Memo
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Photon spectra estimation for 23 neutron beam lines at JSNS

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1 Outline

Photon spectra at 23 neutron beam lines planned at JSNS have been calculated on the basis of the target-moderator-reflector assembly design on August, 2003. The calculation models are shown in **Figs. 1 to 6**. The major parameters and conditions used in the calculation are summarized in **Table 1** in which the names of employed codes are also listed. The photon spectrum has been evaluated using point detector on the neutron beam line center at 10 m from the surface of moderator.

It is noted that the neutron beam line is modeled that just a rectangular port of 10×10 cm^2 is located in a shielding without complicated beam-line components such as neutron beam windows, collimators, guide tubes because the design of neutron beam lines is not determined yet. For the dimension is smaller than the 10×10 cm^2, another calculation is needed. Moreover, the area of viewed surface for the neutron beam line No.16 of a horizontal reflectometer is 5×10 cm^2 of the upper half of the moderator from which two channels begins with different tangential angles with respect to the horizontal plane. Once a particle has gone out of the neutron beam line at the outer region of target monolith with a radius of 4 m, its trajectory is not traced in the calculation by setting the importance as zero.

The photon spectrum consists of the two components. One is the photons emitted from nuclear reactions in the target-moderator-reflector assembly and its surroundings. This photon emission is synchronized with the time structure of the proton beam pulse. The other is the ones from the decay of radioactive nuclei produced by the nuclear reactions. This component is independent of the time structure of the proton beam pulse.

In this calculation, the flight time from the moderator surface to the point detector, that is 33.4 ns, is taken into account. Since the photon's velocity is constant independent of its energy, the time focusing technique used in the calculation of the neutron spectra is not employed.

The photons from the decay of radioactive nuclei are excluded from the final result of this calculation because their time characteristics does not coincide with that of the proton beam pulse. It is necessary to take account of the accelerator operation history as input condition for precise estimation of the photon intensity from the decay process. For simplicity, this photon intensity has been estimated under the condition shown in **Table 2** that the photon production becomes maximum. In this calculation, the components placed about 1.5 m from the proton beam incident point on the target are taken in to account for production of the decay photons. This calculation model excludes the components such as a shutter, collimators, instruments radiation shield and so on around a neutron beam line because precise structure design is not completed yet. It is required to include the geometrical data of those components for more precise estimation of the photon spectra.

2 Results

The calculated result of the time-integrated photon spectrum is given by the units of "(n/cm^2/s/sr/lethargy)" under the condition that the input proton beam power in 1-MW. This is the number of photons emitted from the area of 1 cm^2 at the surface of the moderator in one second in a solid angle toward a neutron instrument. The photon spectrum per second with an energy bin of E_j, $\phi(t, E_j)$ is expressed as follows:

$$\phi(t, E_j) = N(t, E_j) \cdot \frac{S_d}{L^2} \cdot \frac{1}{S_m} \cdot \frac{1}{\ln(E_{j,high}) - \ln(E_{j,low})} \quad (1)$$

where, $N(t, E_j)$ is the number of photons emitted from a viewed surface of a moderator per second with an energy bin of E_j, S_d the area of the point detector, L the distance from center of the viewed surface to the point detector, S_m the area of the viewed surface of the moderator, $E_{j,high}$ and $E_{j,low}$ the upper and the lower values of the energy bin E_j.

As described in the previous section, the values of S_d, S_m and L are 1 cm^2, 100 cm^2 and 10 m, respectively. For the neutron beam line No.16, the value of S_m is 50 cm^2. Since the neutrons and prompt photons are produced in accordance with the repetition rate of 25 Hz, the photon spectrum depending on the individual pulse is also obtained by multiplying a factor of 1/25. This quantity is denoted as time-averaged spectrum in this description. If the user needs the spectrum at an arbitrary position, it is obtained by substituting the variables in Eq. (1) with the values at the position.

The calculated time-integrated photon spectra are shown in **Fig. 7**. It is noted that the beam-lines from No.3 to 5 and No.15 views the coupled moderator, those of No.8 and 19 are for the decoupled poisoned moderator and those of No.11 and 22 are for the decoupled moderator, respectively.

It is apparent that the photon spectra from three different moderators have similar shape and intensity each other. It is commonly observed that peaks appear at about 2 MeV and around 100 MeV. The former is caused by the neutron capture by hydrogen, and the latter is the photon produced by the decay of π^0 meson. The photon by the decay of η particle is included in the energy range above 200 MeV. Due to the limit that the energy range in the MCNP calculation is 1 GeV at maximum, the photons with energies above 1 GeV is included as 1 GeV. As a matter of fact, however, the fraction of the photons above 1 GeV is extremely small.

The calculated results of the energy-integrated time spectra and energy-dependent time spectra are shown in **Figs. 8 to 12**, respectively. They are given in the units of "(n/cm^2/s/sr/pulse)" and "(n/cm^2/s/sr/lethargy/pulse)", respectively. This the number of photons emitted from the moderator by a single proton pulse with a power of 1-MW and a repetition rate of 25 Hz. It is observed from Fig. 8 that the time spectra differs among the three moderators.

The photon spectra in some energy regions for beam lines No.5 and No.8 are shown in Figs. 9 and 10, respectively. Small difference is observed in the shape between No.5 and No.8. Figure 11 shows the time-integrated photon spectra at beam lines No.5 and No.8

in which the photon components emitted from radioactive nuclei are also displayed. The component from radioactive nuclei has energies less than 10 MeV, and is lower by about five order of magnitude at 0.1 MeV and about seven figures at 1 MeV than that of prompt photons by the nuclear reaction.

The energy-integrated time spectra at beam lines No.5 and No.8 are also shown in Fig. 12 with the components emitted from radioactive nuclei. As denoted as "continuous" in the Figure, the components emitted from radioactive nuclei are constant at a value below $1{\times}10^6$.

Table 1: Major parameters used in the calculation.

Item	Sub-item	Tools and parameters
Computation codes	Transport for high energy protons and neutrons	PHITS Ver.1.67
	Sub-neutrons	MCNP-4C3
	Residual radioactive nuclide yield estimation	DCHAIN-SP-2001
Model version		Ver.20.12.04
Proton beam	Beam power	1 MW at proton beam window
	Beam profile	Uniform of 81mm mrad in phase space
		18×7 cm^2 at target surface
	Repetition rate	25Hz
	Deviation	$1\sigma = 0.68$ cm (Horizontal)
	of beam center	$1\sigma = 0.06$ cm (Vertical)
Proton beam window	Material / thickness	Aluminum alloy (A5083) / 2.5 mm^t $\times$ 2
	Coolant / channel width	Light water / 3.0 mm^t
Moderator	Material	Liquid hydrogen(Para 100%), 20K
	Container	Aluminum alloy (A6061)
	Coolant	Light water
Reflector	Inner: Material / dimension	Beryllium / ϕ50 cm$\times$100 cm
	Outer: Material / dimension	Iron / ϕ100 cm$\times$100 cm
	Container	Aluminum alloy (A6061)
	Coolant	Heavy water
Water-cooled shielding	Material	Mixture of 90% SS304L and 10% light water in volume fraction
Middle section of helium vessel	Material	Mixture of 90% SS304L and 10% light water in volume fraction
Neutron beam duct	Dimension	10×10 cm^2, $10^w\times5^h$ cm^2 for No.16
Tally	Type	Point detector
	Position	Center of each neutron beam duct
	Distance	10 m from the viewed surface of moderator
	Number	24 including 2 positions in different height for beam port No.16

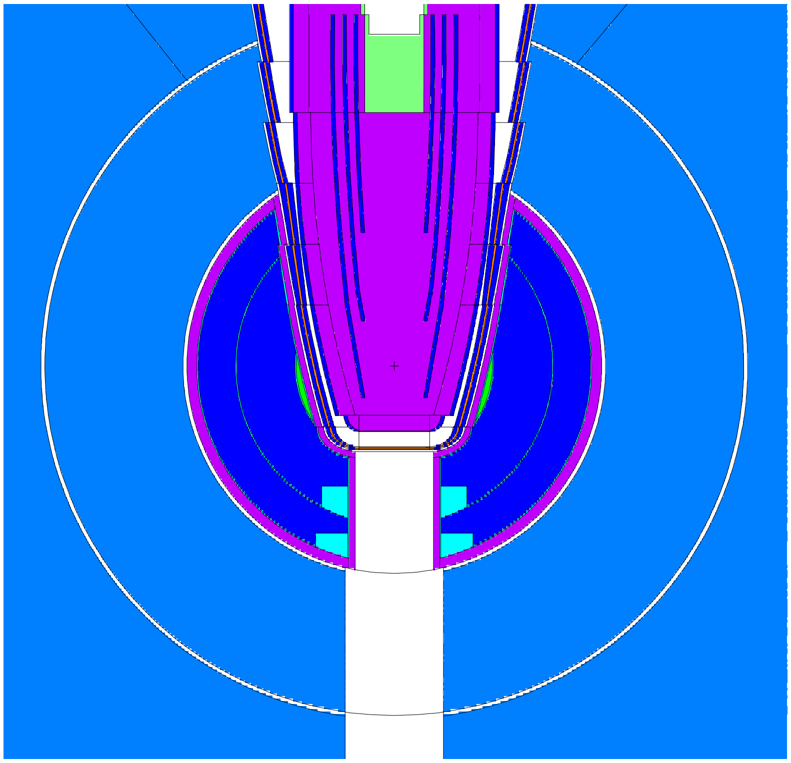

Figure 1: Monte Carlo model of the target and reflector showing plan view at the center elevation of the target.

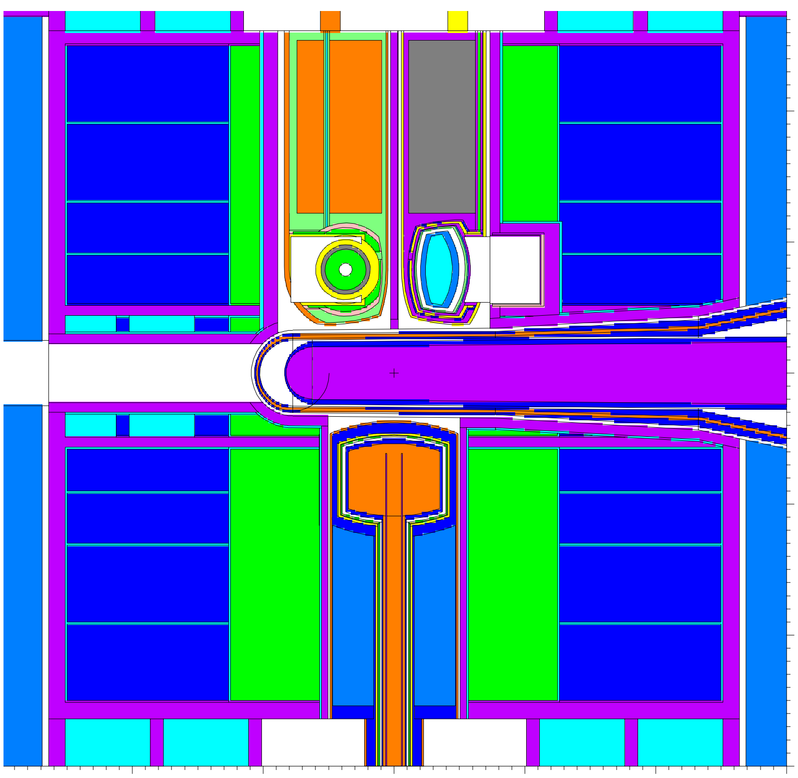

Figure 2: Monte Carlo model of the target-moderator-reflector assembly showing elevation view.

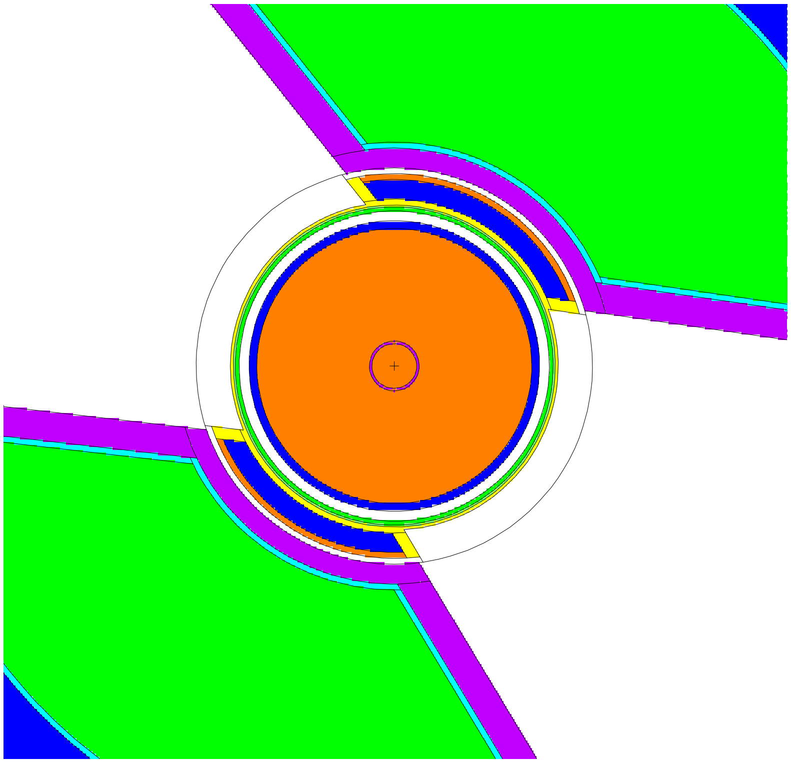

Figure 3: Monte Carlo model of the coupled moderator and its surroundings showing plan view.

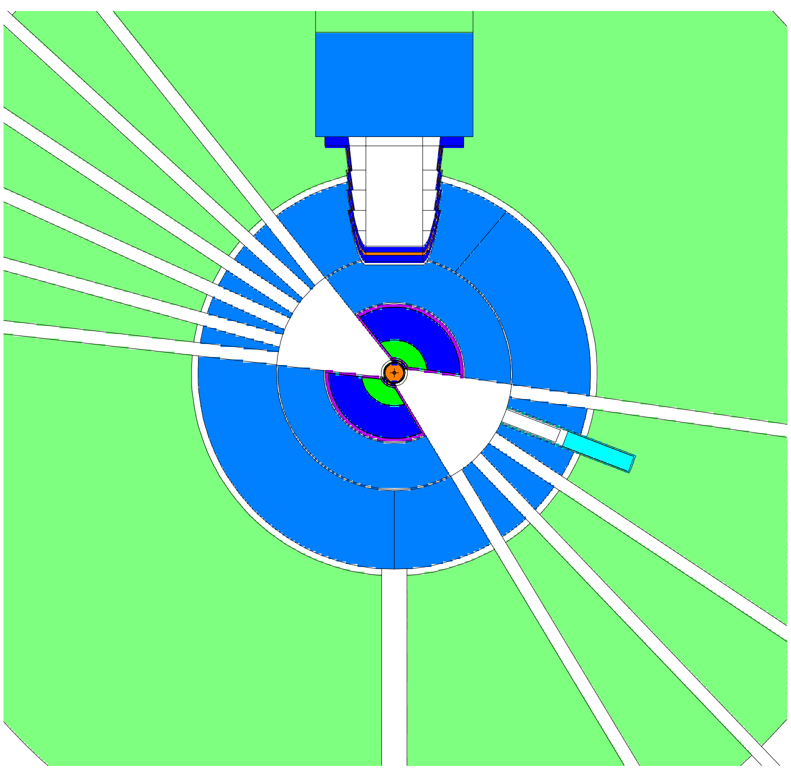

Figure 4: Monte Carlo model of the target station showing plan view. The plan view is taken at the elevation of the couple moderator.

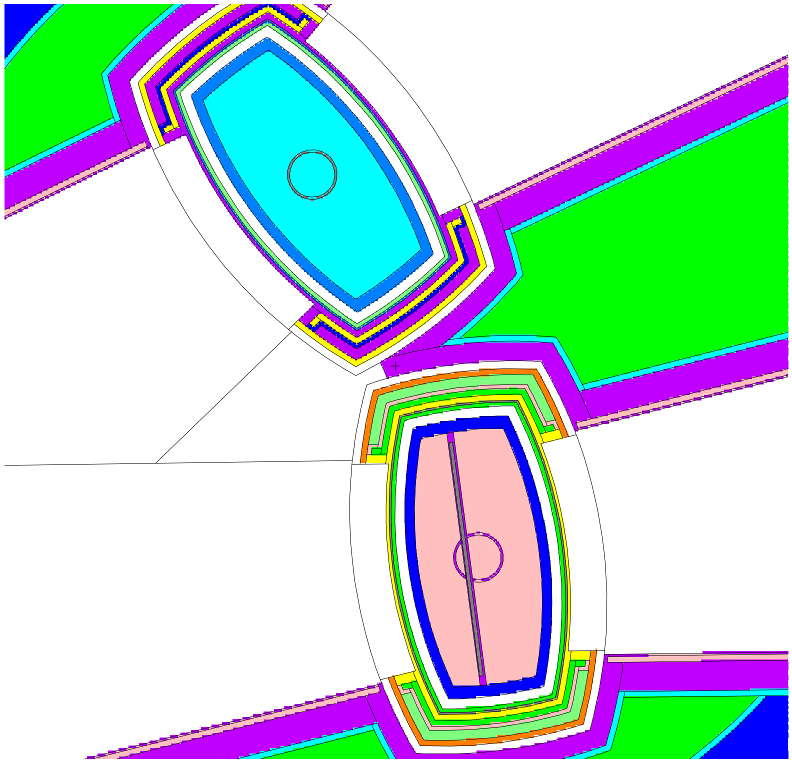

Figure 5: Monte Carlo model of the decoupled moderators and its surroundings showing plan view.

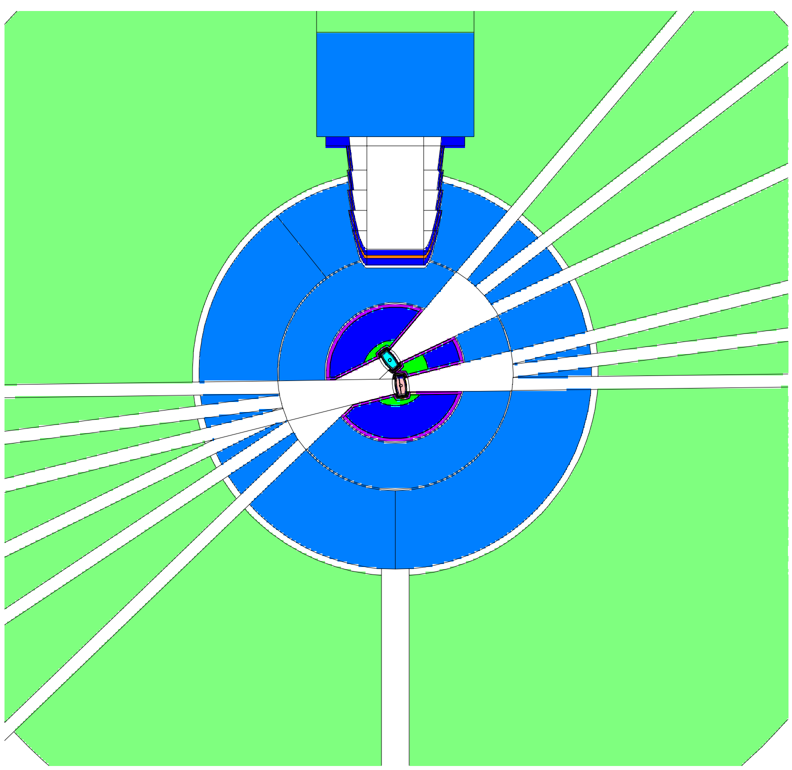

Figure 6: Monte Carlo model of the target station showing plan view. The plan view is taken at the elevation of the decoupled moderators.

Table 2: Calculational conditions for residual radioactive nuclide yield using DCHAIN-SP-2001

Item	tools and parameters
Proton beam power	1MW at proton beam windows
Operation time	5000 h
Cooling time	0 (= at the end of operation period)
Source Structural component	Reflector (Be and Iron), Aluminum alloy container, AIC, Cd (Mercury target and its container are not taken into consideration)

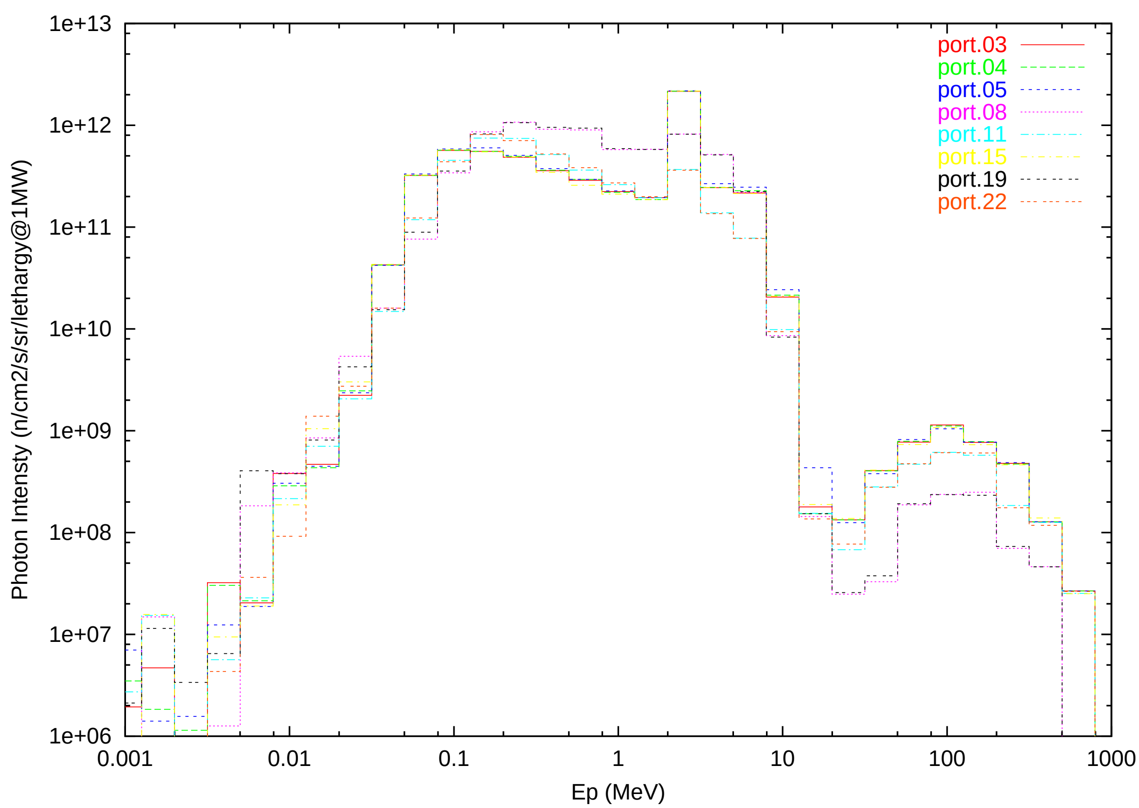

Figure 7: Calculated time-averaged photon spectra at the beam ports of No.3, 4, 5, 8, 11, 15, 19 and 22.

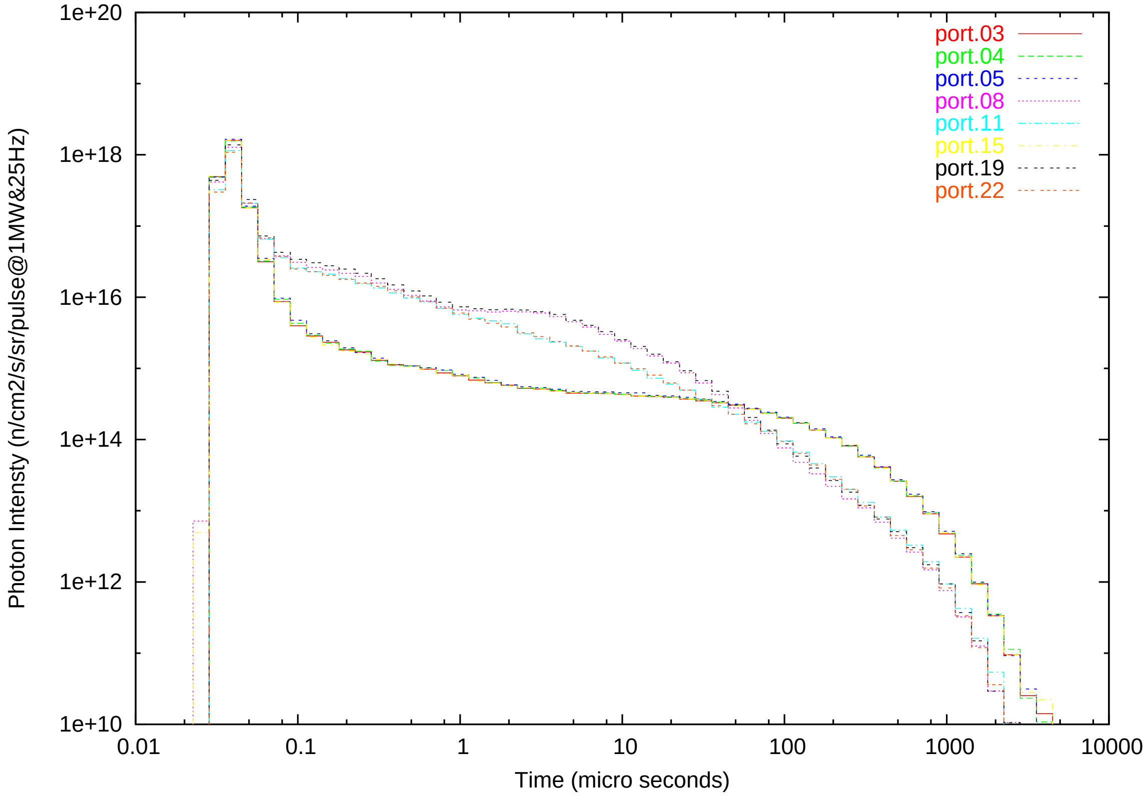

Figure 8: Calculated energy-integrated photon spectra at the beam ports of No.3, 4, 5, 8, 11, 15, 19 and 22.

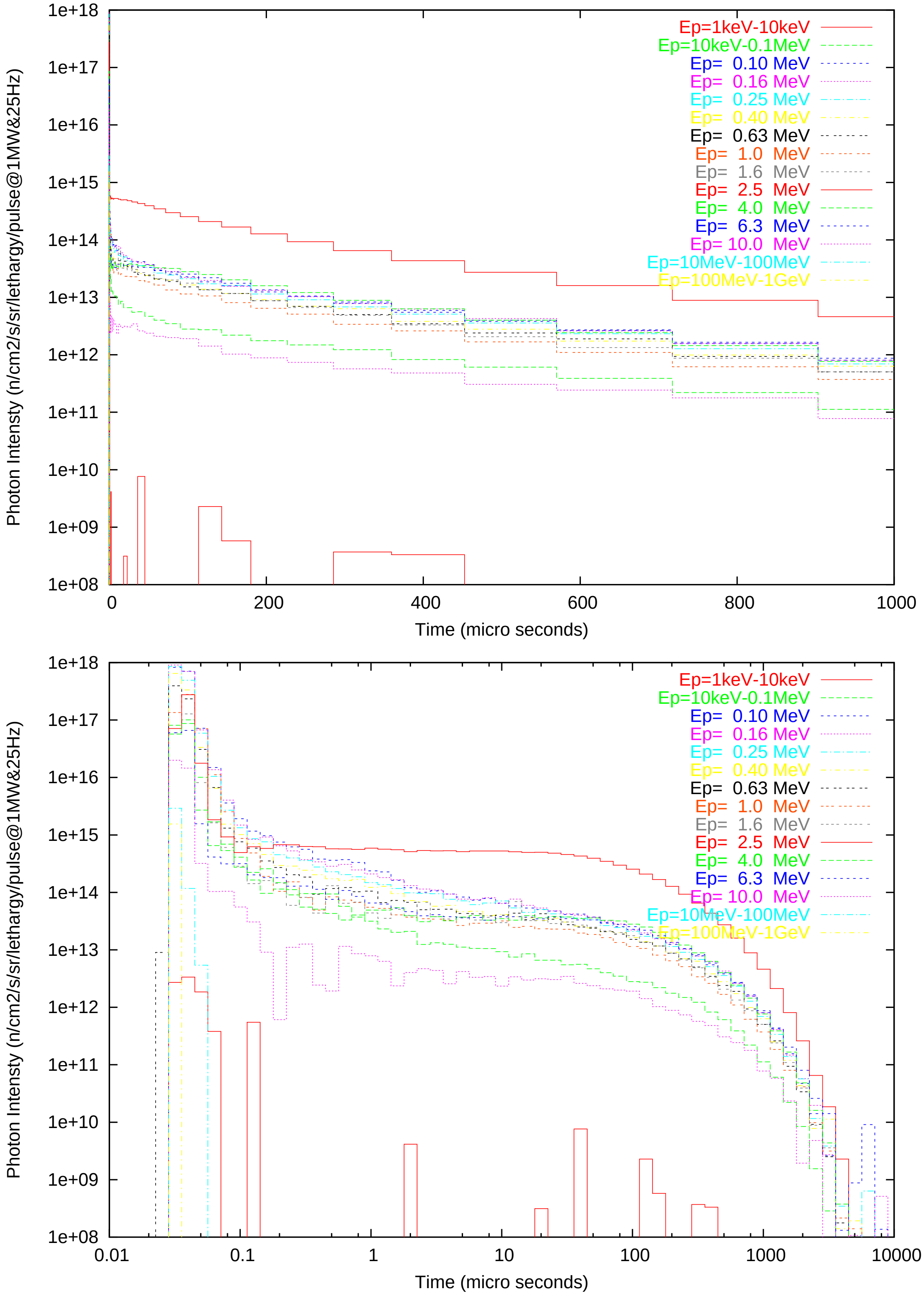

Figure 9: Calculated time spectra of photons in some energy bins at the beam ports of No.5. Upper is for the time range up to 1,000 μs, lower is up to 10,000 μs, respectively.

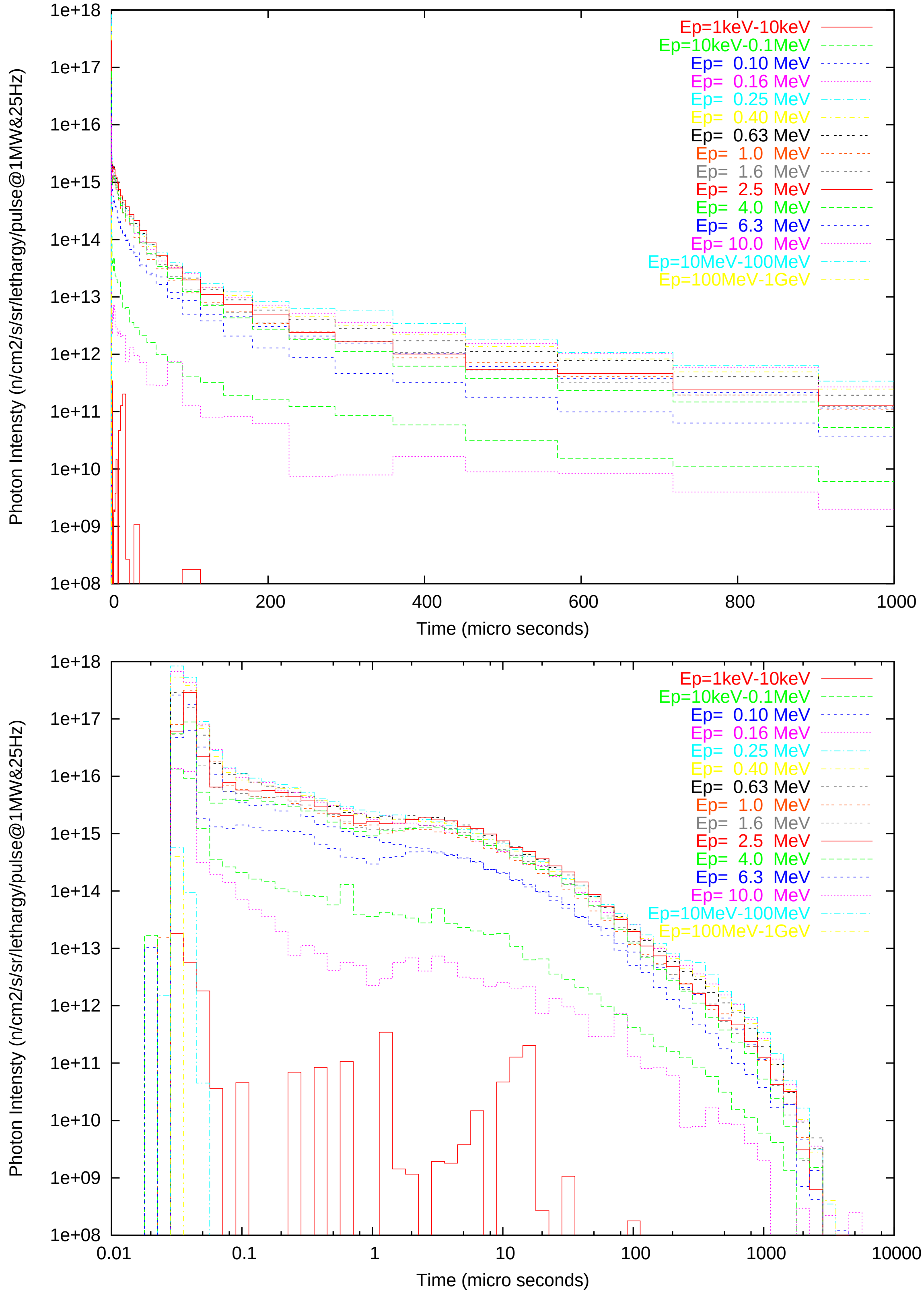

Figure 10: Calculated time spectra of photons in some energy bins at the beam ports of No.8. Upper is for the time range up to 1,000 μs, lower is up to 10,000 μs, respectively.

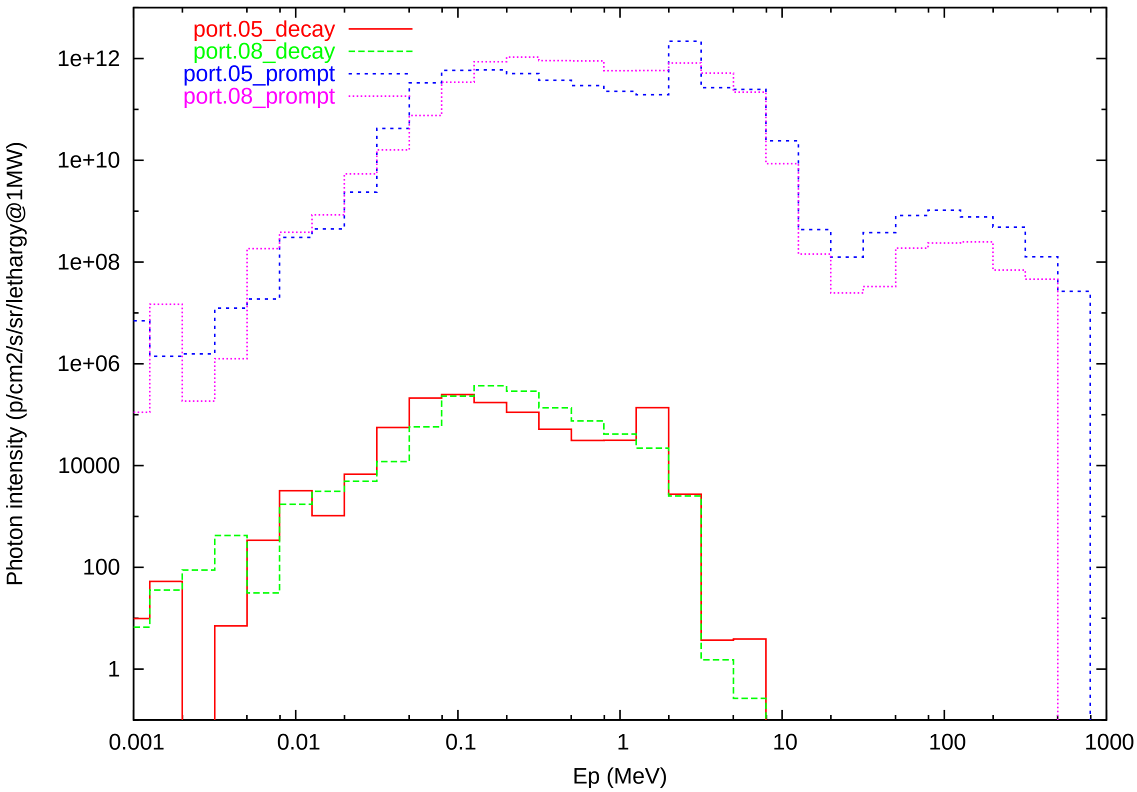

Figure 11: Calculated time averaged photon spectra of photons at the beam ports of No.5 and 8.

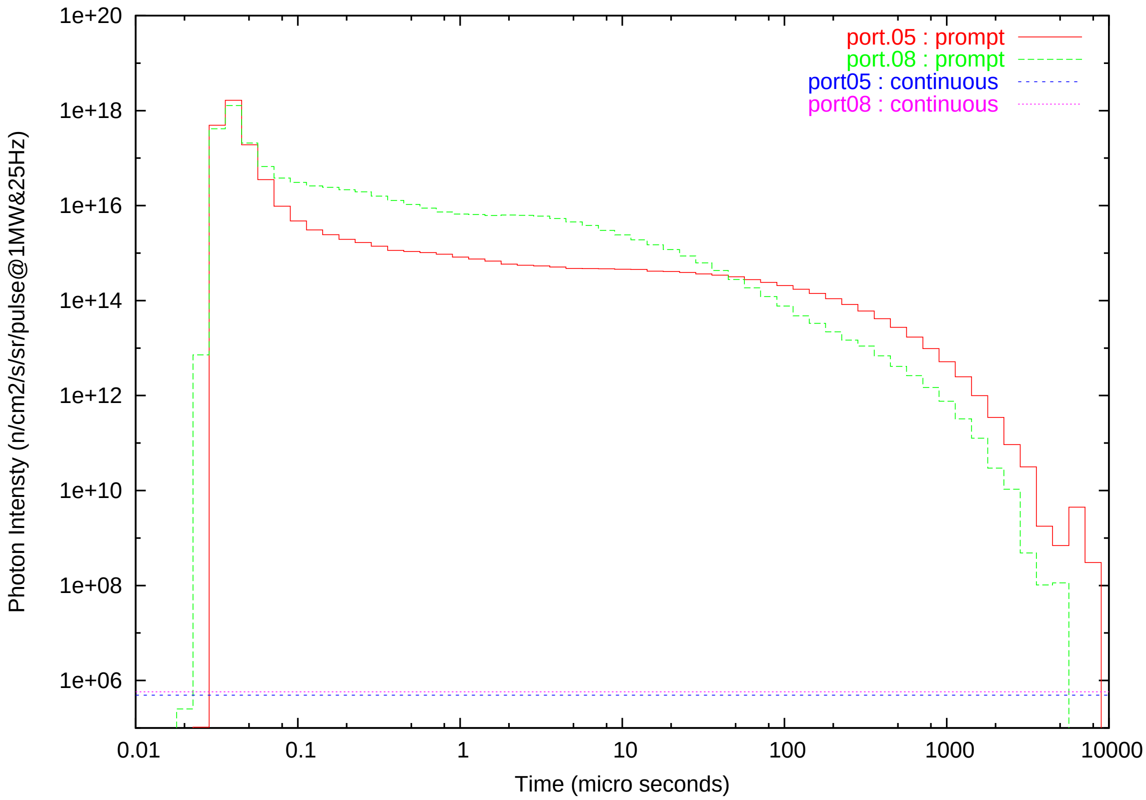

Figure 12: Calculated energy-integrated photon spectra of photons at the beam ports of No.5 and 8.