Kuraray’s Plastic Scintillating Fibers

The history of Kuraray’s scintillating fiber dates back to 1985, when 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 μm—several hundred μm 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.

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Scintillating Fibers - P5-6
Wavelength Shifting Fibers - P7-9
Clear Fibers - P10

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
- Core or Spoke
- Concentration of dye must be clarified in 3HF fiber and MLS fibers.

Examples of writing are as follows:

- SCSF-3HF (1500M) (2mm), 2000m, BSJ
- Round fiber, Multi-cladding, S type, 1.0mm diameter, 2000m length, Fiber is put on spot, and the concentration of 3HF dye is 1500ppm
- S-1 (100), 0.5mm, 10000m BSJ
- Round fiber, Single cladding, Non-S type, 0.5mm diameter, 10000m length, Fiber is put on spot, the concentration of MLS dye is 2000ppm.
- Clear/BS: 0.83mm square, 3m, BSJ
- Scattering fiber, Single cladding, S type, 0.83mm square, 3m length cable.

How to identify the fibers specifications

<table>
<thead>
<tr>
<th>Type of fiber</th>
<th>Diameter</th>
<th>Length (m)</th>
<th>Core Type</th>
<th>Spoke Type</th>
<th>Concentration of dye (ppm)</th>
<th>Diameter (μm)</th>
<th>Diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3HF</td>
<td>1.0</td>
<td>2000</td>
<td>S</td>
<td>BS</td>
<td>1500</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>MLS</td>
<td>0.5</td>
<td>10000</td>
<td>S</td>
<td>BS</td>
<td>2000</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Scattering</td>
<td>0.5</td>
<td>3000</td>
<td>S</td>
<td>BS</td>
<td>800</td>
<td>0.83</td>
<td>0.83</td>
</tr>
</tbody>
</table>

Plastic Scintillating Fibers

<table>
<thead>
<tr>
<th>Type of fiber</th>
<th>Diameter</th>
<th>Length (m)</th>
<th>Core Type</th>
<th>Spoke Type</th>
<th>Concentration of dye (ppm)</th>
<th>Diameter (μm)</th>
<th>Diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3HF</td>
<td>1.0</td>
<td>2000</td>
<td>S</td>
<td>BS</td>
<td>1500</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>MLS</td>
<td>0.5</td>
<td>10000</td>
<td>S</td>
<td>BS</td>
<td>2000</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Scattering</td>
<td>0.5</td>
<td>3000</td>
<td>S</td>
<td>BS</td>
<td>800</td>
<td>0.83</td>
<td>0.83</td>
</tr>
</tbody>
</table>
Kuraray’s Plastic Scintillating Fibers

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Bundling several μm—several hundred μm thin fibers together, which we call multi-fiber was also developed in the past.

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- Description
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- Cladding (Single or Multi)
- Non-S type or S type
- Length and Dimension
- Core or Splice
- Concentration of dye must be clarified in 3HF fiber and MLS fibers.

Examples of writing are as follows:

- SCFF3HF (1500μm) 0.9mm, 2000m, Blady
- Round fiber, Multi-cladding, S type, 1.0mm diameter, 2000m length, Fiber is put on spot, and the concentration of 3HF dye is 1500ppm.
- X-1(200), 0.5mm diameter, 10000m length, Round fiber, Single cladding, Non-S type, 0.5mm diameter, 10000m length, Fiber is put on spot, the concentration of MLS dye is 2000ppm.
- Clear/Bl: 0.83mm(6), 3m, CSU
- Glassy fiber, Single cladding, S type, 0.83mm square, 3m length core.

How to Identify the fibers specifications

SCFF 3HF (1500μm) 0.9mm D 2000mm B S J

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Scintillating Fibers — P5-6

Wavelength Shifting Fibers — P7-9

Clear Fibers — P10
Plastic Scintillating Fibers
- Materials and Structures -

### Materials

<table>
<thead>
<tr>
<th></th>
<th>Materials</th>
<th>Refractive Index</th>
<th>Density (g/cm³)</th>
<th>No. of atom per cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>Polyethylene (PE)</td>
<td>1.59</td>
<td>1.05</td>
<td>4.9 x 10²⁰</td>
</tr>
<tr>
<td>Cladding</td>
<td>Single cladding</td>
<td>1.49</td>
<td>1.19</td>
<td>3.8 x 10²⁰</td>
</tr>
<tr>
<td></td>
<td>for multi-cladding</td>
<td>1.43</td>
<td>1.41</td>
<td>3.7 x 10²⁰</td>
</tr>
</tbody>
</table>

### Cross-section and Cladding Thickness

#### Single Cladding

- Cladding Thickness: T = 2% of D
- Numerical Aperture: NA = 0.65
- Trapping Efficiency: 3.1%

#### Multi-Cladding (2)

- Cladding Thickness: T = 2% of D
- Numerical Aperture: NA = 0.65
- Trapping Efficiency: 3.4%

### 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 cracking caused by bending or handling during assembling.

**B type (B)**:
Core has molecular orientation along drawing direction. This fiber is mechanically stronger against cracking at the cost of transparency.
The attenuation length of this type is nearly 1.0% shorter than standard type.

### Dimensions and Tolerance

**Cross-sectional Dimension**
- Minimum: 0.20mm
- Maximum: 2.00mm, typically as follows.
  - Round (Single and Multi-Cladding): 0.2, 0.5, 1.0, 1.5, 2.0mm dia.
  - Square (Single Cladding): 0.2 x 0.2, 0.5 x 0.5, 1.0 x 1.0, 2.0 x 2.0mm side

**Tolerance of Diameter**
- Cut Fiber (1.5m long):
  - ±0.20% for round fiber
  - ±0.30% for square fiber
- Endpless Spool Fiber:
  - ±0.25% (φ ±0.25mm, Spool Dia.: 900mm)

### Bending Loss and Minimum Bending Diameter

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

### Cladding and Transmission Mechanism

**Single cladding**
- Single cladding fiber is standard type of cladding.

**Multi-cladding**
- Multi-cladding fiber has higher light yield than single cladding fiber because of large trapping efficiency.
- Clear-PS fiber of this cladding has extremely high 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.

### Measurement Method

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

<table>
<thead>
<tr>
<th>Type</th>
<th>2mmΦ Fiber</th>
<th>1mmΦ Fiber</th>
<th>0.5mmΦ Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>S type</td>
<td>200mm</td>
<td>100mm</td>
<td>50mm</td>
</tr>
<tr>
<td>Non-S type</td>
<td>400mm</td>
<td>200mm</td>
<td>100mm</td>
</tr>
</tbody>
</table>
Plastic Scintillating Fibers
- Materials and Structures -

### Materials

<table>
<thead>
<tr>
<th></th>
<th>Materials</th>
<th>Refractive Index</th>
<th>Density (g/cm³)</th>
<th>No. of atom per 10³ cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>Polystyrene (PS)</td>
<td>n = 1.59</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>Cladding</td>
<td>for single cladding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>for multi-cladding</td>
<td>Polyethylene terephthalate (PET)</td>
<td>1.49</td>
<td>1.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fluorinated polymer (FP)</td>
<td>1.42</td>
<td>1.43</td>
</tr>
</tbody>
</table>

### Cross-section and Cladding Thickness

- **Round Fiber (D)**
  - Cladding Thickness: T = 2% of D
  - Numerical Aperture: NA = 0.55
  - Trapping Efficiency: 3.1%

- **Square Fiber (S)**
  - Cladding Thickness: T = 2% of S
  - Numerical Aperture: NA = 0.55
  - Trapping Efficiency: 3.4%

- **Not available**

#### Cladding and Transmission Mechanism

- **Single-cladding**
  - Single-cladding fiber is a standard type of cladding.

- **Multi-cladding**
  - Multi-cladding fiber is higher light yield than single cladding fiber because of large trapping efficiency.
  - Clear PS fiber of this cladding has extremely high 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.

#### 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.

- **B type (S)**
  - Core has molecular orientation along drawing direction.
  - This fiber is mechanically stronger against clacking at the cost of transparency.

#### Dimensions and Tolerance

- **Cross-sectional Dimension**
  - Minimum: 0.20mm
  - 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

- **Endless Spool Fiber**
  - ≤ 2.5% (at m/s, Spool Dia.: 900mm)

#### Bending Loss and Minimum Bending Diameter

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

- **Measurement Method**
  - 17mm² Clear-PSM fiber
  - Multi-Cladding

#### Minimum Bending Diameter

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

<table>
<thead>
<tr>
<th>Type</th>
<th>2mm² Fiber</th>
<th>1mm² Fiber</th>
<th>0.5mm² Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>S type</td>
<td>200mm</td>
<td>100mm</td>
<td>50mm</td>
</tr>
<tr>
<td>Non-S type</td>
<td>400mm</td>
<td>200mm</td>
<td>100mm</td>
</tr>
</tbody>
</table>
Scintillating Fibers

Formulations

<table>
<thead>
<tr>
<th>Description</th>
<th>Emission Color</th>
<th>Emission Spectrum Position</th>
<th>Decay Time (ms)</th>
<th>Attenuation Length (cm)</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCSF-7B</td>
<td>blue</td>
<td>See the following figure</td>
<td>4.50</td>
<td>2.8</td>
<td>Long Att. Length and High Light Yield</td>
</tr>
<tr>
<td>SCSF-B1</td>
<td>blue</td>
<td>See the following figure</td>
<td>4.37</td>
<td>2.4</td>
<td>Long Attenuation Length</td>
</tr>
<tr>
<td>SCSF-BHF(1500)</td>
<td>green</td>
<td></td>
<td>5.30</td>
<td>7</td>
<td>H-F formulation for Radiation Hardness</td>
</tr>
</tbody>
</table>

1) Test fibers are Non-H type 1mm.  
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  
\[ A(x) = A_0 e^{-x/L} \]  
except very near distance. The attenuation length \( L \) is calculated using the data between \( x=100 \text{cm} \) and \( x=300 \text{cm} \).

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 Ministry of Economy, Trade and Industry of Japan is required,  
so we need to confirm the end user and application for each sale.  
We may sell the fibers to you, but we would have to check and confirm the end user and application every time we have an inquiry from you, and we may not be able to accept some inquiries depending on the end user and application.
Scintillating Fibers

Formulations

<table>
<thead>
<tr>
<th>Description</th>
<th>Emission Color</th>
<th>Emission Spectrum Position (nm)</th>
<th>Decay Time (ms)</th>
<th>Attenuation Length (cm)</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCSF-7B</td>
<td>blue</td>
<td>See the following figure</td>
<td>450</td>
<td>2.8</td>
<td>Long Att. Length and High Light Yield</td>
</tr>
<tr>
<td>SCSF-81</td>
<td>blue</td>
<td></td>
<td>437</td>
<td>2.4</td>
<td>Long Attenuation Length</td>
</tr>
<tr>
<td>SCSF-3HF(1500)</td>
<td>green</td>
<td></td>
<td>530</td>
<td>7</td>
<td>3HF Formulation for Radiation Hardness</td>
</tr>
</tbody>
</table>

1) Test fibers are Non-line type. 1mm.
2) Measured by using bialkali PMT and UVA 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

\( A(x) = A_0 \cdot e^{-x/x_0} \)

where \( x \) represents the distance. The attenuation length \( x_0 \) is calculated using the data between \( x = 100cm \) and \( x = 300cm \).

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SCSF-7B / SCSF-81 / SCSF-3HF(1500)

**Technical Data**

**Emission Spectra**

**Transmission Loss**

Measurement Method of Emission Spectra

- L=10, 30, 100, 300cm
- PMT to bottom of each fiber
- Optical Spectrum Analyzer
- UV Light: 340~600nm
- Power: 100mW
Wavelength Shifting Fibers

Formulations

<table>
<thead>
<tr>
<th>Description</th>
<th>Color</th>
<th>Emission Spectra Peak (nm)</th>
<th>Excitation Peak (nm)</th>
<th>Attenuation Length (m)</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-7(100)</td>
<td>green</td>
<td>490</td>
<td>439</td>
<td>&gt;3.0</td>
<td>Blue to Green Shifter</td>
</tr>
<tr>
<td>Y-7(100)</td>
<td>green</td>
<td>511</td>
<td>455</td>
<td>&gt;3.0</td>
<td>Blue to Green Shifter</td>
</tr>
<tr>
<td>Y-11(200)</td>
<td>green</td>
<td>See the following figure</td>
<td></td>
<td></td>
<td>Blue to Green Shifter (K-27 formulation)</td>
</tr>
<tr>
<td>B-2(200)</td>
<td>blue</td>
<td>437</td>
<td>375</td>
<td>&gt;3.5</td>
<td>UV to Blue Shifter</td>
</tr>
<tr>
<td>B-3(200)</td>
<td>blue</td>
<td>450</td>
<td>351</td>
<td>&gt;4.0</td>
<td>UV to Blue Shifter</td>
</tr>
<tr>
<td>O-2(100)</td>
<td>orange</td>
<td>555</td>
<td>535</td>
<td>&gt;1.5</td>
<td>Green to orange Shifter</td>
</tr>
<tr>
<td>R-3(100)</td>
<td>red</td>
<td>610</td>
<td>577</td>
<td>&gt;2.0</td>
<td>Green to red Shifter</td>
</tr>
</tbody>
</table>

1) Test fibers are Non-5 type, 1.0mm.
2) Measured by using bi-axial PMT.
3) Attenuation length measurement method is the same with scintillating fibers which can be confirmed on Page 5.

Technical Data

Emission Spectra

Y-7(100)

Y-8(150)

Y-11(200)

B-2(200)

B-3(200)

O-2(100)
# Wavelength Shifting Fibers

<table>
<thead>
<tr>
<th>Description</th>
<th>Color</th>
<th>Emission Peak(㎜)</th>
<th>Absorption Peak(㎜)</th>
<th>Attenuation Length (m)</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-7(100)</td>
<td>green</td>
<td>490</td>
<td>455</td>
<td>&gt;3.0</td>
<td>Blue to Green Shifter</td>
</tr>
<tr>
<td>Y-4(100)</td>
<td>green</td>
<td>517</td>
<td>455</td>
<td>&gt;3.0</td>
<td>Blue to Green Shifter</td>
</tr>
<tr>
<td>Y-11(200)</td>
<td>green</td>
<td>See the following figure</td>
<td>476</td>
<td>430</td>
<td>&gt;3.5</td>
</tr>
<tr>
<td>B-2(200)</td>
<td>blue</td>
<td>437</td>
<td>375</td>
<td>&gt;3.5</td>
<td>UV to Blue shifter</td>
</tr>
<tr>
<td>B-3(200)</td>
<td>blue</td>
<td>450</td>
<td>351</td>
<td>&gt;4.0</td>
<td>UV to Blue shifter</td>
</tr>
<tr>
<td>O-2(1000)</td>
<td>orange</td>
<td>550</td>
<td>535</td>
<td>&gt;1.5</td>
<td>Green to orange shifter</td>
</tr>
<tr>
<td>R-3(100)</td>
<td>red</td>
<td>610</td>
<td>577</td>
<td>&gt;2.0</td>
<td>Green to red shifter</td>
</tr>
</tbody>
</table>

1) Test fibers are Non-S type 1.6mm.
2) Measured by using bi-alkal PMT.

Attenuation length measurement method is the same with scintillating fibers which can be confirmed on Page 15.

---

### Technical Data

#### Emission Spectra

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

---

**Measurement Method**

- Optical Spectrum Analyzer
- Test Fiber (Ωmm)
- UV Light (400±20nm)
Clear Fibers

Technical Data

Absorption and Emission Spectra

Transmission Loss

Formulations

<table>
<thead>
<tr>
<th>Description</th>
<th>Color</th>
<th>Emission Spectra</th>
<th>Peak (nm)</th>
<th>Act. FT (m²/°)</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear-PS</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>&gt; 10, depend on wavelength</td>
</tr>
</tbody>
</table>

1) Text fibers are Non-5 type, 1mm.ρ.

Technical Data

Transmission Loss

All data presented herein is based on actual measurements performed by Kuraray Co., Ltd.
Kuraray Co., Ltd. accepts no liability for damage or loss resulting from the use or misuse of this information.
Clear Fibers

Technical Data

Absorption and Emission Spectra

Y-7, Y-8, Y-11

B-2, B-3

O-2, R-3

Transmission Loss

Formulations

<table>
<thead>
<tr>
<th>Description</th>
<th>Color</th>
<th>Emission Spectrum</th>
<th>Peak</th>
<th>Actinic%</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear-PS</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>&gt;10</td>
<td>depend on wavelength</td>
</tr>
</tbody>
</table>

1) Test fibers are Non-S type, 1mm.φ.

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