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Updated Summary of Telcordia PMD Measurement of Optical Fiber

Audit of Existing Cable Plant

Prepared for:

OFCNFOEC 2007

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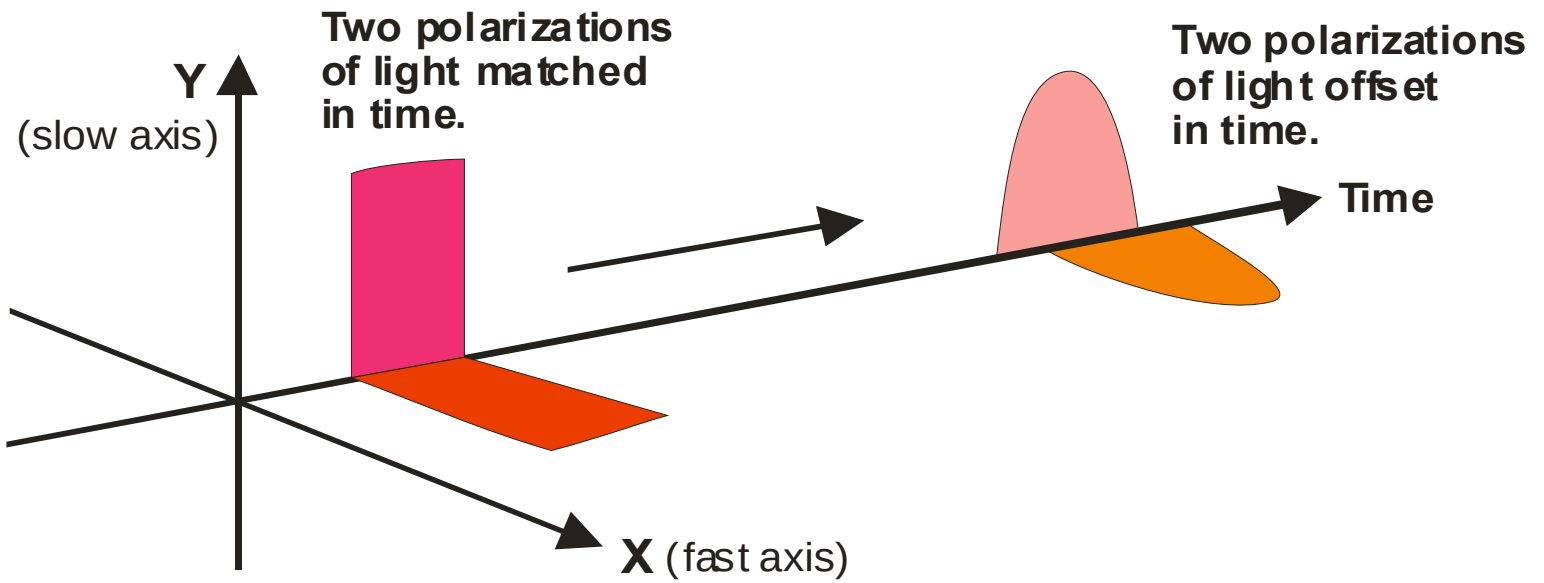
Outline

- Introduction
- PMD in Transmission Systems
- Approaches to PMD Measurements
- Field PMD Measurements
- Laboratory PMD Measurements
- Comparative Review Between Measurement Methods
- Summary & Conclusions

Introduction – Polarization Mode Dispersion

Movement of Light Through the Fiber



PMD characterized by Differential Group Delay the difference in propagation times between minimum and maximum propagation time (eigenstates).

PMD's Impact on Transmission System Performance

- **PMD produces a dispersive effect on fiber systems.**

•Existing plant considered for upgrade to a high bandwidth system is a good candidate for PMD testing before it is chosen as the transport medium for these systems.

•Where high PMD (for OC-768) is found, or dense-WDM transmission is planned, wavelength dependence analysis for dispersion and PMD should be performed. The systems affected are:

- •high-speed SONET (OC-192, NxOC-192, and OC-768),
- •some analog AM-VSB, amplitude-modulated, virtual-sideband, video
- •long optically-amplified non-regenerated cascades, and
- •dense-WDM transmission systems.

PMD Measurement Methods

- **Interferometer-Based Measurements:**
  measures time delay directly
- **Polarimetry-Based Measurements:**
  measures difference in group delay of principal states of polarization as a function of wavelength
  - **Jones Matrix Eigenanalysis**
  - **Poincare Sphere Analysis**
- **Fixed Analyzer Based Measurements:**
  measures mean DGD statistically
  - **Cycle Counting**
  - **Fourier Transform**

Updated Summary of Telcordia PMD Measurement of Optical Fiber: Audit of Existing Cable Plant

Authors:

NFOEC97-John Peters, Ariel Dori, and Felix Kapron

NFOEC06-John Peters, Mustafa Ozgur, Osman Gebizlioglu, Doug Teller

NFOEC07-John Peters

Telcordia Fiber Measurement Audit

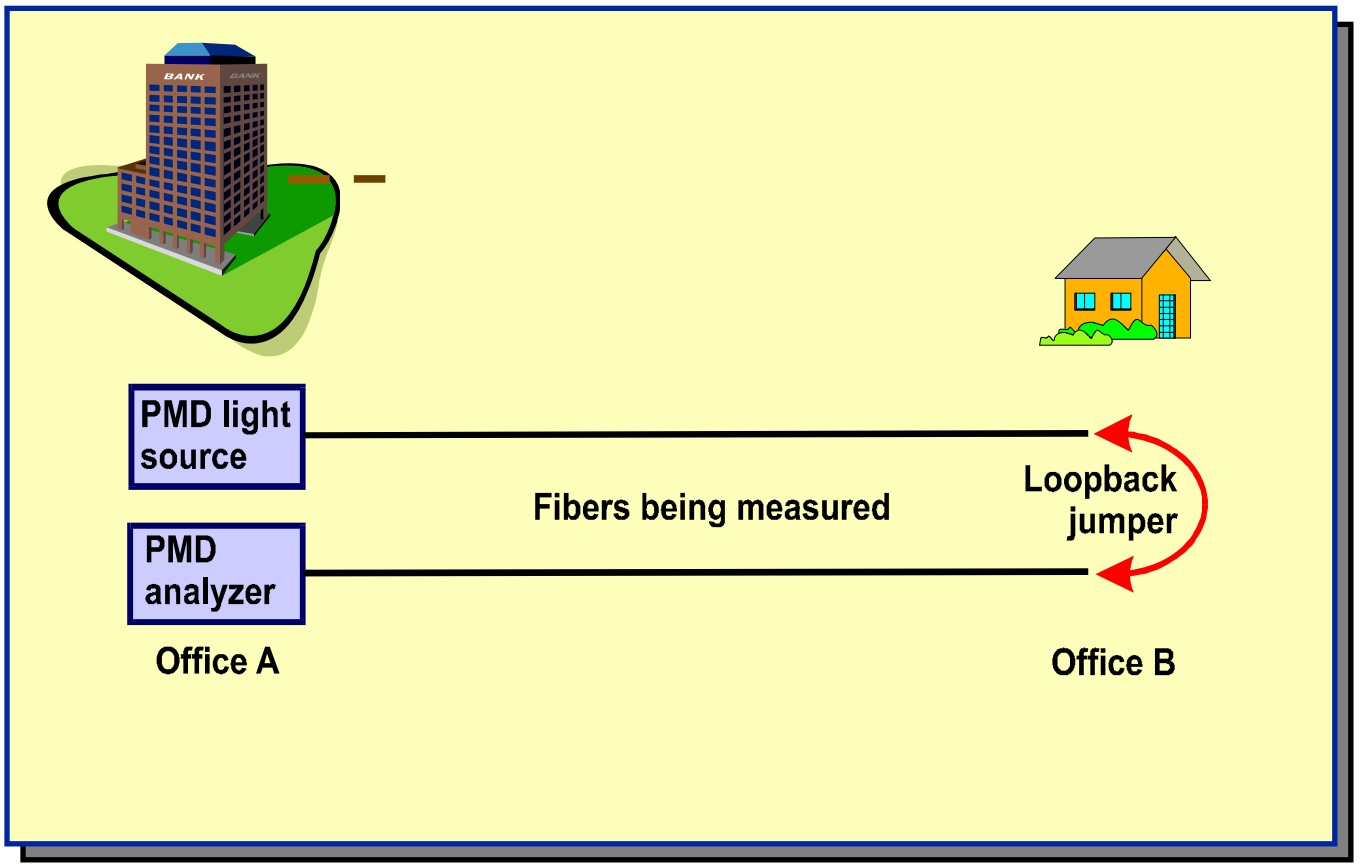
Telcordia has performed field audits of existing plant for domestic and international clients on approximately one-thousand cabled fibers, to determine if the plant can support the following systems:

- high-speed SONET or SDH (OC-192 and future OC-768)
- some analog AM-VSB video
- long optically-amplified non-regenerated cascades.

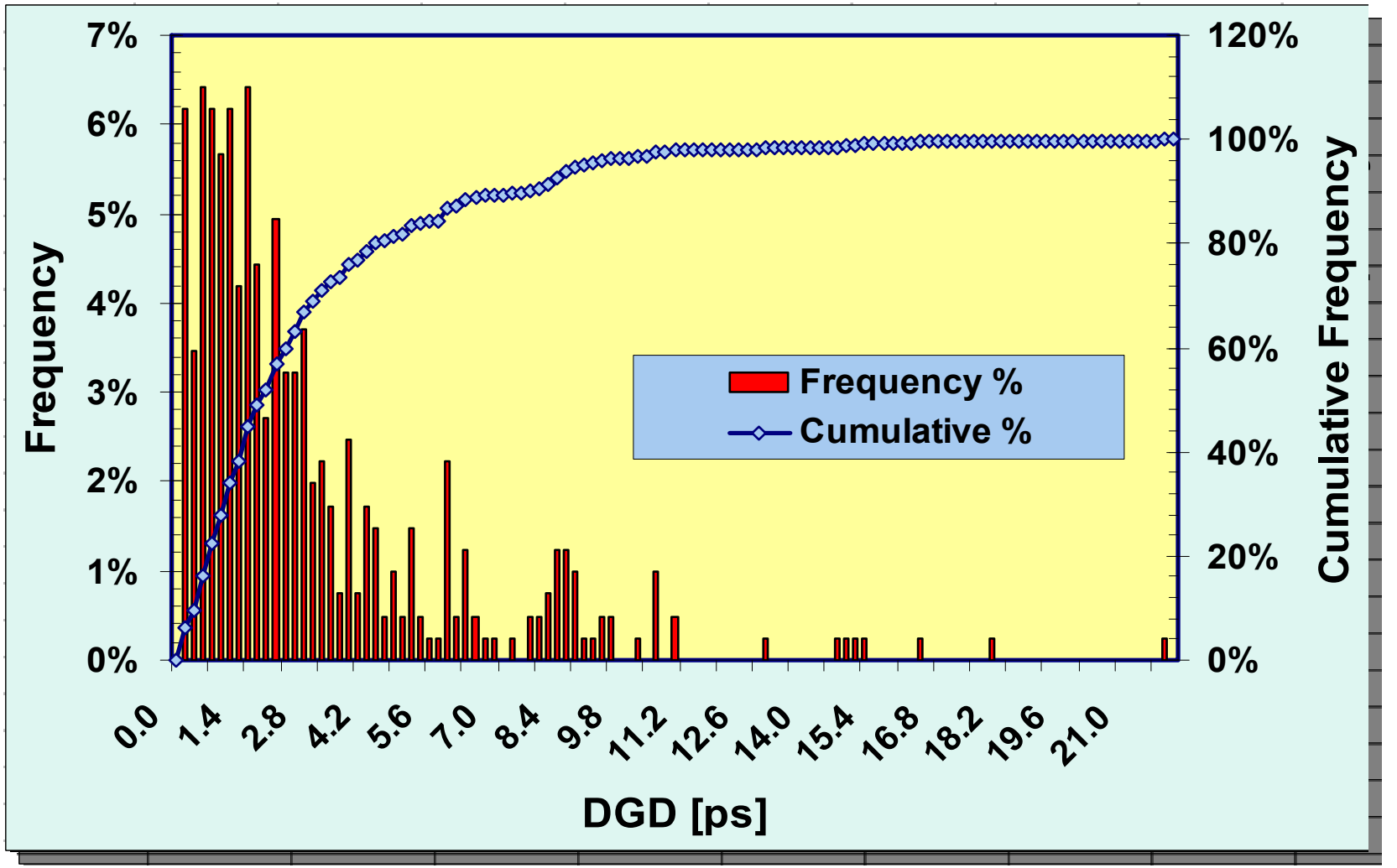
Field Measurements Audit

- fiber link attenuation
- reflectance and ORL
- PMD - to determine the PMD distribution in existing plant
- PMD vs. time - to determine the stability of PMD over diurnal periods
- PMD vs. temperature - to determine the stability of PMD with respect to temperature
- OC-192 BER - to demonstrate error-free operation and find the power penalty due to PMD, chromatic dispersion, and reflections.

Typical PMD Field Measurement Setup

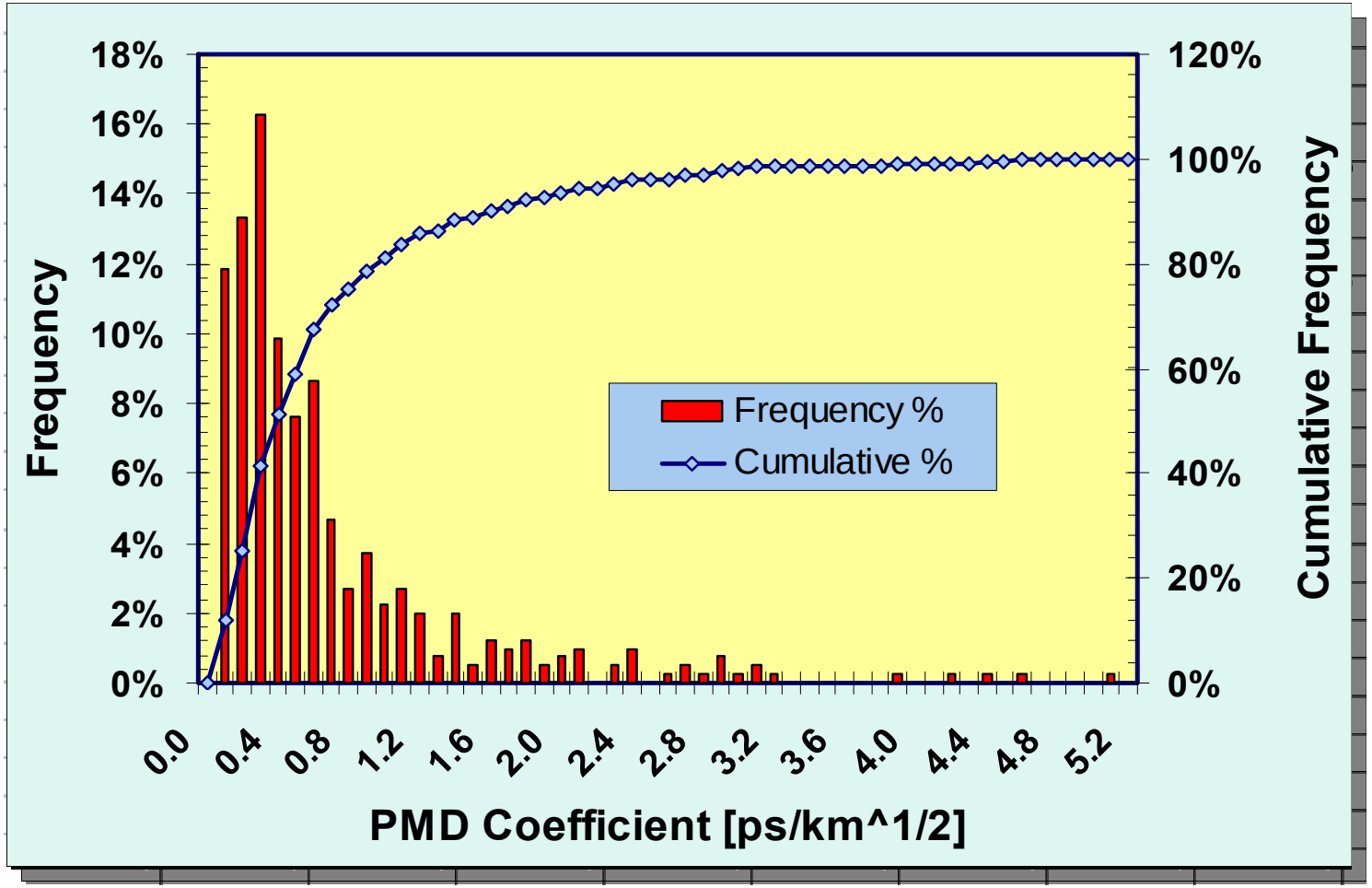


DGD Measurement Summary, Pre-1997



NFOEC'97
BELLCORE'S FIBER MEASUREMENT AUDIT OF EXISTING CABLE PLANT FOR USE WITH HIGH BANDWIDTH SYSTEMS
By John Peters, Ariel Dori, and Felix Kapron

PMD Measurement Summary, Pre-1997



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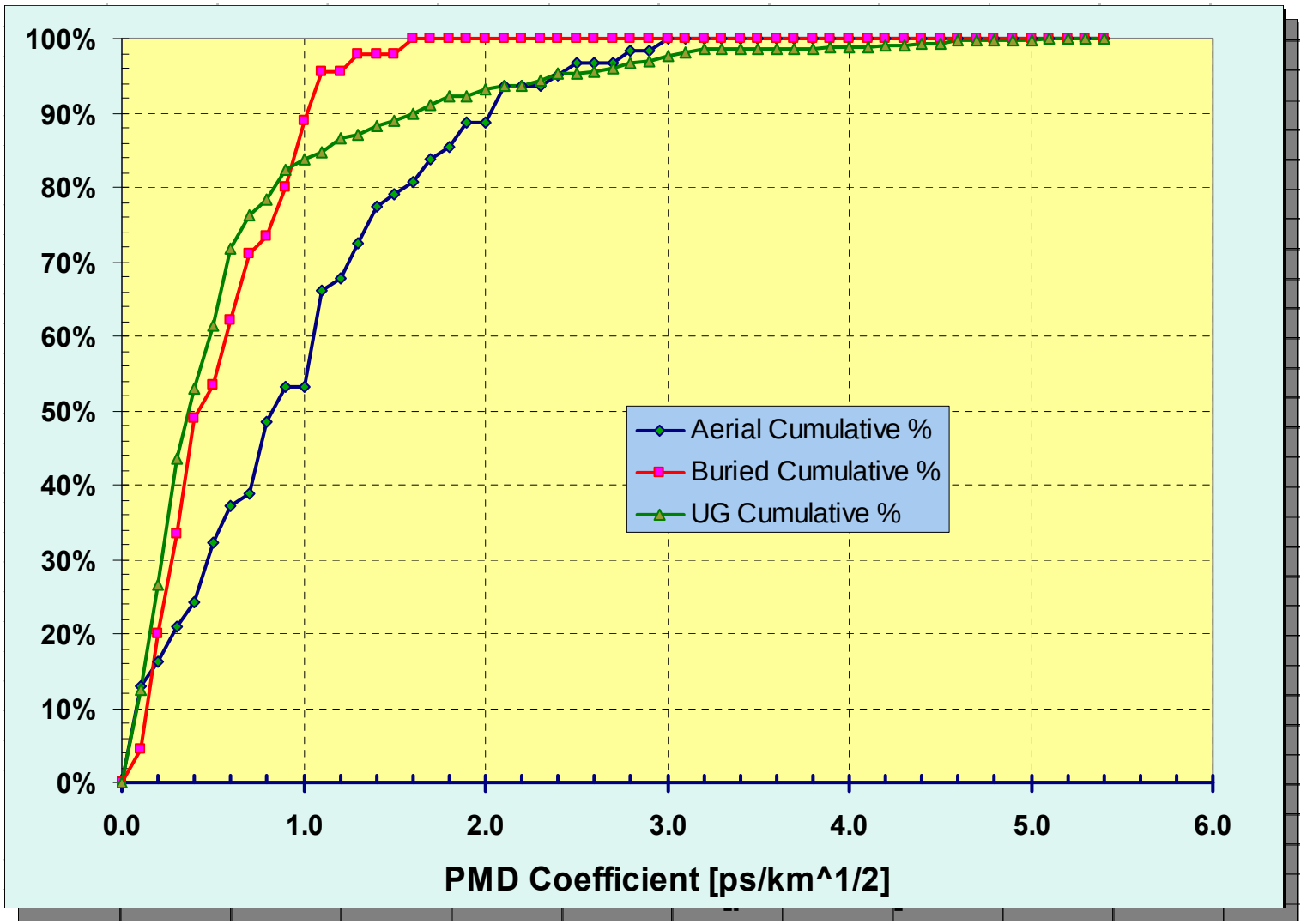
PMD Comparison by Plant Types – Pre-1997



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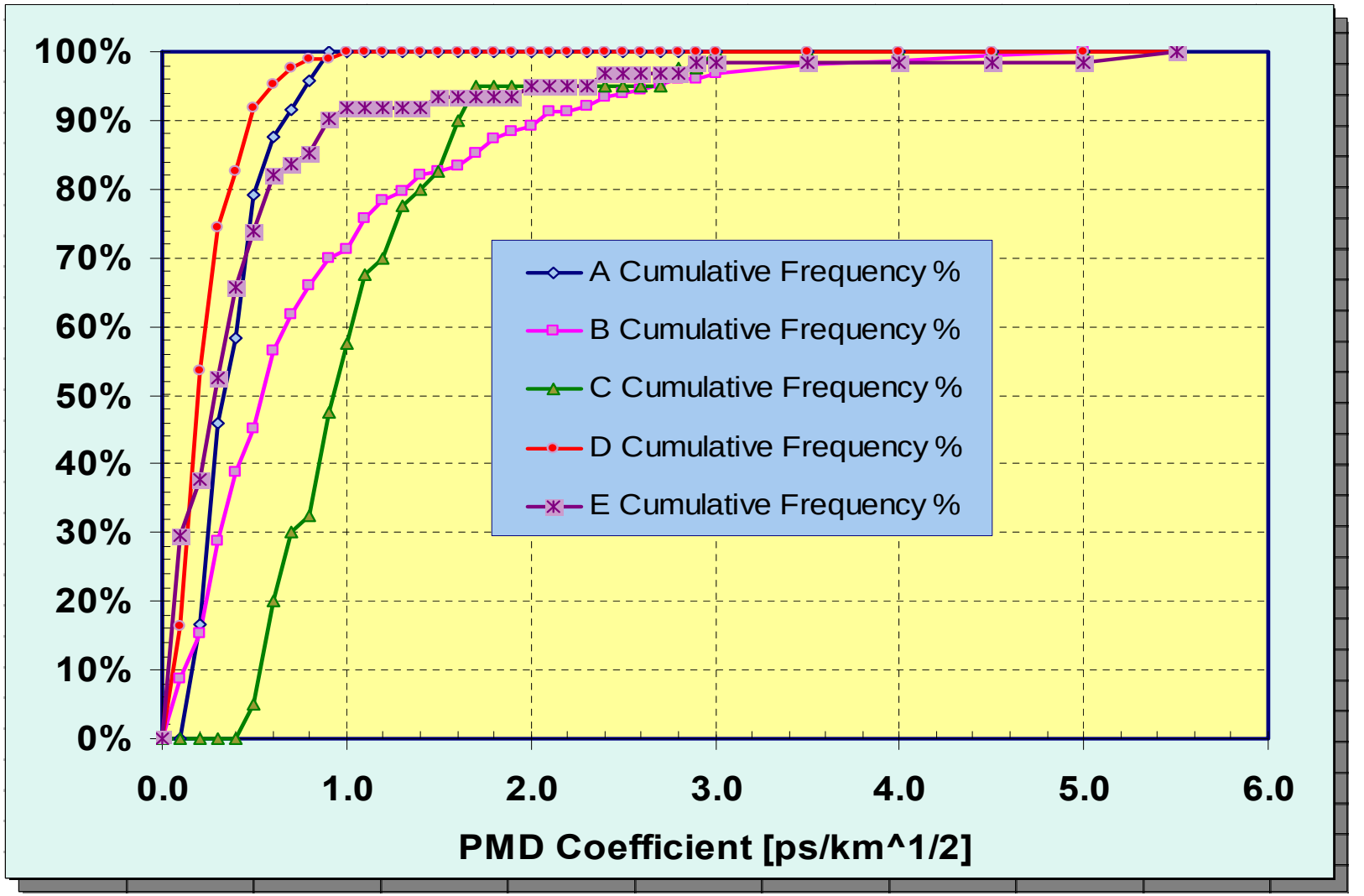
PMD Comparison by Cable Manufacturer – Pre-1997



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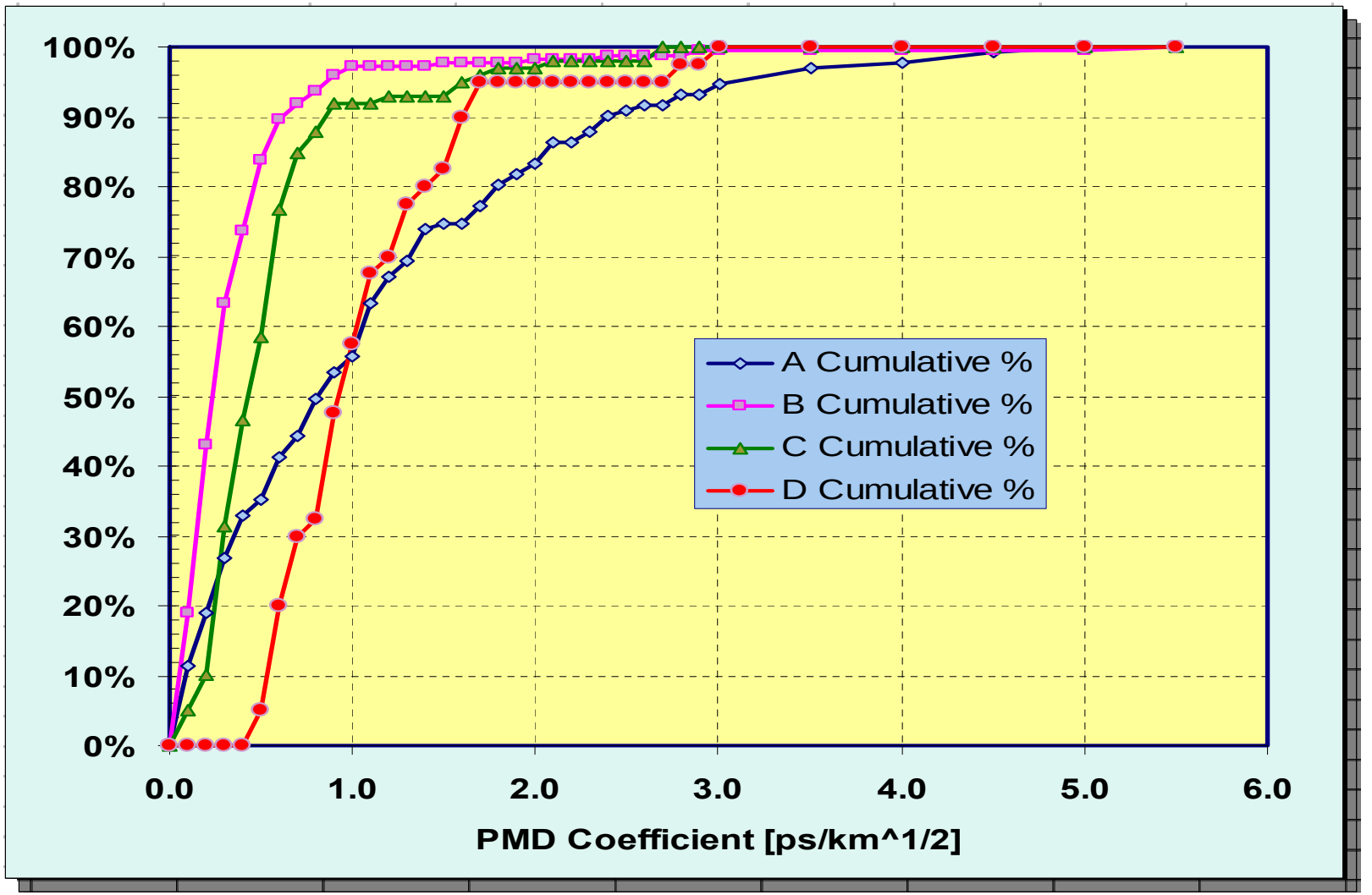
PMD Comparison by Cable Design – Pre-1997



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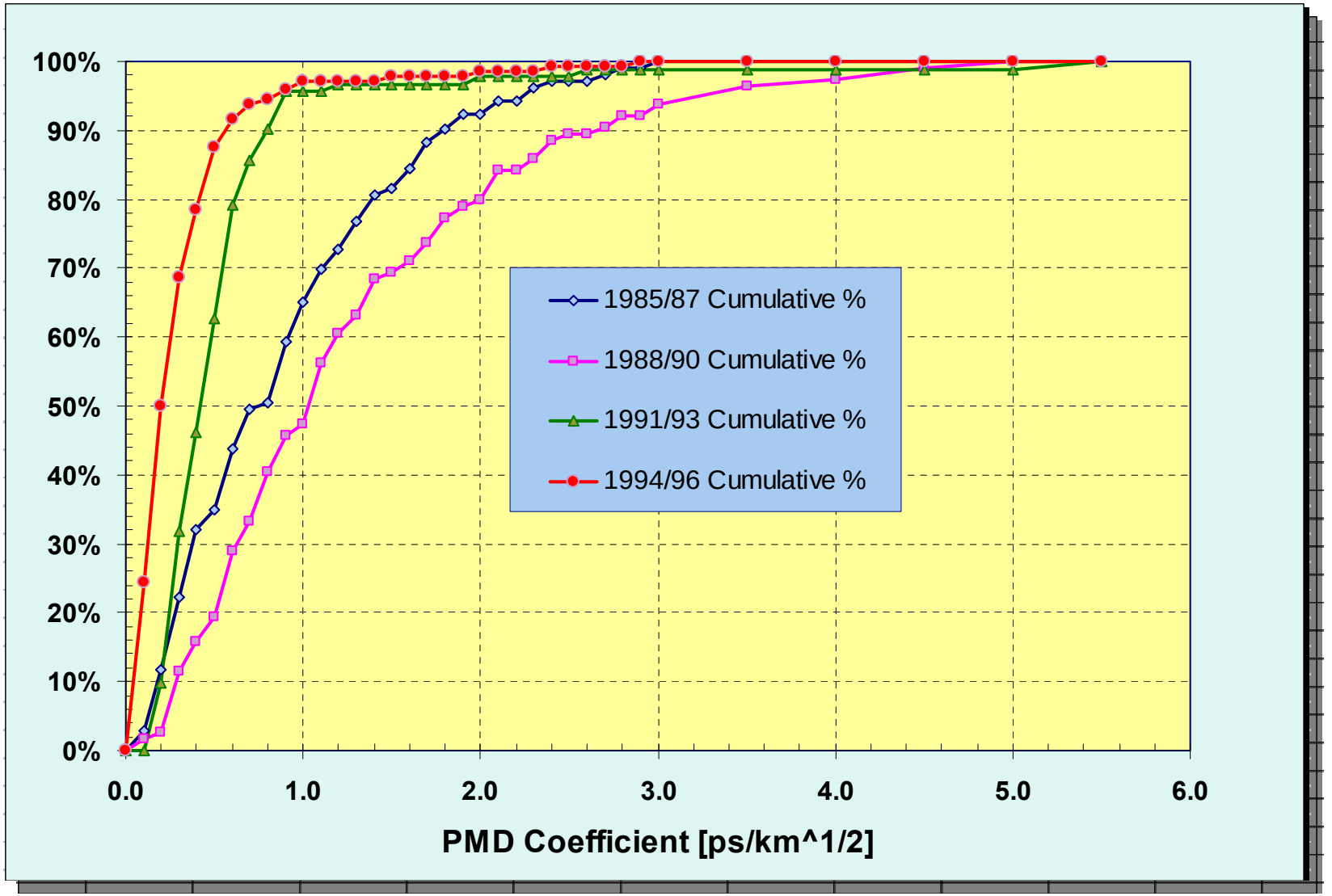
PMD Comparison by Cable Vintage – Pre-1997



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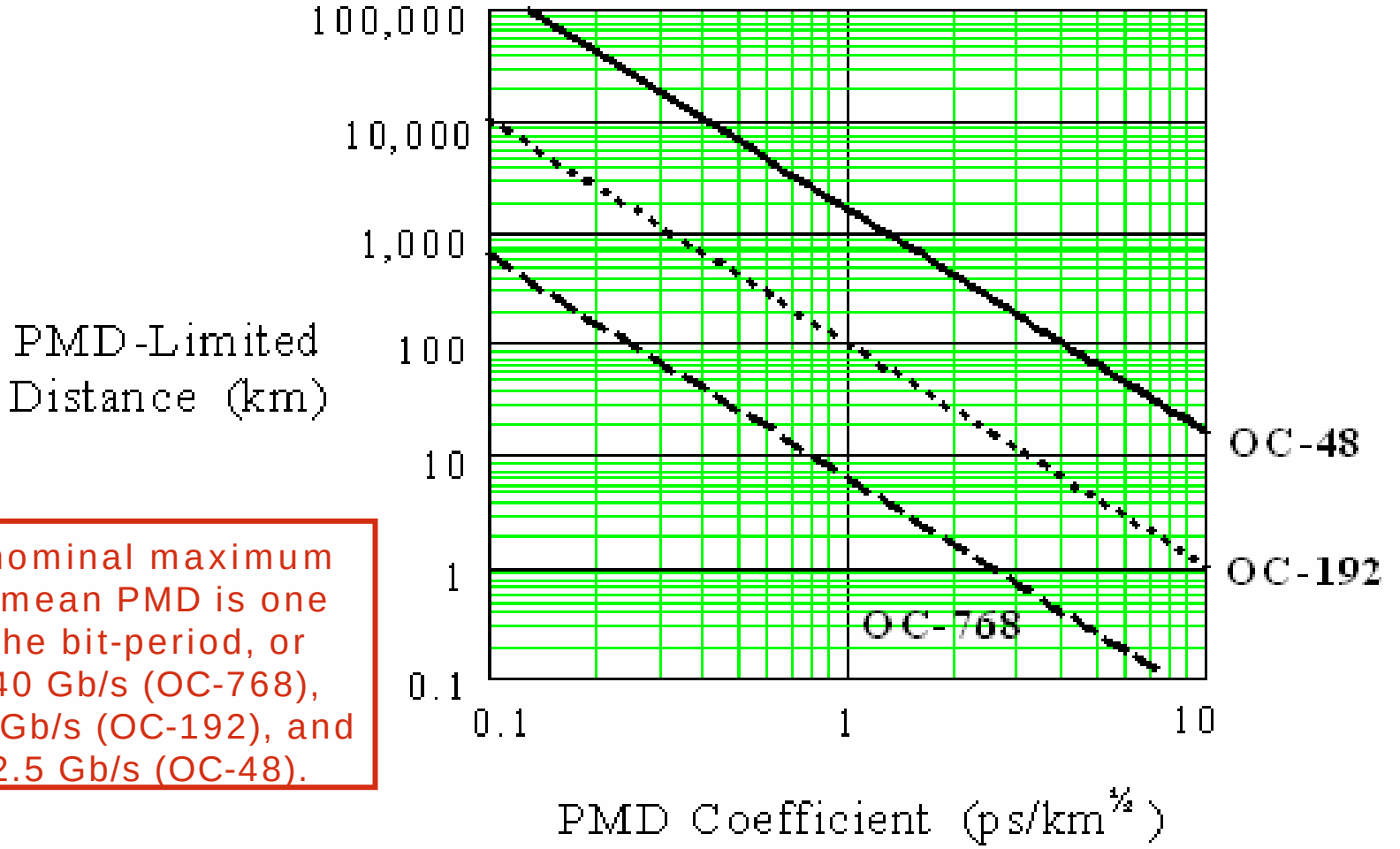
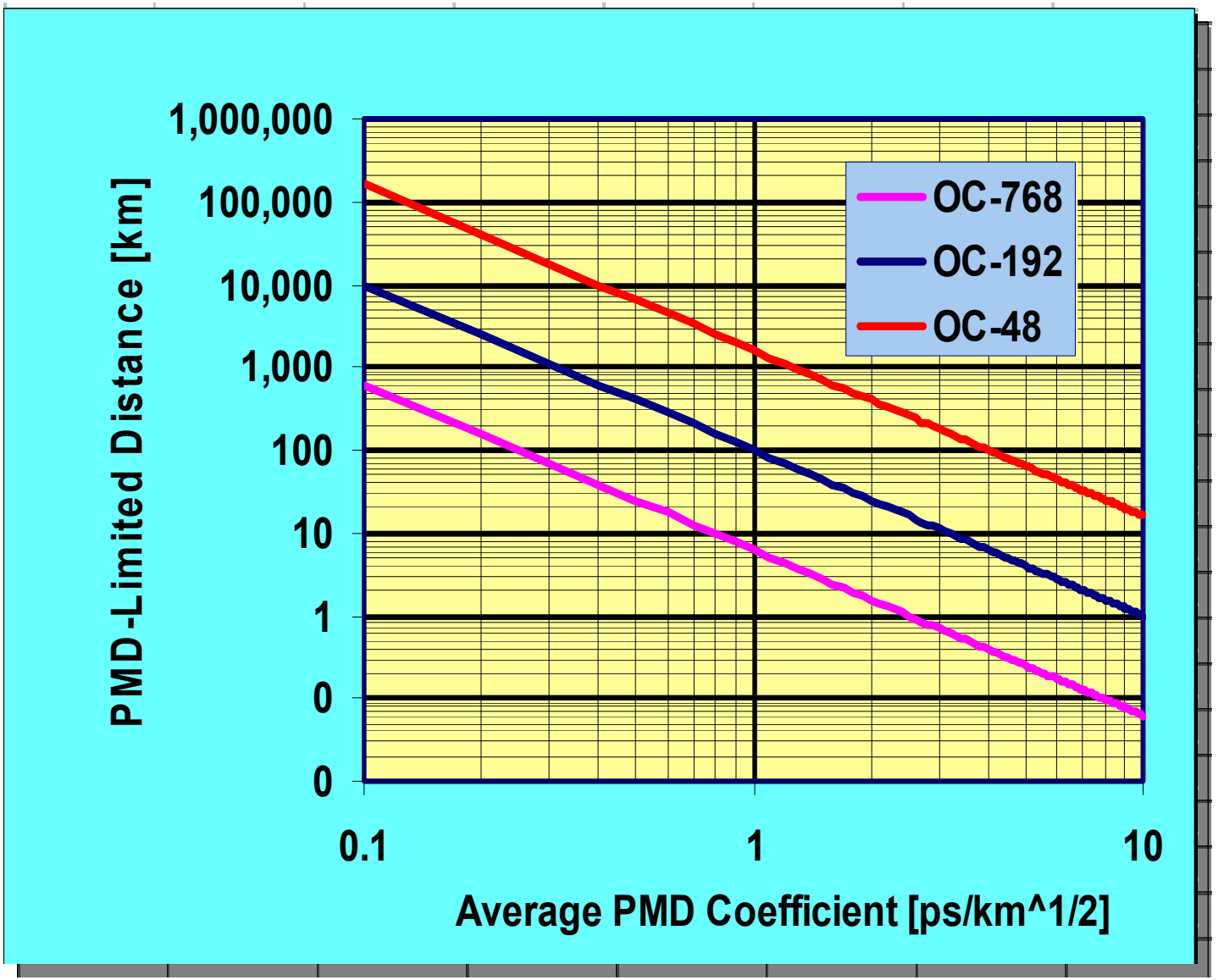
Estimated Digital Transmission Limitations Based Upon PMD



Assumed nominal maximum allowable mean PMD is one tenth of the bit-period, or 2.5 ps at 40 Gb/s (OC-768), 10 ps at 10 Gb/s (OC-192), and 40 ps at 2.5 Gb/s (OC-48).

L_{PMD} (km)= 10^4 × [bit-rate (Gb/s) × PMD coefficient (ps/km^{½})] $^{-2}$.

Estimated PMD Distance Limits



Conclusions

Based on our test results, it appears that PMD depends upon the following factors:

- cable age or vintage
- temperature of cable
- cable design
- cable manufacturer
- plant type.

Telcordia Recommendations

Telcordia recommends PMD testing be considered for any of the following conditions:

- deployment of 10 Gb/s, single-channel service over pre-1993 vintage cable, especially for longer link lengths
- service upgrades scheduled for optical amplification
- service upgrades eventually scheduled to become 40 Gb/s systems
- construction or upgrade of AM-VSB video systems with 80 channel capacity or greater.

Approaches to PMD Measurements

- Interferometric Approach (INTY)
  - Traditional (TINTY)
  - Generalized (GINTY)
- Polarmetric Approach
  - Jones Matrix Eigenanalysis (JME)
  - Poincaré Sphere Analysis (PSA)
- Fixed Analyzer (FA)
  - Wavelength Scanning Approach – Often OSA add-on
    - Cycle Counting (CC)
    - Fast Fourier Transform (FFT)

PMD Measurements

- Optical Fiber Cables – Laboratory Measurements
  - Cable specifications
  - Quality testing at point of manufacture.
- Transmission Network Physical Plant Parameters – Field Measurements
  - PMD measurements made for high bandwidth and analog video systems.
  - Requires the use of portable test equipment
  - Two technicians often required
  - Access often needed to both ends of fiber plant
  - Good communications required between fiber ends
  - PMD of a network combines as the square root of the sum of the square of its components. Enables Office to office links to be measured in several pieces.

Comparative Review

- TIA inter-laboratory, round-robin tests of PMD using different methods:
  - Methods yield systematic and random disagreement between measurements in the range ± 10% to ± 20%.
- Over the years, numerous measurements have shown a similarity between Fixed Analyzer (Cycle Counting) and Jones Matrix Eigenanalysis is, both define PMD as the average DGD over the wavelength range of the measurement.
- It is also generally agreed that the Gaussian responses generated by the Fixed Analyzer (Fourier Transform) and the traditional Interferometric Method should make those two methods equivalent.
- There is some indication that the difference between JME and Interferometric Method could be adjusted if the definition of PMD for JME were changed to RMS DGD instead of average DGD.
- Fixed Analyzer (Cycle Counting) and Fixed Analyzer (Fourier Transform) must exhibit different PMD values because of the relationships just described above. Any change, however, in the definition of PMD for any of the methods will affect the results generated by at least one other method. It is possible that the 1.085 numerical factor relating RMS to mean DGD will be the equating factor between the two Fixed Analyzer methods.

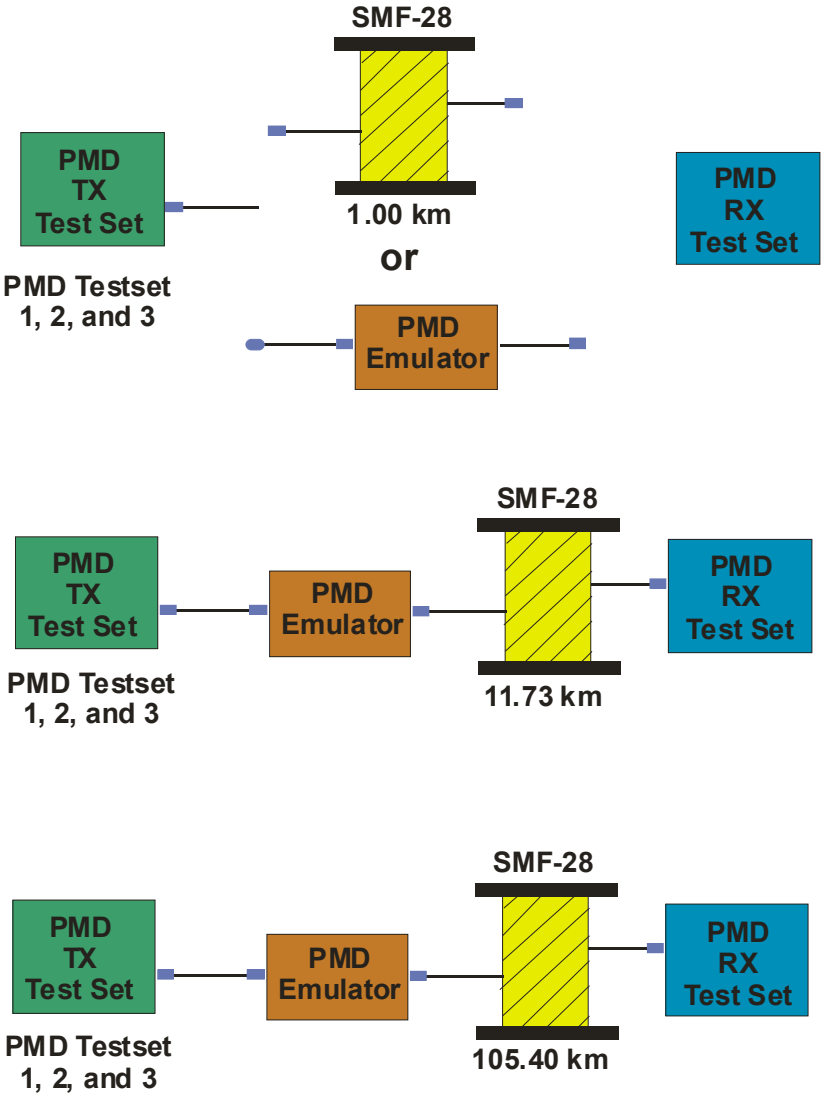
Methods Tested in Laboratory Testing

PMD Test Method Used by Test Set	Measurement Wavelength Range
Jones Matrix Eigenvalue	1525 – 1620 nm
Fixed Analyzer – Cycle Counting	1525 – 1610 nm
Fixed Analyzer – Fast Fourier Transform	1525 – 1610 nm
Interferometry	1510 – 1570 nm

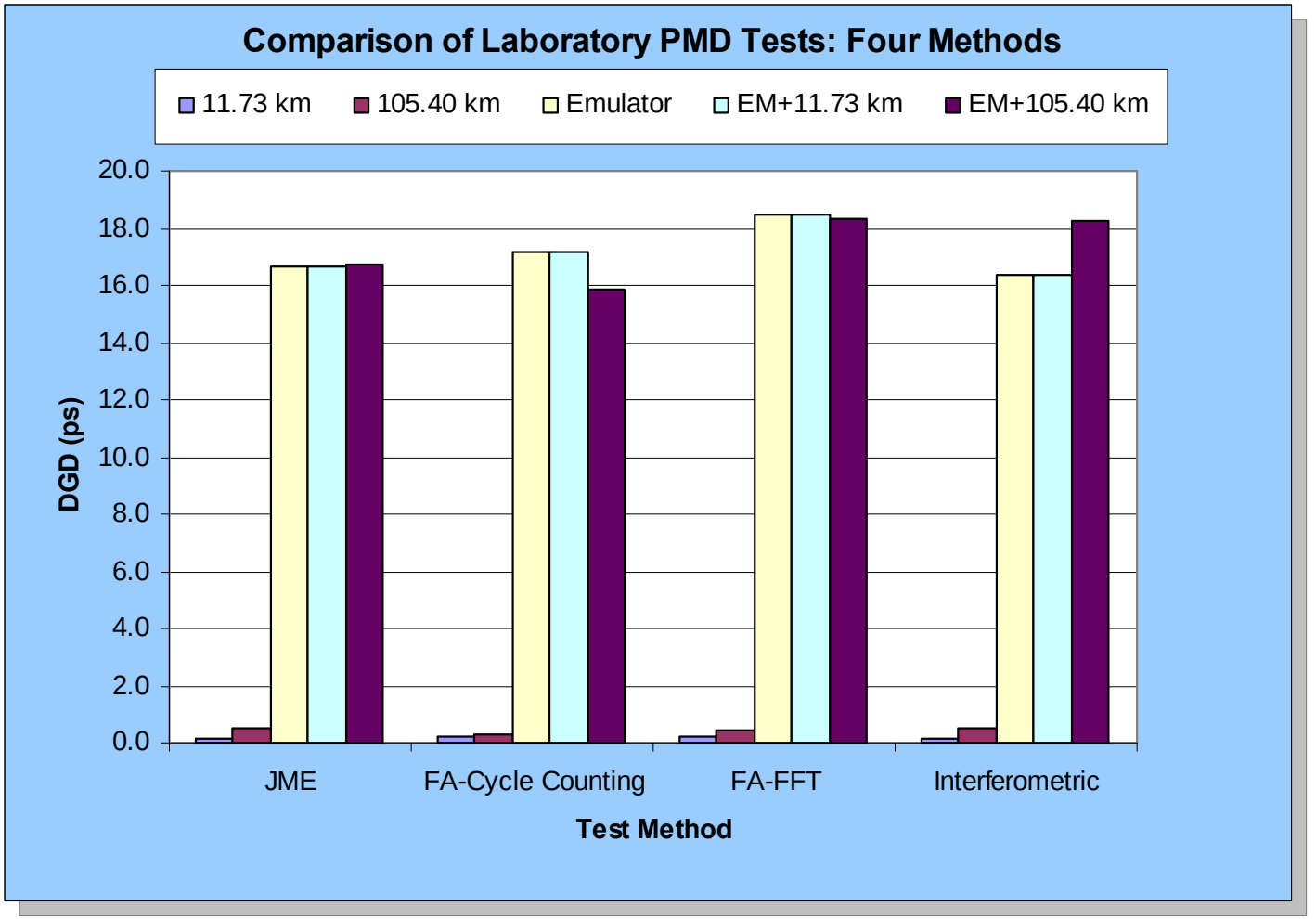
General Test Setup for Laboratory Tests

Laboratory Tests Performed

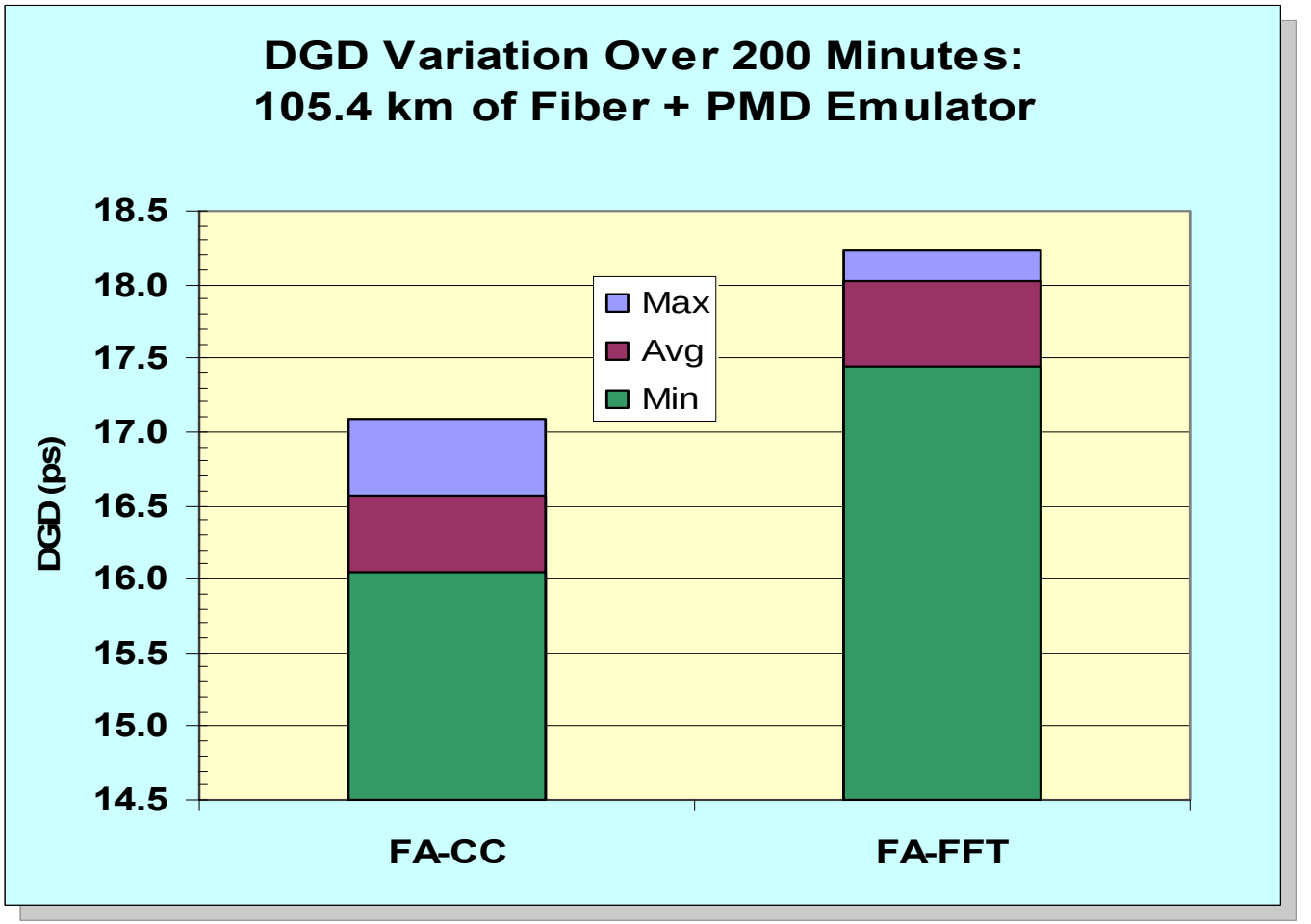
1. 1 km of fiber without PMD emulator
2. 11,730 km of fiber without PMD emulator
3. 105,403 km of fiber without PMD emulator
4. PMD emulator without fiber
5. PMD emulator plus 11,730 km of fiber
6. PMD Emulator Plus 105,403 km of fiber
7. PMD Emulator Plus 105,403 km of fiber – long term measurements using the FA methods.



Comparison of the Four PMD Measurement Results: Laboratory Tests



Variation of PMD Over Short Period of Time: Laboratory Measurement FA Method



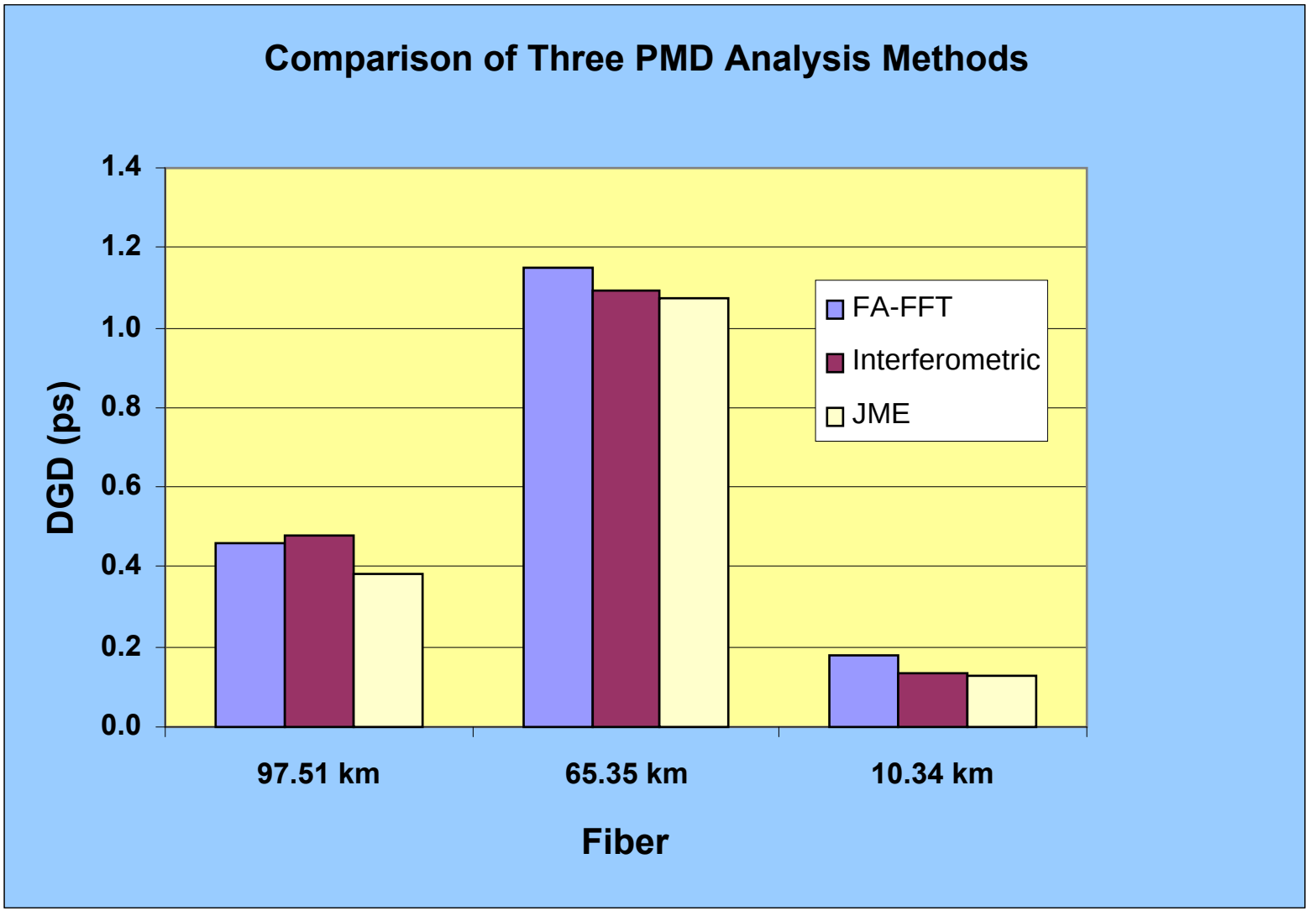
Conclusions from Laboratory Tests

- In general the JME and Interferometry DGD results pair-up well, being equal for 3 of 5 tests (note, the 1 km test results were not included in this analysis because of their small value). For the other 2 of 5 tests the JME and Interferometry tests ranked side-by-side in DGD.
- In all DGD measurements, the two Fixed Analyzer Methods were different.
- In all but the DGD measurement with the 105.4km fiber, the two Fixed Analyzer Methods were well within 10 percent of each other.
- Based upon the results of the Telcordia laboratory tests, the four PMD measurement methods used by the three test sets examined delivered the expected relationships between PMD measurement methods. All three test sets measured the PMD emulator at various dynamic ranges from 1 km to over 105 km with general agreement within plus or minus 10 percent agreement of each other.

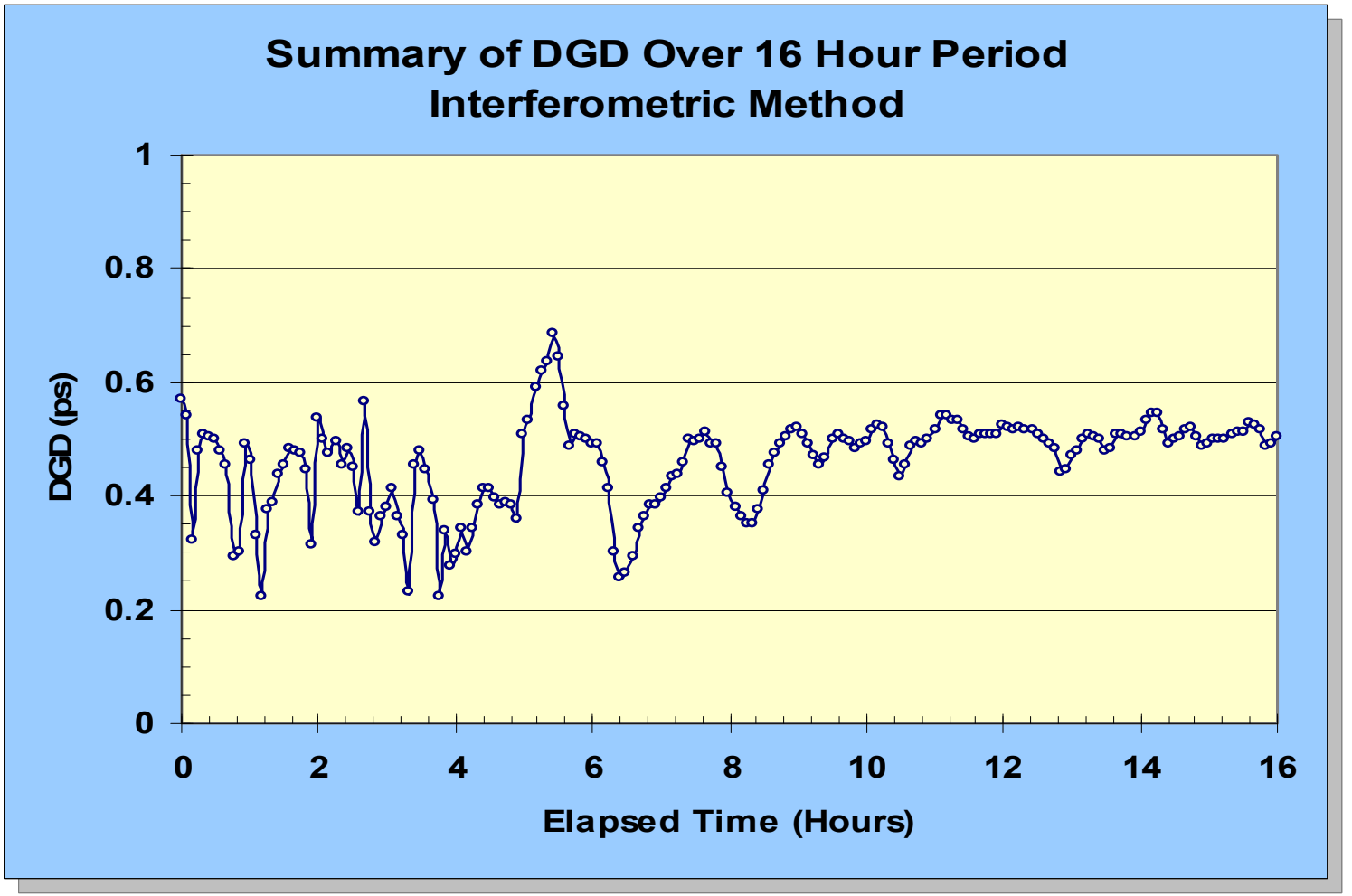
PMD Test Equipment Used for New Orleans Field Measurements

Method	Wavelengths	EIA/TIA Reference	Fiber Lengths
FA/FFT	1485 -1640 nm	FOTP-113	10.34 km 65.35 km 97.51 km
INTY	1510 -1570 nm	FOTP-124	10.34 km 65.35 km 97.51 km
JME	1525 -1610 nm	FOTP-122	10.34 km 65.35 km 97.51 km

Comparison of the Three PMD Measurement Results: N.O. Field Tests



Long Term PMD Field Measurements: Interferometric Method



PMD Concatenation Calculation Checked

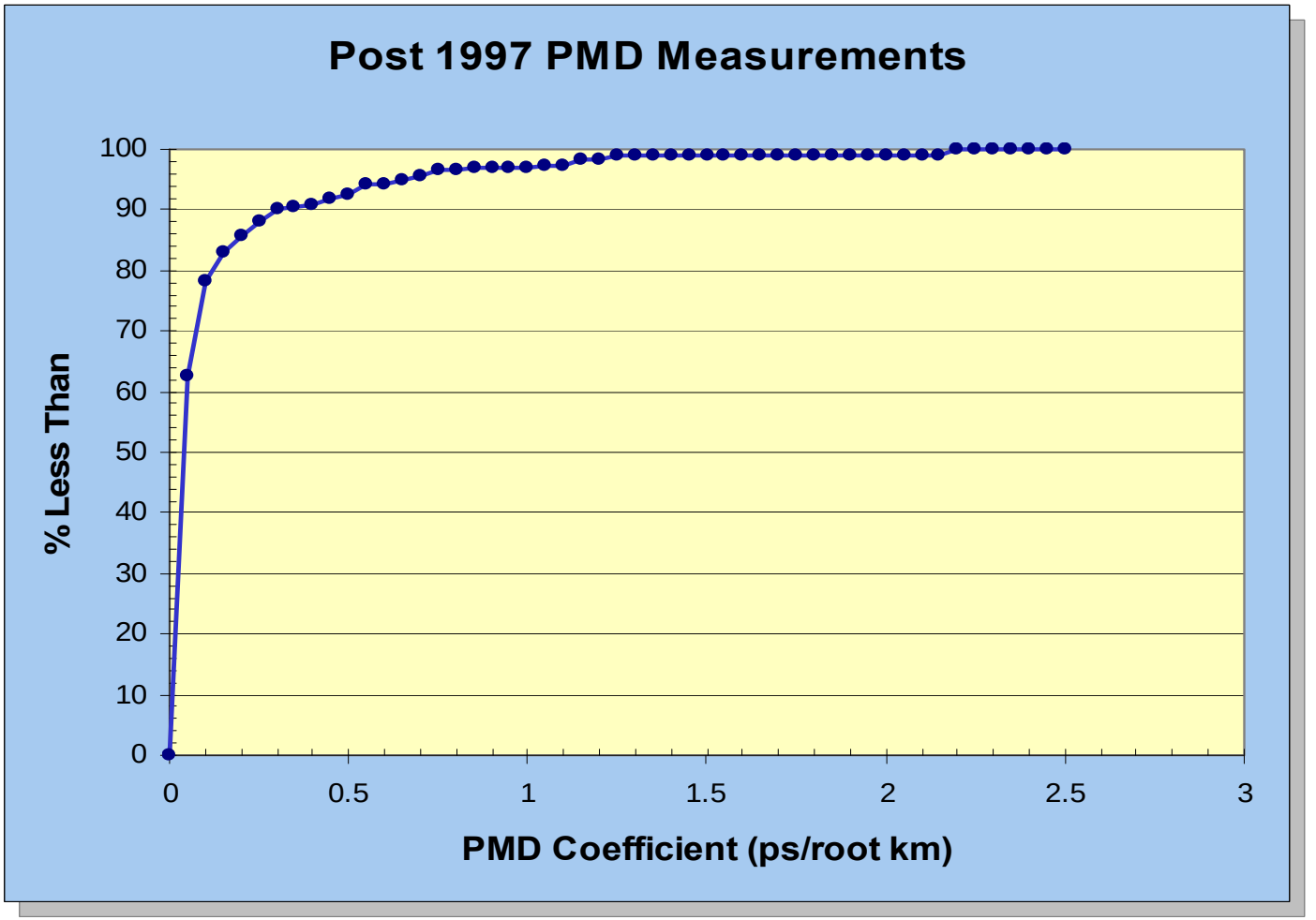
JME Method	Length (km	DGD
Measured	65.35 km	1.07 ps
Measured	10.34 km	0.13 ps
Measured	75.69 km	1.08 ps
Calculated	75.69 km	1.08 ps

$$\text{Calculated DGD} = \sqrt{(1.07)^2 + (0.13)^2}$$

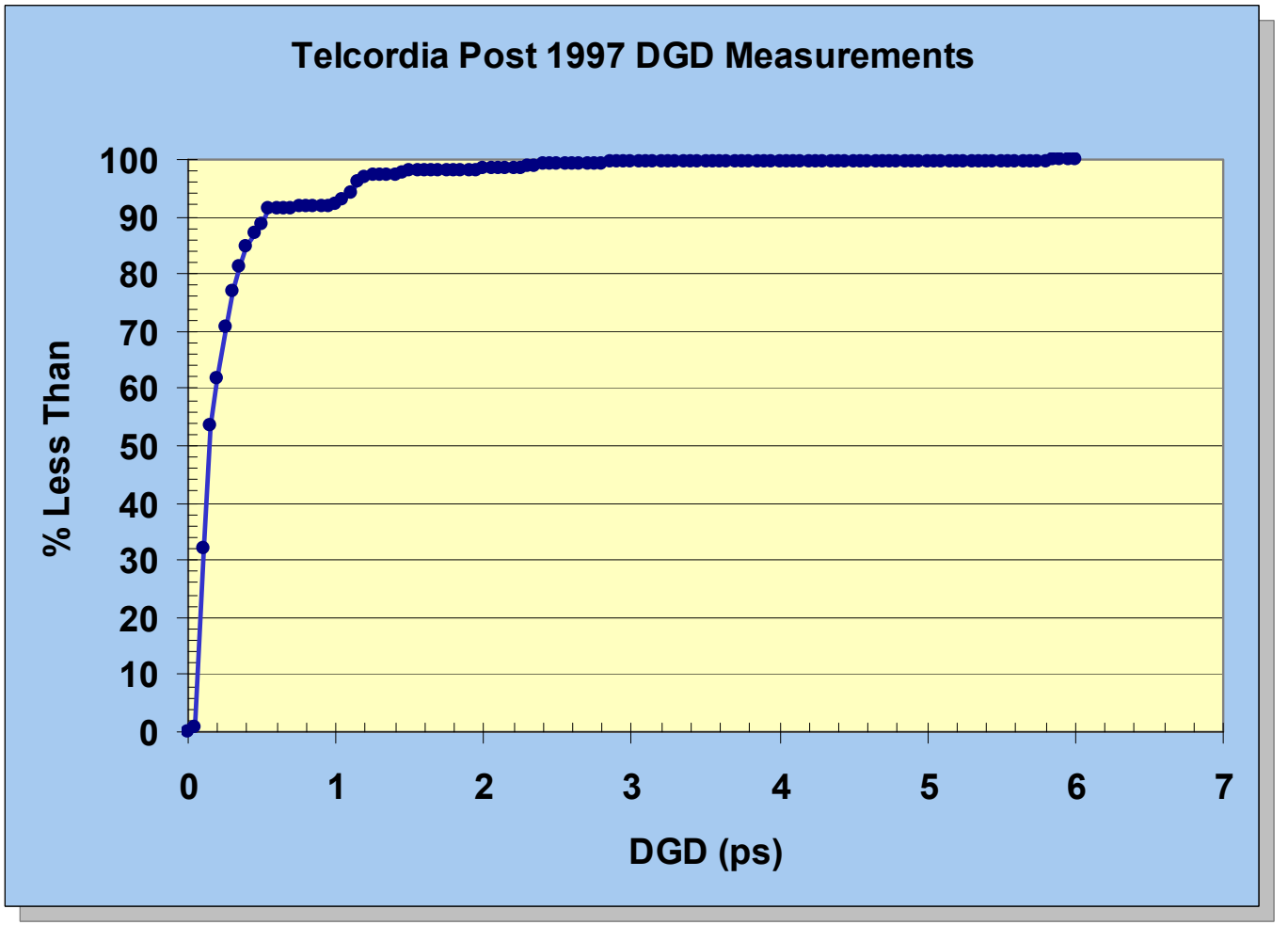
Conclusions Based Upon PMD Field Measurements in N.O.

- All three measurement methods, Fixed Analyzer-FFT, Interferometric, and JME performed quite similarly on all fibers tested, e.g., measurement variation ranging from ± 3.5% to ± 17.5%.
- The variation in PMD measured over a long-term exceeded any variation from the measurement method itself. Long-term DGD measurements averaged 0.461 ps and ranged from a minimum of 0.223 ps to a maximum of 0.687 ps (0.464 ps range) for the 97.5 km fiber. The variation in DGD between measurement methods on the same fiber was 0.100 ps.
- As before, the PMD of a concatenated length of fibers can be estimated by the square root of the sum of the squares of each of its component fibers.
- Suggest that the PMD method and equipment used be the one that is most compatible with its other equipment and that its technicians feel comfortable with.

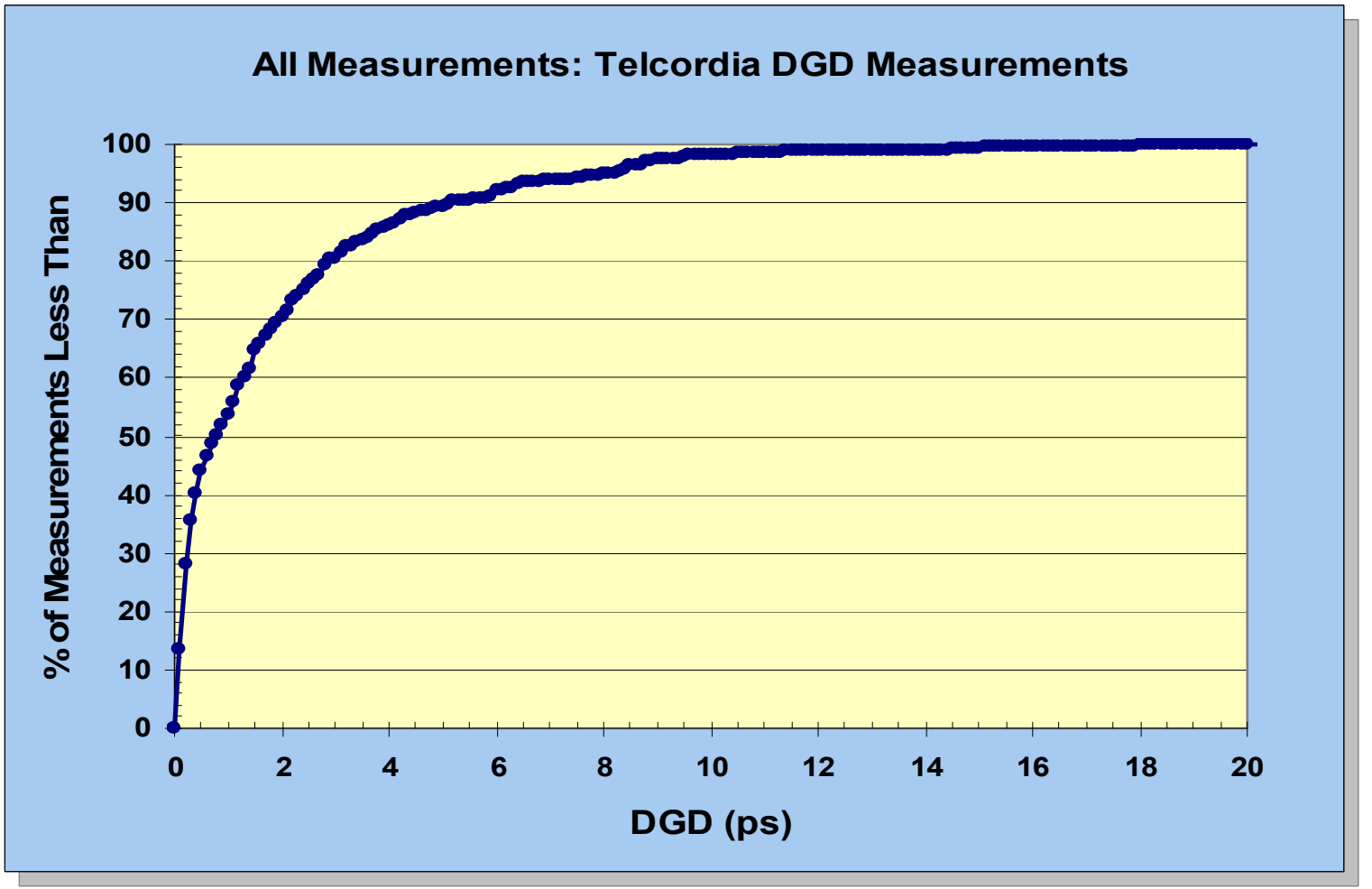
Post 1997 PMD Measurements



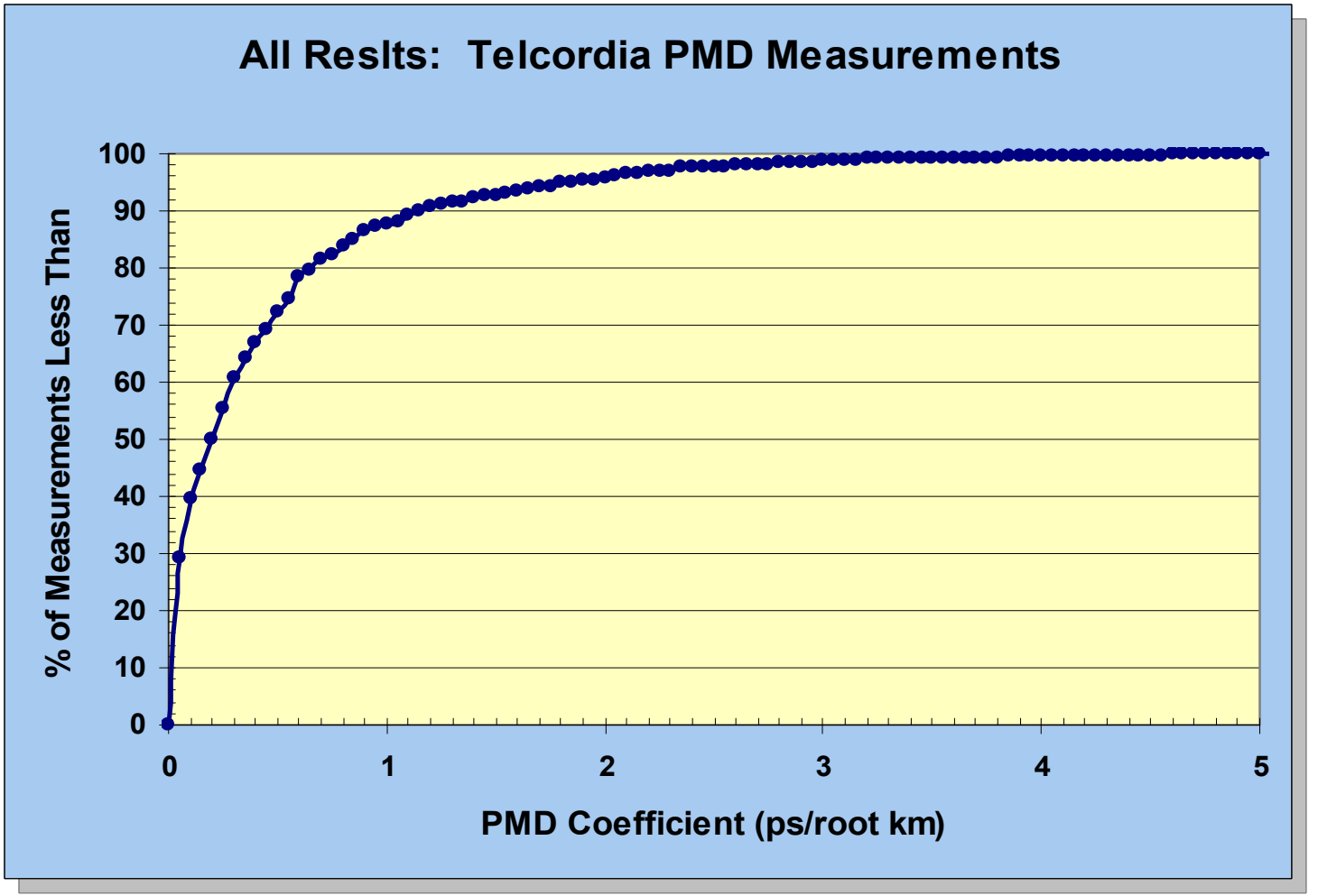
Post 1997 DGD Measurements



Telcordia DGD Measurements: All Measurements



Telcordia PMD Measurements: All Measurements



Percentage of Fibers with 40 Gbit/sec PMD Length Limits > Than Length Shown