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Fiber & Cable in Harsh Environment Recommended Testing Procedures

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In light of the absence of official standards for harsh environment fiber optic cables and the fibers within, the manufacturers of fiber optic cables and of fiber optic fibers for harsh environments as well as users of these fibers and cables created this document as a first step toward having a common set of procedures in order to assess performance in these environments. While exact environmental conditions vary between each application and all details regarding the conditions are not always understood, the recommended testing procedures listed in this document can be modified to be as general or as customized as desired, with the intention that this document be a discussion point between the manufacturer and the customer.

1 Introduction

1.1 Scope

This document describes recommended test procedures for the key parameters of optical fibers and cables used in Oil & Gas applications such as Distributed Temperature Sensing, Logging and other down hole measurements. The intent of the document is merely a series of recommended practices to assess the performance of fiber and cable, and not specification values for the various parameters to be met by the manufacturer.

1.2 Approach

The Fiber & Cable working group recognizes the existence of various standards and documented test methods for some of the fiber/cable parameters. Therefore, wherever applicable, existing methods are recommended throughout this document. Most of the focus for this document is on features and parameters that are specific to the O&G environments and applications that represent important information for the prediction of the lifetime of fiber/cable in operation.

1.3 Definition

"Fiber" is defined as the glass, cladding and coating layers of the optical fiber. Layers beyond this, including buffering, Stainless Steel Tubing (SST), etc, are considered "cable".

SM - Single Mode Fiber
MM - Multimode Fiber

2 Fiber References:

2.1 Measurement Standards

Where there is both a TIA and IEC number, both organizations subscribe to the same standard.

Optical

FOTP-78	TIA-455-78B	IEC-60793-1-40	Spectral Attenuation
FOTP-204	TIA-455-204	IEC-60793-1-41	Bandwidth
FOTP-133	TIA-455-133A	IEC-60793-1-22	OTDR Length
FOTP-80	TIA-455-80C	IEC-60793-1-44	Cutoff Wavelength
FOTP-191	TIA-455-191B	IEC-60793-1-45	Mode Field
FOTP-177	TIA-455-177B	IEC-60793-1-43	Numerical Aperture
FOTP-62	TIA-455-62B	IEC-60793-1-47	Macrobend Loss

Geometry FOTP-176	TIA-455-176A	IEC-60793-1-20	Bare Fiber Geometry
FOTP-195	TIA-455-195A	IEC-60793-1-21	Coating Geometry (Acrylate)

Mechanical

FOTP-31	TIA-455-31C	IEC-60793-1-30	Prooftest (Non-Polyimide)
FOTP-28	TIA-455-28C	IEC 60793-1-33	Dynamic Fatigue Testing
FOTP-178	TIA-455-178A	IEC-60793-1-32	Coating Strip Force

Aging

FOTP-160		IEC-60793-1-50	Damp Heat
FOTP-67		IEC-60973-1-51	Dry Heat
FOTP-234		IEC-60793-1-52	Temp Cycle
		IEC-60793-1-53	Water Immersion

3 Fiber Tests

3.1 Environmental Conditions to be Identified for Testing

a) When each test is performed, the following conditions must be documented:
1. Temperature
2. Pressure
3. Presence Hydrogen - Partial pressure of Hydrogen
4. Atmosphere – i.e. air, Nitrogen, etc.
5. Fiber deployment
6. Duration

3.2 Tests

1) Optical

a) Attenuation
   1. Reference
      a. IEC 60793 -1 -40
   2. Comments/Additions
      a. Use As Is

b) BW (MM Fiber)
   1. Reference
      a. IEC 60793 -1 -41
   2. Comments/Additions
      a. Use As Is

c) MFD (SM Fiber)
   1. Reference
      a. IEC 60793 -1 -45
   2. Comments/Additions
      a. Use As Is

d) Numerical Aperture (NA) (MM Fiber)
   1. Reference
      a. IEC 60793 -1 -43
   2. Comments/Additions
      a. Use As Is

e) Cutoff Wavelength (SM Fiber)
   1. Reference
      a. IEC 60793 -1 -44
   2. Comments/Additions
      a. Use As Is

f) Macrobending
   1. Reference
      a. IEC 60793 -1 -47
   2. Comments/Additions
      a. Use As Is

2) Geometrical

a) Reference
   i) IEC 60793 -1 -20
b) Comments/Additions
   i) Use As Is, Including
   (i) Diameter
      1. Core

2. Clad

(ii) Coating

1. Core to Clad offset
2. Non-Circularity

3) Mechanical

a) Strength (tensile) (Proof test)

1. Reference
   a. IEC 60793-1-30
2. Usability
   a. As is (for acrylates) with the additions below for other coatings.
3. Comments/Additions
   a. Coatings other than acrylates may require different settings.
   b. Care should be given that the fibers are not slipping while under test, which would result in false readings.
4. Data to be Reported
   a. Fiber Identification
   b. Proof test level
   c. Length of fiber tested
   d. Method used for test
   e. Pass or Fail to required level

b) Strip Force/Strip ability

1. Reference
   a. IEC 60793-1-32
2. Usability
   a. As is (for acrylates) with the additions below for other coatings.
3. Comments/Additions
   a. Coatings other than acrylates may require different techniques.
4. Data to be Reported
   a. Fiber Identification

4) Environmental

a) Hydrogen testing

1. Reference Appendix A

b) Temperature Cycling

1. Reference
   a. IEC 60793-1-52
2. Usability
   a. Use as is with additions below.
3. Comments/Additions
   a. Procedure to be modified to accommodate higher max temperature tests.
      (a) Apparatus should be adequate for required temperatures.
   b. Note compatibility of cable fiber will be deployed in.
4. Data to be Reported
   a. As written

c) Water Immersion

1. Reference
   a. IEC 60793-1-53
2. Usability
   a. Use as is with additions below.
3. Comments/Additions
   a. Not Applicable
4. Data to be Reported
   a. As written

d) Humidity (Damp Heat)

1. Reference
   a. IEC 60793-1-53
2. Usability
   a. Use as is
3. Comments/Additions
   a. Not Applicable
4. Data to be Reported
   a. As written

5) Data to Be Reported for Environmental Testing

a) Attenuation
   1. Baseline
   2. At saturation
   3. Delta
   4. Variation down the length of the fiber (Measured using an OTDR)
b) Effective Group Index
c) BW (as applicable)

4 Cable Tests

4.1 Environmental Conditions to Be Identified for Testing

1) When each test if performed, the following conditions must be documented:
   a) Temperature
   b) Pressure
   c) Presence Hydrogen - Partial pressure of Hydrogen
   d) Atmosphere
   e) Cable deployment
   f) Duration

4.2 Tests

a) <u>Tensile Performance</u> (In a STRAIGHT Line)
   1. Applicability
      a. Testing for Installation
   2. Reference
      a. IEC 60794-1-2 Section 5 (p.27)
   3. Usability
      a. Use as is with additions below
   4. Comments/Additions
      a. After perform test, pull to failure and characterize that.
         (a) Three main objectives:
            (i) Max stress
            (ii) UTS – Ultimate Tensile Strength
            (iii) What is the max load that can put on the cable before fiber sees any effects
            (iv) (How that translates into other environments.?)
         (b) Add cable strain measurement (in addition to fiber strain)
            (i) Capture the change in attenuation AND fiber strain AND the cable strain
               1. Not and/or
               2. Clarification point – need to do all tests that are listed. Not a change statement.
         (c) Recommended Max Tensile Load
            (i) per detailed spec
         (d) NOTE : Need to do the stress/strain test and then pull to failure
   5. Data to be Reported
      a. As written. With addition of capturing attenuation over wavelength range as opposed to a single wavelength.

   b) <u>Crush</u>
      1. Applicability
         a. Clamping, termination (passing through the packer), general deployment
      2. Reference
         a. IEC 60794-1-2 Section 7 (p.45)
      3. Usability
         a. Can be used as written with the additions below.
      4. Comments/Additions
         a. Tests shall be performed before test, during crush and after release of crush.
         b. After crush test and all measurements listed in ‘a’ above, cable should be dissected and each component inside should be measured dimensionally for deformation and report change in dimensions from original.

5. Data to be Reported
   a. As listed in the requirements section 7.5 plus additions noted here

c) Impact
1. Applicability
   a. Installation, transportation and general usage
2. Reference
   a. IEC 60794-1-2 Section 8 (p.49)
3. Usability
   a. Use as is.
4. Comments/Additions
   a. Similar to “Crush” test.
   b. Tests shall be performed before test, during impact and after release of impact.
   c. After impact test and all measurements listed in ‘b’ above, cable should be dissected and each component inside should be measured dimensionally for deformation and report change in dimensions from original.
5. Data to be Reported
   a. As written

d) Bending Under Tension (Sheave Test)
1. Applicability
   a. General usage, installation
2. Reference
   a. IEC 60794-1-2 section 20 (p. 117)
3. Usability
   a. OK as written with exceptions that any attenuation increase will be reported with no limits
4. Comments/Additions
   a. Method E18B – Not applicable
5. Data to be Reported
   a. Any change in attenuation and any visible deformation

e) Repeat Bending
1. Applicability
   a. General usage, logging applications
2. Reference
   a. IEC 60794-1-2 section 10 (p.57)
3. Usability
   a. OK as written
4. Comments/Additions
   a. Cold temperature testing recommended if applicable in deployment
5. Data to be Reported
   a. As Written

f) Bend (Wrap around a mandrel and unwrap)
1. Applicability
   a. Mechanical (Bending during installation)
   b. Optical (Before affecting optical signal)
2. Reference
   a. IEC 60794-1-2 section 14 (p.79)
3. Usability
   a. Ok as written
4. Comments/Additions

a. Cold temperature testing recommended if applicable in deployment

5. Data to be Reported
   a. Any attenuation increase will be reported with no limits

g) <u>Torsion</u>

1. Applicability
   a. Reeling and unreeling cable during manufacturing and installation.
2. Reference
   a. IEC 60794-1-2 section 11 (p.63)
3. Usability
   a. Ok as written
4. Comments/Additions
   a. Static vs. dynamic application
5. Data to be Reported
   a. As Written

h) <u>Seepage of Flooding Compound (Compound Flow)</u>

1. Applicability
   a. Performance during usage
2. Reference
   a. IEC 60794-1-2 section 17 (p.97)
3. Usability
   a. OK as written.
4. Comments/Additions
   a. Mechanical Only
5. Data to be Reported
   a. As Written

i) <u>Water Tightness/Hydrostatic - Pressure (Burst/Collapse)</u>

1. Applicability
   a. Performance during usage
2. Reference
   a. IEC 60794-1-2 section 29 (p.157)
3. Usability
   a. OK as written
4. Comments/Additions
   a. For umbilicals – Refer to ISO 13628-5 for this test. (Duration is different)
   b. This test as a function of dents/dings.
5. Data to be Reported
   a. Report attenuation before and after test.

j) <u>Temperature Cycling</u>

1. Applicability
   a. Performance during usage
2. Reference
   a. IEC 60794-1-2 section 23 (p.135)
3. Usability
   a. OK as written.
4. Comments/Additions
   a. Not Applicable
5. Data to be Reported
   a. As Written

k) <u>Aging (Long Term Temperature)</u>

1. Applicability

a. To capture the effects of being in use at temperature during usage.

2. Reference
    a. IEC 60794-1-2 section 28 (p.155)
    b. Written as "under consideration" in IEC document.
3. Usability
    a. OK As is
4. Comments/Additions
    a. Not Applicable
5. Data to be Reported
    a. Not Applicable

l) <u>Abrasion</u>

1. Applicability
    a. Mechanical Only
2. Reference
    a. IEC 60794-1-2 section 6
3. Usability
    a. OK as written
4. Comments/Additions
    a. Only applicable to plastic sheathed constructions and non-metal construction.
5. Data to be Reported
    a. As Written

m) <u>Cut Through Resistance (outer sheath)</u>

1. Applicability
    a. Mechanical only
2. Reference
    a. IEC 60794-1-2 section 15
3. Usability
    a. OK as written
4. Comments/Additions
    a. Only applicable to plastic sheathed construction and non-metal construction
5. Data to be Reported
    a. As Written

n) <u>Stiffness</u>

1. Applicability
    a. Mechanical only
2. Reference
    a. IEC 60794-1-2 section 19
3. Usability
    a. OK as written
4. Comments/Additions
    a. Not Applicable
5. Data to be Reported
    a. As Written

o) <u>Kink</u>

1. Applicability
    a. Mechanical only
2. Reference
    a. IEC 60794-1-2 section 13 (kink) and section 36 (tube kink)
3. Usability
    a. OK as written
4. Comments/Additions

a. Not Applicable

5. Data to be Reported

    a. Report at the minimum bend before the kink

p) <u>Water Penetration</u>

1. Applicability
    a. Performance during usage
2. Reference
    a. IEC 60794-1-2 section 25 (p. 145)
3. Usability
    a. Not Applicable
4. Comments/Additions
    a. Not Applicable
5. Data to be Reported
    a. As Written

5 Appendix A:

***Safety Caution:* This is a potentially dangerous test. Appropriate cautions should be taken. It is recommended that an expert in safe Hydrogen testing setup and procedures be consulted before attempting this test.**

Reference:
"Explosion Characteristics of Hydrogen-Air and Hydrogen-Oxygen Mixtures at Elevated Pressures", By:Schroedeh, Y; Holtappels, K.
International Conference on Hydrogen Safety, 8-10 September 2005, Pisa, Italy
http://conference.ing.unipi.it/ichs2005/Papers/120001.pdf

All of the papers from this conference can be accessed at:
http://conference.ing.unipi.it/ichs2005/ichs.pdf

General Notes for Hydrogen Testing:

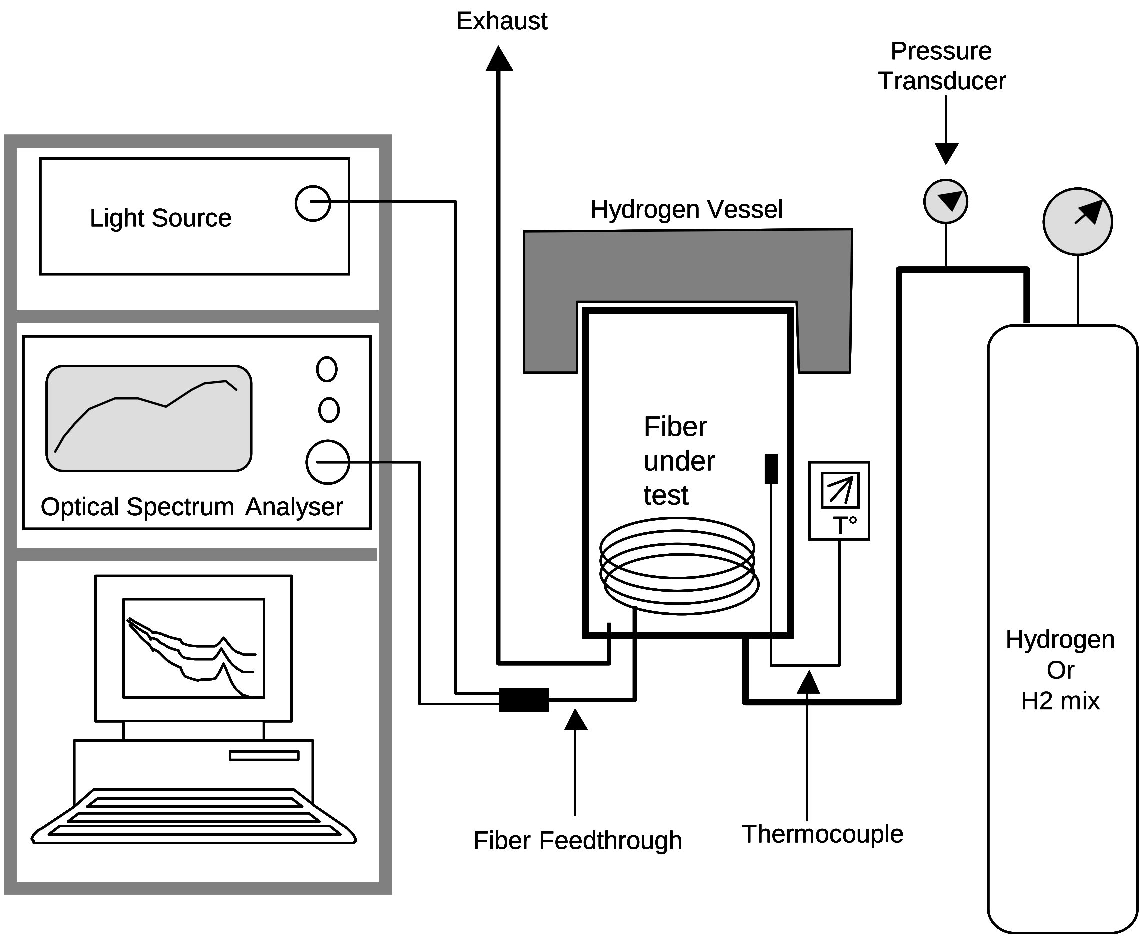
1) The necessary precautions should be taken to verify that the test setup itself and the processes and procedures that are used to set up the test do not damage or precondition the fiber in any way that would skew the results of the testing.
2) Before start of testing, care should be taken that the optical instrumentation that will be used for the measurements is of sufficient lifetime so as to survive the duration of the test without degradation.
3) For online testing, care should be taken that the optical instrumentation that will be used should not be disconnected once the first reference measurement is taken to avoid additional measurement variability. To this point, it is recommended that an optical switch be used to connect the Reference fiber and the fiber under test to the optical instrumentation.

General Notes for Hydrogen Testing Online versus Offline:

1) Both methods, online and offline, for hydrogen testing of fibers are listed in this document as both are acceptable methods. However, it should be noted that the results from the different tests could be slightly different due to the nature of what is actually being measured in each condition if not compared properly. The physical presence of Hydrogen in the fiber during the online testing will vary the results from the offline testing results where the Hydrogen is not actively present in the fiber in the same amounts when the measurements are being taken as it was when the fiber was located in the testing chamber with the Hydrogen during the online measurements.
2) When fiber comes into contact with Hydrogen, there are two main affects.
    a. *Temporary:* An increase in the attenuation of the fiber due to the actual hydrogen molecules present at the time of measurement. This attenuation will decrease over time as the Hydrogen molecules dissipate out from the fiber once the fiber is removed from the presence of Hydrogen.
    b. *Permanent:* An increase in the attenuation of the fiber due to the effects of the Hydrogen on the molecular structure of the fiber. This molecular change is permanent and will not decrease once the Hydrogen has been removed.
3) The offline measurement technique does not allow for the full measurement of the temporary effects of the hydrogen. It should be noted whether the testing was online or offline and care should be taken when comparing results from fibers measured using the different techniques. For example:
    a. Comparison of the offline results of one fiber with the online results of another are not a true comparison.
    b. Comparison of offline and online results measured X hours after removing the fibers from the presence of hydrogen and temperature is a true comparison.

5.1 Schematic of Hydrogen Test Set Up

Proposed Hydrogen Testing Set-up



5.2 Testing Procedure for Online Testing (per diagram above)

Recommended Method

a. Prepare sample for testing and an exact duplicate sample (from the same lot of fiber) to be used as the reference coil.
   1. Sample length should be adequate for the sensitivity of the optical testing equipment.
      a. Recommended Sample Length = 200m – 1,000m, with ideal length = 500m
      b. Exceptions can be requested in the detailed specification. Exact length should be reported with data pack.
   2. Sample should be placed in a loose coil configuration with a diameter large enough to not induce macro-bend loss.
      b. It is recommended that the metal testing vessel be purged with Nitrogen at a temperature that is adequate to purge any trapped Hydrogen inside the testing vessel before placing the fiber into the testing vessel.
      c. Place sample into chamber.

d. Place the reference coil at room temperature, away from the Hydrogen and in the same room/environment as the optical instrumentation.
   (a) The purpose of this reference coil is to monitor and detect shifts in the optical instrumentation. (that is also used to measure through the coil that is in the chamber) due to temperature drifts over time.
   (b) The values measured from the coil in the chamber will be compensated for any drift seen due to the optical instrumentation. shift.
e. Connect fiber ends of the sample to the optical instrumentation.
f. Seal the testing chamber.
g. Purge the chamber with Nitrogen to remove stray Hydrogen that may be present in the chamber
h. Increase the temperature in the chamber to a stable value between 25°C and 40°C
i. Take reference measurements at a stable temperature with no hydrogen present.
   (a) Use care to not disconnect fibers under test from the optical instrumentation once reference measurement has been taken.
j. Introduce a small amount of Hydrogen into the chamber and use a Hydrogen detector at all connection points where Hydrogen is present to verify that there are no leaks in your test setup.
k. Purge the chamber with Nitrogen to remove Hydrogen.
l. Increase the temperature in the chamber to the target testing temperature as specified in the detailed specification utilizing standard ramp rates compatible with testing equipment capabilities.
   Note: Increasing the temperature too quickly could over stress the fibers and cause damage that would invalidate the testing.
   (a) Recommended to perform temperature ramp in 100% Nitrogen. Not mandatory.
m. Take reference measurements once the chamber has stabilized at target temperature with no hydrogen present.
n. Introduce Hydrogen/Hydrogen mix as needed to pressurize the chamber.
o. Exact testing conditions, as listed below, shall be specified in the detailed specification.
   (a) Temperature
   (b) Pressure
   (c) Partial Pressure of Hydrogen
   (d) Duration
p. Take optical measurements at intervals throughout the course of the test appropriate to the type of fiber under test. The duration and intervals should be chosen to be adequate enough to portray the performance of the fiber in that environment.
   (a) Optical Source
      (i) Single wavelength source or Broadband source is acceptable.
      (ii) Type of source should be noted in results
      NOTE: Single wavelength data should not be used to extrapolate a broader range of data.
q. Upon completion of the testing remove Hydrogen and depressurize the chamber
   (a) Either by stopping the flow of Hydrogen or by purging the chamber with Nitrogen
r. Ramp Temperature down to stable temperature (25°C-40°C) using standard ramp rates

s. Take a last reference measurement at a stable temperature with no hydrogen present.

5.3 Testing Procedure for Offline Testing

General Notes for Offline Hydrogen Testing:
Due to the nature of the offline measurement, natural variability will be seen due to the disconnection and reconnection of the fibers as well as the movement of the fibers to complete the measurements.

Recommended Method

a. Prepare sample for testing and an exact duplicate sample (from the same lot of fiber) to be used as the reference coil.
   1. Sample length should be adequate for the sensitivity of the optical testing equipment.
      a. Recommended Sample Length = 200m – 1,000m, with ideal length = 500m
      b. Exceptions can be requested in the detailed specification. Exact length should be reported with data pack.
   2. Sample should be placed in a loose coil configuration with a diameter large enough to not induce macro-bend loss.
      b. It is recommended that the metal testing vessel be purged with Nitrogen at a temperature that is adequate to purge any trapped Hydrogen inside the testing vessel before placing the fiber into the testing vessel.
      c. Connect the sample coil to be tested to the optical instrumentation.
         (a) Use care to use the same instrumentation for each measurement.
         (b) Optical Source
            (i) Single wavelength source or Broadband source is acceptable.
            (ii) Type of source should be noted in results

         NOTE: Single wavelength data should not be used to extrapolate a broader range of data.
   d. Place sample into chamber.
   e. Seal the testing chamber.
   f. Purge the chamber with Nitrogen to remove stray Hydrogen that may be present in the chamber
   g. Place the reference coil at room temperature, away from the Hydrogen and in the same room/environment as the optical instrumentation.
      (a) The purpose of this reference coil is to monitor and detect shifts in the optical instrumentation (that is also used to measure through the coil that is in the chamber) due to temperature drifts over time.
      (b) The values measured from the coil in the chamber will be compensated for any drift seen due to the optical instrumentation shift.
      (c) Connect fiber ends of the reference coil to the optical instrumentation.
      (d) Take a measurement of the reference coil
   h. Increase the temperature in the chamber to a stable value between 25°C and 40°C
   i. Introduce a small amount of Hydrogen into the chamber and use a Hydrogen detector at all connection points where Hydrogen is present to verify that there are no leaks in your test setup.
   j. Purge the chamber with Nitrogen to remove Hydrogen.
   t. Increase the temperature in the chamber utilizing standard ramp rates compatible with testing equipment capabilities.

      Note: Increasing the temperature too quickly could over stress the fibers and cause damage that would invalidate the testing.

(a) Recommended to perform temperature ramp in 100% Nitrogen. Not mandatory.

k. Introduce Hydrogen/Hydrogen mix as needed to pressurize the chamber.

l. Exact testing conditions, as listed below, shall be specified in the detailed specification.
   (a) Temperature
   (b) Pressure
   (c) Partial Pressure of Hydrogen
   (d) Duration

m. Upon the completion of the test, remove Hydrogen and depressurize the chamber
   (a) Either by stopping the flow of Hydrogen or by purging the chamber with Nitrogen

n. Ramp Temperature down to room temperature using standard ramp rates

o. Remove the sample from the chamber

p. Connect the sample to the optical instrumentation and take another measurement.

6 Appendix B:

6.1 Condensed Matrix

Property	Fiber Class			
max temp hydrogen presence	250°C H2 Resistant	177°C H2 Resistant	85°C H2 Resistant	85°C standard
Temp rating (deg C)	-18 to 250	-18 to 177	-20 to 85	-20 to 85
Applicable Sensing Technique	Raman DTS Brillouin			
Applicable Zones	Well head Flow Stream Annulus	Tree Tubing Hanger Well Head Exit	Umbilical Sub sea distribution/ jumpers	Jumpers Sub Sea Canisters Sub sea Distribution Unit Umbilical Termination Assembly
Fiber Type	Raman - SM or MM Brillouin - SM			
Opticals	x			
Geometricals	x			
Mechanicals	x			
Other	x			

This table was created after review of uses and environments of fiber throughout the well system.

7 Appendix C:

7.1 TQP-01: 'Table 1 Service and Test Conditions' Referenced during the establishment of fiber classes

Service Condition	Class A 69MPa/121C (10k/250F)	Class B 103MPa/150C (15k/302F)	Class C 69MPa/177C (10k/350F)	Class D 103MPa/177C (15k/350F)	Class E 138MPa/177C (20k/350F)
Temperature range (T_T)	-18° to 121°C (0° to 250°F)	-18° to 150°C (0° to 302°F)	-18° to 177°C (0° to 350°F)	-18° to 177°C (0° to 350°F)	-18° to 177°C (0° to 350°F)
Working pressure (Pw) internal	0 to 69MPa (0 to 10,000psig)	0 to 103MPa (0 to 15,000psig)	0 to 69MPa (0 to 10,000psig)	0 to 103MPa (0 to 15,000psig)	0 to 138 MPa (0 to 20,000psig)
Test pressure, internal (P_T = 1.5x Pw)	0 to 103MPa (0 to 15,000psig)	0 to 155MPa (0 to 22,500psig)	0 to 103MPa (0 to 15,000psig)	0 to 155MPa (0 to 22,500psig)	0 to 207MPa (0 to 30,000psig)
Working pressure (Pw) external	0 to 34.5MPa (0 to 5,000psig)	0 to 45.5MPa (0 to 6,600psig)	0 to 34.5MPa (0 to 5,000psig)	0 to 45.5MPa (0 to 6,600psig)	0 to 45.5MPa (0 to 6,600psig)
Test pressure, external (P_T = 1.5x Pw)	0 to 52MPa (0 to 7,500psig)	0 to 68MPa (0 to 9,900psig)	0 to 52MPa (0 to 7,500psig)	0 to 68MPa (0 to 9,900psig)	0 to 68MPa (0 to 9,900psig)
Deployment water depth	0 to 3,048m (0 to 10,000ft)	0 to 4,572m (0 to 15,000ft)	0 to 3,048m (0 to 10,000ft)	0 to 4,572m (0 to 15,000ft)	0 to 4,572m (0 to 15,000ft)