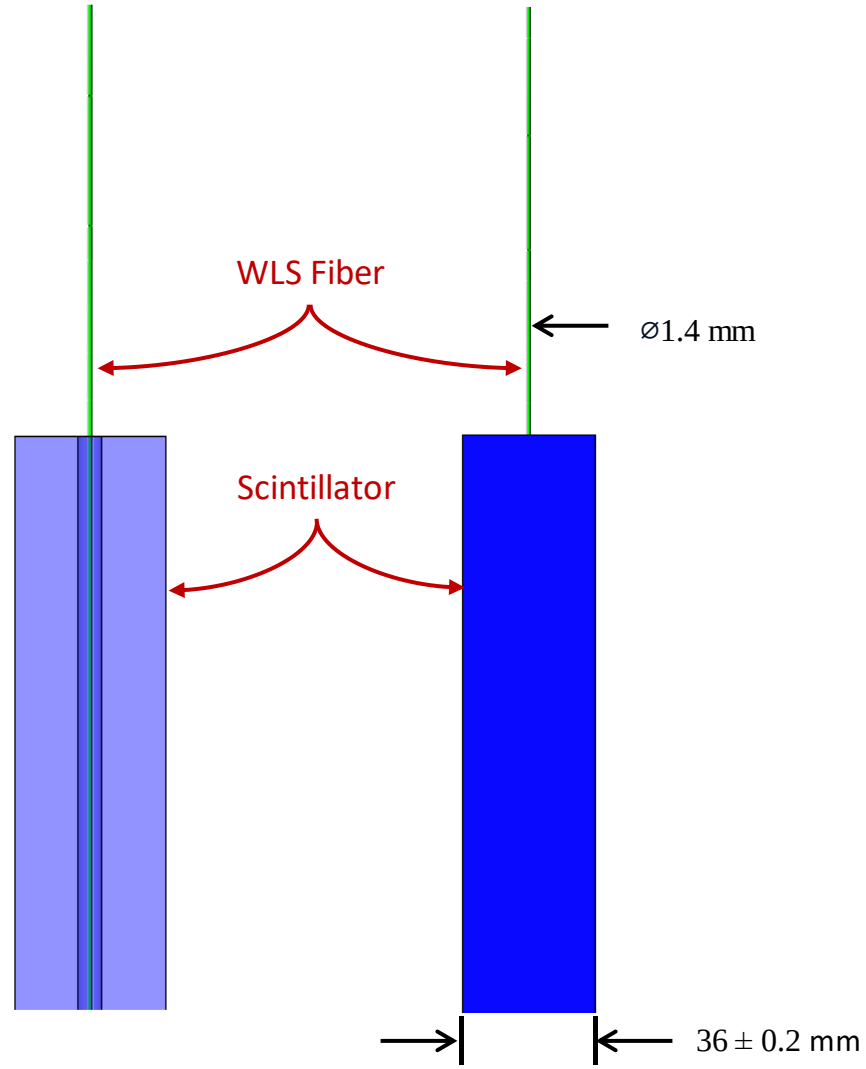
WLS Fiber Bending Radius and Manifold Dimensions

Julianna Abel
11/1/24

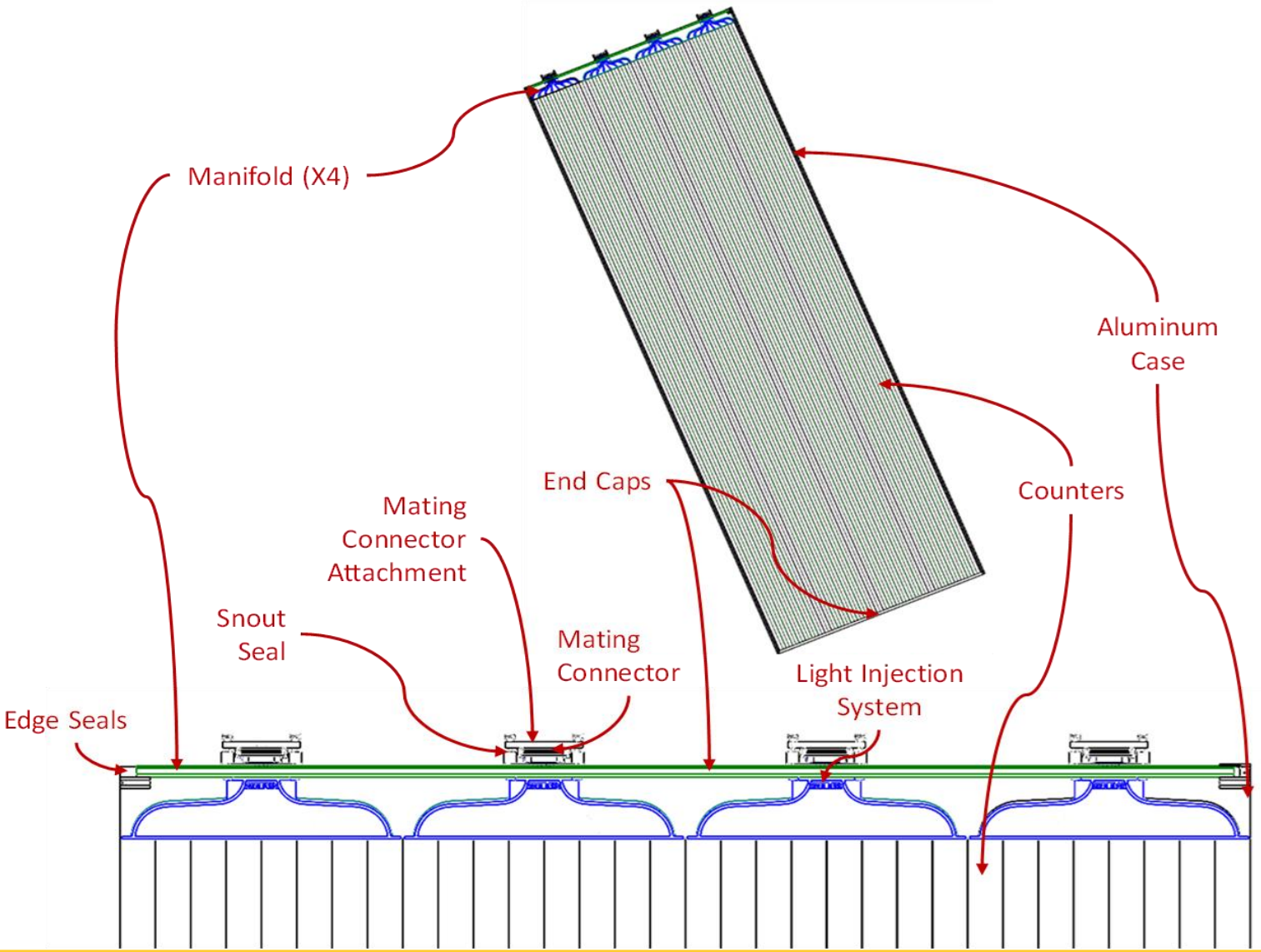
Counters: Scintillator Bars and WLS Fiber

- Wavelength shifting (WLS) fiber:
  - Kuraray Y11 double clad
  - 1.4 mm diameter (d)
  - 28 mm minimum bend radius (R>20d) MINOS Spec
- Scintillator
  - Extruded by Fermilab
  - 36 mm width x 16 mm thick (+/- 0.2 mm)
  - Hole centered within +/- 0.2 mm
  - Width and thickness are critical for system functionality
  - Length (3300/3450 mm) is easily adjustable to fill space to meet physics needs



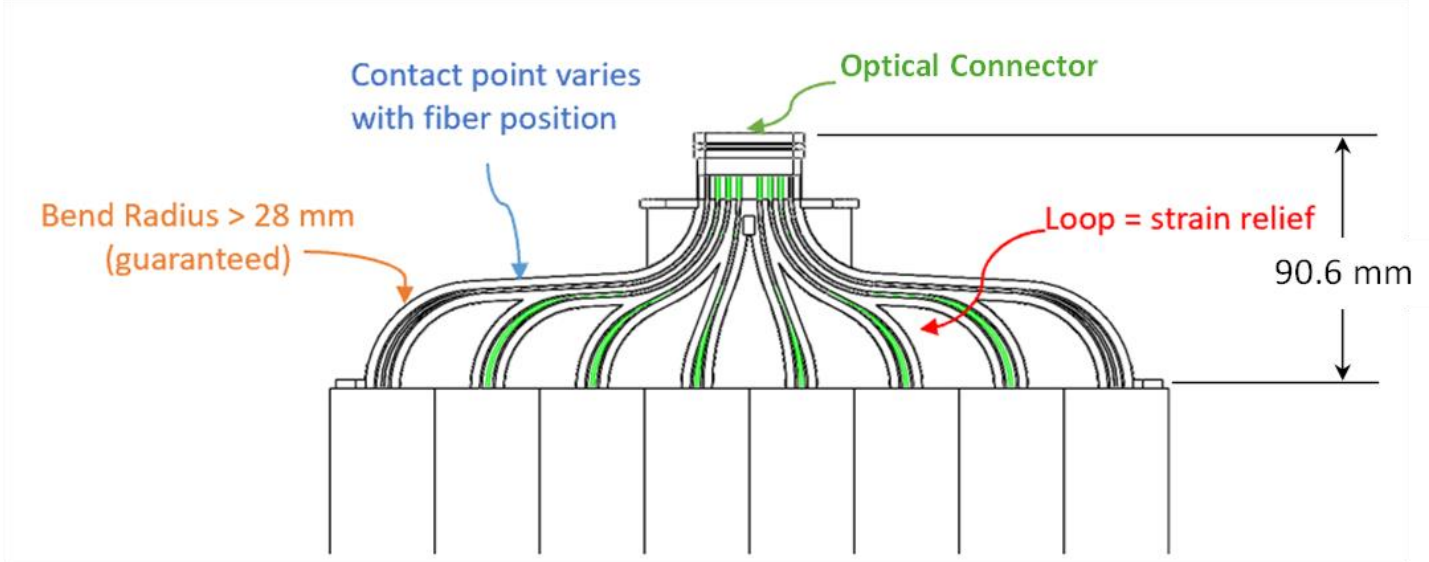
Module Components

1. Counters
2. Manifold and Cover
3. Light Injection System
4. Aluminum Case
5. End Caps
6. Edge Seals
7. Snout Seal
8. Mating Connector
9. Mating Connector Attachment



Manifold & Cover Direct and Protect WLS Fibers

- Routes 8 WLS fibers to optical connector at top of manifold
- Reduces number of locations where light can leak
- Controls fiber bend (R>28 mm)
- Accommodates tolerance buildup from scintillator variation
- Provides some light protection
- Facilitates light injection
- Co-locates WLS fibers for fly-cutting

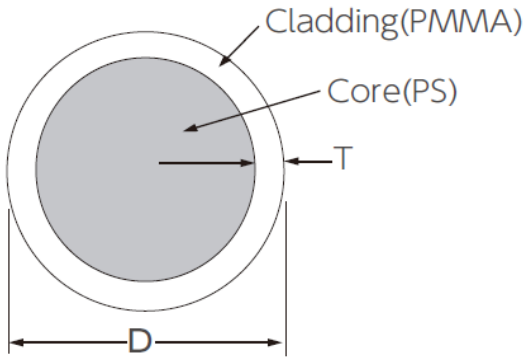
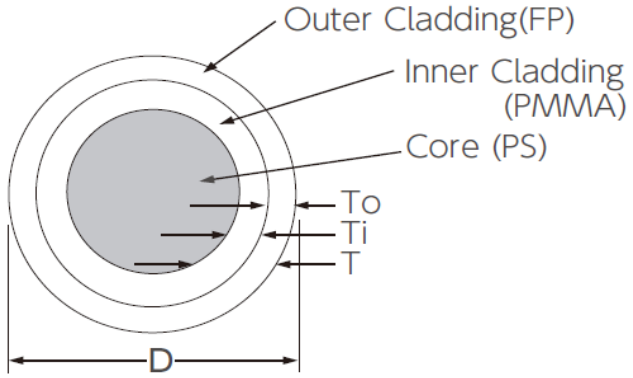


WLS Fiber Cross Section and Cladding

Assumption: Circular Cross Section

Questions:

- Will the fiber be single-cladding (standard) or multi-cladding (higher light yield)?

	Single Cladding	Multi-Cladding (M)
Round Fiber (D)	 Cladding Thickness[1]: T=2% of D Numerical Aperture: NA=0.55 Trapping Efficiency : 3.1%	 Cladding Thickness[2]: T=2%(To)+2%(Ti) =4% of D Numerical Aperture : NA=0.72 Trapping Efficiency : 5.4%

WLS Fiber Polymer Orientation and Dimension

Questions:

- Will the fiber be Standard Type (minimal orientation) or S Type (orientation along drawing direction)?

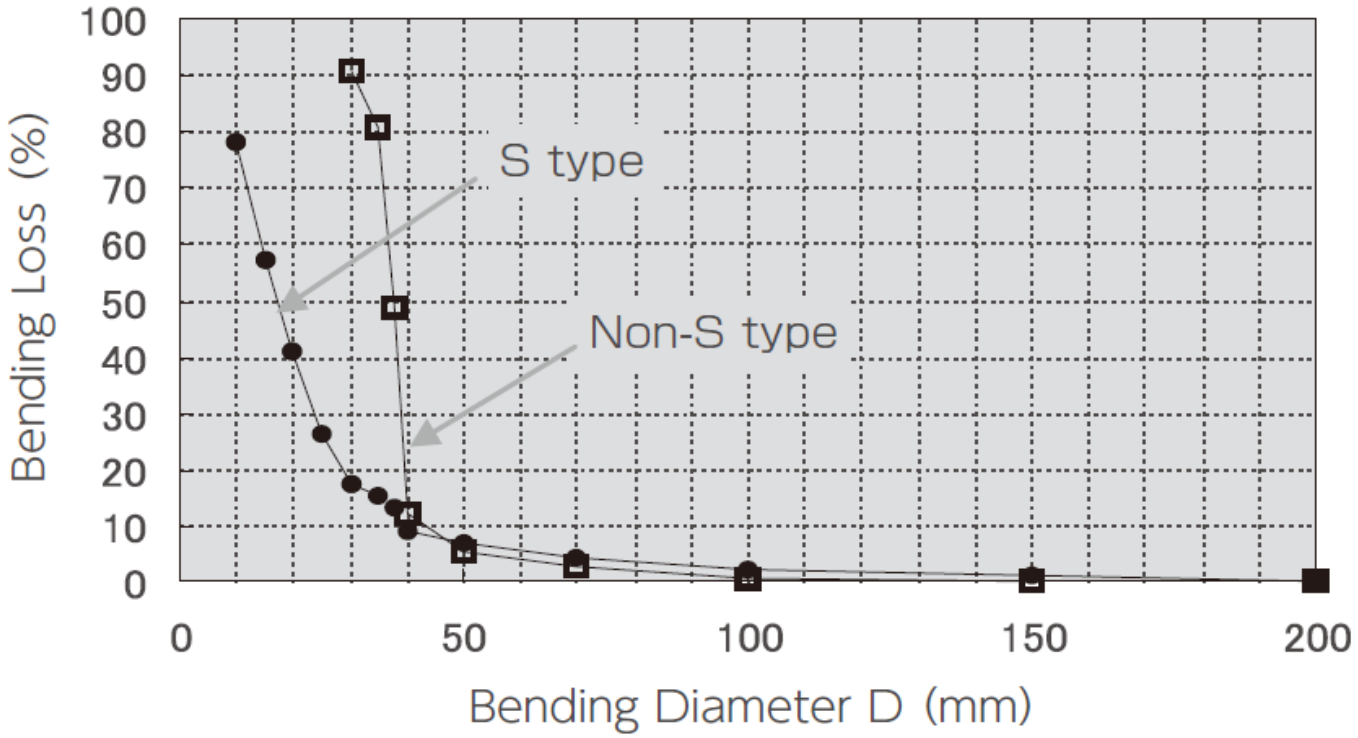
Standard type (Non-S type)
PS core is almost no oriented polystyrene chain and is optically isotropic and very transparent.
This conventional standard type has good attenuation length, but it shows weakness against clacking caused by bending or handling during assembling.

S type (S)
Core has molecular orientation along drawing direction.
This fiber is mechanically stronger against clacking at the cost of transparency.
The attenuation length of this type is nearly 10% shorter than standard type.

- What is the desired fiber diameter?
  - Typical diameters are 0.2, 0.5, 1.0, 1.5, 2.0 mm

Bending Losses for d = 1 mm

WLS Fiber diameter of 1 mm



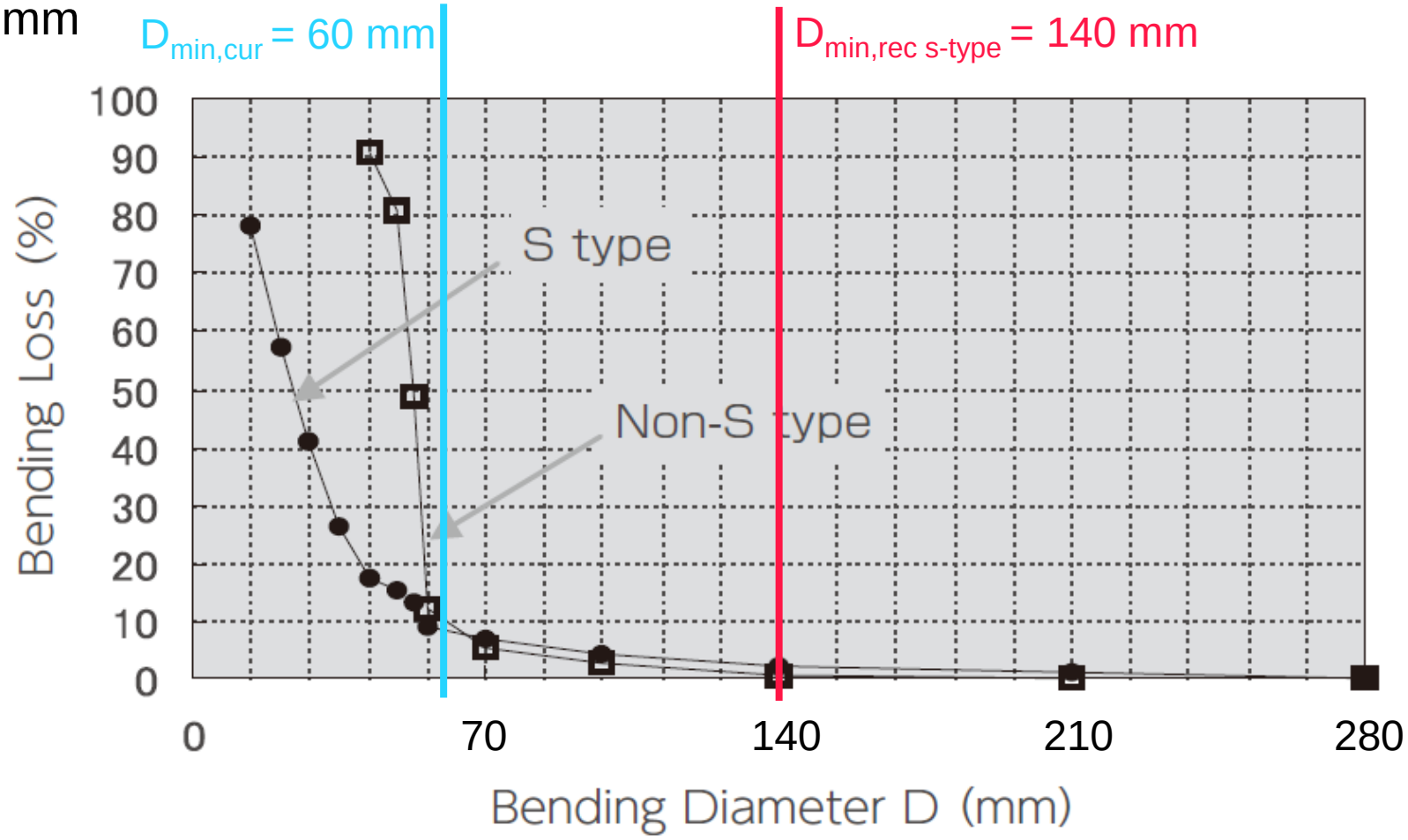
Minimum Bending Diameter

We recommend minimum bending diameter as the following table on safety side and long term reliability.

Type	2mmΦ Fiber	1mmΦ Fiber	0.5mmΦ Fiber
S type	200mm	100mm	50mm
Non-S type	400mm	200mm	100mm

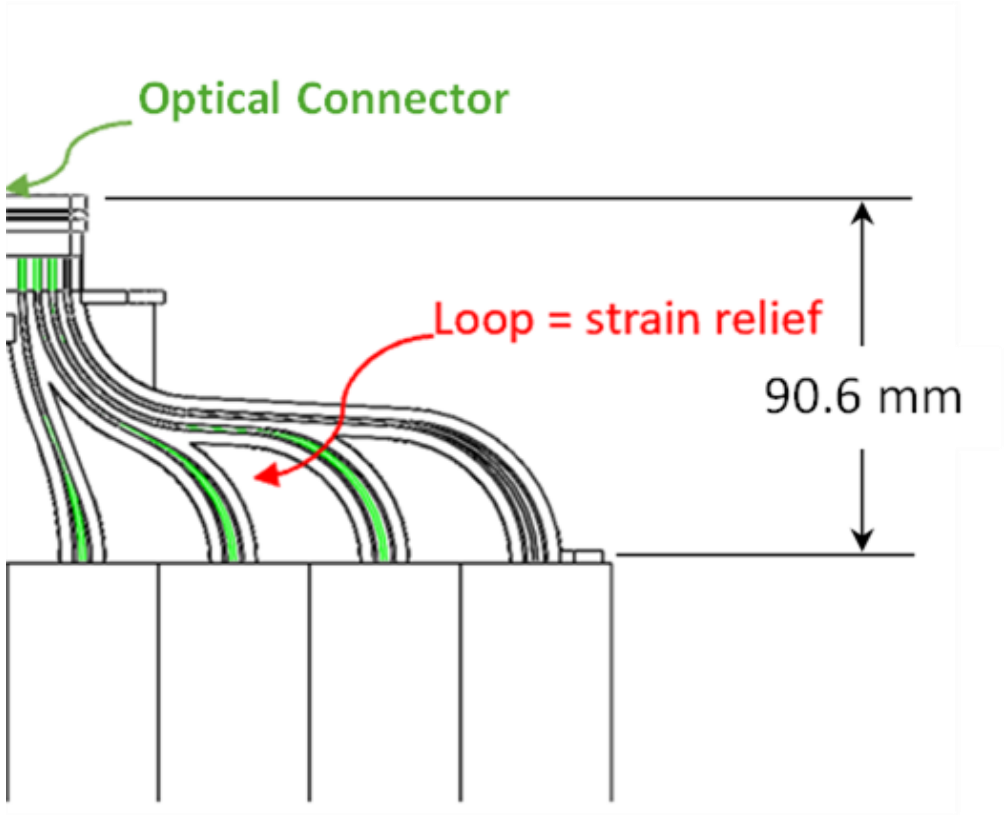
Bending Losses for d = 1.4 mm

Scaled for 1.4 mm

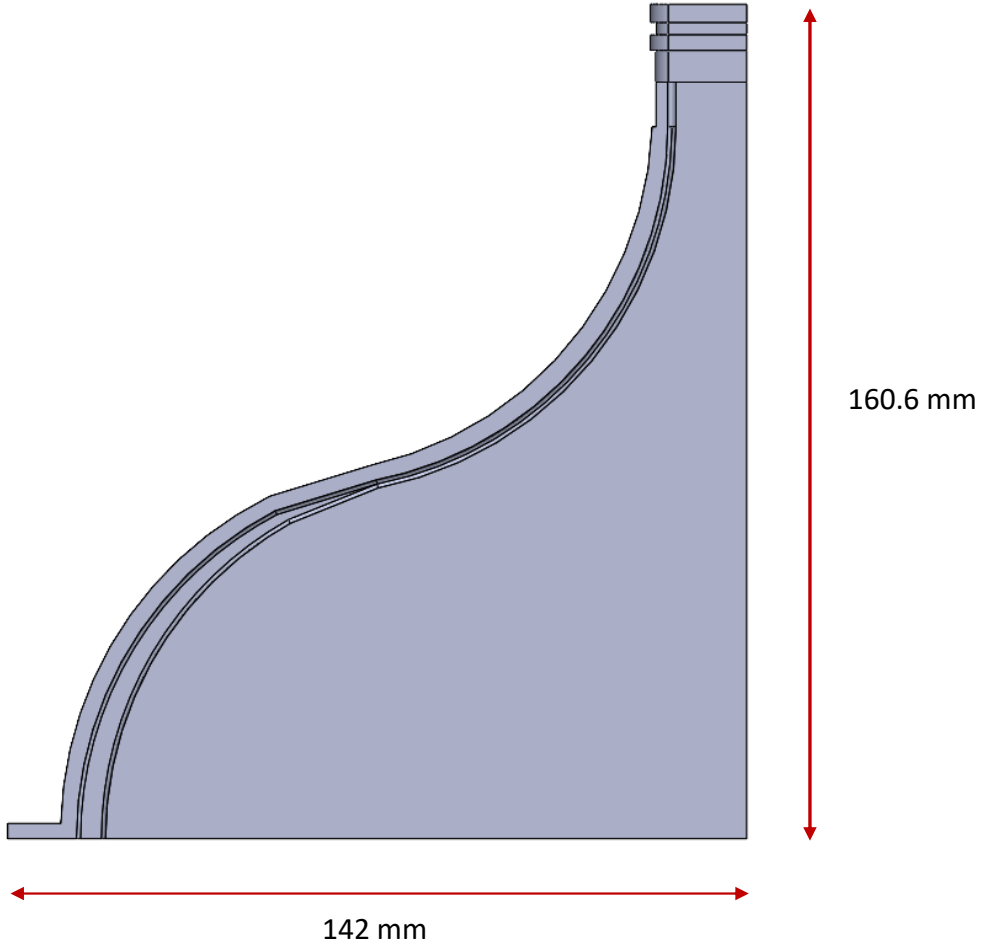


If we follow manufacturer recommendation

Current



Height following Recommendation



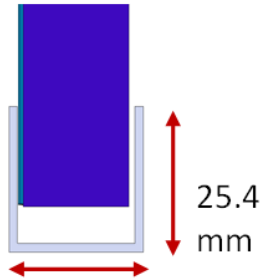
Cassette

The Cassette

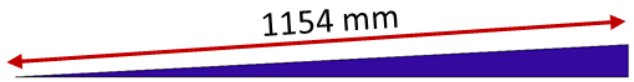
- Constrains 6 modules in desired orientation in X,Y plane
- Enables insertion and retraction between steel planes, and
- Holds output cables

Components:

- Bottom U-Channel
- Triangular Support Wedge (U/V only)
- UHMW-PE Tape for sliding surface
- Top L-Channel
- Cable Management and Extraction Mechanism

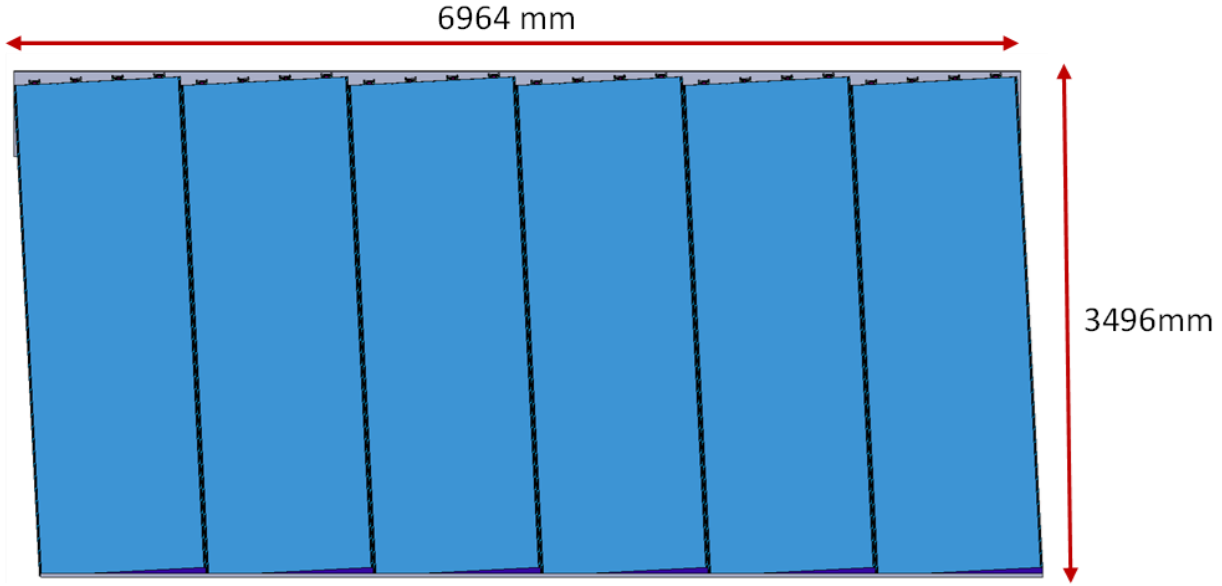


Bottom U-Channel



3° Wedge

Top L-Bracket

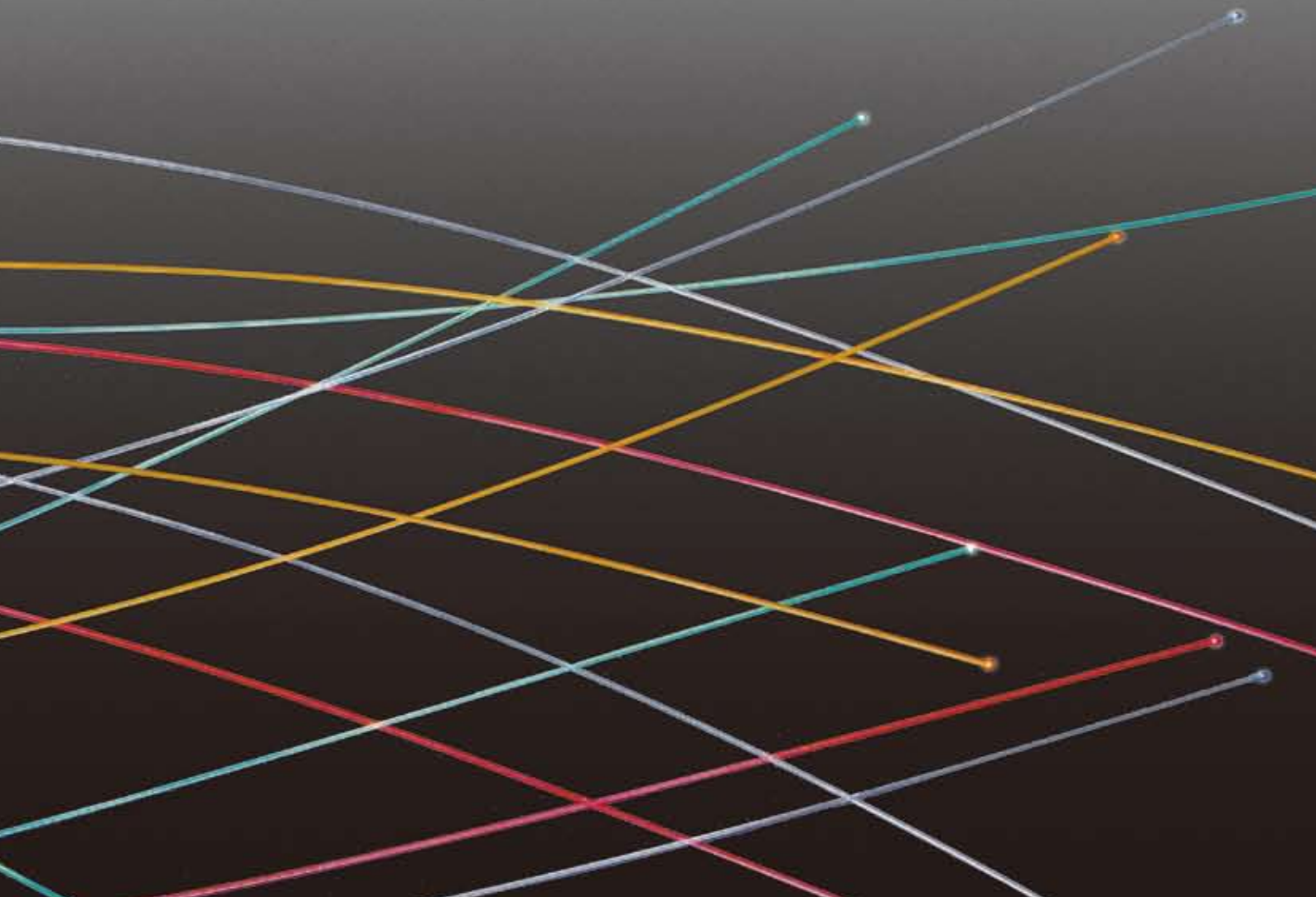


Assembled Cassette

kuraray

Plastic Scintillating Fibers

Scintillating Fibers
Wavelength Shifting Fibers
Clear Fibers



Kuraray's Plastic Scintillating Fibers

The history of Kuraray' s scintillating fiber dates back to1985,
we started to produce the plastic scintillating fibers.
Then wavelength shifting fibers and clear optical fibers
were put on the market in 1990.
Having excellent stability of properties, Kuraray' s plastic fibers
are trusted by many scientists and technical experts.
As a pioneer in the world, we developed
multi-cladding fibers which have 50% higher light yield
than previous single cladding fibers in 1993.
It is well-known that Multi-cladding fibers contributed
to improve the properties of fiber detectors
in the field of high energy physics.
Bundling several ㎛～several hundred ㎛ thin fibers together,
which we call multi-fiber was also developed in the past.

Kuraray's plastic fibers play an active part
not only in the scene of high energy physics, astrophysics,
but in the scene of atomic energy.
We hope to attract attention in the fields of medicine.
There is strong potential for new applications in the future.

This brochure presents only basic technical data.
If you have further questions, please let us know at any time.
We are looking forward to supporting your works and applications.

Index

How to Specify Fibers

In order to specify fibers, the following points must be clarified.

- Description
- Cross-section(Round or Square)
- Cladding(Single or Multi)
- Non-S type or S type
- Length and Dimension
- Cane or Spool
- Concentration of dye must be clarified in 3HF fiber and WLS fibers.

Examples of writing are as follows;

- SCSF-3HF(1500)M,1.0mmD., 2000m, BSJ

→Round fiber, Multi-cladding, S type, 1.0mm diameter, 2000m length. Fiber is put on spool, and the concentration of 3HF dye is 1500ppm.

- Y-11(200), 0.5mmD.,10000m BJ

→Round fiber, Single cladding, Non-S type, 0.5mm diameter, 10000m length. Fiber is put on spools, the concentration of WLS dye is 200ppm.

- Clear-PS, 0.83mmSQ., 3m, CSJ

→Square fiber, Single cladding, S type, 0.83mm square, 3m length cane.

How to indentify the fibers specifications

SCSF-	3HF	(1500)	M	1.00mm	D	2000m	B	S	J
Y	- 11	(200)		1.50mm	SQ	250m	C		J

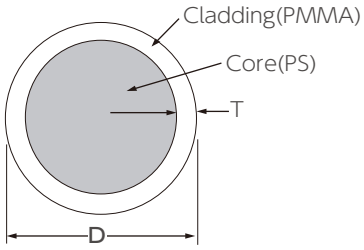
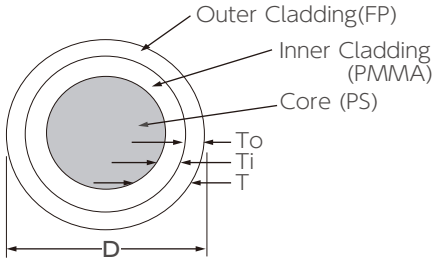
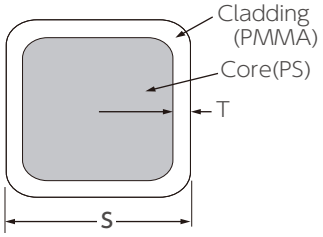
- J: High purity (all product)
- S: Type of polymer orientation of PS core
  - S: S type
  - No mark: Standard non-S type
- B/C: Delivery configuration
  - B: spool type
  - C: cane type
- 250m: Length of the fiber
- D/SQ: Shape of the fiber
  - D: Round fiber
  - SQ: Square fiber
- 1.00mm / 1.50mm: Diameter of the fiber
- M: Type of the cladding
  - M: Multi-cladding
  - No mark: Single cladding
- (1500) / (200): Concentration of the dye in ppm for 3HF scintillating and all wavelength shifting
- 3HF / 11: Grade of the fiber
  - Scintillating: 78, 81, 3HF
  - Wavelength shifting: 2, 3, 7, 8, 11
  - Clear: PS
- SCSF- / Y: Type of the fiber
  - Scintillating: SCSF
  - Wavelength shifting: Y, B, O, R
  - Clear: Clear-PS

Plastic Scintillating Fibers
- Materials and Structures -

Materials

		Materials	Refractive index	Density (g/cm^3)	No. of atom per cm^3
Core		Polystylene(PS)	n_D=1.59	1.05	C: 4.9×10^{22} H: 4.9×10^{22}
Cladding	for single cladding inner for multi-cladding	Polymethylmethacrylate (PMMA)	n_D=1.49	1.19	C: 3.6×10^{22} H: 5.7×10^{22} O: 1.4×10^{22}
	outer for multi-cladding	Fluorinated polymer (FP)	n_D=1.42	1.43	

Cross-section and Cladding Thickness

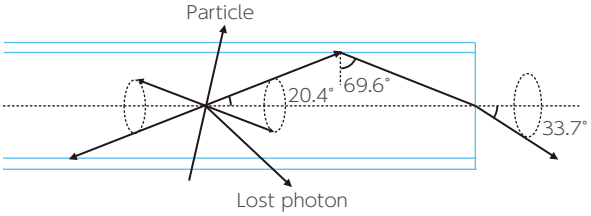
	Single Cladding	Multi-Cladding (M)
Round Fiber (D)	 Cladding Thickness[1]: T=2% of D Numerical Aperture: NA=0.55 Trapping Efficiency : 3.1%	 Cladding Thickness[2]: T=2%(To)+2%(Ti) =4% of D Numerical Aperture: NA=0.72 Trapping Efficiency : 5.4%
Square Fiber (SQ)	 Cladding Thickness : T=2% of S Numerical Aperture: NA=0.55 Trapping Efficiency : 4.2%	Not available

1) In some cases, cladding thickness T is 3% of D. 2) In some cases, cladding thickness T is 6% of D, To and Ti are both 3% of D.

Cladding and Transmission Mechanism

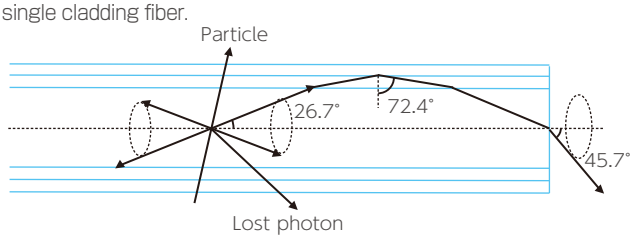
Single cladding

Single cladding fiber is standard type of cladding.



Multi-cladding

Multi-cladding fiber(M) has higher light yield than single cladding fiber because of large trapping efficiency.
Clear-PS fiber of this cladding has extremely higher NA than conventional PMMA or PS fiber, and very useful as light guide fiber.
Multi-cladding fiber has long attenuation length equal to single cladding fiber.



Materials / Structures

Type of Polymer Orientation of PS Core

Standard type (Non-S type)
PS core is almost no oriented polystyrene chain and is optically isotropic and very transparent.
This conventional standard type has good attenuation length, but it shows weakness against clacking caused by bending or handling during assembling.

S type (S)
Core has molecular orientation along drawing direction.
This fiber is mechanically stronger against clacking at the cost of transparency.
The attenuation length of this type is nearly 10% shorter than standard type.

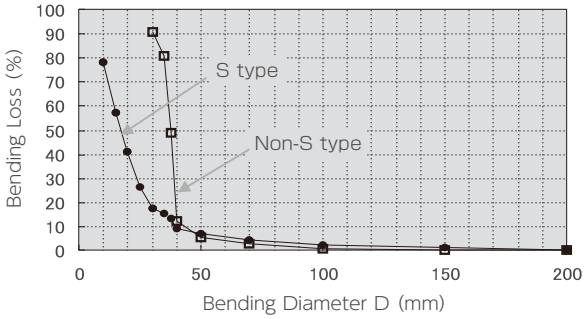
Dimensions and Tolerance

Cross-sectional Dimension
Minimum : 0.2mm
Maximum : 2.0mm, typically as follows.
Round (Single and Multi-Cladding) :
0.2, 0.5, 1.0, 1.5, 2.0mm dia.
Square (Single Cladding) :
0.2x0.2, 0.5x0.5, 1.0x1.0, 2.0x2.0mm side

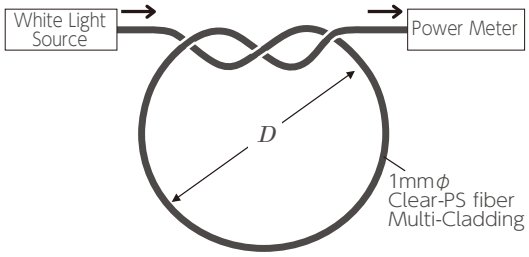
Tolerance of Diameter
Cut Fiber (1-5m long) :
$\left|\frac{\Delta D}{\bar{D}}\right| < 2.0\%$ for round fiber
$\left|\frac{\Delta S}{\bar{S}}\right| < 3.0\%$ for square fiber
Endless Spool Fiber :
$\frac{3\sigma}{\bar{D}} < 2.5\%$ (σ: rms, Spool Dia. : 900mm)

Bending Loss and Minimum Bending Diameter

Bending Loss
The following figure shows bending loss of Clear-PSM and Clear-PSMS.
S type is better than Non-S type.
The rapid increase of bending loss of non-S type is due to cracking of core.
S type does not show such cracking.



Measurement Method



Minimum Bending Diameter

We recommend minimum bending diameter as the following table on safety side and long term reliability.

Type	2mmΦ Fiber	1mmΦ Fiber	0.5mmΦ Fiber
S type	200mm	100mm	50mm
Non-S type	400mm	200mm	100mm

Scintillating Fibers

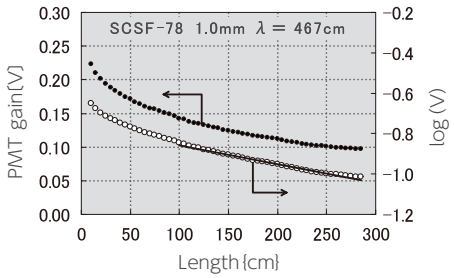
Formulations[1)]

Description	Emission			Decay Time [ns]	Att.Leng.[2)] [m]	Characteristics
	Color	Spectra	Peak[nm]			
SCSF-78	blue	See the following figure	450	2.8	>4.0	Long Att. Length and High Light Yield
SCSF-81	blue		437	2.4	>3.5	Long Attenuation Length
SCSF-3HF(1500)	green		530	7	>4.5	3HF formulation for Radiation Hardness

1) Test fibers are Non-S type, 1mmϕ.
2) Measured by using bialkali PMT and UV light(254nm).
Quality control is made by another measurement of the transmission loss every batch.

Attenuation Length Measurement

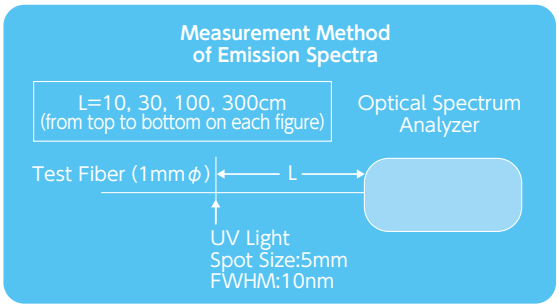
We routinely measure attenuation length by 3m fiber sample for all production.
The attenuation curve (for example) in the figure is approximated by the one exponential expression $I(x)=I_0\exp(-\frac{x}{\lambda})$ except very near distance. The attenuation length λ is calculated using the data between x=100cm and x=300cm.



About "Export Trade Control Order"

The scintillating fiber is assigned in article 1 of the Export Trade Control Order as undermining the maintenance of international peace and safety.
To export this item, an approval of the Minister of Economy, Trade and Industry of Japan is required, so we need to confirm the end user and application for each sales.
We may sell the fibers to you, but we would have to check and confirm the end user and application everytime we have an inquiry from you, and we may not be able to accept some inquiries depending on the end user and application,

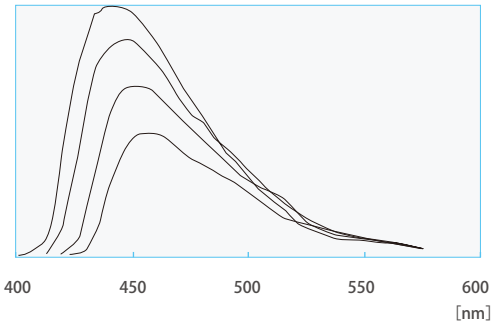
SCSF-78 / SCSF-81 / SCSF-3HF(1500)



Technical Data

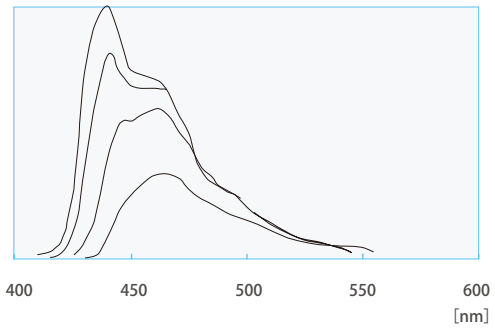
Emission Spectra

SCSF-78



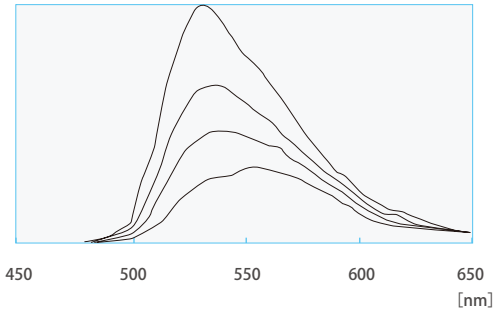
Exiting Wavelength:350nm

SCSF-81



Exiting Wavelength:370nm

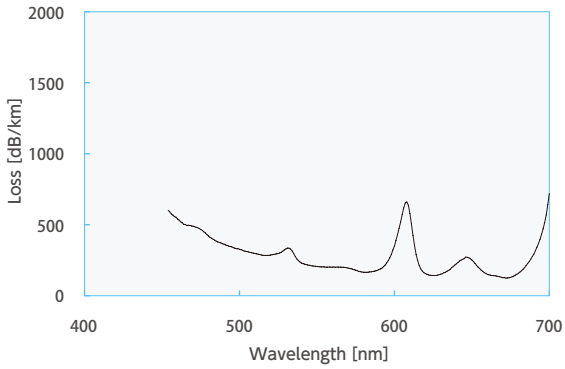
SCSF-3HF(1500)



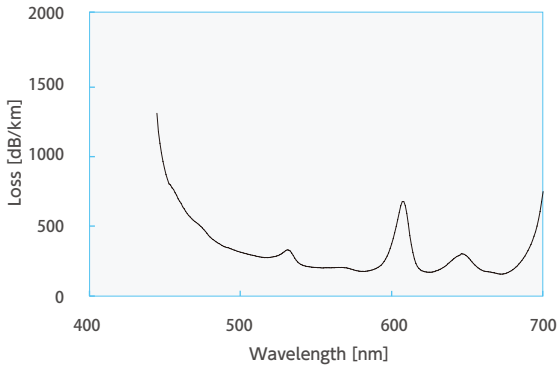
Exiting Wavelength:340nm

Transmission Loss

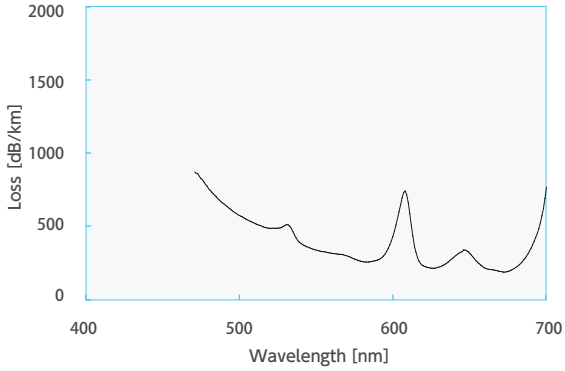
SCSF-78



SCSF-81



SCSF-3HF(1500)

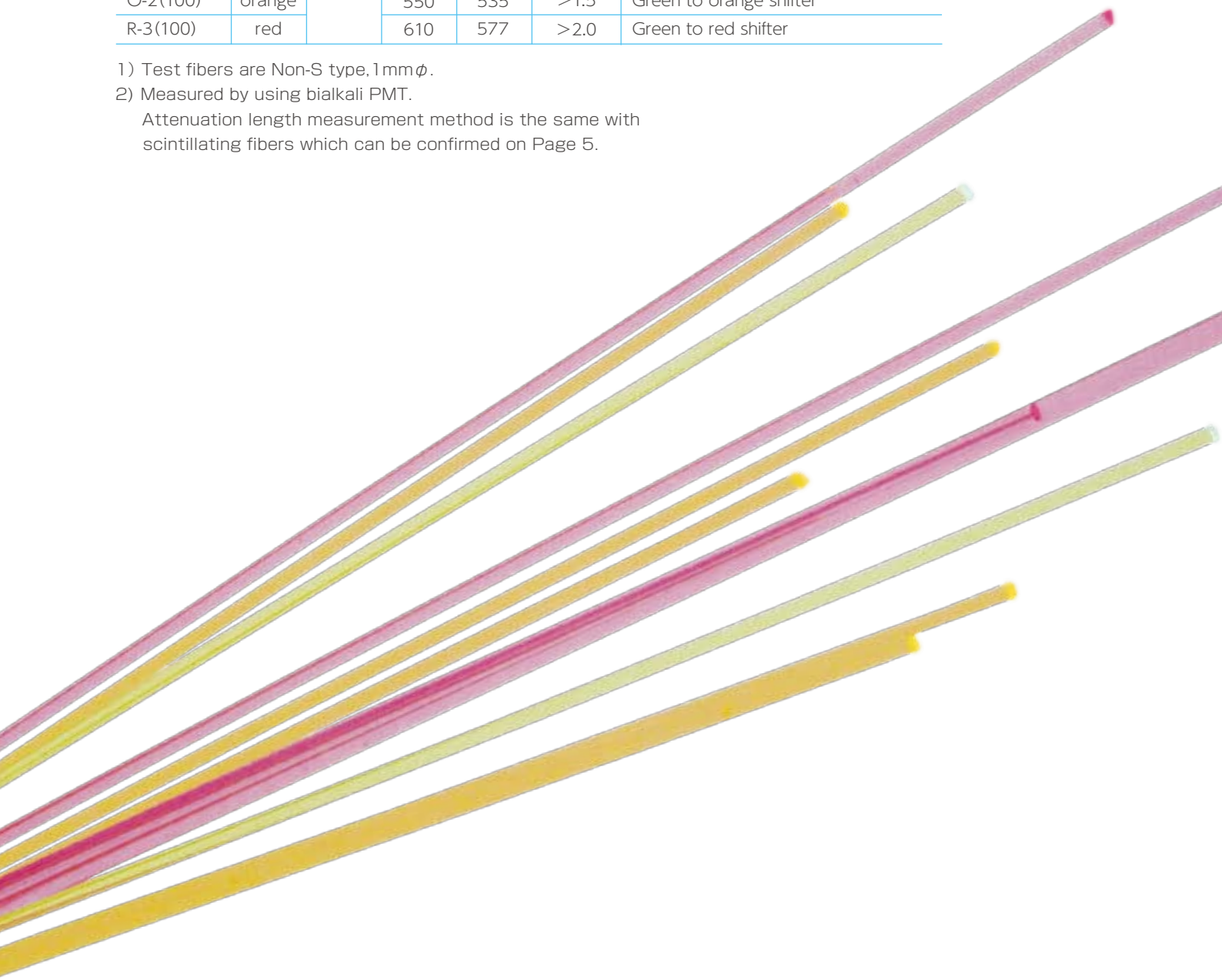


Wavelength Shifting Fibers

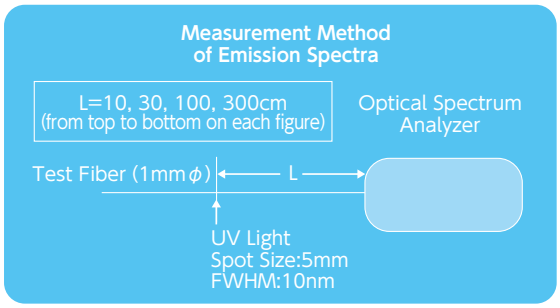
Formulations [1)]

Description	Emission			Absorption Peak[nm]	Att.Leng.[2)] [m]	Characteristics
	Color	Spectra	Peak[nm]			
Y-7(100)	green	See the following figure	490	439	>2.8	Blue to Green Shifter
Y-8(100)	green		511	455	>3.0	Blue to Green Shifter
Y-11(200)	green		476	430	>3.5	Blue to Green Shifter (K-27 formulation) Long Attenuation Length and High Light Yield
B-2(200)	blue		437	375	>3.5	UV to Blue shifter
B-3(200)	blue		450	351	>4.0	UV to Blue shifter
O-2(100)	orange		550	535	>1.5	Green to orange shifter
R-3(100)	red		610	577	>2.0	Green to red shifter

1) Test fibers are Non-S type, 1mmϕ.
2) Measured by using bialkali PMT.
Attenuation length measurement method is the same with scintillating fibers which can be confirmed on Page 5.



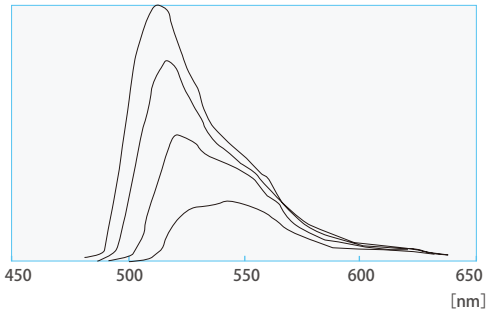
Y-7(100) / Y-8(150) / Y-11(200)
B-2(200) / B-3(200) / O-2(100)



Technical Data

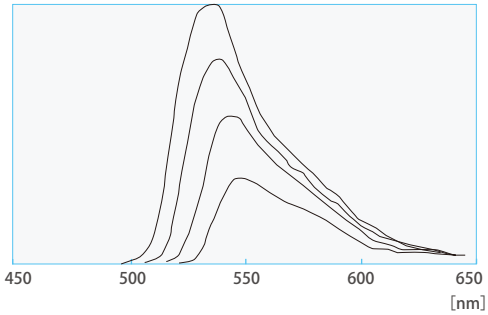
Emission Spectra

Y-7(100)



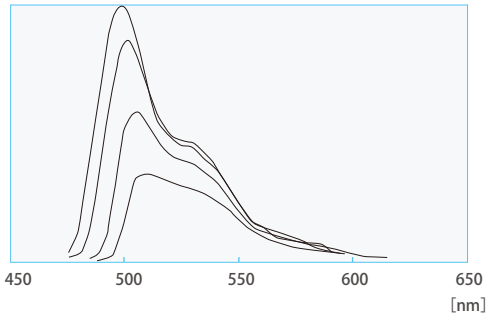
Exiting Wavelength:440nm

Y-8(150)



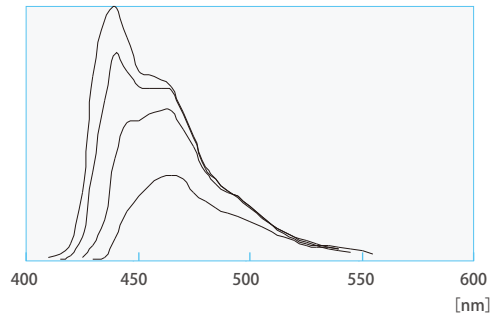
Exiting Wavelength:455nm

Y-11(200)



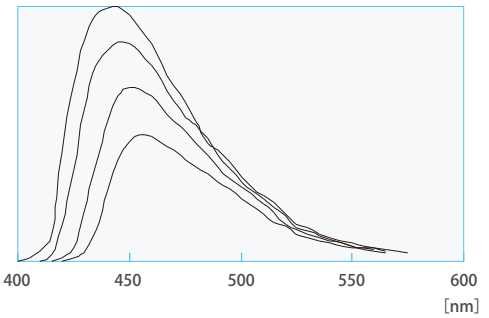
Exiting Wavelength:430nm

B-2(200)



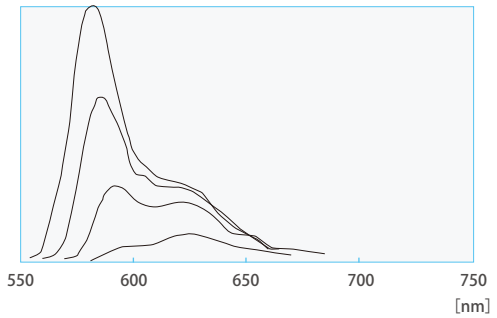
Exiting Wavelength:430nm

B-3(200)



Exiting Wavelength:430nm

O-2(100)



Exiting Wavelength:430nm

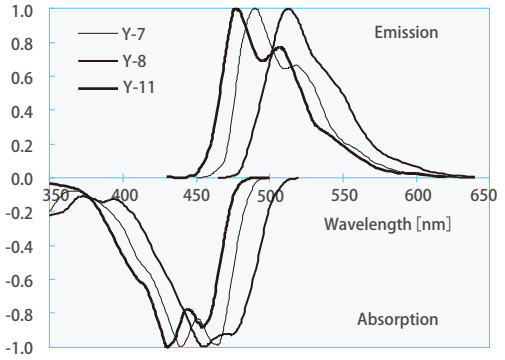
Wavelength Shifting Fibers

Y-7 / Y-8 / Y-11 / B-2 / B-3 / O-2 / R-3

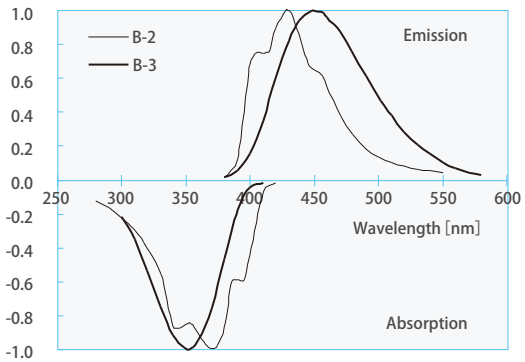
Technical Data

Absorption and Emission Spectra

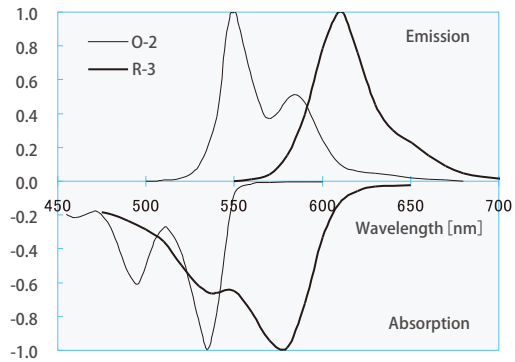
Y-7, Y-8, Y-11



B-2, B-3

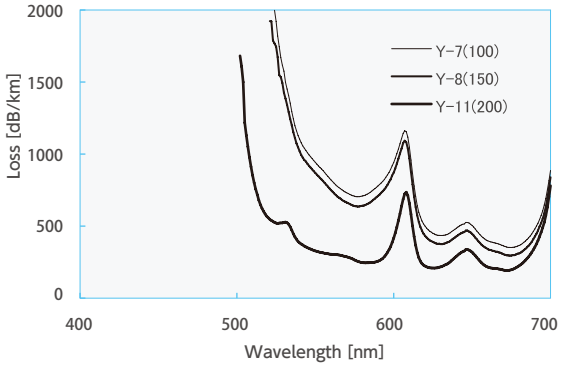


O-2, R-3

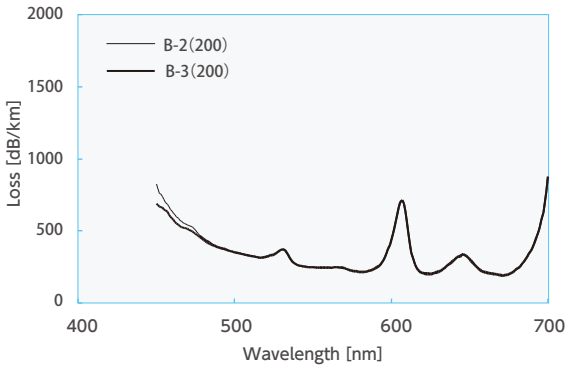


Transmission Loss

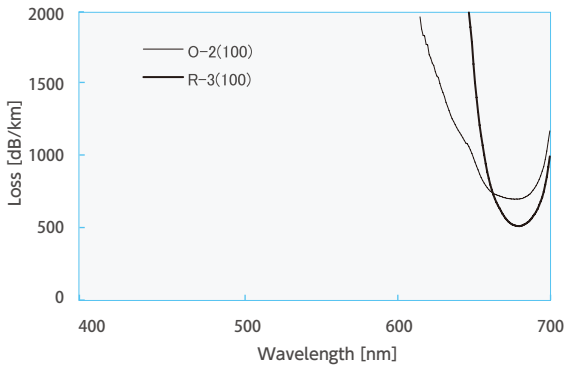
Y-7, Y-8, Y-11



B-2, B-3



O-2, R-3



Clear Fibers

Clear-PS

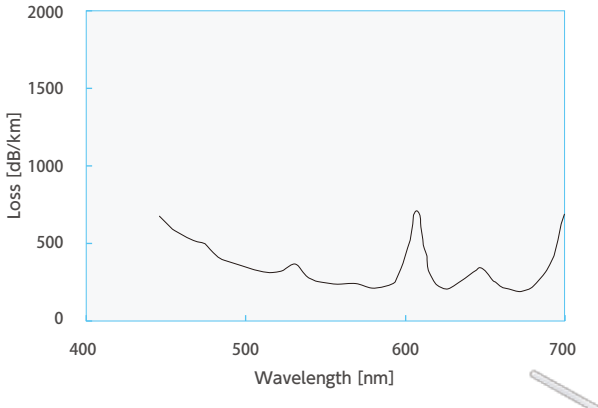
Formulations [1)]

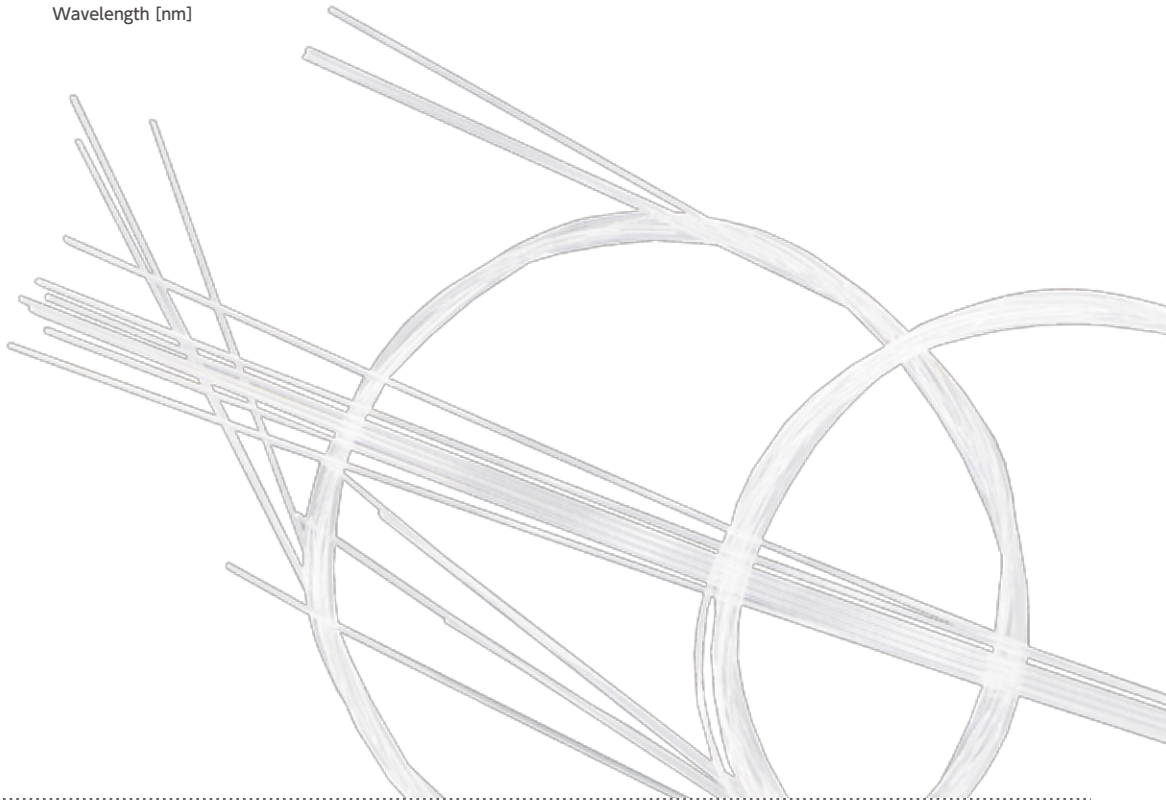
Description	Emission			Att.Leng. [m]	Characteristics
	Color	Spectra	Peak[nm]		
Clear-PS	—	—	—	>10	depend on wavelength

1) Test fibers are Non-S type, 1mmϕ.

Technical Data

Transmission Loss





All data presented herein is based on actual measurements performed by Kuraray Co., Ltd.
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