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SUPPORT OF THE

NATO NUCLEAR EFFECTS TASK GROUP

BY

LOS ALAMOS NATIONAL LABORATORY

P. B. LYONS

LOS ALAMOS NATIONAL LABORATORY

1991 NETG ANNUAL MEETING
SEPTEMBER 1991
MUNICH GERMANY

1991 LOS ALAMOS ACTIVITIES

COMPARISON OF OTDR AND THROUGHPUT MEASUREMENTS

DRAFT PROTOCOL FOR TRANSIENT ATTENUATION MEASUREMENTS

IMPROVED RADIATION RESISTANCE FROM PRE-TREATMENT WITH SIMULTANEOUS RADIATION AND HYDROGEN EXPOSURES

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TRANSIENT ATTENUATION OF IO GUIDES

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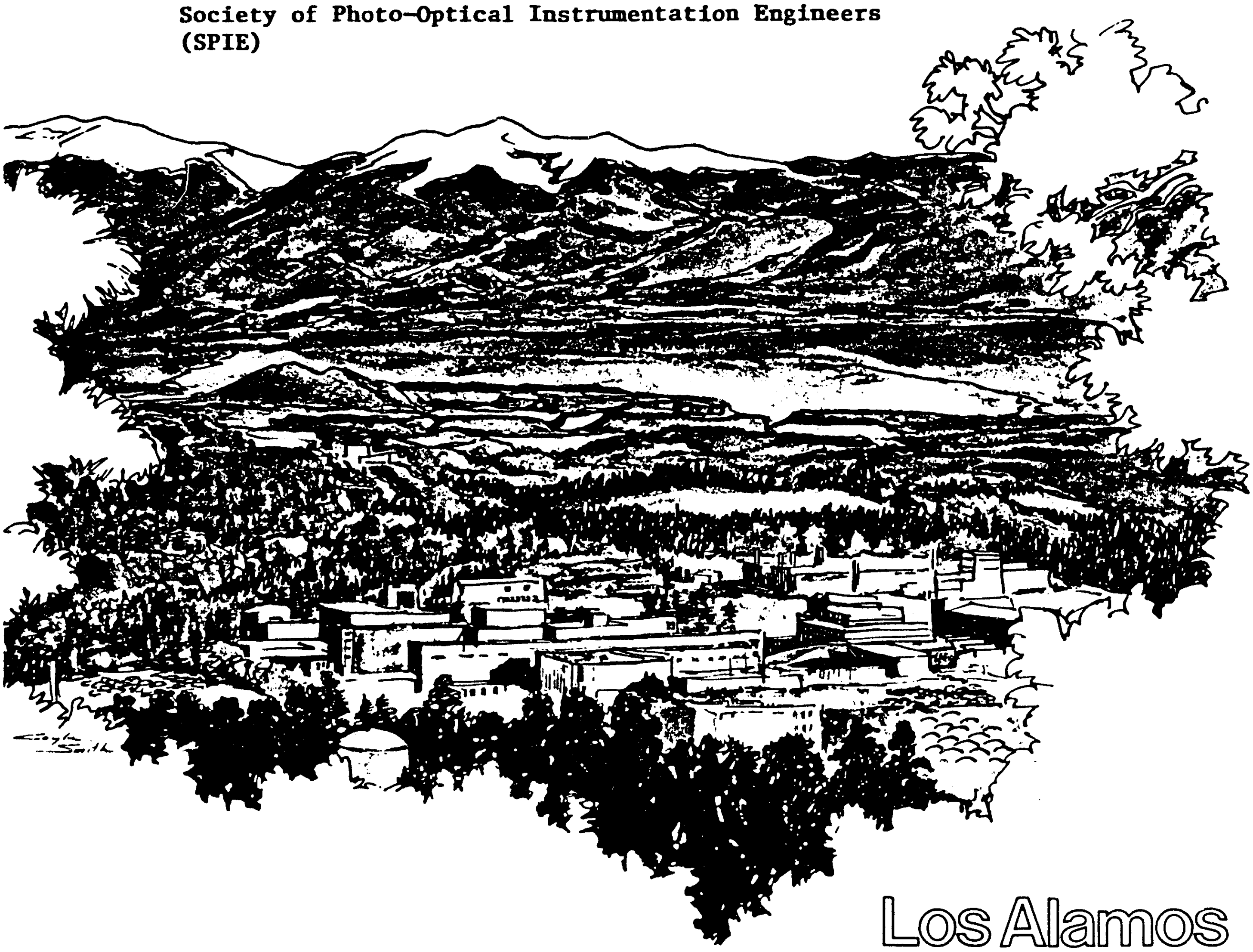
DETERMINATION OF RADIATION-INDUCED ATTENUATION REQUIRES SUBTRACTION OF PRE-IRRADIATION ATTENUATION

LA-UR-91-990

Measurement of radiation-induced attenuation in optical fibers by optical time domain reflectometry

Larry D. Looney and Peter B. Lyons

Society of Photo-Optical Instrumentation Engineers
(SPIE)



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Measurement of radiation-induced attenuation in optical fibers by optical time domain reflectometry

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ABSTRACT

Co^{60} radiation-induced attenuation is measured by optical time domain reflectometry (OTDR) techniques and compared to conventional optical throughput measurements. Relative advantages and disadvantages of the OTDR technique are discussed.

1. INTRODUCTION

Since 1983, the Nuclear Effects Task Group (NETG) formed by NATO RSG.12 (Panel IV, A/C 243) has been utilizing inter-laboratory comparisons of radiation-induced attenuation in optical fibers to develop an international test protocol for these measurements.[1,2,3] The protocol was to be based on the combined experience of participating Laboratories within the NATO countries. Each of these facilities accomplished their previous attenuation measurements by documenting the change in light transmission through the fiber during and following irradiation (i.e., by throughput techniques). NETG results through 1989 have been published.[4,5] These efforts resulted in a finalized test protocol,[6] which has been submitted to several certification organizations for consideration as an international standard.

The NETG protocol defines procedures for measuring attenuation changes due to radiation exposure using throughput techniques. The procedure also includes a section suggesting that similar measurements should be possible using optical time domain reflectometry techniques. However, since no OTDR-based measurements had been completed for radiation-induced attenuation when the current draft of the protocol was finalized, no detailed recommendations were made regarding the use of an OTDR.

At the 1990 NETG meeting at the Royal Military College of Science (Shrivenham, UK), the absence of any data for evaluation of OTDRs for radiation-induced attenuation measurements was cited as a major need within the testing community and several of the participating Laboratories were tasked to investigate this area for subsequent evaluation by the NETG. This paper reports on the OTDR investigation within the Los Alamos National Laboratory. In the process, a better understanding was gained for situations wherein the use of OTDR may be critical for enabling a measurement. In general cases, however, we suggest that the use of OTDR is more cumbersome and less accurate than throughput measurements.

Significant assistance was received from colleagues who are also pursuing OTDR tests[7,8] who have shared their progress with the present authors. Only one paper in the literature, to our knowledge, has previously appeared reflecting their experience.[9]

2. TEST PROCEDURE

Tests utilized a bend resistant single mode fiber that was the test vehicle for the 1990 series of interlaboratory comparisons by the NETG. This fiber has a doped core, which was documented in the 1990 measurements to not be significantly affected by photo-bleaching (i.e., the radiation-induced attenuation was independent of the light level used to probe the attenuation). In 1990, Co^{60}-radiation-induced attenuation measurements with this fiber were completed using the NETG protocol[6] by five Laboratories. All the fiber tested for the 1990 NETG meeting, as well as the present fiber, was drawn from a single preform in a single drawing operation with no variation in draw parameters.

A Laser Precision TD-9960 OTDR was used for the measurements. No attempt was made to inter-compare different OTDR systems, nor to optimally select this OTDR for the planned tests. The output power of the fiber under test was also measured to allow comparison between throughput and OTDR measurements. The experimental configuration is shown in Fig. 1. Note that this arrangement allowed no monitor to be incorporated in the system to verify that the input light remained stable over the duration of the measurements (such an input monitor is recommended in the NETG protocol for throughput measurements). Thus, the uncertainty in the throughput data was not available. Furthermore, the average OTDR light power injected into the fiber-under-test, about 0.25 μW, was well below the NETG recommendation of 1 μW. Most OTDR systems do not allow the input level to be adjusted.

The OTDR provided a 1300 nm wavelength, 1 μsec long, optical pulse to probe the fiber attenuation by sensing the level of Rayleigh backscattered light that was coupled into the fiber core and transmitted back to the fiber input. The repetition rate of the injected pulse was about 1400 Hz. The unit emitted about 7 mW peak power, but a much smaller level was successfully coupled into the single mode pigtail and subsequently into the fiber-under-test. Each measurement of attenuation required about 45 seconds and could be transferred to disc storage in an additional 15 seconds. With this unit, it was not possible to preselect regions of the fiber of maximum interest for concentration of measurements, thus attenuation of the entire fiber (pigtail and fiber-under-test) was evaluated.

Observation of the OTDR traces showed significant saturation of the system occurred at the input end where the pulse is injected into the fiber. This region of saturation would have grossly distorted attenuation measurements attempted near the input of the fiber, so a long single mode pigtail was connected between the OTDR input and the fiber-under-test. Connection between the pigtail and the fiber-under-test was made with a Radiall connector. Reflection from this connector also led to significant system overload, which was greatly reduced by using index-matching gel in the connection. Fig. 2 shows the system saturation with and without the gel. All measurements were made with the gel in place. The length of the fiber-under-test was 500 m to avoid concerns with residual distortions from input connector reflections

Optical throughput of the fiber-under-test was measured with a United Detector Technology Model 371 radiometer and was recorded at the midpoint of each OTDR measurement.

Radiation was provided by a 13 kCi Co^{60} source contained in a remotely-controlled shielding unit. Dosimetry was measured at the position of the fiber using an EG&G,Inc. NBS-traceable 1 cc air ionization chamber with corrections for pressure and temperature. The resulting dose in Roentgens was converted to Rads(SiO_2) using 33.7 ev/ion pair for air. The resulting conversion factor was 0.869 Rad(SiO_2)/Roentgen).[10] The fiber was located 39.8 cm from the source and was wound on a spool of 10 cm diameter. Allowance was made for attenuation in the fiber bundle itself. Dose rate was 1165 rad/min at the center of the irradiated coil of fiber, close to the NETG recommendation of 1300 rad/min.

3. DATA ANALYSIS

The OTDR provided backscatter signal amplitudes, already converted into db, in the convenient format of Fig. 3. Output was on a floppy disc for subsequent analysis.

Analysis of the data of Fig. 3 and the other measurements was accomplished by averaging the backscatter amplitude over 21 meters increments for several different test fiber lengths, between 300 and 200 meters. Standard deviations were calculated based on the scatter in the points at both ends of the evaluated length. Attenuation of the irradiated fiber in db/km was calculated from appropriately weighted averages over these lengths. An alternative, possibly preferable, procedure would have involved a best-fit straight line to the data of Fig. 3. In that case, the slope of the resulting line would provide the best estimate of attenuation. The radiation-induced attenuation was determined by subtracting the fiber loss prior to irradiation from the level determined during the irradiation. (The pre-irradiation attenuation was determined by the OTDR to be 0.52 ± 0.22 db/km.) This process of subtraction further increased the uncertainty in the radiation-induced attenuation.

An OTDR system is hindered by the very low levels of Rayleigh backscattered light coupled back into the very small core of the single mode fiber. This leads to significant scatter in the backscatter signal, evident in the raw data traces in Fig. 3. This scatter led to substantial standard deviations that were calculated for each measurement. These standard deviations were further degraded as the fiber attenuation increased during Co^{60} irradiation. This is evident in Fig. 3, where the scatter in the data significantly increases with distance for the lower (irradiated) trace. [If a multi-mode fiber were being tested, as opposed to the single mode fiber used here, a much larger fraction of the Rayleigh scattered light would be coupled into the core, leading to larger return amplitudes and improved detection statistics.]

In addition, the measurement of light power exiting the fiber during each OTDR measurement allowed radiation-induced attenuation to be directly determined by the throughput method.

4. DATA ANALYSIS

During the 1990 NETG meeting, data from five Laboratories were presented for the same fiber tested in the present work and those data are shown in Fig. 4. The data acquired in the present work are shown in Fig. 5, overplotted on Fig. 4. Both throughput and OTDR data are shown, together with typical error bars for selected OTDR measurements. The absence of a monitor detector precluded determination of uncertainties for the throughput measurements. Fig. 6 also shows the present measurements together with the NETG data acquired after the fiber was recovering from the Co^{60} exposure. Fig. 7 compares the throughput data with the OTDR measurements; calculated uncertainties are shown with the OTDR data.

Good agreement is noted both between throughput and OTDR measurements and between the present measurements and the 1990 NETG measurements. However, the uncertainties on the OTDR data are significant. Longer averaging times would reduce the uncertainties, but longer data acquisition time is not appropriate when attenuation is varying on a time scale comparable to the data acquisition time. Of course, for the pre-irradiated conditions where attenuation is constant, multiple or longer data acquisitions are acceptable and were used in the present work.

5. CONCLUSIONS

Agreement between throughput and OTDR measurements, as should be anticipated, was demonstrated in the present work. However, the uncertainties in the OTDR data are significantly larger than could be obtained with a throughput system operating with a stable light source and an input power monitor.

While the present fiber was chosen to be free from photo-bleaching concerns, many other types of fibers are susceptible to such effects. The use of an OTDR in the simple geometry used here does not allow the input light level to be varied. For that reason, a variation in the experimental geometry to that shown in Fig. 8 may be preferable, wherein a separate light source is coupled into the fiber-under-test and may be independently varied. Depending on the circuitry of the OTDR being utilized , it might be necessary to shut off the second source during data acquisition by the OTDR.

The overload condition experienced at the fiber input or any subsequent fiber junction should be anticipated when an OTDR system is incorporated. As done in the present work, care must be exercised that any initial overload or signal distortion is allowed to dissipate before data acquisition is initiated. This was simply done by selecting a length of the fiber-under-test for determination of attenuation after (both in length and in time) recovery of the OTDR detection and processing system, but this approach prevents some portion of the fiber-under-test from being used in the measurement.

The averaging time required for an OTDR to acquire data can compromise some measurement requirements. The OTDR system would be extremely difficult to use for accurate measurements on short time scales unless extremely high input light power was injected into the fiber.

To summarize the limitations of OTDR, as opposed to throughput, techniques discussed above:

a) input light power levels may be fixed by the OTDR instrumentation,
b) the averaging time required by the OTDR precludes following rapid changes in fiber attenuation,
c) an OTDR is a more complex and costly item of instrumentation than that required for throughput measurements,
d) OTDR overload problems must be avoided,
e) accuracy of attenuation measurements is generally degraded unless very long data acquisitions are allowed to obtain many averages, and
f) determination of radiation-induced attenuation requires subtraction of the pre-irradiation attenuation value from the value obtained during irradiation. The pre-irradiation attenuation is itself subject to uncertainty, and this subtraction contributes to further degradation in measurement accuracy.

Despite these precautions and limitations on use of an OTDR-based radiation-induced attenuation measurement, several situations may well benefit from its use. Two obvious features deserve discussion:

a) measurement requires access to only one end of the test fiber, and
b) measurement need not depend on existence of a stable input light source over the duration of the measurement.

The first feature facilitates measurements involving a fiber of unknown resistance to radiation or in an environment of unknown radiation level. Even if radiation-induced attenuation increases the attenuation so much that light throughput is decreased below detection limits at the output end, the OTDR can always be used to determine attenuation from the input end.

In a practical application, use of a fiber as a distributed sensor for radiation might involve long lengths of fiber routed within a complex. Such a system might be designed to provide access to both ends of the fiber (enabling routine throughput measurement). But, if radiation levels exceeded expectations and forced transmission to very low values, the use of an OTDR would still allow measurements, as well as localizing the specific regions of high attenuation (and radiation exposure) along the fiber length.

The second feature will be of importance when extremely long duration measurements are required, such as for the very low dose rates typical of multi-year space requirements. In such a case, use of throughput techniques might require dedicating a measurement system to the fiber for the duration of the test or performing multiple two-point cutback measurements throughout the test. The ability of an OTDR to make measurements without concerns for the long term stability of measurement equipment is a definite advantage. However, concerns over photo-bleaching would temper this advantage. If a specific light level were anticipated to be propagating in the fiber during a proposed application and if the fiber were susceptible to photobleaching, it would be necessary to maintain the anticipated light level during the duration of the radiation exposure and measurements. In that case, where a portion of the instrumentation required for throughput measurements must already be dedicated during the entire exposure time, the advantage of the OTDR is reduced.

6. ACKNOWLEDGMENTS

Personnel (Ron Head and Carl Wilson) at EG&G, Inc. in Las Vegas, NV operated and calibrated the Co^{60} source. Earl Pope and John Duran of EG&G, Inc. in Las Vegas, NV provided support for the fiber optic operations. Data from the 1990 NETG meeting were presented by H. Henschel of Fraunhofer-INT, R. H. West of Royal Military College of Science, E. W. Taylor of Air Force Systems Command Phillips Laboratory, C. E. Barnes of Jet Propulsion Laboratory, and J. A. Krinsky of Boeing Aerospace and Electronics Co.

7. REFERENCES

1. R. A. Greenwell and P. B. Lyons, "Development of Radiation Test Procedures for Fiber Optic Systems," *SPIE* Vol. 1314, pp. 218-222, 1990.
2. E. J. Friebele and E. W. Taylor, "Standardized Testing of the Radiation Response of Optical Fibers," DoD Fiber Optics Conference '90, McLean, Va., March 1990.
3. E. W. Taylor, E. J. Friebele, and P. B. Lyons, "Standardized Measurements for Determining the Radiation-Induced Attenuation in Optical Fibers," Symposium on Optical Fiber Measurements, Boulder, Co., September 1990. Los Alamos report number LA-UR-90-1994.
4. E. J. Friebele, P. B. Lyons, J. Blackburn, H. Henschel, A. Johan, J. A. Krinsky, A. Robinson, W. Schneider, D. Smith, E. W. Taylor, G. Y. Turquet de Beauregard, R. H. West, and P. Zagarino, "Interlaboratory Comparison of Radiation-Induced Attenuation in Optical Fibers. Part III: Transient Exposures," *IEEE Journal of Lightwave Technology*, Vol. 8, pp. 977-989, June 1990.
5. E. W. Taylor, E. J. Friebele, H. Henschel, R. H. West, J. A. Krinsky, and C. E. Barnes, "Interlaboratory Comparison of Radiation-Induced Attenuation in Optical Fibers. Part II: Steady-State Exposures," *IEEE Journal of Lightwave Technology*, Vol. 8, pp. 967-976, June 1990.
6. NATO Nuclear Effects Task Group, "Procedure for Measuring Steady State Gamma Radiation-Induced Attenuation in Optical Fibers and Optical Cables," Los Alamos report number LA-UR-90-1901, May 1990.
7. R. H. West, Royal Military College of Science (Shrivenham, UK), private communications, 1991.
8. H. Henschel, Fraunhofer-INT (Euskirchen, Germany), private communications, 1991.
9. H. Henschel, O. Köhn, U. U. Schmidt, "Influence of Dose Rate on Radiation-Induced Loss in Optical Fibres," Asia-Pacific Conference on Optical Technology, Singapore, October 1990. To be published in *SPIE* Vol. 1399.
10. U. S. Department of Health, Education, and Welfare, *Radiological Health Handbook*, 1970.

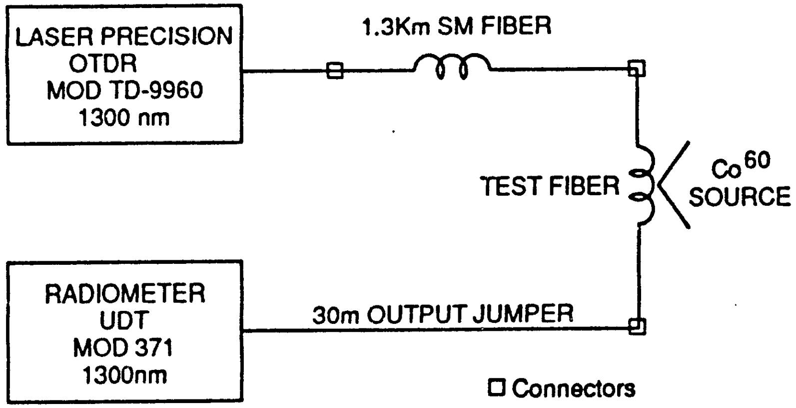

Fig. 1. Experimental configuration for the measurements.

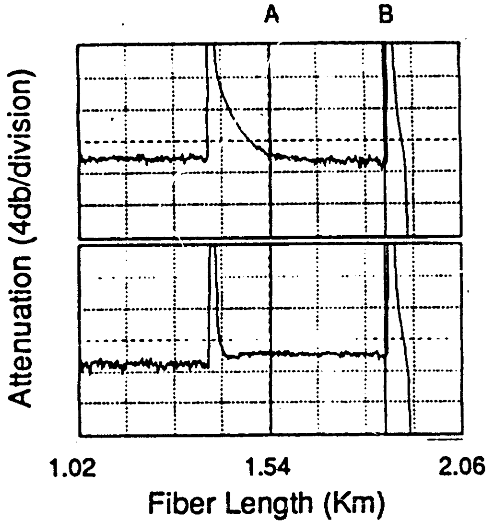

Fig. 2. Comparison of backscatter data for the portion of fiber immediately following the Radiall connector joint to the fiber-under test. The upper trace involves a dry joint, while the lower trace included index-matching at the interface between the two fibers. Note that the system saturation caused by reflections at the non-index-matched joint seriously distorts the backscatter data for some distance after the joint. All measurements made with index-matching gel in the joint.

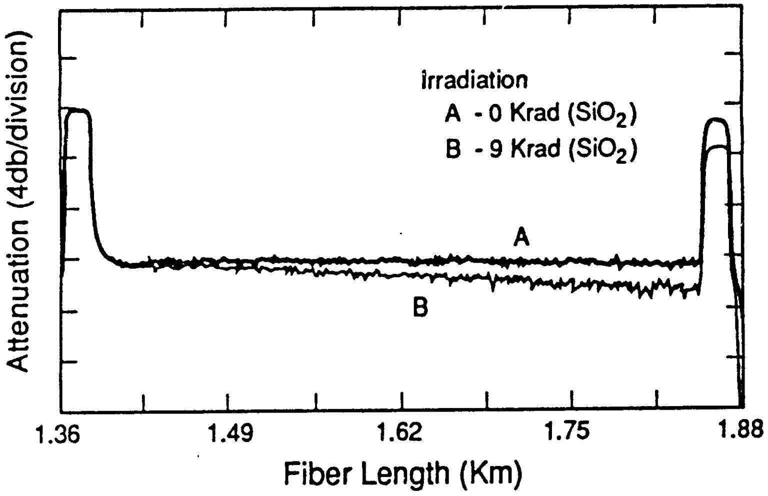

Fig. 3. Comparison of OTDR back-scatter traces for the fiber before any Co^{60} irradation and during irradiation [dose = 9 krad (SiO_2)] of the fiber. Note the difference in slopes reflecting the greater attenuation during irradiation

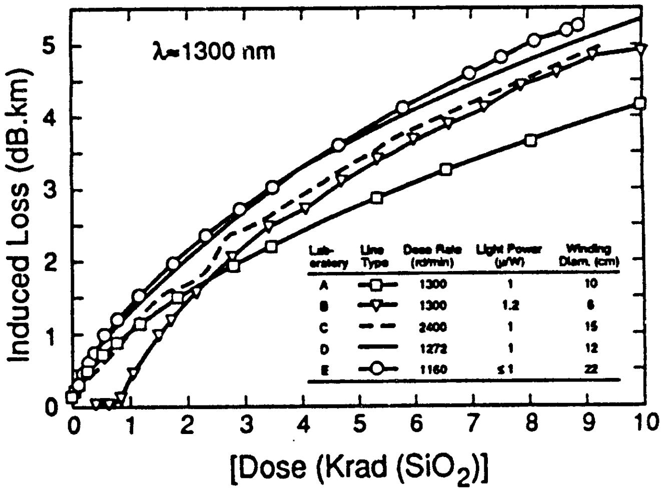

Fig. 4. Radiation-induced attenuation measurements were provided by five Laboratories participating in the 1990 NATO NETG meeting at the Royal Military College of Science. These data were all acquired with throughput measurements using the NETG protocol.[6] Data from each Laboratory are represented by a different symbol; specific Laboratories are not identified.

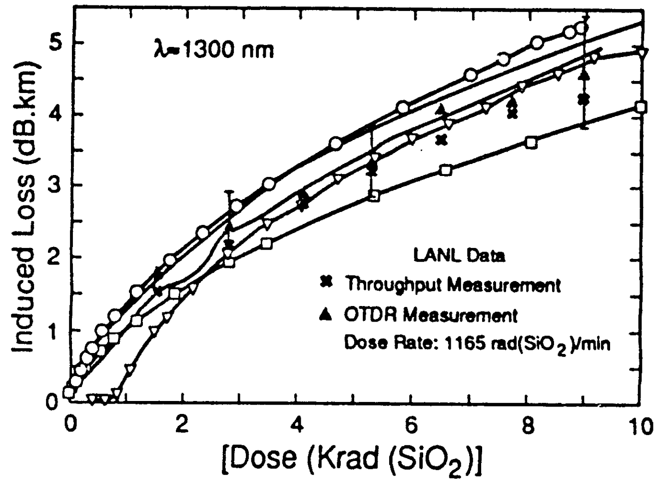

Fig. 5. Comparision between OTDR and throughput radiation-induded attenuation data obtained with the single mode fiber-under-test during Co^{60} irradiation and similar data obtained for the same fiber in the1990 NETG meeting (cf. Fig. 4). Both throughput and OTDR data are shown, together with typical standard deviations for the OTDR measurements. The absence of a monitor detector precluded determination of uncertainties for the throughput measurements. Laboratory symbols are unchanged from Fig. 4.

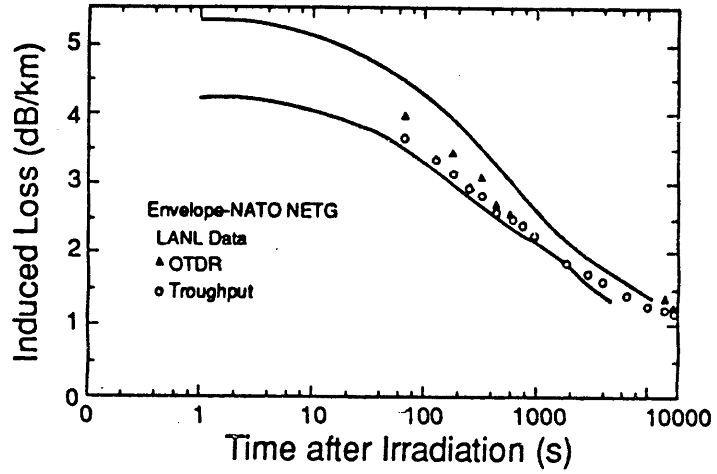

Fig. 6. Comparison of OTDR and throughput radiation-induced attenuation data obtained with the single mode fiber-under-test during the recovery phase of the test. The two lines serve to bracket the recovery data measured by the partticipating test Laboratories in the 1990 NETG meeting.

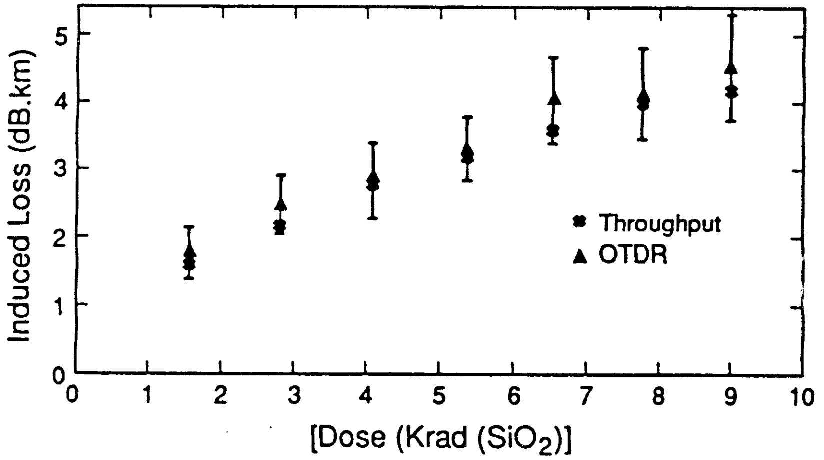

Fig. 7. Comparison of OTDR measurements and standard deviations with throughput measurements during Co^{60} irradiation.

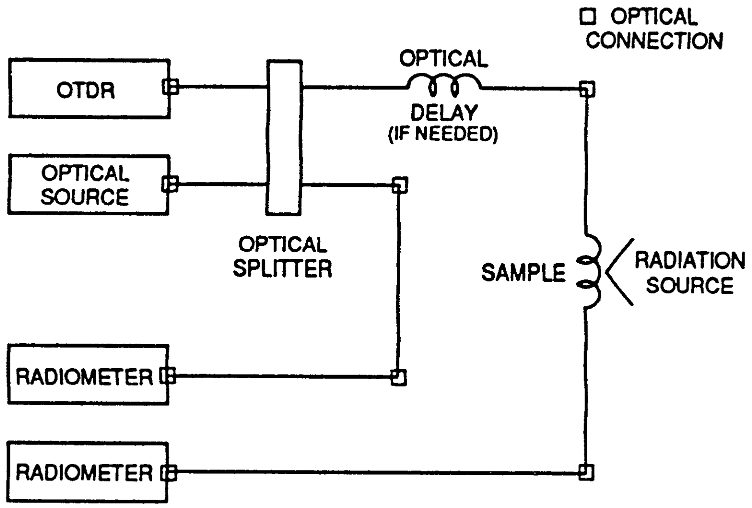

Fig. 8. A more complicated alternative experimental configuration that would provide greater accuracy and flexibility than the system used herein. This variation allows an imput light level to be preset and subsequently maintained and verified by a monitor detector. This configuration would be critical for fibers in which photo-bleaching occurs where an anticipated application would employ some average power propagating in the fiber at all times.

DRAFT

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

under consideration by

NATO Nuclear Effects Task Group
A/C 243, PANEL IV (RSG.12)
September 1991

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DRAFT

1. INTENT

This test procedure outlines a method for measuring the transient attenuation of optical fibers and/or cables exposed to a pulse of radiation (gamma rays, x-rays, electrons, protons, neutrons, etc). It can be employed to determine the level of radiation-induced attenuation (in units of dB/km as a function of time) produced in single-mode or multi-mode optical fibers, in either cabled or uncabled form, due to pulsed exposure to radiation. This test is not a materials test for the non-optical components of a fiber optic cable. Other test methods may be required to evaluate degradation of cable materials due to radiation exposure. [The procedure specifically addresses x-ray or electron pulsed exposures, but would be applicable to other pulsed radiation sources 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 optical (photobleaching) or by thermal processes causes recovery (a decrease of radiation-induced attenuation). Recovery occurs along with darkening during exposure and is evident immediately after irradiation. Recovery of the attenuation after a single pulse of radiation may depend on many variables, including the temperature of the test sample, the configuration of the sample, the spectrum and type of radiation employed, 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 by four or more decades during the recovery process.

This test procedure addresses the time-varying (i.e., transient) behavior of an optical fiber after exposure to a single pulsed dose of radiation. 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.

This procedure may be used to document transient attenuation from gamma or x rays (of few MeV energies) or moderate energy (few MeV) electron sources, i.e., sources for which significant damage to the fiber by displacement mechanisms will not occur. Interaction of gamma rays involves processes that generate electrons or positrons of energy comparable to the gamma ray energy. Since few pulsed gamma/x-ray sources exist that can deliver large (>500 rad) radiation doses over significant volumes, most testing of such phenomena at large doses has involved pulsed electron sources. It should be noted that if specific application of a fiber requires exposure to radiations (neutrons or protons, for example), which can produce significant displacements in the fiber material, then care should be taken to utilize a radiation source that will duplicate the relative fractions of displacement *vs* ionization interactions.

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, 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. The Detail Specification must specify the times at which measurements are to be made, based on the intended application.

Radiation exposure may result in luminescence phenomena that generate light in the fiber. In addition, in exposures of optical fibers to energetic gamma rays or electrons, light will be generated through the Cerenkov process (the spectrum of Cerenkov light varies as the inverse third power of wavelength). Although this procedure discusses only measurements of attenuation, the presence of this burst of broadband Cerenkov light or luminescent light must be anticipated by users. In this procedure, output filters limit the fraction of the luminescent or Cerenkov light reaching the detector, which could overload recording instrumentation and compromise system accuracy.

This specification primarily focuses on measurements conducted at short times, generally less than a few minutes. For time scales of minutes, or longer, the procedures described in a companion specification "Procedure for Measuring Steady State Gamma Radiation-Induced Attenuation in Optical Fibers and Optical Cables" may be readily applied. In this previous procedure, input power levels are precisely specified. In the present procedure, power levels are specified only for times longer than 10 µs. Photobleaching has not been observed at times below 10 µs even at high power levels. At longer times power levels must be carefully 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. REFERENCED DOCUMENTS

Test or inspection requirements may 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"

Los Alamos National Laboratory Document LA-UR-90-1901, "Procedure for Measuring Steady State Gamma Radiation-Induced Attenuation in Optical Fibers and Optical Cables"

3. TEST EQUIPMENT — SEE FIGURE 1

3.1 Radiation Source

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 brehmsstrahlung 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 versus displacement events in the fiber material will be decreased with the higher energy sources, potentially leading to different recovery processes. Specific applications would, therefore, benefit from specification of the desired source characteristics to be used for attenuation testing.

The source should provide a variation in dose across the fiber sample not exceeding ±10%. Average total dose should be expressed in Gray(Si) [1 Gy = 100 rad(Si)] to a precision of ± 10%, traceable to national standards.

If T represents the earliest time specified in the Detail Specification for measuring transient attenuation, the radiation source pulse width should be at no longer than 0.1T to avoid competition between recovery and damage mechanisms.

The source should be capable of delivering absorbed radiation doses to the optical fibers of 5, 100, and 1000 Gy (or as required in the Detailed Specification). In the case of low energy photon or electron source, 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.

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 830 ± 25, 1300 ± 50, and 1550 ± 50 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. For measurements specified for times below 10 µs, the optical power is not limited (and increased power may be required to achieve adequate detection/recording bandwidth and signal and to avoid complications arising from the level of the Cerenkov light generated during the pulsed irradiation). For longer times, the optical power coupled from the source into the test sample shall average -30 dBm (1 µW), or as listed in the Detail Specification.

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

Note: Even at 1 µW power level, photobleaching may occur at times beyond 10 µs, dependent 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.

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. At the output end of the fiber, a filter and/or monochromator may be necessary to avoid saturation or non-linearities of the detector and recording instrumentation by the prompt burst of Cerenkov light that occurs coincident in time with a radiation pulse of high energetic electrons or photons.

3.4 Cladding Mode Stripper

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

3.5 Fiber Support and Positioning Apparatus

A means of stably supporting the input end of the test sample shall be arranged, such as a clamp, connector, splice, or weld. During an attenuation measurement, alignment of the source and fiber shall not be changed.

3.6 Optical Splitter — See Figure 1

An optical splitter or fiber optic coupler may divert some portion of the input light to a reference detector. 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.)

Caution: If a polarized light source, like a laser, is used, only a polarization insensitive coupler should be used.

3.7 Input Launch Simulator

3.7.1 Class Ia Fibers — (Graded Index Multimode Fiber) An equilibrium mode simulator shall be used to attenuate higher order propagating modes and to establish a steady-state mode condition near the input end 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 employed 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 end spatially and angularly. A mode filter shall be employed to remove high order modes in the wavelength range greater than or equal to the cutoff wavelength of the test fiber. The test condition specified in Section 4.1 of FOTP-80 satisfies this requirement.

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 Detection/Recording time response

The time response of the overall detection system including the data recording system must be carefully evaluated for transient measurements. Both the high frequency and 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/recording system shall be 10x less than the earliest time at which measurements are to be recorded as specified in the Detail Specification. This impulse response is most easily measured by injecting an optical pulse (whose pulse width is itself 10x less than the detection/recording system impulse response) into the detector and measuring the full width at half maximum (FWHM) on the data recorder.

Note: If capabilities exist to unfold (or deconvolve) the system time response from all observed data (using, for example, Fourier transforms), the requirement specified here (for documentation of the system FWHM with a much narrow pulse) 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 frequency response of the entire detector/recording system should extend at low frequencies to zero frequency, i.e., a completely dc-coupled system should be employed if at all possible. If 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 dc 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 (since most light sources can deliver higher outputs in a short puse mode than in a dc mode) to obtain adequate light levels that simplify detection and recording considerations.]

A simple test for low frequency response involves injection of a flat-topped optical pulse of variable width into the detector/recorder system. If the recorder demonstrates return of the observed output power to zero at the trailing edge of the pulse independent of the optical pulse width (in a time commensurate with the system impulse width measured in section 3.8.1), then the system has dc-coupling characteristics. If the measured power does not return to zero on this time scale, then the system is limited in low frequency response.

If the detector/recorder system is not dc-coupled, the light source must be used in a pulsed mode. The maximum light source pulse width that can be used should yield a departure from zero on the trailing edge of the pulse (as discussed in the proceeding paragraph), that is at least 10x less than the power transmitted through the test fiber at any time before or during irradiation or during the subsequent recovery of the radiation-induced attenuation. This limitation on the width of the pulsed light source specifies a limit to the longest time at which reliable measurements of transient attenuation can be obtained.

3.9 Elements of the detector/recorder system

3.9.1 Detector — Signal Detection Electronics. An optical detector which is linear and stable over the range of intensities that are encountered shall be used. A typical system might include a PIN photodiode with a preamplifier or an avalanche photodiode.

3.9.2 Optical Power Meter. Assuming that the source can be operated in the dc mode (see section 3.8.2), an optical power meter may be used to determine that the power coupled from the optical source into the test sample is 1.0 µW (for observations at times longer than 10 µs) or the level listed in the Detail Specification. (Some types of optical power meters can be used to determine average power with a pulsed light source, although a duty factor correction would then need to be applied to obtain the pulsed power level from the observed average power level.) Alternatively, a calibrated detector/preamplifier/recording system may be used to measure the pulsed level of optical power injected into the test sample.

3.9.3 Data Recorder. A suitable data recording system must be incorporated that provides a bandwidth commensurate with the tests specified in Section 3.8. An analog oscilloscope with either a film or digital camera, or a digital sampling oscilloscope coupled to data display unit may be used.

3.10 Radiation Dosimeter

Dosimetry traceable to National Standards shall be used and expressed in Grays(Si). 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.

3.11 Temperature Controlled Container

Unless otherwise specified, the temperature controlled container shall have the capability of maintaining the specified temperature to within $\pm 2^{o}C$.

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 duplicating 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 the subsequent attenuation measurement. During that time, the maximum fluctuation in observed system output should be converted into an apparent change in optical attenuation due to system noise ($\Delta\alpha_n$) in dB/km using either Equation 6.1.A (if no optical splitter and reference detector are used) or 6.2.A (if an optical splitter and reference detector are used). Any subsequent measurement must be rejected if the observed ΔA_t (defined in Section 6) does not exceed 10 x $\Delta\alpha_n$ (or as defined in the Detail Specification).

3.14 Baseline stability

Baseline stability shall also be verified for a time comparable to the attenuation measurement with the light source 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 x P_n.

4. TEST SAMPLE

4.1 Specimens

4.1.1 Fiber Specimen. The test specimen shall be a representative sample of the fiber specified in the Detail Specification or as specified in Section 4.1.2. An unirradiated sample of fiber should be used in each test.

4.1.2 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. An unirradiated sample of cable should be used in each test.

4.2 Test Specimen for Transient Attenuation Measurement

The length of the test sample is dependent on the time regime for which measurements are required in the Detail Specification. The irradiated fiber length should be short enough that the transit time of light through the irradiated region must be at least 10x shorter than the shortest time T 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 specification LA-UR-90-1901 (cf. sec 2.0), (but this recommendation can not be followed if the radiation source is not capable of covering an irradiation volume large enough to hold the fiber coil). Further limits on the test specimen length may be required from the system baseline stability test of Sec. 3.14.

4.3 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.

4.4 Ambient Light Shielding

The fiber sample shall be shielded from ambient light to prevent photobleaching by any external light sources. An absorbing fiber coating or jacket can be used as the light shield provided it has been demonstrated to block ambient light.

5. 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. 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 measuremen., the TLDs shall not be used more than once. TLDs should be used only in the dose region where they maintain a linear response. Per Section 3.1, the variation in dose across the fiber reel volume shall not exceed ± 10%.

Other types of dosimetry may also be incorporated, such as radiachromic film, microcalorimeters, or a Faraday cup (for electron beam measurements). Of these alternatives, the microcalorimeter and radiachromic film can potentially provide a response calibrated directly in absorbed dose. Depending on the composition of the microcalorimeter or the radiachromic film and the radiation source employed (electron or bremsstrahlung), it may be necessary to correct the observations to obtain dose actually deposited in the optical fiber material. Such corrections should include attention to dose build-up and/or attenuation factors that may occur due to materials (fiber cable material, fiber buffer material, reel composition, self-shielding of a fiber coil, etc). Similar materials (such as thin aluminum foils, for example) may be placed before the dosimeter to mock-up these phenomena. [If a low energy x-ray source 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.]

A Faraday cup should be used only as a transfer (not as the primary dose-measuring instrument) standard and should be calibrated against one of the above absorbed dose instruments (TLD, radiachromic film, or microcalorimeter) prior to its use. (The Faraday cup will measure only charge on the cup, 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.) [With radiochromic film, multiple radiation pulses may be required to obtain adequate signal levels on the film. In this case, a Faraday cup provides a convenient pulse-to-pulse normalization method.]

Total dose should be measured on each pulse of the radiation source, unless previous tests have verified the shot-to-shot stability of the radiation source to within ±10%.

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.

5.3.1 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°C prior to proceeding (or at the test temperature specified in the Detail Specification).

5.3.4 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. 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.

5.3.5 The test sample input end shall again be prepared in accordance with Section 5.2. The light source shall be coupled into the input end of the fiber, as described in Section 3. The output end of the fiber shall again be postioned such that all light exiting the fiber impinges on the active surface of the detector 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. 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 the sample attenuation 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 and recorded. For measurements at time longer than 10 µs the input power should be adjusted to be in compliance with the value specified in Section 3.2.

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

5.3.7 Prior to irradiation the system stability and baseline stability tests specified in Sections 3.13 and 3.14 shall be performed.

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

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

TABLE I: TOTAL DOSE

Total Dose, Gray(Si)
5
100
1000

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

5.3.10 The output power from the test sample shall be recorded both prior to the pulse of radiation and for the duration of the transient measurement as specified in the Detail Specification. The power level of the reference detector, if used, shall also be recorded during the same time period. These power levels are required as inputs to the calculations described in Sec. 6. A typical recorder output is shown in Fig. 2.

5.3.11 Steps 5.3.1 through 5.3.11 should be repeated for other required test temperatures, time regimes, and wavelengths. A non-irradiated fiber/cable specimen must be used for such new measurements.

6. CALCULATIONS

6.1 For continuous output power measurements.

The radiation-induced change in sample attenuation ΔA_t at time t shall be calculated by

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

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

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

6.2 If a reference detector is used

The radiation-induced change in sample attenuation ΔA_t should be calculated by modifying Eq. 6.1.A to:

$$\Delta A_t = -10\ \{\log(P_t/P_b) - \log(P_{t'}/P_{b'})\}/L \qquad \text{[in dB/km]} \quad \text{(Eq. 6.2.A)}$$

where:
$P_{t'}$ = power measured by the reference detector at time t
$P_{b'}$ = power measured by the reference detector before irradiation.

6.3 The change in attenuation:

ΔA_t should be reported at a times t specified in the Detail Specification. P_t, P_b, $P_{t'}$, and $P_{b'}$ must be measured relative to a baseline of zero light.

7. REPORT

7.1 The folowing data shall be reported:

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 for times specified in the Detail Specification.
7.1.8 Reference detector characteristics, if used.
7.1.9 Characteristics of test sample such as fiber type, cable type, dimensions, and composition.
7.1.10 Recorder output data
7.1.11 Description of radiation source
7.1.12 Test dose and time duration of pulse
7.1.13 Energy and type of radiation source
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 apparatus.
7.1.21 Documentation of detector/recorder system bandwidth
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. SPECIFYING INFORMATION

8.1 The Detail Specification should include as a minimum:

8.1.1 Identification of fiber type and cable type
8.1.2 Request for dose level
8.1.3 Request for 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.

Figure 1. Schematic Instrumentation Diagram

Figure 2. Typical data traces

FIGURE 1 AND 2 TO BE SUPPLIED IN MUNICH

RADIATION-INDUCED ATTENUATION
of
HIGH-OH OPTICAL FIBERS
after
HYDROGEN TREATMENT
in the
PRESENCE of IONIZING RADIATION

P. B. LYONS AND L. D. LOONEY
LOS ALAMOS NATIONAL LABORATORY

RADECS '91
MONTPELLIER FRANCE
SEPTEMBER 1991

EFFECTS OF HYDROGEN ON OPTICAL FIBERS

INCREASED ATTENUATION AT LONG WAVELENGTH
- CONCERN OF HYDROGEN IN UNDERSEA ENVIRONMENTS

SUPPRESSED RADIATON-INDUCED ABSORPTION
- H_2 PERMEATION BEFORE OR AFTER IRRADIATION
- HYDROGEN BINDING INTO INTERNAL DEFECTS

HYDROGEN MITIGATION OF DRAW-INDUCED DEFECTS

HYDROGEN TREATMENT TO IMPROVE UV TRANSMISSION

HYPOTHESIS FOR CURRENT WORK

SIMULTANEOUS PRESENCE OF:
- HYDROGEN IN FIBER
- DEFECTS PRODUCED BY IRRADIATON

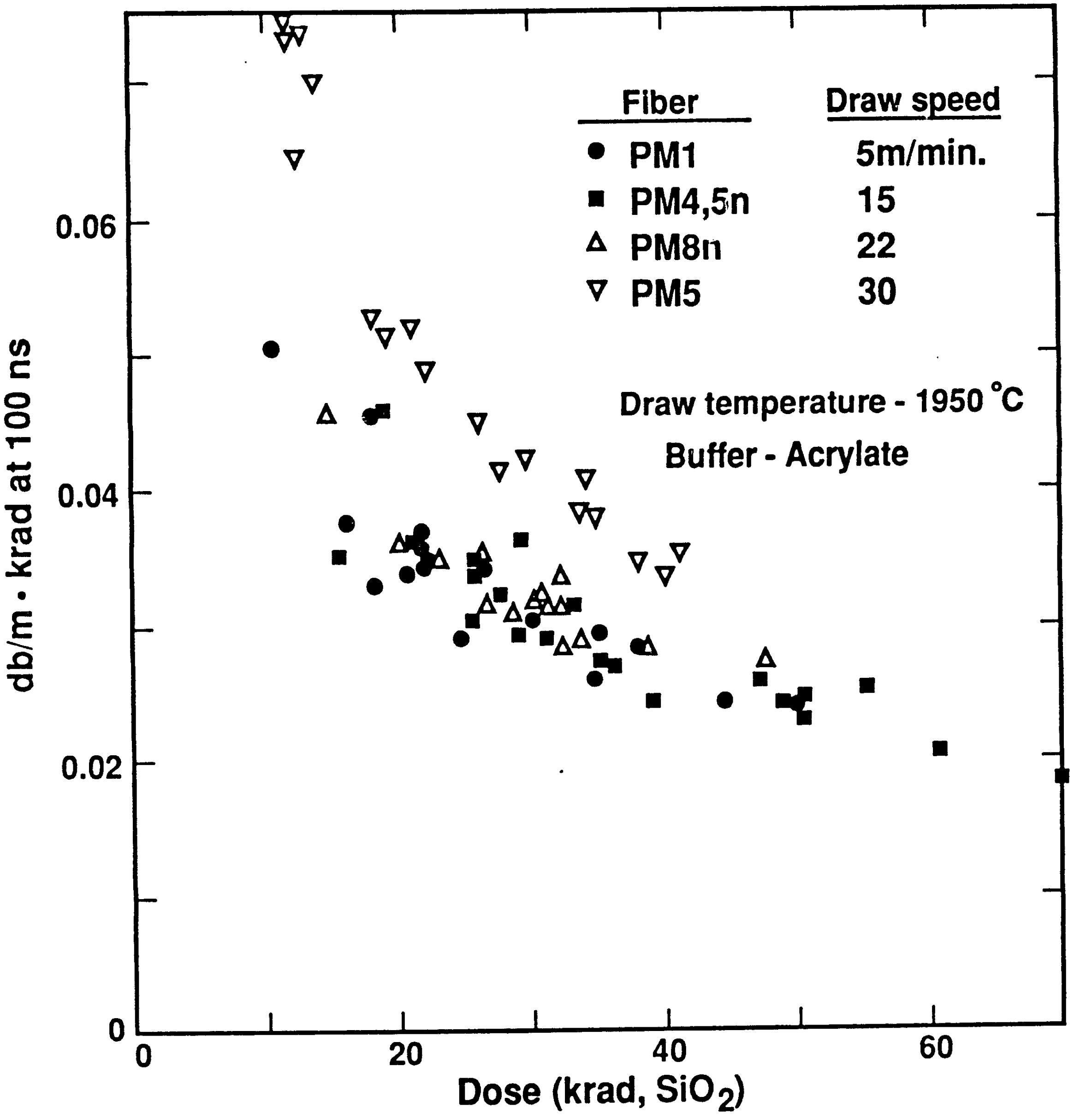
MIGHT LEAD TO:
- PREFERENTIAL BREAKING OF WEAK BONDS
- BINDING OF HYDROGEN INTO THOSE SITES

WHICH COULD RESULT IN
- REDUCED RADIATION-INDUCED ATTENUATION

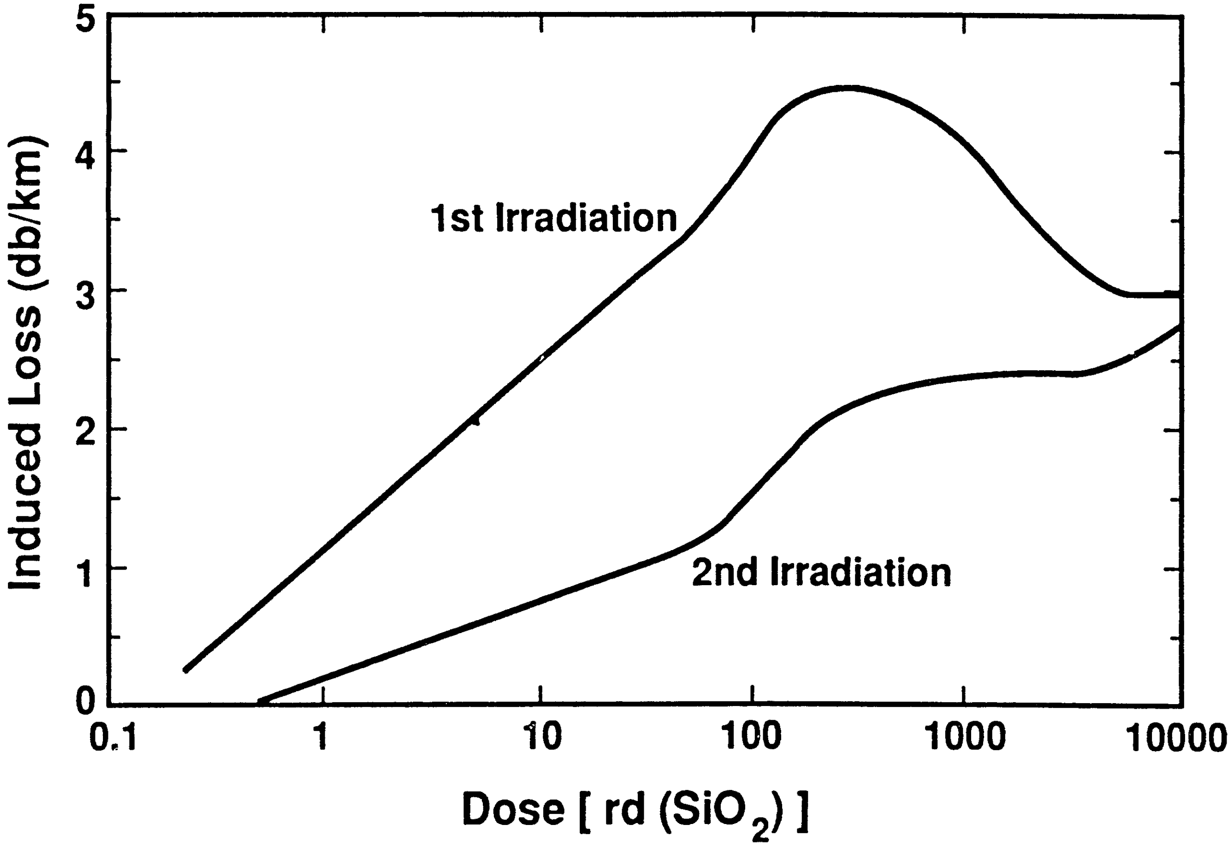
DEPENDENT ON ASSUMPTION:
- HYDROGEN BONDS STRONGER THAN THE ORIGINAL WEAK BONDS

GSO9-1838 8/89 /125

TRANSIENT ATTENUATION DATA



Co^{60} DATA



Fiber: PM6bn
Dose Rate: 1300 rad/min
Power: 1 μ w

Temperature: 22 °C
Wavelength: 865 nm
Time between irradiations: 45 min.

FIBER PARAMETERS

HIGH-OH SUPRASIL CORE FIBER

PREFORM FROM HERAEUS QUARZGLAS
DRAWN BY POLYMICRO TECHNOLOGIES

FIBER CONSTRUCTION

CORE 100 μM
CLAD 110 μM
POLYMIDE BUFFER
ACRYLATE BUFFER

FIBER TREATMENT PARAMETERS

FIBER #	H_2 EXPOSURE	PRE-IRRADIATION
1	NO	NONE
1 H	YES	NONE
2	NO	1 KRAD
2 H	YES	1 KRAD
3	NO	10 KRAD
3 H	YES	10 KRAD
4	NO	50 KRAD
4 H	YES	50 KRAD

TEST SEQUENCE

HYDROGEN EXPOSURE PARAMETERS

100 HOURS @ 107 ^{o} C
COLD STORAGE UNTIL PRE-IRRADIATION
    FIBER PRE-IRRADIATION @ 25^{o} C

ATTENUATION TESTS

CO^{60}
    7 DAYS AFTER H_2/CO^{60} TREATMENT
    ROOM TEMPERATURE STORAGE

PULSED ELECTRONS
    60 DAYS AFTER H_2/CO^{60} TREATMENT
    ROOM TEMPERATURE STORAGE

Figure 1

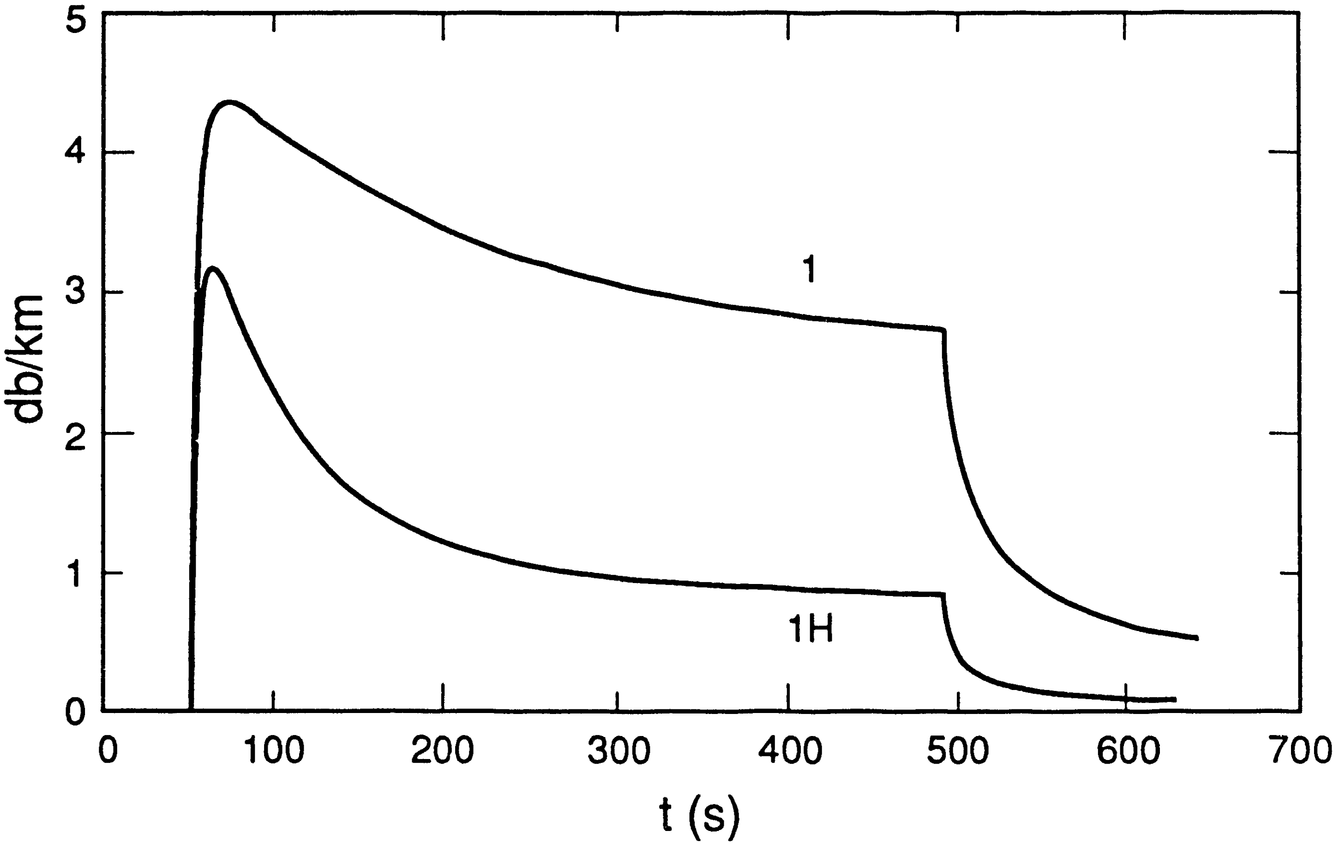
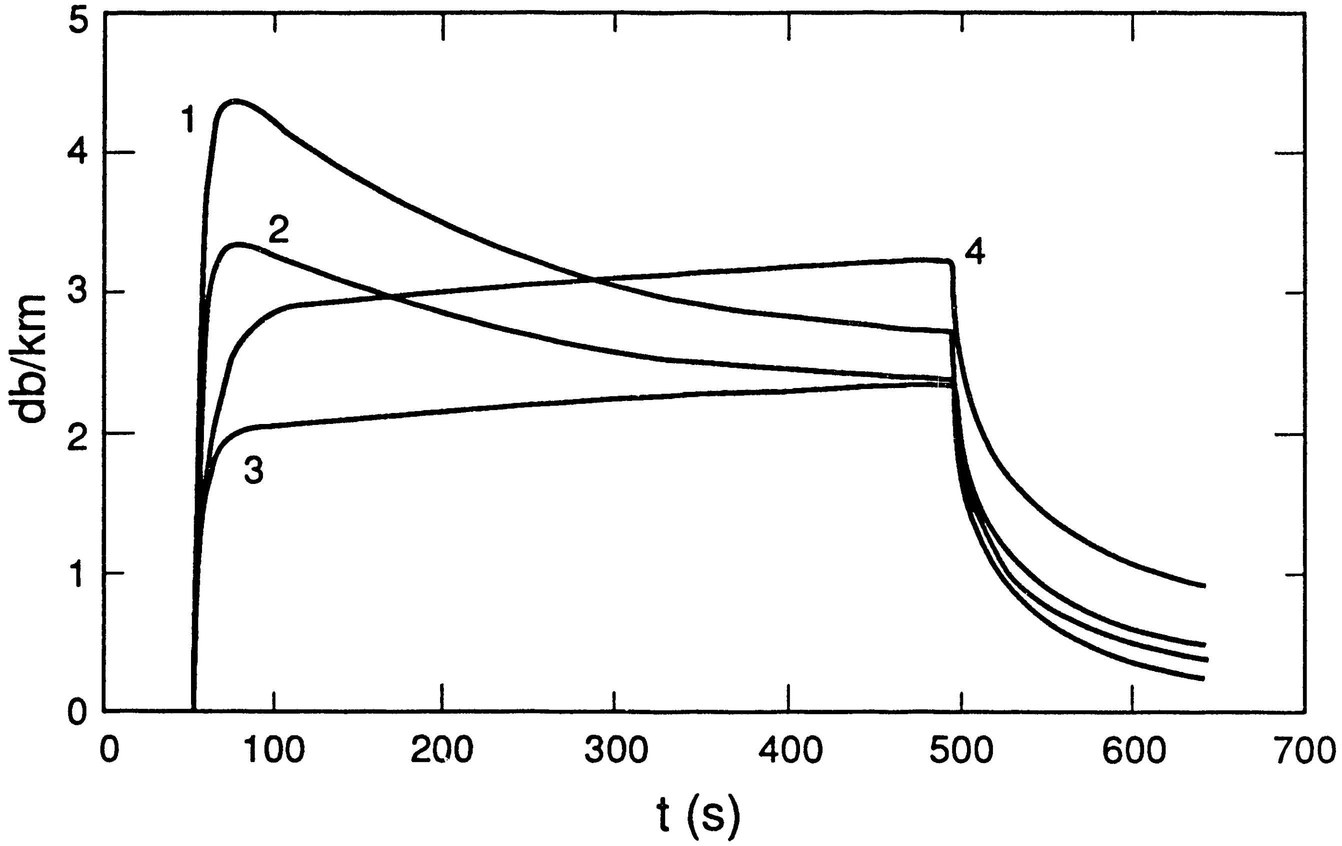
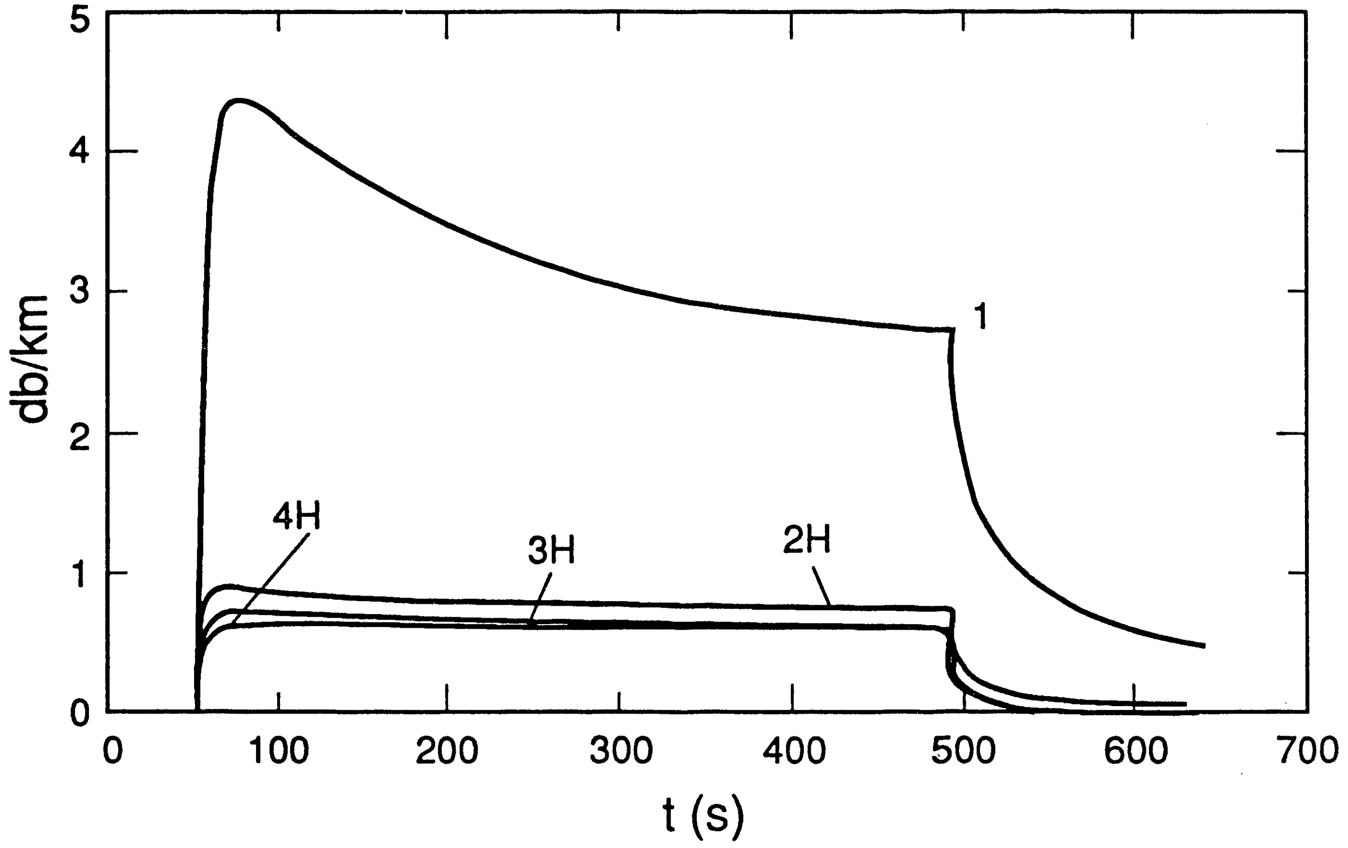


Figure 2



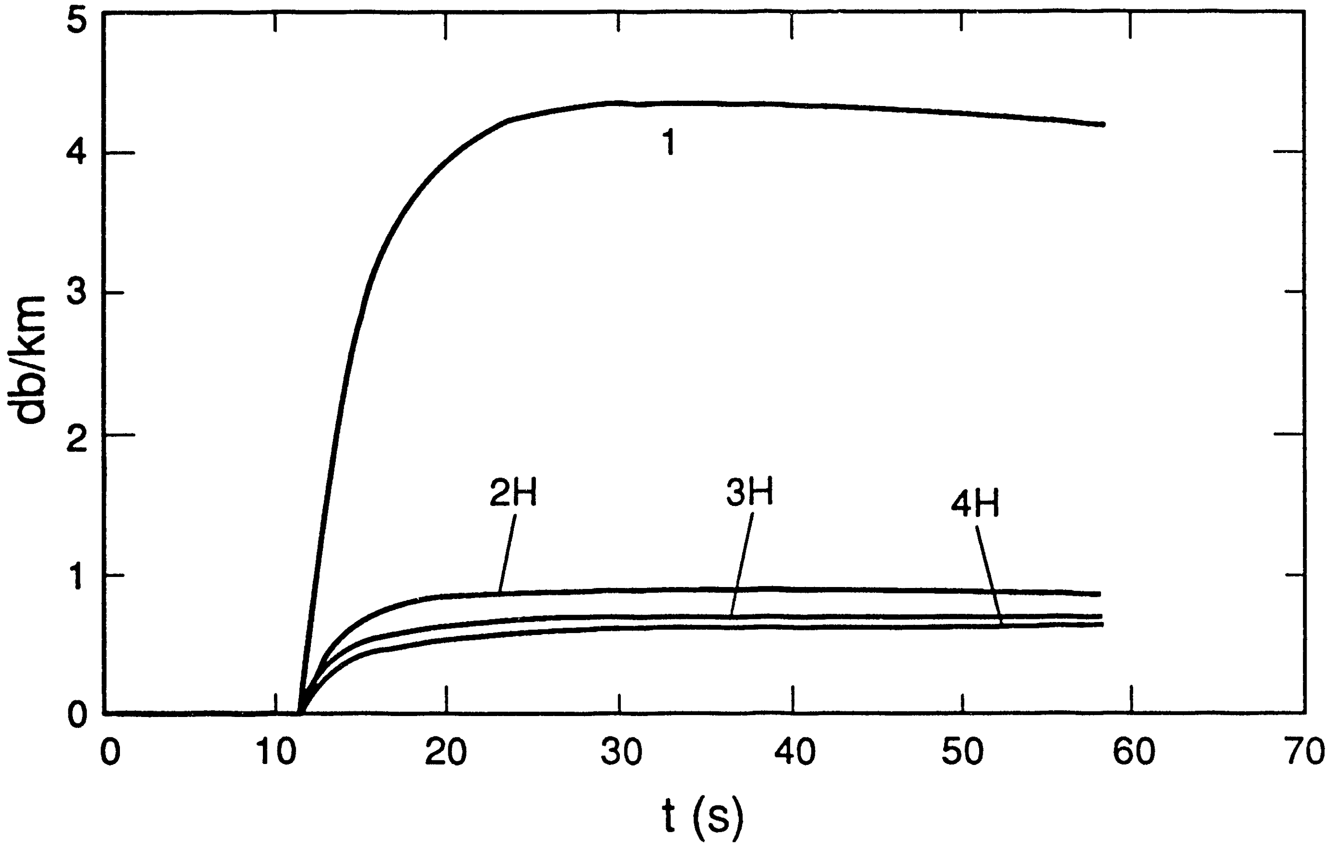
IS-12/91-3515/132

Figure 3

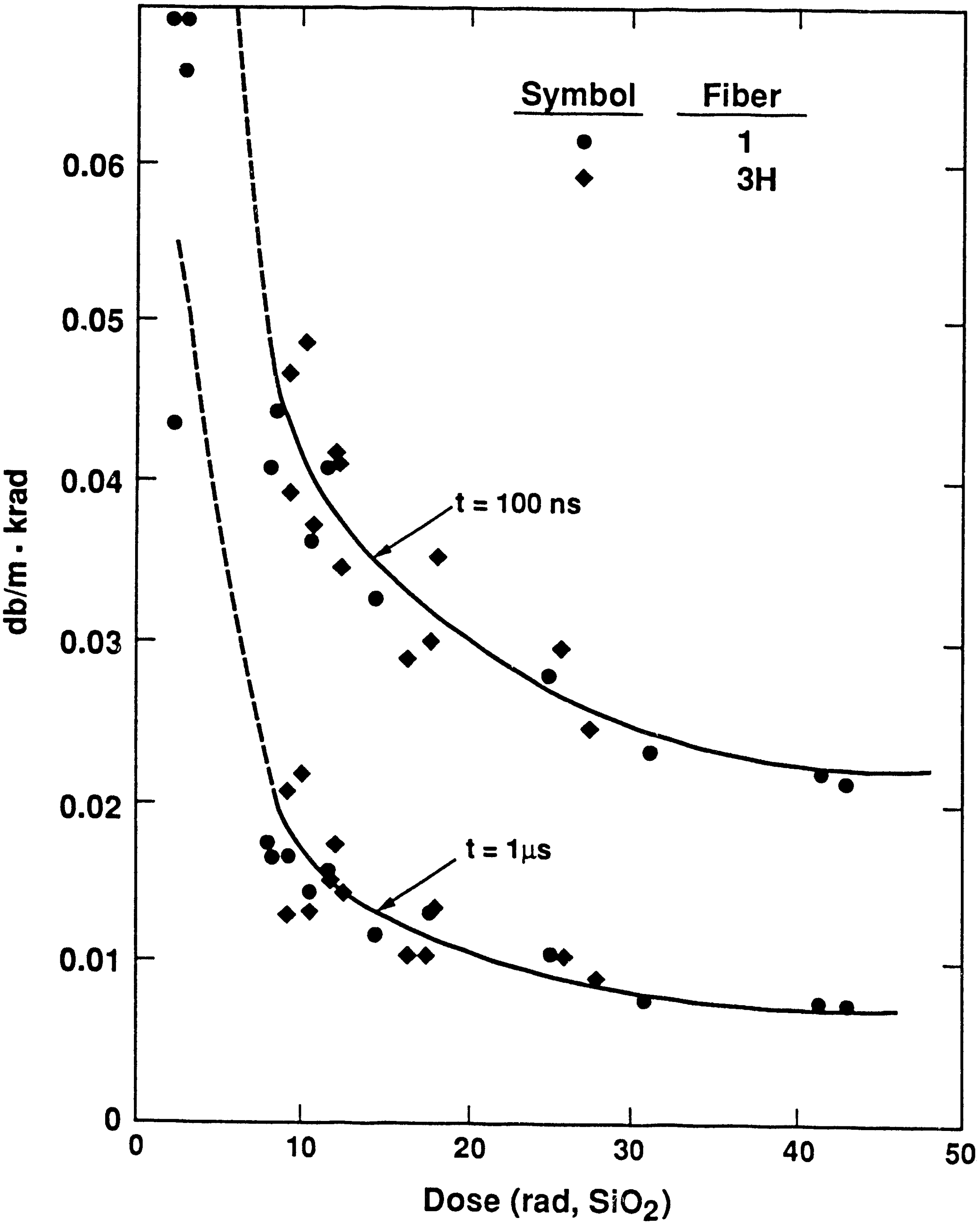


IS-12/91-3516/132

Figure 4

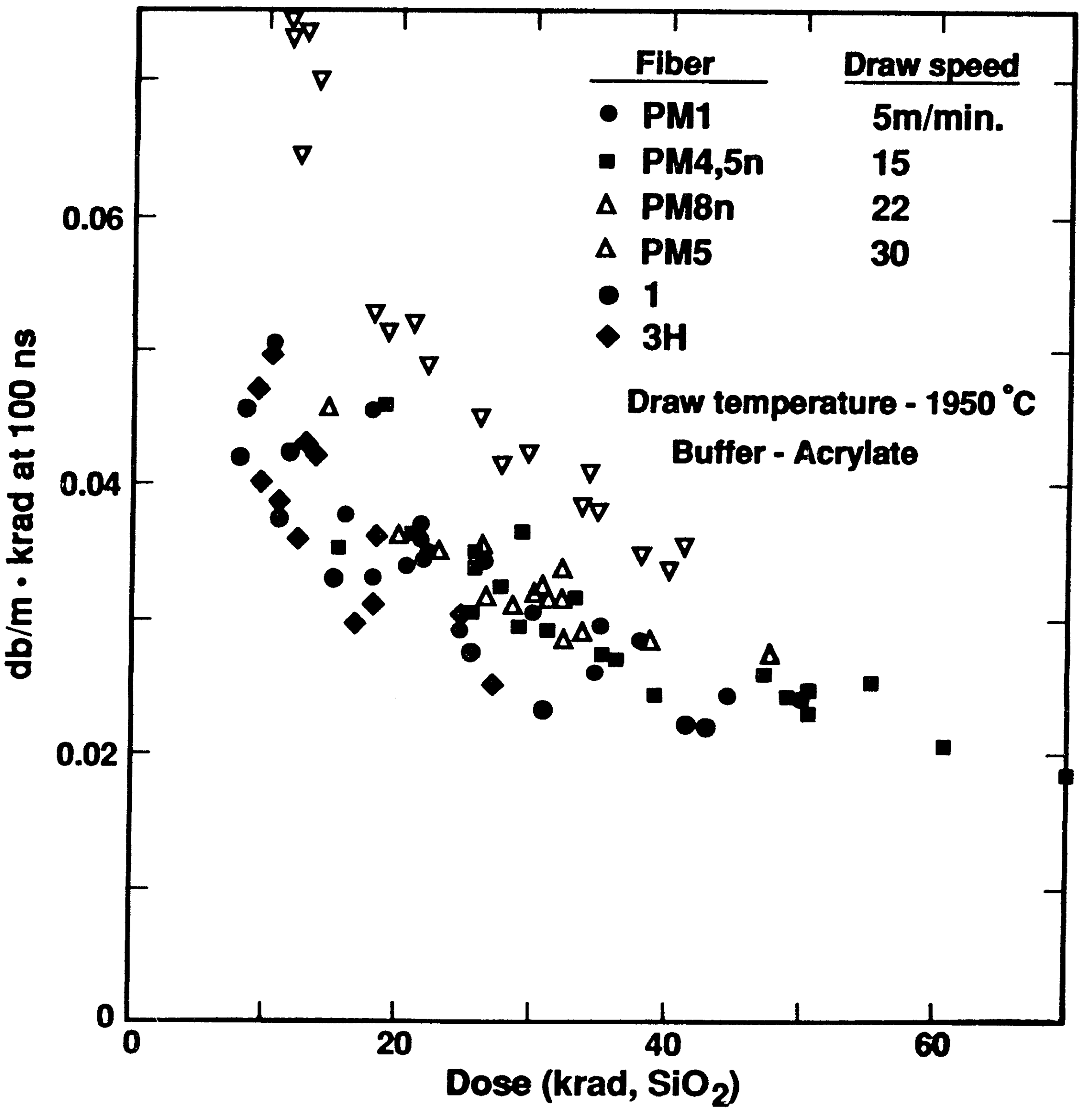


TRANSIENT ATTENUATION DATA



GSO9-1838A 9/91 /125

TRANSIENT ATTENUATION DATA



CONCLUSIONS

SIMULTANEOUS HYDROGEN/RADIATION TREATMENT

- **SIGNIFICANTLY (8x) IMPROVES CO^{60} PERFORMANCE**
- **NO IMPROVEMENT: TRANSIENT (<1µS) PERFORMANCE**

REQUIREMENTS FOR FURTHER STUDIES

STRENGTH OF HYDROGEN BONDS

DOSE/DOSE RATE OPTIMIZATION

TREATMENT IN PREFORM STAGE

INTERACTION WITH DRAW PARAMETERS

conf paper already
received into data
base was removed.
dls

END

DATE FILMED

11 / 19 / 91