and mechanical environmental loads specified and their correlation with the design qualification acceptance testing level, shall be derived as general rule by the margin policy stated, [R25, paragraph 3.1].

Figure 4.1 shows the different parameter ranges, tolerances and margins applied. Note that for certain parameters both high and low limits need not to be specified.

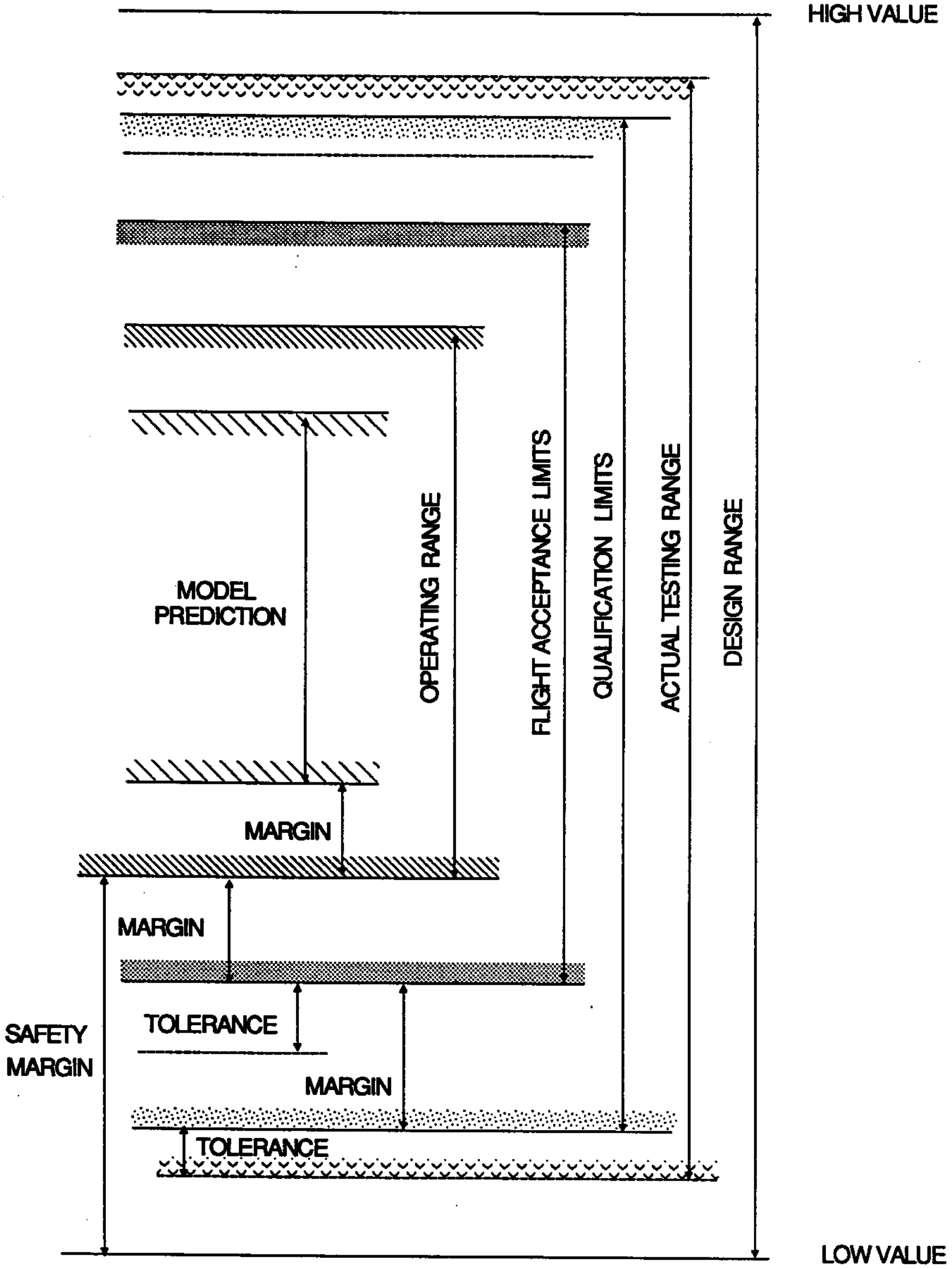

Fig.4.1 Parameter ranges

4.2 Background information for selection of environmental parameters and severities for classes

The actual environment conditions to which a component is exposed are normally complex and composed of a number of environmental parameters. When defining the environmental conditions for a certain component application it is necessary to:

- list the environmental parameters involved;
- select appropriate severities for each component;
- assess the risk of failure (-consequences).

The problem is to define relevant environmental conditions covering normal, short-term extreme and local conditions which may be met by a component when being transported, installed, stored, and used (launching and orbiting).

In terrestrial applications it is normal practise to group environmental parameters in severity classes. The classes given can be used for defining the maximum short-term environmental stresses, but do not give information on long-term, or total life duration of the component.

It is normally accepted that certain parameters limits are exceeded either for an insignificant part of the continuous exposure time (e.g temperature conditions), or an insignificant fraction of the total number of events (e.g. shocks). The probability of exceeding the parameter limits has been defined. Although available data do not make it possible to give an exact figure on the probability level used in the classification, it is usually considerably less than 0.01. [R24]

A component will be simultaneously exposed to a large number of environmental parameters. Some of the parameters are statistically dependent, for example, low air velocity and low temperature, sun radiation and high temperature. Other parameters are statistically independent, for example vibration and temperature (normally). The probability of simultaneous exposure to extreme severities of independent environmental parameters x and y is equal to the product of the probabilities of exposure to each of the parameters.

It should be noted that in many cases, the component is exposed for only limited periods to the environment from which the statistical data have been collected. In such cases severities in the classification have been selected which have a probability higher than 0.01 of being exceeded. Consequently the probability of the combination of parameters, the component is being exposed to the environment and the class limit severity, is reasonable (in the order of magnitude of 0.01).

It is suggested that the same principle as described above should apply to space applications.

Separate groups of classes should be given for different component applications (e.g. inside and outside) and to equipment performing a safety/reliability critical function. The classes should also take into account the degree of restriction of use of the component from very restricted conditions (e.g. in temperature controlled applications) to unrestricted conditions, and to local conditions (model prediction). It should be possible for the manufacturer and user to define restrictions in the transportation, storage or use of the component which will bring the application into compliance with a lower severity class. In addition, the classes must reflect the philosophy of margins/tolerances described in [R25].

Accidental incidents are normally not to be included, but the possibility of their occurrence may need to be taken into account for components vital to the safety/reliability of the installation in question.

The environmental classes may be used as a basis for the choice of design and test levels. This does not imply that zero failure rate should be required at the class limits. Design and test levels should always be chosen from case to case with respect to acceptable risk of failure, i.e. with higher or lower severity depending on expected consequences of failure. Component qualification testing should normally be performed at more severe conditions than the specified operating range. Qualification testing is normally destructive in the sense that the component's properties may change during the testing.

The manufacturer or user of the component may reduce the severity of an environmental parameter by protecting the product e.g. by using an enclosure for transportation and storage or by mounting the component on vibration or shock isolators. The environmental severities given shall then be applied to the product including its protection, not to the component itself.

4.3 Environmental parameters

The phases considered are: transportation, handling, storage, pre-launch, launch/ascent, transfer to orbit and on-station. During normal operation components may f.inst. dissipate heat and emit electromagnetic signals affecting components in the vicinity. Such local effects must be taken into consideration.

The environmental parameters given in Table 4.1 have been collected from the applicable and reference documents listed, and are examples of environmental design requirements. In instances where the parameter range is not defined in any of the available documentation, the parameter box is blank. If the range is to be determined at a later stage it is marked with 'TBD'. If the parameter range is considered not relevant/applicative to fibre optic components this is marked with 'NA'. Suggested ranges have been type set in *holsatia italics.*

In cases where different ranges have been identified in the basis documentation, the values given in [R25] have been adopted.

EXAMPLE OF ENVIRONMENTAL DESIGN REQUIREMENTS

Parameter	Transportation/ handling	Storage	System testing	Pre-launch	Launch/ascent	On-station	Proposed test range
Conditions		The satellite and equipment shall be stored in an sealed purged GN_2 environment. The containers for flight standard equipment shall provide protection against the following natural environments: sand storms, dust storms, salt-laden fog, rain, snow, hail. [R25]			Launching shall not take place during adverse weather conditions e.g. local lightning activity. [R25]		NA
Temperature, - max/min: M - gradient: G - inside: I - outside: O	TBD	TBD	TBD	MIO: -30 to +70°C [R25]	MIO: -30 to +70°C [R25]	MI: -30 to +70°C [R25] MO: -50 to +100°C [A6]	MI:-30 to +70°C [R25] *MO:-55 to +125°C* GO:$\Delta T/\Delta t$=0.4°C/s GO:$\Delta T/\Delta L$=20°C/m near equipment GO:$\Delta T/\Delta L$=5°C/m for other locations [A6]
Humidity (%RH) - inside: I - outside: O	O:55% ±10% [R25]		O: ≤ 60% [R25]	O: ≤ 60% [R25]	O: ≤ 60% [R25]	NA	*0 to ≤ 95%*
Movement of surrounding medium (air/water)					Air flow: Ariane fairing: Temperature: 15-25°C Flow: 1200 ±300 Nm^3/h Velocity: < 2m/sec [R25]		

Table 4.1a

EXAMPLE OF ENVIRONMENTAL DESIGN REQUIREMENTS							
Parameter	**Transportation/ handling**	**Storage**	**System testing**	**Pre-launch**	**Launch/ascent**	**On-station**	**Proposed test range**
Steady mechanical force - tension: T - impact: I - crash: C	*T: 250 N* *I: 20 Nm* *C: 1000 N*	*T: 250 N* *I: 20 Nm* *C: 1000 N*	*T: 250 N* *I: 20 Nm* *C: 1000 N*	*T: 250 N* *I: 20 Nm* *C: 1000 N*	*T: 250 N* *I: 20 Nm* *C: 1000 N*	*T: 250 N* *I: 20 Nm* *C: 1000 N*	TBD
Rolling and pitching	NA	NA	NA	NA	NA	NA	NA
Steady state accelerations				Vertical lifting: z axis: 2g x,y:0.1g Horizontal lifting: x (y): 2g y,z(x,z):0.1g Ground: All axis: 3g Air: All axis: 1.5g [R25]	Refer to [R25-3.10] The max. value specified is 22g at propulsion truss axial Z_2.		
Vibration	Z-axis: 5-6 Hz; 8.6mm 6-100 Hz; 1.25mm X,Y-axes 5-18 Hz; 1.0mm 18-100 Hz; 0.8mm [R25]	Z-axis: 5-6 Hz; 8.6mm 6-100 Hz; 1.25mm X,Y-axes 5-18 Hz; 1.0mm 18-100 Hz; 0.8mm [R25]	Z-axis: 5-6 Hz; 8.6mm 6-100 Hz; 1.25mm X,Y-axes 5-18 Hz; 1.0mm 18-100 Hz; 0.8mm [R25]	Z-axis: 5-6 Hz; 8.6mm 6-100 Hz; 1.25mm X,Y-axes 5-18 Hz; 1.0mm 18-100 Hz; 0.8mm [R25]	Z-axis: 5-6 Hz; 8.6mm 6-100 Hz; 1.25mm X,Y-axes 5-18 Hz; 1.0mm 18-100 Hz; 0.8mm [R25]	Z-axis: 5-6 Hz; 8.6mm 6-100 Hz; 1.25mm X,Y-axes 5-18 Hz; 1.0mm 18-100 Hz; 0.8mm [R25]	Peak accel.: 20g Freq. : .1-2kHz Cross-over: 50Hz Test: MIL-STD-750, No.2056 [A1]
Shock						Refer to [R25-3.13]	Peak accel.:1500g Pulse dur.: 0.5msec No. of shock: 5 Test: MIL-STD-750, No.2016.2 [A1]

Table 4.1b

EXAMPLE OF ENVIRONMENTAL DESIGN REQUIREMENTS

Parameter	Transportation/ handling	Storage	System testing	Pre-launch	Launch/ascent	On-station	Proposed test range
Pressure - Absolute: A - Rapid depress.: R - Vacuum: V	A:0.96 to 1.035 bar [R25]	A: 0.96 to 1.035 bar [R25]	A: 0.96 to 1.035 bar [R25] The spacecraft shall be subjected to thermal vacuum and solar simulation test and shall be operated under thermal vacuum conditions simulating worst case on station and transfer orbit environments.	A: .74 to 1.08 bar ±5% [R25]	R: $2x10^3$ N/m^2/sec from sea level to vacuum [R25]	V=10^{-10} Torr [R25]	R: From atmospheric pressure to 5 Torr in less than 5 sec. [A1] V: 10^{-10} Torr [R25] V: (test/thermal vacuum): 10^{-5} Torr [R25]
Radiation (nuclear) -Polar orbit <u>Unshielded</u> Ionisation dose:IUP Neutron fluence:NUP <u>Shielded (2mm Al)</u> Ionisation dose:ISP Neutron fluence:NSP -USS orbit <u>Unshielded</u> Ionisation dose:IUU Neutron fluence:NUU <u>Shielded (2mm Al)</u> Ionisation dose:ISU Neutron fluence:NSU	NA	NA	NA	NA	NA	Refer to [R25-3.8]	IUP:$5x10^5$ rad/yr NUP:$6x10^{12}$n/cm^2/yr ISP:$6x10^3$ rad/yr NSP:$4x10^{11}$n/cm^2/yr IUU:$3x10^5$ rad/yr NUU:$4x10^{11}$ n/cm^2/Yr ISU:$4x10^3$ rad/yr NSU:$1x10^{11}$ n/cm^2/yr [A1]

Table 4.1c

EXAMPLE OF ENVIRONMENTAL DESIGN REQUIREMENTS

Parameter	Transportation/ handling	Storage	System testing	Pre-launch	Launch/ascent	On-station	Proposed test range
Radiation (heat)		0 to 1422 W/m^2 [R25]			1.135 kW/m^2 Max thermal flux for 1 sec: 3 kW/m^2 Radial flux: < 0.5 kW/m^2 [R25]	Refer to [R25-3.7.1] regarding the true solar energy distribution, and [R25-3.9.4] regarding solar irradiance throughout the year. Max. 1.399kW/m^2. [A5]	
Flammability resistance	TBD	TBD	TBD	TBD	TBD	TBD	Refer to [A20-9.22]
Biological condition (flora, fauna)	NA	NA	NA	NA	NA	NA	NA
Chemically active substances (gases, aerosoles, solvents)							Refer to [A20-9.21] and Appendix C
Mechanically active substances (dust)			Flight equipment: Class 100,000 (FED, STD, 209B) [R25]	Flight equipment: Class 100,000 (FED, STD, 209 B) Ariane Fairing: Class 10,000 (FED, STD, 209 B) [R25]			
Micrometeroids	NA	NA	NA	NA	NA	Refer to [R25-3.6.1]	
Electromagnetic field - stationary: S							
Electromagnetic field - alternating: A - discharge: D							System and equipment shall be designed in accordance with the requirements of SPE/DRS/0322/SES
Acoustic	NA	NA	NA	NA	NA	NA	Refer to [R25-3.12]

Table 4.1d

4.4 Component evaluation and approval programme

Demonstration of the capability of the component to meet the environmental condition includes a number of activities. A component evaluation and approval programme is described in the document ESA PSS-01-60 [A11]. The principles given in this document (or modified) should be adopted in the evaluation process.

Design and application assessment shall be supported by the practical results obtained from evaluation samples to demonstrate that the component type is suitable for the application. These tests shall take into account the derating requirements contained in ESA PSS-01-301.

The testing should be made by selecting environmental parameters, or sometimes combinations thereof that are of interest. An environmental test requirement is described by:

- environmental parameter,
- testing procedure,
- testing severities.

It is customary for a the designer of test requirements to add margins to cover:

- tolerances of test and control devices,
- inequalities between the sample used for testing and other specimens of the product,
- other factors.

In addition requirements are given to specific product, e.g. rating, functional requirements, acceptable degradation, reliability. The qualification testing is relevant to design and application assessment including evaluation and type approval testing.

The testing procedures shall describe:

- purpose of testing,
- quality assurance measures,
- methods,
- preparations,
- selection of specimen,
- testing equipment,
- succession of tests,
- severity of test parameters, duration of test and gradients,
- observations to be made before, during and after the test,
- reporting.

In Part 2 of the report strategies for testing of each passive fibre optic component is treated.

5. RELEVANT COMPONENTS

The project is concerned with the passive optoelectronics components which are used in fibre optic transmissions systems. A schematic of a simple point-to-point system is shown in Fig. 5.1a. It consists of an optical transmitter, an optical fibre link and an optical receiver. The transmitter and receiver are active devices and were therefore not considered. The passive components are the fibre optic cable, the connectors and the splices. The transmitter and receiver will normally have connectorized inputs and outputs. Connectors can be mounted directly onto the cable ends, but often the cable is terminated in a suitable termination panel where a short, simple connectorized cable is spliced to the incoming cable and routed to the transmitter/receiver. The splices are given some suitable protection and placed in splice organisers and closures which are mounted in the termination panels.

If the incoming signal might be too large, an attenuator can be mounted in the front of the receiver, see Fig. 5.1b. Attenuators are, however, mainly used for testing purposes.

If the transmitted signal is to be distributed to several receivers, a coupler or branching device is used, see Fig. 5.1c. Similarly, the signal from several transmitters can be sent to one or several receivers by means of a suitable branching device.

Switches can be used to route the signal to a different receiver or branch, see Fig. 5.1d. Similarly, a switch can be used for connecting another transmitter unit to the system. F.inst. in case one transmitter fails, a stand-by unit can be coupled to the system as a replacement.

Wavelength multiplexing (WDM) is normally used for expanding the transmission capacity of the fibre. Several optical carrier waves at different wavelengths are transmitted simultaneously over the fibre. One or more signal channels can be multiplexed onto each carrier wave. As indicated in Fig. 5.1e, a wavelength multiplexing device is used to combine signals from several transmitters at different wavelengths onto one fibre. At the receiver end a wavelength demultiplexing device is used to separate out the various signal wavelengths and have them routed to the appropriate receivers.

Finally, in some cases reflections from connectors, splices and other components can propagate back to the source and cause the source output to fluctuate. This is mainly a problem with laser diodes and not with LED's. To prevent reflections an optical isolator can be placed immediately down stream from the source, see Fig. 5.1f. This is ideally a device which will transmit signal only in one direction and block any signal in the opposite direction.

A number of fibre optic communication systems for space use have been considered in other ESTEC projects, see report for Contract No. 7483/87/NL/PB(SC). Although these systems are relatively more complex than those described here, the passive components involved are the same. In addition to the optical components discussed, there is also a need for some accessories such as cable termination racks, cable clamps, splice boxes and splice protection.

The passive fibre optic components considered in the project and for which quality standards are needed, are given in Table 5.1.

- Optical fibres
- Optical fibre cables
- Fibre optic connectors
- Fibre optic splices
- Splice organizers and closures
- Fibre optic attenuators
- Fibre optic branching devices (couplers)
- Fibre optic switches
- Fibre optic wavelength multiplexers/demultiplexers
- Fibre optic isolators
- Combined electric/fibre optic cable

Table 5.1 Passive fibre optic components considered in the project

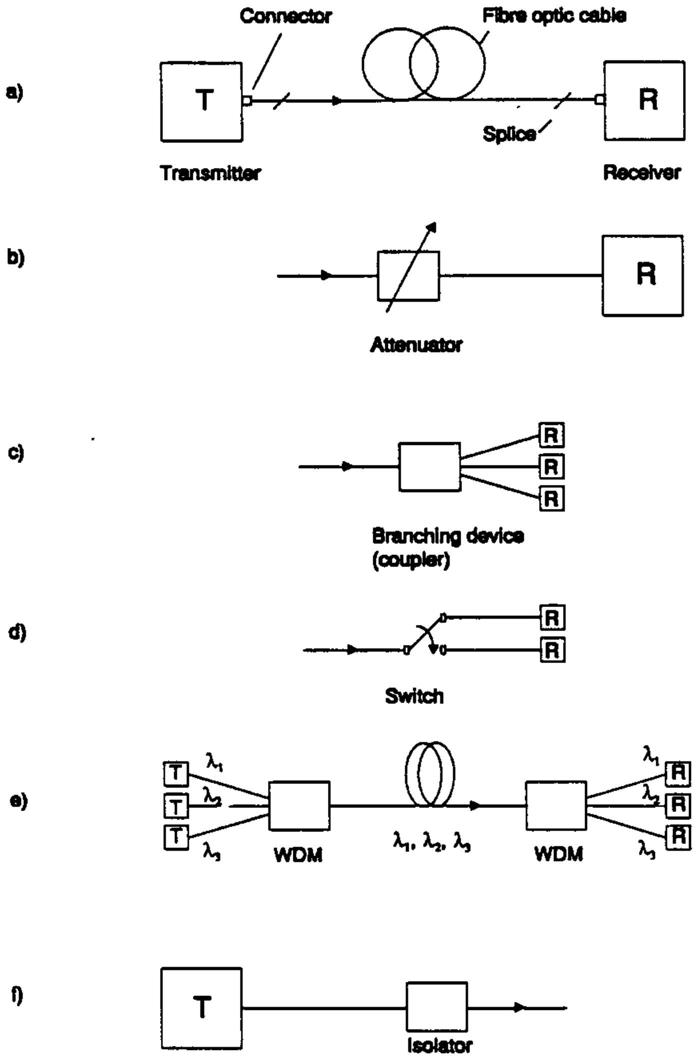

Fig. 5.1 a) Simple point-to-point fibre optic transmission system, b) attenuator to reduce received signal, c) coupler or branching device to distribute signal to several receivers, d) switch to change routing of signal, e) wavelength multiplexing/demultiplexing of signal, f) isolator to prevent reflections.

6. OPTICAL/MECHANICAL/ENVIRONMENTAL CHARACTERISTICS OF PASSIVE FIBRE OPTIC COMPONENTS

6.1 Introduction

In this chapter a detailed listing will be given of the characteristics which have to be specified for each of the components listed in Table 5.1. To determine if the specified requirements for each characteristic are being met, a suitable test strategy and appropriate tet methods are needed. These topics are addressed in Part 2 and 3, respectively.

For the optical and mechanical characteristics the requirements and test methods will in general be the same for terrestrial and space applications. Components to be used in space will, however, meet an environment which in some respect is different or more severe than that met in most terrestrial applications. Environmental conditions which can be said to be of special concern in space applications are:

- temperature extremes,
- rapid temperature cycling,
- vibrations,
- mechanical shock,
- rapid depressurisation,
- operation in vacuum,
- ionizing radiation.

One or more of these conditions might also be encountered in certain terrestrial applications, but generally not all of them at the same time.

The environmental characteristics of special concern for space application will be included in the listings given in this Chapter. A detailed discussion of how the space related characteristics and space application effect test strategies and test methods will be given in Chapter 7.

There are a number of international and national organisations engaged in establishing standards for fibre optic components and systems. There is, however, an extensive cooperation between the various organisations, and one attempts to arrive at uniform standards. All the major countries developing and producing fibre optic components and systems are active in the IEC, and the IEC has already published a number of standards with regard to fibre optics, see Chapter 3. New documents covering new areas and components are steadily being worked out.

In Part 3 where the required test methods have been selected, perference has been given to the test methods established by the International Electrotechnical Commission (IEC) if found applicable.

The lists of characteristics given in the tables are based on the characteristics specified by the IEC, but some items of interest for space applications have been added. The IEC terminology is also being used.

6.2 Optical fibres

Definition:

An optical fibre is a filament shaped optical waveguide made of dielectric materials.

Classification:

To classify and describe an optical fibre the following characteristics are needed:

fibre type:	step index multimode, graded index multimode, single mode and appropriate subclass, fibre material (quartz, plastic), type of dopant, polarization properties (birefringence, polarization preserving).
fibre geometry:	core diameter, cladding diameter, non-circularity, concentricity, fibre length.

Characteristics:

The important optical characteristics are listed in Table 6.1. For some of the properties measurement methods have been indicated in parenthesis.

The mechanical characteristics are listed in Table 6.2. Mechanical characteristics such as shock and vibration will not influence the fibre itself, but rather attachment points such as connectors and splices. These characteristics are therefore not included here, but in the respective component's characteristics. It can be noted that tests with respect to crush, impact, torsion, flexing, snatch and kink are usually not done on the primary coated fibre, but rather after the fibre has been added protection.

Characteristics	Remarks
Attenuation (cut back, insertion loss, backscattering)	
Bandwidth (impulse response, frequency response, pulse delay, phase shift)	
Continuity	
Change in optical transmittance (tansmission, backscattering)	
Polarization cross-coupling	-if applicable
Beat length	-if applicable
Numerical aperture	
Cut off wavelength	
Mode field diameter	
Bending sensitivity (macrobend, microbend)	

Table 6.1 Optical characteristics of an optical fibre

Characteristics	Remarks
Tensile strength	Short and long lengths
Bending	
Proof test	
Strippability	
Abrasion	For buffers and coatings
Crush	
Impact	
Torsion	
Flexing	
Snatch	
Kink	

Table 6.2 Mechanical characteristics of an optical fibre

The environmental characteristics are listed in Table 6.3. Main parameters that can be affected are attenuation and change in mechanical and/or geometrical properties. The ionizing radiation might also affect the fibre bandwidth.

Characteristics	Remarks
Temperature cycling	
Vacuum operation, including temperature cycling	
Solar radiation	
UV radiation	
Ionizing radiation	
Ageing	

Table 6.3 Environmental characteristics of an optical fibre

Material parameters:

Fibre coatings and buffers must be made of space qualified materials.

6.3 Optical fibre cable

Definition:

An optical fibre cable is a cable structure containing one or more optical fibres or optical fibre bundles, fabricated to meet optical, mechanical and environmental specifications.

Classification:

To classify and describe an optical fibre cable the following characteristics are needed.

cable type:	fibre type, number of fibres.
structure:	any special requirements on cable design, shape, dimensions, weight.

Characteristics:

The optical characteristics are listed in Table 6.4. Characteristics such as bandwidth, numerical aperture, mode field diameter, beat length and bending sensitivity is given by the fibre characteristics and will probably not be necessary to measure in the cable. These are therefore not listed in the table. Test methods for optical characteristics of the cable are the same as for the uncabled fibre.

Characteristics	Remarks
Attenuation (cut back, insertion loss, backscattering) Cut-off wavelength	

Table 6.4 Optical characteristics of an optical fibre cable

The mechanical characteristics of an optical fibre cable are listed in Table 6.5. Mechanical characteristics such as vibration and shock are included because such disturbances may influence the relative position of the fibre in the cable and as such increase the attenuation. They may also affect the cable structure. Main test parameters are change in attenuation, ability to survive test, tension on fibre and in addition a visual inspection should be made.

Characteristics	Remarks
Tensile strength Abrasion Crush Impact Repeated bending Torsion Flexing Snatch Kink Bend Vibration	

Table 6.5 Mechanical characteristics of an optical fibre cable.

The environmental characteristics of an optical fibre cable are listed in Table 6.6. Main test parameters are attenuation and visual inspection for change in component appearance and cable structure.

Characteristics	Remarks
Temperature cycling	
Rapid temperature cycling	
Vacuum operation, including temperature cycling	
Effects on state of polarization	-if applicable
Solar radiation	
UV radiation	
Ionizing radiation	
Cold bend	
Contamination	
Sheath integrity	
Flammability	
Ageing	
Rapid depressurisation	

Table 6.6 Environmental characteristics of an optical fibre cable.

Material parameters:

All materials used in the cable must be space qualified. The cable must be properly marked and the fibres coded so that they are easy to identify.

6.4 Fibre optic connectors

Definition:

A fibre optic connector is a component normally attached to an optical cable or piece of apparatus, for the purpose of providing frequent optical interconnection/disconnection of optical fibres or cables.

Classification:

To classify and describe a fibre optic connector the following characteristics are needed:

type:	fibre type, number of fibres, connection principle (butt-butt, lens coupling, index match, physical contact),
structure:	shell design, hybrid connections, dimensions, tolerances.

Characteristics:

The optical characteristics of a fibre optic connector are listed in Table 6.7. Product specifications on several different connector types are available from the IEC.

Characteristics	Remarks
Insertion loss Cross talk Susceptibility to ambient light coupling Return loss Modal noise Dependence on modal distribution Bandwidth Spectral loss	

Table 6.7 Optical characteristics of a fibre optic connector

The mechanical characteristics of a fibre optic connector are listed in Table 6.8. Main test parameters are change in loss and visual inspection for change in connector appearance or structure.

Characteristics	Remarks
Fibre or ferrule retention Static load Engagement and separation force Strength of cable retention and cable entry Strength of coupling mechanism Gauge retention force Bending moment Crush resistant Bump Axial compression Impact Acceleration Connector drop (with cable) Vibration Shock	

Table 6.8 Mechanical properties of a fibre optic connector.

The environmental characteristics are listed in Table 6.9. Main test parameters are change in loss, visual inspection for change in appearance and structure, and engagement and separation forces. For multifibre connectors crosstalk will have to be measured as well.

Characteristics	Remarks
Climatic sequence Temperature extremes (high temperature, cold temperature) Dry heat Rapid change in temperature Vacuum operation, including temperature cycling Condensation Corrosive atmosphere Dust Flammability Sealing Solar radiation UV radiation Ionizing radiation Mechanical endurance Rapid depressurisation Ageing Intermateability Resistance to solvents and contaminating fluids	

Table 6.9 Environmental characteristics of a fibre optic connectors.

Material parameters:

All materials used in the connector must be space qualified. The connectors must be properly marked.

6.5 Fibre optic splice

Definition:

A fibre optic splice is a permanent or separable (meant to be permanent, but it can be separated) joint between two optical fibres. It generally provides protection from damage which might result from normal handling.

Classification:

To classify and describe a fibre optic splice the following characteristics are needed:

type:	fusion splice, mechanical splice, permanent, separable
style:	type of mechanical splice, single or multiple, use of index matching, splice protection.
structure:	dimensions of splice protection, material and finish of splice protection, sealing

Characteristics:

The optical characteristics are listed in Table 6.10.

Characteristics	Remarks
Insertion loss	
Return loss	-reflected power
Crosstalk	-for multiple splices only
Susceptibility to ambient light coupling	
Spectral dependence of insertion loss	

Table 6.10 Optical characteristics of a fibre optic splice.

The mechanical characteristics are listed in Table 6.11. Main test parameters are change in loss and visual inspection for change in appearance or structure.

Characteristics	Remarks
Tensile strength	
Proof test level	
Effectiveness of clamping device against fibre or cable pulling, cable bending and cable torsion	
Vibration	
Shock	
Acceleration	
Crush resistance	
Impact	
Drop	
Bump	
Axial compression	

Table 6.11 Mechanical characteristics of a fibre optic splice.

The environmental characteristics of a fibre splice are listed in Table 6.12. Main test parameters are change in loss and visual inspection for change in appearance or structure.

Characteristics	Remarks
Climatic sequence	
Temperature extremes	
Rapid change in temperature	
Vacuum operation, including temperature cycling	
Condensation	
Corrosive atmosphere	
Dust	
Flammability	
Sealing	
Solar radiation	
UV radiation	
Ionizing radiation	
Resistance to solvents and contaminating fluids	-as required
Water vapour penetration	
Assembly and disassembly of closure	
Mechanical endurance	
Ageing	-of separable splices
Rapid depressurisation	

Table 6.12 Environmental characteristics of a fibre optic splice.

Material parameters:

All materials (protection, index matching gel) used in the splice must be space qualified.

6.6 Splice holder, splice organiser and splice closure

Definitions:

A splice holder is a device in which a number of protected fibre splices are stored and which may or may not be a part of the splice organiser.

A splice organiser is a device which contains and organises splice holder (s) and/or protected fibre splices and excess fibre length required for splicing procedures. It protects the fibre and fibre splice against mechanical damage, may control the minimum permissible bending radius and permits a stressfree storage for fibres in an orderly manner. The splice organisers are intended for use in a closure.

A splice closure is a device which protects fibre splices and splice organisers against mechanical and environmental effects.

Classification:

To classify and describe a splice holder, a splice organiser and a splice closure the following characteristics are necessary:

structure:	dimensions, maximum number of fibre splices, maximum outer fibre diameter, excess length of fibres which can be stored, radius curvature of stored fibre, configuration (organisation of splices and excess lengths, location entrance and exit ports), fixing points, material and finish, sealing.

Characteristics:

IEC has not yet published a standard for splice holders, organisers and closures, but a draft exists, and this forms the basis for the listed characteristics. The optical characteristics of the splice holder, splice organiser and splice closure are listed in Table 6.13. The only optical characteristic they can effect is the optical loss due to bending and/or clamping.

Characteristics	Remarks
Insertion loss after assembling of fibre splices in closure is completed	

Table 6.13 Optical characteristics of splice holders, organisers and closures.

The mechanical characteristics are listed in Table 6.14. Main test parameters are change of loss and visual inspection for change in appearance or structure.

Characteristics	Remarks
Effectiveness of clamping device against fibre or cable pulling, cable torsion, cable bending Vibration Shock Crush resistance Impact Drop Bump Axial compression Acceleration	

Table 6.14 Mechanical characteristics of a splice holder, a splice organiser and a splice closure.

The environmental characteristics of splice holders, organisers and closures are listed in Table 6.15. Main test parameters are change of loss and visual inspection for change of appearance or structure.

Characteristics	Remarks
Climatic sequence Temperature extremes Rapid change in temperature Vacuum operation, including temperature cycling Condensation Corrosive atmosphere Dust Flammability Sealing Solar radiation UV radiation Ionizing radiation Resistance to solvents and contaminating fluids Mechanical endurance (separable components) Assembly and disassembly of closures Ageing Rapid depressurisation	-as required

Table 6.15 Environmental characteristics of a splice holder, an organiser and a splice closure.

Material parameters:

All materials used in the splice holder, splice organiser or splice closure must be space qualified.

6.7 Fibre optic attenuators

Definition:

A fibre optic attenuator is a device intended to decrease the optical power in an optical waveguide transmission line.

Classification:

To classify and describe a fibre optic attenuator the following characteristics are needed:

type:	fixed, variable, continuous, stepwise, gradually filtering, reflection type, absorption type, mechanically variable
structure:	type of ports (fibre or connector including fibre or connector type), dimensions, shape, orientation and locations of ports, sealing.

Characteristics:

The optical characteristics are listed in Table 6.16.

Characteristics	Remarks
Attenuation Accuracy of calibration Return loss Spectral loss Polarisation dependence Modal noise Bidirectionality	

Table 6.16 Optical characteristics of a fibre optic attenuator

The mechanical characteristics are listed in Table 6.17. Main test parameters are variation in attenuation and return loss and visual inspection of change in appearance and structure.

The environmental characteristics are listed in Table 6.18. Main test parameters are change in attenuation, stability and visual inspection of change in appearance and structure.

Characteristics	Remarks
Vibration Shock Crush resistance Impact Drop Acceleration Bump Strength of attachment of fibre Static load (resistance to shearing forces)	

Table 6.17 Mechanical characteristics of a fibre optic attenuator.

Characteristics	Remarks
Climatic sequence	
Temperature extremes	High temp.
Rapid change in temperature	
Vacuum operation, including temperature cycling	
Condensation	
Corrosive atmosphere	
Dust	
Flammability	
Sealing	
Solar radiation	
UV radiation	
Ionizing radiation	
Resistance to solvents and contaminating fluids	-as required
Ageing	
Rapid depressurisation	

Table 6.18 Environmental characteristics of a fibre optic attenuator.

Material parameters:

All materials used in the attenuator must be space qualified.

6.8 Fibre optic branching device (coupler)

Definition:

A passive fibre optic branching device is a component possessing three or more optical ports and which acts to share light among its ports in a predetermined fashion.

Classification:

To classify and describe a fibre optic branching device (coupler) the following characteristics are needed:

type:	4 port directional coupler, transmission star coupler, reflection star coupler, polarization splitter etc.
structure:	number of ports, type of port (fibre or cable including fibre and connector type), material and finish, dimensions, cable, fibre or connector retention means, orientation and location of ports, sealing, adjustment means (if provided with adjustable tap ratio)
internal design:	principle of operation, potted or non-potted, adjustment means.

Characteristics:

The optical characteristics are listed in Table 6.19. The term transfer coefficient can be described as follows. The power transfer from an input port to the various output ports is described by an

NxN matrix. N is the number of ports, and the matrix coefficients represent the fractional optical power transfer between the designated ports. The transfer matrix is given as

$$\begin{bmatrix} t_{11} \cdots\cdots & & t_{1N} \\ \cdot & & \\ \cdot & & \\ \cdot & t_{ij} & \\ & & \\ t_{N1} & & t_{NN} \end{bmatrix}$$

where t_{ij} is the fractional optical power out of port j with unit power into port i. The t_{ij}s can depend on wavelength, modal distribution and state of polarisation of the incident light.

Characteristics	Remarks
Optical branching efficiency	
Dependence on modal distribution	-if applicable
Polarisation sensitivity	-if applicable
Stability of transfer coefficients	
Bandwidth	-if applicable
Susceptibility to ambient light coupling	
Optical power handling capability	

Table 6.19 Optical characteristics of a fibre optic branching device (coupler).

The mechanical characteristics are listed in Table 6.20. Main test parameters are change of loss, stability of transfer coefficients and visual inspection for change in appearance or structure.

Characteristics	Remarks
Vibration	
Shock	
Acceleration	
Crush resistance	
Impact	
Drop	
Bump	
Strength of attachment of fibre	
Static load (resistance to shearing forces)	

Table 6.20 Mechanical characteristics of a fibre optic branching devices (coupler)

The environmental characteristics are listed in Table 6.21. Main test parameters are change of loss, stability of transfer characteristics and visual inspection for change in appearance or structure.

Characteristics	Remarks
Climatic sequence Temperature extremes Rapid change in temperature Vacuum operation, including temperature cycling Condensation Corrosive atmosphere Dust Flammability Sealing UV radiation Ionizing radiation Solar radiation Resistance to solvents and contaminating fluids Ageing Rapid depressurisation	-as required

Table 6.21 Environmental characteristics of a fibre optic branching device (coupler).

Material parameters:

All materials used in the branching device should be space qualified.

6.9 Fibre optic switches

Definition:

A fibre optic switch is a device that upon demand couples optical radiation from one port to one or more other ports.

Classification:

To classify and describe a fibre optic switch the following characteristics are needed.

type:	mechanical, electrical, integrated optics etc.
structure:	type of ports (fibre or connector including fibre and connector type), materials and finish, dimensions, cable, fibre or connector retention means, orientation of ports on housing, housing shape, seals, means of mounting, means for actuation interface.
internal design:	operation principle, actuation means

Characteristics:

The optical characteristics are listed in Table 6.22.

Characteristics	Remarks
Insertion loss for the various transmission paths at the operational wavelengths Crosstalk and isolation between various optical paths Dependence on modal distribution Return loss Bandwidth Susceptibility to ambient light coupling Switching speeds and chattering Stability of optical performance	

Table 6.22 Optical characteristics of a fibre optic switch.

The mechanical characteristics are listed in Table 6.23. Main test parameters are variation in insertion loss, variation in cross-talk, effects on actuating mechanism and visual inspection for change in appearance or structure. For actuating mechanism the test parameters are change in properties (insertion loss, switching speed, actuation signal) for an increasing number of operations.

Characteristics	Remarks
Vibration Shock Acceleration Crush resistance Impact Drop Bump Strength of attachment of fibre Static load (resistance to shearing forces) Actuating mechanism	

Table 6.23 Mechanical characteristics of a fibre optic switch.

The environmental characteristics are listed in Table 6.24. Main test parameters are variation in insertion loss, variation in cross-talk, effects on actuating mechanism and visual inspection for change in appearance or structure.

Characteristics	Remarks
Climatic sequence	
Temperature extremes	
Rapid change in temperature	
Vacuum operation, including temperature cycling	
Condensation	
Corrosive atmosphere	
Dust	
Flammability	
Sealing	
UV radiation	
Ionizing radiation	
Solar radiation	
Resistance to solvents and contaminating fluids	-as required
Ageing	
Rapid depressurisation	
Electromagnetic field	-stationary and alternating

Table 6.24 Environmental characteristics of a fibre optic switch.

Material parameters:

All materials used in the switch must be space qualified.

6.10 Fibre optic wavelength multiplexer/demultiplexer

Definition:

A wavelength division multiplexer is a branching device with two or more input ports and one output where the light in each input port is restricted to a preselected wavelength range. The output port is a combination of the light from these preselected wavelength ranges.

A wavelength division demultiplexer is a branching device which performs the inverse operation of a wavelength multiplexer. The input is an optical signal comprising two or more wavelength ranges. The output light at each of the output ports is restricted to a preselected wavelength range.

Classification:

To classify and describe a wavelength division multiplexer/demultiplexer the following characteristics are needed:

type:	nominal operational wavelengths
structure:	number of ports, type of port (fibre or connector including fibre or connector type), material and finish, dimensions, cable, fibre or connector retention means, orientation and location of ports, sealing, adjustment means (if provided with adjustable tap ratio)
internal design:	principle of operation, potted or non-potted, adjustment means.

Characteristics:

The optical characteristics are listed in Table 6.25. The transfer matrix of a wavelength multiplexer/demultiplexer can be described as follows. For a device with N output ports (and one input port) the transfer matrix is given by

$$\left[\begin{array}{c|ccc} 0 & t_{12} & & t_{1,N+1} \\ \hline & & & \\ t_{21} & & & \\ & & 0 & \\ & & & \\ t_{N+1,1} & & & \end{array}\right]$$

The regions indicated by '0' are nominally zero. Note that the output port is different for each optical wavelength of operation. At a given wavelength of operation the output ports other than the one to which the optical power is being coupled are nominally isolated from the output light. The coefficients t_{ji} and t_{ij} are nominally one when the wavelength of operation is λ_j and zero otherwise.

Characteristics	Remarks
Optical branching efficiency	
Dependence on modal distribution	
Polarisation sensitivity	-if applicable
Stability of transfer coefficients	
Bandwidth	
Susceptibility to ambient light coupling	
Wavelength sensitivity	
Optical power handling capability	-if applicable

Table 6.25 Optical characteristics of a fibre optic wavelength division multiplexer/ demultiplexer.

The mechanical characteristics are listed in Table 6.26. Main test parameters are change in loss, stability of transfer coefficients and visual inspection for change in appearance or structure.

Characteristics	Remarks
Vibration Shock Acceleration Crush resistance Impact Drop Bump Strength of attachment of fibre Static load (resistance to shearing forces)	

Table 6.26 Mechanical characteristics of a fibre optic wavelength multiplexer/ demultiplexer.

The environmental characteristics are listed in Table 6.27. Main test parameters are change of loss, stability of transfer characteristics and visual inspection for change in appearance or structure.

Characteristics	Remarks
Climatic sequence Temperature extremes Rapid change in temperature Vacuum operation, including temperature cycling Condensation Corrosive atmosphere Industrial atmosphere Dust Flammability Sealing UV radiation Ionizing radiation Solar radiation Resistance to solvents and contaminating fluids Ageing Rapid depressurisation	-as required

Table 6.27 Environmental characteristics of a fibre optic wavelength multiplexer/ demultiplexer.

Material parameters:

All materials used in a fibre optic wavelength multiplexer/demultiplexer should be space qualified.

6.11 Fibre optic isolator

Definition:

A fibre optic isolator is a two port non-reciprocal optical device intended to suppress backward reflections, while having minimum insertion loss in the forward direction. The device is based on the Faraday effect.

Classification:

To classify and describe a fibre optic isolator the following characteristics are needed:

type:	nominal operational wavelength.
structure:	type of ports (fibre or connector including fibre and connector type), material and finish, dimensions, cable, fibre or connector retention means, orientation and location of ports, sealing, optional adjustment means.
internal design:	principle of operation, (bulk isolator, all fibre, etc.), potted or non-potted, adjustment means.

Characteristics:

The optical characteristics are listed in Table 6.28. There is no IEC standard for this component, but a draft exists and a standard will probably be available within the next one to two years.

Characteristics	Remarks
Insertion loss Polarisation dependence Backward loss Return loss Spectral loss Susceptibility to ambient light coupling Maximum input capability	

Table 6.28 Optical characteristics of a fibre optic isolator.

The mechanical characteristics are listed in Table 6.29. Main test parameters are variation in insertion loss, return loss and backward loss and visual inspection for change in appearance or structure.

Characteristics	Remarks
Vibration	
Shock	
Acceleration	
Crush resistance	
Impact	
Drop	
Bump	
Strength of attachment of fibre	
Static load	-resistance to shearing forces

Table 6.29 Mechanical characteristics of a fibre optic isolator.

The environmental characteristics are listed in Table 6.30. Main test parameters are variation in insertion loss, return loss and backward loss and visual inspection for change in appearance or structure.

Characteristics	Remarks
Climatic sequence	
Temperature extremes	
Rapid change in temperature	
Vacuum operation, including temperature cycling	
Condensation	
Corrosive atmosphere	
Dust	
Flammability	
Sealing	
UV radiation	
Ionizing radiation	
Solar radiation	
Resistance to solvents and contaminating fluids	-as required
Susceptibility to external magnetic fields	
Ageing	
Rapid depressurisation	

Table 6.30 Environmental characteristics of a fibre optic isolator.

Material parameters:

All materials used in the isolator must be space qualified.

6.12 Combined electric/fibre optic cable

General:

Combined electric/fibre optic cables can for instance be used if it is convenient to combine the electric power transmission and signal transmission to an area in one cable or if the fibre optic transmission/receiver units have to be remotely powered. The combined cable can consist of one or several electrical and fibre optic cables which are bundled in some fashion inside a common jacket, or the electrical conductor and optical fibres are integrated into one common cable structure.

The electrical part of the cable must meet the same requirements as an equivalent separate electrical cable. The optical part of the cable must meet the same requirements as an equivalent fibre optic cable. In addition the optical fibre part must function as specified when the electrical cable is energised. The electromagnetic field generated by the electric cable will not interfere with the optical signal, but the heating caused by the electric current may effect the cable structure and induce losses in the optical fibre. High temperature can also damage the fibre coating and cable materials unless the cable is designed properly. There is no need to test the electrical properties with the optical cable carrying a signal. The optical signal will have no measurable influence on the electric signal or the material properties.

The optical characteristics are listed in Table 6.31, and are the same as for the optical fibre cable without electrical conductors. In addition the electrical characteristics shall be as specified for the appropriate electrical cable.

Characteristics	Remarks
Attenuation, (cut back, insertion loss, backscattering) Cut-off wavelength	Attenuation should be specified with and without electrical load.

Table 6.31 Optical characteristics of an optical fibre cable with electrical conductors.

The mechanical characteristics of an optical fibre cable are listed in Table 6.32 and are the same as for the optical fibre cable without electrical conductors.

The environmental characteristics of an optical fibre cable are listed in Table 6.33 and are the same as for an optical fibre cable without electrical conductors. The temperature tests should be performed with specified load on the electrical cable.

Material parameters

All materials used in the cable must be space qualified. The cable must be properly marked and the fibres and electrical conductors coded so that they are easy to identify.

Characteristics	Remarks
Tensile strength Abrasion Crush Impact Repeated bending Torsion Flexing Snatch Kink Bend Vibration	

Table 6.32 Mechanical characteristics of an optical fibre cable with electrical conductors

Characteristics	Remarks
Temperature cycling Rapid temperature cycling Vacuum operation, including temperature cycling Solar radiation UV radiation Ionizing radiation Freezing Cold bend Contamination Sheath integrity Flammability External static pressure Water penetration Ageing Rapid depressurisation	-With electric load as specified

Table 6.33 Environmental characteristics of optical fibre cable with electrical conductors.

7. AREAS OF SPECIAL CONCERN WITH RESPECT TO ESTABLISHING QUALITY STANDARDS FOR SPACE APPLICATIONS

7.1 Introduction

It was stated in Ch. 6 that the environmental conditions of special concern in space applications are:

- temperature extremes,
- rapid temperature cycling,
- vibrations,
- mechanical shock,
- rapid depressurisation,
- operation in vacuum,
- ionizing radiation.

Tests exist for evaluating a component's performance when subjected to ionizing radiation, varying temperatures, shock and vibration, but not for operation in vacuum and large temperature gradients. In 7.2 - 7.6 a discussion will be given of the problem areas of concern when developing tests for these environmental conditions, and the applicability of existing tests to space applications will be evaluated.

From Chapter 6 it can also be noted that for splice enclosures and isolators no established standards are yet available. The IEC has, however, issued draft documents for these components, and it is expected that approved standards will be issued within one to two years. It would be unfortunate to develop separate standards which might be at variance with the IEC standards unless there was a special use related reason. Some of the special problems that might be encountered with regard to splices will, however, be discussed in 7.7.

Finally, there is a more fundamental question which is not special for space applications. How ensure that a test which of necessity will be performed on a new component and for a short time, is representative for the performance of the component over its intended lifetime. This question is of special concern when considering the mechanical strength of fibres and will be discussed in Chapter 7.8.

7.2 Ionizing radiation

Ionizing radiation may effect the fibre as well as other parts of a passive fibre optic component. It must, however, be assumed that the materials surrounding the fibre are space qualified (see ESA-PSS-01-70) and that they as such, will not significantly change behaviour when they are exposed to radiation. The main concern will therefore be how ionizing radiation affects the optical fibre itself, and a test method will have to be established to indicate how the fibre will behave when it is exposed to radiation in space. Other components will also have to be tested to ensure that there are no unexpected problems, but the test for these components may use the fibre test as a basis, and only minor, if any, modifications will be needed. The test must take into account the characteristics of the radiation in space and the effects of different test parameters.

IEC has recently published a procedure for measuring gamma irradiation effects in optical fibres and optical cables (IEC 793-1-D3). The procedure is based on FOTP-49A issued by EIA. Testing with respect to ionizing radiation is, however, dependent on many parameters, and a test procedure will have to be specified in great detail in order to give representative and repeatable results. A discussion of radiation effects in optical fibres and how the test parameters may influence these are therefore included before an evaluation of the test procedure is presented.

7.2.1 Radiation effects in optical fibres

When an optical fibre or a fibre optic component is subjected to ionizing radiation the characteristics of the fibre will change. The most important effect is change in attenuation. One has also observed a reduction of fibre bandwidth [1], but the effect of this is less significant and will probably only be of concern in systems where one operates close to the available fibre bandwidth. In such a case the effects of radiation on the bandwidth should be determined.

Radiation could possibly also affect the mechanical strength of the fibre, but we have seen no reports on such effects. The mechanical strength of a fibre is mainly determined by cracks and damage at the fibre surface, and radiation is not expected to influence the quality of this surface. The radiation may, however, affect the properties of the fibre coating if not properly chosen. This can indirectly affect the fibre strength.

The increased attenuation of an optical fibre exposed to ionizing radiation is due to the creation of colour centres in the glass. The colour centres are created when the radiation excites electrons and holes in the glass, and these electrons and holes are trapped by existing defects or defects created by the radiation. The colour centres act as absorbers and thus lead to increased attenuation.

When the fibre is removed from the radiation field, the attenuation will gradually decrease. This is due to thermal and light-induced (photo-bleaching) annealing of the fibre. Thermal annealing is due to thermally induced recombination of excited electrons and holes. The recombination rate increases with increasing temperature. Photobleaching is due to recombination induced by photons. This effect is both dependent on the wavelength and the power level, being most effective for shorter wavelengths and higher power. Photobleaching and thermal annealing also take place when the fibre is exposed to radiation, and the induced loss will therefore depend on temperature and transmitted power.

The induced attenuation depends on several factors [2]. Fibre parameters such as core and cladding composition, fibre structure, type and concentration of the dopants, the conditions and methods for preform fabrication, fibre drawing conditions and type of coating are all important for the resulting induced attenuation. More important for the aspect of a repeatable and representative testing of the attenuation induced in the fibre, is the dependence on test parameters such as fibre length, fibre geometry, signal power level, signal wavelength and operating temperature. The induced attenuation will also depend on the characteristics of the radiation source, the most important parameters are total dose, dose rate, time after exposure, energy spectrum of the radiation, type of radiation, and radiation history.

7.2.2 Radiation environment

The optical fibres inside or outside an spacecraft will be exposed to a radiation field of long duration. Dose rates are high compared with terrestrial environment, but low compared with the radiation field arising from a nuclear explosion. The radiation environment is described in chapter 4, typically dose rates vary between 10^3 and 10^5 rad/year. At these dose rates both thermal annealing and photobleaching will have measurable impact on the induced attenuation. Space flights usually lasts for years, and the fibre is exposed to a large total dose. However, the time available for testing is limited, and if one wants to achieve the same total dose as during the space flight, the test must be performed at an elevated dose rate. This will not allow for the same annealing processes to take place. The measured attenuation in the test will therefore be greater than what may be expected in the actual application, and this may lead to an overspecification of the fibre or component. This may result in rejection of fully adequate fibres and as such increase the cost.

7.2.3 Important test parameters

Testing for radiation effects in optical fibres is difficult because the result depends on several parameters such as the character of the radiation source and environmental and optical parameters. The test specifications must be defined so as to give representative and repeatable results, and results which indicate how the fibre will behave in the specific system. If the test does not allow for the natural recovery processes to take place, one might put such strict requirements on the fibre that few fibre candidates may be found satisfactory for space applications. The preliminary results of a recent experiment [3] where different fibres were carried on a 4.5 year long space flight show that the losses experienced by the fibres in space were less than expected from previous experiments in the laboratory.

7.2.3.1 Radiation source specifications

The characteristics of the radiation source will of course play an important part in the testing procedure. The main issue is to get a realistic simulation of the space environment with an easy accessible and easily controlled radiation source. There are several important features.

* *Radiation type and energy spectrum.*

The space radiation consists of cosmic rays (gamma and X-rays), charged particles (electrons and protons) and neutrons. α and β particles have very short ranges in air as well as most other materials [4]. As it is very unlikely that bare fibres will be applied, at least low energy α and β particles will be stopped by the surrounding materials. Because neutrons is an uncharged particle the range is much larger than for α and β particles. The effect of neutrons is related to their ionising ability. Experiments have shown that a reasonable conversion factor is that a radiation of 10^{12} n/m^2 gives the same loss as about 200 rad [5]. The conversion factor will however be somewhat energy dependent, but the size indicates that the effect of neutron radiation will be small. Most of the testing today is done with an ionising source, preferable the radiation from ^{60}Co or X-ray sources. These will have an energy spectrum limited to one or a few spectral lines where as the radiation in space will be distributed over a much wider range. The effect this difference may have on the fibre is not fully understood and must be investigated further before conclusions can be drawn. The preliminary results from a space flight [3] show that the induced attenuation was less than expected from experiments performed and indicate that using ^{60}Co will not underestimate the loss experienced during a space flight.

To measure the dose rate and total dose level for low dose rate and long exposure times, careful attention must be paid to the accuracy and stability of the dosimeter.

* *Dose rate and total dose*

The radiation induced attenuation in optical fibres is dependent on the dose rate if there are annealing processes on the time scale of the exposure. A given total dose will therefore give less maximum induced attenuation if it is applied at a low dose rate, than it would if the same dose was applied at a higher rate [2].

The attenuation induced by radiation is dependent on the radiation history of the fibre, ie if the fibre has been previously exposed to radiation the induced attenuation per rad will decrease [6]. This effect is called radiation hardening. A fibre exposed to low dose rate radiation will therefore experience radiation hardening during the time of exposure such that it is not as sensitive to the later part of the radiation as to the earlier.

The recovery processes (thermal annealing and photobleaching) have time constants varying from 1 second or less up to minutes, hours or even more. This means that the times at which the measurements take place are important. Measurements should be made during the irradiation, immediately after or so long after the fibre has been exposed to the radiation field that all recovery processes are completed and the fibre has reached "steady state".

There can also be saturation effects since there can be a limited number of sites where colour centres can be created. After a certain dose the supply is exhausted, and the induced attenuation saturates, ie it is no longer proportional to the applied dose. It will therefore be important to continuously monitor the induced attenuation while the fibre is exposed to the radiation to see how loss develops versus time (and total dose).

The radiation sensitivity of a fibre is commonly given in dB/km/rad. However, the induced loss will be dependent on the dose rate and the total dose used in the experiment and also to some degree the type of source used. A given value of the radiation sensitivity must therefore be used with care unless the test parameters are known.

7.2.3.2 Environmental test specifications

* *Temperature conditions*

The fibre or fibre optic component will be exposed to large temperature extremes, rapid temperature changes and large temperature gradients during a space flight. The temperature environment directly affects the characteristics of the fibre, but the temperature will also affect the radiation induced loss by the process of thermal annealing. A decrease in temperature will lead to an increased radiation induced attenuation because of the reduced thermal annealing as is shown in Figure 7.1 [7].

If the fibre is to be tested for the worst case situation, the temperature during the radiation testing should be the lowest specified for the flight. The fibre will, however, experience an average temperature higher than this temperature extreme, and testing at the lowest temperature will give a higher attenuation compared to the one expected for the flight. This will lead to an over-specification of the fibre and the possible rejection of adequate devices. The temperature dependence is not predictable in such a way that by testing at one temperature one can estimate the attenuation at other temperatures. The temperature will therefore have to be chosen as either a worst case low temperature, or an average temperature.

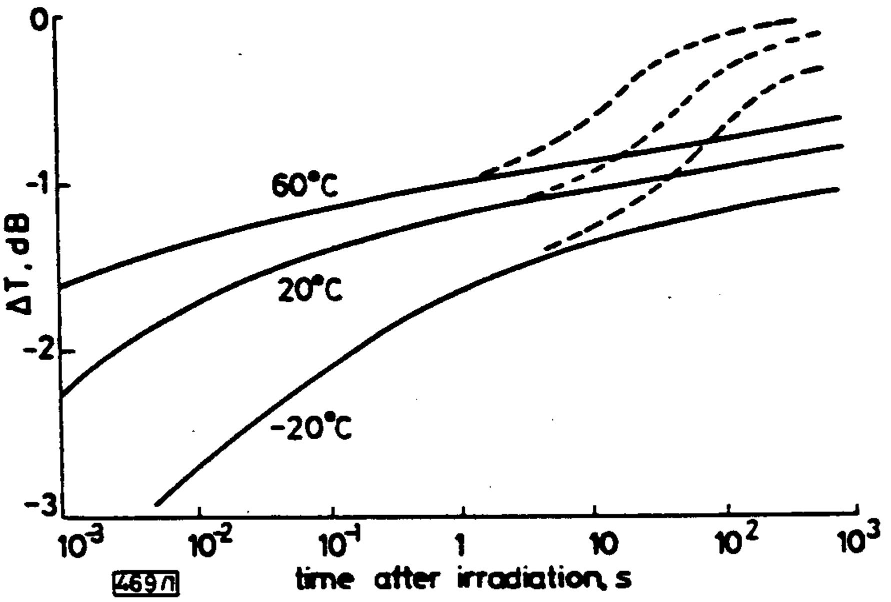

Figure 7.1 Loss (in dB) versus elapsed time after exposure with temperature as parameter. Dotted lines show the effect of applying a 1 µW optical signal to the fibre. [7]

* *Ambient light*

Ambient light as well as light passing through the fibre will give rise to the photobleaching process. External light sources will therefore have to be controlled during the test.

7.2.3.3 Light source specifications

The radiation induced attenuation is dependent on light source parameters such as transmission wavelength and signal power.

* Signal power

Because of the process of photobleaching, the induced attenuation is dependent on the light power transmitted through the fibre. Even at relatively low levels of optical power the attenuation is seen to be signal power dependent [6]. Figure 7.2 shows the result of an experiment where the fibre was exposed to radiation with light being transmitted through the fibre only each time a measurement was made. The other samples (of the same fibre and same production length) were exposed to 1 µW, and as can be seen the attenuation is significantly less. Afterwards the fibre was exposed to the same dose rate, but with 0.5 µW light power continuously propagating through the fibre. The loss at this power level was significantly less than without light at all, but not much different than for the same fibres with 1 µW. This is due to radiation hardening since the fibre had been previously radiated. The signal power during testing should be carefully considered. If testing is performed with a signal level lower than what is expected during the flight, an attenuation greater than what could be expected during the flight is measured, and again there will be a danger of overspecifying the component.

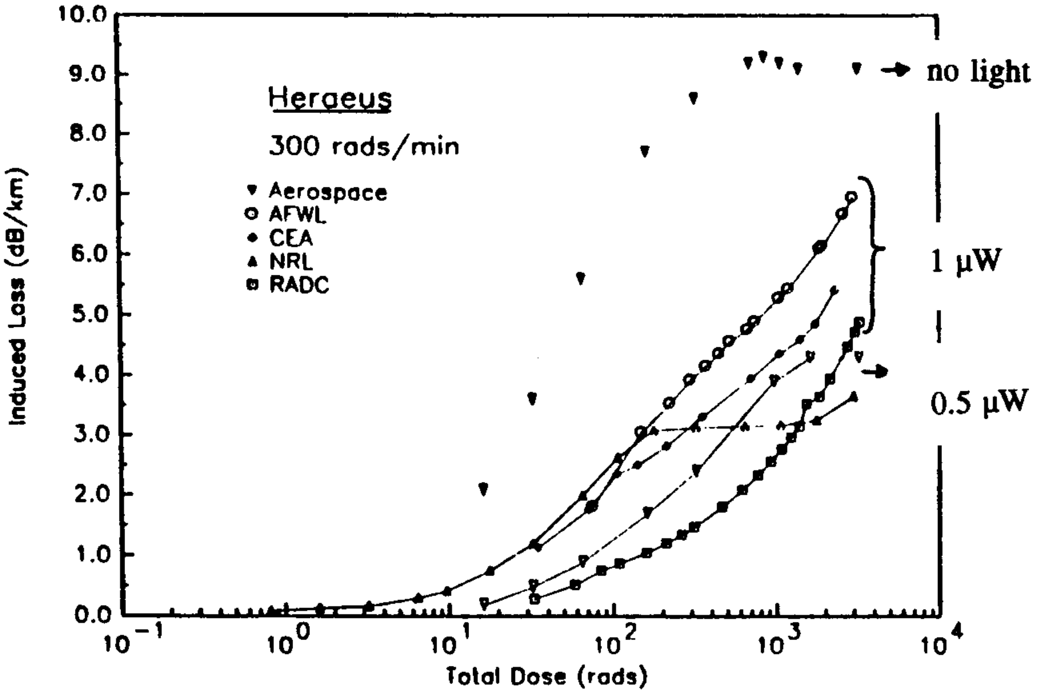

Figure 7.2 Induced loss versus total dose under various photobleaching conditions. See text for details.[6]

* *Signal wavelength*

The wavelength of the signal is an important test parameter since both the attenuation and the photobleaching is dependent on the signal wavelength. The radiation induced colour centres have highest absorption in the visible region with decreasing losses as one moves into the infrared. The radiation induced losses will be lower at 1300 nm than at 850 nm, but there seems to be only minor differences between 1300 and 1550 nm. The test should be performed at the operational wavelength (s).

7.2.3.4 Test fibre specifications

Test sample characteristics such as fibre length and fibre wrap diameter are important for the test result. Further, any prior irradiation of the fibre must be known since the radiation will change the fibre properties (radiation hardening). Finally, some of the induced loss will be permanent, and in that sense the test is destructive.

If too long lengths (compared with typical system fibre lengths) are used for testing, the signal power at the end of the fibre will be smaller than what can be expected during flight, and photobleaching will be less efficient. The measured attenuation will be too large compared with what can be expected and again there will be a danger of overspecifying the fibre. A similar situation can arise if the fibre sample is coiled with a small coil diameter in order to facilitate test conditions such as size of radiation source, radiation uniformity and size of temperature chamber. In such a case bending loss can occur, giving decreased signal power and thereby reduce the effect of photobleaching. Figure 7.3 shows the result of an experiment where four lengths of the same fibre where exposed to different test geometries. The upper set is with a fibre coil diameter of 8 cm and fibre lengths of 50 and 200 m. The photobleaching effect is larger for the shorter fibre length. The lower set, with less induced attenuation, are for the same fibre lengths, but with a fibre coil diameter of 57 cm. [6] Other test parameters such as radiation source etc. were strictly controlled and similar. The results illustrate the effect of different fibre length and wrap diameter for this specific fibre. The decreased attenuation at high dose rates is due to radiation hardening.

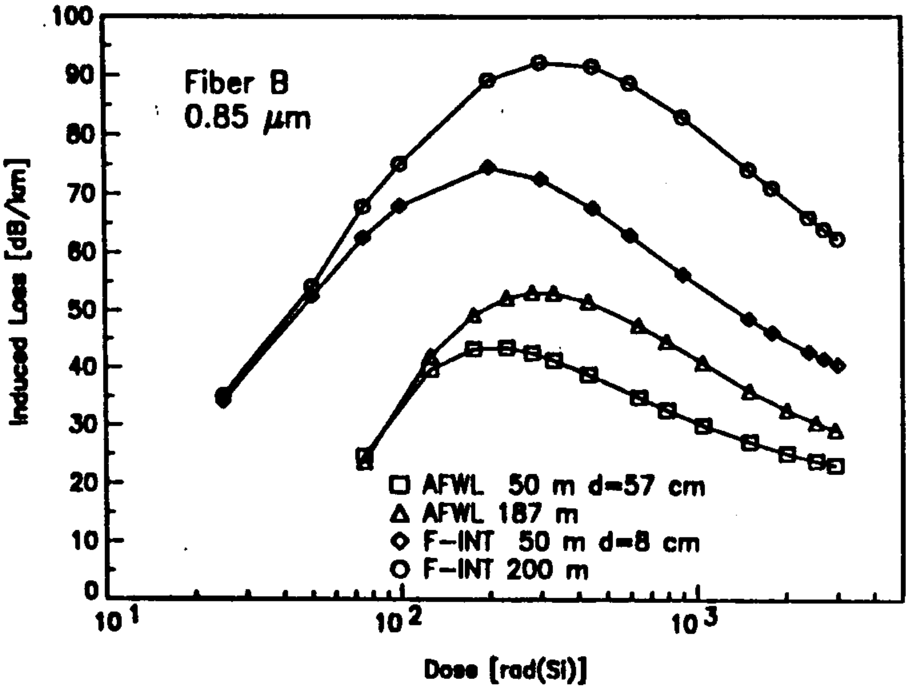

Figure 7.3 Induced loss versus dose for different fibre lengths and different fibre wrap diameters.

7.2.4 Test standards

The IEC test method 793-1-D3 describes two different test methods for measuring gamma irradiation effects in optical fibres, an environmental background test and a test for adverse nuclear environment. In the adverse environment test the dose rate varies between 5 rad/s and 200 rad/s, much higher than what can be expected in space. The specified total time varies between 10 and 90 minutes with the maximum total dose being approximately 1 Mrad. The background radiation test specify at least 5 hours of irradiation at a dose rate less than 20 rad/h. For space applications a test with an intermediate dose rate and longer duration will be appropriate.

The two test methods are otherwise quite similar differing only in some details. For our purpose the test for adverse environments (except for dose rate) seems best suited.

To compare the IEC procedure for measuring gamma irradiation effects in optical fibres and cables with standard tests for electrical components we have used the military standard MIL-STD-883, method 1019.3. Table 7.1 shows the specifications of the two test methods.

	IEC 793-1-D3	Test method 1019.3
Radiation characteristics		
Radiation source	^{60}Co or equivalent ionising source	^{60}Co or electron accelerator
Dose rate	5 - 200 rad/s	100-300 rad/h
Total dose	up to 1 Mrad	to be specified
Dose uniformity		± 10 %
Dosimetry	TLDs (Thermoluminescence Dosimetry)	TLDs or calculations
Calibration of source	before each measurement (TLDs)	* before each measurement (TLDs) * every three year with dosimetry traceable to NBS (National Bureau of Standards)
Correction for decay		Yes
Environmental characteristics		
Temperature	to be specified	25 °C
Temperature limits	± 2°C	± 5°C
Ambient light	shielding	
Optical source characteristics		
Optical power	≤ 1 μW or as specified	
Wavelength	as specified or: 850 ± 20 nm 1300± 20 nm 1550± 20 nm	
Reference light path	Yes	
Intermediate measurements	Continuously	
Final measurements	within 2 hours	within 2 hours
Fibre sample characteristics		
Fibre coil diameter	to be specified	
Fibre length	250 m or as specified	

Table 7.1 Comparison of tests for radiation effects

As can be seen from the table test method 1019.3 is specified in greater detail than IEC 793-1-D3 when it comes to radiation characteristics. The IEC procedure does not include any specification for dose uniformity, but since fibre samples obviously will have a spatial extent a requirement on dose uniformity will have to be included. The MIL-STD specification of ± 10 % seems reasonable and is apparently achievable with current sources.

The dose rate in space varies from approximately 0.5 rad/h for the USS orbit, shielded case, to approximately 60 rad/h for the polar orbit, unshielded case (see Chapter 4). The dose rate during testing will therefore have to be chosen for a specific application, instead of one standard for all cases. The total dose will have to be significantly higher than what is indicated in the IEC test since an expected total dose during a space flight may be in the order of Mrad.

The environmental characteristics are very strictly specified in the IEC 793-1-D3. The specific test temperature is left for the detailed specification to decide, but the temperature must be carefully controlled. As discussed in the previous chapter the test temperature should be chosen either as a worst case low temperature or an average value.

The test fibre specifications in IEC 793-1-D3 do to a certain extent take the effects presented in the previous discussion into account. With the specified signal power ($\leq 1\ \mu W$) photobleaching can occur, and one could consider using a system determined power level, if the purpose was to test the fibre for a given system.

The time at which the measurements should be made will have to be considered carefully. In addition to a final measurement it will be important to continuously monitor the induced attenuation, to reveal any effects of saturation.

7.2.5 Conclusion

Testing the radiation sensitivity of optical fibres is not a straight forward matter as many parameters will play an important part in determining the result. The test has to be carefully specified both regarding radiation parameters, environmental parameters and optical parameters.

It is important to bear in mind that different fibre types may have different sensitivities to the various test parameters. For example pure silica core fibres are known to have strong photobleaching effects and test results with this fibre would be more influenced by test parameters such as signal power, fibre length etc. Multimode fibres may experience higher macrobend losses and would be more sensitive to fibre sample geometry.

The existing standard can form a good basis for specifying a test for space applications, but the radiation dose rate and dose level must be adjusted. Further, the test parameters should carefully reflect the actual operating conditions of the fibre.

7.3 Operation in vacuum

Operation in vacuum can cause outgassing effects. To minimise problems associated with outgassing only space qualified materials (see ESA-PSS-01-70) should be used in the manufacture of the various components. Outgassing can cause changes in material properties and dimensions and this could for instance cause bending or squeezing of a fibre and thereby induce losses. It would therefore be recommended to do a thermal cycling test in vacuum to ensure that the various components do perform as specified.

The test could in terms of temperatures and temperature cycling be quite similar to the tests performed at normal atmospheric condition.

During such a test the optical performance of the various components should be monitored in addition to do a visual inspection after the test.

De Goede et al [8] have in a recent publication described tests that were done on fibre optic components intended for space applications. They performed a thermal vacuum cycling test similar to the thermal cycling test on a connectorized cable assembly, the only difference being that the test was done in vacuum. For one of the assemblies a significant difference was found in induced loss between the test done at atmospheric pressure and the test in vacuum.

During the launch phase a component will be subjected to a rapid pressure fall from approximately one atmosphere to a high vacuum condition. Trapped air can cause problems due to at least a temporary pressure difference. Among the components being considered, the fibre optic cable appears most vulnerable to such effects. Unless the cable is properly designed, the pressure gradient could cause the various cable elements to move with respect to each other. Such movements could induce losses in the fibre(s) and even breakage if the fibre was squeezed or crushed between various cable elements. The losses could be temporary or permanent. Other components which could meet problems unless designed properly, are attenuators, switches, connectors and splice boxes. Attenuators and switches will in general have moveable parts which means there will be open spaces inside the component. The same will be the case inside splice boxes and to a lesser extent, connectors.

Components like couplers, WDM devices and isolators can be made quite compact with no need for air pockets. But is still would be recommended that all components be subjected to a rapid depressurisation test. The optical performance should be monitored both during the depressurisation period and for a period after a stable vacuum has been reached. In addition a visual inspection should be done.

Tests with regard to rapid depressurisation of fibre optic components are not available and will be proposed in Part 3.

7.4 Temperature effects

Very likely the optical fibre to be used in space applications will be a fused silica fibre. Fused silica has a very low coefficient of thermal expansion when compared to metals and plastics likely to be used in the various fibre optic components. This means that the fibre can be subjected to thermal strain at both high and low temperatures, and this can induce losses and even fibre breakage unless proper precautions are taken in the design.

Maybe the most typical example of such thermally induced losses is found in fibre optic cables. If the cable is cooled down, the fibre becomes longer than the surrounding cable structure, and the fibre must buckle to find room. This will cause so-called macrobending losses. If the cable is heated, the fibre becomes shorter than the surrounding cable structure, and the fibre is put under tension. This will likely mean that the fibre will be pressed against internal surfaces in the cable causing so-called microbending of the fibre, and losses are induced. Cable designs have been developed to avoid these problems, but typically the cable attenuation will be independent of temperature only for a certain temperature range.

The various materials in other components can also have different thermal expansion, and the resulting thermal strain can directly or indirectly affect its performance. Finally, long term heating can cause changes in materials, f.inst. shrinkage of plastics, and a shrinkage can affect the fibre or other properties of the component. Examples could be changes in the primary coating of the fibre, changes in the packing material surrounding the fibres in a branching device, and changes in the cable and fibre retention means. All of which could result in bending losses and affect the mechanical properties.

Temperature effects are well known also in terrestrial use. But in space applications there are three aspects which can be different:

- operation at both higher and lower temperatures
- larger temporal temperature gradients
- large spatial temperature gradients

7.4.1 Operation at temperature extremes

The operational temperature range for a space born component will often be both higher and lower than what is typical on earth. For components outside a spacecraft temperature extremes of -55°C to +125°C are possible, see Ch. 4. Further to allow a safety margin, such a device should withstand even a larger temperature range. This must of course be considered in the design of a component and in the material selection.

Procedures for testing a device's performance under varying temperatures are well established, see Part 3. These procedures should also be applicable for the temperature ranges of interest for space use provided appropriate test equipment is selected.

With regard to ageing tests it should be noted that the optical and mechanical properties of fused quartz are not much temperature dependent in the temperature range in question. The test conditions should thus be based on the properties of the other materials in a specific component.

7.4.2 Temporal temperature gradients

A rapid change in the external temperature will create thermal gradients in a component and thus thermal stresses. Such stresses can effect the integrity of the component and influence both its optical and mechanical properties. Changes as fast as 0.4°C per second can be encountered, see Chapter 4. The actual temporal temperature change of the component will depend on its thermal properties, and the thermal mass of the object to which it is attached.

IEC Publication 68-2-14 Test Na describes a procedure for testing a component's performance when subjected to a rapid change of temperature. In the test the test objects are temperature stabilised in one temperature chamber and then transfered to another chamber in a prescribed time. The procedure appears well suited also for our application. The components to be tested in our case are small, and a rapid transition could easily be made from one chamber to the other. The optical transmission through the components in question should be monitored during the whole test. It is recommended that the experimental arrangement is such that the optical loop is kept intact during the transfer from one chamber to the other. Disconnection and reconnection can give variation in loss. A visual inspection should also be made after completion of the test to look for cracks or other damage.

7.4.3 Spatial temperature gradients

Spatial temperature gradients as large as 20°C per m can be encountered, see Ch. 4. With the exception of the fibre optic cable and maybe the splice box, the components considered here will have dimensions well below one meter. Large spatial temperature gradients thus appear of concern only for cables and maybe splice boxes if located in such an area.

Practical experience with typical fibre cables indicates, however, that thermal gradients do not effect the cable performance provided the cable properly terminated. During temperature tests the cable will be fed through the wall of the temperature chamber. The section passing through the wall will experience the temperature difference between the outside and inside. The difference can typically be 40 - 50°C over a distance of 10 - 20 cm, and the general experience is that such a gradient will not affect cable performance.

To ensure that thermal gradients are of no concern, one could specify that the cable should pass through the chamber wall when performing temperature tests.

7.5 High vibration levels

Vibration tests are necessary for all components except the fibre. The fibre will not experience any degradation when it is exposed to vibration, but attachment points such as connectors or retention means might be damaged. Optical cables, attenuators, couplers etc may be degraded because the vibration break or loosen parts of the component, or because vibration puts the fibre within the component under tension.

Examples of vibration level for space applications is given in Chapter 4. Maximum level given there is a peak acceleration of 20 g and a frequency range between 100 and 2000 Hz. Tests for effects of vibration are given both by the IEC, the EIA (FOTP 11A) and the MIL-STD for electronic, semiconductors and microelectronic components. The test parameters in the FOTP-11A corresponds to the maximum level given in Chapter 4, and indicates that testing optical components with this vibration level is possible.

Vibration tests includes both sinusoidal vibration and random vibration tests. In previous experiments for space application only sinusoidal vibrations have been included [1,8].

High vibration levels are expected during the launch and pre-launch phase of a flight. During the on-station phase it is assumed that high vibration levels only occur for a limited period of time such as when the space craft changes orbit, or the space craft is hit by a meteor. Testing the component for vibration fatigue is therefore probably not necessary.

Previous measurements indicate that fibre optic components can be made to withstand such high vibration levels. Results from an previous experiment [8] gave an attenuation increase less than 0.1 dB when optical fibre cable assemblies were exposed to vibration levels of 20 g. Another experiment [1] also indicates that vibration is not a problem for cable and connector assemblies and couplers, but for mechanical switches the attenuation increase was significant. (10 dB). This switch was however of the electromechanical type and other designs such as integrated optics will be less vulnerable to high levels of vibration. Test results from manufacturers of fibre optic couplers confirm these results. Testing for vibration effects in fibre optic couplers are performed with no significant change of optical performance. [9,10].

It is clear that components dependent on mechanical alignment is more vulnerable to vibration than other components. Testing with the specified qualification limit should, however, be performed on all components to ensure that they conform with the required standard.

7.6 High shock levels

High shock levels will not affect the bare fibre, but rather attachment points such as connectors or retention means, and components comprising two or several parts, which might loosen, break or become misaligned during the shock pulse. Cables, connectors, couplers etc. should therefore be exposed to a test for effects of high shock level. Test parameters are change in attenuation and visual inspection for change in appearance or structure (loosened or damaged parts).

Examples of possible shock levels is given in Chapter 4 with reference to MIL-STD. The shock tests exist within IEC (for some components), the EIA (FOTP 14) and the MIL-STD for electronic, semiconductor and microelectronics.

The listed shock level 1500 g, 0.5 s, is considerably higher than the ones within the IEC and EIA standards. Fibre couplers are, however, tested up to a shock level of 1000 g without any significant change in performance [10]. In [1] connectors and coupler were subjected to a shock level of approximately 800 g without any significant change of performance.

Testing for effects of high shock level could be done by adjusting the existing test parameters so that they conform with the qualification tests limit.

7.7 Components and characteristics where standards are lacking

As noted in Chapter 6 neither IEC nor EIA have yet established standards for splice enclosures and isolators. IEC has, however, issued draft documents for these components, and one would expect approved standards to be available within one to two years.

In addition to the general lack of defined tests for f.inst. vacuum operation, there are also several cases where the test for a certain characteristic has been described for one component but not for another component. An example is that a test with regard to acceleration has been defined by the IEC for fibre optic connectors and splices, but not for branching devices. These components would be used in the same environment and should thus be able to meet the same requirements. The same test procedures should, however, be useable for various components, but with some variations in detail to fit the pertinent component. The Electronic Industry Association has taken this approach and in several cases issued one document which describes one test covering several component types.

Some comments are also in order with regard to fibre optic splices. Splicing of fibres is often necessary when installing a fibre optic system. It can also be done as part of the manufacturing of a component. One usually distinguishes between fusion splices and mechanical splices. In a fusion splice the two fibre ends are fused together using either an electronic discharge or a flame. In a mechanical splice the two fibre ends are mated together in some type of precision made tube, and the fibres are kept together by mechanical means or glue.

In both cases the splices are made on the spot, and the only splice properties that usually can be tested are optical loss and tensile strength, and in addition a visual inspection can be made. It is thus important that a well defined and tested splicing procedure has been established and that the procedure is followed with great care when making the splice.

The recommended method to measure the optical loss of the completed splice is the optical time domain reflectometry (OTDR) technique. The technique is based on launching a short light pulse into the fibre and then measure the Rayleigh scattered light in the backward direction as a function of position. The two fibres which are spliced together, may have different scattering cross-sections, and this will cause problems in the determination of the splice loss unless measurements are made both ways through the splice. Access to both ends is thus necessary.

In space applications one can expect that the fibre lengths involved on both sides of a splice will be short. To avoid problems associated with end effects, the fibre lengths beyond the splice should be at least 5 - 10 times the spatial resolution of the OTDR instrument. At present OTDR instruments with a spatial resolution below 1 meter are available.

If it is not practical to use the OTDR technique, one can couple a suitable light source to one end of a link and then measure the transmitted signal each time a new section is spliced to the link. In this case corrections must made for any loss in the fibre between the splice and detector. The installation must be planned so that such a method can be used. The method is not included in the IEC draft for splices.

To ensure the mechanical strength of the splice so-called prooftesting is done. The spliced section is subjected to a specified stress for a specified time, and the fibre shall not break. To determine the appropriate proof test level, one must know or estimate the expected stress to which the splice will be subjected during its lifetime. Further, the strength distribution which is achieved with the used splicing procedure must be known. With this knowledge one can calculate the prooftest level necessary to achieve a certain probability of survival. This again points up the need for a well established and documented splicing procedure.

7.8 Determination of mechanical test criteria to ensure a desired lifetime

A problem which is met in any attempt to set up a test program , is how select the test parameters so that one can ensure that the component will survive the stresses of various kinds to which it is expected to be subjected during its intended lifetime.

Apart from the optical fibre the materials which can be found in the various components will be materials generally known from other applications. Test parameters for f.inst. ageing or to determine safety margins, will have to be decided with due consideration of the properties of these known materials used in a specific component.

In subchapter 7.2 we have discussed the effects of ionizing radiation on the optical properties of the fibre and the problems associated with defining a test procedure and test parameters. We will here discuss the mechanical properties of the fibre and in particular how determine the test requirements on tensile strength. This problem is well known also for terrestrial applications, but the potential operation in vacuum for a space applied system gives an interesting side benefit.

Quartz has a very high inert strength. However, when manufacturing long lengths of fibre, flaws such as surface cracks and impurities imbedded in the surface will appear along the fibre. It is the size and distribution of these flaws which in practice will determine the tensile strength properties of the fibre. Further, when the fibre is under strain, the flaws will grow in size reducing the fibre strength. This is called fatigue or stress corrosion. The crack growth is due to a stress induced chemical reaction, and water and some other chemicals affects this reaction. The growth rate thus depends on the applied stress as well as the environmental conditions, and the breakage strength will be a function of both the duration of the load and of the fibre's environment.

Over the last 15 - 20 years an extensive amount of research has been done with the aim of understanding what determines the mechanical properties of optical fibres and develop theoretical models which can be used to determine test criteria. We will here just present a simple model which is often used to determine the proof test level for a fibre when the load to which the fibre will be subjected during its lifetime, is known.

It can be shown that if a fibre is subjected to a time varying stress σ (t) one has to good approximation [11]

$$\int_0^{t_f} \sigma^n(t)\,dt = constant \qquad (7.1)$$

Here t_f is the time to failure, and n is the so-called stress susceptibility constant which is dependent on the environment. For a constant stress σ:

$$\sigma^n\ t_f = constant \qquad (7.2)$$

To ensure that a produced fibre has a certain mechanical strength , the fibre is subjected to a certain proof stress σ_p for a given time t_p as part of the manufacturing process. From Eq. (7.2) one finds that for a fibre which has survived the proof test, the minimum time to failure t_f when subjected to a constant stress σ is:

$$t_f = t_p\left(\frac{\sigma_p}{\sigma}\right)^n \qquad (7.3)$$

To determine the proof test level the value of n must be known. As mentioned, n is dependent on the environment and in particular the humidity. The lower the humidity the higher the n-value. Thus for operation in vacuum a high n-value can be expected. This is borne out by experiments [11]. It is also well known that fibres with so-called hermetic coatings which are impervious to water, have high n-values.

The temperature dependence of n at constant humidity appears to be small at least for the temperatures of interest here, but this an area where only limited studies have been made [12]. Experiments indicate also that the inert strength is about the same at liquid nitrogen temperature and at room temperature in vacuum [11, 13].

For room temperature operation and normal humidity one can assume n $\approx$ 20. For hermetic fibres and probably also for vacuum n $\approx$ 200 or larger can be assumed. Although for vacuum the available data are limited [11].

To illustrate the consequences of the two n-values, let us assume t_p = 1 second which is quite typical and that we want a lifetime of 30 years.

From Eq. (7.3) one finds that the ratio between the proof test level and the expected static stress should be at least:

$$\frac{\sigma_p}{\sigma} > 2.8 \qquad n=20$$

$$\frac{\sigma_p}{\sigma}>1.1 \qquad n=200$$

The example shows that for operation in vacuum the static stress can be close to the proof test level, while for operation at normal terrestrial conditions the proof test level should be approximately three times the static stress level. This means that the proof test level probably will be determined more by the stresses to which the fibre will be subjected before launch than when in orbit.

The simple model used here has a built-in margin of safety since the actual strength of the fibre is larger than σ_p . The time to failure should thus be larger than calculated by Eq. (7.3). A conservative choice of n-value and/or an increase in σ_p above that given by Eq. (7.3) also give a safety margin.

Finally, it should be remarked that the theoretical model presented here is somewhat simplified since it does not take into account the statistical nature of the fibre's breaking strength. If the strength distribution is known, the proof test level necessary to achieve a specified probability of survival for a certain time dependent stress scenario, can be calculated. However, the simple model presented here is much used in practice.

7.9 Summary

A survey has been made of the problem areas which may be encountered in the development of quality standards for passive fibre optic components suited for space applications.

The most problematic area seems to be the development of reliable and representative testing procedures with regard to losses induced in optical fibres by ionizing radiation. The difficulties can be summarised as follows:

- Test parameters such as dose rate, total dose, type of radiation, transmitted optical power, optical wavelength, temperature, fibre length, fibre coil diameter, and past radiation history, can all effect the test results. The test parameters must therefore be specified in detail and be representative of the application in question.
- It is difficult to make good estimates of the effects of long term exposure from short term exposure experiments. Short term experiments can give an upper limit on the expected induced loss, but the use of results from short term experiments without any adjustments will give unnecessary strict acceptance requirement.

The IEC has recently published a test procedure with respect to testing the effects of ionizing radiation on optical fibres. For our application the test must, however, be somewhat revised, and some test parameters should be specified in more detail. The problem of extrapolating short term results to long term performance is not addressed.

Also the other fibre optic components should be tested with regard to possible effects of ionizing radiation. Although space qualified materials should be used in the components, one should ensure that no unexpected problems will occur, and in particular radiation induced effects that directly or indirectly can effect the optical fibres. Such tests need likely only be done as part of the qualification programme.

Accepted test procedures with respect to operation of fibre optic components in vacuum are not available. This pertains both to long term operation at various temperatures and rapid pressure fall from atmospheric pressure to high vacuum. It should, however, be possible to base tests for fibre optic components on existing tests for thermal cycling and vacuum operation. The test arrangement must, however, allow the optical performance to be monitored during the test.

The existing IEC test procedures for temperature cycling, high and low temperatures and rapid temperature changes all seem applicable even though the temperature extremes and temporal variations encountered in space may be larger than those met in typical terrestrial application. For spatial thermal gradients a special test does not appear necessary. But it can f.inst. for cables be incorporated in other thermal tests.

The IEC and EIA tests for vibration and shock are also applicable although the specified shock parameters are significantly lower than those necessary for space applications. The test procedures can, however, be used.

For splices, splice enclosures and isolators no generally accepted standards are yet available, but IEC draft documents have been issued for comments. Special procedures for the determination of splice loss may be needed for some cases. Also, since splices often are made on the spot during installation of a system, the opportunity for testing is limited. Qualified splice procedures will therefore have to be established.

The mechanical lifetime of a fibre is determined by stress corrosion or fatigue. Stress corrosion increases with increasing humidity. Operation in vacuum is thus more favourable than operation under normal atmospheric condition. The requirement on fibre strenght may well be determined by the mechanical stresses to which the fibre is subjected before launch rather than when operating in space. Theoretical models exist for predicting lifetime of a fibre subjected to a certain tensile stress using data from short term tensile strength experiments. Such models can be used to estimate necessary proof test levels for the fibre.

8. REFERENCES

[1] ESTEC Contract No 6588/66/NL/IW (SC) "Characterisation/adaption of new optical fibre devices for space applications". December 1987

[2] E.J. Friebele, C.G. Askins, M.E. Gingerich, K.J. Long, "Optical fiber waveguides in radiation environment". Nuclear Instruments and Methods in Physics Research B1 (1984) 355-369, North-Holland Physics Publishing Division (1984), Amsterdam.

[3] C. Barnes, L. Dorsky, A. Johnston, L. Bergmann, E. Stassinopoulos, " Overview of Fiber Optics in Natural Space Environment". SPIE Vol 1366 Fiber Optics Reliability: Benign and Adverse Environment IV (1990). (9-16)

[4] J. Shah, "Effects of Environmental Nuclear Radiation on Optical Fibers" The Bell System Technical Journal. Vol 54, No 7, September 1975.

[5] R. H. West, "Interpreting radiation tests on fibre optics" SPIE vol 734 Fibre Optics'87: Fifth International Conference on Fibre Optics and Opto-electronics (1987).

[6] E. J. Friebele, E.W Taylor, G. T. de Beauregard, J. A. Wall, C.E. Barnes, "Interlaboratory Comparison of Radiation Induced Attenuation in Optical Fibers. Part I: Steady-State Exposures" Journal of Lightwave Technology, Vol 6, No 2, February 1988 (165-171)

and
E. W. Taylor, E. J. Friebele, H. Henschel, R.H. West, J. A. Krinsky, C.E. Barnes, "Interlaboratory Comparison of Radiation Induced Attenuation in Optical Fibers. Part II: Steady-State Exposures" Journal of Lightwave Technology, Vol 8, No 6, June 1990 (967-976)

[7] R. H. West, "Temperature Dependence of Radiation-Induced Losses in Fibre Optics" Electronic letters 25th October 1984, Vol 20, No 22. (905-906)

[8] G. M. de Goede, W. C. Chen, A. R. Jackson, "Evaluation of Fiber Optic System Components for Use in Spacecraft Environments" International Wire and Cable Symposium Proceedings 1990 (528-535)

[9] Qualification and Lifetime testing of Corning Couplers. Corning Application Note.

[10] D. R. Moore, " Long term Reliability Tests on Fused Biconical Taper Couplers" SPIE Vol 1366 Fiber Optics Reliability: Benign and Adverse Environments IV (1990)

[11] W. Griffoen, G. Segers, E. van Loenen, "Two point bending apparatus, fracturing optical fibres at different speeds in one run; measurements in standard and vacuum environment", Int. Wire & Cable Proc. 1990, pp. 368-372 (1990).

[12] C. R. Kurkjian, D. Inniss, "Understanding mechanical properties of lightguides - a commentary", Optical Engineering 30, pp. 681-689 (1991).

[13] W. J. Duncan, P. W. Frank, K. J. Beales, "Effect of service environment on proof testing of optical fibres", Seventh Europ. Conf. on Optical Commun. Copenhagen, 8-11 September 1981, Paper 4.5 (1981).

1. INTRODUCTION

This Part contains Task 2 Report of the ESTEC Contract No.8906/90/NL/PM(SC).

2. OBJECTIVE OF WORK TASK 2

The objective of this Task has been to prepare standard test strategies for passive optoelectronic components, taking as guidelines the existing standards in the SCC system for electric cables and electric connectors, i.e.:

- Define essential mechanical/geometrical/environmental/optical characteristics required to be tested.
- Define tests relevant to each component.
- Describe test strategies for evaluation, final production, qualification, lot acceptance, and screening.

3. DOCUMENTATION

The work has been performed in accordance with the specific articles listed in the Contract. Besides the work is based on additional documentation received from ESTEC and other relevant references listed in Part 1. Literature references have been listed in Chapter 16.1. References used has been given in brackets e.g. [A4].

4. GENERAL

4.1 Introduction

In this Chapter, a general description of the testing strategies (procedures) will be given. The strategies for testing of optoelectronic components have been based on the existing procedures described in the ESA/SCC specifications, e.g. No.20100.

The objective of testing may be to:

- assess the characteristics of a component,
- determine the operational limits with respect to environmental parameters,
- overstress specific characteristics in order to identify failure modes,
- convert latent defects to failures,
- determine if a component meets its specifications.

The testing procedures shall describe: the purpose of testing, quality assurance measures, test methods, preparations, selection of specimen, testing equipment, succession of tests, severity of test parameters, duration, observations to be made, and reporting.

During a test, the properties of the component may be affected. If the properties are changed in an adverse manner, the test is considered to be destructive. Tests may be divided into two categories, viz. destructive and non-destructive. In connection with procurement, components that have undergone non-destructive testing will normally form part of a delivery lot. On the other hand if one may assume that the quality of the component has been reduced to an unacceptable level, the tested component shall not form part of the delivery lot.

Important aspects when designing and setting up tests are to:

a) specify suitable testing conditions obtainable in the laboratory/factory that give test results equivalent to actual service conditions existing in the operating phases,
b) determine a representative sample,
c) obtain reproducibility of the results of the tests,
d) define failure criteria
e) enable a firm decision after the test,
f) make generic tests valid for a range of components,
g) make cost effective test procedures.

A further discussion of these aspects and description of the testing procedures is given in Part 3.

4.2 Component evaluation and approval programmes

The ESA/SCC qualification approval shall be a status given to optoelectronic components which have been manufactured, under controlled conditions, by an individual manufacturer and which have been shown to meet all the requirements of the applicable specification, and relevant ESA/SCC generic and detail specifications. The different phases and activities in the qualification procedure are shown in Table 4.1. The broad outline of qualification and procurement are shown in Chart 4.1 and 4.2. Refer to ESA/SCC 20100 [A23] for further information.

Phase	Remark
Formal application	- Brief details of the component - Description of the production and quality procedures - Description of the manufacturer's organisation - Samples of the component - Complete details of its optical and mechanical characteristics - All existent test data - Information regarding the manufacturing organisation - Quality assurance plan - Production flow chart
Review of application	- Qualifying Space Agency (QSA) reviews the application - QSA performs a construction analysis of a sample - QSA approve the initial documentation - If necessary, the manufacturer may be requested to provide further samples and documents - QSA agrees to support the application
Evaluation of the manufacturer	- Survey of the overall manufacturing facilities, organisation, and management - Survey of the manufacturer's inspection and manufacturing control - Survey of the production line
Evaluation of the component	- Establishment of an evaluation test programme - Evaluation testing of component(s) - Definition of any corrective actions - Documentation review - Finalisation of information to be contained in Process Identification Document (PID) for the component
Qualification testing	- All documentation essential for the production and testing of a component is reviewed by QSA - A specific quantity of that component is subjected to qualification test programme - PID to be prepared by the manufacturer - The manufacturer shall compile a schedule showing date and duration when important production operations and key points in production are to take place - Components to be subjected to testing shall be produced strictly in accordance with PID - Components to be tested to relevant testing level - QSA may accept recent valid test data as an alternative - Certification by the ESA/SCC Inspector - Test report to be compiled upon completion of testing - QSA reviews the test report - QSA formally requests the approval of ESA for qualification

Table 4.1 Different phases and activities in ESA/SCC qualification procedure.

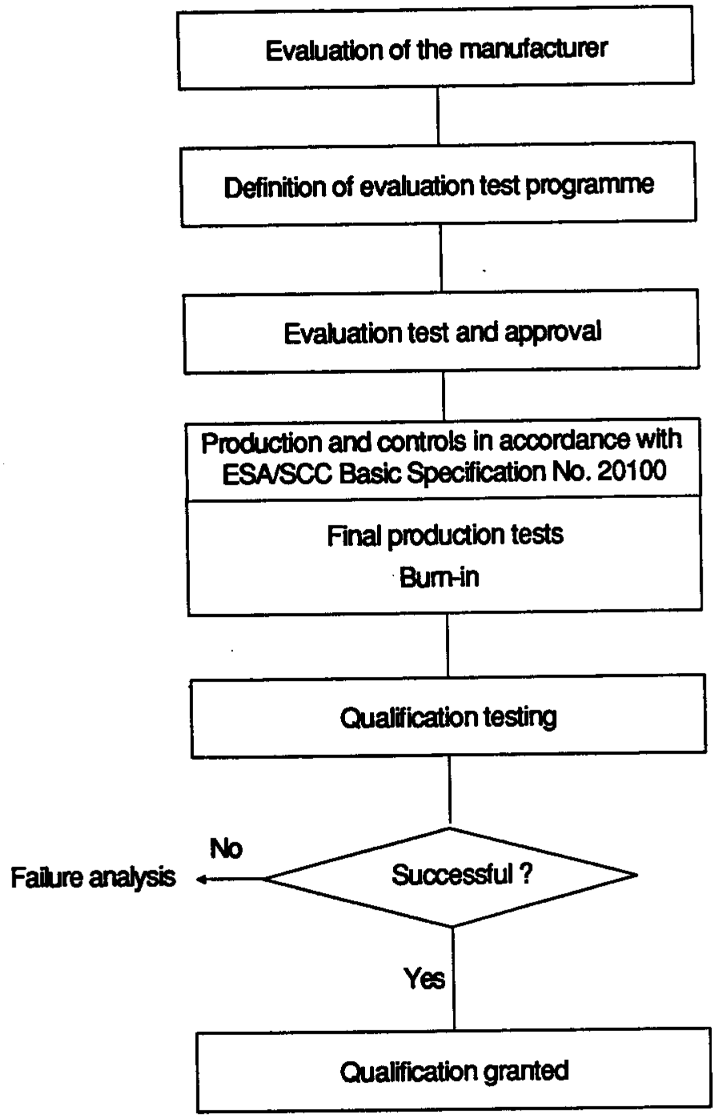

Chart 4.1 The outline of qualification for passive optoelectronics

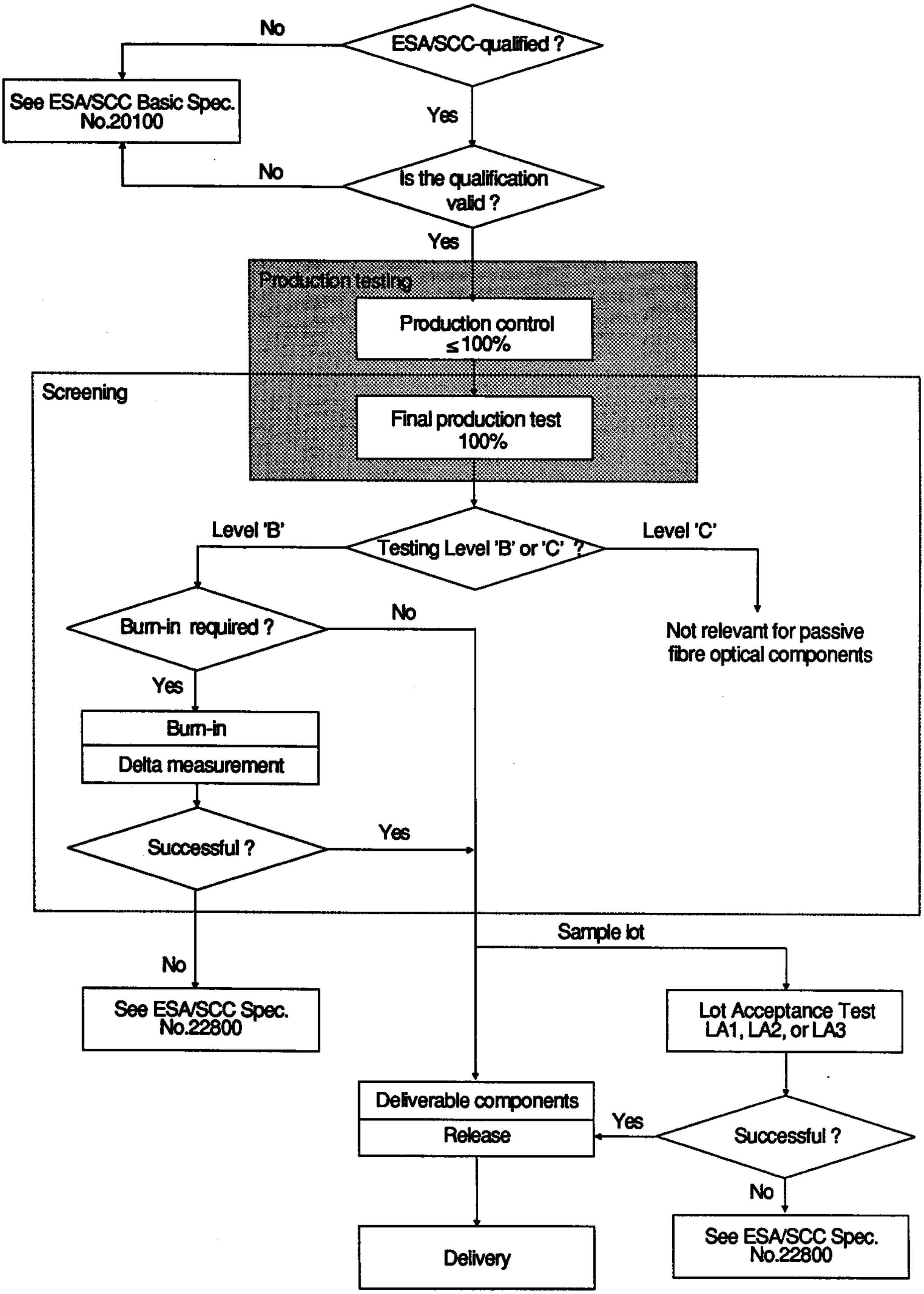

Chart 4.2 The outline of procurement for passive optoelectronics

The quality standards established by SCC describe these tests, analyses and testing levels:

- Evaluation testing
  The purpose of the evaluation testing is to decide in the most cost-effective manner, if there is sufficient justification to proceed to qualification testing of the component for space application, with a high level of confidence in the results. The objective of the testing is to determine the operational limits of the components with respect to critical environmental parameters, to overstress specific characteristics in order to identify failure modes, and to get information which can be of value for a detailed planning of the test programme to be used in the component procurement.

- Production testing
  Production testing comprises 'production control' and 'final production testing'. The purpose of production testing is to ensure that the components are made according to the specification. Final production testing is required to be performed on 100% of components that enter the final production sequence, however, for the testing that forms the production control tests, these can be (-and generally are) performed on a sample basis. Production control testing may be carried out before assembly if this is appropriate. Final production testing is carried out on the components after the manufacturing.

- Destructive physical analysis (DPA)
  DPA is a series of inspections and analyses performed on a sample of components to verify that the material, design and workmanship used for its construction, as well as the construction itself, meet the requirements of the relevant specification and are suitable for intended application. DPA is generally performed by a contractor as the final step of a flight procurement on a small sample of devices so as to check that the component/item is constructed and manufactured to the required quality and to the approved design. A DPA is not performed during all flight components procurements, and is normally only performed on the 'more critical' components. Refer to ESA/PSS 01-60 [A11] paragraph 5.5.2 for further information.

- Screening
  Screening covers/includes both 'final production testing' and 'burn-in testing'. Screening is an 100-percent inspection on component lots, prior to their ultimate application, intended to stabilise their characteristics, and to identify early failures and removing defective parts. Different screening methods may be utilised, e.g. thermal cycling and vibration tests. 'Burn-in' is a screening method commonly used for electronic devices. This method entails exposure of components at elevated temperatures for a certain time.

  Screening may also be performed during evaluation testing phase to determine the suitability of a material for use in a space environment. Refer to ESA PSS-01-704.

  All components to be incorporated into flight-standard hardware shall normally be subjected to screen test in connection with final production testing. Regarding passive optical components, burn-in is considered not applicable.

- Qualification testing
  Qualification testing is part of the qualification programme. The purpose of the qualification testing is to demonstrate, by analysis or test or combination of both, that an item is built to a defined standard and can meet its performance requirements for its specified lifetime under simulated conditions more severe than those expected from ground handling, launch and orbital operations.

The qualification test is to uncover deficiencies in design and method of manufacture. It is not intended to exceed design safety margin or to introduce unrealistic modes of failure. The qualification test programme shall include all tests of relevance not already done in the final production testing. The qualification testing will thus mainly be concerned with mechanical and environmental characteristics.

The test should be performed on specified samples, chosen at random from components which have successfully passed the final production test and burn-in (-if relevant). The qualification testing shall be performed at the manufacturer's premises or at a location approved by ESA.

- Lot Acceptance Tests (LAT)
  LAT is a series of tests performed on a sample selected from the procurement lot to ensure that the lot concerned meets the defined quality requirements. LAT is divided in three levels i.e. LA3, LA2 and LA1.

  The LA3 tests are to be designated as Quality Assurance subgroup and comprise tests to prove the assembly capability of the component. LA3 testing shall be performed by the manufacturer's QA personnel using dedicated quality assurance equipment whenever possible. In instances when the tests for LA3 are considered to be non-destructive, components so tested may form part of the delivery lot. In other case when LA3 may be considered as destructive testing, the components tested shall not form part of the delivery lot.

  The LA2 tests shall comprise the tests of LA3 plus tests on optoelectronic and endurance subgroup. For optoelectronic and endurance subgroup the following shall apply: The tests in this Subgroup are considered to be destructive and therefore components of testing shall not form part of the delivery lot.

  The LA1 testing shall comprise tests for LA3 and LA2 plus tests on environmental and mechanical subgroup. For the environmental subgroup the following shall apply: The tests in this subgroup are considered to be destructive and therefore components tested shall not form part of the delivery lot.

  All components shall be subject to Lot Acceptance Testing as defined in the ESA/SCC specifications. If LA1 has not been carried out within the previous 24 months, then LA1 shall be performed. If neither LA1 nor LA2 has been carried out within the previous 12 months, then LA2 shall be performed. In other instances, LA3 shall be performed.

- Testing levels
  Two testing levels are described by SCC, i.e. Level B and Level C. These test levels are normally associated with a device that undergo a burn-in with (for Level B) or without (for Level C) delta measurements. For Level B, all data shall refer to the relevant serial numbers. For Level C, a test result summary, (i.e. the total number of components subjected to, and the total number rejected from, each of the tests and inspections) shall be provided. Only Level B is relevant for passive optoelectronic components.

Table 4.2 shows the different tests, test levels and content of each test. For further detailed information refer to [A11].

Test	Level	Content	Destructive	Remarks
Evaluation		-Environmental -Mechanical -Endurance -Quality Assurance	Yes	
Production control		-Quality Assurance	No	
Screening (incl. final production testing and 'burn-in')		-Environmental -Mechanical -Endurance -Quality Assurance	No	'Burn-in' with or without delta measurement
Qualification		-Environmental -Mechanical -Endurance	Yes	
Lot Acceptance	LA1	-Environmental -Mechanical -Endurance -Quality Assurance	Yes	
	LA2	-Endurance -Quality Assurance	Yes	
	LA3	-Quality Assurance -Inspection	Yes	

Table 4.2 Component evaluation and approval programmes, and levels.

The test strategies for the various components are described in Chapters 5 through 15. The test programme include evaluation testing, production testing, qualification testing and lot acceptance testing. For each type of testing a detailed set of tests including the test sequence is described and justified. Geometrical, optical, mechanical and environmental characteristics are covered. All test methods are tabulated and described in Part 3.

It should be noted that the proposed test programmes for the various passive optoelectronic components include tests for a wide scope of mechanical and environmental loads. Some of the tests are of interest only for certain applications. Hence it may be cost-effective to adjust the scope of the test programme to the specific application of the component in question.

4.3 Materials

In a space environment the components are exposed to different influences such as heat, pressure, radiation, gases, vibrations. These influences control chemical and physical processes affecting the materials of the components, and can cause permanent and temporary changes to the material itself. Such changes may have an adverse impact on the system, although useful effects may occur.

Before a material can be used in space systems and associated equipment, it must be approved by ESA. The evaluation on non-space proven materials is dealt with in the ESA specification

PSS-01-70/-700 where the main tests which should be considered when developing an evaluation programme are listed. Reference is also made to the document 'Materials Evaluation at ESTEC/ESA' [8]. In the latter document a three level evaluation programme is described, i.e. screening tests, short duration and long duration. The material under test shall pass to the next level of the programme only if it has satisfied the conditions of the previous level.

The evaluation of materials includes also combination of materials, accessories used in the fabrication and installation. Examples are thermal coatings and films, coatings, adhesives tapes, primers and surface protection treatments, glues, and solderness/mechanical electrical techniques.

The purpose of the evaluation is to verify that the material is fundamentally suitable for intended use, i.e. is able to withstand the environmental strains and has no harmful effect on other components or systems.

The tests, measurements and analyses that could be relevant to materials of passive fibre optical components have been listed in Table 4.3. The tests which should be carried out for particular material will depend on the application.

Test, measurement, analysis	Reference	Remark
Thermal vacuum test	PSS-01-702	
Flammability test	PSS-01-721 and NASA NHB 8060-1B	
Outgassing test	PSS-01-702	
Offgassing and toxic analysis	PSS-01-729 and NASA NHB 8060-1B	
Resistance to microbial growth	PSS-01-7xx	
Chemical spray or clean test		Spray with isopropyl alcohol
Humidity test		7 days at 50°C, 95% RH
Thermal cycling test	PSS-01-704	
Thermal shock test		Transfer samples 10x from oven at 50°C to liquid N_2
Adhesion test	PSS-01-713	
Particles and UV radiation test	PSS-01-706	
'Red plague' corrosion test	PSS-01-720	
Mechanical test	PSS-01-745/-746	
Chemical resistance test		
Charging test	PSS-01-743	
Atomic oxygen test	PSS-01-7xx	

Table 4.3 Test, measurement and analysis of a material

4.4 Environmental conditions

Table 4.4 shows the maximum anticipated severities for some parameters. A list of all essential parameters have been given in Part 1. The values given below have been used as a minimum/maximum reference for severities in the evaluation tests for the various components specified in the succeeding chapters. For an actual application the parameter values may even exceed the listed values.

Parameter	Value	Remark
Temperature, - max/min: M - gradient: G - inside: I - outside: O	MI:-30 to +70°C [R25] MO:-55 to +125°C GO:$\Delta T/\Delta t=0.4$°C/s GO:$\Delta T/\Delta L=20$°C/m near equipment GO:$\Delta T/\Delta L=5$°C/m for other locations [A6]	
Vibration	Peak acceleration: 20 g Frequency: 100-2000 Hz Cross-over: 50 Hz [A1]	Test: MIL-STD-750, No.2056
Shock	Peak acceleration.:1500 g Pulse duration.: 0.5 ms No. of shocks: 5 [A1]	Test: MIL-STD-750, No.2016.2
Pressure - Rapid depress.: - Vacuum: - Vacuum (thermal):	 1 atm to 5 Torr in less than 5 s [A1] 10^{-10} Torr [R25] 10^{-5} Torr [R25]	
Radiation (nuclear) *-Polar orbit* Unshielded Ionisation dose: Neutron fluence: Shielded (2mm Al) Ionisation dose: Neutron fluence: *-USS orbit* Unshielded Ionisation dose: Neutron fluence: Shielded (2mm Al) Ionisation dose: Neutron fluence:	 $5\text{x}10^{5}$ rad/yr $6\text{x}10^{12}$ n/cm^2/yr $6\text{x}10^{3}$ rad/yr $4\text{x}10^{11}$ n/cm^2/yr $3\text{x}10^{5}$ rad/yr $4\text{x}10^{11}$ n/cm^2/yr $4\text{x}10^{3}$ rad/yr $1\text{x}10^{11}$ n/cm^2/yr [A1]	

Table 4.4 Maximum anticipated severities for environmental parameters

4.5 Control group

In the evaluation testing a control group is often used to ensure that the measurement equipment and procedures are not undergoing changes during a particular test. When measurement is made on samples under test, the samples from the control group are also measured at the same time using the same equipment and measurement procedure.

In the evaluation test programmes proposed for the various fibre optic components the use of a control group is appropriate only for a limited number of tests. In some of the tests one makes measurement of various component properties before and after the component has been subjected to a certain stress. In such a case the use of a control group can be of value. However, in many of the tests the transmitted power through the component is measured while the component is being stressed. The purpose of the test being to determine change in transmitted power (and thus loss) as a function of load. In such a case some means should be provided to ensure the stability of the source. Alternatively a reference channel can be established by using a branching device to monitor the source output. The reference channel may include an unstressed sample of the component under test.

In those cases where the use of a control group is recommended, this will be stated in the test description.

5. OPTICAL FIBRES

5.1 Introduction

There are many types of optical fibres. The main difference between the various types is with respect to optical and geometrical characteristics and materials. The test strategies to be discussed in this chapter will in general pertain to all fibre types, but some properties and corresponding tests are of relevance only to certain fibre types. This will be noted in the text, as appropriate.

It is common usage that the term optical fibre encompasses the actual fibre and the primary coating or buffer. This usage will also be employed here.

It is assumed that in space applications the fibre will be enclosed in a cable structure. The fibre will thus be protected against some mechanical and environmental loads. The main proposed test programmes are applicable to fibres assumed to be used in a cable. However, for completeness tests applicable to fibres to be used uncabled have also been included. The character and sequence of these latter tests will, however, not be discussed in any great detail.

The general test strategy for all fibre optic components has been described in Chapter 4 and will also be followed here. Each test method has been given a number, and these numbers are tabulated and described in Part 3 Chapter 5.

5.2 Evaluation testing

5.2.1 Purpose

The purpose of the evaluation testing is to determine the operational limits of the optical fibre with respect to critical environmental parameters, to overstress specific characteristics in order to identify failure modes, to demonstrate the suitability of the fibre for proceeding on to qualification testing, and to get information which can be of value for a detailed planning of the test programme to be used in the procurement of the fibre.

5.2.2 Properties to evaluate

The main properties of interest to include in the evaluation testing are:

- strippability
- tensile strength
- macrobend losses
- microbend losses
- effects of high and low temperature
- effects of vacuum operation
- effects of ionizing radiation

For fibres which are not intended to be protected in a cable additional tests can be necessary with respect to:

- abrasion
- crush
- impact
- torsion
- flexing

- snatch
- kink
- solar radiation including UV radiation

Finally, for some special applications the optical power handling capability of the fibre is of importance.

Coatings and buffers should be made from space qualified materials, see Chapter 4. However, an evaluation of their properties when applied to the fibre is still considered necessary to ensure that unexpected problems do not occur. One difficulty in the testing of the materials could be to simulate the curing conditions experienced by the coatings when applied to the fibre in the production process. Further, the material tests do not take into account possible interactions between the coating/buffer and the actual fibre.

In the following a more detailed discussion is given regarding why these properties are of concern.

5.2.2.1 Strippability

Primary coating and buffer must be removed when the fibre is to be spliced or connectorized. The ease by which the coating can be removed without causing damage to the fibre surface is of considerable importance during installation and repair work.

5.2.2.2 Tensile strength

Optical fibres intended for space applications will very likely be made from fused silica. Fused silica has a very high inert strength, but in practice the tensile strength is determined by surface flaws [1]. The density and type of flaws can vary along the fibre giving a corresponding variation in tensile strength. The magnitude and distribution of tensile strength should thus be determined. In addition, the data are needed to calculate the probability of fibre breakage when the fibre is subjected to a certain tensile load versus time [2,3].

It should be realised that fused silica does not suffer plastic flow under tensile stress, but will elongate elastically until break.

5.2.2.3 Macrobend losses

If a fibre is bent, some of the propagating power will be lost. The loss increases with decreasing radius of curvature. Theoretical models exist for estimating the fibre loss as a function of radius of curvature. But for multimode fibres in particular the models are not very practical, and an accurate determination should be made experimentally. The results are of interest for the cable design and for the shape and size of splice enclosures where one usually will store spare fibre lengths in a coil.

5.2.2.4 Microbend losses

A fibre will suffer microbend losses when it is subjected to a spectrum of small perturbations such as f.inst. if the fibre is pressed against a rough surface. This can happen in a cable, and one therefore prefers a fibre which exhibit small microbend losses. The microbend losses experienced in a particular case will depend on both the fibre and coating properties.

5.2.2.5 Temperature effects

For fused silica and other glass fibres the glass material itself should not be affected at the operating temperatures in question, see Chapter 4. For these fibres the main concern is the effects of high and low temperature and of ageing on the fibre coating and buffer. Due to difference in thermal expansion coefficient between the fibre itself and the coating, microbend losses may be induced at high and low temperatures. The coating can also be expected to be damaged at high temperatures affecting the mechanical properties of the fibre. For plastic fibres also the fibre material itself will have a rather limited temperature range. Plastic fibres will, however, probably not be used in space due to their high susceptibility to radiation induced optical and mechanical damage [4].

5.2.2.6 Vacuum operation

The main concern is that vacuum operation can cause damage or changes in the fibre coating which then indirectly can affect fibre loss and mechanical properties. Operation in vacuum will not affect the glass material itself.

5.2.2.7 Ionizing radiation

In space applications fibres can be exposed to high levels of ionizing radiation which will induce losses in the fibre. The refractive index profile may also be affected causing a change in such properties as bandwidth, numerical aperture, mode field diameter etc. Finally, the fibre coating may be changed, and this may affect the mechanical properties of the fibre.

This topic was discussed at length in the Part 1. It was pointed out that the induced effects are highly fibre dependent. Each fibre type being considered and also fibres of nominally the same type, but from different manufacturers, should be subjected to evaluation testing.

5.2.2.8 Abrasion, crush, impact, torsion, flexing, snatch, kink

If the fibre is enclosed in a cable, the cable structure will protect the fibre from these types of loads. It is therefore common to subject the cable and not the fibre to tests with regard to these properties. However, if the uncabled fibre is known or expected to suffer loads of this type, an evaluation test programme should be carried out.

5.2.2.9 Solar radiation, UV radiation

For fibres enclosed in a cable, the fibres will be shielded from solar radiation in the IR, visible and UV range. If a fibre is used uncabled, solar radiation in the IR and visible could effect coating properties. UV radiation in the 200 nm range can induce losses similar to that of ionizing radiation [5], and UV radiation can also affect the coating.

5.2.2.10 Optical power handling capability

There are four types of phenomena which possibly can limit the power handling capability of an optical fibre:

- heating due to the absorbed power
- radiation induced colour centres which will cause loss
- various non-linear optical effects
- formation of cracks, pits etc.

Fibre optic communication systems generally operate at wavelengths with low loss and at power levels of the order of 1 mW or less. In such cases none of the above phenomena are of concern.

However, there are some applications where a fibre may carry high power. One example would be that the fibre is used as an optical power conductor. Another example is a communication system where a high power transmitter is used to achieve long range. Even for such cases the heating effect is very small. As an example we can consider a fibre with a loss of 5 dB/km transmitting 1 W optical power. Assuming as a worst case that all lost power is absorbed and that only radiative losses are present, it can be shown that for this case the temperature increase is less than 1°C.

Formation of colour centres can occur if the transmitted power is in the UV range. For very high power levels colour centres can also be formed by multiphoton absorption.

The non-linear effects are of main concern [6,7]. Such effects can cause changes in the refractive index and thus distort the transmitted signal. Other non-linear effects can cause part of the transmitted power to be shifted to other wavelengths. Examples of the latter effects are stimulated Raman and Brillouin scattering. It should be noted that the non-linear effects usually are dependent on the spectral character of the optical signal and the fibre length. The evaluation testing should therefore be done with a representative source and fibre length.

At very high intensities the glass can be damaged due to heating of inclusions or dielectric breakdown which can cause formation of cracks and pits in the glass. For fused silica the damage threshold is of the order of 10^{10} W/cm^2, but it is somewhat dependent on material quality [6]. Damage may, however, also be caused at lower intensities due to stimulated Brillouin scattering [7].

5.2.3 Sample distribution and test programme sequence

5.2.3.1 Sample distribution

It is expected that the length of fibre which will be procured for a certain space vehicle will be somewhat limited (maximum a few km). The number of fibre lengths to be tested will reflect this fact.

Number of fibre lengths: 3 for test purposes, 1 for control purposes
Length of each fibre: 2300 m

The three lengths for test purposes should come from three different preforms to get a picture of the variation in properties from preform to preform. The preforms should be selected at random from a representative production lot of at least 6 preforms. The length for control purposes can come from any of the same three preforms or a separate preform.

The needed fibre length will depend on the extent of tests deemed necessary for the intended application. A length of 2.3 km is regarded to be sufficient to carry out the complete evaluation test programme.

To carry out the actual evaluation tests samples of various lengths (a few m to ca 200 m) will be cut from each fibre length.

Generally, it is recommended to increase a load until the fibre has suffered physical destruction or a substantial deterioration in performance, as appropriate. However, in the environmental tests the test levels have been limited to the most severe loads expected, (see Chapter 4) with a suitable margin. If more severe loads are expected, the test levels should be increased accordingly.

Since all tests are or can be destructive, new samples will be needed for each test.

All results should be recorded. One should keep track of from which fibre length each sample is taken and assign the results to the appropriate sample.

5.2.3.2 Test programme sequence

The specified tests are summarised in Chart. 5, see end of Chapter. The test shown inside the dotted box under mechanical measurements and the tests with respect to solar and UV radiation are only recommended in case the fibre is to be used uncabled. The test for optical power is also shown inside a dotted box to indicate that this test is necessary only for the special case that the fibre will be used for transmitting high power.

The initial measurements are all optical measurements and will thus have no effects on the properties of the test fibres. There is thus no recommended order as far as making a proper determination of the initial fibre properties. The indicated order is based on the importance of the various properties. The OTDR measurement is done first to establish both the uniformity and magnitude of the fibre loss. The uniformity is of importance since samples will later be cut from each fibre for the various measurements. The spectral loss, bandwidth and coating dimensions are of interest for all fibre types. The remaining properties of numerical aperture, cut-off wavelength, mode field diameter, polarization cross-coupling and beat length are of relevance only for certain fibre types.

For the actual evaluation tests new samples will be used for each test, since all tests can be destructive, see 5.2.3.1. Further, by doing tests on new samples the effects of a specific load can more easily be discerned. Since new samples are used, the test order is of no importance for the test results. It is generally recommended that those tests which are considered easiest and the least expensive to perform are done first and the more complicated and expensive tests are done at the end. Should the fibre not show satisfactory results in the more simple tests, the test programme can be stopped before a large expense has been incurred.

It is recommended that the mechanical tests are done first. These tests are relatively simple to do, but the mechanical properties are of considerable importance with respect to the fibre's handling and cabling capability. The main mechanical properties to evaluate are the strippability and the tensile strength of the fibre. The strippability test is listed first since it is the easiest to do.
The tensile strength will also be measured after several of the environmental tests (post test investigations) to determine if any change in strength has occurred due to the environmental load.

As noted earlier, mechanical characteristics with respect to abrasion, crush, impact, torsion, flexing, snatch and kink are of interest only if the fibre is to be used uncabled. This is regarded as unlikely, but the tests are listed for completeness.

The tests for macro- and microbending loss are also fairly simple to do. These properties are of importance with respect to cable design and for how small bend radii one can use without suffering losses. (The mechanical bend properties can be evaluated from the tensile strength tests).

The environmental tests are generally more complicated and expensive to do requiring special chambers and test facilities. The simplest tests to do are the high/low temperature test and the ageing test requiring only a temperature chamber. The ageing test is listed after the temperature test since the test results from the latter may be required for setting the test parameters in the ageing test.

The vacuum test is somewhat more complicated to do requiring a heated vacuum chamber. The most complicated test to perform is the one for the effects of ionizing radiation. The test shall be done at high radiation levels (5 rad(Si)/s) and at both room temperature and -55 °C. The sensitivity to radiation induced losses is a very key property for a fibre to be used in space. One could therefore argue that the test be done earlier in the test sequence. The test is, however, quite complicated and expensive to perform, and it seems advisable to ensure that the fibre can meet the various other requirements, which are much easier to evaluate, before starting investigating the effects of ionizing radiation.

The optical power handling test is only of interest for special applications. It may require a laser of the same type as in the actual application, see 5.2.2.10.

The tests for solar and UV radiation are only applicable if the fibre is to be used uncabled. This is not very likely.

5.2.3.3 Use of control group

The use of a control group can be of value in some cases.

In some of the tests measurements are made of various fibre properties before and after the fibre has been subjected to a certain load. To ensure that the measurement equipment and procedures have not been changed between the two measurements, it is recommended that a control group is used where appropriate. This is a fibre which is kept at room temperature and whose properties is assumed unchanged. Samples are taken from this fibre for the various control measurements.

In many of the tests the transmitted power is measured while the fibre is being stressed. In this case some means should be provided to ensure stability of the source, or the source output should be monitored.

5.2.4 Inspection

The purpose of the inspection is to make sure that the samples are suited for testing. All samples should be inspected.

5.2.4.1 Visual inspection

The inspection should be carried out in accordance with ESA/SCC Basic Specifications No. 20500. Of special importance is to ensure that there is good access to both fibre ends since this is necessary for many of the initial measurements.

5.2.4.2 Marking

All samples must be marked in accordance with the standard procedure of the manufacturer in such a way that the preform from which a fibre is made, can be identified. The requirements stated in 5.2.3. The length of the fibre shall be indicated on the spool.

5.2.5 Initial measurements

The purpose of the initial measurements is to determine the actual value of the various optical properties. These values will be used as baseline data for the later measurements. Further, one wants to ascertain that the various samples actually meet the specified requirements, and one gets a picture of the spread in values. This is of particular interest for those properties where the requirement is that the value shall be above a certain figure (f.inst. bandwidth) or below a certain figure (f.inst. loss). The spread in values gives an indication of how well the production process is controlled.

The initial measurements should be done on all samples. Most of the measurements require that short fibre lengths be cut from the total length. One must keep records of all the lengths removed so as to know the remaining length on the spool.

5.2.5.1 OTDR measurement

To ensure that the fibre loss is uniform along the fibre an OTDR (optical time domain reflectometry) measurement should be made on each of the complete fibre lengths. The measurement is of importance since we later are going to compare attenuation measurements made on short samples with the data from measurements made on the complete length. Provided the group velocity of the fibre is known, the fibre length can also be checked.
Test method: 5.2.3

5.2.5.2 Spectral loss measurement

The measurement should be done over the typical operating wavelength range of the fibre and on the complete fibre length. A similar measurement will be done after the fibre has been exposed to ionizing radiation.
Test method: 5.2.1.

5.2.5.3 Bandwidth

The bandwidth should be measured at the operating wavelength.
Test method: 5.2.4 or 5.2.5, for multimode fibres.Test method 5.2.6 for singlemode fibres.

5.2.5.4 Coating dimensions

The test is mainly done so as to be able to compare coating dimensions before and after the temperature test, vacuum test and test with ionizing radiation. But it also allows a check to be made of coating dimensions and uniformity of coating. The measurement should be done on 3 samples from each end of each fibre length. Each sample should be taken from locations at least one meter apart.
Test method: 5.1.8 or 5.1.9.

5.2.5.5 Numerical aperture

The numerical aperture (NA) should be measured at the operating wavelength. The test is relevant only for multimode fibres.
Test method: 5.2.12.

5.2.5.6 Cut-off wavelength

The test is only relevant for singlemode fibres.
Test method: 5.2.13.

5.2.5.7 Mode field diameter

The test is only relevant for singlemode fibres. It should be done at the operating wavelength.
Test method: 5.2.14.

5.2.5.8 Polarization cross-coupling

The test is relevant only for single mode polarization maintaining fibres. It should be done at the operating wavelength.
Test method: 5.2.10.

5.2.5.9 Beat length

The test is relevant only for birefringent single mode fibres. It should be done at the operating wavelength.
Test method: 5.2.11

5.2.6 Mechanical measurements

The main mechanical properties to test are the tensile strength of the fibre and the strippability. Mechanical characteristics with respect to abrasion, crush, impact, torsion, flexing, snatch and kink should be included in the evaluation testing only if the fibre is to used uncabled.

5.2.6.1 Strippability

The manufacturer shall recommend a method for removing the fibre coating, either a mechanical or chemical technique. Due to the expected spread in values the coating shall be removed on at least 4 fibre samples taken from each of the three fibre lengths. For mechanical removal the stripping force shall be measured. Any fibre breakage shall be noted.
Test method: 5.3.4

5.2.6.2 Tensile strength

Twenty samples should be selected from each of the three fibre lengths. Each test sample must be long enough to allow approximately 1 meter free length in the test set-up. The sample should be tested at a strain rate of approximately 2% per minute. Each sample shall be tested to break. The results should preferably be plotted in a so-called Weibull diagram [2]. The number of samples has been chosen so as to allow such a diagram to be plotted in a meaningful way.
Test method: 5.3.1

5.2.6.3 Abrasion

In this test a short section of fibre is kept under tension while subjected to a stream of abrasive powder until break.

Number of samples:	Six. Two from each of the three lengths.
Sample length:	A few meters.
Duration of powder streams:	Until break
Test method:	5.3.5

5.2.6.4 Crush

Number of samples: Six. Two from each of the three lengths.

Sample length: A few meters
Starting load: Specified value
Duration: 1 minute
Step increase in load: 20% of specified value
Continue load increase until break.
Test method: 5.3.6

5.2.6.5 Impact

Number of samples: Six. Two from each of the three lengths.
Sample lengths: A few meters
Starting energy: Specified level
Number of impacts per energy level: 5 or until break
Increase in energy per step: 20% of specified level
Test method 5.3.7

5.3.6.6 Torsion

Number of samples: Six. Two from each of the three lengths
Samples length: Test length 1 meter plus needed length for fastening
Load: 1N or as specified
Number of cycles
(clockwise and anti-clockwise): to break, max 100 or twice specified value which ever is higher.
Test method 5.3.8

5.2.6.7 Flexing

Number of samples: Six. Two from each of the three lengths
Sample length: A few meters
Pulley diameter: 100 mm
Load: 1N or as specified
Carrier speed: 10 cycles per min
Number of cycles: To break, max 100 or twice specified value which ever is higher
Test method 5.3.9

5.2.6.8 Snatch

Number of samples: Six. Two from each of the three lengths
Starting weight: As specified
Number of cycles per weight: 10 or to break
Weight increase per step: 20% of starting weight
Test method 5.3.10

5.2.6.9 Kink

Number of samples: Six. Two from each of the three lengths
Sample length: Approximately 50 cm
Decrease diameter of loop until kink (break) is formed
Test method: 5.3.11

5.2.7 Bending sensitivity

There are two tests, one for so-called macrobending and one for so-called microbending, see 5.2.2.

5.2.7.1 Macrobending

The purpose of this test is to determine loss versus bend radius. Typically a suitable fibre length is wound on a cylinder and the induced loss measured versus number of turns. This measurement is done for various cylinder diameters.

Number of samples: One from each of the three fibre lengths
Sample length: 50 m
Smallest cylinder diameter: Sufficient to give a loss of 100 dB/km
Wavelength: Anticipated operational wavelength
Test method: 5.2.15

5.2.7.2 Microbending

The purpose of the test is to determine the fibre's susceptibility to microbend losses. However, it should be realised that the test gives only a qualitative picture in this respect. The data can with some care be used to make a qualitative comparison between various fibres with regard to losses which may be induced in a cable f.inst. at high temperatures. The test is performed by placing a suitable fibre length between two plates covered with sandpaper, and the induced loss versus applied load is measured. Due to expected spread in results, at least three samples from each fibre length should be used.

Number of samples: Three from each of the three fibre lengths
Sample length: 5 m
Max. load: Until fibre breakage or severe damage to coating
Test method: 5.2.16

5.2.8 High and low temperature test

The purpose of this test is to determine the highest and lowest temperature for short term exposure. The optical transmission at the anticipated operational wavelength will be monitored during the tests.

5.2.8.1 Temperature test

Number of samples: One from each of the three fibre lengths
Fibre length: 200 m
Thermal cycle: First low, then high temperature
Low starting temperature: Lowest specified operating temperature or -40°C if not given
Low temperature: Sufficient to give an induced loss of 2 dB/km, but not lower than -70°C
High starting temperature: Highest specified long term operating temperature or +90°C if not given.
High temperature: Sufficient to give an induced loss of 2 dB/km or severe damage to coating, but not above 150°C
Step change in temperature: 10°C
Duration of stay at each temperature: 1 hour
Test method: 5.4.1

5.2.8.2 Post test investigation:

Visual inspection
Coating diameter (2 samples from each end)
Test method: 5.1.8 or 5.1.9

5.2.9 Ageing

It is expected that it is mainly the coating which will be affected by ageing, but change in coating properties can indirectly affect transmission loss and mechanical strength. The optical transmission shall be continuously monitored during the test at the anticipated operational wavelength.

5.2.9.1 Ageing test

Number of samples:	One from each of the three fibre lengths
Fibre length:	200 m
Temperature:	20°C above specified operational temperature, but at least 10°C below high temperature limit established in 5.2.8
Duration:	Until induced loss has reached 2dB/km or coating is severely damaged. But maximum duration 1000 hours.

Test method: 5.4.6

5.2.9.2 Post test investigation

Visual inspection.
Coating diameter (two samples from each fibre end). Test method 5.1.8 or 5.1.9.
Tensile strength. Repeat of measurement in 5.2.6.2

5.2.10 Vacuum test

It is expected that it is mainly the coating which will be affected by operation in vacuum. The coating materials should be space qualified (see Chapter 4), and the purpose of the test is to ensure that no unexpected problems will come up. The optical transmission loss will only be measured after the test since one would expect any vacuum induced loss to be permanent. In addition, a check will be made to look for changes in tensile strength. The test conditions are similar to that used in the vacuum test of materials, see PSS-01-702.

5.2.10.1 Vacuum test

Number of samples:	One from each of the three fibre lengths
Fibre length:	200 m
Vacuum:	10^{-3} Pa or less
Temperature:	125°C
Duration:	24 hours
Test method:	5.4.2

5.2.10.2 Post test investigation:

Visual inspection.
Coating diameter (two samples from each fibre end). Test method 5.1.8 or 5.1.9
Fibre attenuation including control fibre.
Test method: 5.2.1, 5.2.2 or 5.2.3

Tensile strength.	Repeat of measurement in 5.2.6.2

5.2.11 Effects of ionizing radiation

The ionizing radiation will mainly affect the fibre loss. However, it may also affect the refractive index distribution resulting in changes in optical properties such as bandwidth, numerical aperture, cut-off wavelength etc. If the coating is affected, the mechanical properties of the fibre could also be changed.

The test is carried out by exposing the samples to ionizing radiation (^{60}Co) while monitoring the induced loss. The induced loss is dependent on temperature and on the optical power being transmitted (photobleaching). Tests should therefore be done at normal room temperature and a low temperature (f.inst. -55°C) where the loss is expected to be higher. Further, the test should include samples with continuous transmission of optical power and samples with no transmitted power except during the periodic measurements of induced loss. Optical and mechanical tests will also be made on the samples after exposure.

The proposed dose rate corresponds to the maximum rate recommended in SCC Basic Specification 22900. The maximum dose of 3 Mrad corresponds to ca 1 week exposure. The highest expected dose rate according to Chapter 4 is 0.5 Mrad/year.

5.2.11.1 Radiation induced loss, room temperature

Number of samples:	2 samples from each of the three fibre lengths
Sample length:	200 m
Temperature.	Room temperature
Optical power:	One sample from each length with an incident power of approximately 1µW. One sample from each length with power transmission only during the periodic measurements.
Wavelength:	Expected operational wavelength
Dose rate:	5 rad(Si)/s
Duration:	The irradiation should last until a) The induced loss is 100 dB/km or b) The induced loss has reached saturation. In such a case the irradiation should continue until the total dose has reached 10 x saturation level or c) The total dose has reached 3 Mrad
Test method:	5.4.5

5.2.11.2 Post irradiation tests, room temperature exposure

To determine the possible effects of the ionizing radiation a number of measurements should be done on the exposed samples. The results of these measurements are to be compared with the initial measurements, see 5.2.5. It is important that the measurements are made quickly to reduce thermal deexcitation.

The following tests should be done on all samples and control fibre immediately after the radiation test has been completed:

Spectral loss measurement see 5.2.5.2
Bandwidth, see 5.2.5.3

One of the sample lengths from 5.2.11.1 where power has been transmitted only periodically shall be used for studying the thermal deexcitation. The sample shall be left at room temperature, and the transmission loss measured periodically over a sufficient period to estimate the decay rate. With knowledge of the induced loss due to a short-term exposure of a certain dose and the decay rate, one can estimate the induced loss due to a long term exposure of the same dose.

One sample shall be taken from each end of the remaining 5 samples lengths from 5.2.11.1 and from control fibre and measurements made as appropriate of:

Coating dimensions,	see 5.2.5.4
Numerical aperture,	see 5.2.5.5
Cut-off wavelength,	see 5.2.5.6
Mode field diameter,	see 5.2.5.7
Polarization cross coupling,	see 5.2.5.8
Beat length,	see 5.2.5.9

Tensile strength measurements should be done on remaining lengths of the three samples which had an incident power of 1µW. Test procedure as in 5.2.6.2

5.2.11.3 Radiation induced loss, low temperature

This is a repeat of 5.2.11.1, but the test shall be done at ca - 55°C. Otherwise the test conditions are the same. The test temperature of - 55°C has been chosen since it is both the minimum expected operational temperature and is a typical test temperature in many published works. A comparison with tests performed on other fibres can then more easily be made. New fibre samples must be used.

The purpose of the test is to determine the increase in loss due to the lower temperature. The loss will be larger at lower temperature due to less thermal deexcitation of the radiation induced colour centers.

5.2.11.4 Post irradiation tests, low temperature exposure

It is expected that compared to room temperature exposure it is mainly the optical properties which will be affected by the low temperature.

The following tests should be done as appropriate:

Spectral loss measurement,	see 5.2.5.2
Bandwidth,	see 5.2.5.3
Numerical aperture,	see 5.2.5.5
Cut-off wavelength,	see 5.2.5.6
Mode field diameter,	see 5.2.5.7
Polarization cross coupling,	see 5.2.5.8
Beat length,	see 5.2.5.9

The measurement should be done immediately after the exposure has been completed to minimise effects of thermal deexcitation. Measurements should be made on all samples and on the control fibre.

5.2.12 Optical power handling capability

It was pointed out in 5.2.2.10 that the optical power handling capability is of no concern for typical fibre optic communication systems operating with a transmitted output of a few mW or less. It was further stated that the main phenomena which can limit the power handling capability are probably various non-linear effects. Such effects can increase the bit-error rate in digital systems and increase noise and cross talk in analog systems. In the worst case the fibre itself may be damaged.

The nonlinear effects depend not only on intensity, but also on fibre length, linewidth of laser and format of signal being transmitted. The evaluation testing of the fibre should therefore be done under conditions which are representative for the application.

5.2.12.1 Test for optical power handling capability

Number of samples:	one from each of the three fibre lengths
Fibre length:	representative for the application
Laser source:	same type as the one in the intended application.

Input power level should be increased in steps and measurements made of

- output power versus input power
- spectral character of output signal
- bit-error rate/signal to noise ratio of signal (if applicable)

The entrance and exit surfaces should also be examined for damage.

Maximum input power which can be used will very likely in practice be limited by the available source.

Test method: 5.2.17.

5.2.13 Solar radiation including UV radiation

As noted in 5.2.2.9 the fibre will be exposed to solar radiation in the IR, visible and UV only if uncabled. Further, even an uncabled fibre would very likely be shielded from solar radiation by some enclosure and at least the walls of the space craft. However, if it is expected that the fibre itself will be exposed to solar radiation, tests should be done to evaluate its properties in this respect.

Two tests are proposed, one for solar radiation which covers the IR and visible range, and one for the UV range.

The optical transmission shall be continuously monitored during the test at the operational wavelength.

5.2.13.1 Solar radiation test

Number of samples:	one from each of the three fibre lengths
Fibre length:	200 m
Temperature:	room temperature
Radiation source:	source with representative spectral output

Duration:	until induced loss has increased to 2 dB/km or visible damage to coating or twice specified dose
Test method:	5.4.3

5.2.13.2 Post irradiation tests

Visual inspection.
Coating diameter (two samples from each fibre end). Test method 5.1.8 or 5.1.9.

5.2.13.3 UV radiation test

Number of samples:	one from each of the three fibre lengths
Temperature:	room temperature
Radiation source:	representative UV source
Transmitted power:	ca 1 µW incident
Duration:	The irradiation should last until a) The induced loss is 100 dB/km or b) The induced loss has reached saturation. In such a case the irradiation should continue until the total dose has reached 10 x saturation level or c) The maximum anticipated total dose has been reached
Test method:	5.4.4

5.2.13.4 Post irradiation test

Visual inspection
Coating diameter (two samples from each fibre end). Test method 5.1.8 or 5.1.9.

5.3 Production testing

5.3.1 Introduction

A number of non-destructive optical measurements can be made on a fibre. It is common practice among the fibre manufacturers that such measurements are made as part of the final production testing to ensure that the fibre meets its specifications. Geometrical properties are partly controlled within some specified limits in the production process and partly measured on samples afterwards. The tensile strength is checked by subjecting the whole fibre length to a specified proof strain at the end of the production process. It is also recommended that the strippability be checked. Although the latter test is destructive it requires only a few short samples to be removed from the produced length.

Non-destructive temperature tests could be done, but are not proposed since the temperature induced effects are mainly related to the material in the primary coating/buffer. Any material connected problems should have been identified and solved in the evaluation phase.

All fibres shall meet the specified requirements.

5.3.2 Production control

The fibre diameter and outer coating diameter shall be controlled within the specified limit during the fibre drawing process.

The whole fibre length shall be subjected to a proof strain of a specified magnitude and duration.

The fibre length shall be measured and the length marked on each spool.

5.3.3 Final production testing

These measurements are to be made on each produced length or on short samples from each length as appropriate. These short lengths will be taken from the production length and will not be delivered. Some of the tests are of relevance only for certain fibre types, as noted. The tests are listed in Chart 5.2. The tests are independent of each other, and the cost of each test does not vary a great deal. The order in which the test are done is thus not critical. The order indicated is based on the importance of the various properties.

The external visual inspection is to ensure that the fibre has no obvious fault and is ready for testing. The first tests listed are for attenuation and bandwidth which are basic properties of the fibre and at the same time give a good indication of the success of the production process. The geometrical properties are then checked. These tests can be done in one test set-up. The remaining optical properties are then measured. As noted before these properties are of relevance only to certain fibre types. Finally, the strippability is measured on samples taken from both fibre ends.

5.3.3.1 External visual inspection

The inspection should be carried out in accordance with ESA/SCC Basic Specification No. 20500. Of special importance is to ensure that there is a good access to both fibre ends since this is necessary for many of the initial measurements.

5.3.3.2 Attenuation

Measurement to be made on the whole length and at the specified wavelength(s).
Test method: 5.2.1 or 5.2.2 or 5.2.3

5.3.3.3 Bandwidth

Measurement to be made on the whole length at the operating wavelength(s)
Test method: 5.2.4 or 5.2.5 for multimode fibre
Test method: 5.2.6 for singlemode fibre

5.3.3.4 Core diameter

Measurement to be made on samples from both ends. Multimode fibres only.
Test method: 5.1.1 or 5.1.2 or 5.1.3

5.3.3.5 Fibre diameter

Measurements to be made on samples from both ends.
Test method: 5.1.4 or 5.1.5 or 5.1.6 or 5.1.7.

5.3.3.6 Concentricity

Measurement to be made on samples from both ends.
Test method: 5.1.14 or 5.1.15 or 5.1.16

5.3.3.7 Non-circularity

Measurement to be made on samples from both ends.
Test method: 5.1.10 or 5.1.11 or 5.1.12 or 5.1.13

5.3.3.8 Coating diameter

Measurements should be done on samples from both ends.
Test method: 5.1.8 or 5.1.9

It can be noted that measurements 5.3.3.4 through 5.3.3.8 can be done by the same test set-up and on the same sample.

5.3.3.9 Numerical aperture

Measurement to be made on samples from both ends at the operating wavelength.
Multimode fibre only.
Test method: 5.2.12

5.3.3.10 Cut-off wavelength

Measurement to be made on sample from both ends. Single mode fibre only.
Test method: 5.2.13

5.3.3.11 Mode field diameter

Measurement to be made on samples from both ends at the operating wavelength. Single mode fibre only.
Test method: 5.2.14

5.3.3.12 Polarization cross-coupling

Measurement to be made on samples from both ends at the operating wavelength. Polarization maintaining fibres only.
Test method: 5.2.10

5.3.3.13 Beat length

Measurement to be made on samples from both ends at the operating wavelength. Single mode, birefringent fibres only.
Test method: 5.2.11

5.3.3.14 Strippability

Measurement to be made on samples from both ends.
Test method: 5.3.4

5.3.3.15 Marking

All lengths to be delivered must be marked in accordance with the standard procedure of the manufacturer. The length of the fibre shall be indicated as well as fibre type.

5.4 'Burn-in'

'Burn-in' is not relevant for optical fibres.

5.5 Qualification testing

The qualification test programme should include all tests of relevance not already done in the final production tests. All geometrical properties and most optical properties have been measured in the final production test. The optical properties not measured are bending sensitivity (macrobend and microbend) and optical power handling capability.

Macrobending and microbending losses are dependent on fibre design (core diameter, refractive index profile). The ease by which microbends can be induced on a fibre is also dependent on coating thickness, stiffness of the coating material and fibre diameter. The optical power handling capability depends on fibre design and fibre material. All these properties are thus related to the nominal design of fibre and coating and were considered in the evaluation testing. Any important deviations from the intended fibre design should have been noted in the final production testing. Core, fibre and coating diameters are measured and deviations in refractive index profile would show up in measurements of bandwidth, numerical aperture or modefield diameter. It therefore does not seem necessary to repeat tests for the bending losses in the qualification testing.

The qualification testing will thus only be concerned with mechanical and environmental characteristics. The tests shall be performed in accordance with Chart 5.3. As noted in the text some of the tests need only be done if the fibre is intended for special applications. These tests are shown inside a dotted box in Chart 5.3.

In view of the rather limited amount of fibre expected to be procured and the rather extensive evaluation testing done, it is proposed that only three fibre lengths coming from three different preforms be used for the qualification test unless otherwise specified. Approximately 800 m fibre is needed from each preform to carry out the complete test programme. All samples should meet the specified requirements.

5.5.1 Mechanical measurements

The mechanical properties of general interest are those for strippability and tensile strength. The strippability is checked in the final production testing. The tensile strength may be affected by the cleanliness in the fibre drawing area and should thus be checked.

As discussed in 5.2.2.2 and 5.2.6.2 the purpose of the tensile strength test is to determine the magnitude and distribution of the breaking strength, and the purpose of the qualification testing is to ascertain that the fibre meets the specification in this respect. It is proposed to do the tensile test on a fresh fibre. One could consider doing the tensile test after the temperature test, see 5.2.2. The mechanical properties of the fibre itself should not be affected by the temperature test. There could be coating materials whose properties could be changed in such a way during the temperature test as to affect the strength properties. But a coating material having such an effect should have been discovered in the evaluation testing and not be approved. One should also bear in mind that the fibre likely will be subjected to its largest tensile stress during the cable manufacturing process and during installation, and this will be before any long term heating during operation.

As noted before the tests for abrasion, crush, impact, torsion, flexing, snatch and kink shown in the dotted box are only of interest if it is expected that the fibre will be used uncabled. This is considered unlikely, and the tests are listed for completeness.

A test for bending (mechanical properties) has not been included. As noted in 5.2.2.2 fused silica fibres behave as elastic bodies until break. A bending test would thus not give any information in addition to that from the proof test and the tensile strength test. For plastic fibres a bending test would be recommended. Such fibres will, however, not likely be used in space.

5.5.1.1 Tensile strength

This is a test to determine the strength distribution along the fibre. The results can be used to estimate the probability of finding a weak point along a certain fibre length.
At least 10 samples from each end of each fibre length.
Test method: 5.3.1

5.5.1.2 Abrasion

One sample from each end of each fibre length.
Test method: 5.3.5

5.5.1.3 Crush

One sample from each end of each fibre length.
Test method: 5.3.6

5.5.1.4 Impact

One sample from each end of each fibre length.
Test method: 5.3.7

5.5.1.5 Torsion

One sample from each end of each fibre length.
Test method: 5.3.8

5.5.1.6 Flexing

One sample from each end of each fibre length.
Test method: 5.3.9

5.5.1.7 Snatch

One sample from each end of each fibre length.
Test method: 5.3.10

5.5.1.8 Kink

One sample from both ends of each fibre length.
Test method: 5.3.11

5.5.2 Environmental measurements

The important properties to check are effects of temperature and ionizing radiation. As discussed in 5.2.2.5 it is the temperature effects on the coating rather than on the fibre itself which is of concern. Variations in coating thickness and changes in coating properties could make the coated fibre more susceptible to temperature induced losses. It is proposed to do an ageing test followed by a temperature cycling test. The two tests should be done on the same sample so as to increase the accumulated time at high temperature. The ageing test is done first since long term heating may cause shrinkage of the coating and thus make the fibre more susceptible to low temperature induced losses.

The loss induced by ionizing radiation is dependent on many factors some of which might be batch related. Examples of the latter are the fibre drawing conditions (draw temperature, pulling speed, pulling force) and concentration of OH-ions and chlorine which are dependent on details in the preform fabrication process. Skutnik et al [9] have published results on measurements made on fibres made from three lots with the same fabrication parameters. Induced loss for the saturation dose was within 15 ± 3 dB/km for the three lots. Lyons et al [10] have studied in detail how well the draw parameters ought to be controlled. One problem pointed out in this article is the difficulty in making accurate absolute temperature measurements in the draw furnace. This means that a change of furnace or heating element might require some run-in period to arrive at the optimised draw conditions.

It is difficult to know how representative these data are for the fibre(s) which could be considered for a particular space application since the production process varies from fibre type to fibre type and also to some degree from manufacturer to manufacturer. The evaluation testing would give some information about the variation from lot to lot at the manufacturer being evaluated. The information about the lot variation should further be related to the accuracy by which the induced loss need to be known for the particular application. Since the need for a qualification test with respect to ionizing radiation can be dependent on fibre type, fibre fabrication method and applications, it is proposed to include the test in the qualification programme with the provision that the need be evaluated after the evaluation test is completed.

A test for vacuum operation is not included. Behaviour under vacuum operation should be mainly related to the type of materials being used in the primary coating/buffer. These characteristics should have been thoroughly studied in the material and evaluation testing.

Tests for solar and UV radiation are only of interest if the fibre is to be used uncabled and not being shielded by other means from such radiation. The effects of this type of radiation on the coating should mainly be dependent on the coating material(s) and should thus have been sufficiently studied in the material and evaluation testing. A test for solar radiation in the IR and visible in thus not included in the qualification test programme.

Short wavelength UV radiation can, however, induce losses in fibres similar to those from radiation. One might therefore expect that the ionizing radiation test (see 5.5.4.3) where a ^{60}Co source is used, would be a more severe test than one with UV radiation. However, only limited studies have been made of UV-induced losses, and there does not appear to be sufficient experimental data available to be certain of such a conclusion. It is thus proposed to include a UV radiation test. However, data from the evaluation test programme should be used to evaluate if the test is necessary for the fibre in question.

5.5.4.1 Ageing

This is a long term test at a high temperature. The properties to measure are induced loss and changes in coating dimensions and properties.
Test method: 5.4.6

5.5.2.2 Temperature cycling

The purpose of the test is to check that any induced loss due to high or low temperature is within specifications. The test should be done on the same sample used in 5.5.4.1.
Sample length: 200 m from each fibre length.
Test method: 5.4.1

5.5.2.3 Ionizing radiation

This test is to measure the loss induced by the ionizing radiation. The test should be done at the operating wavelength, at room temperature and with an optical power typical for the application. The changes induced by the ionizing radiation in other optical properties, mechanical strength and coating properties should normally be small. Any fibres not meeting this requirement should have been identified in the evaluation testing and normally not be of interest for space applications.

Sample length: at least 200 m from each fibre length.
Test method: 5.4.5

5.5.2.4 UV radiation

UV radiation may affect the fibre coating and fibre loss. The test is to check fibre loss, only.
Sample length: 200 m from each fibre length
Test method: 5.4.4

5.6 Lot Acceptance Testing

Lot acceptance testing (LAT) shall be performed on every lot delivered by the manufacturer. The purposes of the tests to be included in the various LAT-levels have been discussed in Chapter 4.

The proposed tests for LA1 and LA2 require that short or long samples be taken from a long fibre length. The tests are or may be destructive. The fibre samples used in LA1 and LA2 can thus not be delivered.

The LAT shall be carried out in accordance with Chart 5.4.

5.6.1 Lot Acceptance Level 3 Testing (LA3)

All optical and geometrical characteristics are measured in the Final Production Testing. As a check of these measurements it is proposed that the attenuation be measured for one fibre length if 10 or less lengths are to be delivered or two if more than 10 lengths are to be delivered. Further a visual inspection should be made.

All tested fibres must meet specifications.

5.6.1.1 External visual inspection

The inspection should be carried out in accordance with ESA/SCC Basic Specifications No. 20500.

5.6.1.2 Attenuation

Measurement shall be made on the whole length and at the specified wavelength(s). The measurement should be made using OTDR since this will also allow the fibre length and uniformity of loss to be checked.
For number of deliverable lengths ≤ 10, select one length at random. For number of deliverable lengths > 10, select two lengths at random.

Test method: 5.2.3

5.6.2 Lot Acceptance Level 2 Testing (LA2)

LA2 encompasses LA3 and tests for endurance. The fibre will therefore be subjected to an ageing test. All tested fibres shall meet specifications.

5.6.2.1 Ageing

The properties to measure are induced loss and change in coating dimensions and properties. Sample(s) should be selected at random from delivered lot.

Number of samples:	One if number of deliverable lengths ≤ 10. Two if number of deliverable lengths > 10.
Sample length.	200 m.
Test method:	5.4.6

5.6.3 Lot Acceptance Level Testing (LA1)

LA1 encompasses LA3 and LA2 and tests for mechanical and environmental properties.

The mechanical properties most likely to be affected by changes in the production process are the mechanical strength and strippability. A good check on the mechanical strength is provided by the requirement on prooftesting. The strippability is included in the Final Production Test.

Properties like abrasion, crush, impact, torsion, flexing, snatch and kink are more related to coating thickness and choice of coating material and are therefore not included in LA1. Also, as noted before the use of uncabled fibre is not likely.

The environmental properties that could be affected by the production process are the effects of high and low temperature on the coating and the effects of ionizing and UV radiation on the fibre itself. A temperature test is proposed to ensure that the coating properties are maintained. The losses induced by ionizing radiation are dependent on several production factors as discussed in 5.5.2. A test for these properties is therefore included, but with the same provision as in 5.2.2. Due to the similarities of the mechanisms inducing losses by ionizing radiation and UV radiation, a test for the latter is not considered necessary.

All tested fibres shall meet specifications.

Sample(s) should be selected at random from deliverable lot.

5.6.3.1 Temperature cycling

The test should be done on the same sample used in LA2, Test 5.6.2.1. Ageing.

The property to measure is induced loss versus temperature and time.

Number of samples: One if number of deliverable lengths ≤10. Two if the number of deliverable lengths > 10.
Sample length: 200 m
Test method: 5.4.1

5.6.3.2 Ionizing radiation

The property to measure is induced loss versus dose. The test to be done at room temperature, at the operating wavelength and with an optical power typical for the intended application.

Number of samples: One if number of deliverable lengths ≤ 10. Two if number of deliverable lengths > 10.
Sample length: 200 m.
Test method: 5.4.5

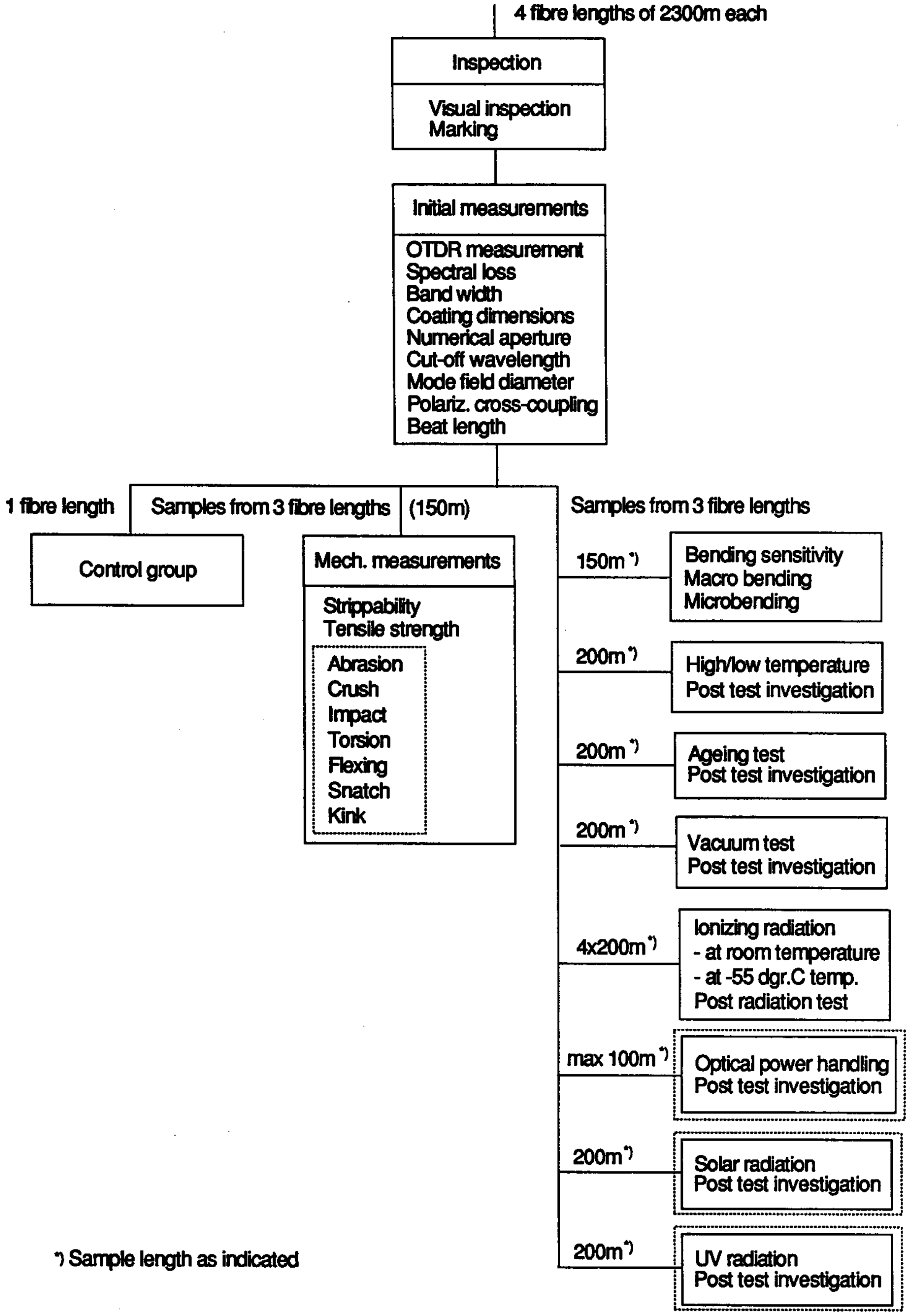

Chart 5.1 Evaluation testing for optical fibre

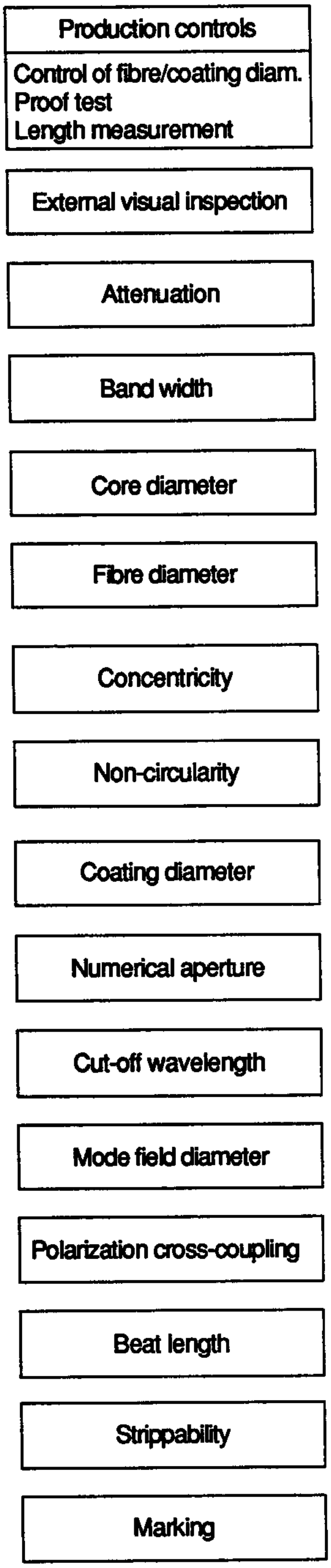

Chart 5.2 Final production testing for optical fibre

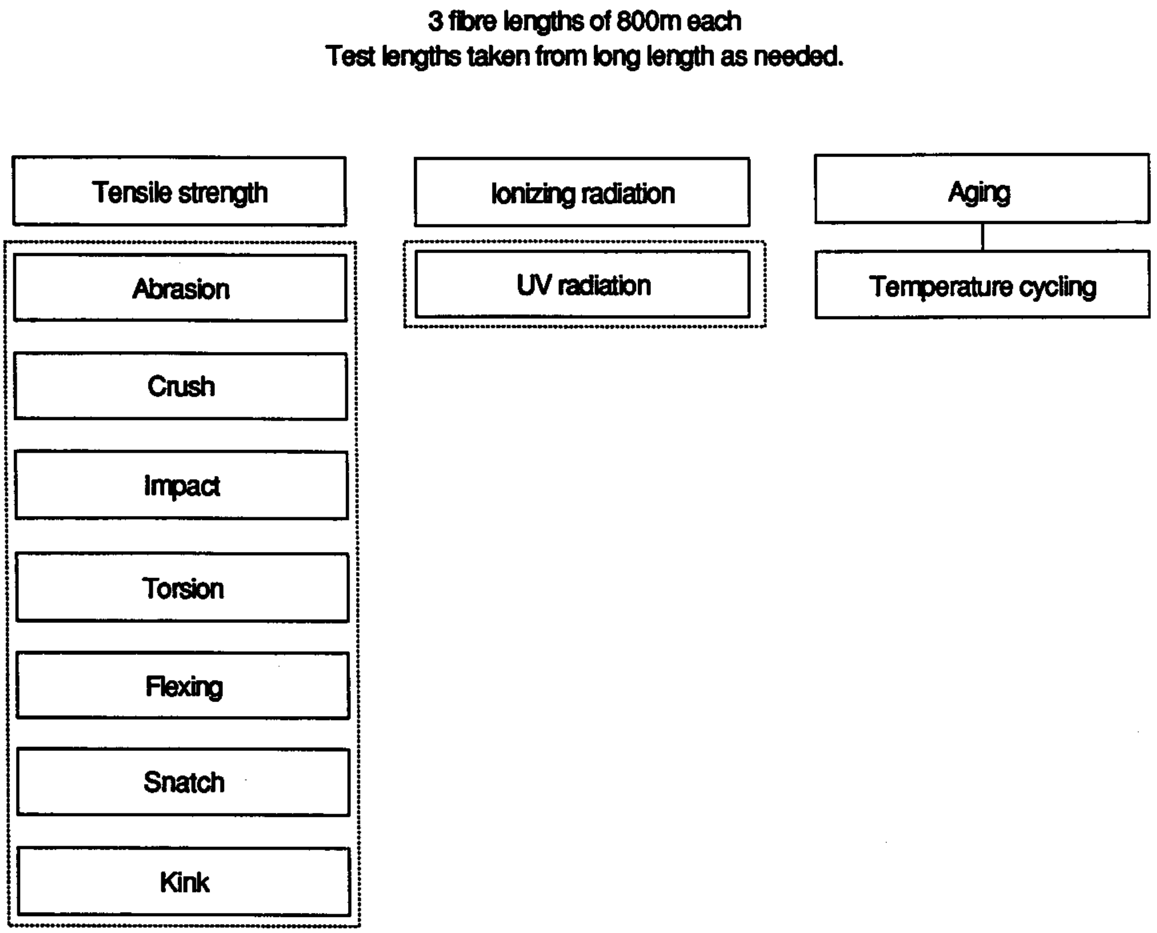

Chart 5.3 Qualification testing for optical fibre

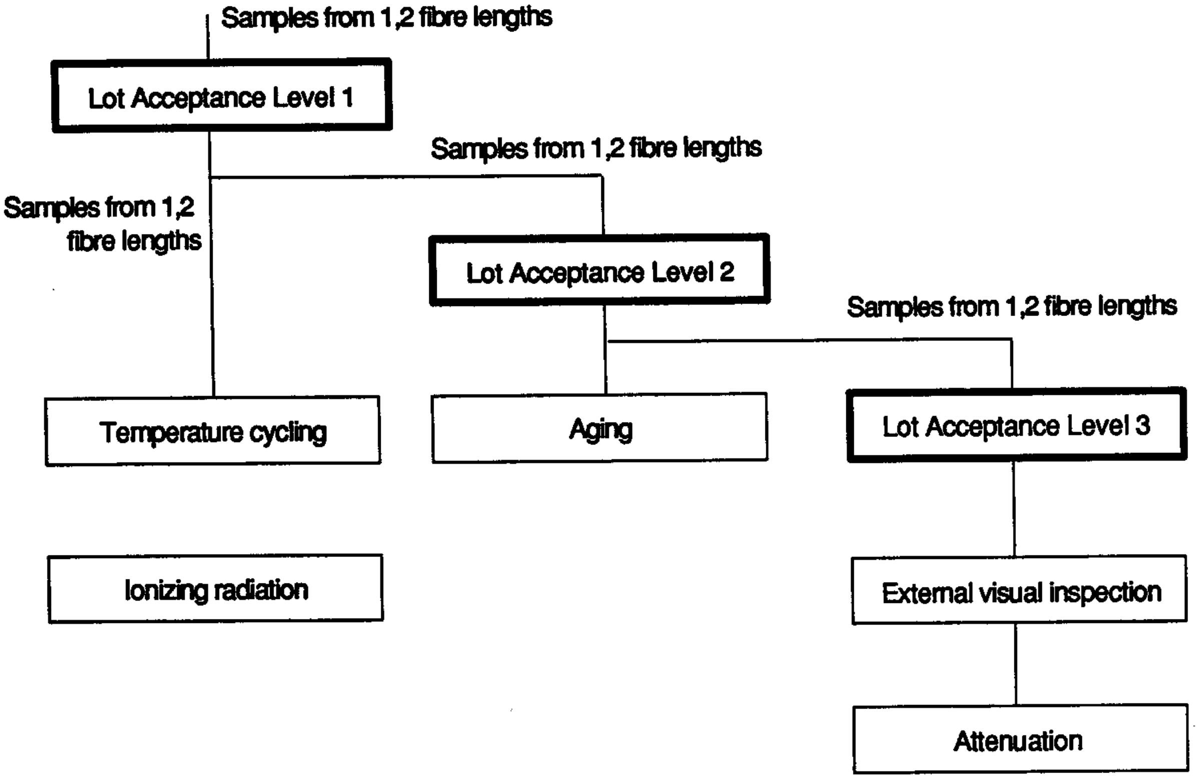

Chart 5.4 Lot acceptance testing for optical fibre

6. OPTICAL FIBRE CABLES

6.1 Introduction

The optical fibre is vulnerable to various mechanical and environmental loads. For most applications the fibre has to be protected by an appropriate cable structure. Cables of a variety of designs exist, and the cable may contain from one to many hundred fibres.

The cable may affect the fibre attenuation and for single mode fibres possibly also the cut-off wavelength and polarization properties. Other optical characteristics such as bandwidth, numerical aperture, mode field diameter, beat length and bending sensitivity are not affected. These properties are specified for the fibre and will not be treated in this chapter.

The general test strategy is described in Chapter 4 and will also be followed here. Each test method has been given a number, and these numbers are tabulated and described in Part 3 Chapter 6.

6.2 Evaluation testing

6.2.1 Purpose

The purpose of the evaluation testing is to determine the operational limits of the optical cable with respect to critical mechanical and environmental parameters, to overstress specific characteristics in order to identify failure modes, demonstrate the suitability of the cable for proceeding on to qualification testing, and to get information which can be of value for a detailed planning of the test programme to be used in the procurement of the cable.

6.2.2 Properties to evaluate

The properties of interest to include in the evaluation testing are:

- mechanical properties
- tensile strength
- crush
- impact
- repeated bending
- torsion
- flexing
- snatch
- kink
- bend under tension
- bend at low temperature (cold bend)
- ability to withstand vibration
- temperature effects
- operation at high and low temperature
- ageing
- rapid temperature changes

- flammability
- effects of rapid depressurisation
- effects of operation in vacuum
- radiation effects
- ionizing radiation
- UV radiation
- solar radiation
- resistance to fluids

For coherent (single mode) transmission and sensor systems the state of polarization (SOP) of the transmitted light is for concern, and the cable will effect the SOP. However, it does not seem possible to prevent the SOP to be effected. The detection system must therefore be able to handle variations in the SOP, and appropriate methods are available [11]. Polarization preserving fibres may also be used. The effect of the cable on the SOP will thus not be considered.

For single mode fibres the cut-off wavelengths can change when the fibre is cabled, for example if the fibre is stranded. The cut-off wavelength must therefore be defined for the cabled fibre. But there is no purpose served by doing an evaluation testing in this respect. It can be noted that the effect of the cable on the cut-off wavelength can be simulated using an uncabled fibre.

It is assumed that the various materials used in the construction of the cable all have been tested to ensure that they are qualified for space applications, see Chapter 4. The material tests should include investigations of possible changes in mechanical properties as well as shrinkage. However, it is still considered prudent to include tests for the effects of vacuum operation and radiation on the cable. This is to ensure that the combination of various materials do not cause unexpected problems and that the changes in properties which the materials may suffer under these environmental loads, do not adversely affect the cable properties.

In the following a discussion is given why these properties are of concern.

6.2.2.1 Mechanical properties

The main purpose of the cable structure is to protect the fibre(s) against various mechanical loads. Such loads may cause losses to be induced in the fibres and even fibre breakage. The cable will probably be subjected to the most severe loads during installation when the cable may be stretched, bent, crushed and twisted, and there may also be accidental loads due f.inst. to falling objects. It is important that the cable is easy to handle, but at the same time the fibre must not be subjected to unacceptable loads during the handling.

One would expect a fibre optic cable mainly to remain in a fixed position after installation. In such a position is could be subjected to a constant tensile load, bending, clamping and vibration. There might, however, also be cases where the cable is meant to be moved and thus subject to loads such as repeated bending, flexing and even cold bend.

The tensile strength is of special interest. In addition to know the breaking strength it is of importance to know the relationship between fibre loss and tensile force and the relationship between fibre strain and tensile force/cable elongation. As discussed in the Part 1, the fibre will be subjected to stress corrosion when under strain resulting in a time dependent breaking strength. It is thus necessary to know the relationship between fibre strain and cable tensile load to determine allowable tensile load conditions.

Vibrations can effect the performance of a cable if just a section of the cable is fastened to a support which vibrates. In such an application the cable will be strained in the transition region between the vibrating and non-vibrating part, and it is for such cases recommended to evaluate the cable's ability to withstand vibration. The possible problems encountered when the cable is attached to another component such as a connector, coupler etc. will be dealt with in the test programme for the appropriate component.

A test for abrasion has not been included. For electrical cables there is concern that the insulation can get damaged and expose the electrical conductor(s) possibly causing a short circuit and maybe also constitute a health hazard. This is not a concern with a fibre optic cable. Damages to the cable jacket can, however, leave the fibres less protected. An abrasion test is included in the qualification testing.

6.2.2.2 Temperature effects

The optical fibre has a much lower coefficient of thermal expansion than typical cable materials. High and low temperatures can therefore be expected to give thermally induced strain on the fibre causing macro- and microbending losses. Long term operation at high temperature can further cause ageing effects such as shrinkage of the cable materials and thus change the operational temperature range of the cable.

In case of rapid temperature changes thermal gradients will be set up across the cable. Depending on the difference in thermal expansion coefficient between the various cable materials, thermally induced strain could affect the cable structure.

6.2.2.3 Flammability

The flammability of the cable is a matter of great concern. The purpose of the evaluation is twofold. Firstly, to confirm the results of the flammability tests done on the individual cable materials. But in addition there may be applications where it is desirable or even required that the cable is able to function for a certain period during a fire. This latter ability should also be investigated.

6.2.2.4 Rapid depressurisation

The cable will not be compact, but have air filled sections and pockets. When the cable is subjected to rapid depressurisation, such as during launch, pressure gradients can be set up both between the outside and inside of the cable and between sections inside the cable. This could cause movement of the various cable elements and affect the fibre and possibly damage some of the cable elements.

6.2.2.5 Vacuum operation

Long term vacuum operation may affect the properties of the cable material and thus change the operational properties of the cable. Although the ability of the individual cable materials to withstand vacuum operation should have been tested, it is, recommended to investigate how the cable is effected by long term vacuum operation to confirm the previous findings.

6.2.2.6 Radiation effects

It is well known that ionizing radiation and also UV radiation will induce losses in the optical fibre. (See Part 1 and Chapter 5). The purpose of the tests proposed here is to investigate the effects of possible changes in the cable materials caused by ionizing radiation, UV radiation and solar radiation on the operational properties of the cable. In particular, it is of interest to determine if additional fibre losses are induced.

6.2.2.7 Resistance to fluids.

Potential cable materials may be damaged by certain fluids used in connection with assembly, launch and operation of spacecrafts. If it expected that the cable may come in contact with such fluids during installation or when in use, the resistance of the cable to the appropriate fluids should be investigated.

6.2.3 Sample distribution and test programme sequence

6.2.3.1 Sample distribution

The length of fibre optic cable procured for a certain space vehicle will very likely be short, probably only a few hundred meters. The number of cable lengths to be tested will reflect this fact.

Number of cable lengths:	2
Length of each cable:	2 lengths, 550 m - 1600 m depending on number of fibres in cable.

The two cable lengths should come from two different production runs to get a picture of possible variation in properties from run to run. Two lengths for control purposes will be cut from these lengths after the initial measurements.

Each cable spool must be marked for identification.

The needed cable length will depend on the number of fibres in the cable. For many of the tests a certain fibre length is required to get sufficient accuracy. For multi-fibre cables this can be achieved by looping several fibres in the test sample.

To carry out the various tests samples of various lengths (a few m to max 200 m) will be cut from each cable length.

Generally, it is recommended to increase a load until the cable has suffered physical destruction or a substantial deterioration in performance, as appropriate. However, in the environmental tests the test levels have been limited to the most severe loads expected (see Chapter 4) with a suitable margin. If more severe loads are expected, the test levels should be increased accordingly.

Since all tests are or can be destructive, new samples will be needed for each test.

All results should be recorded. One should keep track of from which cable length each sample is taken and assign the results to the appropriate sample.

6.2.3.2 Test programme sequence

The specified tests are summarised in Chart. 6.1. Some tests are shown inside a dotted box indicating that they are of interest only for some applications as discussed later.

The initial measurements include determination of dimensions and the attenuation of the various fibres using optical time domain reflectometry (OTDR). Although several methods exist for measuring fibre loss, the OTDR technique has been chosen since it will give information about possible loss variations along the cable. The uniformity of loss says something about the quality of the cable. It is also of importance since samples will later be cut from the two cable lengths for the various tests.

New samples will be used for each test since all tests can be destructive, see 6.2.3.1. Further, by doing tests on new samples the effects of a specific load can more easily be discerned. Since new samples are used, the test order is of no importance for the results. It is generally recommended that those tests which are considered easiest and the least expensive to perform are done first and the more complicated and expensive tests are done at the end. Should the cable not show satisfactory results in the more simple tests, the test programme can be stopped before a large expense has been incurred.

It is recommended that the mechanical tests are done first. The tests are relatively simple to do requiring standard test equipment for cables. But the mechanical properties are of importance for installation, operation and ease of handling. The first test is for tensile strength. The ability of the cable to withstand tensile loading without inducing unacceptable fibre losses and fibre strain, is a good measure of how well the cable is designed and if it has met its design goals.

Resistance to crush and impact are tested next to study how well the fibre is protected inside the cable structure. Tests with respect to repeated bending, torsion, flexing, snatch, kink, and bend under tension are related to the ease of handling and how installation friendly the cable is. The test for cold bend is deemed necessary only in case the cable is intended to be bent or could possible be bent at low temperatures. Finally, the vibration is necessary only in cases where just a section of the cable is attached to a vibrating support, see 6.2.2.1.

The environmental tests are generally more complicated, expensive and time consuming to do than the mechanical tests. The high/low temperature test is done first. It is an important property of a properly designed cable that it can operate over a large temperature range. The test is thus a good measure of how well the cable is designed and produced. The ageing test is listed after the temperature test since the test results from the latter may be required for determining the test parameters in the ageing test. A new temperature test is, however, done as part of the post test investigation to establish any permanent change in operational temperature range. The test with respect to rapid change in temperature is also done after the high/low temperature test since the results from the latter are used to establish the test parameters of the former.

The flammability test is done next since it is regarded simpler to do than the other remaining tests. The vacuum related tests follow. The rapid depressurisation is done first since there is no purpose to the vacuum test if the cable cannot tolerate a rapid depressurisation. The two tests can be done on the same samples.

The purpose of the remaining tests are all to confirm the results from the material tests. As noted before, the ionizing and UV radiation will induce losses in the fibre. The purpose of these tests is to investigate if radiation induced changes in the cable materials and cable structure can induce losses in the fibres. The test for ionizing radiation is listed first of the three tests. A cable used in space will always be subjected to such radiation. The two remaining tests are listed in dotted boxes, see Chart. 6.1, since the cable might in some applications be shielded from UV and solar radiation removing the need for the tests. The test with respect to resistance to fluids should be carried out if this is deemed necessary for the intended application. The range of fluids will depend on the application.

The tested samples shall be subjected to a construction analysis to determine the failure modes.

6.2.3.3 Use of a control group

In the proposed tests the transmitted power is measured while the cable is subjected to the various loads, and an important object of the test programme is to determine how the transmitted power and thus loss is effected by the load in question.

Where appropriate a transmission measurement is also done after the load is removed as part of the post test investigation. It is important that some means are provided to ensure stability of the source or alternatively that the source output is monitored. Use of a control group would here serve no purpose since the control measurement would have to be made with a different set of equipment. A cable length is, however, included as a control group to be used for comparison purposes in the construction analysis.

6.2.4 Inspection

The purpose of the inspection is to make sure that the cables lengths are suited for testing. All cables should be inspected.

6.2.4.1 Visual inspection

The inspection should be carried out in accordance with ESA/SCC Basic Specification No. 20500. It should be ensured that there is good access to both cable ends for later optical transmission measurements.

6.2.4.2 Marking

All cable lengths must be marked in accordance with the standard procedure of the manufacturer and the requirements stated in 6.2.3.1. The length of each cable length should be indicated.

6.2.5 Initial measurements

The purpose of the initial measurements is to determine the cable dimensions and the actual value of the fibre attenuation in the cable. These values will be used as base line data for the later measurements. Further, one can ascertain that the various cable lengths actually meet the specifications, and one can determine the spread in values which is a good indication of how well the production process is being controlled.

The initial measurements should be done on all cable lengths. It is important to keep track of the results being obtained for each fibre.

6.2.5.1 Cable dimension

The test is done so as to be able to compare cable dimensions (cross-section) before and after various tests. It also allows a check to be made of cable dimensions and uniformity. The measurement should be done on 3 positions at each end of the cable lengths. Each position should be at least one meter apart.
Test method: 6.1.3

6.2.5.2 OTDR measurement

The attenuation of each fibre in the cable should be determined at the anticipated operational wavelength. The measurement should be made on the complete cable length.
Test method: 6.2.3

6.2.6 Mechanical tests

In all these tests, except for kink, the optical transmission is measured as a function of the load. For multifibre cables several fibres can be looped together for the transmission measurement so as to be able to monitor several fibres simultaneously and also to increase the length of fibre being subjected to the load. The load should increase until fibre break or until the load has exceeded the value stated in the test description.

6.2.6.1 Tensile strength

Number of samples:	Two. One from each length
Sample length:	at least 50 m

Increase load until fibre break. Optical transmission shall be measured at the operational wavelength and induced loss versus tensile load determined. The induced strain versus tensile load shall be measured for one or several looped fibres.

Fibres to include in measurement:

Cables with 1 - 6 fibres:	all fibres
Cables with 7 - 20 fibres:	at least 6 fibres
Cables with 21 or more fibres:	at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 6.3.1

6.2.6.2 Crush

Number of samples:	Four. Two from each length
Sample length:	A few meters
Starting load:	Specified value
Duration:	1 minute
Step increase in load:	20% of specified value

Measure optical transmission versus load. The cable shall be visually inspected after each load to look for cracks or other damage to the cable sheath.
Continue load increase until fibre breaks.

Fibres to include in measurement:

Cables with 1 - 6 fibres:	all fibres
Cables with 7 - 20 fibres:	6 fibres
Cables with 21 or more fibres:	at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 6.3.3

6.2.6.3 Impact

Number of samples: Four. Two from each lengths.
Sample lengths: A few meters
Starting energy: Specified level
Number of impacts per energy level: 5 or until break
Increase in energy per step: 20% of specified level

Measure optical transmission versus load. Continue load increase until fibre-break. The cable shall be visually inspected after each load to look for cracks or other damage to the cable sheath.

Fibres to include in measurement:

Cables with 1 - 6 fibres: all fibres
Cables with 7 - 20 fibres: at least 6 fibres
Cables with 21 or more fibres: at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 6.3.4

6.2.6.4 Repeated bending

Number of samples: Four. Two from each length
Sample length: A few meters
Bending radius: Specified value for bend diameter
Load: As specified or 10% of breaking load
Number of bends: Until fibre-break, but maximum 1000

Measure optical transmission versus number of bends. The cable shall be visually inspected after each 100 bends to look for cracks or other damage to the cable sheath.

Fibres to include in measurement:

Cables with 1 - 6 fibres: all fibres
Cables with 7 - 20 fibres: 6 fibres
Cables with 21 or more fibres: at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 6.3.5

6.2.6.5 Torsion

Number of samples: Four. Two from each length
Sample of length: As specified (Typically a few meters)
Load: As specified
Number of cycles
(clockwise and anticlockwise): to fibre-break, max. 50 or twice specified value whichever is higher.

Measure optical transmission versus load. The cable shall be visually inspected after end of the test to look for cracks or other damage to the cable sheath.

Fibres to include in measurement:
Cables with 1 - 6 fibres: all fibres
Cables with 7 - 20 fibres: at least 6 fibres
Cables with 21 or more fibres: at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 6.3.6

6.2.6.6 Flexing

Number of samples:	Four. Two from each length
Sample length:	As specified (Typically a few meters)
Pulley diameter:	As specified
Load:	As specified
Carrier speed:	10 cycles per min or as specified
Number of cycles:	To fibre-break, max. 1000 or twice specified value whichever is higher.

The optical transmission shall be measured as a function of the number of cycles. The cable shall be visually inspected after the completion of the test to look for cracks or other damage to the cable sheath.

Fibres to include in measurement:
Cables with 1 - 6 fibres: all fibres
Cables with 7 - 20 fibres: at least 6 fibres
Cables with 21 or more fibres: at least 30% of fibres.

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 6.3.7

6.2.6.7 Snatch

Number of samples:	Four. Two from each length
Sample length:	A few meters
Starting weight:	As specified
Number of cycles per weight:	10 or to break
Weight increase per step:	20% of starting weight

The optical transmission shall be measured as a function of load. The cable shall be visually inspected after completion of the test with each weight to look for cracks or other damage to the cable sheath.

Fibres to include in measurement:
Cables with 1 - 6 fibres: all fibres
Cables with 7 - 20 fibres: at least 6 fibres
Cables with 21 or more fibres: at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the

transmission measured through the loop.
Test method: 6.3.8

6.2.6.8 Kink

Number of samples: Four. Two from each length
Sample length: A few meters

Decrease diameter until kink (break) is formed.
Test method: 6.3.9

6.2.6.9 Bend under tension

The purpose of this test is to determine the cable's ability to withstand bending around a cylindrical mandrel.

Number of samples: Four. Two from each length
Sample length: A few meters
Starting mandrel diameter: As specified
Number of turns: To fibre-break, but max. six or twice specified whichever is greater
Number of cycles for one diameter: To fibre-break, but max. ten or twice the specified value whichever is greater
Decrease in mandrel diameter per step: 1 cm for starting diameter less than 10 cm
2 cm for starting diameter larger than 10 cm
Load: as specified

The optical transmission shall be measured as a function of load. The cable shall be visually inspected after the completion of the test for each diameter to look for cracks or other damage to the cable sheath.

Fibres to include in the measurement:

Cables with 1 - 6 fibres: all fibres
Cables with 7 - 20 fibres: at least 6 fibres
Cables with 21 or more fibres: at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 6.3.10

6.2.6.10 Cold bend

This is a test similar to that in 6.2.6.9, but the test shall be performed at a low temperature.
Mandrel diameter: as specified
Starting temperature: as specified
Step change in temperature: 10 °C
Low temperature: sufficient to cause fibre-break or break of cable sheath, but not lower than -70 °C.
For other test conditions, see 6.2.6.9.
Test method: 6.3.12

6.2.6.11 Vibration

Number of samples:	Two. One from each length
Sample length:	25 m unless otherwise specified
Vibration frequency:	100 - 2000 Hz
Starting acceleration:	as specified
Step increase in acceleration:	20% of specified level until the level has reached 30 g or until fibre-break
Duration:	90 minutes

The optical transmission shall be measured during the test.

Fibres to include in the measurement:

Cables with 1 - 6 fibres:	all fibres
Cables with 7 - 20 fibres:	at least 6 fibres
Cables with 21 or more fibres:	at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped for the measurement.

The cable shall be visually inspected after the test.

Test method: 6.3.11

6.2.7 High and low temperature test

The purpose of this test is to determine the highest and lowest short term operational temperature. The optical transmission at the anticipated operational wavelength should be monitored during the tests. Several fibres may be looped for the transmission measurement.

6.2.7.1 Temperature test

Number of samples:	Two. One from each cable length
Sample length:	Sufficient to get at least 200 m of looped fibre. Min. cable length: 50 m.
Thermal cycle:	First low, then high
Low starting temperature:	Lowest specified operating temperature or -40 °C if not known
Low temperature:	Sufficient to give an induced loss of 2 dB/km, but not lower than -70 °C
High starting temperature:	Highest specified operating temperature or +90 °C if not given
High temperature:	Sufficient to give an induced loss of 2 dB/km, but not higher than 150 °C
Step change in temperature:	10 °C
Duration of stay at each temperature:	Until cable temperature has stabilised, but at least 1 hour

Fibres to include in test:

Cables with 1 - 4 fibres:	all fibres
Cables with 5 or more fibres:	at least 4 fibres selected at random

The fibres may be looped and the transmission measured through the loop.

Test method: 6.4.1

6.2.8 Ageing

Long term operation at a high temperature can affect the properties of the cable materials which to a great extent will be various types of plastics. One potential problem is shrinkage which can cause macrobend losses to be induced in the fibre. The mechanical properties of the cable material may also be affected.

6.2.8.1 Ageing test

Number of samples:	Two. One from each cable length
Sample length:	Sufficient to get at least 200 m of looped fibre. Min. cable length: 50 m.
Temperature:	20 °C above specified operational temperature, but at least 10 °C below high temperature limit established in 6.2.7.1
Duration:	Until loss has increased to 2 dB/km or visual changes are clearly evident. Maximum duration: 1000 hours.

The optical transmission should be measured during the test at the anticipated operational wavelength.

Fibres to include in test:

Cables with 1 - 4 fibres:	all the fibres
Cables with 5 or more fibres:	at least 4 fibres selected at random

The fibres may be looped and the transmission measured through the loop.
Test method: 6.4.8

6.2.8.2 Post test investigation

At the end of the ageing test a test should be done to determine if the test has caused the operational temperature range of the cable to change. The cable should be exposed to the following temperature cycle:

Max. temperature:	Max. specified operating temperature
Min. temperature:	Min. specified operating temperature
Temperature at end of cycle:	20 ± 5°C

Experimental conditions as in 6.2.7.1, otherwise.

At the end of the temperature cycle the following tests should be done:

- Visual inspection
- Cable dimensions (cross-section), see 6.2.5.1.

6.2.9 Rapid change in temperature

The purpose of the test is to investigate if thermal gradients across the cable will affect the cable structure.

6.2.9.1 Test for rapid change in temperature

Number of samples:	Two. One from each cable length
Sample length:	50 m
High temperature:	10 °C below high limit established in 6.2.7.1

Low temperature: 10 °C above low limit established in 6.2.7.1

The optical transmission should be measured during the test at the anticipated operational wavelength.

Fibres to include in the test:
Cables with 1 - 4 fibres: all fibres
Cables with 5 or more fibres: at least 4 fibres selected at random

The fibres may be looped and the transmission measured through the loop.
Test method: 6.4.2

6.2.9.2 Post test investigation

The transmission should be measured after the cable has been brought back to room temperature. This should be followed by a visual inspection.

In case the cable has failed to meet its specifications, a construction analysis should be done, see 6.2.15.

6.2.10 Flammability resistance

Number of samples: Two. One from each cable length
Sample length: A few meters

Unless otherwise specified the test conditions (flame temperature, duration) shall be as described in ESA/SCC Generic Specifications No. 3901, Para. 9.20.

Duration of first test cycle: as specified for cable or as specified in ESA/SCC Generic Specification No. 3901, Para 9.20
Step increase in duration, subsequent test cycles: Increase duration of time burner is applied by duration of first cycle
Number of cycles: Until fibre-break, but max. duration five times original cycle.

The optical transmission shall be measured during the test. A visual inspection shall be made of the cable after each test cycle and its condition noted.

Fibres to include in the measurement:

Cables with 1 - 6 fibres: all fibres
Cables with 7 - 20 fibres: at least 6 fibres
Cables with 21 or more fibres: at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 6.4.7

6.2.11 Rapid depressurisation

The purpose of this test is to investigate if rapid depressurisation can induce losses in the fibres or cause damage to the cable structure.

6.2.11.1 Rapid depressurisation test

Number of samples:	Two. One from each cable length.
Sample length:	Sufficient length to get at least 200 m of looped fibre. Min. cable length: 50 m.

The optical transmission should be measured during the test.

Fibres to include in test:

Cables with 1 - 4 fibres:	all fibres
Cables with 5 or more fibres:	at least 4 fibres selected at random

The fibres may be looped and the transmission measured through the loop.
The cable is regarded to have failed if it does not meet the specified requirement with respect to rapid depressurisation.
Test method: 6.4.9

6.2.11.2 Post test investigation

Visual inspection
Cable dimensions (cross-section), see 6.2.5.1
In case of failure the cable shall also be subjected to a construction analysis, see 6.2.16

6.2.12 Vacuum operation

The purpose of the test is mainly to confirm that any changes in the properties of the cable materials will not affect the cable properties in an adverse way. After completion of the test a visual inspection should be made of the cable. In addition, a temperature cycling test similar to the one specified in 6.2.8.2 should be performed. The purpose of the latter test is to determine if the possible changes in material properties (f.inst. shrinkage) have affected the operating temperature range. The proposed test conditions are similar to those used in the vacuum test of materials, see PSS-01-702.

6.2.12.1 Vacuum test

Number of samples:	Two. One from each cable length. Sample from 6.2.11 can be used
Sample length:	Sufficient length to get at least 200 m looped fibre. Min. cable length: 50 m
Vacuum:	10^{-3} Pa or less
Temperature:	125 °C, but not above max. operating temperature
Duration:	24 hours, unless otherwise specified

The optical transmission should be measured during the test.

Fibres to include in test:

Cables with 1 - 4 fibres:	all the fibres
Cables with 5 or more fibres:	at least 4 fibres selected at random

The fibres may be looped and the transmission measured through the loop.
Test method: 6.4.3

6.2.12.2 Post test investigations

Visual inspection
Cable dimensions (cross-section), see 6.2.5.1
Temperature cycling test, see 6.2.8.2

6.2.13 Ionizing radiation

The purpose of this test to determine if the ionizing radiation has affected the cable materials in such a way as to induce losses in the fibres. Since the ionizing radiation will induce losses in the fibres directly, it will be difficult to distinguish between the two loss mechanisms unless the cable induced losses are significant with respect to the losses induced directly in the fibres. It must be assumed that the optical fibres used in the cable are so well characterised that the losses induced directly in the fibres can be estimated with confidence.

The only post test investigations proposed are to make a visual inspection and to measure cable dimensions.

6.2.13.1 Test for ionizing radiation

Number of samples:	Two. One from each cable length
Sample length:	Sufficient length to get at least 200 m of looped fibre. Min. cable length: 50 m
Temperature:	Room temperature
Incident optical power:	Ca 1 µW
Wavelength:	Expected operational wavelength
Dose rate:	5 rad(Si)/s
Duration:	The irradiation should last until a) The induced loss from the cable is equal that induced directly in the fibre or b) The total dose has reached 3 Mrad

The optical transmission should be measured during the test.

Fibres to include in test:
Cables with 1 - 4 fibres: all fibres
Cables with 5 or more fibres: at least 4 fibres selected at random

The fibres may be looped and the transmission measured through the loop.
Test method: 6.4.6

6.2.13.2 Post test investigation

Visual inspection
Cable dimensions (cross-section), see 6.2.5.1

6.2.14 Solar radiation including UV radiation

As noted in Chapter 5 UV radiation can induce losses in optical fibres. It seems, however, reasonable to assume that the cable sheath etc. will protect the fibre from UV radiation. Any fibre induced losses observed in the tests should thus be caused by changes in the cable due to the UV/solar radiation. As discussed in 6.2.3.2 these tests are of interest only if the cable is exposed to UV and solar radiation.

6.2.14.1 Solar radiation

Number of samples:	Two. One from each cable length
Sample length:	Sufficient length to get at least 200 m of looped fibre. Min. cable length: 50 m
Radiation source:	Source with representative spectral output
Duration:	Until induced loss increase to 5 dB/km or visible damage to the cable or twice specified dose

The optical transmission should be measured during the test.

Fibres to include in test:

Cables with 1 - 4 fibres:	all the fibres
Cables with 5 or more fibres:	at least 4 fibres selected at random

The fibres may be looped and the transmission measured through the loop.
Test method: 6.4.4

6.2.14.2 Post test investigation

Visual inspection
Cable dimensions (cross-section), see 6.2.5.1

6.2.14.3 UV radiation

Number of samples:		Two. One from each cable length
Sample length:		Sufficient length to get at least 200 m of looped fibre. Min. cable length: 50 m
Radiation source:		representative UV source
Duration:		The irradiation shall last until a) The induced loss is 5 dB/km
	or	b) Twice specified dose has been reached

The optical transmission should be measured during the test.

Fibres to include test:

Cables with 1 - 4 fibres:	all fibres
Cables with 5 or more fibres:	at least 4 fibres selected at random

The fibres may be looped, and the transmission measured through the loop.
Test method: 6.4.5

6.2.14.4 Post test investigation

Visual inspection
Cable dimensions (cross-section), see 6.2.5.1

6.2.15 Resistance to fluids

The test should be carried out using the same procedure as for electrical cables. A range of fluids is listed in the description of the test method. Which fluids to include in the test will depend on the application.

A visual inspection should be made after the immersion of the cable in the fluid.

Number of samples:	Two. One from each cable length
Sample length:	1 - 2 m
Test method:	6.4.10

6.2.16 Construction analysis

A number of post test investigations have already been proposed in connection with the environmental measurements. In addition the damaged cable sections from the mechanical measurements should be cut open and compared to similar sections from the control cable in an attempt to identify failure mechanisms.

6.3 Production testing

6.3.1 Introduction

The measurements that are practical and desirable to make during the production process are highly dependent on the cable design and the steps in the production process. It is thus possible only to give some general rules with regard to the production control. In the final production test both optical and geometrical measurements can be made. The optical measurements are non-destructive. For the geometrical measurements short samples will have to be cut from the produced length. In addition to these measurements it is proposed to do a temperature test.

6.3.2 Production control

The cable diameter (cross-section) shall be controlled within the specified limit during the various steps of the cable production process.

If the cable design and production process allows, measurements should be made of the fibre attenuation after the completion of key steps in the process. Examples could be after completion of stranding of the fibres and the extrusion of an inner jacket.

In case the cable design is based on the fibre having a certain excess length with respect to the cable, means should be provided to control the excess length during the production process.

The cable length shall be measured, and the length marked on each spool.

6.3.3 Final production testing

Measurements are to be made on each cable length or on samples from each cable as appropriate. The tests shall be done in accordance with Chart. 6.2. The tests are independent of each other. The order in which the tests are done is thus not critical.

The visual inspection and marking are done first to assure that the cable has no obvious fault and is ready for testing. Measurement of mass and outer dimensions are simple tests to do and give the first indications that the cable has been produced according to specifications. The fibre attenuation is measured next to assure that the cabling process has not induced unacceptable losses in the fibres. Finally, a temperature test is done. Such a test gives a good check on the successfulness of the cable production process. It is proposed that the temperature test is done on the complete cable length and not just on a sample since it is assumed the procured length(s) will be somewhat limited. The test should be done over the temperature range specified to give no permanent losses. Finally, for single mode fibres the cut-off wavelength should be measured. This test can also be done on uncabled fibres.

All produced lengths shall meet specifications.

6.3.3.1 External Visual Inspection

To be performed in accordance with ESA/SCC. Basic specification no. 20500. It should be assured that there is good access to both cable ends since this is necessary for the later measurements.

6.3.3.2 Marking

The cable and spool shall be marked according to specifications.

6.3.3.3 Mass

Samples should be taken from each cable length
Test method: 6.1.5

6.3.3.4 Outer dimensions

Samples should be taken from each cable length.
Test method: 6.1.3

6.3.3.5 Attenuation

Measurement should be made on all fibres and on the complete cable length and at the specified wavelength(s).
Test method: 6.2.1 or 6.2.2 or 6.2.3

6.3.3.6 Thermal cycling

The measurement shall be done on the complete length and at the specified wavelength.

Max. temperature:	Max. temperature specified not to give permanent loss
Min. temperature:	Min. temperature specified not to give permanent loss
Number of cycles:	One

The optical transmission shall be measured during the test.

Fibres to include in the test:

Cables with 1 - 4 fibres:	all fibres
Cables with 5 or more fibres:	at least 4 fibres selected at random

Several fibres may be looped, and the transmission measured through the loop.
Test method: 6.4.1

6.3.3.7 Cut-off wavelength

A sample should be taken from every cable length. The cut-off wavelength should be measured for all fibres. This test applies only to single mode fibres. The test can also be simulated using uncabled fibres.
Test method: 6.2.4

6.4 'Burn-in'

'Burn-in' is not relevant for optical fibre cables.

6.5 Qualification testing

The qualification test programme should include all tests of relevance not already done in the final production test. Optical and geometrical parameters have been measured in the final production test. It is assumed that the necessary tests of the additional optical and geometrical parameters related to the fibres themselves have been performed on the fibres before cabling. The qualification testing will thus be concerned with mechanical and environmental characteristics. The tests shall be performed in accordance with Chart 6.3.

Tests for all the mechanical properties are included in the qualification testing since they can be effected by the production process. The quality of the cable jacket materials is dependent on how well the various extrusion parameters are controlled. The incorporation of the fibre(s) in the cable by stranding or some other method is also a critical process and can effect how well the cable is able to protect the fibres from mechanical loads. Finally, the adhesion or friction between the various layers in the cable will effect its mechanical properties.

The proposed environmental tests are limited to those related to temperature. The temperature characteristics of the cable may be effected by the production process for much the same reasons as the mechanical properties. Tests for flammability, vacuum operation, radiation related effects and resistance to fluids have not been included. These properties are related to the choice of materials used in the cable and the basic cable design, and any problems in this respect should have been discovered in the evaluation testing.

One cable length shall be used for the qualification testing. The required length will depend somewhat on whether or not the complete test programme is to be performed. To carry out the complete programme at least 450 m is needed, as indicated in Chart 6.3.

All samples should meet the specifications for the cable type being tested.

6.5.1 Mechanical tests

The mechanical tests are all done on samples from the cable and mostly the samples are only 3 - 5 meter in length. It is recommended that all tests be done on fresh samples. If we leave out the tensile test, the other tests are related to loads which, when the cable is in use, will be applied locally to a short section of the cable. It seems rather unlikely that the same short section would be exposed to several of the various types of loads in an actual application. It thus seems more realistic to use fresh samples and not use the same samples for several tests. In the tensile test the sample is stressed to break, and the sample is thus damaged.

Since fresh samples are used, the sequence of tests is not critical. The order shown in Chart. 6.3 is based on the importance of the various test. Reference is made to 6.2.3.2. for a further discussion. The test for vibration is regarded necessary only if in the intended application a section of the cable is attached to a support which vibrates with respect to the remaining part of the cable.

It may be noted that no test is included for strippability. Generally, in the specifications for fibre optic cables only some general remarks are made with respect to ease of stripping the cable. The main concern is with the fibre, and the strippability of the fibre is considered in the tests for fibres, see Chapter 5.

The sample length recommended for the various tests are given in Chart 6.3 unless otherwise stated in the detailed specifications. Two samples should be used in each test, one sample from each end.

6.5.1.1 Tensile strength

The fibre loss and elongation should be measured as a function of tensile load. The cable should be stressed to break.
Test method: 6.3.1.

6.5.1.2 Crush

Test method: 6.3.3

6.5.1.3 Impact

Test method: 6.3.4

6.5.1.4 Repeated bending

Test method: 6.3.5

6.5.1.5 Torsion

Test method: 6.3.6

6.5.1.6 Flexing

Test method: 6.3.7

6.5.1.7 Snatch

Test method: 6.3.8

6.5.1.8 Kink

Test method: 6.3.9

6.5.1.9 Bend under tension

Test method: 6.3.10

6.5.1.10 Abrasion

Test method: 6.3.2

6.5.1.11 Vibration

Test method: 6.3.11

6.5.2 Environmental tests

As discussed before, only tests related to temperature are included. The tests involve measuring temperature induced losses, and the tests must therefore be done on sufficient lengths to allow any change in loss to be measured with the required accuracy. In addition, a certain cable length is required to get information about possible variations in properties along the cable. A minimum length of 200 m is recommended, see Chart. 6.3. For multifibre cables several fibres may be looped together for the transmission measurements.

A test to check the temperature operating range is included in the production test. The qualification test is started with an ageing test followed by a temperature cycling test to see if the ageing test has affected the temperature operating range, f.ex. due to shrinkage of the cable jacket. The temperature cycling test can be done as a continuation of the ageing test. It is therefore done before the test for rapid change in temperature which requires a different test set-up.

Two mechanical tests are proposed after the temperature test, one for bending at room temperature and one for cold bend to see if the ageing process has affected the cable jacket. If the cable should be subjected to bend in space, this could well be after it has been subjected to high and low temperatures. However, one would expect a fibre optic cable to be subjected to bend only in some special applications. The test should be done on two short samples taken from each end of the samples used in the temperature tests. Separate samples are used for the two tests.

The cable will likely be subjected to the heaviest mechanical loads during installation, and this should be before it has been exposed to ageing. It should thus not be necessary to do any additional mechanical tests on the sample which has undergone the ageing test.

6.5.2.1 Ageing

Test method: 6.4.8

6.5.2.2 Temperature cycling

Test method: 6.4.1

6.5.2.3 Rapid change in temperature

Test method: 6.4.2

6.5.2.4 Bend under tension

Test method: 6.3.10

6.5.2.5 Cold bend

Test method: 6.3.12

6.6 Lot Acceptance Testing

Lot acceptance testing (LAT) shall be performed on every lot delivered by the manufacturer. The purposes of the tests to be included in the various LAT-levels have been discussed in Chapter 4.

The tests proposed for LAT3 can be done on a complete cable length. The tests are non-destructive, and the cable length can be delivered.

The proposed tests for LAT1 and LAT2 require that samples of various lengths be cut from a longer cable length. The tests are or may be destructive. The samples cannot be delivered.

The LAT shall be carried out in accordance with Chart. 6.4.

6.6.1 Lot Acceptance Level 3 Testing (LA3)

All optical and geometrical characteristics have been measured in the Final Production Testing of the cable or the fibre. As a check of the measurement of attenuation, the most important optical characteristic, it is proposed that the attenuation be measured on one of the cable lengths to be delivered. Further, a visual inspection should be made.

The cable must meet all tested specifications including the loss specifications for all fibres in the cable.

6.6.1.1 External visual inspection

The inspection should be carried out in accordance with ESA/SCC Basic Specification No. 20500.

6.6.1.2 Attenuation

The measurement should be made on the whole cable length on all fibres and at the specified wavelength(s). It is recommended that the measurement be made using OTDR (optical time domain reflectometry) since this will allow the uniformity of the loss along the cable to be checked.
Test method: 6.2.3

6.6.2 Lot Acceptance Level 2 Testing (LA2)

LA2 encompasses LA3 and the environmental/endurance subgroup. The proposed tests are for ageing, temperature cycling and when appropriate, bend under tension and cold bend. The temperature tests are included since they give a very good indication of how successful the production process has been. As noted before, the fused silica fibres have a much smaller coefficient of thermal expansion than other typical cable materials. Variation in temperature may therefore cause micro- and macrobending of the fibres resulting in added losses unless the cable is properly designed and fabricated.

The sequence of test and needed test lengths were discussed in 6.5.2. All tested samples shall meet specifications.

6.6.2.1 Ageing

Test method: 6.4.8

6.6.2.2 Temperature cycling

Test method: 6.4.1

6.6.2.3 Bend under tension

Test method: 6.3.10

6.6.2.4 Cold bend

Test method: 6.3.12

6.6.3 Lot Acceptance Level Testing (LA1)

LA1 encompasses LA3 and LA2 and the mechanical subgroup. The proposed tests are for tensile strength, crush, impact and flexing. The test for tensile strength gives a good indication of how successful the production has been with respect to an important design goal. By measuring the fibre loss and fibre strain versus tensile load, a good check is obtained on how successfully the fibres have been incorporated into the cable structure. The test with respect to crush resistance gives some of the same information and also tells how well the various cable layer have been put together. The tests with respect to impact and flexing gives information on the quality of the cable jacket as well as the cable structure and the positioning of the fibres in the cable. A successful outcome of the four proposed tests in the mechanical subgroup together with the tests in LA2 and LA3 should thus give a good assurance that the production process is under proper control.

The sequence of tests is discussed in 6.5.1

The recommended sample lengths are given in Chart. 6.4 unless otherwise stated in the detailed specification. Two samples should be used in each test, one sample from each cable end.

All tested samples shall meet specification.

6.2.3.1 Tensile strength

Test method: 6.3.1

6.6.3.2 Crush

Test method: 6.3.3

6.6.3.3 Impact

Test method:6.3.4

6.6.3.4 Flexing

Test method: 6.3.7

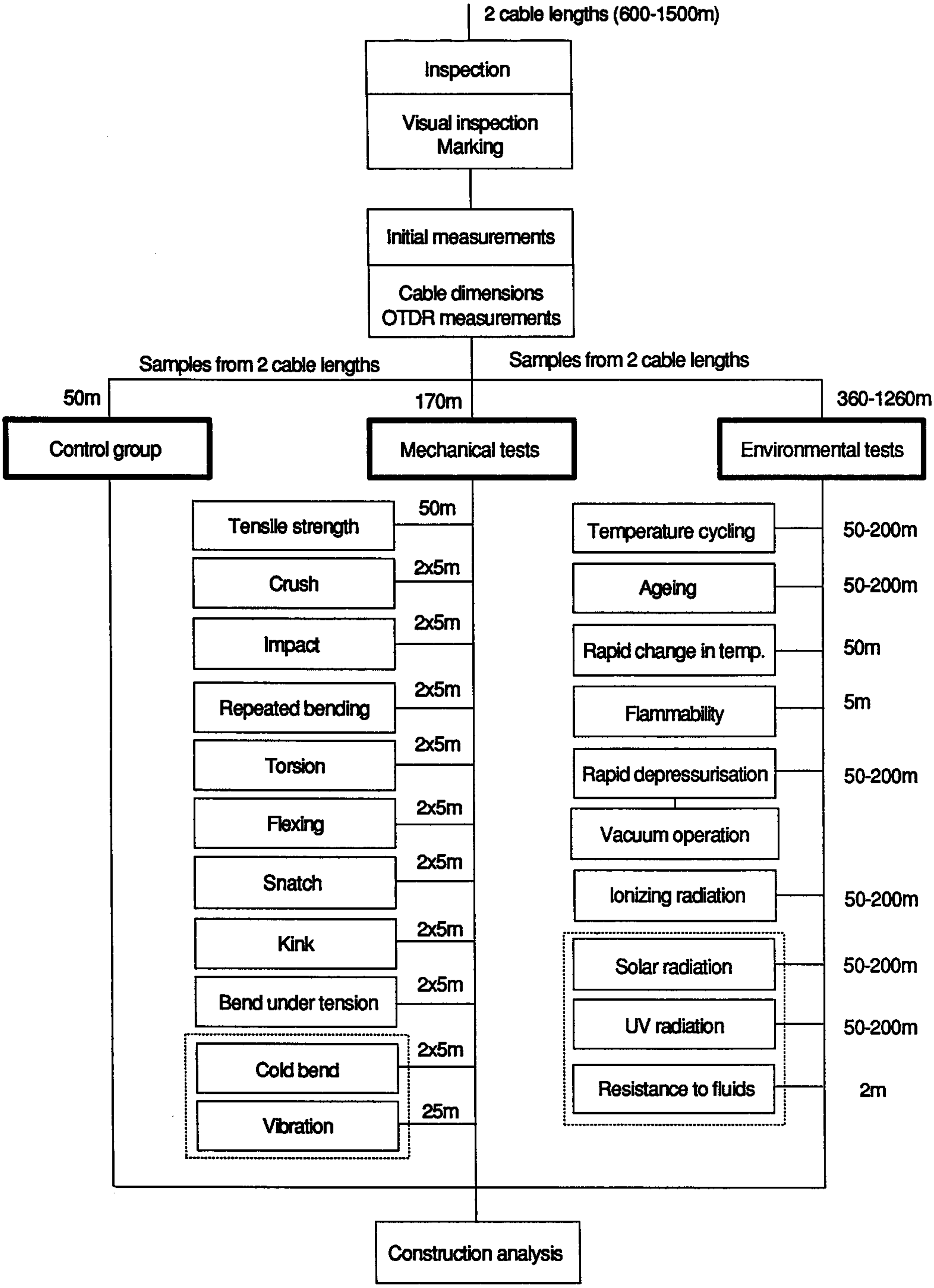

Chart 6.1 Evaluation testing, fibre optic cables.

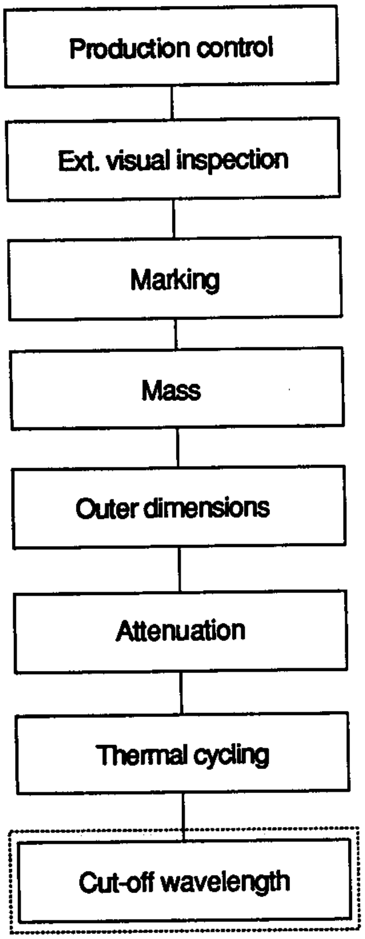

Chart 6.2 Final production testing, fibre optic cables

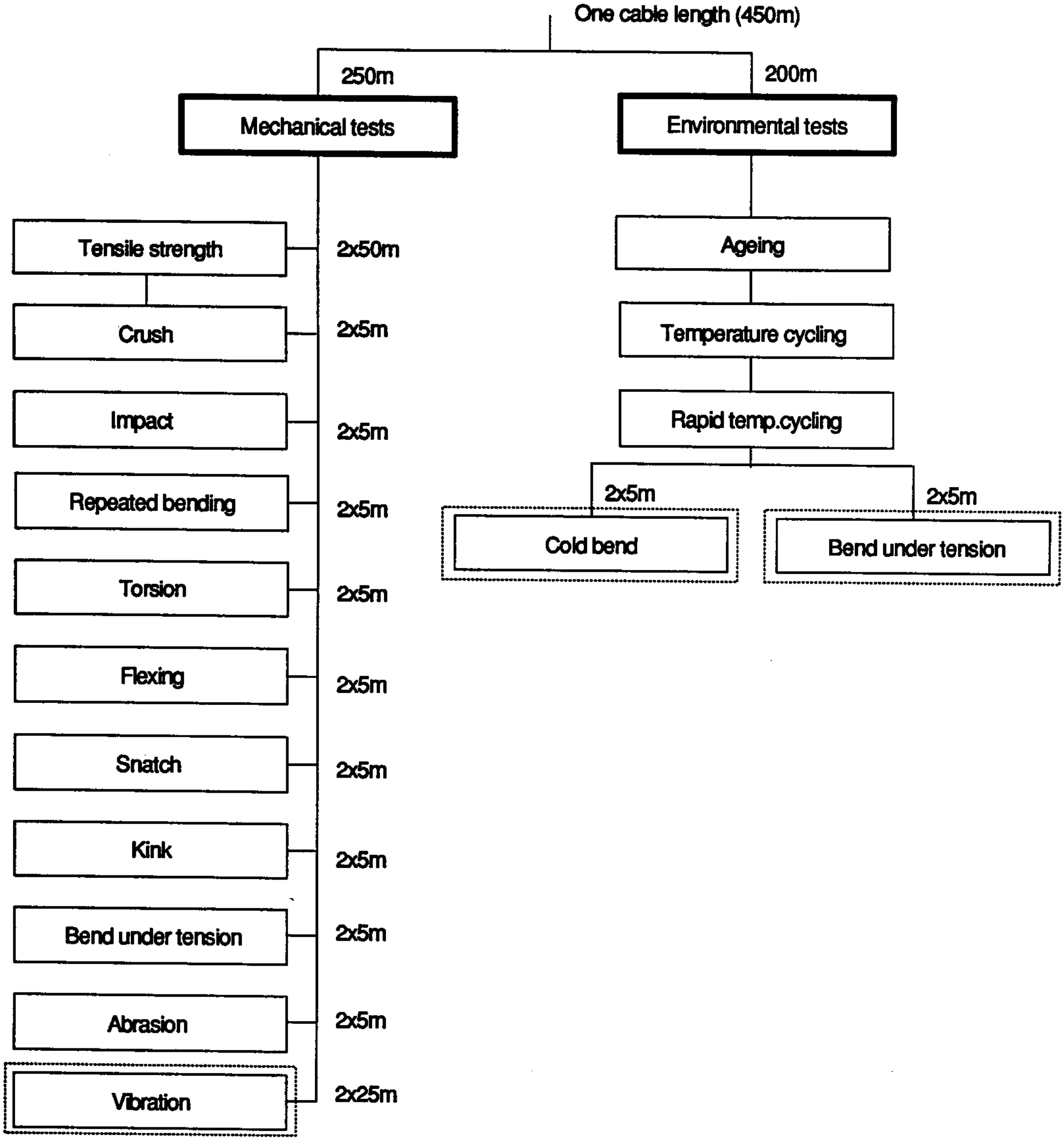

Chart 6.3 Qualification testing, fibre optic cables

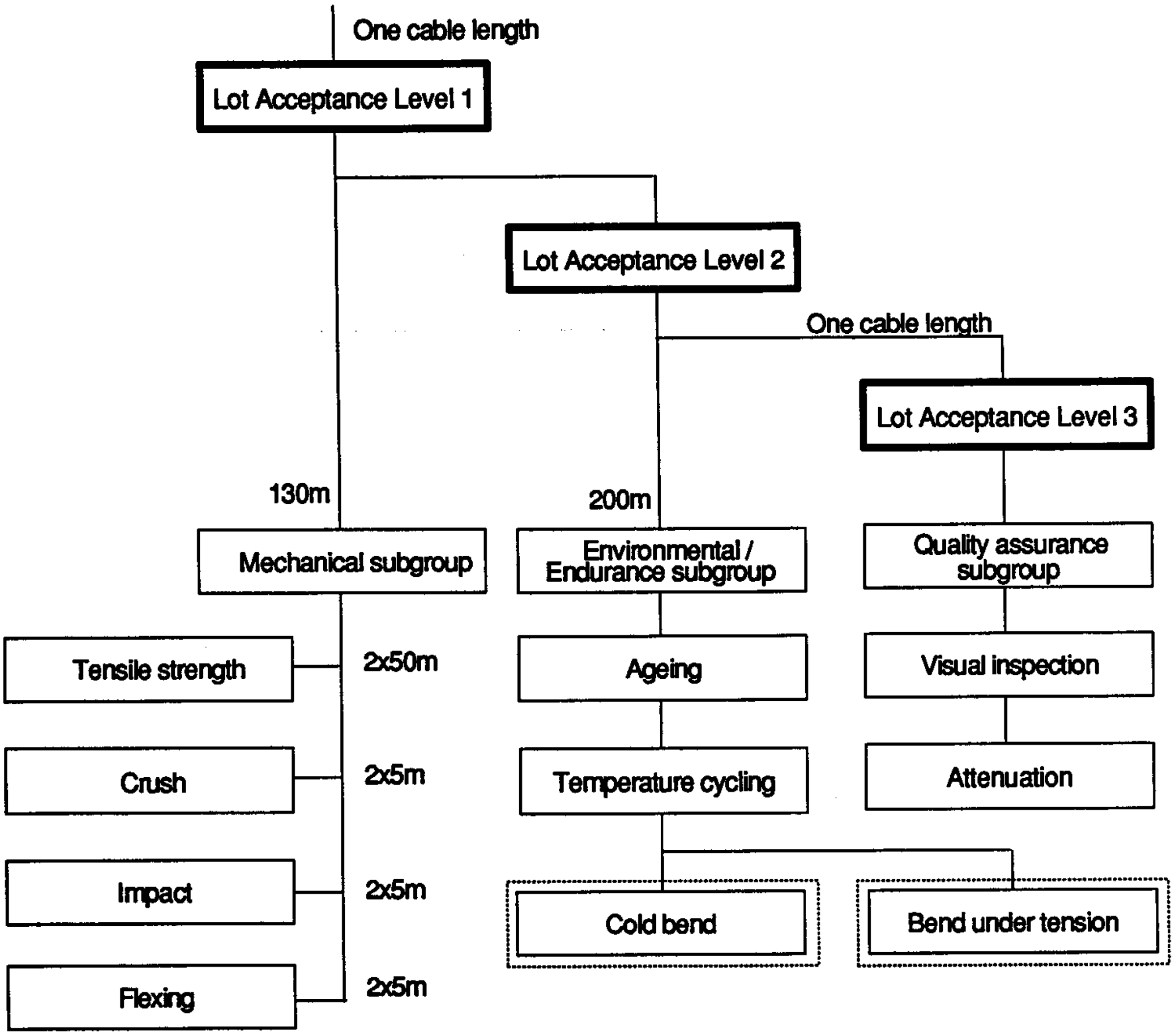

Chart 6.4 Lot acceptance testing, fibre optic cables

7 FIBRE OPTIC CONNECTORS

7.1 Introduction

The purpose of a fibre optic connector is to provide a low loss, separable connection between two fibres or several pairs of fibres. A fibre optic connector may be applied in systems where the connection is intended to be separable, but it may also be applied in systems to provide an easy installation, without the need for mechanical or fusion splices (see Chapter 8).

Fibre optic connectors exist in different versions with respect to optical and mechanical design. The optical design differs with respect to coupling method, i.e. lens coupling or butt-butt coupling. The mechanical design differs with respect to means of fibre or ferrule alignment, fastening mechanism, environmental protection and cable retention means.

The most critical part of the connector is the fibre or ferrule alignment. Low insertion loss may be dependent on mechanical alignment in the range of 1 µm. Multimode connectors and connectors based on lens coupling are somewhat less critical than single mode connectors. In space applications the mechanical alignment must be maintained over a wide temperature range and for high levels of shock and vibration, which put heavy demands on the design and choice of materials.

The same style of connectors can be applied with different fibre and cable types. Some of the properties will be related to the type of fibre or cable used, such as insertion loss, cross talk and strength of fibre or cable entry. The connector should therefore be qualified with a specific fibre and cable. Properties such as resistance to crush, drop, impact and bump are, however, related to the connector design and materials and will be independent of the type of fibre or cable. If a connector has been previously qualified with another fibre or cable, it might not be necessary to repeat these tests if the fibre or cable is changed.

7.1.1 Attachment to cable

A fibre optic connector as an individual component does not contain any optical fibre and will have to be attached to a fibre or cable before any optical measurements can be performed. Production control and final production testing are thus only possible to perform on the geometrical dimensions of the connector. The evaluation, qualification and lot acceptance testing are performed on connectors attached to a specified fibre/cable according to a specified procedure.

The attachment of the fibre/cable should be performed according to the specified procedure. Experiments have shown that the strength of the fibre and thus the reliability of the connector and the fibre link is strongly dependent on the stripping method and the handling of the bare fibre [12, 13]. Care should therefore be taken to ensure proper stripping, handling of bare fibre and attachment to cable.

7.2 Evaluation testing

7.2.1 Purpose

The purpose of the evaluation testing is to determine the operational limits of the fibre optic connector with respect to critical mechanical and environmental parameters, to overstress specific characteristics in order to identify failure modes, to demonstrate the suitability of the connector for proceeding on to qualification testing and to get information which can be of value for a detailed planning of the test programme to be used in the procurement of the connector.

7.2.2 Properties to evaluate

The main properties of interest are :

- mechanical properties
- effects of high levels of vibration and shock
- effects of temperature extremes
- effects of rapid depressurisation and vacuum operation
- effects of ionizing radiation
- effects of solar radiation and UV radiation
- resistance to solvents and contaminating fluids

For some special applications the optical power handling capability may be of concern.

The resistance to corrosive atmosphere may also be of concern in some applications. Panel/barrier sealing can be required in some applications. The connector may also be required form a hermetic seal for liquids or gases.

It is expected that the fibre used in the connector is characterised with respect to space applications. It is thus not necessary to include tests for fibre properties such as bandwidth, coating dimensions, numerical aperture, etc. in the evaluation testing. The characteristics of the fibre with respect to environmental loads such as ionizing radiation and temperature extremes should also be known.

Coatings, buffers and materials used in the connector shall be space qualified, see Chapter 4. However, an evaluation related to their properties may be necessary to eliminate any undesired interactions between the various materials and effects of changes in the material properties on the behaviour of the device.

The flammability of the connector is not expected to be a problem. The materials used should all undergo a test in this respect in the material evaluation, see Chapter 4. These properties will not depend on the manufacturing or the assembly of the connector, and the test is not included. A test with respect to dust is not included because this is not expected to be of concern in space applications.

7.2.2.1 Mechanical properties.

The fibre or ferrule retention should be tested in order to establish the mechanical strength. The fibre or cable entry shall be tested with respect pulling, axial compression, flex and torsion. The coupling mechanism should be tested with respect to properties such as strength of coupling mechanism and resistance to static load and bending moment. These properties will be independent of fibre or cable used in the connector. Mechanical properties such as resistance to acceleration, crush, drop, impact and bump should also be tested. This will also be a test of the protection and fastening mechanism for the connector and not dependent on fibre type. These tests might thus not be necessary to repeat if the connector has been previously evaluated with another fibre/cable.

7.2.2.2 Temperature extremes

A fibre optic connector might be comprised of several materials with probably different coefficients of thermal expansion. This may lead to misalignment of the different parts and a temperature dependent insertion loss variation. Thermal expansion may also induce microbend loss on the fibre within the connector or put the fibre under strain [12].

The fibre optic connector should also be tested with respect to a climatic sequence. Epoxy or another adhesive is often used to mount the fibre and such materials can be affected by combined humidity/heat.

7.2.2.3 Rapid change of temperature

Rapid change of temperature may cause excessive tension as the thermal response of the connector may be slower than the rate of change of temperature. Large thermal gradients across the connector may therefore arise, challenging the mechanical alignment and the strength of the mounting of each part of the connector. The connectors involved are usually quite small which should reduce the effect of rapid change of temperature.

7.2.2.4 Resistance to corrosive atmosphere

If the fibre optic connector is comprised of metallic parts, the connector should be tested with respect to corrosion. The test with respect to corrosion will be a test of the materials ability to withstand a corrosive atmosphere. It might also be performed after certain mechanical loads to investigate whether these mechanical loads have damaged the materials in a way impossible to reveal by other post test investigations.

7.2.2.5 Sealing

If the fibre optic connector is applied on a panel or barrier sealing may be an important property. It may also be important in those cases where the connector/cable is meant to form a hermetic seal for external gasses or liquids.

7.2.2.6 Rapid depressurisation

Rapid depressurisation may cause mechanical stresses because trapped air in pockets inside the connector may give large pressure gradients. Fibre optic connectors are usually made quite compact and the fastening mechanism designed to withstand large mechanical loads. The effects of rapid depressurisation should thus be very small, but the connector is subjected to such a test to reveal any unexpected effects.

The test with respect to the effect of rapid depressurisation will not be necessary if connectors with similar design have been previously evaluated.

7.2.2.7 Vacuum operation

The materials used in the connector shall all be space qualified, see Chapter 4. This means that the effects of vacuum operation (outgassing, change of material properties) should be very small. Interactions between the different materials may, however, arise with deleterious effects such as misalignment of the different parts of the connector and mechanical stresses. The effects of vacuum operation is of special concern if index matching liquid or glue is applied within the connector.

The test with respect to vacuum operation might not be necessary if connectors with a similar design and structure, but different fibres/cables have been previously evaluated.

7.2.2.8 Ionizing radiation

In space applications fibre optic connectors are exposed to high levels of ionizing radiation which may induce losses in the optical connector as well as change the properties of the materials. Even if the materials in the connector are space qualified, see Chapter 4, interactions may occur. Any possible interaction should be revealed during the evaluation of the connector.

The test with respect to the effects of ionizing radiation might not be necessary if connectors with identical design, but different fibre/cable have been previously evaluated.

7.2.2.9 Solar and UV radiation

Solar and UV radiation could affect the properties of the materials in the connector.If the connector is not properly designed, solar and UV radiation may also be coupled into the optical path and interfere with the signal propagation.

The test with respect to solar and UV radiation might not be necessary if connectors with identical design, but different fibres have been previously evaluated.

7.2.2.10 Resistance to solvents and contaminating fluids

During installation or service the fibre optic connector might be exposed to solvents and other contaminating fluids. These fluids may deteriorate connector materials such as glue, indexmatching liquid or metal coatings.

7.2.2.11 Optical power handling capability

The power handling capability of a fibre optic connector can be limited by the same phenomena as discussed for fibre in Chapter 5. For the connectors the end faces of the fibre to be connected are of special concern. As discussed in Chapter 5, fibre optic systems are usually operated at wavelengths with low loss and power levels in the order of 1 mW or less. The above phenomena will only be of concern in special applications were the connector is used to transmit high power levels.

7.2.3 Sample distribution and test programme sequence

7.2.3.1 Sample distribution

The fibre optic connector shall be selected at random from a lot which is 2 or 3 times larger than the number of selected samples. The connectors shall be attached to a fibre/cable according to the specified procedure.

Number of samples:	28-79, dependent on the extent of the test programme, as discussed in the text

The number of devices needed for the evaluation test programme is quite extensive. New devices are used for each test, both because each test is considered destructive and to be able to distinguish between the effects of the different parameters. The number of samples for each test is shown in Chart 7.1, see end of Chapter. In order to get a picture of the spread in values, the number of samples of each test is 3 or larger. The evaluation test programme will give a better picture of the statistical fluctuations if more connectors were used for each test. A sample size of 3 will however, give an indication of the variations. If large variations are observed, the number of samples should be increased.

7.2.3.2 Test range and failure criteria

The different tests are performed on a step stress basis. This means that the load is increased in steps from a starting value. Generally, the load is increased until the connector has suffered physical destruction or a substantial deterioration in performance, as appropriate. In some of the tests the upper stress limit is determined from the most severe loads expected, as listed in Chapter 4, with some margin added. If more severe loads are expected, the upper test level should be increased accordingly.

The criteria for failure will be defined with respect to the change in insertion loss. The purpose of the evaluation test programme is to establish the limits of performance of the connector by overstressing it with respect to mechanical and environmental loads. A larger variation in insertion loss will therefore be tolerated in the evaluation programme than in a system application of the connector. We have chosen to use a variation in insertion loss of 2 dB as a criteria for defining the connector as failed. All results shall be recorded.

7.2.3.3 Test programme sequence

The specified tests are summarised in Chart 7.1. The mechanical and environmental tests which may be dependent on the application, fibre type and previous evaluation of similar connectors are shown in a dotted box.

The initial measurements are measurements without any influence on the properties of the tested connector. The indicated order is based on the importance of the different parameters. The engagement/separation forces and the insertion loss are measured first to establish the basic performance of the connector. In multifibre connectors, the measurement shall be performed on every fibre pair and the crosstalk shall also be measured. The return loss shall be measured to establish the level of backreflection. The dependence on modal distribution shall be measured on multimode connectors. The susceptibility to ambient light coupling shall be measured for all types of connectors.

The test programme is comprised of tests with respect to mechanical and environmental loads, endurance and interchangeability. For the mechanical, environmental and endurance tests new test samples are used for each test. The test order will therefore not affect the test result and is as such of no importance. It is generally recommended to perform the easiest and least expensive tests first and the more complicated and expensive tests in the end. If the connector fails during the cheap and least expensive part of the test programme, it can be stopped before large expenses have been incurred.

We suggest to do the interchangeability tests first. The interchangeability tests include the intermateability test and the gauge retention force test. The intermateability test is performed first to establish whether the connector is compatible with a standard connector of the same style. The gauge retention test is performed to establish the tolerances to geometrical dimensions. The intermateability test is a go-nogo test and if the connectors have passed this test they should be used in the test for gauge retention force.

The mechanical tests are performed thereafter to test the connector's ability to withstand mechanical loads, the strength of the coupling mechanism and fibre or cable attachment. The fibre or ferrule retention are tested first as this will be a basic property of the connector and establish the maximum axial force and/or torque one can apply to the fibre or ferrule retention. The connector cable or fibre entry should be tested with respect to fibre or cable pulling, axial compression, flex and torsion. The connector should thereafter be tested with respect to coupling mechanism, this include tests with respect to coupling strength, static load and bending moment. The resistance to mechanical loads such as acceleration, impact, crush, drop and bump should be tested afterwards.

The environmental tests are performed after the mechanical tests. We recommend to do the temperature tests first. Testing with respect to temperature will both reveal fundamental temperature dependent properties of the optical and mechanical design and temperature dependent properties of the materials. The temperature tests include testing with respect to temperature extremes, rapid change of temperatures and climatic sequence. The test with respect to temperature extremes shall be performed first to establish the limits for the other tests.

The resistance to a corrosive atmosphere should be performed thereafter to establish the performance of the connector in a corrosive atmosphere. If sealing of the connector is required, this should also be performed at this early stage of the evaluation test programme. The reason why these tests are performed before the tests for vibration and shock is that if resistance to a corrosive atmosphere and sealing is required, these properties are important to establish before the connectors are tested with respect to other properties.

The tests with respect to the effects of vibration and shock are tested before the vacuum and ionizing radiation test. The materials applied in the connector are, in advance, tested with respect to the latter effects. The tests are performed to ensure that no unexpected effects occur. The characteristics of the connector when it is exposed to loads such as vibration and shock are less predictable and in addition easier and less expensive to perform.

The tests with respect to the effects of rapid depressurisation and vacuum operation are performed on the same samples. The effects of rapid depressurisation should be tested before the effects of vacuum operation. If the connector fails in the rapid depressurisation test, there will be no point in proceeding to the test with respect to vacuum operation.

The effect of radiation (ionizing as well as solar and UV radiation) is tested in the end, such that only connectors that have passed the other tests are subjected to this test. Radiation resistance is a fundamental requirement for components in space applications. The connector should be based on materials and fibres exhibiting minimal radiation effects, and the test is performed to ensure that no unexpected effects will occur.

In those cases where it is of special concern the resistance to solvents and contaminating fluids shall be tested.

The endurance tests are ageing and optical power handling capability, if applicable. The conditions during the ageing test are determined by the test with respect to temperature extremes. The test will thus have to be started after this test. This is a long term test with measurements at regular intervals and can be performed in parallel with the other tests.

7.2.3.4 Use of control group

The use of a control group is not considered necessary in the mechanical and environmental tests. In these tests the parameters of interest are usually monitored while the test is performed. The stability of the source output and the repeatability of the measurements are ensured by a control of the output power. If the post test investigations include optical measurements not performed during the test, the measurements shall also be performed on the control group. This may include measurements of insertion loss as a function of wavelength.

A control group is used in the construction analysis to be able to compare the connectors that have been exposed to environmental and mechanical loads with a "fresh" sample.

7.2.3.5 Post test investigations

The standard test procedures given in Chapter 7 Part 3 often specify that after the exposure to mechanical or environmental load is completed, some measurements should be made to look for permanent changes in one or more critical properties. In the evaluation programme there are in many cases specified additional tests to analyse the failure mechanisms, but also to reveal whether the load has induced changes not observed directly during the tests or revealed by the standard post test investigations. An example of such a test would be testing of the strength of fibre or cable entry after the test with respect to temperature extremes, to investigate whether temperature extremes have affected the materials in the fibre attachment in such a way that the strength is reduced.

7.2.4 Inspection

The purpose of the inspection is to make sure that the samples are suited for testing. All samples shall be inspected.

7.2.4.1 Visual inspection

The visual inspection shall be carried out in accordance with ESA/SCC Basic Specifications No. 20500.

7.2.4.2 Dimensions

Test method: 7.1.1/7.1.2/7.1.3/7.1.4

7.2.4.3 Mass

Test method: 7.1.5

7.2.4.4 Marking

All samples shall be marked in accordance with the standard procedure of the manufacturer.

7.2.5 Initial measurements

The purpose of the initial measurements is to determine the initial values of the most important optical parameters. The result from these initial measurements will be used as a basis for the evaluation of later measurements. Further, one wants to ascertain that the various samples meet the specified requirements and to get a picture of the spread in values. The spread in values will give an indication of the production control.

The initial measurements as well as the rest of the test programme are performed on connectors attached to a cable.

The initial measurements shall be performed on all samples.

7.2.5.1 Engagement and separation forces

Test method: 7.3.3

7.2.5.2 Insertion loss

The measurement shall be performed over the specified wavelength range. For multifibre connectors the measurement shall be performed on every fibre pair.

Test method: 7.2.1/7.2.6

7.2.5.3 Cross talk

The measurement applies to multifibre connectors only.

Test method: 7.2.2

7.2.5.4 Return loss

Test method: 7.2.4

7.2.5.5 Modal distribution

Test method: 7.2.5

7.2.5.6 Susceptibility to ambient light coupling

Test method: 7.2.3

7.2.6 Interchangeability tests

7.2.6.1 Intermateability

The connector is mated with another connector of the same style. The insertion loss and the engagement and separation forces are measured.

Number of samples: 3 connector pairs
Test method: 7.4.16

7.2.6.2 Gauge retention force

The test is performed to test the tolerances of the connector with respect to geometrical dimensions.

Number of samples: 3 connector pairs (same samples as in 7.2.6.1 can be used)
Test method: 7.3.6

7.2.7 Mechanical tests

The main mechanical properties to test are strength fibre or ferrule retention, strength of fibre or cable retention which includes tests for pulling, axial compression, flex and torsion and tests for strength of coupling mechanism which includes coupling strength and bending. The connector should also be tested with respect to mechanical loads such as crush, impact, drop, bump and acceleration.

7.2.7.1 Fibre or ferrule retention

The test is performed to establish the maximum axial force and/or torque it is possible to apply without inducing damage to the connector. The change in insertion loss shall be measured in each step of the test.

Number of samples: 2 connector pairs
Start value: as specified
The torque/axial force shall be increased in steps of 20% of the initial value until the connector has failed or exhibits visible changes in structure or damage has occurred.
Test method: 7.3.1

7.2.7.2 Strength of cable or fibre entry

The test with respect to strength of cable or fibre entry includes pulling, axial compression, flex and torsion tests.

7.2.7.2.1 *Pulling*

In this test the cable or fibre is subjected to increasing load until the fibre attachment breaks. For each connector pair each connector shall be subjected to the test on an individual basis.

Number of samples: 2 connector pairs

The tensile force shall be applied smoothly and controlled, the magnitude of the force shall be increased at a specified rate. The tensile force shall be increased until the fibre or cable breaks.
Test method: 7.3.4

7.2.7.2.2 *Axial compression*

The fibre or cable shall be subjected to axial compression to establish the ability of the retention means to withstand axial compression. In each connector pair each connector shall be tested on an individual basis.

Number of samples: 2 connector pairs

The axial compression shall be applied smooth and controlled, the magnitude of the force shall be applied with the specified rate. The axial compression shall be increased until the fibre or cable breaks.
Test method: 7.3.10

7.2.7.2.3 *Flex*

The test is intended to determine the ability of the fibre or cable retention to withstand flexing. For each connector pair each connector shall be tested on an individual basis.

Number of samples: 2 connector pairs
Start load: as specified
The load shall be increased in steps of 20% of the initial value until the fibre breaks.

Test method: 7.3.4

7.2.7.2.4 *Torsion*

The test is intended to determine the ability of the cable or fibre retention to withstand torsion. In each connector pair each connector shall be tested on an individual basis.

Number of samples: 2 connector pairs

The torque shall be increased until the cable or fibre breaks.
Test method 7.3.4

7.2.7.3 Coupling mechanism

7.2.7.3.1 *Strength of coupling mechanism*

The test is performed to establish the strength of the coupling mechanism. A tensile force shall be applied to the connector pair. The force shall be increased until the connector set is damaged. The change in insertion loss shall be measured during the test.

Number of samples: 3 connector pairs
Start value: as specified.
Test method: 7.3.5

7.2.7.3.2 *Bending moment*

The connector pair shall be subjected to a bending moment is such a way that the coupling mechanism is stressed. The change in insertion loss shall be measured during the test.

Number of samples: 3 connector pairs
Start value: as specified
The bending moment shall be increased until the coupling mechanism is damaged.
Test method: 7.3.7

7.2.7.3.3 *Static load*

The test is only applicable for fixed connectors and shall be performed to establish the mated connector's ability to withstand shearing forces. The change in insertion loss shall be measured during the test.

Number of samples: 3 connector pairs
Start value: as specified
The static load shall be increased until the coupling mechanism is damaged.
Test method: 7.3.2

7.2.7.4 Acceleration

Number of samples: 3 connector pairs
Start acceleration: as specified
The acceleration shall be increased until the component has failed or has suffered physical destruction.
Test method: 7.3.12

7.2.7.5 Impact

Number of samples: 3 connector pairs
Start energy: as specified
The energy in the impact shall be increased in steps of 20 % of the specified value. The load shall be increased until the component has failed or suffered physical destruction.
Test method: 7.3.11

7.2.7.6 Crush resistance

Number of samples: 3 connector pairs
Start force: as specified
The force shall be increased in steps of 20 % of the specified value. The load shall be increased until the component has failed or suffered physical destruction.
Test method: 7.3.8

7.2.7.7 Drop

Number of samples: 3 connector pairs
Start height: as specified
The height shall be increased in steps of 20 % of the initial value. The load shall be increased until the component has failed or suffered physical destruction.
Test method: 7.3.13

7.2.7.8 Bump

Number of samples: 3 connector pairs
Number of bumps: 4000 at each level of acceleration
Start acceleration: 40 g

The acceleration shall be increased in steps of 10 g. The load shall be increased until the component has failed or suffered physical destruction.
Test method: 7.3.9

7.2.8 Environmental tests

7.2.8.1 Temperature extremes

The change in insertion loss shall be measured in the specified wavelength range at each temperature.

Number of samples: 3 connector pairs
Thermal cycling: first low, then high
Low temperature: sufficient to induce connector failure, but not below - 70°C.
High temperature: sufficient to induce connector failure, but not above 150°C.
Low starting temperature: lowest specified temperature, or - 40°C if not given.
High starting temperature: highest specified temperature or 90°C if not given.
Step change in temperature: 10°C
Duration of stay at each temperature: 1 hour
Test method: 7.4.2

7.2.8.1.1 *Post test investigation*

The post test investigation include a repetition of the measurement of insertion loss after the connector has reached room temperature. The engagement and separation forces shall be measured to reveal any temperature induced changes. A visual inspection and dimensional check shall be performed on each device to check any changes in material appearance. One of the samples used in the temperature test shall be subjected to constructional analysis. The remaining samples shall be tested with respect to fibre attachment to ensure that the materials in the cable or fibre attachment are not influenced by temperature extremes.

Insertion loss,	ref: 7.2.5.2
Engagement and separation forces,	ref: 7.2.5.1
Visual inspection,	ref: 7.2.4.1
Dimensions,	ref: 7.2.4.2
Cable or fibre entry, pulling strength.	ref:7.2.7.2.1
Constructional analysis	ref: 7.2.10

7.2.8.2 Rapid change of temperature

The change in insertion loss shall be measured as a function of wavelength immediately before and after the temperature change. The insertion loss shall be measured during the change of temperature.

Number of samples: 3 connector pairs
High temperature: 10°C below high temperature limit established in 7.2.8.1
Low temperature: 10°C above low temperature limit established in 7.2.8.1
Rate of change of temperature: as specified
Test method: 7.4.3

7.2.8.2.1 *Post test investigation*

The insertion loss shall be measured when the connector has reached room temperature after the test is finished. The engagement and separation forces shall be measured to reveal any changes. A visual inspection shall be performed on the devices. One of the samples shall be subjected to a constructional analysis to investigate whether rapid change of temperature has changed the internal structure of the device.

Insertion loss	ref: 7.2.5.2
Engagement and separation forces	ref: 7.2.5.1
Visual inspection	ref: 7.2.4.1
Constructional analysis	ref: 7.2.10

7.2.8.3 Climatic sequence

The change in insertion loss shall be measured at regular intervals during the test.

Number of samples: 3 connector pairs
Low temperature: 10°C above low temperature limit established in 7.2.8.1
High temperature: 10°C below high temperature limit established in 7.2.8.1
Initial humidity: as specified
Duration of damp heat: as specified

The humidity shall be increased in steps of 10% until the connector has failed or a relative

humidity of 100 % is achieved.
Test method: 7.4.1

7.2.8.3.1 *Post test investigation*

The insertion loss shall be measured after the test. The engagement and separation forces shall be measured. The devices shall be subjected to a visual inspection and a dimensional check to look for changes in material structure and appearance. Constructional analysis is included in the post test investigation to find out whether combined humidity/heat would change any of the internal materials. The remaining samples shall be tested with respect to strength of fibre attachment to investigate the effect on the materials in the fibre mounting.

Insertion loss	ref: 7.2.5.2
Engagement and separation forces	ref: 7.2.5.1
Visual inspection,	ref: 7.2.4.1
Dimensions,	ref: 7.2.4.2
Cable or fibre retention, pulling strength,	ref: 7.2.7.2.1
Constructional analysis	ref: 7.2.10

7.2.8.4 Corrosive atmosphere

Number of samples: 3 connector pairs
The connector shall be exposed to a corrosive atmosphere according to IEC Publication 68-2-11. The connector shall be subjected to a visual inspection and a measurement of insertion loss and engagement and separation forces after the test is completed.
Test method: 7.4.6

7.2.8.5 Sealing

Number of samples: 3 connector pairs
Barrier/panel sealed and hermetic sealed connectors shall be subjected to the appropriate test procedure according to IEC publication 68-2-17.
Test method: 7.4.9

7.2.8.6 Vibration

The change in insertion loss shall be measured during the test.

Number of samples:	3 connector pairs
Vibration frequency:	100-2000 Hz
Starting acceleration:	as specified
The increase in acceleration:	steps of 20% of specified level until the level has reached 30 g or the component has failed
Duration:	90 minutes
Test method:	7.3.14

7.2.8.6.1 *Post test investigation*

The insertion loss shall be measured when the device has settled after the test. The engagement and separation forces shall be measured. The device shall be subjected to a visual inspection to look for changes in structure or appearance. Vibration may damage the coating of the metal surfaces in a way not possible to reveal by visual inspection and optical measurements. One of the samples is therefore subjected to a test with respect to corrosive atmosphere. Possible rifts or cracks in this coating may cause corrosion when the connectors are exposed to a corrosive atmosphere. Another sample is subjected to constructional analysis to investigate whether vibration induce any changes in the internal structure of the device.

Insertion loss	ref: 7.2.5.2
Engagement and separation forces	ref: 7.2.5.1
Visual inspection	ref: 7.2.4.1
Corrosive atmosphere	ref: 7.2.8.4
Constructional analysis	ref: 7.2.10

7.2.8.7 Shock

The change in insertion loss shall be measured during the test.

Number of samples: 3 connector pairs
Pulse duration: 0.5 ms
Starting acceleration: as specified
The increase in acceleration: steps of 20% of specified level until the level has reached 2000 g or the component has failed.
Test method: 7.3.15

7.2.8.7.1 *Post test investigation*

The insertion loss shall be measured when the device has settled after the test. The engagement and separation forces shall be measured. The device shall be subjected to a visual inspection to look for changes in structure or appearance. Shock may damage the coating of the metal surfaces in a way not possible to reveal by visual inspection and optical measurements. One of the samples is therefore subjected to a test with respect to corrosive atmosphere. Possible rifts or cracks in this coating may cause corrosion when the connectors are exposed to a corrosive atmosphere. Another sample is subjected to constructional analysis to investigate whether shock induce any changes in the internal structure of the device.

Insertion loss	ref: 7.2.5.2
Engagement and separation forces	ref: 7.2.5.1
Visual inspection	ref: 7.2.4.1
Corrosive atmosphere	ref: 7.2.8.4
Constructional analysis	ref: 7.2.10

7.2.8.8 Rapid depressurisation

The change in insertion loss shall be measured during the rapid depressurisation.

Number of samples: 3 connector pairs
Test method: 7.4.14

7.2.8.6.1 *Post test investigation*

The post test investigation shall include measurement of insertion loss. The engagement and separation forces shall be measured. If any of the connectors fail, a failed sample shall be subjected to constructional analysis to investigate whether rapid depressurisation may have influenced the internal structure of the connector. If all connectors pass the test, they shall be used in the test with respect to vacuum operation (7.2.8.9).

Insertion loss,	ref: 7.2.5.2
Engagement and separation forces,	ref: 7.2.5.1
Visual inspection,	ref: 7.2.4.1
Constructional analysis,	ref: 7.2.10

7.2.8.9 Vacuum operation

The insertion loss is not measured during the vacuum test, because any changes is expected to be permanent.

Number of samples: 3 connector pairs
Vacuum: 10^{-3} Pa or less
Temperature: 125°C or high temperature limit established in 7.2.8.1, whichever is lower
Duration: 24 hour
Test method: 7.4.4

7.2.8.9.1 *Post test investigation*

The post test investigation shall include measurement of the insertion loss of the tested samples as well as the control group. The engagement and separation forces shall be measured. The device shall be subjected to visual inspection to look for changes in structure or appearance. One of the samples shall be subjected to constructional analysis to investigate whether vacuum operation influenced the internal structure of the device.

Insertion loss	ref: 7.2.5.2
Engagement and separation forces	ref: 7.2.5.1
Visual inspection	ref: 7.2.4.1
Constructional analysis	ref: 7.2.10

7.2.8.10 Ionizing radiation

The change in insertion loss shall be measured at regular intervals during the exposure.

Number of samples: 3 connector pairs
Temperature: Room temperature
Optical power: As specified
Wavelength: As specified
Dose rate: 5 rad(Si)/s
Duration: The irradiation shall last until the component has failed or the total dose has reached 3 Mrad.
Test method: 7.4.12

7.2.8.10.1 *Post test investigation*

The insertion loss shall be measured when the exposure has been removed. The engagement and separation forces shall be measured. One of the samples shall be subjected to constructional analysis to investigate whether ionizing radiation has influenced the internal structure.

Insertion loss	ref: 7.2.5.2
Engagement and separation forces	ref: 7.2.5.1
Visual inspection	ref: 7.2.4.1
Constructional analysis,	ref: 7.2.10

7.2.8.11 Solar radiation

The insertion loss shall be measured at regular intervals during the test.

Number of samples: 3
Temperature: Room temperature
Radiation source: source with representative spectral output
Duration: until the component has failed or the maximum anticipated total dose has been reached
Test method: 7.4.10

7.2.8.11.1 *Post test investigation*

The insertion loss shall be measured after the test is completed. The engagement and separation forces shall be measured. The device shall be subjected to a visual inspection to look for changes in structure or appearance. One of the samples shall be subjected to constructional analysis to check whether solar radiation has influenced the materials inside the connector.

Insertion loss	ref: 7.2.5.2
Engagement and separation forces	ref: 7.2.5.1
Visual inspection,	ref: 7.2.4.1
Constructional analysis,	ref: 7.2.10

7.2.8.12 UV radiation

The change in insertion loss shall be measured at regular intervals during the exposure.

Number of samples: 3
Temperature: room temperature
Radiation source: representative UV source
Duration: until the component has failed or the maximum anticipated total dose has been reached.
Test method: 7.4.11

7.2.8.12.1 *Post test investigation*

The insertion loss shall be measured after the test is completed. The engagement and separation forces shall be measured. The device shall be subjected to a visual inspection to look for changes in structure or appearance. One of the samples shall be subjected to constructional analysis to check whether the materials inside the connector has changed during exposure.

Insertion loss	ref: 7.2.5.2
Engagement and separation forces,	ref: 7.2.5.1
Visual inspection,	ref: 7.2.4.1
Constructional analysis,	ref: 7.2.10

7.2.8.13 Resistance to solvents and contaminating fluids

Number of samples: 3 connector pairs
The connectors shall be subjected to the appropriate liquids and solvents. Reference is made to ESA/SCC Generic Specification No 3901, paragraph 9.21. No visible changes in connector appearance shall be induced. The engagement and separation forces and the insertion loss shall be measured after the tests.
Test method: 7.4.17

7.2.9 Endurance tests

7.2.9.1 Ageing

The change in insertion loss shall be measured at regular intervals during the test.

Number of samples:	3 connector pairs
Temperature:	20°C above specified operating temperature, but at least 10°C below high temperature limit established in 7.2.8.1
Duration:	Until the component has failed or the test has lasted 1000 hours.
Test method:	7.4.15

7.2.9.1.1 *Post test investigation*

The insertion loss shall be measured after the test. The engagement and separation forces shall be measured. The device shall also be subjected to a visual inspection and dimensional check to look for changes in the appearance and structure of the device. One of the samples shall be subjected to a constructional analysis to investigate whether long term high temperature has introduced changes in the internal structure. Another sample shall be tested with respect to fibre attachment to investigate whether long term high temperature have influenced the materials used in the fibre attachment.

Insertion loss	ref: 7.2.5.2
Engagement and separation forces	ref: 7.2.5.1
Visual inspection,	ref: 7.2.4.1
Dimensions,	ref: 7.2.4.2
Strength of attachment of fibre, pulling strength	ref: 7.2.7.2.1
Constructional analysis,	ref: 7.2.9

7.2.9.2 Mechanical endurance

The test is performed to see whether the engagement and separation forces and/or the insertion loss is influenced by an excessive numbers of engagement/separation.

Number of samples:	3 connector pairs
Number of engagement/separations:	until the connector pair has failed or the engagement separation forces have exceeded twice the specified value or 1000 cycles have been performed. The engagement/ separation forces shall be measured every 100 cycle.
Test method:	7.4.13

7.2.9.3 Optical power handling capability

Number of samples:	3 connector pairs
Laser source:	as specified

Input power level shall be increased in steps and measurements made of insertion loss. The entrance and exit surfaces shall also be examined for visual damage. Input power level shall be increased until the component has failed or visual damage has occurred. The maximum input level will very likely be limited by the available optical source.
Test method: 7.2.7

7.2.10 Constructional analysis

A sample from the control group and samples exposed to the other tests, as noted under the post test investigation, shall be subjected to constructional analysis. This involves that the package is opened and the internal structure of the device is investigated. The constructional analysis may include investigation of any fracture surfaces. It may also include an examination of the optical path of the system by means of visible light, for example a HeNe laser.

7.3 Production testing

7.3.1 Introduction

The production testing of a fibre optic connector includes geometrical measurements and mass. No optical measurements is possible before the connector is attached to a cable.

7.3.2 Production control

The dimensions as well as the mass of all parts shall be controlled prior to assembly.

7.3.3 Final production testing

The tests shall be performed according to Chart 7.2. Unless otherwise specified, all samples shall be tested. The final production testing includes visual inspection of the connector, in addition to a geometrical measurements and a final mass control. The engagement/separation forces shall be tested with the connector mated to a test specimen. The gauge retention force shall be tested. These tests are included to ensure that the connector is compatible with a standard connector of the same kind and that the tolerances with respect to geometrical dimensions are as specified.

7.3.3.1 Visual inspection

To be performed in accordance with ESA/SCC Basic Specification No. 20500.

7.3.3.2 Dimensions

Test method: 7.1.1/7.1.2/7.1.3/7.1.4

7.3.3.3 Mass

Test method: 7.1.5

7.3.3.4 Engagement and separation forces

Test method: 7.3.3

7.3.3.5 Gauge retention force

Test method: 7.3.6

7.4 Burn-in

Burn-in is not relevant for fibre optic connectors.

7.5 Qualification testing

The mechanical and environmental effects on a fibre optic connector cannot be determined without optical measurements. The qualification testing shall therefore be performed on connectors attached to a cable according to the specified procedure. The qualification test programme will thus include optical as well as mechanical and environmental tests. The sensitivity to mechanical and environmental loads was evaluated in the evaluation test programme. Several of the characteristics of the connector are dependent on design and technology rather than production parameters. It will therefore not be necessary to repeat some of the tests in the qualification test programme. This is noted, as appropriate, in the discussion of the qualification test strategy.

The qualification testing is divided in tests for endurance, mechanical and environmental properties. All samples supplied for testing shall however be exposed to a climatic sequence before it is exposed to the other tests. This climatic sequence is performed to expose mechanical mounting and glue to temperature variations and humidity before any other test is performed, which may change the properties of these components.

All samples are exposed to temperature extremes and a seal test, if appropriate, at the end of the test programme. This temperature cycling may reveal temperature dependent failures induced by the other environmental/mechanical loads, such as material weakening, damage to the alignment or change of properties of epoxy during the test with respect to ageing. A similar environmental stress sequence is also seen in other test programmes [14, 15]. The seal test should reveal whether changes in the connector structure have occurred that have influenced the sealing.

The environmental tests included in the qualification testing is climatic sequence, vibration, shock and temperature extremes. The effects of rapid change of temperature, vacuum operation, rapid depressurisation, radiation (including ionizing radiation, solar and UV radiation) and resistance to solvents and contaminating fluids have all been investigated during the evaluation process. Any effects of these loads will be related to technology and design and not to production, and it will therefore not be necessary to repeat the tests in the qualification test programme.

The tests for connector endurance include the effects of long term temperature endurance (ageing) and mechanical endurance when the connector is engaged/separated an excessive number of times. These properties could be affected by production parameters such as change in material properties and dimensional variations. The mechanical endurance is tested after the ageing test to reveal any failures induced by the long term high temperature.

The mechanical tests are performed to ensure that the connector meet the specified mechanical requirements. The tests include fibre or ferrule retention, cable or fibre entry (pulling, axial compression, flex and torsion) and drop. Strength of coupling mechanism is also included to reveal any variation in materials used for the fastening mechanism. The resistance to static loads and bending is dependent on material and design and is evaluated in the evaluation phase. Any production related failure in material should be revealed by the test for strength of coupling mechanism. Testing with respect to crush, bump and impact is not included because this is all testing of the materials and design of the mechanical parts of the connector. These characteristics are evaluated in the evaluation phase. Production related failures will probably be revealed by the drop test. This test is chosen to evaluate the mechanical characteristics because this will be the most likely mechanical load during the system lifetime. (drop of connector while the connection is changed on a panel board). Mechanical properties which may affect the internal mounting of the connector, for example acceleration, are covered by the vibration and shock tests.

Each group consists of 4 connectors. The number of samples are chosen to get an indication of the spread in values. The qualification test programme uses few devices for each test, thus all samples shall meet the requirements.

7.5.2 Environmental tests

7.5.2.1 Climatic sequence

Test method: 7.4.1

7.5.2.2 Vibration

Test method: 7.3.14

7.5.2.3 Shock

Test method: 7.3.15

7.5.2.4 Temperature extremes

Test method: 7.4.1

7.5.2.5 Sealing

Test method: 7.4.9

7.5.3 Endurance tests

7.5.3.1 Ageing

In those cases were the connector is intended to be used in a humid atmosphere, the component shall be exposed to humidity at a specified level together with the high temperature level. Humidity may induce changes and failures not seen in an atmosphere of dry heat.
Test method: 7.4.15

7.5.3.2 Mechanical endurance

Test method: 7.4.13

7.5.4 Mechanical tests

7.5.4.1 Fibre or ferrule retention

Test method: 7.3.1

7.5.4.2 Cable or fibre retention

Test method: 7.3.4

7.5.4.3 Strength of coupling mechanism

Test method: 7.3.5

7.5.4.4 Drop

Test method: 7.3.13

7.6 Lot acceptance testing

Lot acceptance testing (LAT) shall be performed on every lot delivered by the manufacturer. The purpose of the tests which have been included in the LAT-test programme is discussed in 7.2. The sequence of the tests in each level is discussed in 7.2 and 7.5.

The delivery of a lot fibre optic connectors does not include any optical fibres or cables. The properties of the connector is strongly related to the type of fibre/cable used and the attachment operation, the lot acceptance testing should thus be performed on connectors attached to cables according to the prescribed procedure.

LAT is divided in three levels, as discussed in Chapter 4. The connectors are attached to a cable and will not form part of the delivered lot.

It is expected that a limited number of connectors will be procured. The number of connectors to test is thus small.

All tested samples shall meet specifications.

The LAT shall be carried out in accordance with Chart 7.4

7.6.1 Lot acceptance level 3 testing (LA3)

Since the final production testing includes only geometrical measurements, the LA3 testing for fibre optic connectors is much more comprehensive than for other passive fibre optic components. The LA3 testing includes optical measurements as well as a temperature cycle to ensure that the connector is produced according to specifications.

7.6.1.1 Visual inspection

The visual inspection shall be performed according to ESA/SCC Basic Specification No 20500.

7.6.1.2 Insertion loss

The measurement shall be performed over the specified wavelength range.
Test method: 7.2.1

7.6.1.3 Cross talk

The measurement applies to multifibre connectors only.

Test method: 7.2.2

7.6.1.4 Temperature extremes

Test method: 7.4.2

7.6.2 Lot acceptance level 2 testing (LA2)

In addition to the tests included in the LA3 testing, the LA2 is comprised of tests with respect to ageing and strength of fibre attachment. The tests are considered destructive. The test with respect to the strength of the fibre attachment is performed after the ageing test to reveal any ageing related defects.

7.6.2.1 Ageing

The test shall include humidity if required by the application.
Test method: 7.4.15

7.6.2.2 Strength of fibre/ferule retention

Test method: 7.3.1

7.6.2.3 Strength of cable retention/cable entry

Test method: 7.3.4

7.6.2.4 Mechanical endurance

Test method: 7.4.13

7.6.2.5 Sealing

Test method: 7.4.9

7.6.3 Lot acceptance level 1 testing (LA1)

In addition to the tests included in the LA2 testing, the LA1 is comprised of tests with respect to mechanical and environmental properties. The tests are considered destructive. The sequence is discussed in 7.2 and 7.5.

7.6.3.1 Temperature extremes

Test method: 7.4.2

7.6.3.2 Vibration

Test method: 7.3.14

7.6.3.3 Drop

Test method: 7.3.13

7.6.3.4 Corrosive atmosphere

Test method: 7.4.6

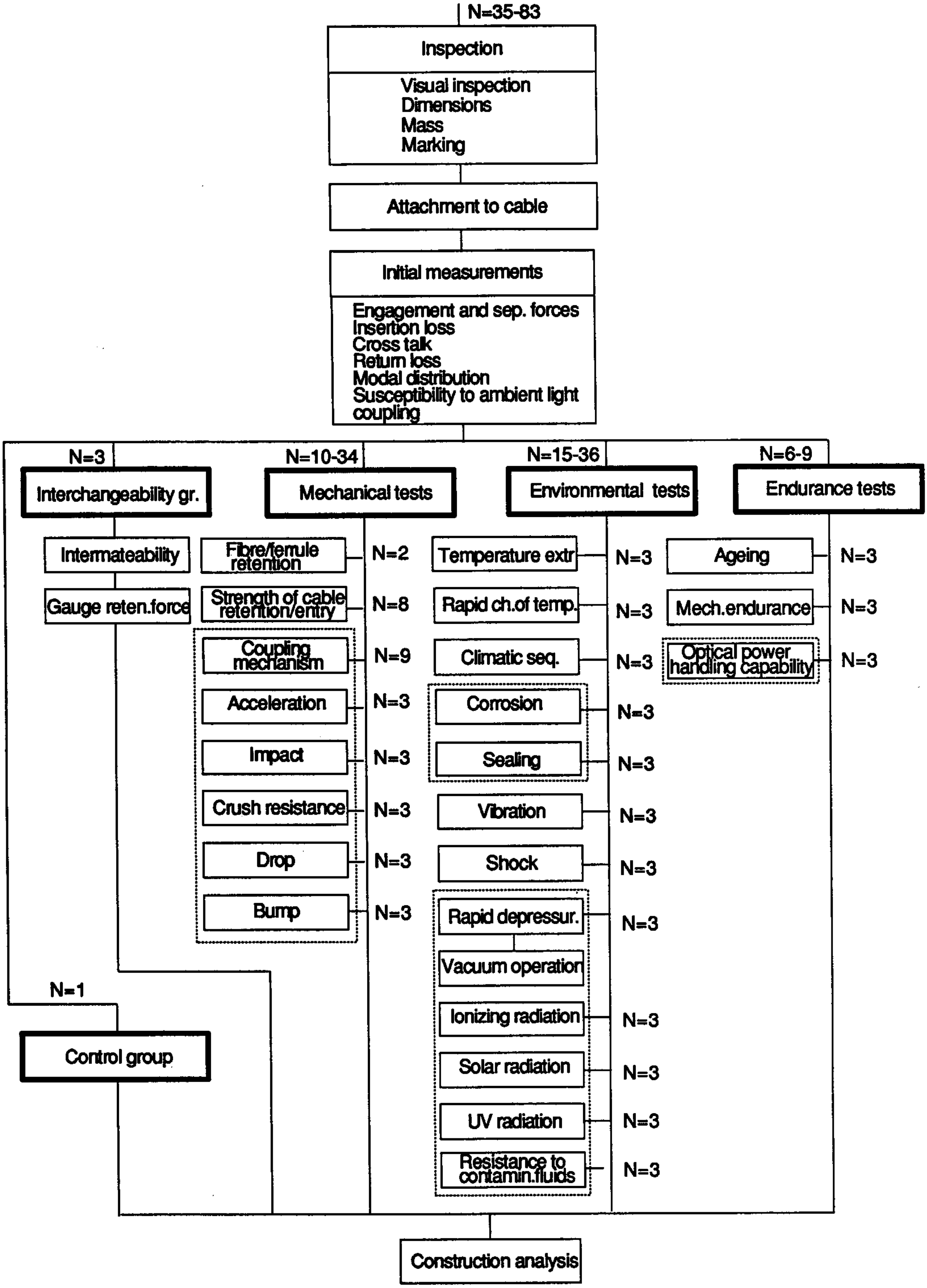

Chart 7.1 Evaluation testing for fibre optic connectors

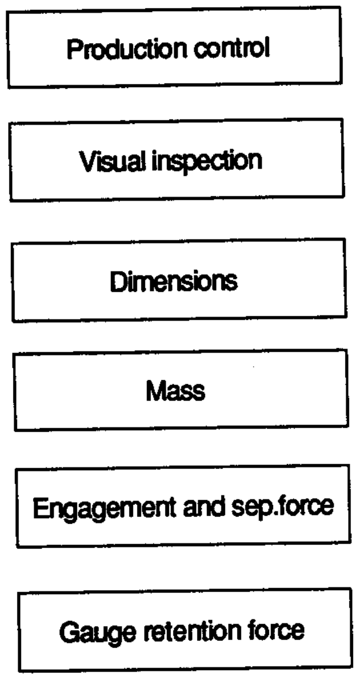

Chart 7.2 Final production testing for fibre optic connectors

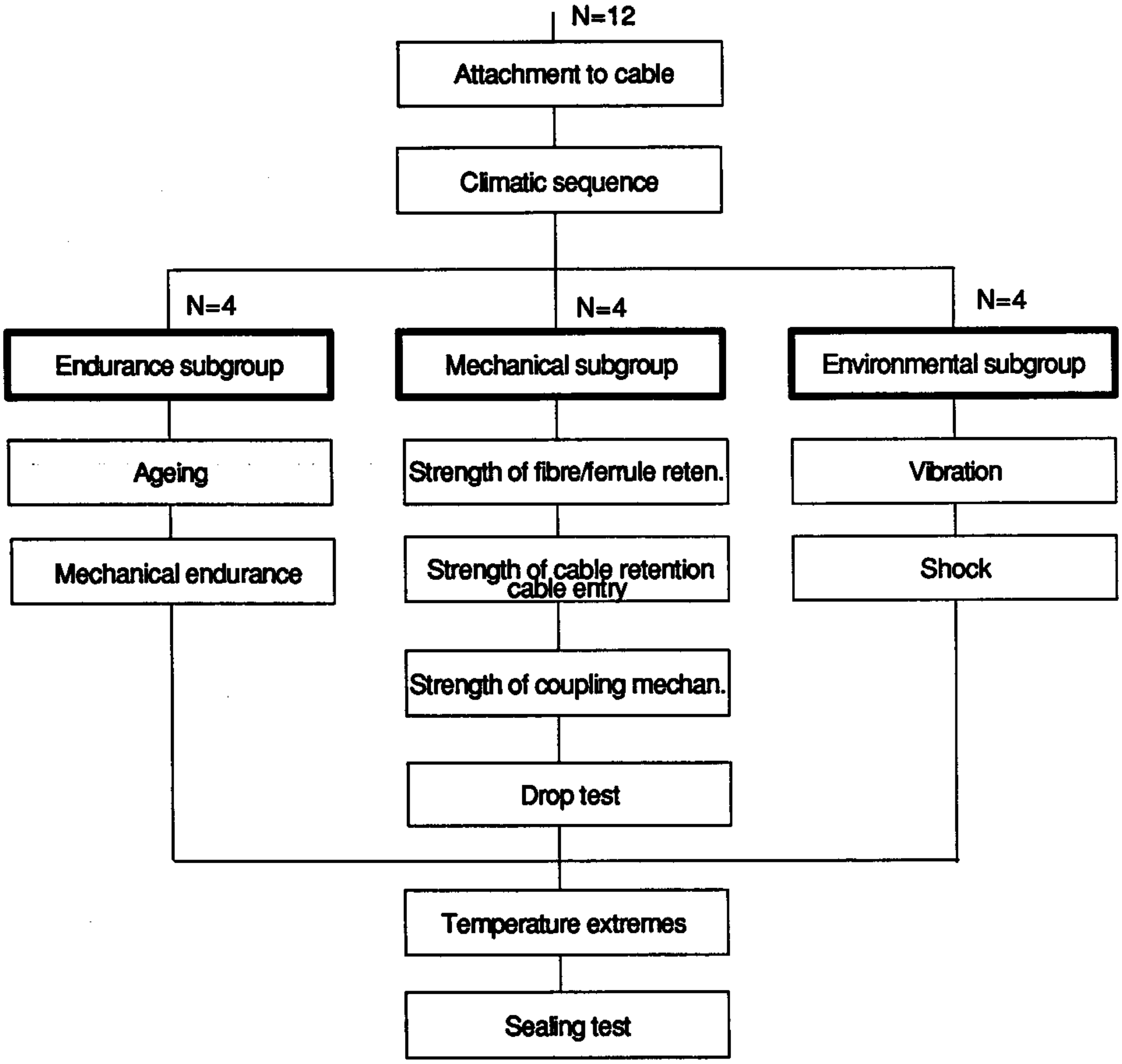

Chart 7.3 Qualification testing for fibre optic connectors

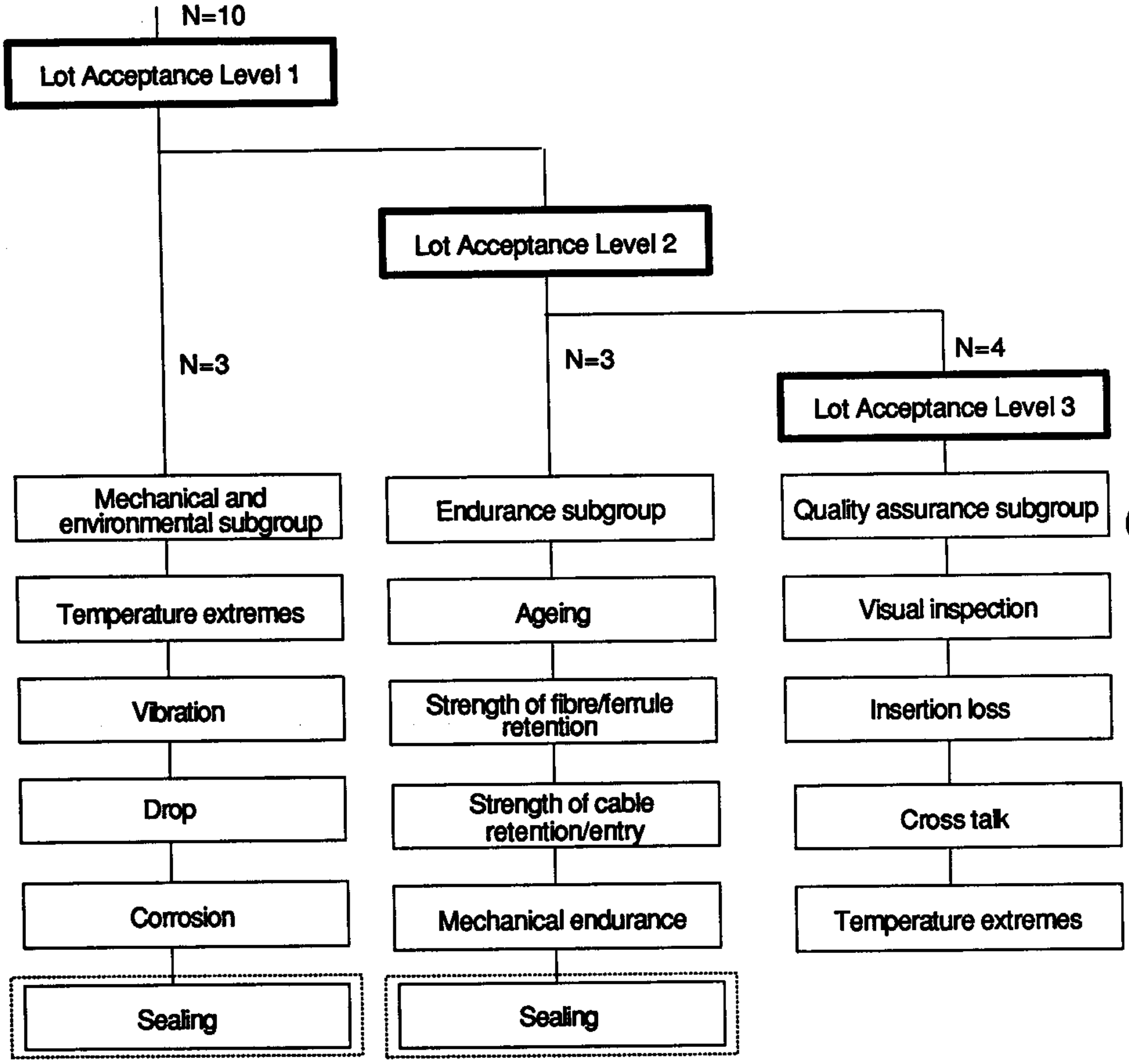

Chart 7.4 Lot acceptance testing for fibre optic connectors