

## A2. Light Source

The important prerequisite for the success of a radiation experiment is to properly understand the properties of each type of light source. The present document is part of the "SPring-8 Insertion Device Handbook '96" which will aid in the process. A brief overview of the light intensity units, which are quite elementary but are crucial for the understanding of light sources, and attached figures are given below.

### (i) Units of light intensity

SPring-8 is a third-generation synchrotron radiation facility, in which the insertion devices (especially the undulators) have been optimized to yield maximum "brightness." As is well known, "brightness" is one possible measure of light intensity. Other units used are "(angular) photon flux density" and "flux," but it should be noted that these units are often confused. Therefore, the definitions of the above units will be reviewed.

#### **Brilliance (Europe) or Brightness (U.S.A.)**

The commonly used unit of this quantity is photons/sec/mm<sup>2</sup>/mrad<sup>2</sup> in 0.1% b.w. The unit corresponds to the flux density in six-dimensional phase space, and is the number of photons per unit surface area of the light source, per unit solid angle (mrad<sup>2</sup>), per 0.1% relative bandwidth, per unit time (seconds). This quantity is purely an expression of density and not of the total number of photons! Optical matching can be performed (e.g., an image of the light source can be formed at the aperture of the optical system by mirror collimation), and the aperture (surface area / solid angle) of the optical system is narrower than the size/angular dispersion of the light beam imaged at the same position in optical systems which benefit from high brightness.

#### **(Angular) Photon Flux Density**

The commonly used unit is photons/sec/mrad<sup>2</sup> in 0.1% b.w., corresponding to the number of photons per unit solid angle (mrad<sup>2</sup>), per 0.1% relative bandwidth, per unit time (seconds). Note that this quantity is also a density. In optical systems which benefit from having a higher photon flux density than brightness, optical matching cannot be performed, and the aperture (solid angle) of the optical system is narrower than the light beam angular divergence. In the SPring-8 X-ray optical systems, optical matching generally cannot be performed, thus the photon flux density is more important than the brightness.

#### **Flux**

The commonly used unit is photons/sec in 0.1% b.w., corresponding to the number of photons obtained in unit time (seconds) in a limited range of solid angles (on the aperture and sample of the optical system) per 0.1% relative bandwidth. The photon flux over all solid angles ( $4\pi$ ) is called the total flux. Optical systems which benefit from having higher total flux than brightness or photon flux density have a wider optical system aperture (solid angle) than any angular divergence of the light source.

Let us compare the performance of each type of light sources (deflector, wiggler, and undulator types) using each of the above units. In a comparison of the brightness and photon flux densities, the undulator type unquestionably ranks first. The wiggler type is one-hundredth of the undulator, and the bending magnet type is one-hundredth of the wiggler. There are almost no differences between the light source types in the total flux performance.

Improved performance of the accelerator (storage ring), assuming that the emittance, beam energy, and current are held stationary, will affect the brightness characteristics than the photon flux density characteristics. Naturally, it has no effect on the total flux characteristics. Also, the effect varies for different types of light sources. In the undulator type, the brightness and photon flux density improve, and the total flux alone remains unchanged. On the other hand, in wiggler and bending magnet types, the brightness may increase slightly (since the beam size decreases) while the photon flux density and total flux remain constant.

## (ii) Beam size and divergence

The size and divergence of the photon beam emitted from the light source is obtained as a convolution between the electron beam size  $\Sigma_{x,y}$  (divergence,  $\Sigma_{x',y'}$ ) and the photon beam size  $\sigma_r$  (divergence,  $\sigma_{r'}$ ) emitted by a single electron.  $\sigma_r$  ( $\sigma_{r'}$ ) is a function of the photon energy and the characteristics of the light source such as the type, length and magnetic field. The electron beam size and divergence at the SPring-8 are shown in Appendix A1.

## (iii) Attached figures

The figure is explained using the standard beamline (in-vacuum undulator) as an example. The results are calculated with the electron beam parameters of the low emittance operation. The light source performance at the fundamental, third order, and fifth order harmonic wavelengths are shown in the figure. For example, consider the case where the fundamental wavelength is used to extract light of 10 keV at a resolution of  $10^4$ . Let the aperture of the optical system to be  $50 \times 50 \mu\text{rad}^2$ . This solid angle is compatible with the aperture size of  $2 \times 2 \text{ mm}^2$  of a monochromator placed 40 meter away from the light source. It can be seen from the figure (bottom) that a brilliance of  $1.5 \times 10^{20}$  photons/sec/mm<sup>2</sup>/mrad<sup>2</sup>/0.1%b.w., a photon flux density of  $2.0 \times 10^{18}$  photons/sec/mrad<sup>2</sup>/0.1%b.w, and a total flux of  $1.5 \times 10^{15}$  photons/sec/0.1%b.w. can be obtained. The light flux achievable by the optical system is  $1.1 \times 10^{15}$  photons/sec/0.1%b.w. (degradation in flux due to the aperture is not significant). Taking into account the  $10^4$  resolution of the optical system, the number of photons which can be obtained every second is  $1.1 \times 10^{14}$  photons. However, it should be kept in mind that this value will certainly be degraded depending on the efficiency of the optical system (efficiency of the spectrometer, the absorption due to filters, etc.).

On one hand it can be seen from the figure (top) that the power density is 265 kW/mrad<sup>2</sup>, and the total power is 3600 W, although the power collected into the optical system may be as little as 15% of the total power, down to 540 W. The reduction in power due to the aperture is in contrast to the case of the flux. This result suggests the drastic effect of the presence of the slit.

All the data shown in the attached figures are calculated using SPECTRA, the synchrotron radiation calculation code developed at SPring-8. For details, refer to below.

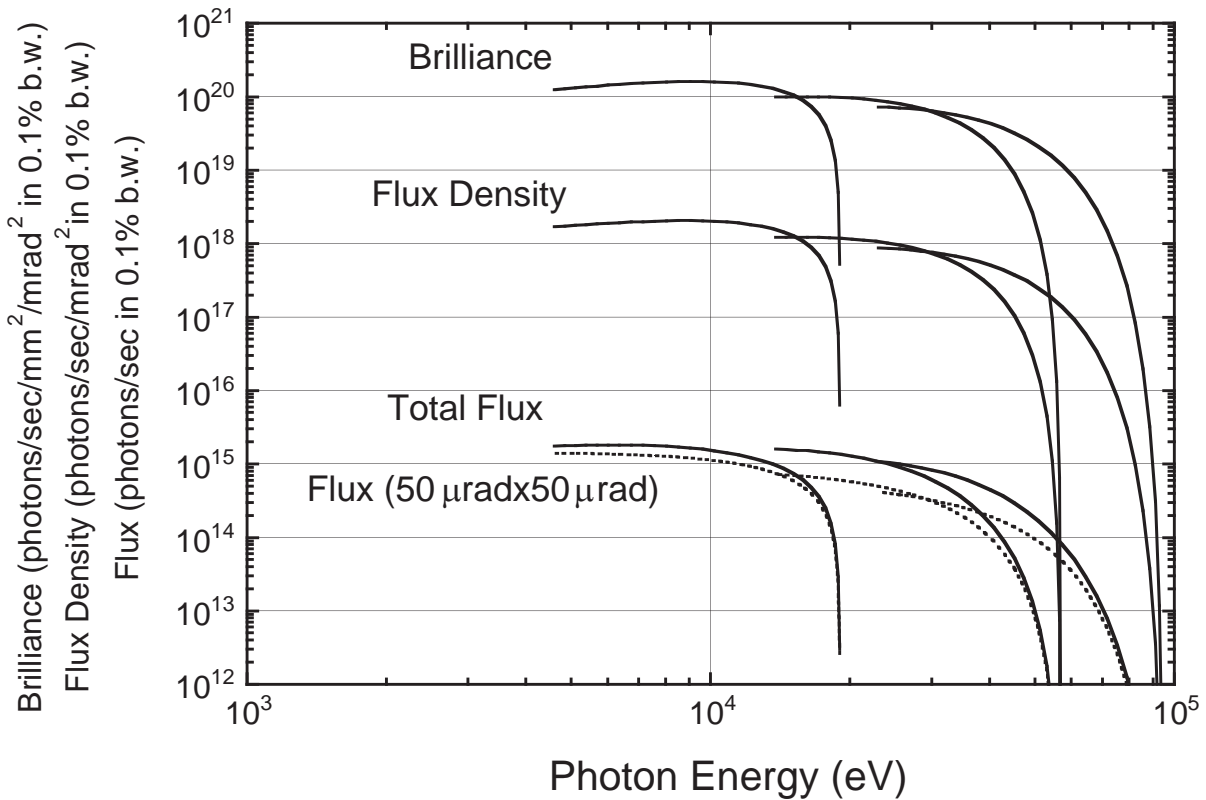
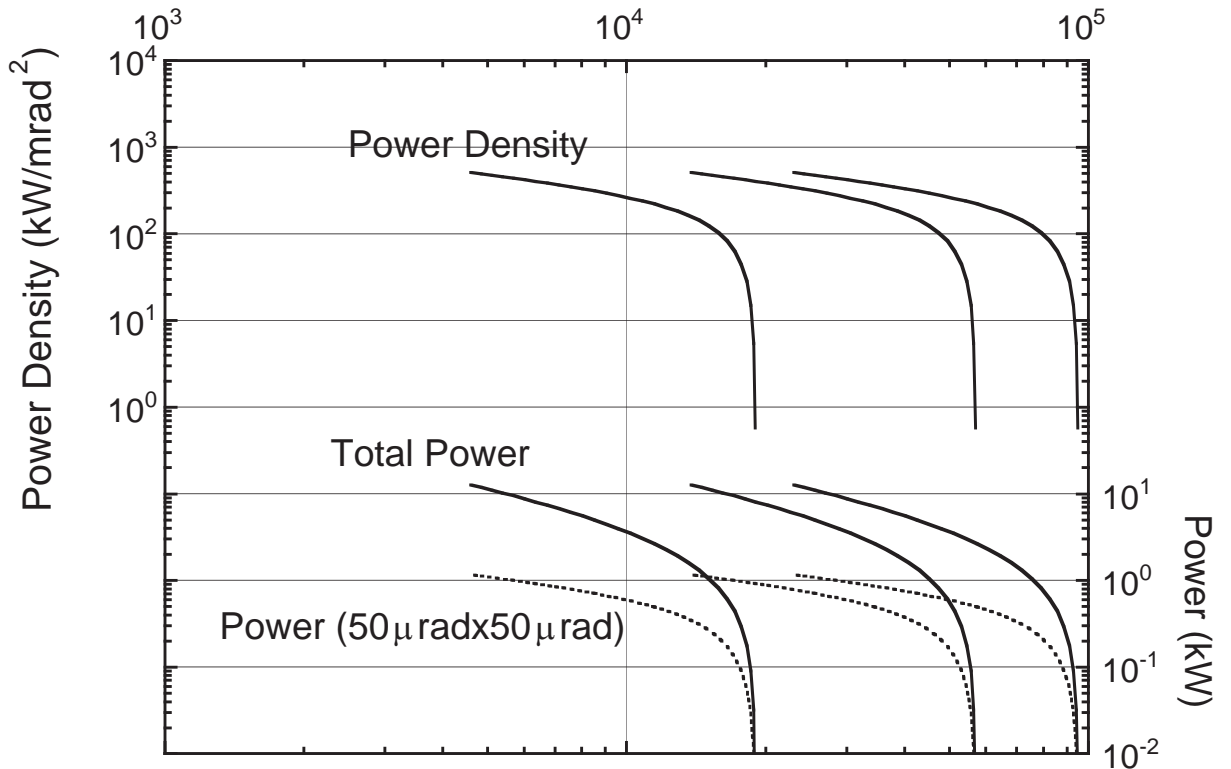
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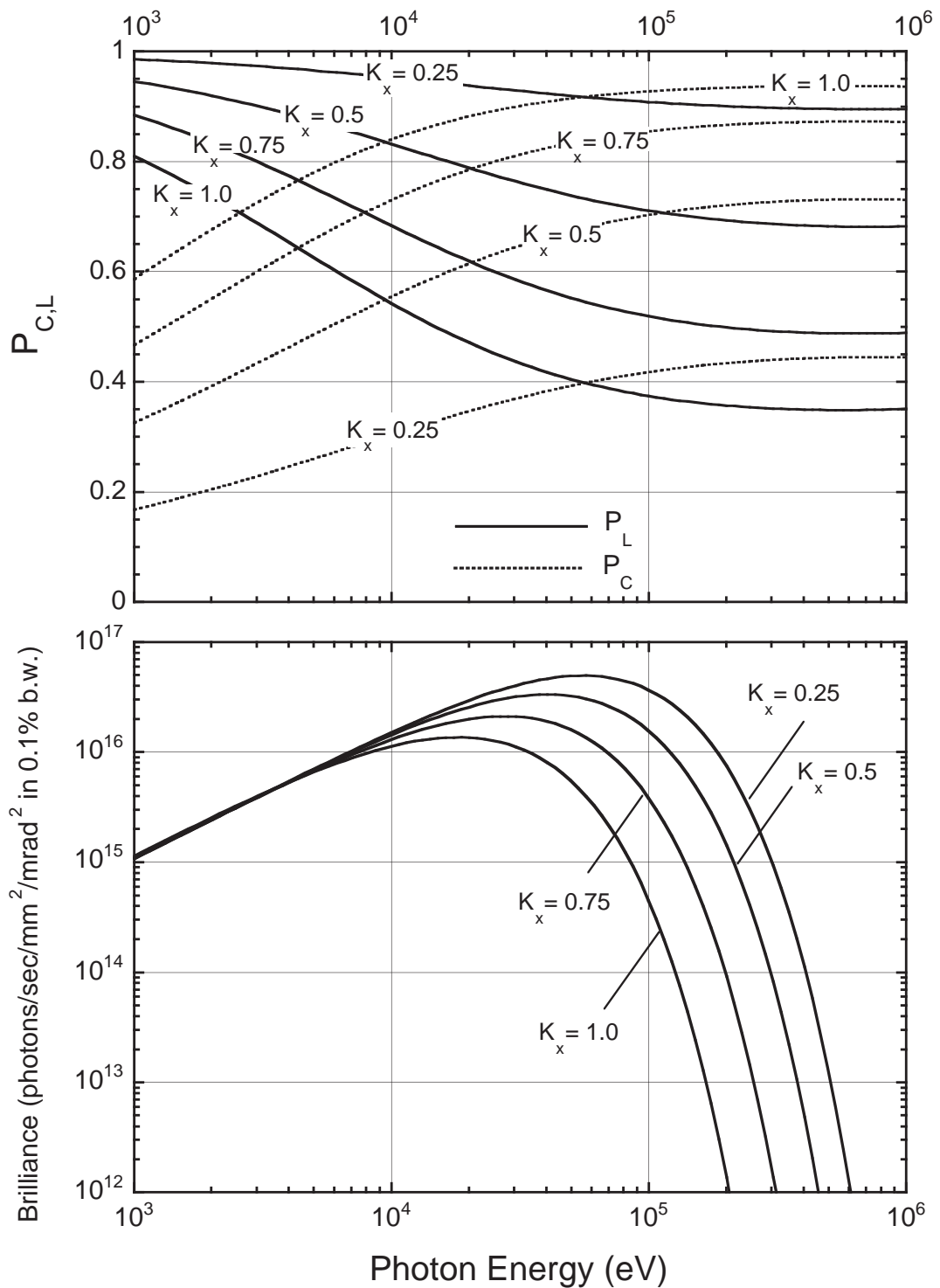
Hideo Kitamura  
(Beamline division)

Note: The minimum gap is assumed to be 8 mm.

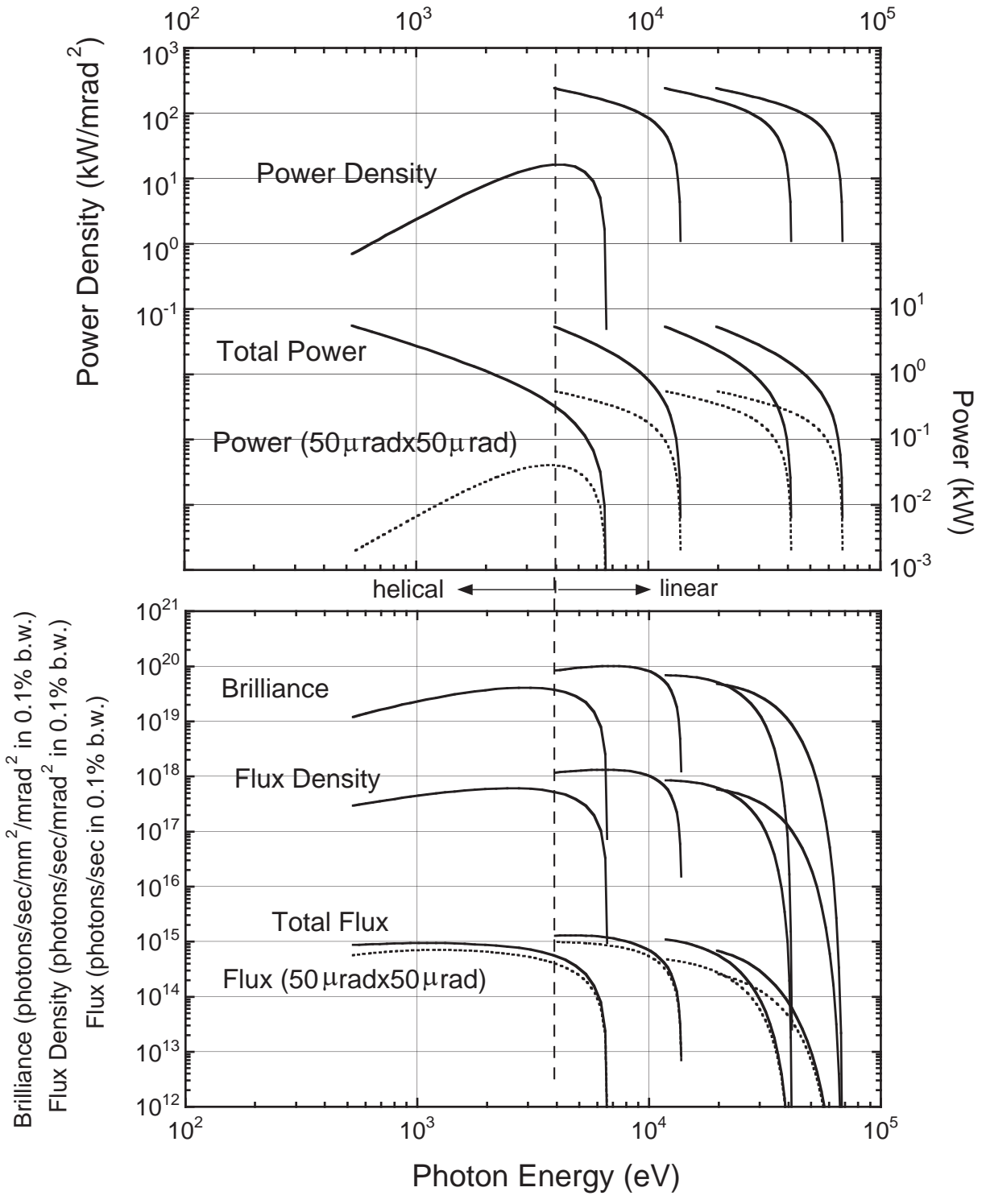
Type	In-vacuum	Tunable energy range	4.4 ~ 18.5 keV(1 <sup>st</sup> )
Undulator period	32 mm		13.2 ~ 51 keV(3 <sup>rd</sup> )
Numer of periods	140		22 ~ 75 keV(5 <sup>th</sup> )
Length	4.5 m		
Maximum field	0.86 T	Maximum total power	13 kW
Maximum K value	2.5	Maximum power density	510 kW/mrad <sup>2</sup>



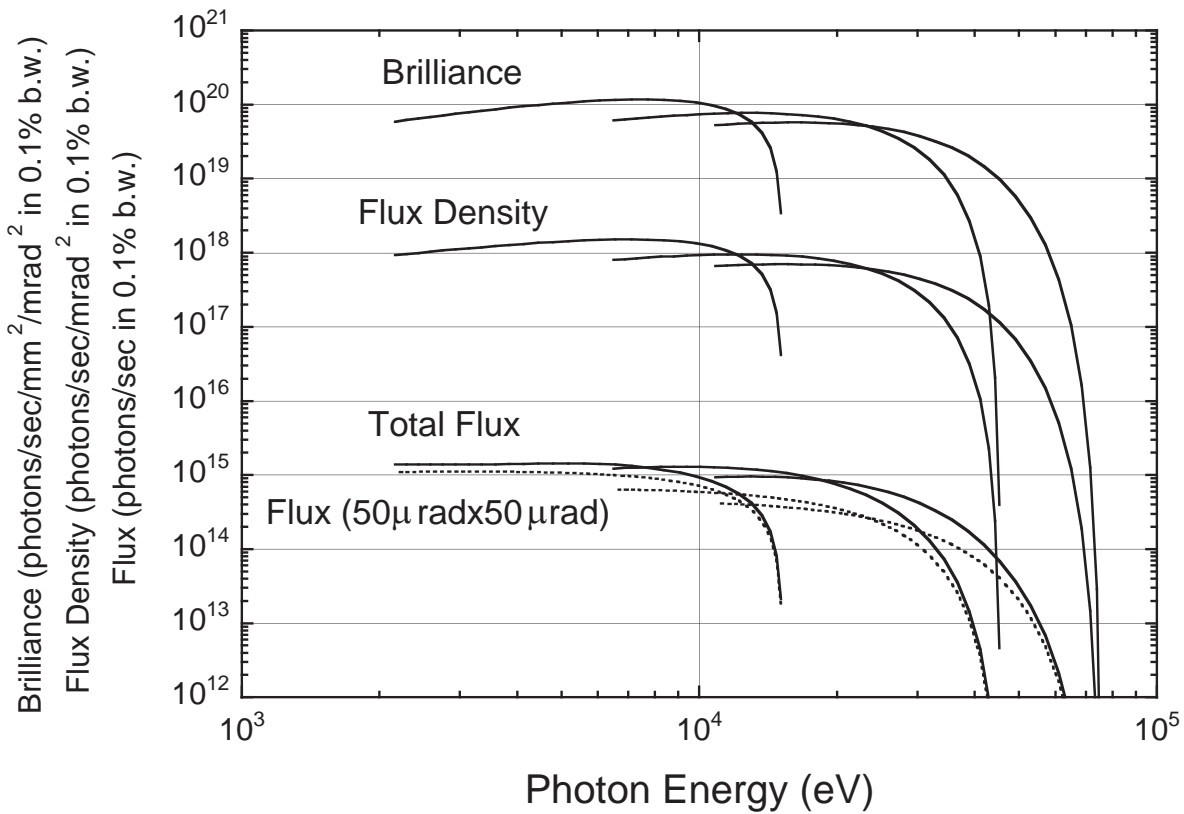
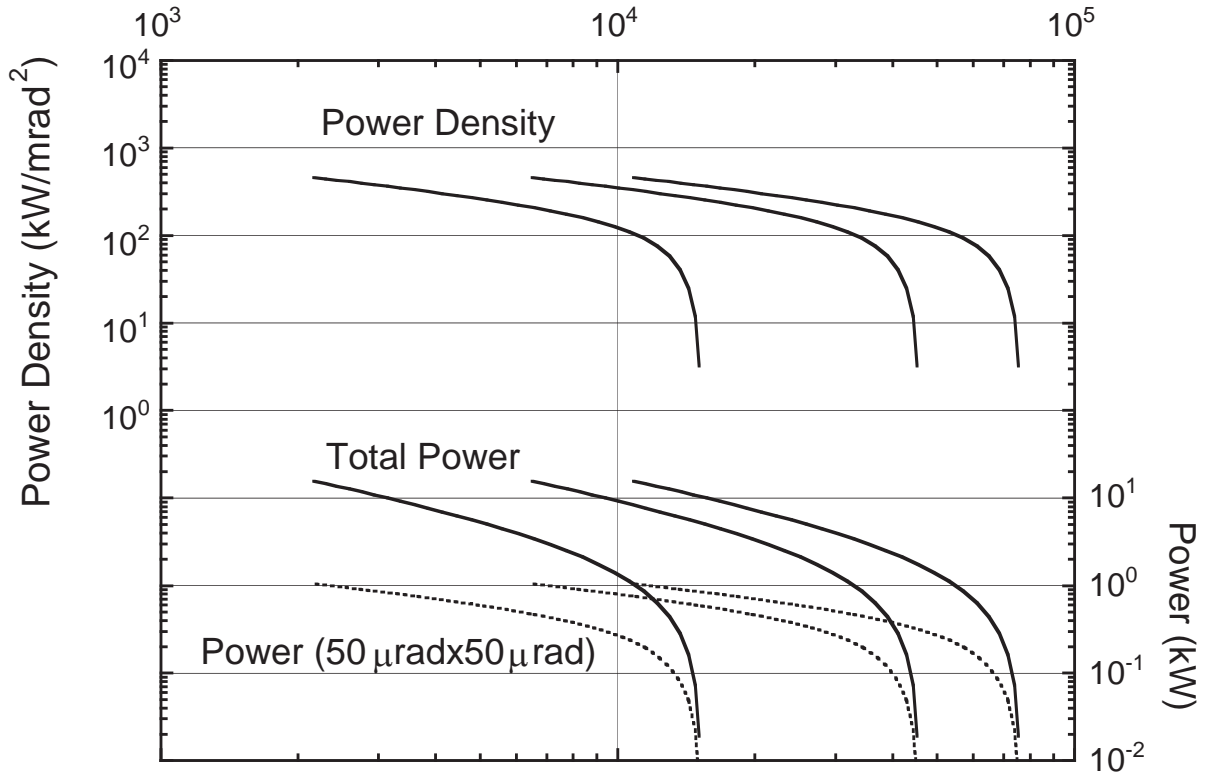
Type	Elliptical Multipole Wiggler		
Wiggler period	120 mm		
Numer of periods	377		
Length	4.5 m		
Maximum field	1.17 T (Vert.) 0.11 (Horiz.)	Maximum total power	24.4 kW
Maximum K value	13.0 (Ky) 1.25 (Kx)	Maximum power density	26.6 kW/mrad <sup>2</sup>



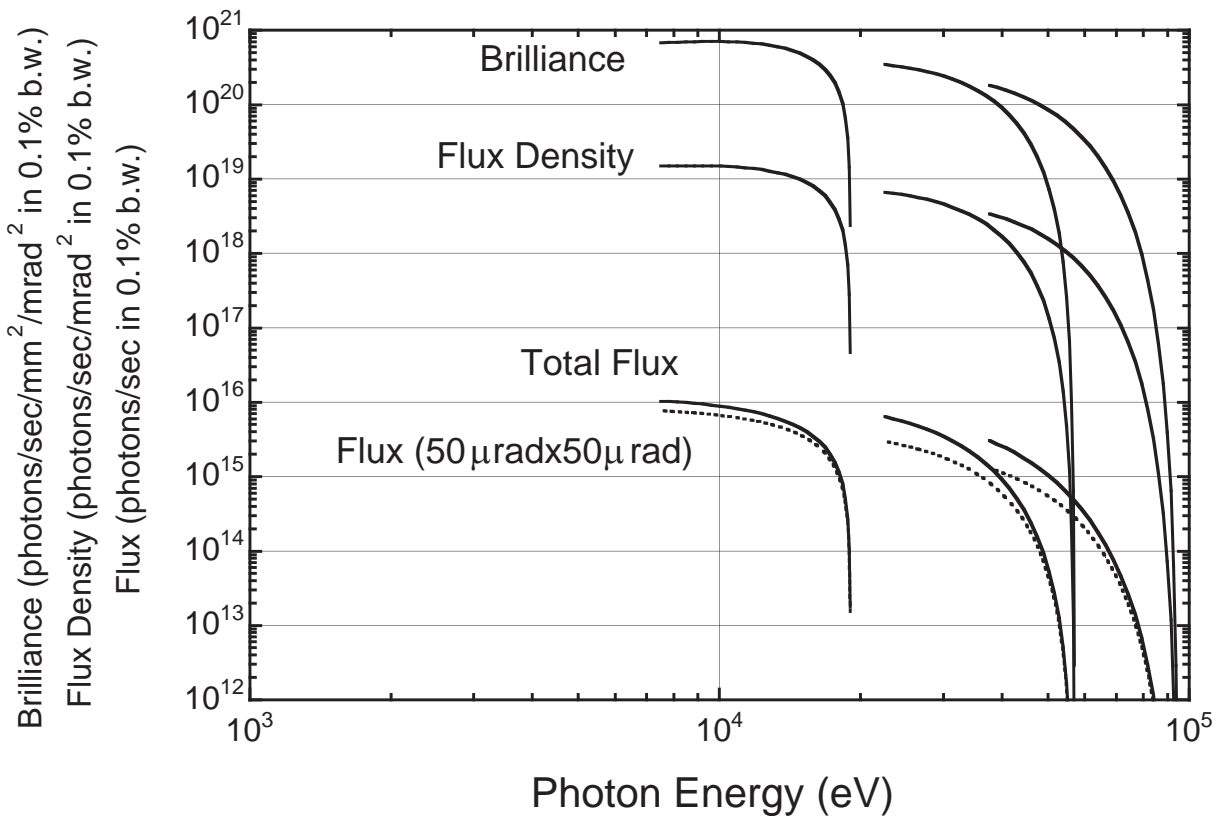
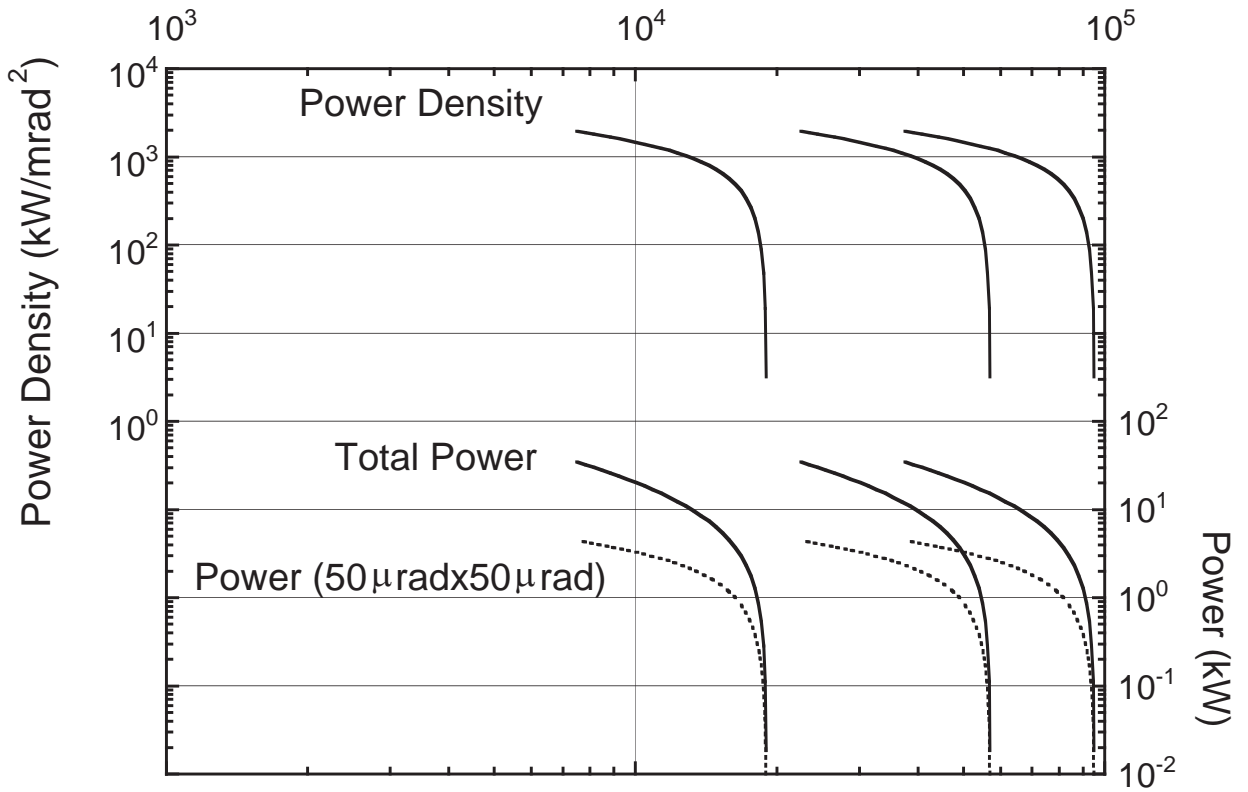
Type	Revolver Linear + Helical	Tunable energy range	Helical: 5 ~ 5 keV (Helical) Linear: 4.4 ~ 18.5 keV(1 <sup>st</sup> ) 13.2 ~ 51 keV(3 <sup>rd</sup> ) 22 ~ 75 keV(5 <sup>th</sup> )
Undulator period	44 mm (Linear) 92 mm (Helical)		
Numer of periods	102 (Linear) 48 (Helical)		
Length	4.5 m		
Maximum field	0.54 T (Linear) 0.40 T (Helical)	Maximum total power	5.6 kW (Helical)
Maximum K value	2.2 (Linear) 3.4 (Helical)	Maximum power density	240 kW/mrad <sup>2</sup>



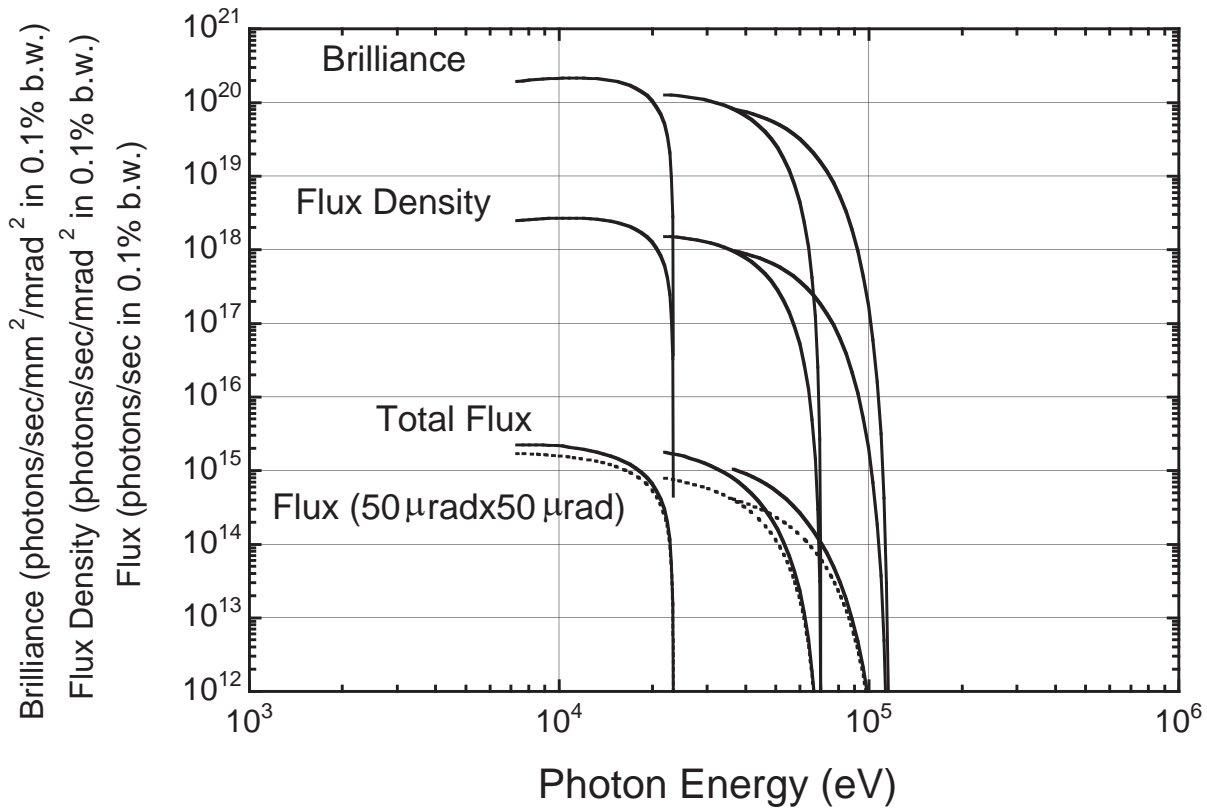
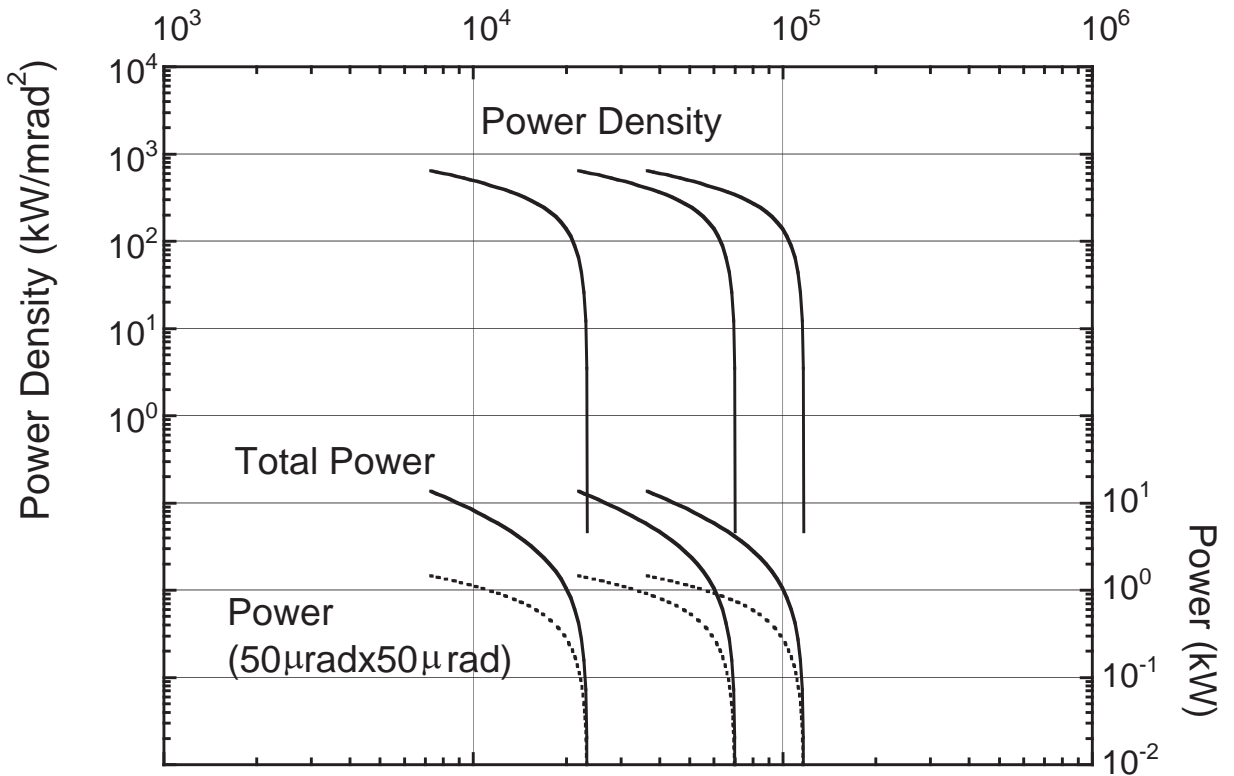
Type	In-vacuum	Tunable energy range	2.2 ~ 15 keV(1 <sup>st</sup> )
Undulator period	40 mm		6.6 ~ 36 keV(3 <sup>rd</sup> )
Numer of periods	112		11 ~ 56 keV(5 <sup>th</sup> )
Length	4.5 m		
Maximum field	0.93 T	Maximum total power	15.6 kW
Maximum K value	3.5	Maximum power density	455 kW/mrad <sup>2</sup>



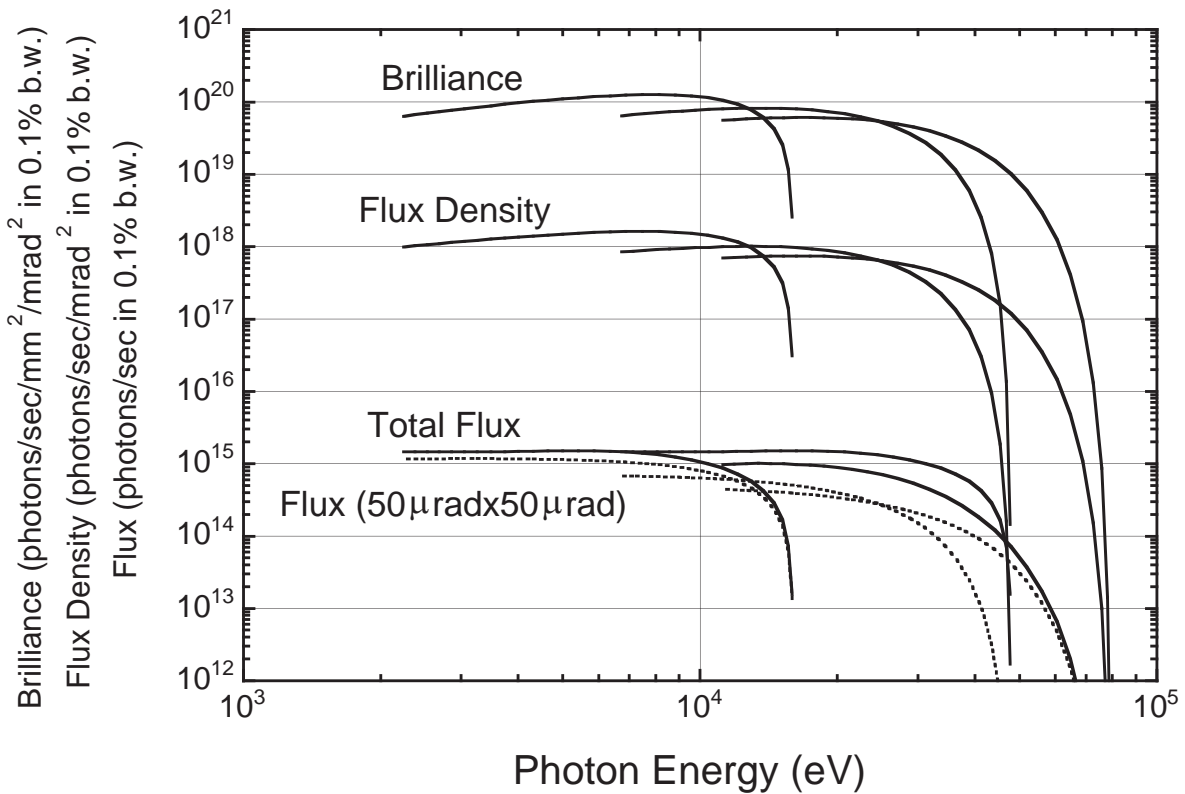
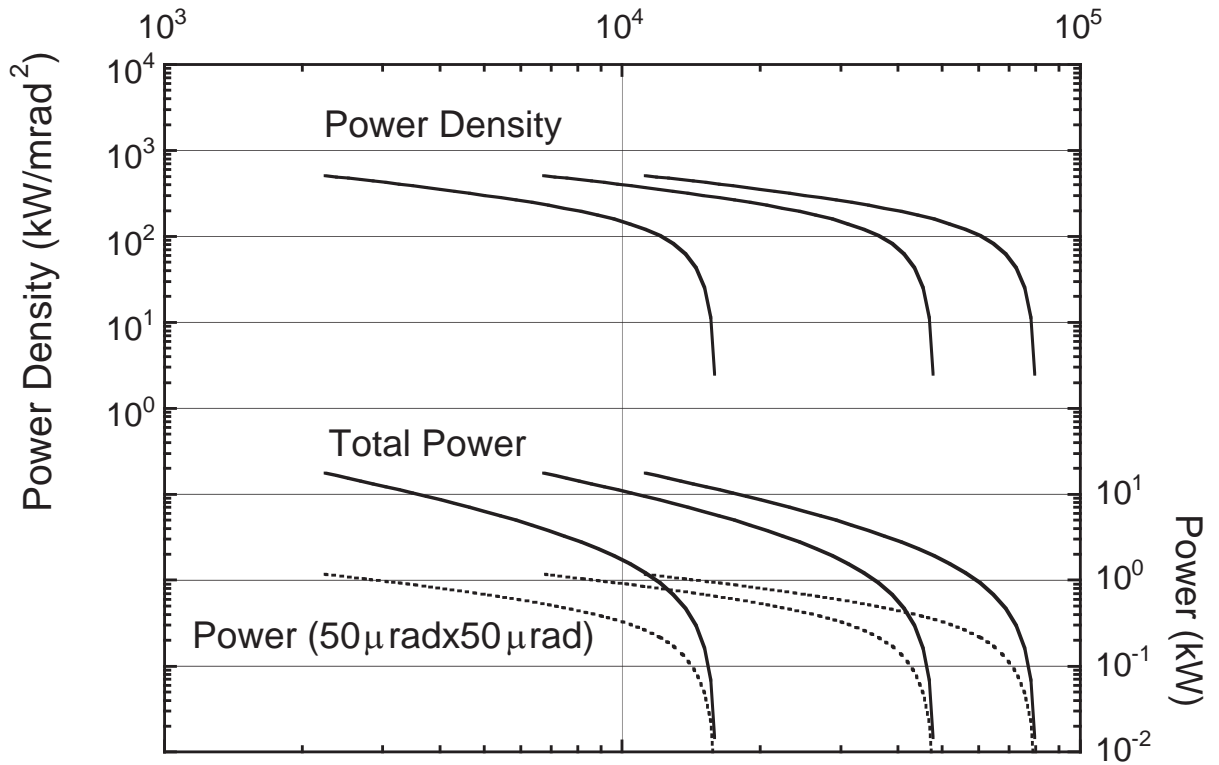
Type	In-vacuum	Tunable energy range	7.5 ~ 18.5 keV(1 <sup>st</sup> )
Undulator period	32 mm		22.5 ~ 51 keV(3 <sup>rd</sup> )
Numer of periods	781		37.5 ~ 75 keV(5 <sup>th</sup> )
Length	25 m		
Maximum field	0.56 T	Maximum total power	34.9 kW
Maximum K value	1.7	Maximum power density	1970 kW/mrad <sup>2</sup>



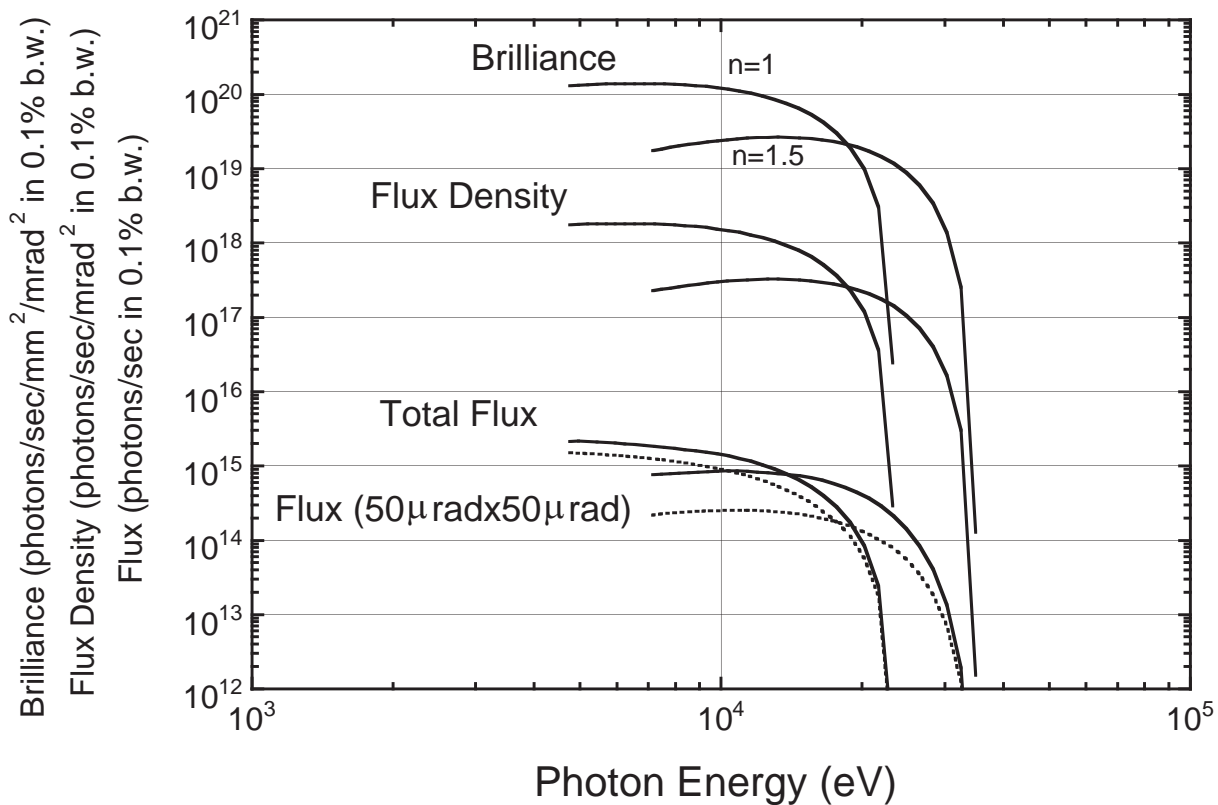
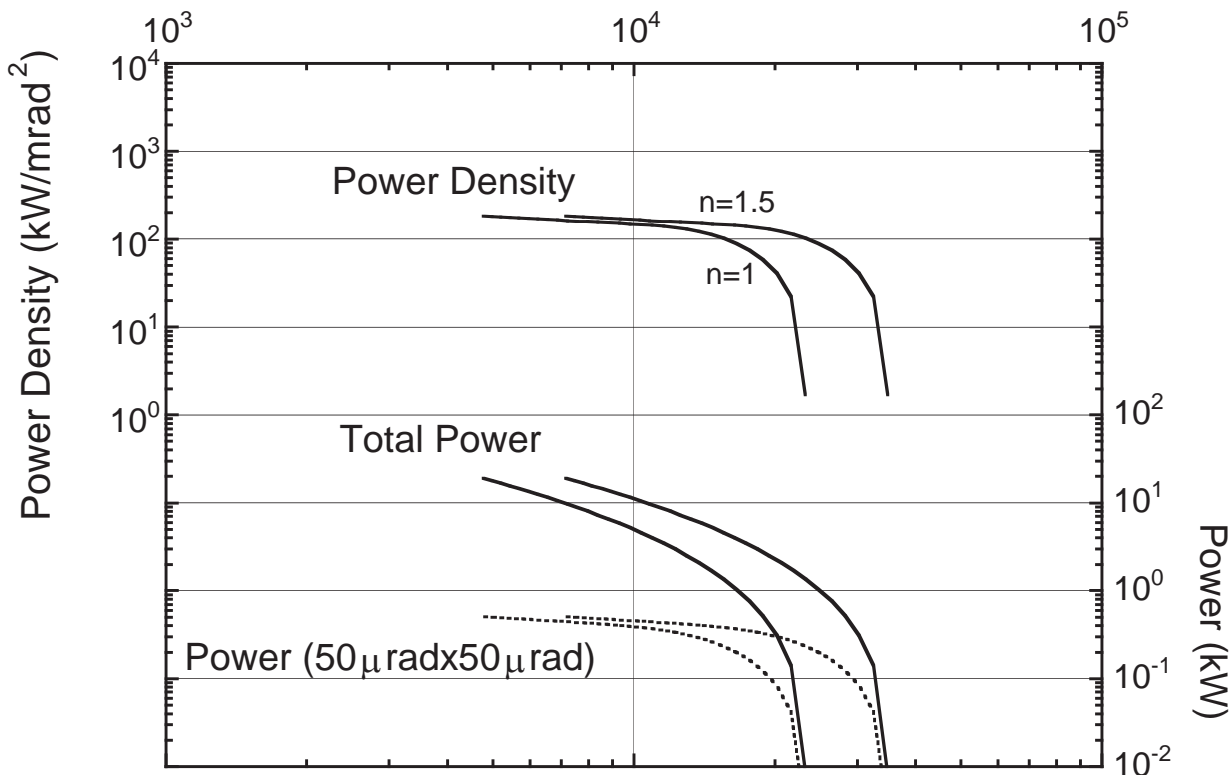
Type	In-vacuum	Tunable energy range	7.2 ~ 21 keV(1 <sup>st</sup> )
Undulator period	26mm		21.6 ~ 57 keV(3 <sup>rd</sup> )
Numer of periods	173		36 ~ 86 keV(5 <sup>th</sup> )
Length	4.5 m		
Maximum field	0.87 T	Maximum total power	13.8 kW
Maximum K value	2.1	Maximum power density	651 kW/mrad <sup>2</sup>



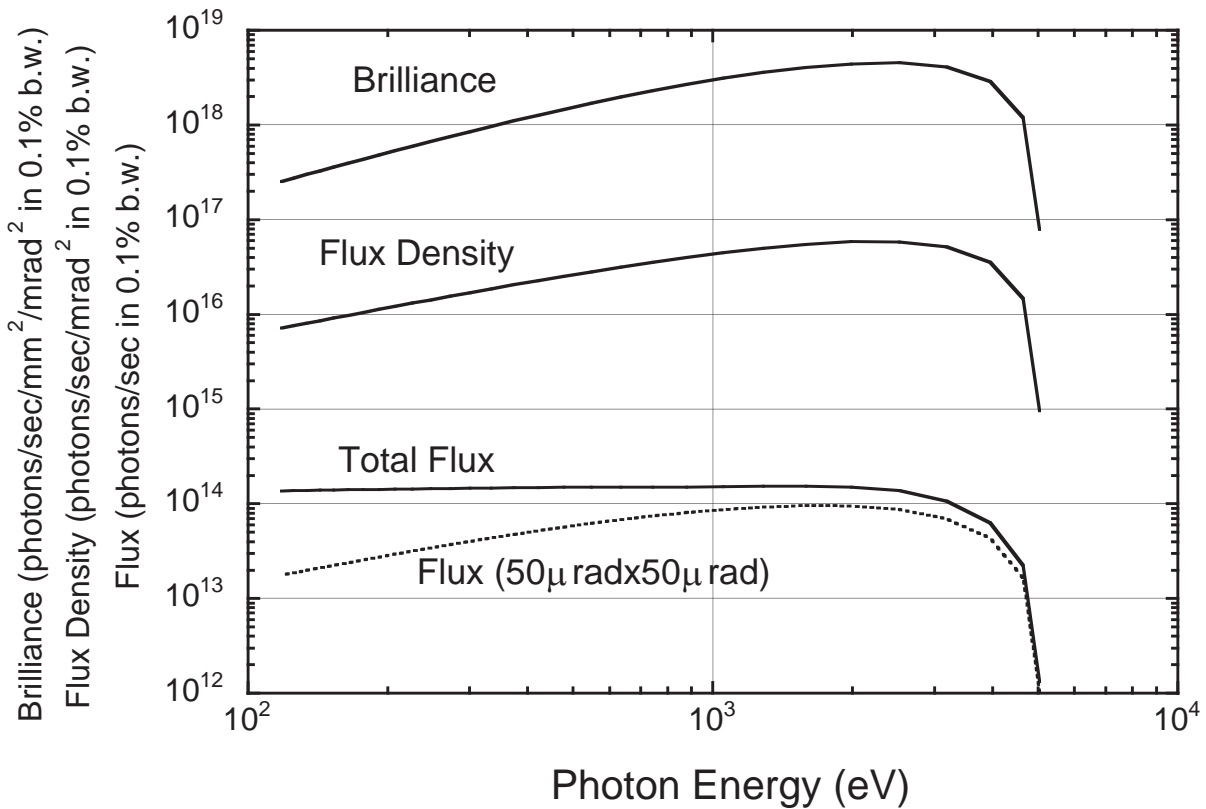
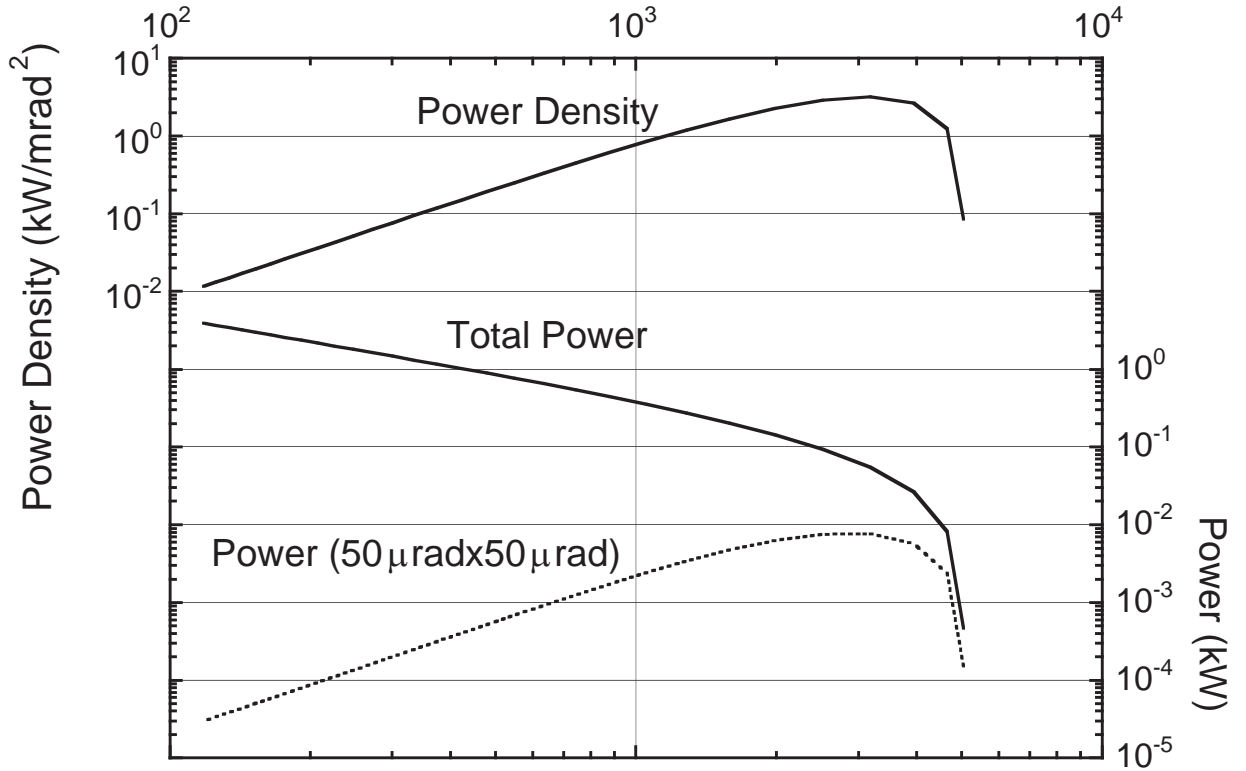
Type	In-vacuum	Tunable energy range	2.3 ~ 14 keV(1 <sup>st</sup> )
Undulator period	38 mm		6.9 ~ 42 keV(3 <sup>rd</sup> )
Numer of periods	118		11.5 ~ 70 keV(5 <sup>th</sup> )
Length	4.5 m		
Maximum field	0.974 T	Maximum total power	17 kW
Maximum K value	3.45	Maximum power density	510 kW/mrad <sup>2</sup>



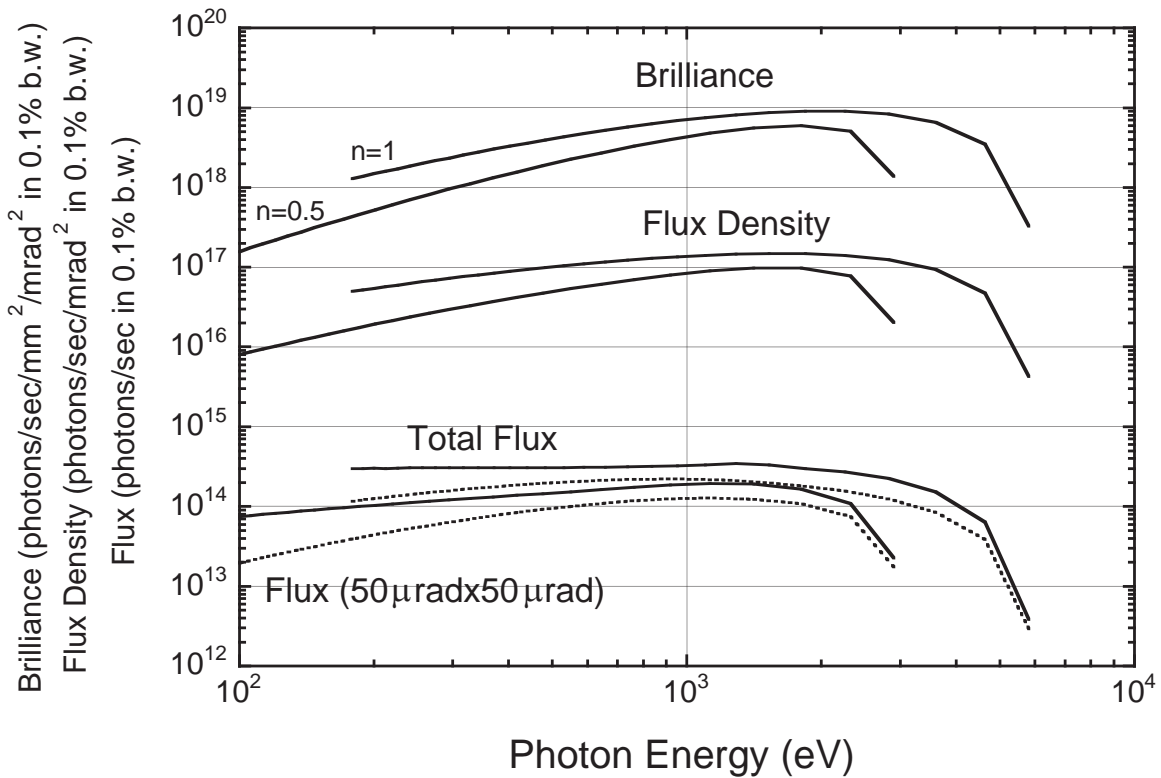
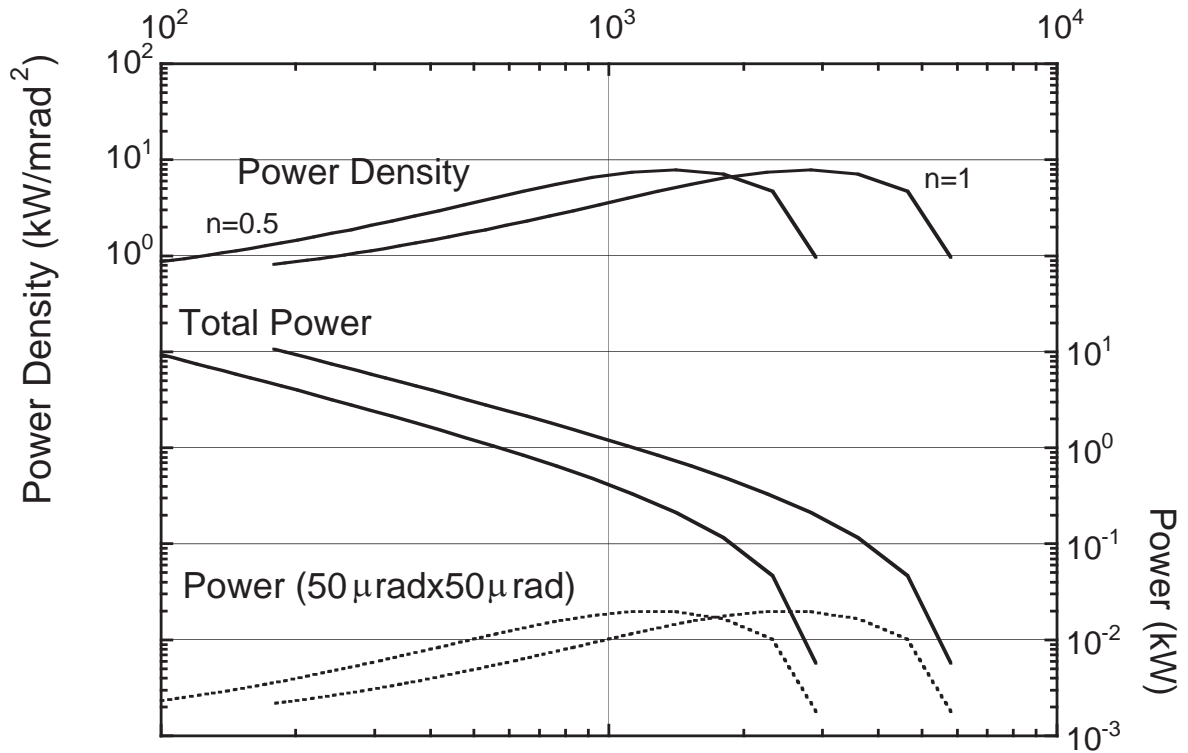
Type	In-vacuum	Tunable energy range	4.8 ~ 22 keV(1 <sup>st</sup> ) 7.1 ~ 30 keV(3 <sup>rd</sup> )
Undulator period	26 mm		
Numer of periods	173		
Length	4.5 m		
Maximum field	0.98 T (Vert.) 0.30 T (Horiz.)	Maximum total power	19 kW
Maximum K value	2.39 (Ky) 1.45 (Kx)	Maximum power density	182 kW/mrad <sup>2</sup>



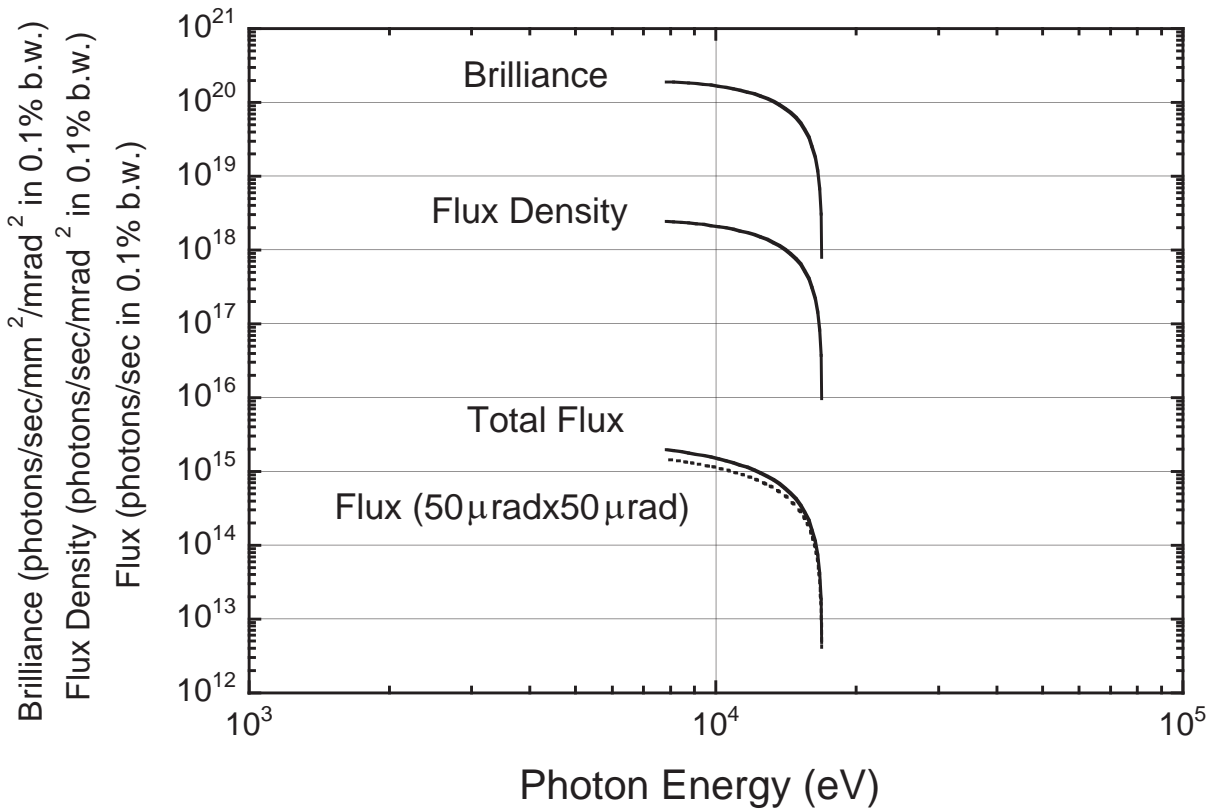
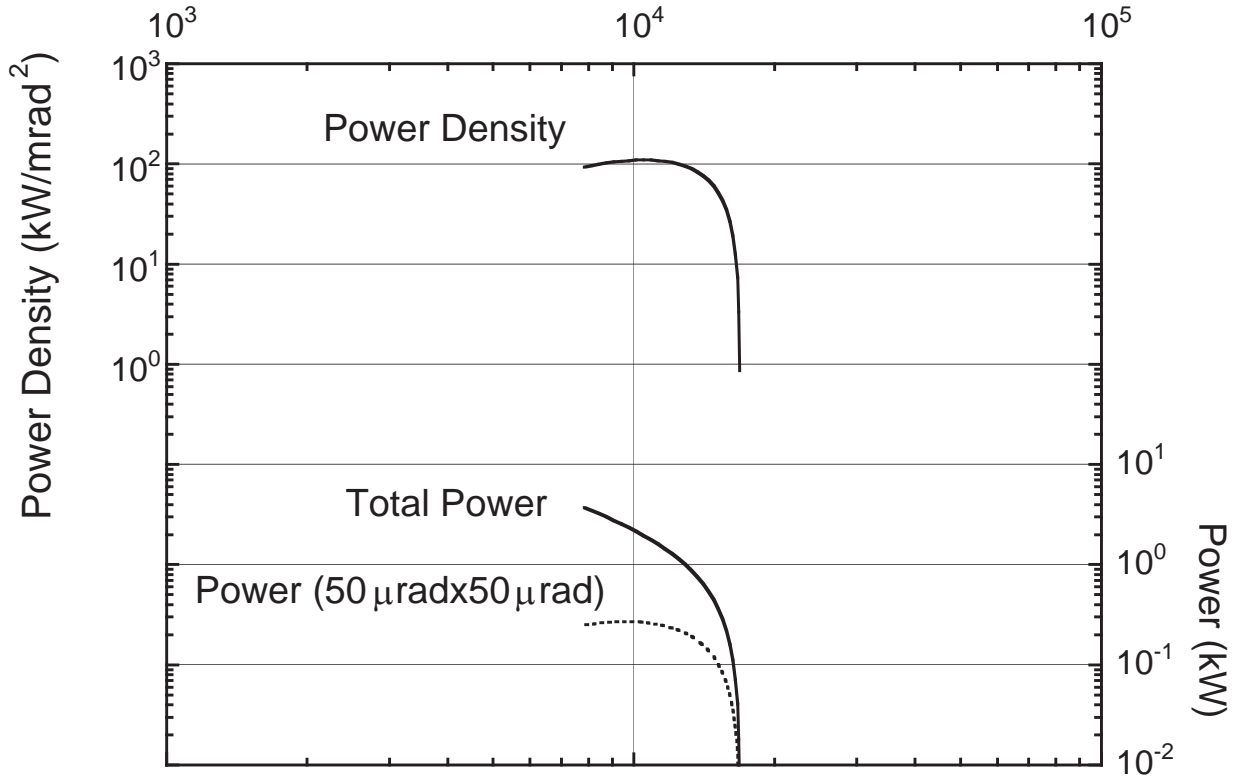
Type	Helical	Tunable energy range	0.12 ~ 5 keV(1 <sup>st</sup> )
Undulator period	120 mm		
Numer of periods	12 × 2		
Length	1.5 m × 2		
Maximum field	0.57 T	Maximum total power	3.7 kW
Maximum K value	6.5	Maximum power density	3.0 kW/mrad <sup>2</sup>



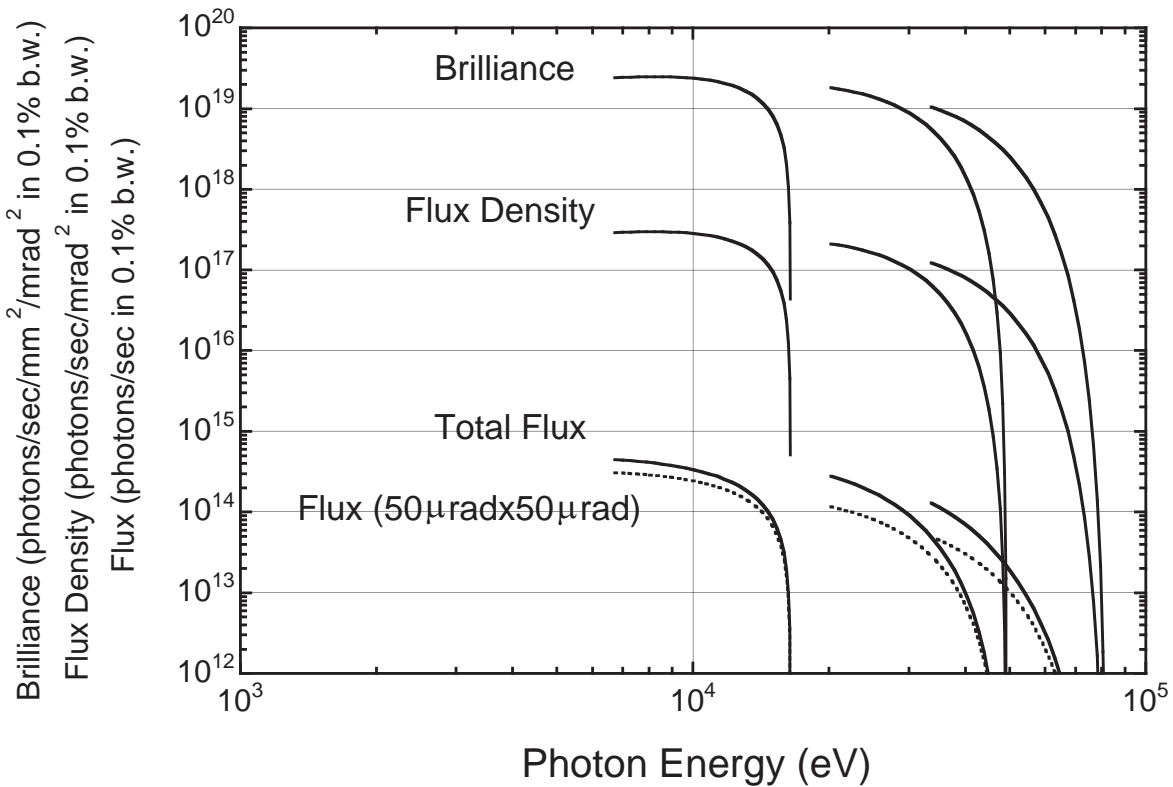
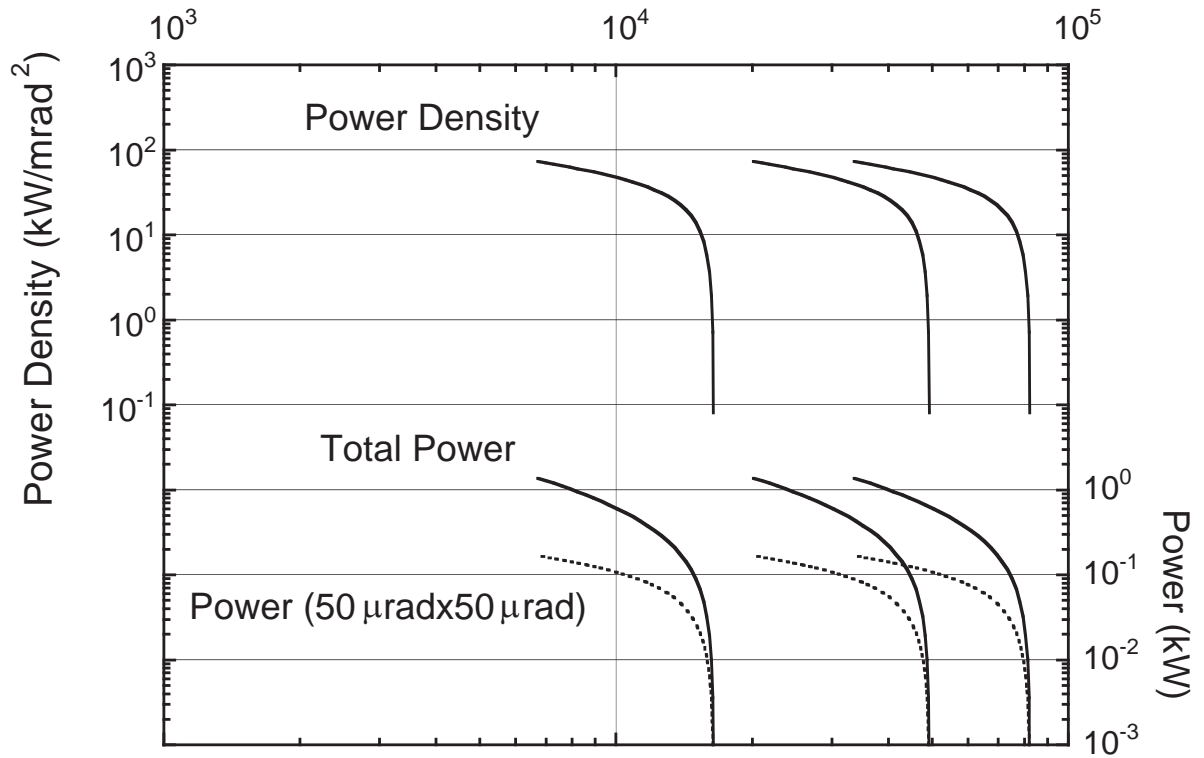
Type	Figure-8	Tunable energy range	0.05 ~ 2.5 keV (0.5 <sup>th</sup> ) 0.1 ~ 5 keV(1 <sup>st</sup> )
Undulator period	100 mm		
Numer of periods	44		
Length	4.5 m		
Maximum field	1.0 T (Vert.) 0.26 T (Horiz.)	Maximum total power	19 kW
Maximum K value	4.8 (Ky) 9.6 (Kx)	Maximum power density	7.7 W/mrad <sup>2</sup>



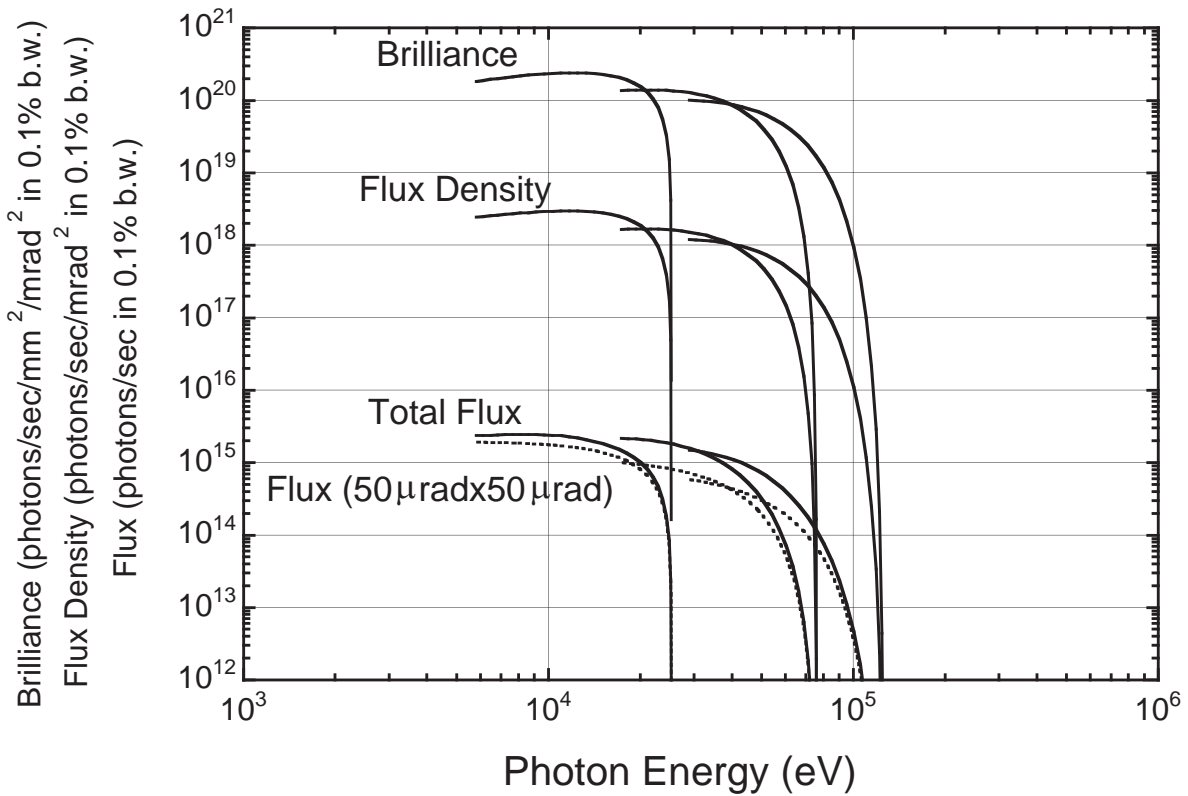
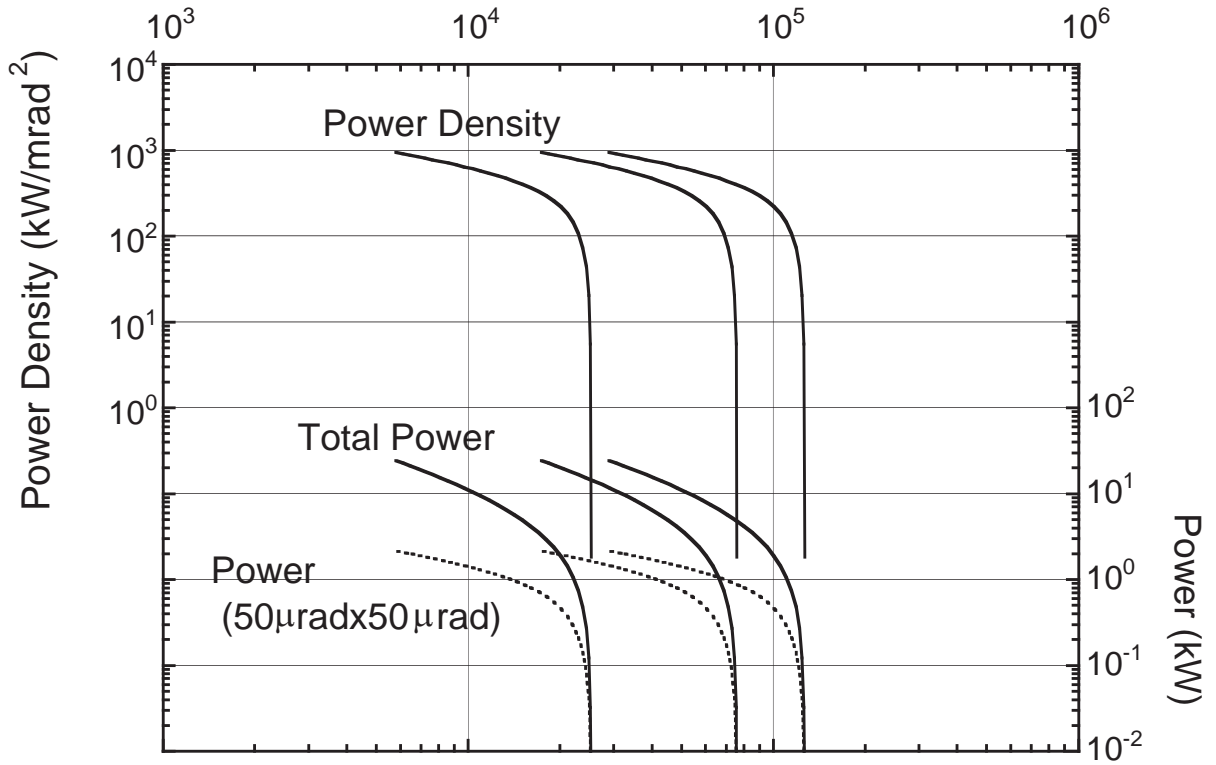
Type	In-vacuum helical	Tunable energy range	7.9 ~ 16.8 keV(1st)
Undulator period	36 mm		
Numer of periods	123		
Length	4.5 m		
Maximum field	0.32 T	Maximum total power	3.7 kW
Maximum K value	1.1	Maximum power density	109 kW/mrad <sup>2</sup>



Type	In-vacuum helical	Tunable energy range	6.7 ~ 15 keV(1 <sup>st</sup> ) 20.1 ~ 43 keV(3 <sup>rd</sup> ) 33.5 ~ 60 keV(5 <sup>th</sup> )
Undulator period	37 mm		
Numer of periods	37 × 2		
Length	1.5 m × 2		
Maximum field	0.50 T	Maximum total power	1.4 kW
Maximum K value	1.7	Maximum power density	73 kW/mrad <sup>2</sup>



Type	In-vacuum	Tunable energy range	5.8 ~ 24 keV(1 <sup>st</sup> )
Undulator period	24 mm		17 ~ 58 keV(3 <sup>rd</sup> )
Numer of periods	187		29 ~ 95 keV(5 <sup>th</sup> )
Length	4.5 m		
Maximum field	1.15 T	Maximum total power	19 kW
Maximum K value	2.6	Maximum power density	182 kW/mrad <sup>2</sup>



Bending-magnet beamline

Maximum field	0.679 T	Total power	0.15 kW
		Power density	1.5 kW/mrad <sup>2</sup>

