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Procedure for Measuring Radiation-Induced Attenuation in Optical Fibers and Optical Cables

NATO Nuclear Effects Task Group
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This test procedure outlines methods for measuring both the steady state response of optical fibers and cables exposed to continuous radiation and the transient response of optical fibers and cables exposed to a pulse of radiation. It can be used to determine the level of radiation-induced attenuation produced in single-mode or multimode optical fibers, in either cabled or uncabled form.

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PROCEDURE FOR MEASURING RADIATION-INDUCED ATTENUATION IN OPTICAL FIBERS AND OPTICAL CABLES

1.0 INTENT

This test procedure outlines methods for measuring both the steady state response of optical fibers and cables exposed to continuous radiation and the transient response of optical fibers and cables exposed to a pulse of radiation. It can be used to determine the level of radiation-induced attenuation produced in single-mode or multimode optical fibers, in either cabled or uncabled form. This test procedure is not intended to test the non-optical components of a fiber-optic cable. Other test methods may be required to evaluate the degradation of cable materials resulting from radiation exposure. [The procedure specifically addresses steady state gamma-ray, and transient gamma-ray, X ray, or electron pulsed exposures, but it would be applicable to other radiation sources (e.g., protons, neutrons) as well, with appropriate changes in dosimetry and shielding considerations.]

1.1 Background

The attenuation of optical fibers generally increases when exposed to radiation. This is primarily due to the trapping of radiolytic electrons and holes at defect sites in the glass, i.e., the formation of color centers. The depopulation of color centers by thermal or optical (photobleaching) processes causes recovery, usually resulting in a decrease of radiation-induced attenuation. Recovery occurs simultaneously with darkening during exposure and is evident immediately after irradiation. Recovery of the attenuation after an irradiation depends on many variables, including the temperature of the test sample, the configuration of the sample, the spectrum and type of radiation used, the total dose applied to the test sample, and the light level used to measure attenuation. Under some conditions, recovery is never complete. The attenuation of an optical fiber can vary as a function of time following pulsed exposure by four or more decades during the recovery process.

This test procedure addresses both the steady state and pulsed radiation environment. Steady state measurements generally use radioactive isotope sources for which the turn-on and turn-off times are typically comparable to 1 s. This corresponds to the times required to move the source itself, shields, or test samples in and out of the source. The instrumentation used for steady state measurements typically has a time response of ~0.1 s. There are two extremes of steady state exposure: the low dose rate regime for estimating the effect of environmental background radiation, and the high dose rate regime for estimating the effects of adverse nuclear environments, e.g., nuclear weapons detonation, specific areas of nuclear power plants, and accelerators. The effects of environmental background radiation are tested by a two-point attenuation measurement approach similar to FOTP-46 or FOTP-78. Alternatively, an optical time domain reflectometer (OTDR) may provide a more convenient measurement capability in some circumstances. The effects of adverse nuclear environments are tested by measuring the attenuation of the optical power (by monitoring either the transmitted or reflected light; the latter are tested by OTDR) before, during, and after exposure of the

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The Nuclear Effects Task Group of NATO A/C 243. Panel IV (RSG.12) modified the FOTP-49A procedure based on their collective experience in over five years of effort to develop reliable technique to measure radiation-induced attenuation in optical fibers. This procedures has been submitted to EIA as FOTP-64.

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test sample to gamma radiation. The Detail Specification should specify the times at which measurements are to be made, based on the intended application.

The response of fibers to the pulsed environment addresses the time-varying (transient) behavior of an optical fiber after exposure to a single pulsed dose of radiation. This pulsed dose, with durations of <1 s, is typically generated by various types of accelerators. The transient protocol is applicable where the radiation is not only delivered in a short pulse, but where fiber performance is to be determined on a time scale ≤ 1 s. For measurements at times after irradiation that are long compared to 1 s or measurements of the *average* response ($\tau > 1$ s) of fibers to a series of short pulses, the steady state protocol is applicable. The transient radiation-induced attenuation is tested by monitoring transmitted light power before, during, and after exposure of the test sample to the radiation pulse.

The transient procedure can be used to document transient attenuation from gamma rays, X rays, or electrons. (Interaction of gamma and X rays involves processes that generate electrons or positrons having energies comparable to the gamma ray energy.) Since few pulsed gamma/X-ray laboratory sources exist that can deliver large (>500 rad) radiation doses over significant volumes, most testing of such phenomena has involved pulsed electron sources. These irradiations yield the same results because the interaction of gamma rays and X rays with matter produces energetic electrons by the Compton process. Different applications of optical fibers may require drastically different recovery capabilities after a single pulse of radiation. For some applications near accelerators, for example, data may be transmitted through the fibers in coincidence with the radiation pulse. For some military applications involving control systems or telecommunications, system "down times" of milliseconds may be tolerable; other applications may be able to accommodate down times of minutes. For these reasons, this procedure does not specify times at which measurements are to be made. That information must appear in the Detail Specification based on the intended application.

Radiation exposures may result in luminescence phenomena that generate light in the fiber. Light will be generated during the pulsed radiation with gamma rays, X rays, or electrons through the Čerenkov process. Although the described procedure discusses only measurements of attenuation, the presence of transient Čerenkov or other luminescent light must be anticipated by users. These sources of light could overload recording instrumentation and compromise system accuracy. In this procedure, output filters limit the fraction of the out-of-band luminescent or Čerenkov light reaching the detector. A short wavelength cutoff filter to eliminate all light just below the test wavelength of interest could be sufficient for Čerenkov light because the spectral intensity is proportional to $1/\lambda^3$.

The transient procedure primarily focuses on measurements conducted at short times, generally less than a few minutes. For time scales comparable to one minute or longer, the steady state procedure may be readily applied. Photobleaching (light-induced annealing) has not been observed at times < 10 μs, even at high optical power levels (500 μW). At longer times, as well as in the steady state procedure, light power levels must be precisely specified to minimize photobleaching in some types of fibers.

1.2 Caution

Carefully trained and qualified personnel must be used to perform this test since radiation (both ionizing and optical) and electrical hazards will be present.

2.0 REFERENCED DOCUMENTS

Test or inspection requirements include the following references:

FOTP-46 (EIA-455-46) "Spectral Attenuation Measurement for Long-Length, Graded-Index Optical Fibers"
FOTP-50 (EIA-455-50) "Light Launch Conditions for Long-Length Graded-Index Optical Fiber Spectral Attenuation Measurements"
FOTP-57 (EIA-455-57) "Optical Fiber End Preparation and Examination"
FOTP-78 (EIA-455-78) "Spectral Attenuation Cutback Measurement for Single-Mode Optical Fibers"
FOTP-80 (EIA-455-80) "Cutoff Wavelength of Uncabled Single-Mode Fiber by Transmitted Power"

3.0 TEST EQUIPMENT

Figures 1a and 1b show schematic diagrams of test equipment.

3.1 Radiation Source

The source should provide a variation in dose across the fiber sample not exceeding ±10%. Average total dose should be expressed in gray [1 Gy = 100 rad] to a precision of ±5% (steady state) or ±10% (transient), traceable to national standards. For typical doped silica core fibers, dose should be expressed in Gy calculated for SiO_2, i.e., Gy(SiO_2); if a non-silica-based light guiding material is used, dose should then be expressed in Gy calculated for that material composition.

3.1.1 Steady State Measurements

Caution: The energy of the gamma rays emitted by the source should be above 500 keV to avoid serious complications with rapid variations in total dose as a function of depth within the fiber and/or cable sample.

Dose rate must be constant for at least 95% of the shortest irradiation time of interest.

3.1.1.i Testing of Environmental Background Radiation

A Co^{60} or other gamma ray source shall be used to deliver radiation at a dose rate of 0.20 Gy/hour (or as specified in the Detail Specification).

3.1.1.ii Testing of Adverse Steady State Nuclear Environments

A Co^{60} or other gamma ray source shall be used to deliver radiation at dose rates ranging from 3 to 100 Gy/minute (or as specified in the Detail Specification).

3.1.2 Transient Measurements

Many types of pulsed electron accelerators are available and may be used for testing. Either the electron beam may be used to directly irradiate samples, or the electron beam may be converted (via the bremsstrahlung process) to deliver an X-ray radiation pulse to the samples.

Note: Theoretical analyses and some data suggest that use of electron/gamma ray sources with energies above about 10 MeV may not duplicate irradiations with lower energy sources. The relative importance of ionizing events vs displacement events in the fiber material will be decreased with the higher energy sources, potentially leading to different recovery processes. Note that if application of a fiber requires exposure to radiations that can produce significant atomic displacements in the fiber material [neutrons, energetic electrons (above a few MeV), or protons, for example], then care must be taken to use a radiation source that will duplicate the relative fractions of displacement vs ionization interactions. This is also true if the intended application involves a pulsed environment with a complex pulse structure; in such cases the test conditions should duplicate this pulse structure as closely as possible. Specific applications would, therefore, benefit from specification of the desired source characteristics to be used for attenuation testing.

If t_1 represents the earliest time specified in the Detail Specification for measuring transient attenuation, the radiation source pulse width (full width at half-maximum, FWHM) should be less than $0.1t_1$, unless otherwise specified, to avoid competition between recovery and damage mechanisms.

The source should be capable of delivering absorbed radiation doses to the optical fibers of 5 or 100 Gy (or as required in the Detail Specification). In the case of low-energy photon or electron irradiations, corrections to the absorbed dose may be required to compensate for fiber buffer or cable materials that attenuate the beam before interacting with the optical fiber. If a low-energy X-ray source (<100 keV) is used, the variation of dose through the fiber dimensions may be so extreme that detailed transport calculations must be used to relate measured dose to the dose actually deposited in the fiber core. X-ray sources should be filtered to >100 keV unless confidence in dose profiles in the different materials comprising the fiber, buffer coating, jacket, and cable has been demonstrated.

3.2 Light Source

A light source such as a tungsten-halogen lamp, set of lasers, or LEDs shall be used to produce light at wavelengths of 850 ± 25, 1310 ± 20, and 1550 ± 20 nm, or at wavelengths specified in the Detail Specification. Only one wavelength should be used during any single test, unless specified in the Detail Specification.

3.2.1 Steady State Measurements

The optical power coupled from the source into the test sample shall average -30 dBm (1 μW), or as listed in the Detail Specification, determined by an optical power meter or calibrated detector/preamplifier/recorder system accurate to within $\pm 8\%$. The light source may be modulated at a 50% duty cycle to enable phase-locked detection techniques.

3.2.2 Transient Measurements

For measurements specified for times less than 10 μs, the optical power is not limited, and increased power may be required to achieve adequate detection/recording signal and to avoid complications arising from the level of Čerenkov light generated by the radiation pulse. For longer times, the optical power coupled from the source into the test sample shall average -30 dBm (1 μW), measured as in Section 3.2.1, or as listed in the Detail Specification. A modulated light source may be used, subject to the average power limitations expressed above.

Depending on the details of the detection and recording system, it may be necessary to pulse the light source (see Section 3.8).

Note: Even at 1 μW power level, photobleaching may occur at times beyond 10 μs, depending on the fiber type and test temperature.

Note: Use of long fiber lengths can lead to a significant variation in the light power available for photobleaching at different positions in the fiber. Calculating attenuation in dB/km by multiplying the measured induced loss (dB) by $1000/L$, where L is the test length in m, is allowed only when fibers show no significant photobleaching.

3.3 Optical Filters/Monochromators

A filter or monochromator at the input end of the fiber may be required to restrict wavelengths to the limits of Section 3.2. During a transient test, a filter and/or monochromator or short wavelength cutoff filters (see Section 1.1) should be used at the output end of the fiber to avoid saturation or nonlinearities of the detector and recording instrumentation by transient light sources (Čerenkov or other luminescence phenomena).

3.4 Cladding Mode Stripper

A device that extracts cladding modes shall be used at the input end of the test sample unless it has been demonstrated that the fiber coating materials completely strip the cladding modes.

3.5 Optical Interconnections

The input and output ends of the test sample shall have a stabilized optical interconnection, such as a clamp, connector, splice, or weld. During an attenuation measurement, the interconnection shall not be changed or adjusted except as necessary to perform a two-point cutback measurement. (See Section 5.3.4.)

3.6 Optical Splitter

An optical splitter or fiber-optic coupler may divert some portion of the input light to a reference detector (Figure 1). The reference path may then be used to monitor system fluctuations for the duration of a measurement. (If the reference detector is used, all requirements for the detector/recorder bandwidth discussed in Section 3.8, apply to it as well.) Note that if a polarized light source, like a laser, is used, a polarization-insensitive coupler should be used.

3.7 Input Launch Conditions

3.7.1 Class Ia Fibers - (Graded Index Multimode Fiber). A means to establish an equilibrium mode distribution must be developed to establish a steady-state mode condition in the irradiated region of the fiber. Refer to FOTP-50.

3.7.2 Class IV Fibers - (Single-Mode Fiber). An optical lens system or fiber pigtail may be used to excite the test fiber. If an optical lens system is used, a method of making the positioning of the fiber less sensitive is to overfill the fiber core spatially and angularly. A mode filter shall be used to remove high-order modes whose cutoff is in the wavelength range less than or equal to the fundamental mode cutoff wavelength of the test fiber. The test condition specified in Section 4.1 of FOTP-80 satisfies this requirement. When testing polarization-maintaining fiber, particular care must be given to understanding and documenting the polarization state of light, both injected into the test fiber (and any reference detector) and detected after exiting the test fiber.

3.7.3 Class Ib/Ic Fibers - (Quasi-graded and Step Index Fibers). The minimal requirement shall be for the input light to fill the numerical aperture of the test fiber. Launch conditions shall be specified in the Detail Specification.

3.8 Optical Detection

An optical detector that is linear and stable over the range of intensities that are encountered shall be used. A typical system might include a PIN photodiode amplified by a current input preamplifier. Although the stability of avalanche photodiodes is not sufficient for steady state measurements, they may be used for transient measurements, provided their stability meets the requirements of Sections 3.13 and 3.14. For steady state measurements, synchronous detection by a lock-in amplifier can be used.

For transient measurements, the time response of the overall detection system, including the data recording system, must be carefully evaluated. Limited high frequency or low frequency response of the system may distort measurements unless the following conditions are documented.

3.8.1 High-Frequency Response

The impulse response width (in seconds) of the total detection and recording system shall be 10× less than the earliest time at which measurements are to be recorded or as specified in the Detail Specification. This impulse response is most easily verified by injecting an optical pulse, whose pulse width is 10× less than the detection/recording system impulse response, into the detector and measuring the full width at half maximum (FWHM) as displayed with the data recorder. Alternatively, a modulated light source can be used in conjunction with a network analyzer. The high and low bandwidth limits (3 dB points) are determined by changing the modulation frequency from low values (>50 Hz) to the highest value of interest (e.g. 500 MHz).

Note: If capabilities exist to unfold or deconvolve the system time response from all observed data (using, for example, Fourier transforms), the 10× requirement specified above can be relaxed. However, even in that case, detailed knowledge of the actual system response will be essential in the unfolding process.

3.8.2 Low Frequency Response

The low-frequency response of the entire detector/recording system should extend to zero frequency, with a flat gain curve from dc to the high frequency cutoff, i.e., a completely dc-coupled system should be used. If such a dc-coupled system is used, the light source may be run in a continuous mode, and complications involving operation of the source in a pulsed mode, and timing the light source pulse to the radiation pulse are avoided. The cw mode of light source operation also simplifies all absolute optical power measurements. [However, for measurements at extremely short times, it may be advantageous to use a pulsed source to obtain adequate light levels that simplify detection and recording considerations since most light sources can deliver higher outputs in a short pulse than in a cw mode.]

If the detector/recorder system is not dc-coupled, the light source must be used in a pulsed mode. A single, flat-topped light pulse may be used for measurements to times $<<1/f_L$, where f_L is the low frequency 3 dB point of the recorder. Such a single pulse must be appropriately timed relative to the radiation pulse. The low frequency limit of the system will introduce distortion in the observed pulse at times comparable to $1/f_L$. In an ac-coupled system, repetitive pulses or a modulated signal can also be used (and *must* be used for measurements to times $\geq 1/f_L$), but the modulation frequency f of the pulse train must be $>10\,f_L$, and $1/f$, i.e. the time between pulses or cycles, must be considerably shorter (by at least 10×) than t_1.

3.9 Elements of the Recorder System

A suitable data recording system must be incorporated. For steady state measurements, a chart recorder or computer can be used; for transient measurements, the recording system must provide a bandwidth commensurate with the tests specified in Section 3.8. Examples include: a transient digitizer or storage oscilloscope, an analog oscilloscope with either a film or digital camera, a digital sampling oscilloscope coupled to a data display unit, coherent demodulation of the modulated light signal by a lock-in amplifier (for times $>>1$ μs), or incoherent demodulation with a high frequency amplifier and demodulator.

3.10 Radiation Dosimeter

Dosimetry traceable to National Standards shall be used. Dose should be measured in the same geometry as the actual fiber core material to ensure that dose-build-up effects are comparable in the fiber core and the dosimeter. The dose must be expressed in Gy calculated for the core material.

3.11 Temperature Controlled Container

Unless otherwise specified, the temperature-controlled container shall have the capability of maintaining the specified temperature to within $\pm$ 2°C or as specified in the Detail Specification. The influence of the temperature-controlled container on the dose within the test object must be taken into consideration.

3.12 Test Reel

The test reel shall not act as a shield for the radiation used in this test or, alternatively, dose must be measured in a geometry that duplicates the effects of reel attenuation. The diameter of the test reel and the winding tension of the fiber can influence the observed radiation performance. If reel diameter and fiber tension are not specified in the Detail Specification, the fiber should be loosely wound on a reel diameter exceeding 10 cm. (Some radiation sources will require a much more compact fiber geometry, which should be noted in the report discussed in Section 7.)

3.13 System Stability

Stability of the total system under illumination conditions, including the light source, light injection conditions, variations in fiber microbend conditions, light coupling to a detector, the detector, and the recording device, must be verified prior to any measurement for a time exceeding that required for determination of the output power prior to irradiation P_b and the output power during the duration of the attenuation measurement P_t (see Section 6). During that time, the maximum fluctuation in observed system output shall be converted into an apparent change in optical attenuation due to system noise ($\Delta\alpha_n$) in dB/km by using either Equation 6.1.A (if no optical splitter and reference detector is used) or 6.2.A (if an optical splitter and reference detector are used). Any subsequent measurement must be rejected if the observed ΔA (defined in Section 6) does not exceed $10 \times \Delta\alpha_n$.

3.14 Baseline Stability

Baseline stability shall also be verified for a time comparable to the attenuation measurement with the light source turned off. The maximum fluctuation in output power P_n shall be recorded. Any subsequent measurement must be rejected if the transmitted power out of the irradiated fiber is not greater than $10 \times P_n$.

4.0 TEST SAMPLE

Either a fiber or cable specimen may be tested. An unirradiated sample shall be used in each test unless otherwise specified in the Detail Specification.

4.1 Fiber Specimen

The test specimen shall be a representative sample of the fiber specified in the Detail Specification.

4.2 Cable Specimen

The test specimen shall be a representative sample of the cable described in the Detail Specification and shall contain at least one of the specified fibers.

4.3 Test Specimens

A length at the ends of the test sample shall reside outside of the irradiation chamber and shall be used to connect the fiber into the optical measurement system. In addition, the fiber length must be adjusted to meet the system stability limits of Section 3.13 and the baseline stability limits of Section 3.14. (If a system is seriously unstable, no fiber length may meet the requirements of Section 3.13 and 3.14. In such a case, the measurement cannot proceed until the measurement apparatus is improved.) The irradiated length of the test sample shall be reported.

4.3.1 Environmental Background Radiation Test

Unless otherwise specified in the Detail Specification, tne irradiated length of the test sample shall be 500 ± 10 m. The length outside the test chamber shall be sufficient for a minimum of two cutback measurements (refer to Section 5.3).

4.3.2 Adverse Nuclear Environments Test

Unless otherwise specified in the Detail Specification, the irradiated length of the test sample shall be 100 ± 5 m.

4.3.3 Transient Test

The length of the test sample is dependent on the total dose, the time regime for which measurements are required in the Detail Specification, and the beam size/uniformity of the irradiation source. The irradiated fiber length shall be such that the transit time of light through the irradiated region is at least 10× shorter than t_l specified for attenuation measurements. For measurements only at times beyond 1 ms, 100 m length of fiber is recommended for direct comparison to the steady state specification. This recommendation cannot be followed if the radiation source is not capable of uniformly exposing an irradiation volume large enough to hold the fiber coil or if the induced attenuation in that length of fiber results in power throughputs violating the baseline stability test of Sec. 3.14.

4.4 Test Reel

The test sample shall be spooled onto a reel per Section 3.12. Allowance shall be made for the unspooling of a measured length of the test sample from each end of the reel for attachment to the optical measurement equipment.

4.5 Ambient Light Shielding

The irradiated fiber length shall be shielded from ambient light to prevent photobleaching by any external light sources and to avoid apparent baseline shifts in the zero light level. An absorbing fiber coating or jacket can be used as the light shield provided it has been demonstrated to block ambient light and its influence on the dose within the fiber core has been taken into consideration.

5.0 TEST PROCEDURE

5.1 Calibration of Radiation Source

Calibration of the radiation source for dose uniformity (at a minimum of four locations) and dose level shall be made prior to introduction of fiber test samples. Regardless of dosimeter used, per Section 3.1, the variation in dose across the fiber reel volume shall not exceed ±10%.

If thermoluminescent detectors (TLDs) are used for the measurements, four TLDs shall be used to sample dose distribution at each location. The readings from the multiple TLDs at each location shall be averaged to minimize dose uncertainties. To maintain the highest possible accuracy in dose measurement, the TLDs shall not be used more than once. TLDs should be used only in the dose region where they maintain a linear response.

5.1.1 Steady State Sources

Total dose shall be measured with an irradiation time equal to subsequent fiber measurements. Alternatively, the dose rate may be measured, and the total dose calculated from the product of the dose rate and irradiation time. Source transit time (from off-to-on and on-to-off positions) shall be less than 5% of the irradiation time.

5.1.2 Transient Sources

Various types of dosimetry may be used for source calibration, such as thermoluminescent dosimeters (TLDs), microcalorimeter, radiachromic film, or Faraday cup (for electron beam measurements). Of these alternatives, the TLD, microcalorimeter, and radiachromic film can potentially provide a response calibrated directly in absorbed dose. Depending on the composition of the TLD, microcalorimeter, or radiachromic film and the energy spectrum and type (electron beam or bremsstrahlung) of radiation source used, it may be necessary to correct the observations to obtain the dose actually deposited in the optical fiber material. Such corrections should include dose build-up and/or attenuation factors that may occur due to materials (such as fiber cable material, fiber buffer material, reel composition, or self-shielding of a fiber coil) and differing electron stopping powers in the detector and fiber materials. Similar materials (such as thin aluminum foils, for example) may be placed in front of the dosimeter to simulate these phenomena.

A Faraday cup shall be used only as a transfer standard for electron beams, not as the primary dose-measuring instrument, and it shall be calibrated against one of the absorbed dose instruments (TLD, microcalorimeter, or radiachromic film) prior to its use. The Faraday cup will measure only total charge, and this quantity may be complicated by a variety of charge loss or gain mechanisms. It does not measure any quantity directly related to absorbed dose. If radiachromic film is used, multiple pulses may be required to obtain adequate darkening of the film. In this case, a Faraday cup provides a convenient pulse-to-pulse normalization method.

Total dose shall be measured on each pulse of the radiation source, unless stated otherwise in the Detail Specification.

5.2 Fiber End Preparation

The test sample shall be prepared such that its endfaces are smooth and perpendicular to the fiber axis, in accordance with FOTP-57.

5.3 Data Acquisition Process

5.3.1 The reel of fiber or cable shall be placed in the attenuation test setup shown in Figure 1. Sufficient fiber should be available on the input end of the fiber to allow an attenuation measurement using the two-point cutback method to be performed.

5.3.2 The light source shall be coupled into the input end of the fiber, as described in Section 3.7. The output end of the fiber shall be positioned such that all light exiting the fiber impinges on the active surface of the detector.

5.3.3 The test sample shall be stabilized in the temperature chamber at 23 ± 2^{o}C prior to proceeding (or at the test temperature specified in the Detail Specification).

5.3.4 For all steady state tests and for those transient tests requiring precise power injection level (i.e., tests requiring attenuation measurements at times longer than 10 μs), a two-point attenuation measurement shall be completed without disturbing the fiber on the test reel in the temperature chamber. The procedure of FOTP-46 shall be used for Class Ia fibers. The procedure of FOTP-78 shall be used for Class IV fibers. (If the OTDR procedure of 5.3.10.i.b.3

is being used, the fiber attenuation can be directly measured.) The attenuation A_1, in dB/km, of the fiber sample on the reel shall be calculated and recorded. Note that the length of the fiber used in this measurement must necessarily be longer than the length on the test reel because of the leads and the length used for the cut-back measurement, if performed.

5.3.5 The system baseline test of Section 3.14 shall be completed and the results recorded, unless the OTDR procedure in 5.3.10.i.b.3 is being used. For the steady state adverse environment test, a continuous measurement device shall be connected to the detection system so that a continuous power measurement can be made. The measurement equipment shall be set up such that the detection signal does not exceed the limits of the equipment.

5.3.6 If a two-point attenuation measurement was done in Section 5.3.4, the test sample input end shall again be prepared in accordance with Section 5.2. The light source shall be coupled to the input end of the fiber, as described in Section 3. The output end of the fiber shall again be positioned such that all light exiting the fiber impinges on the active surface of the power meter or detector. The light power exiting the test sample shall be measured with the power meter or the detector/recorder system (see Sec. 3.9) and recorded. If A_1 was determined using Section 5.3.4, the power level at the input end of the test sample (Point A in Figure 1) shall be determined by using the known length of the fiber (in km) from Point A to the exit end and A_1 (in dB/km) determined in Section 5.3.4 to scale the measured exit power to that in the fiber at Point A. For measurements at times longer than 10 μs, the input power should be adjusted to be in compliance with the value specified in Section 3.2.

5.3.7 The complete detector/recording system shall be placed in operation.

5.3.8 Prior to irradiation, the system stability and baseline stability tests specified in Sections 3.13 and 3.14 shall be performed unless the OTDR procedure in 5.3.10.i.b.3 is being used.

5.3.9 During the irradiation and subsequent throughput power measurements, the input coupling conditions and power levels shall not be changed.

5.3.10 Dose Rates and Attenuation Measurement Procedures

5.3.10.i Environmental Background Test

5.3.10.i.a Environmental background radiation effects, due to exposure to gamma radiation, shall be determined by subjecting the test sample to a dose rate of 0.20 Gy/h. The test sample shall be exposed to a total dose of 1 Gy over 5 hours. Different dose rates and doses may be required by the Detailed Specification.

5.3.10.i.b Attenuation shall be measured at least immediately after the 1 Gy irradiation, and at other times and doses specified in the Detail Specification. Depending on System Stability (Section 3.13) and equipment availability, either of three types of measurements may be made:

(1) a continuous measurement of system output power P_t may be made, allowing determination of attenuation via Section 6.0. This procedure requires that the System Stability criteria of Section 3.13 be maintained throughout the irradiation time. For extremely long times, this may not be possible.

(2) a two-point cutback attenuation measurement (analogous to the procedures specified in Section 5.3.4) may be made to determine the attenuation after irradiation times corresponding to selected total doses. In this case, the System Stability criteria of Section 3.13 need be satisfied only during the time required to accomplish the attenuation measurement. If sufficient fiber is available outside the irradiation volume, the irradiation may be continued to achieve additional dose on the fiber. To continue the irradiation, the procedure should return to Section 5.3.6 to reset the input power level to the level required in Section 3.2. However, the attenuation measured in the latest cut-back measurement should be used in place of A_1 to scale the observed exit power to the input light level at Point A.

(3) an optical time-domain reflectometer may be used to document the fiber attenuation along its length. Use of the OTDR simplifies concerns with long-term source stability that would complicate measurements, especially if very small attenuations are being observed. The optical module of the OTDR must match the fiber type (single-mode or multimode) to be tested. The OTDR shall be used for measurements at selected times required in the Detail Specification. However, because of the time required for an OTDR measurement, it should not be used when the attenuation in the fiber is rapidly changing. The attenuation of the test sample measured by the OTDR prior to exposure shall be used in place of the preirradiation A_1 specified in 5.3.6 to calculate the input light level at Point A.

When an attenuation measurement is required, the OTDR pulse shall be injected into the fiber. Since the OTDR measurement is performed only periodically and since there is usually no adjustment of the average power injected into the fiber by the OTDR instrument, a means for maintaining 1 μW optical power (or as required by the Detail Specification) continuously injected into the test fiber length as measured at point A shall be established.

Accurate measurement of fiber loss can be obtained only over the fiber length where the attenuation remains within the dynamic range of the instrument. In addition, it is extremely important to establish an equilibrium-mode distribution in multimode fibers and to ensure that light is not propagating in the cladding. See Sections 3.4 and 3.7. The length of fiber to be irradiated should be preceded by at least 50 m of lead-in fiber, which serves as a self-reference and assists in removal of high-order lossy modes in multimode fibers. Preferably, this lead-in fiber should be an additional length of the test fiber, but a similar fiber fusion-spliced to the test fiber may be used.

5.3.10.ii Adverse Nuclear Environment Test

Adverse effects due to exposure to gamma radiation shall be determined by subjecting the test sample to one of the dose rate/total dose combinations specified in Table I or as specified in the Detail Specification.

Source Geometry shall be adjusted to maintain dose rates within ±10% of values of Table I or as specified in the Detail Specification.

TABLE I
TOTAL DOSE/DOSE RATE COMBINATIONS

Total Dose, Gy	Dose Rate, Gy/min
30	3
100	13
1000	13
10000	100

The output power from the test sample shall be recorded prior to (P_b) and for the duration of (P_t) the gamma irradiation cycle. The output power shall also be recorded for at least 1000 s after completion of the irradiation process or as specified in the Detail Specification. The power levels of the reference detector, if used, shall also be recorded before (P_b') and during (P_t') both the irradiation time and the recovery time after completion of the irradiation. The output powers P_t and P_b (and P_t' and P_b') must be measured relative to a baseline of zero light; see Section 6.

5.3.10.iii Transient Test

A single pulse from the radiation source shall be directed onto the exposed length of optical fiber/cable, using one of the total absorbed doses (measured at the fiber) specified in Table II or as specified in the Detail Specification.

TABLE II: TOTAL DOSE

Total Dose, Gy
5
100

Source geometry shall have been adjusted to maintain doses within ±10% of values of Table II or as specified in the Detail Specification.

The output power from the test sample shall be recorded both prior to (P_b) the pulse of radiation and for the duration of the transient measurement (P_t) as specified in the Detail Specification. The power levels of the reference detector (P_b' and P_t', respectively), if used, shall also be recorded during the same time period. The output powers P_t and P_b (and P_t' and P_b') must be measured relative to a baseline of zero light; see Section 6. A typical recorder output is shown in Figure 2.

5.3.11 For an environmental background radiation test, unless otherwise specified in the Detail Specification, the radiation-induced change in attenuation ΔA_t should be reported at a time $t = 5$ h after a total dose of 1 Gy.

For an adverse nuclear-environment measurement, unless otherwise specified in the Detail Specification, ΔA_t should be reported at a time t corresponding to the total dose of the test level selected from Table I and at a time $t = 1000$ s after cessation of the radiation. See Section 6.

5.3.12 Steps 5.3.1 through 5.3.11 should be repeated for other required test temperatures, time regimes, and wavelengths. An unirradiated fiber/cable sample shall be used in each test unless otherwise specified in the Detail Specification.

6.0 CALCULATIONS

6.1 Measurements Without a Reference Detector

The radiation-induced change in ΔA_t at t shall be calculated from

$$\Delta A_t = -10\,[\log (P_t/P_b)\,]/L \qquad \text{[in dB/km]} \qquad \text{(Eq. 6.1.A)}$$

where: P_t is the power output of the test sample at time t,
P_b is the power output of the test sample before irradiation, and
L is the length in km of irradiated test sample (excluding unirradiated fiber external to the irradiation environment.

P_t and P_b must be measured relative to a baseline of zero light. (Note the alternative equation in Section 6.2 if a reference detector is incorporated in the measurement procedure.)

Alternatively, for environmental background radiation tests, A_t at a time t may have been obtained from a two-point cutback technique, as discussed in Section 5.3.10.i.b.2. In this case, ΔA_t at time t is given by

$$\Delta A_t = A_t - A_1 \qquad \text{[in dB/km]} \qquad \text{(Eq. 6.1.B)}$$

where: A_1 is the attenuation of the test sample prior to exposure to gamma radiation, from Section 5.3.4.

6.2 Measurements with a Reference Detector

If a reference detector is used, the radiation-induced change in sample attenuation ΔA_t at time t should be calculated by modifying Eq. 6.1.A to:

$$\Delta A_t = -10\,[\log(P_t/P_b) - \log (P_t{}'/P_b{}')]/L \qquad \text{[in dB/km]} \qquad \text{(Eq. 6.2.A)}$$

where: $P_t{}'$ is the power measured by the reference detector at time t, and
$P_b{}'$ is the power measured by the reference detector before irradiation.

P_t, P_b, $P_t{}'$, and $P_b{}'$ must be measured relative to a baseline of zero light.

7.0 REPORT

7.1 Report Data.

7.1.1 Date of Test

7.1.2 Title of test.
7.1.3 Length of test sample exposed to radiation.
7.1.4 Test wavelength.
7.1.5 Test temperature
7.1.6 Test reel diameter, composition, and geometry.
7.1.7 Change in attenuation ΔA_t

7.1.7.i Environmental background steady state test: after t = 5 h and 1 Gy total dose.

7.1.7.ii Adverse environment steady state test: after time t corresponding to the specified total dose and t = 1000 s after cessation of irradiation.

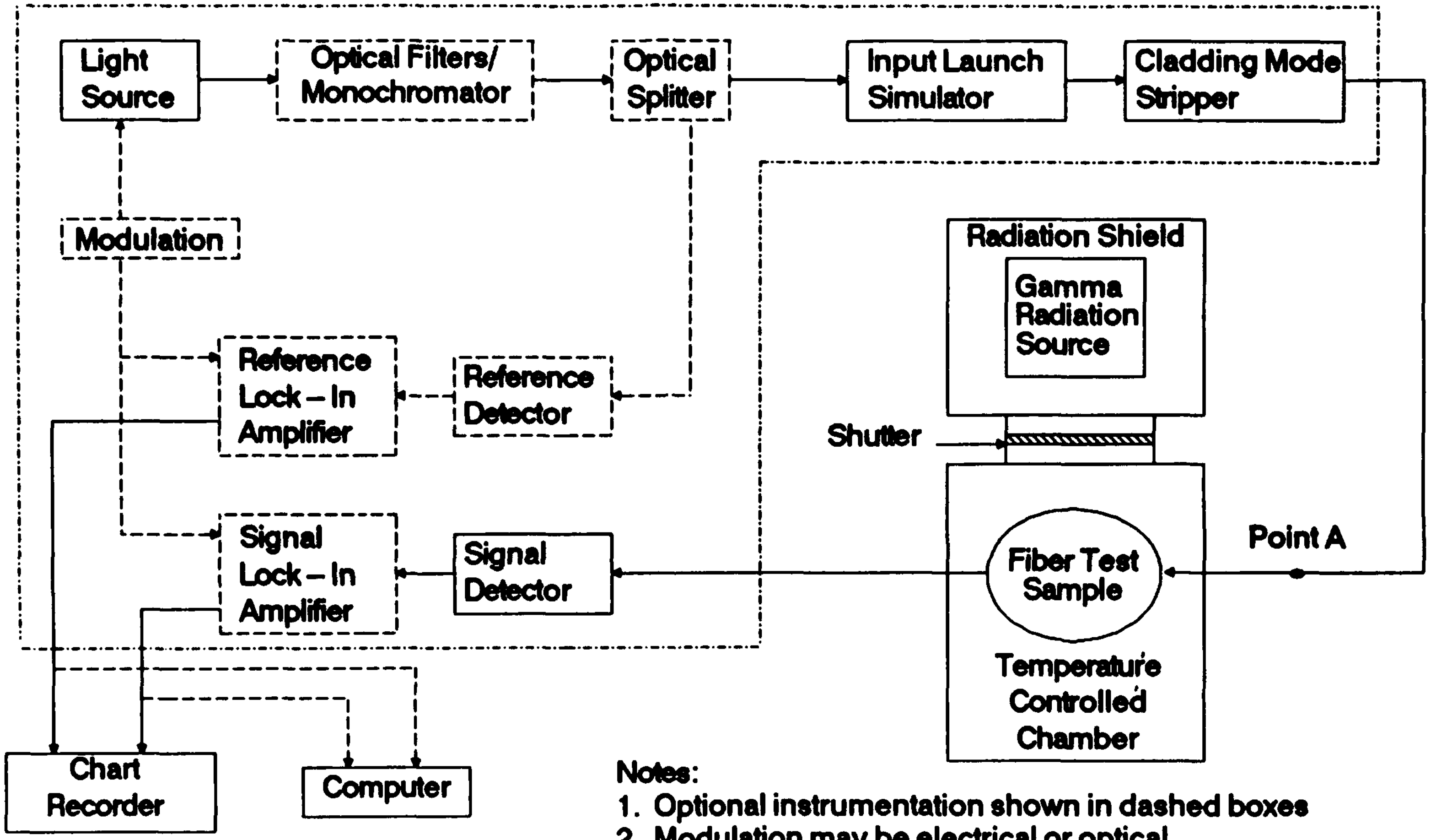
7.1.7.iii Transient test: for times specified in the Detail Specification.

7.1.8 Reference detector characteristics, if used.
7.1.9 Method used to determine input power if different from Section 5.3.6.
7.1.10 Characteristics of test sample: fiber/cable type, dimensions, and composition.
7.1.11 Recorder output data.
7.1.12 Description of radiation source, including energy and type.
7.1.13 Test dose, dose rate (steady state), and time duration of test pulse (transient).
7.1.14 Description of dosimeters and dosimetry procedures.
7.1.15 Description of optical source.
7.1.16 Description of input and output optical filters or monochromators.
7.1.17 Description of cladding mode stripper.
7.1.18 Description of input launch simulator and launch conditions used.
7.1.19 Description of any optical splitter used.
7.1.20 Description of detection and recording system.
7.1.21 Documentation of detector/recorder system bandwidth. (Not required for steady state tests.)
7.1.22 System stability and background test data.
7.1.23 Description of characteristics of temperature chamber.
7.1.24 Date of calibration of test equipment.
7.1.25 Name and signature of Operator.

8.0 SPECIFYING INFORMATION

8.1 Detail Specification

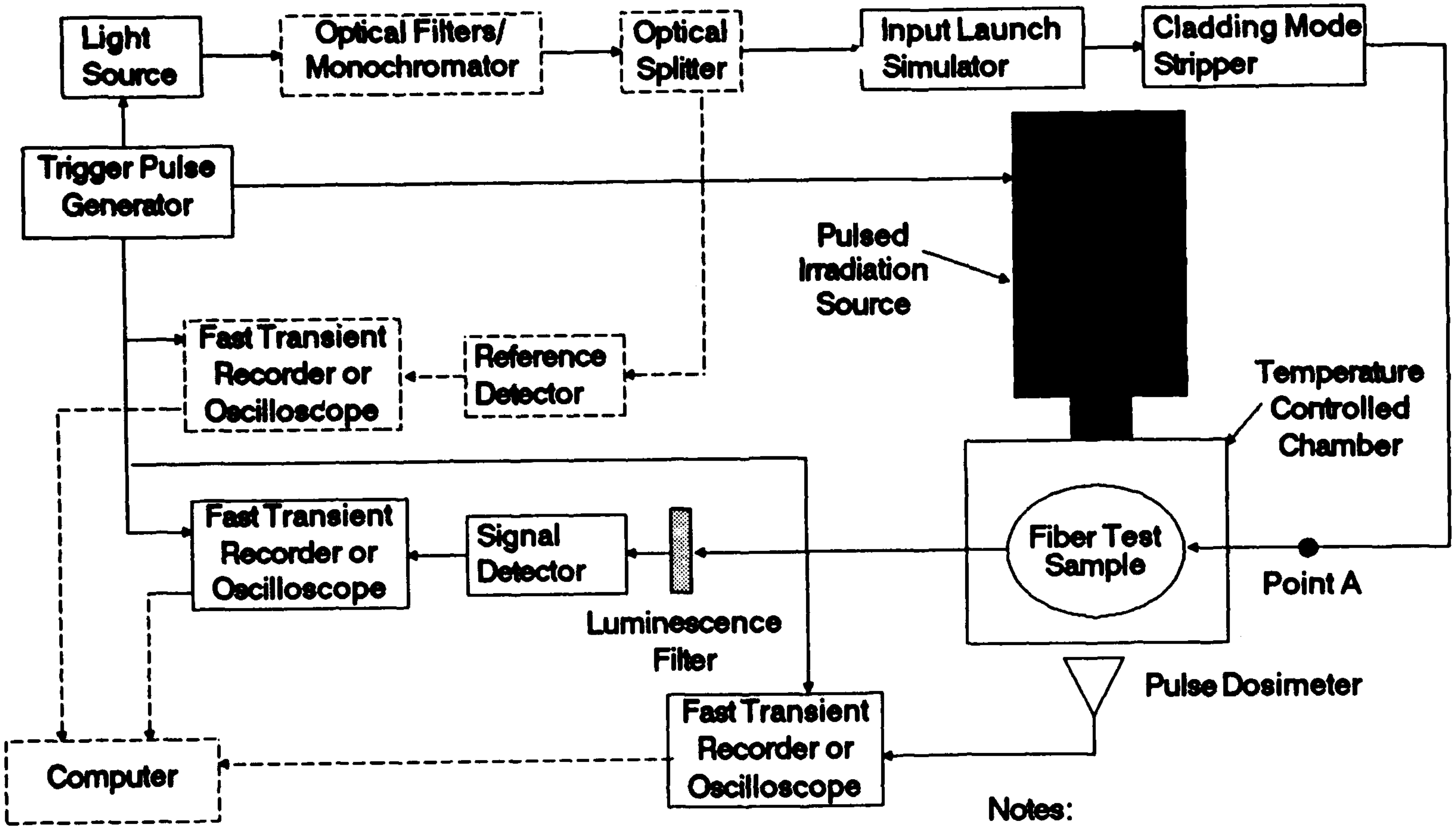
8.1.1 Identification of fiber type and cable type
8.1.2 Request for type of test: environmental background steady state, adverse nuclear environment steady state, or transient. For transient tests, request for dose level and time range of measurement.
8.1.4 Other information pertinent to the tests for which the standard conditions of this Procedure do not match the intended system application of the optical fiber and/or optical cable.



Notes:

1. Optional instrumentation shown in dashed boxes
2. Modulation may be electrical or optical
3. If an OTDR is used for the Environmental Test, it may be inserted in place of the instruments in the dashed box. See Sect. 5.3.10.i.b.3
4. A cladding mode stripper may not be needed. See Sect. 3.4

Figure 1a. Schematic Instrumentation Diagram – Steady State Tests



Notes:
1. Optional instrumentation shown in dashed boxes
2. A cladding mode stripper may not be needed. See Sect. 3.4

Figure 1b. Schematic Instrumentation Diagram – Transient Tests

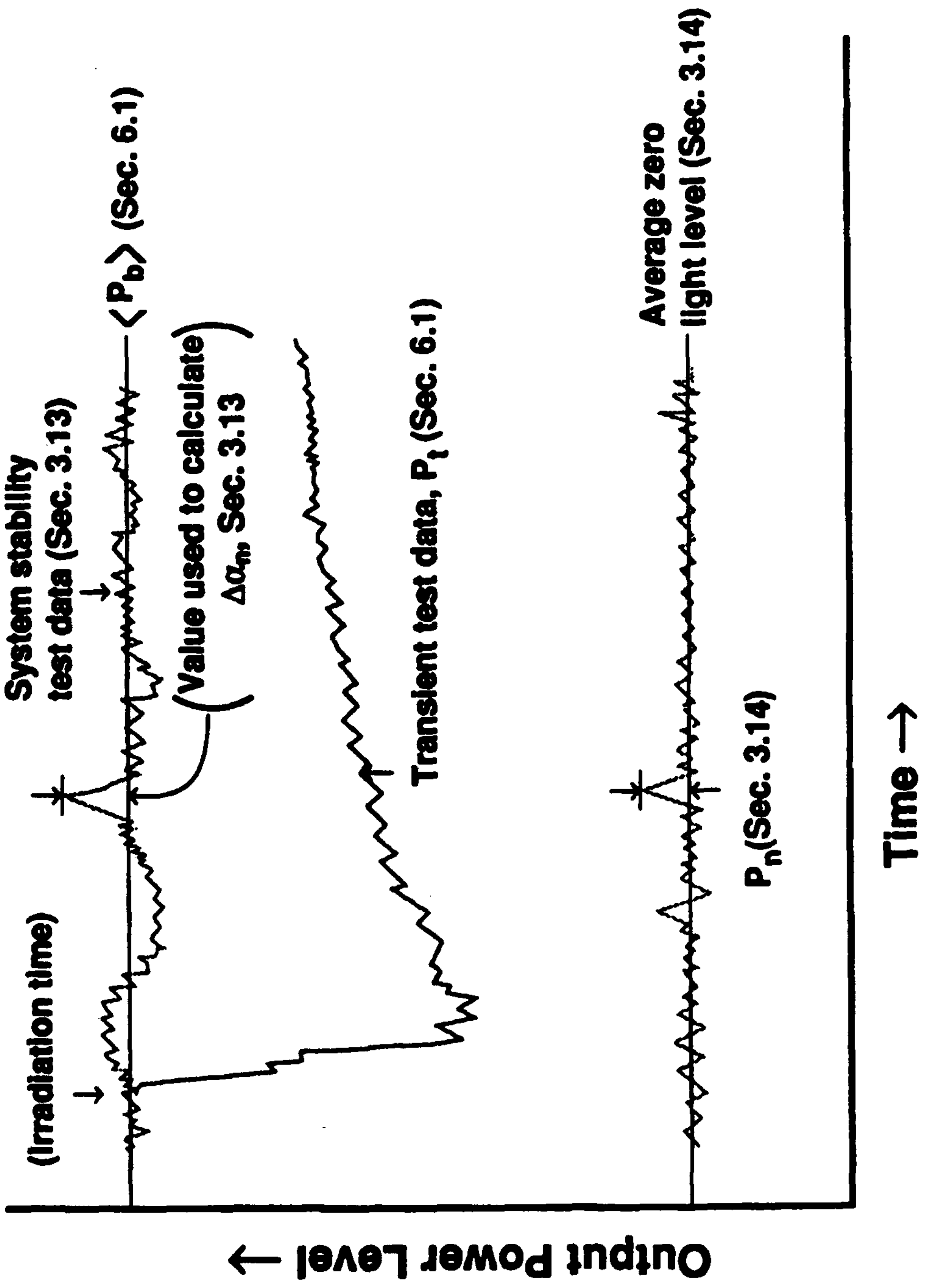


Figure 2. Typical Transient Data Traces