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ATTENUATION MEASUREMENTS ON OPTICAL FIBER WAVEGUIDES: AN INTERLABORATORY COMPARISON AMONG MANUFACTURERS

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Contents

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G. W. Day and G. E. Chamberlain

In late 1978, the National Bureau of Standards invited U.S. manufacturers of optical fiber waveguide to participate in an interlaboratory comparison of attenuation measurements. Seven manufacturers performed four different measurements on each of two fibers. The range of results was typically 1 to 1.5 dB/km for fibers with 3 to 7 dB/km nominal attenuation. This report contains the results and an analysis based on additional data taken by NBS.

Key words: Attenuation; fiber optics; interlaboratory comparison; measurements; optical communications; quality control.

1. Introduction

While it is widely recognized that multimode optical fiber waveguides are more difficult to characterize than analogous components in other parts of the electromagnetic spectrum, little data have been available to demonstrate the magnitude of the problem. A few large organizations have conducted comparisons among their own systems, but few results have been made public. Comparisons between organizations have been rare, and to our knowledge, unreported. As a result of this lack of knowledge about measurement uncertainties, the designer must be cautious both in specifying components and in establishing system margin requirements.

Several standards groups have responded to the need for improved measurements and have drafted or are now drafting standard measurement procedures. As yet, however, manufacturers use a variety of procedures for specifying their products.

In order to provide some data about the variability of product specification for the system designer and to provide a basis from which the continuing efforts of standards groups can be judged, NBS, in late 1978, invited U.S. manufacturers of optical fiber waveguide to participate in a measurement comparison. Attenuation was the parameter selected for comparison, as it is one of the most important parameters in system design and the comparison was more straightforward than would have been the case if some other parameter had been chosen. Comparisons of other parameters may be undertaken later.

Seven manufacturers, listed in Appendix A, chose to participate. Two fibers were sent to each of these participants between January and April 1979, with specific instructions and a request for several measurements on each. In this report we describe the procedures used, the results obtained, an analysis of the results, and some recommendations for future comparisons.

2. Procedure

Since our intent was to learn about product specifications, we asked each participant to adhere as closely as practical to his procedures for measuring attenuation in quality control. Our specified conditions, indicated below, in many cases required some departure from quality control procedure. Some additional departures may have been necessary and may or may not have been reported. However, we believe that in most cases the results given here were obtained in a manner reasonably close to normal procedure.

Two graded index fibers were selected to provide samples that were fairly typical of medium grade (in attenuation) products now available in the U.S. Both were buffered fibers (tight jacket). This choice was made to avoid the necessity of relieving the tension on the fiber before measurements were made. It does mean, however, that the results are not truly indicative of what measurement quality can be obtained for non-buffered fibers.

One of the fibers (later identified as 0308) was thickly buffered with a soft material and wound in numerous layers on a small (10 cm dia nominal) spool. The other (identified as 0614) had a thin ($\sim$ 25 μm) hard buffer and was wound, mostly in a single layer, on a large (30 cm dia) spool. We expected, therefore, that the degree and character of mode coupling might be very different in these two cases.

Two wavelengths were chosen for purposes of comparison. One of these was 850 nm, in the region where most present optical communications systems operate. The second was 1000 nm, near where some future systems may operate, and within the range of the silicon photo detectors used in many measurement systems.

Two launch numerical apertures (LNA) were specified. One, LNA = 0.24 (f/2) was chosen to be comparable to or larger than the acceptance angles of the fibers. The other, LNA = 0.09 (f/5.6) was in both cases significantly less than the acceptance angle. We expected that some differences in precision might be found between these two cases. (Where these wavelengths and LNA's were not available to a participant, we asked that he make the measurement at the closest available wavelength or LNA and report accordingly.)

Each participant was given certain information about the physical and optical characteristics of each fiber (see Appendix B). The length, nominally 1200-1400 m, of the fiber was monitored by NBS and was reported to each participant when he received the fiber. Stripping instructions, etc., were also provided.

In addition to reporting four values of attenuation for each fiber, participants were asked to report their estimated precision (reproducibility) and details of their measurement process. All reports were made anonymously according to a code. NBS has not maintained any records which could be used to identify any participant with a particular set of results.

3. Characterization of Fibers by NBS Prior to Comparison

Figures 3.1 and 3.2 give the results of NBS measurements made on the two fibers, 0308 and 0614, prior to their first shipment.

The present NBS system for measuring attenuation in fibers is shown in figure 3.3. A tungsten-halogen lamp illuminates the optical system which selects the wavelength, spot diameter and numerical aperture of the radiation launched into the optical fiber. An interchangeable source aperture A_1 controls the spot size imaged onto the fiber by the camera lens L_2. The demagnification ratio is 23X. Calibrated pinhole apertures were used to determine that about 80% of the light is included in the calculated spot size.

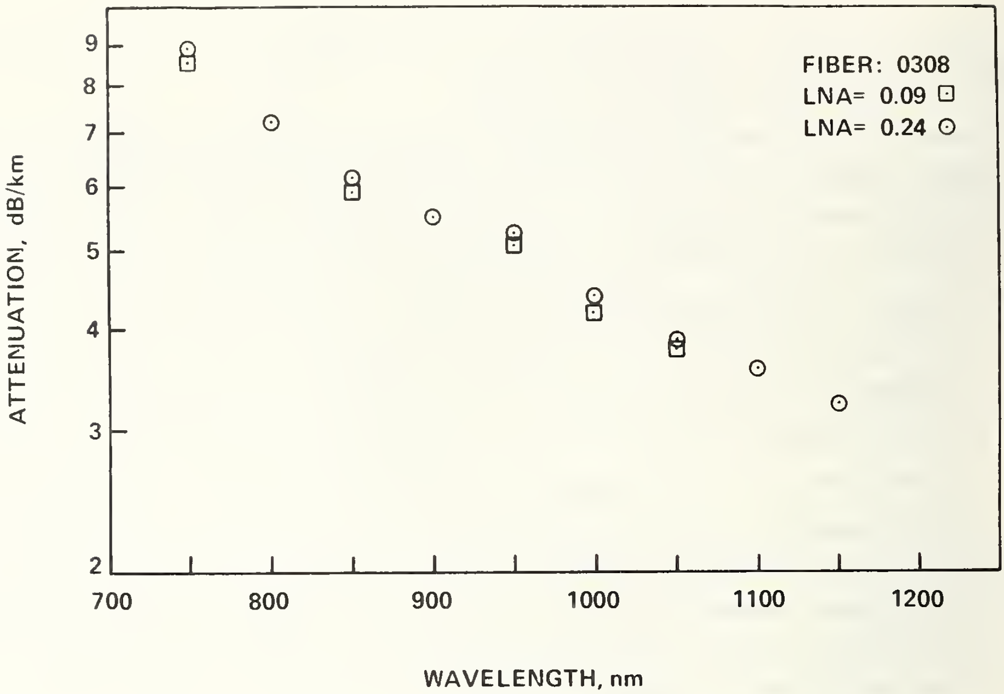
A diaphram in the lens L_2 controls the launch numerical aperture, LNA. Measurements of about 20% accuracy showed the LNA to be in agreement with the f-number stop of the lens.

Interference type filters, nominally 10 nm FWHM, mounted in a filter wheel, F, select the wavelength. A wedge beam splitter, B, made of fused silica, enables the silicon detector D_M to monitor the lamp intensity before launch. The silicon detector D_V measures the light intensity transmitted by the optical fiber. Light from the source is interrupted by a chopper wheel, C. Narrowband, lock-in detection is used to provide the transmitted power signal and the monitor reading.

For convenience in making repeated measurements, we have used two separate fibers to measure attenuation. The short (reference) fiber is typically between one and four meters long. The degree to which this procedure degrades the precision is unknown at this time.

The cleaved fiber ends were visually inspected with a 40X microscope and considered acceptable if they appeared smooth and nearly normal to the fiber axis. A mode stripper consisting of ten cm of black felt wetted with index matching liquid was used on the input ends of the fibers. The fiber ends were positioned to maximize the transmitted signal.

The measurement quality obtained with this system is currently under investigation. Typically, however, we find that several measurements made under similar conditions agree to within 0.1 dB/km.



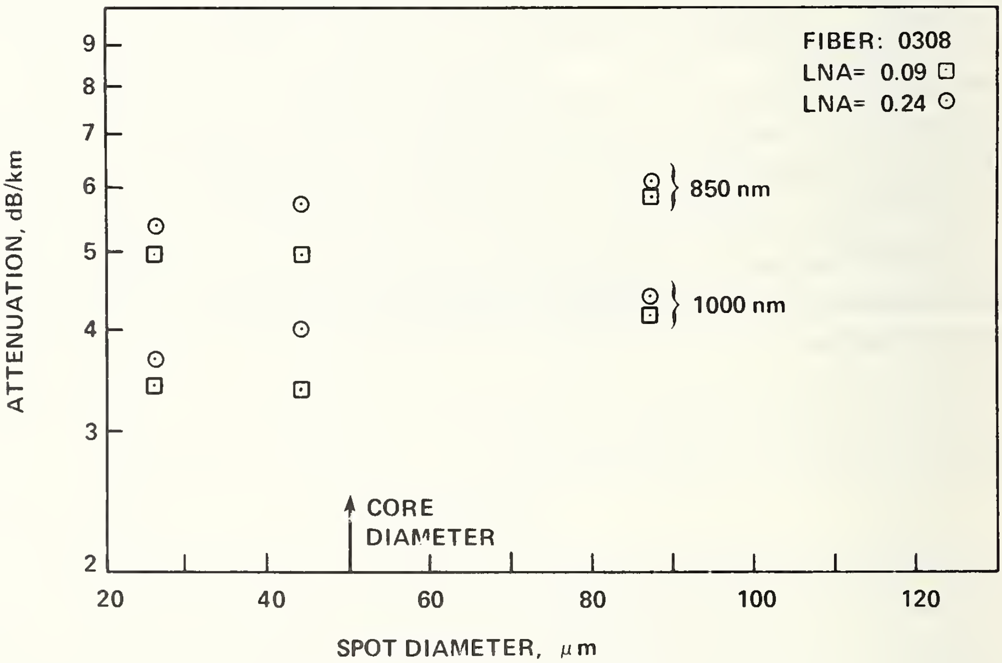
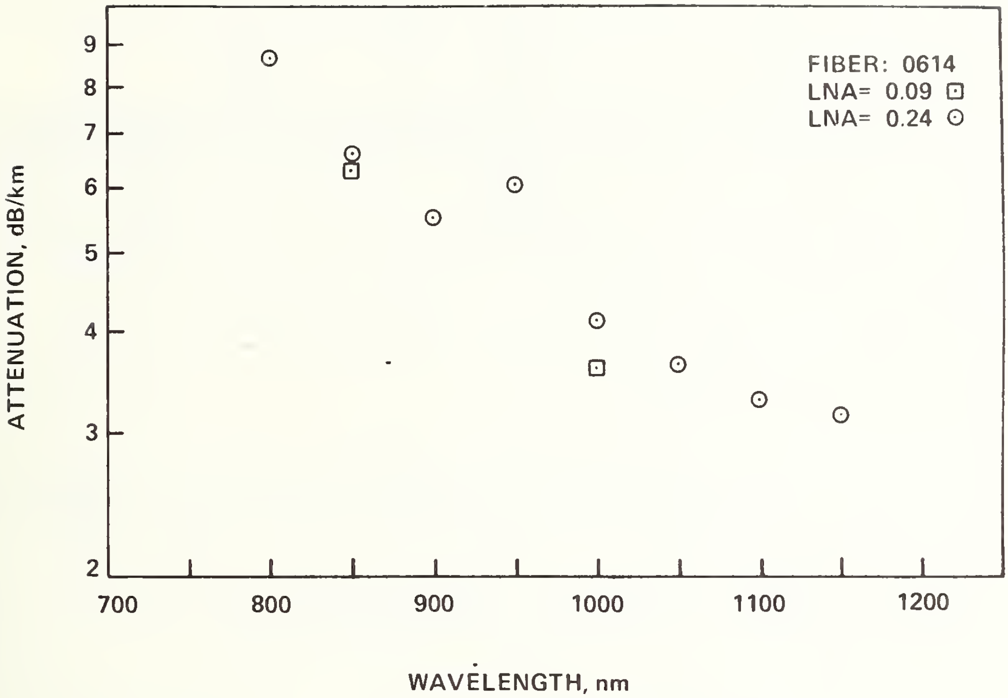


Figure 3.1 NBS data on fiber 0308 prior to comparison.



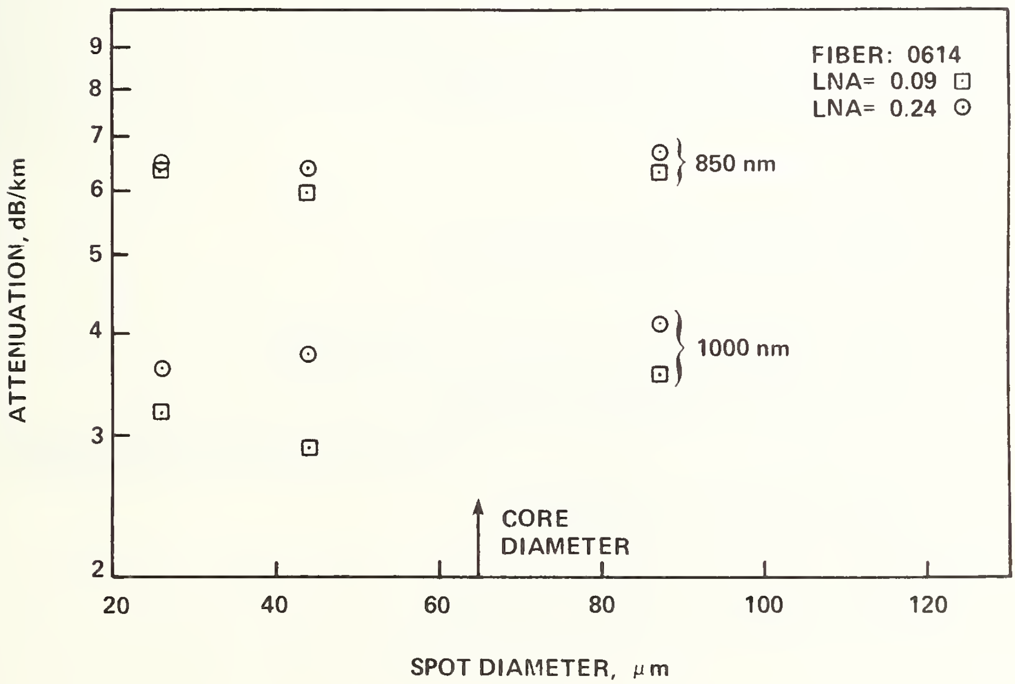
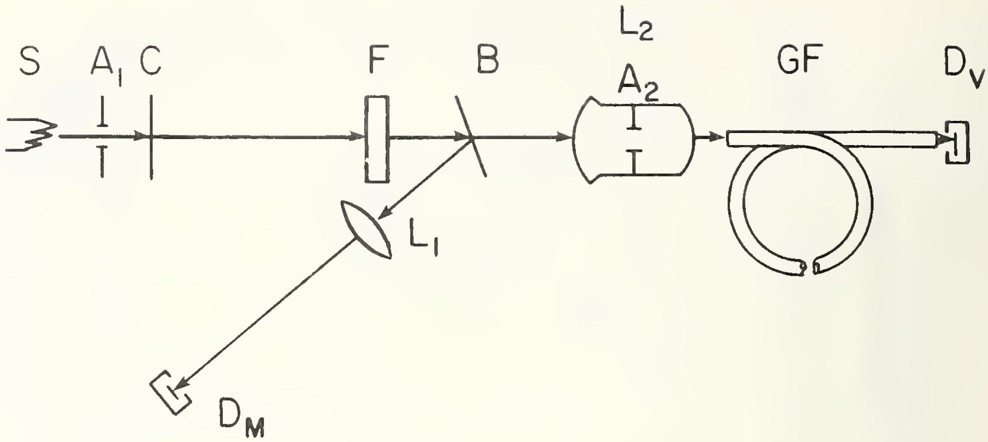


Figure 3.2 NBS data on fiber 0614 prior to comparison.



S INCANDESCENT SOURCE, TUNGSTEN-HALIDE FLAT FILAMENT

A_1 SOURCE APERTURE, 0.6 - 2mm DIAMETER
NOTE: APERTURE CONTROLS SPOT SIZE

C LIGHT CHOPPER, 70 Hz

F FILTER WHEEL, 633 -1150nm, 10nm FWHM

B BEAM SPLITTER, SiO_2, 1° WEDGE

L_1 LENS

D_M SOURCE MONITOR DETECTOR

L_2 LAUNCH LENS, 12.5 mm FOCAL LENGTH AND

A_2 APERTURE STOP, 0.34 - 0.02 NA
NOTE: LAUNCH LENS L PROVIDES 23X DEMAGNIFICATION AS USED

GF GLASS FIBER UNDER TEST

D_V TRANSMITTED LIGHT DETECTOR

Figure 3.3 Block diagram of NBS attenuation measurement system.

4. Results

4.1 Reported Values

Table 4.1 and figure 4.1 show data obtained on fiber 0308. This fiber had a nominal core diameter of 50 μm and a numerical aperture of 0.25 (manufacturer's specifications). It was heavily buffered with a soft material and wound on a small (10 cm dia nominal) drum.

Table 4.2 and figure 4.2 show data obtained on fiber 0614. This fiber has a nominal core diameter of 65 μm and a numerical aperture of 0.19 (again, manufacturer's specifications). It was thinly buffered with a hard coating and wound, mostly in a single layer, on a large (30 cm dia nominal) drum.

Values given in these tables and figures by laboratory code are in random order. The numbers of significant figures are as reported. Estimated precision (reproducibility) was not defined carefully, but presumably represents in some way the degree to which several measurements at that facility could be expected to agree. Note that precision values quoted range from 0.05 to 0.5 dB/km.

In two cases, a participant was unable to or chose not to measure at the wavelengths specified. In one case because of a misunderstanding a participant measured a fiber at a temperature substantially below room temperature. In these cases we have presented the data as reported, but have, in addition, estimated the effect of these departures from intended procedures and have provided adjustments accordingly. The bases for these adjustments can be found in the spectral attenuation data of section 3 and the temperature dependence data of section 4.4.

Table 4.1 Results on fiber 0308.

Case	Lab Code	Reported Value (dB/km)	Estimated Precision (dB/km)	Adjustment	Adjusted Value
Fiber: 0308	14518	5.85	± 0.1	0.	5.85
λ = 850 nm	11412	9.61	± 0.5	0.	9.61
LNA = 0.09	11913	6.4	± 0.3	-0.6†	5.8
	11673	5.85	± 0.15	0.	5.85
	11377	5.4	± 0.1	-0.6†	4.8
	11770	*	*	*	*
	11621	5.8	± 0.1	0.	5.8
	11369	5.37	± 0.05	0.	5.37
Fiber: 0308	14518	6.07	± 0.1	0.	6.07
λ = 850 nm	11412	7.00	± 0.5	0.	7.00
LNA = 0.24	11913	6.3	± 0.3	-0.6†	5.7
	11673	5.90	± 0.15	0.	5.9
	11377	*	*	*	*
	11770	5.20	± 0.05	0.	5.20
	11621	6.0	± 0.1	0.	6.0
	11369	5.99	± 0.05	0.	5.99
Fiber: 0308	14518	4.17	± 0.1	0.	4.17
λ = 1000 nm	11412	8.50	± 0.5	0.	8.50
LNA = 0.09	11913	4.7	± 0.3	+0.5†	5.2
	11673	4.22	± 0.15	0.	4.22
	11377	*	*	*	*
	11770	*	*	*	*
	11621	4.5	± 0.1	0.	4.5
	11369	3.65	± 0.05	0.	3.65
Fiber: 0308	14518	4.37	± 0.1	0.	4.37
λ = 1000 nm	11412	5.54	± 0.5	0.	5.54
LNA = 0.24	11913	4.6	± 0.3	+0.5†	5.1
	11673	4.21	± 0.15	0.	4.21
	11377	*	*	*	*
	11770	4.10	± 0.05	0.	4.10
	11621	4.7	± 0.1	0.	4.7
	11369	4.34	± 0.05	0.	4.34

* No value reported
† Adjusted for wavelength based on NBS data

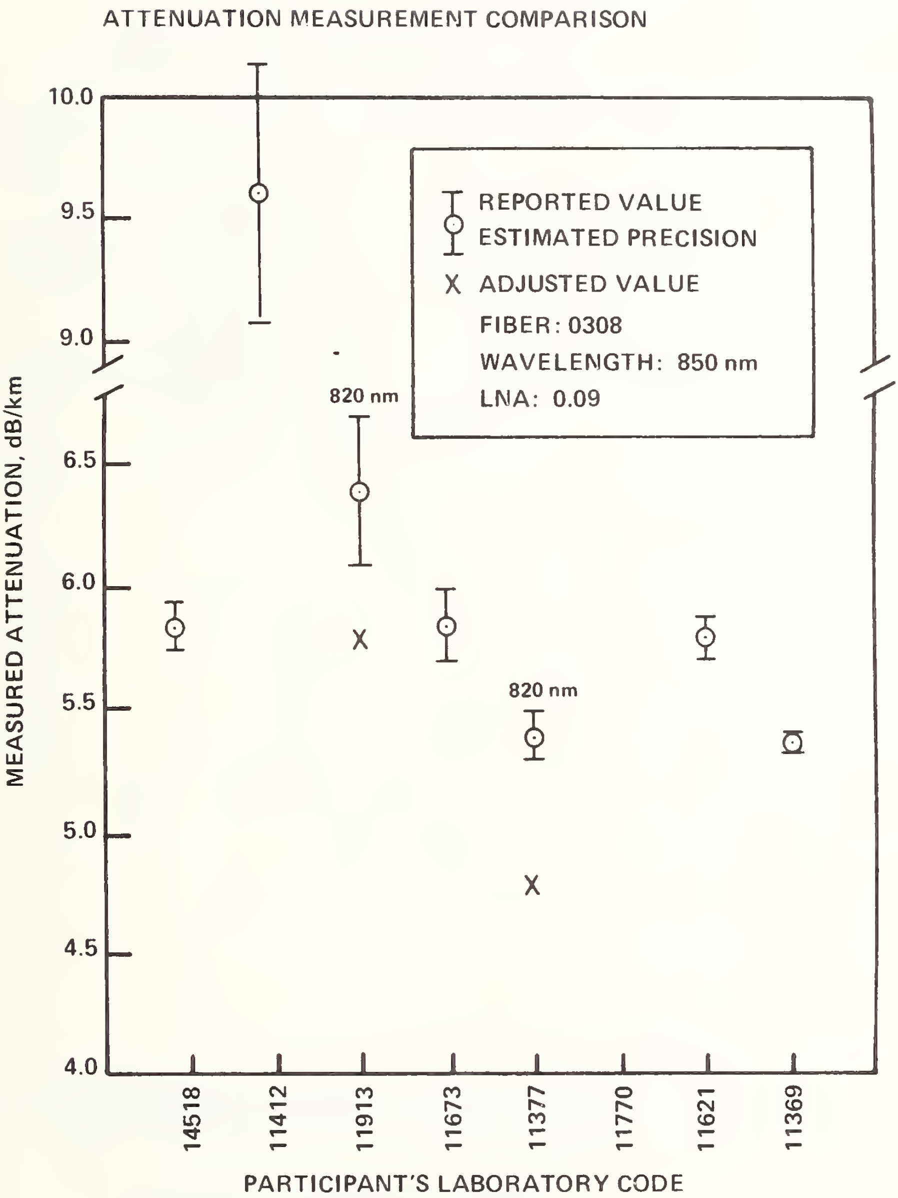


Figure 4.1a Results on fiber 0308.

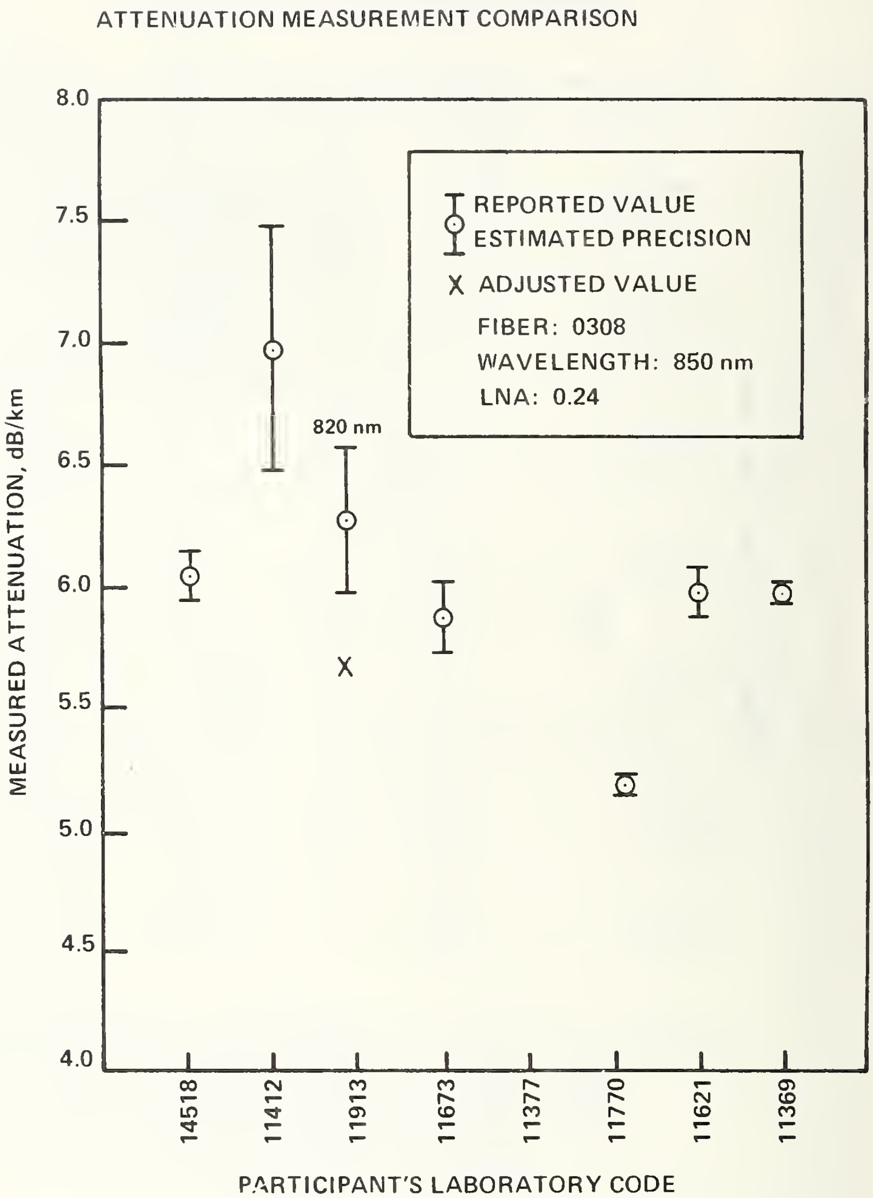


Figure 4.1b Results on fiber 0308.

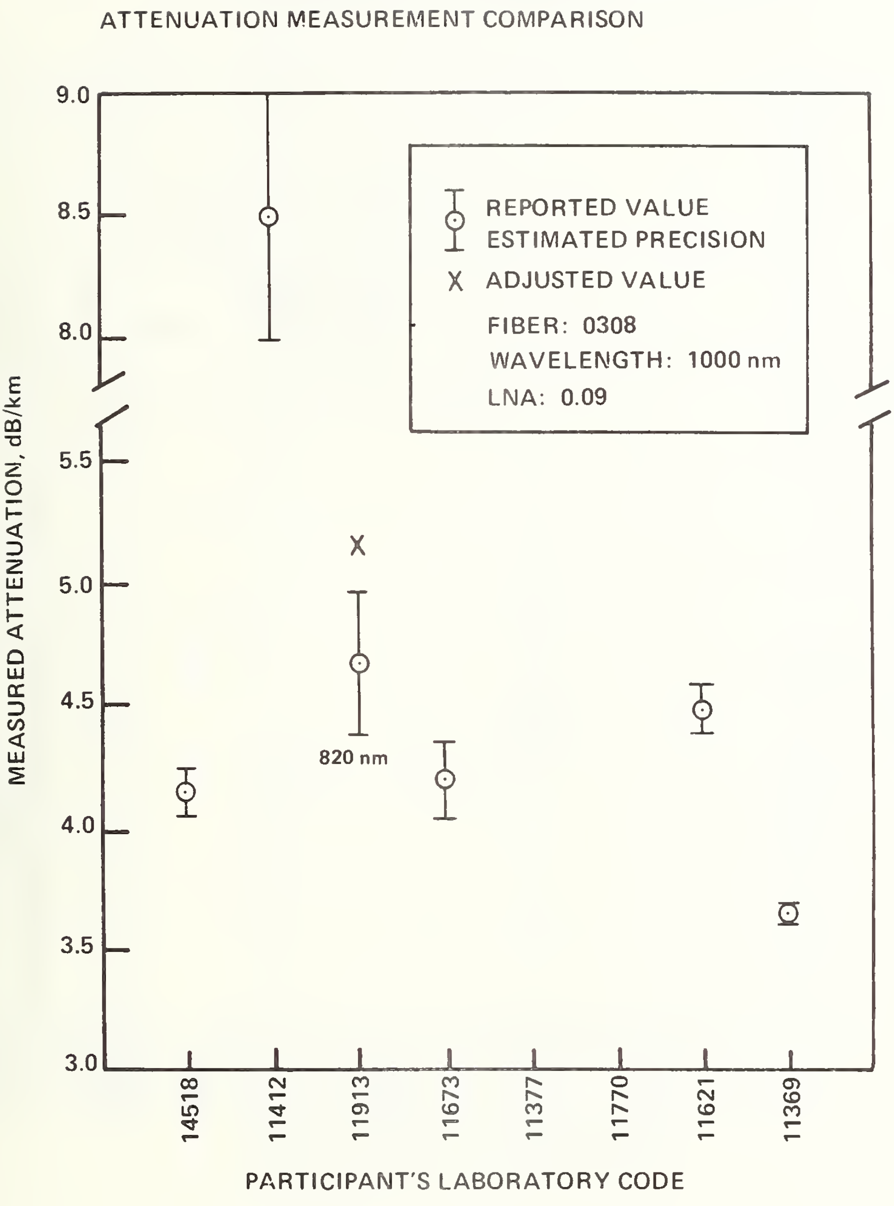


Figure 4.1c Results on fiber 0308.

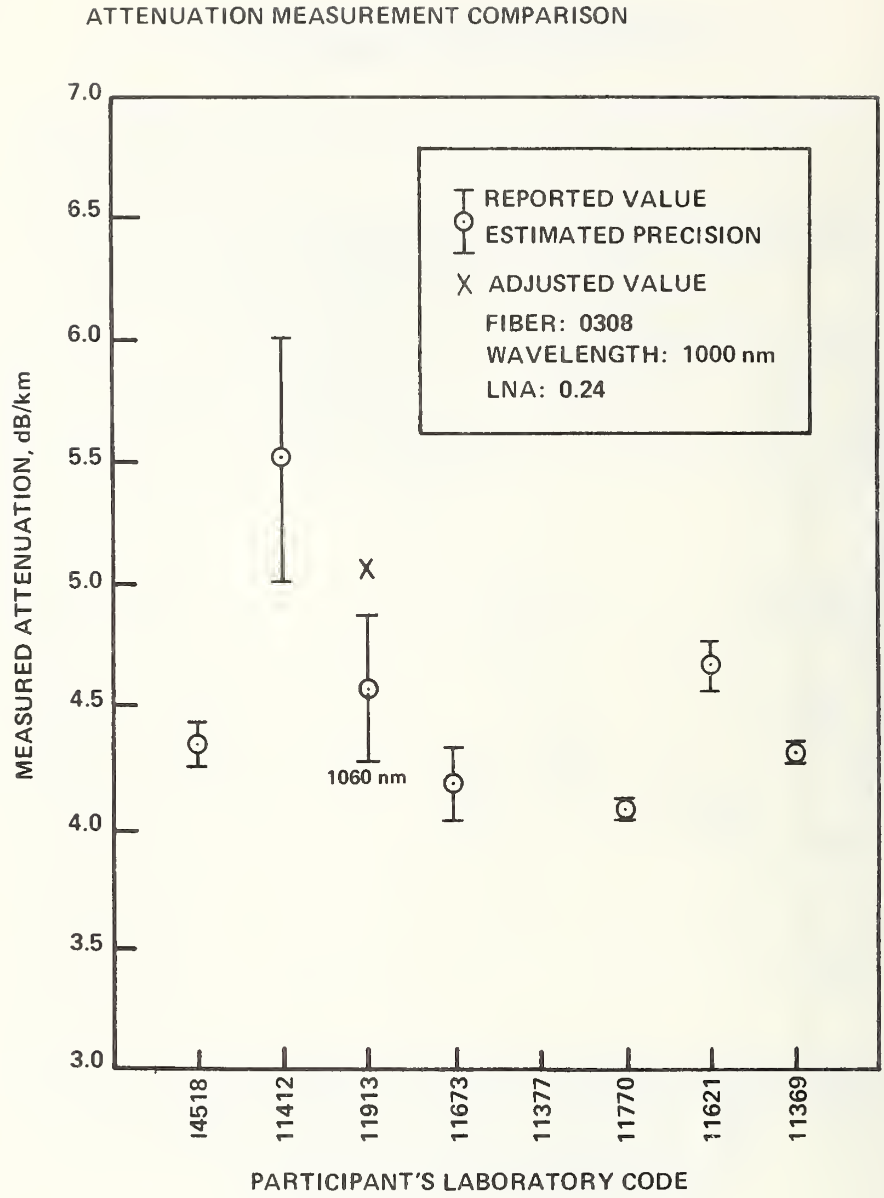


Figure 4.1d Results on fiber 0308.

Table 4.2 Results on fiber 0614.

Case	Lab Code	Reported Value (dB/km)	Estimated Precision (dB/km)	Adjustment	Adjusted Value
Fiber: 0614	14518	6.31	± 0.1	0.	6.31
λ = 850 nm	11412	6.60	± 0.5	0.	6.60
LNA = 0.09	11913	5.6	± 0.3	-0.5 ††	5.1
	11673	6.42	± 0.15	0.	6.42
	11377	6.6	± 0.1	-0.9 †	5.7
	11770	*	*	*	*
	11621	5.3	± 0.1	0.	5.3
	11369	6.36	± 0.05	0.	6.36
Fiber: 0614	14518	6.65	± 0.1	0.	6.65
λ = 850 nm	11412	6.78	± 0.5	0.	6.78
LNA = 0.24	11913	5.7	± 0.3	-0.5 ††	5.2
	11673	6.81	± 0.15	0.	6.81
	11377	*	*	*	*
	11770	5.91	± 0.05	0.	5.91
	11621	5.9	± 0.1	0.	5.9
	11369	6.45	± 0.05	0.	6.45
Fiber: 0614	14518	3.54	± 0.1	0.	3.54
λ = 1000 nm	11412	3.59	± 0.5	0.	3.59
LNA = 0.09	11913	3.1	± 0.3	+0.7 ††	3.8
	11673	3.71	± 0.15	0.	3.71
	11377	*	*	*	*
	11770	*	*	*	*
	11621	2.9	± 0.1	0.	2.9
	11369	3.64	± 0.05	0.	3.64
Fiber: 0614	14518	4.09	± 0.1	0.	4.09
λ = 1000 nm	11412	4.05	± 0.5	0.	4.05
LNA = 0.24	11913	3.4	± 0.3	+0.7 ††	4.1
	11673	4.36	± 0.15	0.	4.36
	11377	*	*	*	*
	11770	3.22	± 0.05	0.	3.22
	11621	3.5	± 0.1	0.	3.5
	11369	3.95	± 0.05	0.	3.95

* No value reported

† Adjusted for wavelength based on NBS data

†† Adjusted for wavelength and temperature (to 22°C) based on NBS data

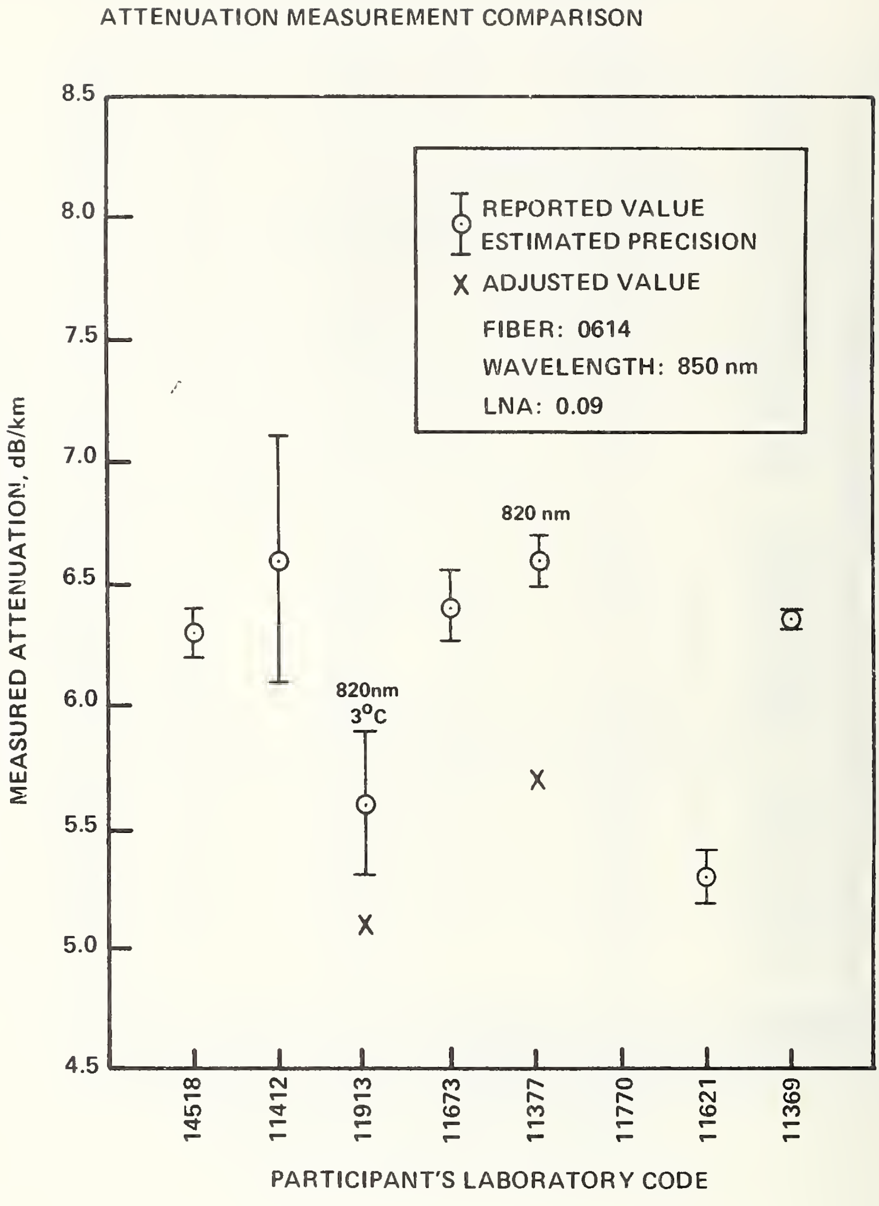


Figure 4.2a Results on fiber 0614.

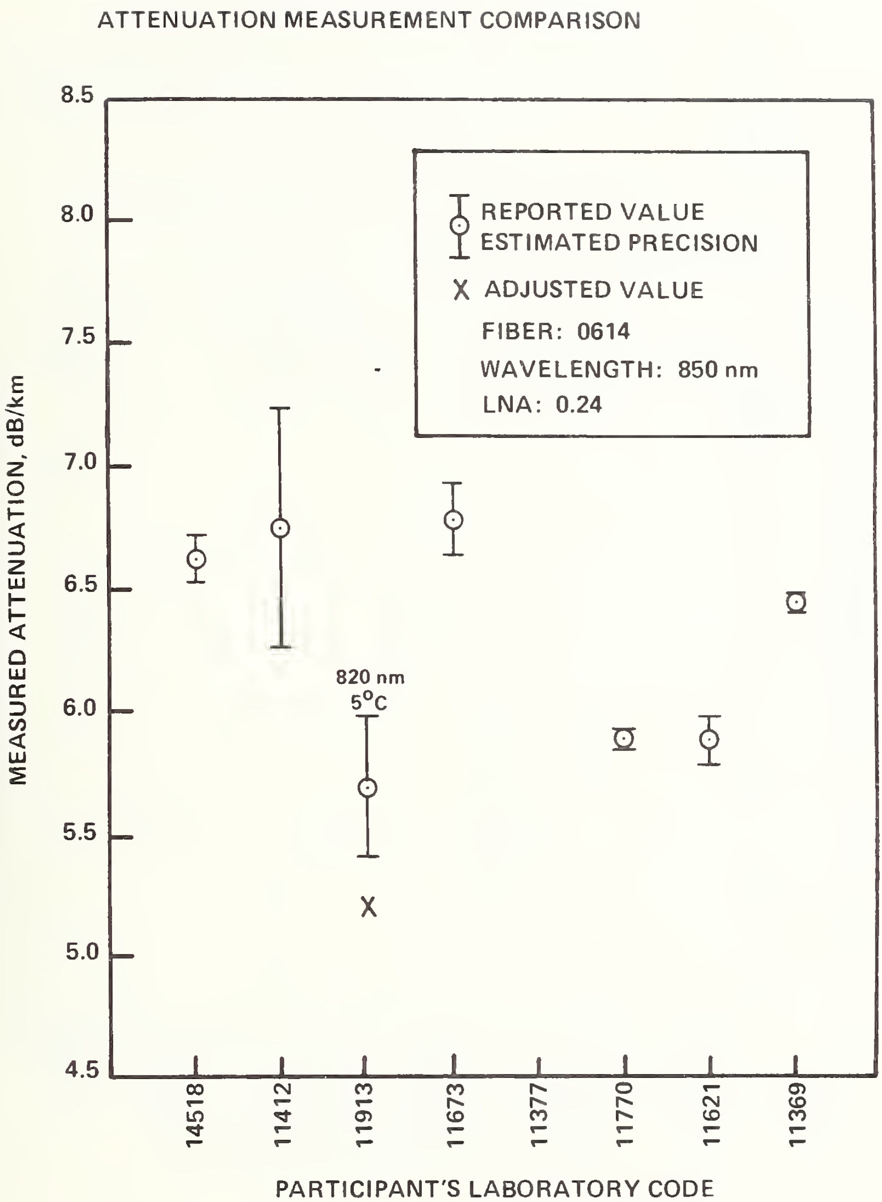


Figure 4.2b Results on fiber 0614.

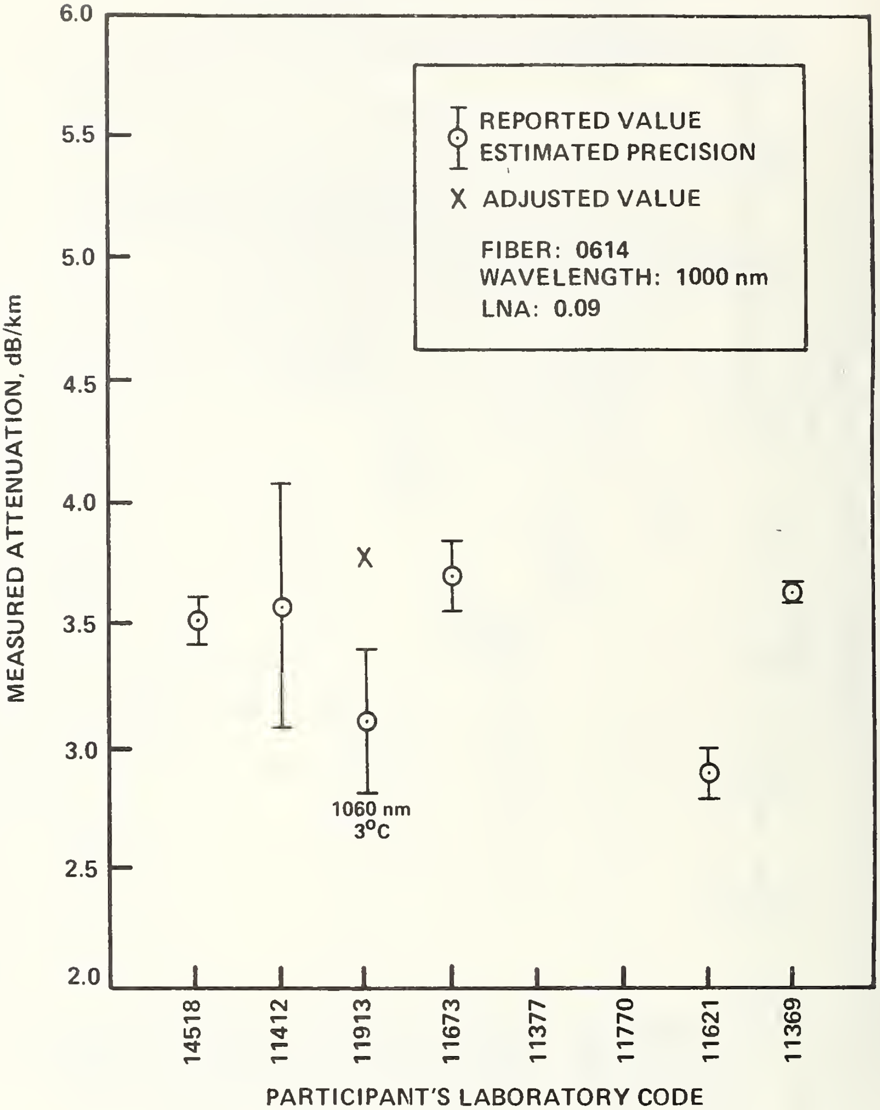


Figure 4.2c Results on fiber 0614.

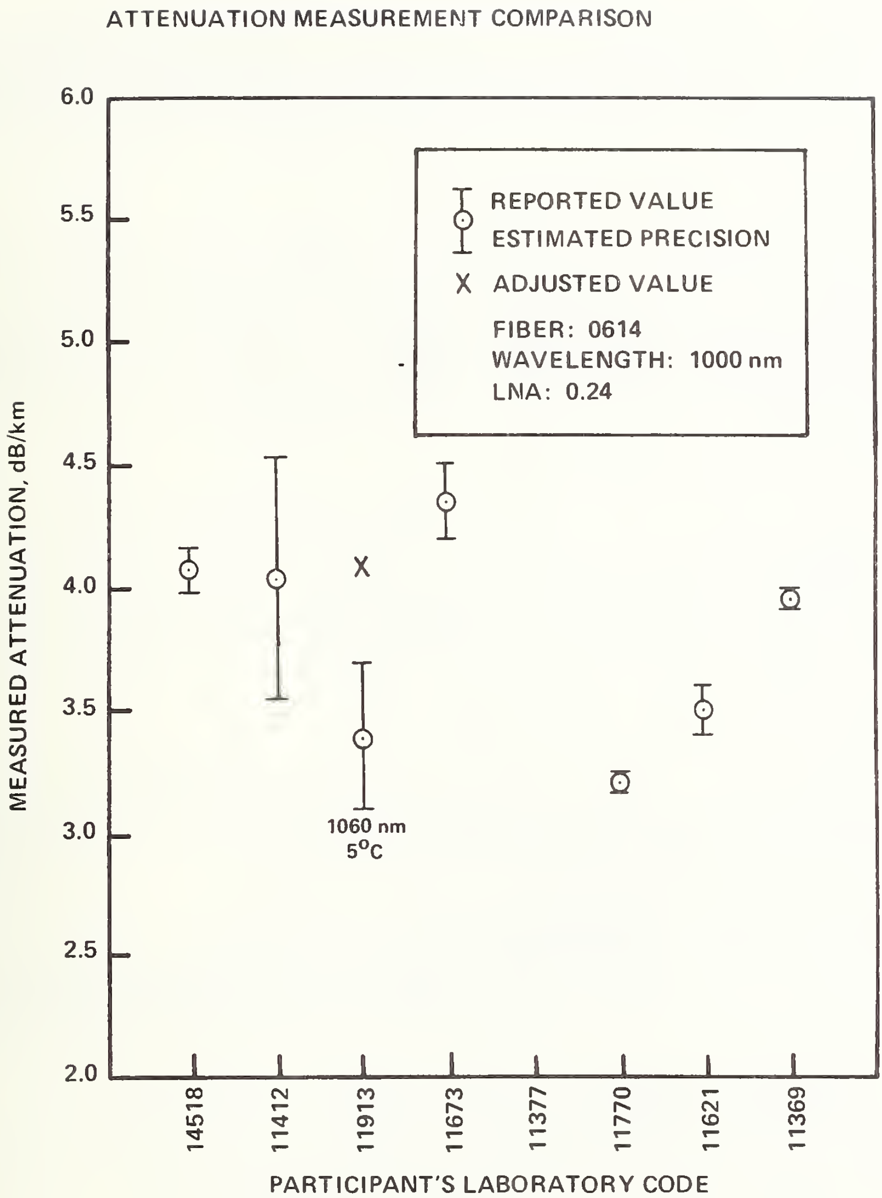


Figure 4.2d Results on fiber 0614.

4.2 Measurement Conditions

The measurement details given by each participant on page 3 of the reporting form (see Appendix B) are summarized below. We have edited the details to maintain a consistent format and, in some cases, restated details which could have resulted in identification of the participant.

Laboratory: 14518

Source: Tungsten-Halogen with interference filters
Spectral width: 8 nm @ 850 nm; 10 nm @ 1000 nm
Spot size: 87 μm dia
Mode strippers: Black felt/oil, 10 cm long
Length of reference section: 1.56 m (0308); 1.95 m (0614)
Temperature: 19°C
Additional details: (none reported)

Laboratory: 11412

Source: Quartz-Halogen
Spectral width: 10 nm @ 850 nm; 10 nm @ 1000 nm
Spot size: 400 x 300 μm
Mode strippers: bending with index matching liquid
Length of reference section: 2 m (0308); 2 m (0614)
Temperature: 26°C
Additional details: (none reported)

Laboratory: 11913

Source: Tungsten-iodide coil with monochromator
Spectral width: $<$ 4.5 nm @ 820 nm; $<$ 4.5 nm @ 1060 nm
Spot size: 150 μm × 250 μm
Mode strippers: Infrared absorbing glass with glycerol
Length of reference: 1.62 to 2.46 m
Temperature: 18-19°C (0308); 3-5°C (0614)
Additional details: Note temperature, wavelengths; precision quoted at 3σ

Laboratory: 11673

Source: Tungsten with filters
Spectral width: 10 nm @ 850 nm; 10 nm @ 1000 nm
Spot size: 230 μm dia.
Mode strippers: ∿ 7-10 cm at input and output, painted on fiber
Length of reference section: 1.1 m (0308); 1.3 m (0614)
Temperature: 25°C
Additional details: (none reported)

Laboratory: 11377

Source: GaAlAs laser, 820 nm
Spectral width: (not reported)
Spot size: 65 μm
Mode strippers: Tape, 2.5 cm long
Length of reference section: 1.6 m (0308); 1.4 m (0614)
Temperature: 24°C
Additional details: Note wavelength; attempted to establish equilibrium conditions

Laboratory: 11770

Source: Incandescent with filters
Spectral width: 13.4 nm @ 850 nm; 14.3 nm @ 1000 nm
Spot size: 200-300 μm dia.
Mode strippers: designed to approximate equilibrium conditions
Length of reference section: 2 m (0308); 2 m (0614)
Temperature: 27°C
Additional details: Note LNA = 0.20

Laboratory: 11621
Source: White light with spectrometer
Spectral width: (not reported)
Spot size: 1000 μm dia.
Mode strippers: Glycerin
Length of reference section: 1 m (0308); 1 m (0614)
Temperature: 22°C
Additional details: (none reported)

Laboratory: 11369

Source: Tungsten ribbon, with filters
Spectral width: 10 nm @ 850 nm; 5 nm @ 1000 nm
Spot size: > 800 μm
Mode strippers: liquid, n = 1.62
Length of reference section: 4 m (0308), 3.6 m (0614)
Temperature: 23°C
Additional details: (none reported)

With one exception, participants used white light sources with either filters or a monochromator for wavelength selection. The spectral width was generally in the 5-15 nm range. The exception was the use of a cw GaAlAs laser diode, the spectral width of which was not reported.

All participants illuminated the input of the fiber with a spot which was as large as or larger than the manufacturer's specification of the core diameter. All used some form of mode stripping, although the type of mode stripper varied widely. Those employing index matching or absorbing material presumably were designed to only remove power from the cladding. Others, which involved bending, removed higher order propogating modes as well.

The relatively wide range of measurement temperature (19 to 27°C, in one case 4-5°C) should be noted. The effect of this variation will be discussed in section 4.3.

4.3 Summary of Results

The complete set of data resulting from the comparisons is summarized in the histograms of figures 4.3 and 4.4. Adjusted values were used in this presentation because the basis for the adjustment was clear, the magnitude of the adjustment readily determined and the result, we believe, therefore, valid. The adjustments do, in fact, improve the appearance of certain results (e.g., 11913 in Fig. 4.1a) but often are neutral or tend to worsen the appearance of others.

One group of results, specifically 11412 on fiber 0308 is consistently high, in some cases by as much as 3-4 dB/km greater than the nearest neighbors. Results by the same participant on fiber 0614 do not show the same offset. After several discussions with this participant we conclude that the results on fiber 0308 result from non-recurring experimental difficulties and are not representative of the measurement capability at that laboratory. We therefore include these results for completeness but do not use them in further data reduction.

Because the data sets are small and doubt exists about their randomness we chose not to compute the standard deviation for each case but to, instead, tabulate the full ranges of results. These values, which are found in table 4.3, should be used only in conjunction with the distribution information contained in the histograms.

Table 4.3 Ranges of results by case.

Case Fiber; Wavelength (nm); LNA	Range of Reported Values (dB/km)	Range of Adjusted Values (dB/km)	Comments
0308; 850; 0.09	1.0	1.1	one value deleted
0308; 850; 0.24	1.1	0.9	"
0308; 1000; 0.09	1.1	1.5	"
0308; 1000; 0.24	0.6	1.0	"
0614; 850; 0.09	1.3	1.5	full set
0614; 850; 0.24	1.1	1.6	"
0614; 1000; 0.09	0.8	0.9	"
0614; 1000; 0.24	1.1	1.1	"

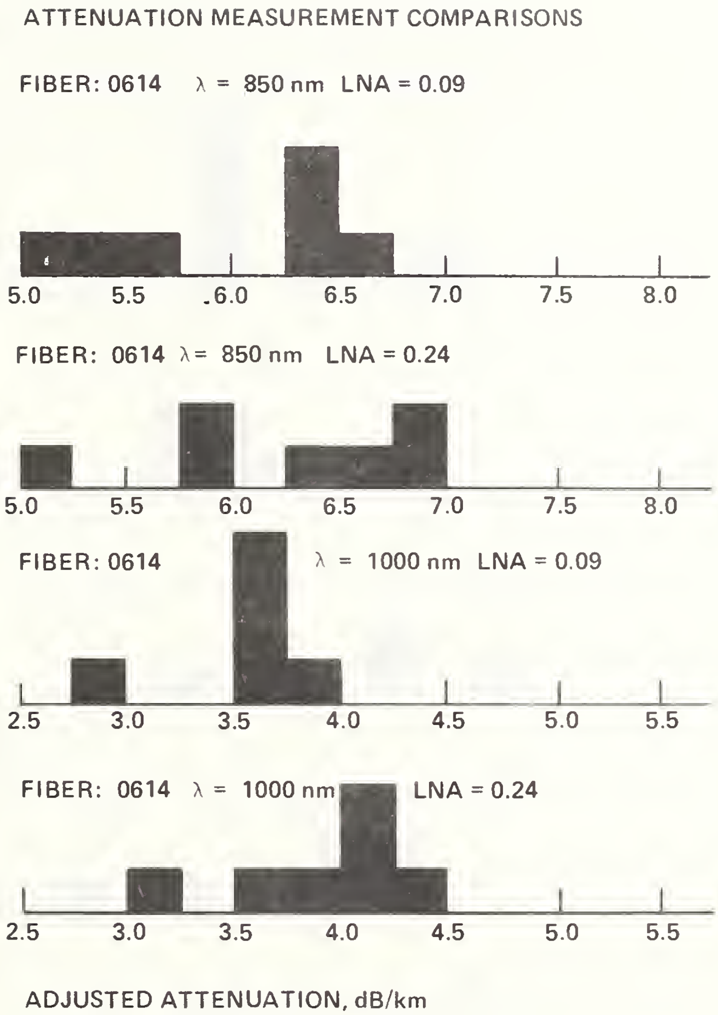


Figure 4.3 Histogram of results on fiber 0308.

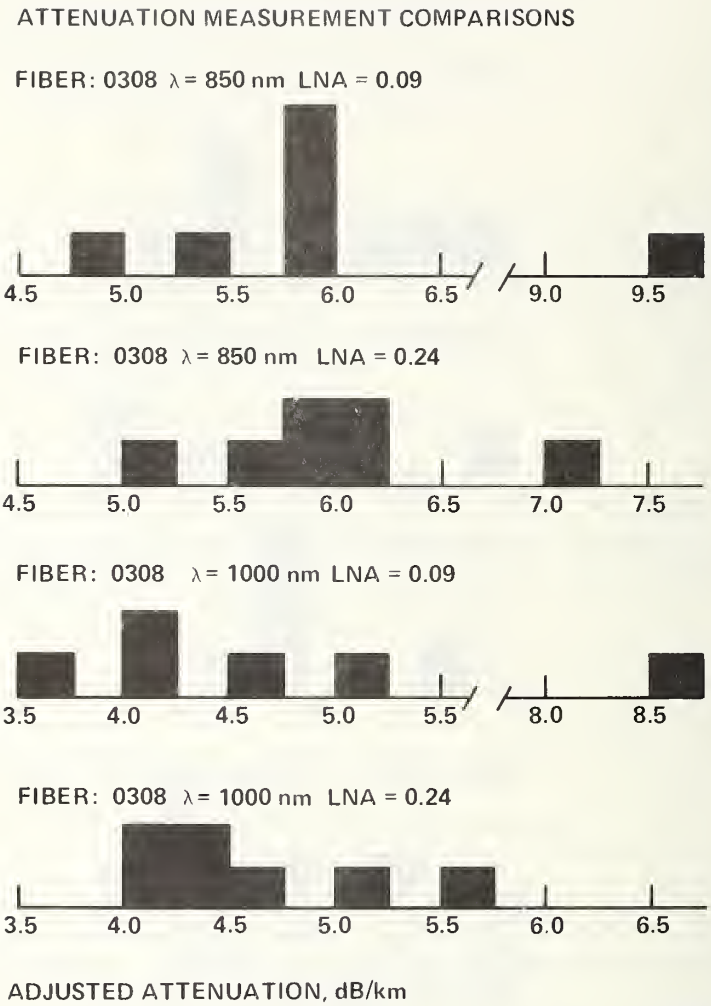


Figure 4.4 Histogram of results on fiber 0614.

4.4 Additional Analysis

After the fibers had been circulated to all participants and the data reported, we made a variety of additional measurements on the fibers. One particular concern was whether or not the characteristics had changed during the course of the comparisons, either from temperature cycling or handling. The full set of before and after measurements is given in table 4.4. These data were all taken at about the same temperature (19-20°C) and using the same facility and procedure.

Table 4.4 Test for stability of fiber attenuation. Nominal precision of measurements is 0.1 dB/km.

Case Fiber; Wavelength (nm); LNA	NBS Measured Attenuation Dec 1978 (dB/km)	April 1979 (dB/km)
0308; 850; 0.09	5.85	5.91
0308; 850; 0.24	6.07	6.01
0308; 1000; 0.09	4.17	4.23
0308; 1000; 0.24	4.37	4.32
0614; 850; 0.09	6.31	6.02
0614; 850; 0.24	6.65	6.27
0614; 1000; 0.09	3.54	3.26
0614; 1000; 0.24	4.09	3.80

Fiber 0308 shows no evidence of change. Our measurements on this fiber do, however, seem to show a greater dependence on procedural details (mode stripping, reference length, end preparation, etc.) than we generally observe for other fibers. Since only a small number of measurements was made on each date the apparent lack of change could be fortuitous.

The attenuation of fiber 0614 seems to have decreased by 0.3-0.4 dB/km during the course of the comparisons. While we cannot be certain that this apparent change did not result from a systematic error in one or the other of our measurements, we believe that it is real. It does not, in our judgment, appear to be a major factor in determining the range of results. Steps to minimize such changes should definitely be taken in future comparisons.

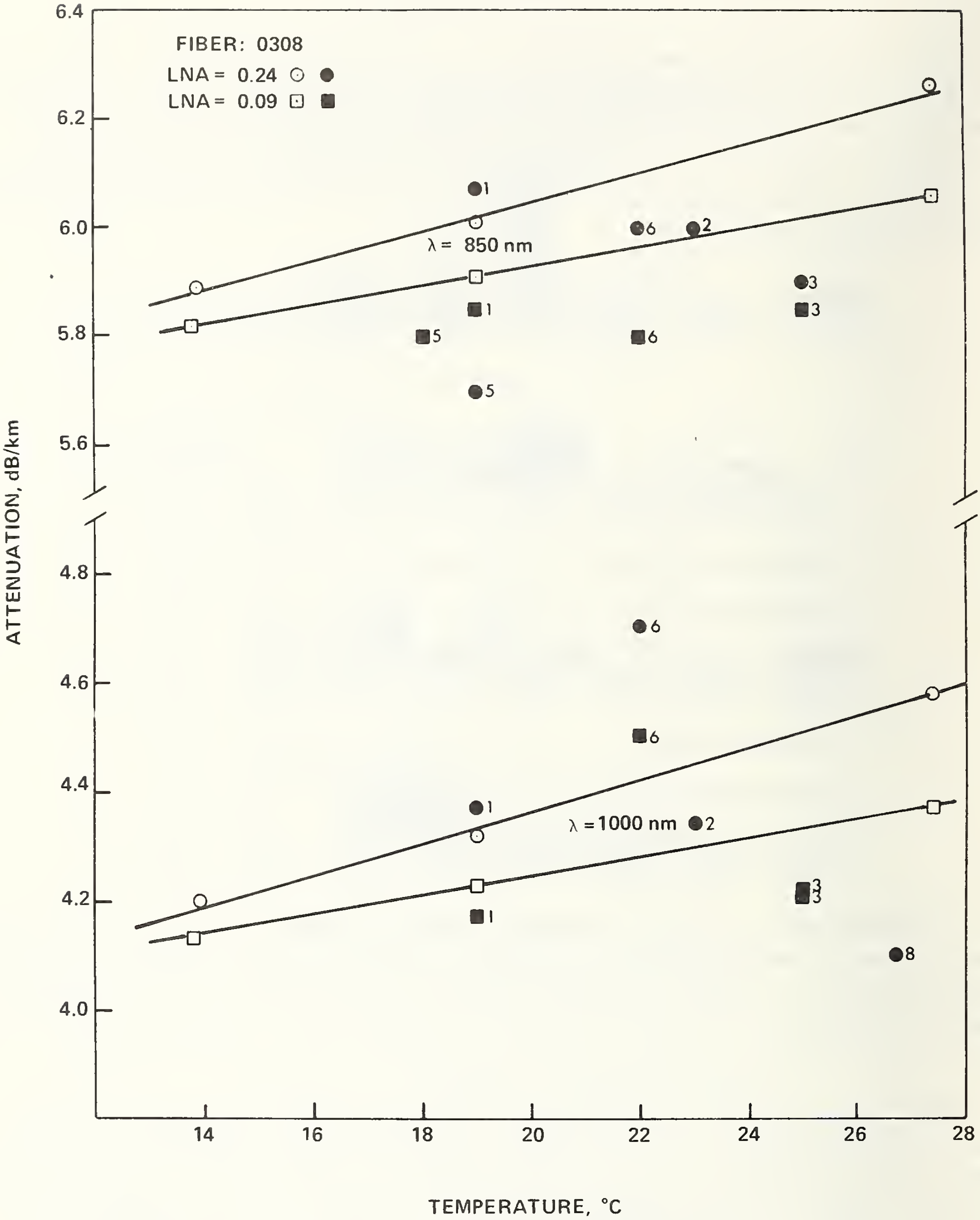


Figure 4.5 Test for temperature coefficient on fiber 0308. Open points are NBS data after comparison. Solid points are participant's points labeled in chronological order.

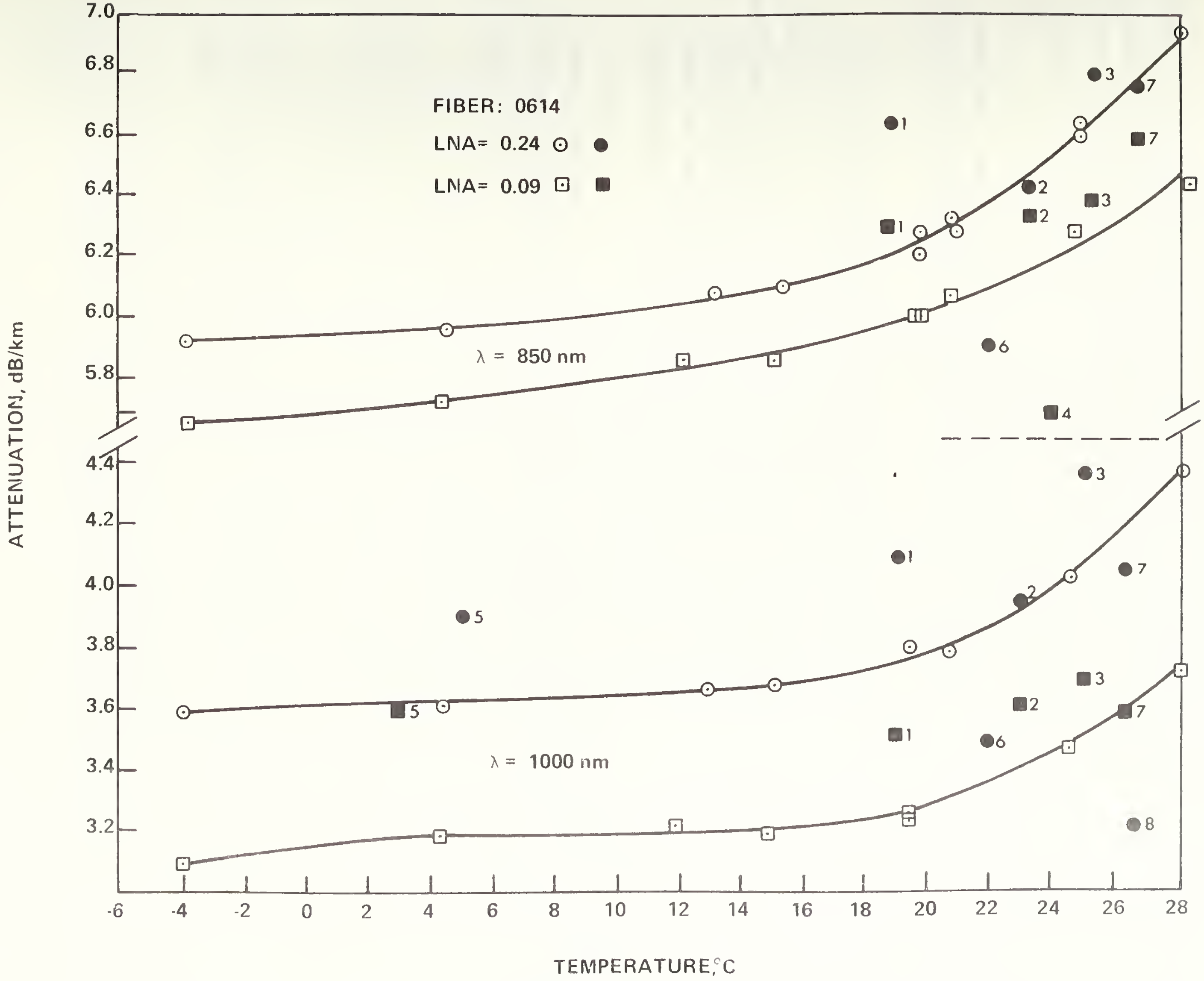


Figure 4.6 Test for temperature coefficient on fiber 0614. Open points are NBS data after comparison. Solid points are participant's points labeled in chronological order.

The effect of ambient temperature differences in participants' laboratories was another concern. After the comparison had been completed, the attenuation of each fiber was measured as a function of temperature. In the case of fiber 0614 absolute attenuation was measured but, for technical reasons, only relative attenuation vs. temperature measurements were made on fiber 0308. These were then normalized to room temperature data. Attenuation vs. temperature for all eight cases is shown in figures 4.5 and 4.6. Participants' results which fall near these curves are also plotted.

Both fibers show an increase in attenuation with increasing temperature. For fiber 0308 this amounts to .02-.03 (dB/km)/°C or at most 0.2 dB/km over the range of temperatures that measurements were made.

Fiber 0614 shows little temperature sensitivity below room temperature but at room temperature and above shows a temperature coefficient of .05-.08 (dB/km)/°C or as much as 0.6 dB/km over the full range of measurements. This represents, for the worst case about half of the observed range and thus must, at least in this case, be considered a significant contributor to the total scatter of data. We cannot be certain of the reasons for this attenuation vs. temperature characteristic but we suspect that the fiber may have been wound on the spool at about 20°C. If so, higher temperatures would result in increased tension on the fiber and presumably increased microbending loss.

Numbers placed near individual results in figures 4.5 and 4.7 indicate the chronological order in which measurements were made. This was done for fiber 0614, particularly, to test for sudden changes in measured results. No sudden changes are observed, suggesting that the decrease noted in table 4.4 was gradual.

5. Conclusions and Recommendations

The results of this investigation seem to be, superficially at least, remarkably clear and consistent. Each participant performed several different tests on each of two, rather different fibers; in almost every case the results ranged over 1-1.5 dB/km out of a total attenuation of 3-7 dB/km.

While it is difficult to say just what level of uncertainty may be acceptable in fiber attenuation measurements, it is likely most workers would agree that the above variations are unacceptable. One reason is that the difference in cost between two fibers which differ by only 1-2 dB/km in attenuation is often significant.

The first step toward improving the quality of these measurements is to understand the causes for the discrepancies. We presume the causes can be grouped into three categories. One is a lack of control on the systems and procedures used by the participants. The second is the fundamental difficulty associated with establishing and maintaining reproducible mode distributions in highly multimode transmission elements such as these. The third, closely related to the second, is the lack of stability of these components resulting from changes in mode coupling with handling, temperature, or other causes.

Recognition of the problem through such comparisons as this is often the most important factor in improving measurement control. Experience in previous interlaboratory comparisons of other quantities suggests that if the identical investigation were repeated a noticeable improvement in results would be found.

The second category of problems is now being attacked by standards writing groups. Agreement on procedures, particularly for coupling into fibers under test, should lead to improvement if the procedures are chosen wisely. Unfortunately, the data and analysis presented here does not greatly help clarify that choice.

The third category, lack of stability, has been discussed in detail in earlier sections. For the fibers used in this investigation it seems to have been a minor, though significant factor. It may be further minimized for comparison purposes by better selection of fiber and fiber buffering. Perhaps cabling of the fiber will be necessary.

As soon as standard procedures have been drafted, accepted, and implemented and manufacturers have been able to assess the results presented in this report, it is likely that another investigation will be undertaken to determine what improvement has been realized.

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FIBER ATTENUATION
TEST RESULTS
PAGE 1

LABORATORY CODE:

FIBER IDENTIFICATION: 0308

FIBER DATA:

TYPE: GLASS, GRADED INDEX, PLASTIC JACKET

LENGTH PRIOR TO MEASUREMENT:

CORE DIAMETER(MANUFACTURER'S DATA): 50 MICROMETERS

CLADDING DIAMETER(MANUFACTURER'S DATA): 125 MICROMETERS

NUMERICAL APERTURE(MANUFACTURER'S DATA): 0.25

TEST RESULTS:

CASE	ATTENUATION(DB/KM)	ESTIMATED PRECISION(DB/KM)
LAMBDA=850 NM NA=0.09		
LAMBDA=850 NM NA=0.24		
LAMBDA=1000 NM NA=0.09		
LAMBDA=1000 NM NA=0.24		

FIBER ATTENUATION
TEST RESULTS

LABORATORY CODE:

FIBER IDENTIFICATION: 0614

FIBER DATA:

TYPE: GLASS, GRADED INDEX, RESIN JACKET

LENGTH PRIOR TO MEASUREMENT:

CORE DIAMETER(MANUFACTURER'S DATA): 65 MICROMETERS

CLADDING DIAMETER(MANUFACTURER'S DATA): 125 MICROMETERS

NUMERICAL APERTURE(MANUFACTURER'S DATA): 0.19

TEST RESULTS:

CASE	ATTENUATION(DB/KM)	ESTIMATED PRECISION(DB/KM)
LAMBDA=850 NM NA=0.09		
LAMBDA=850 NM NA=0.24		
LAMBDA=1000 NM NA=0.09		
LAMBDA=1000 NM NA=0.24		

FIBER ATTENUATION
TEST RESULTS
PAGE 3

LABORATORY CODE:

MEASUREMENT CONDITIONS:

SOURCE TYPE(INCLUDE WAVELENGTH SELECTION):

SPECTRAL WIDTH(FWHM): NM@850 NM, NM@1000NM

SPOT SIZE AT FIBER INPUT: MICROMETERS DIAMETER

WHAT MODE STRIPPERS WERE USED(INCLUDE TYPE)?

LENGTH OF REFERENCE(SHORT) SECTION: METERS (0308)

METERS (0614)

TOTAL LENGTH OF FIBER REMOVED: METERS (0308)

METERS (0614)

TEMPERATURE OF FIBER AT MEASUREMENT: C

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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

In late 1978, the National Bureau of Standards invited U.S. manufacturers of optical fiber waveguide to participate in an interlaboratory comparison of attenuation measurements. Seven manufacturers performed four different measurements on each of two fibers. The range of results was typically 1 to 1.5 dB/km for fibers with 3 to 7 dB/km nominal attenuation. This report contains the results and an analysis based on additional data taken by NBS.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Attenuation; fiber optics; interlaboratory comparison; measurements; optical communications; quality control

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