Detailed SNS Neutronics Calculations for Scattering Instrument Design
SNS/TSR-203
POI5 Configuration

E. B. Iverson

13 September 2000

This document describes the neutronic performance characteristics predicted for a particular configuration of moderators in the Spallation Neutron Source High Power Target Station (SNS-HPTS). The configuration described herein is denoted "POI5."

1 Model Description

Configuration POI5 includes four moderators, two of which are viewed from both sides. All moderators have nominal viewed faces of 100 mm (horizontal) by 120 mm (vertical). The inner reflector (out to a radius of ≈320 mm) is beryllium and is cooled with heavy water. This inner reflector is surrounded by heavy water-cooled lead. Table 1 summarizes relevant characteristics of the target station configuration used for this set of calculations. Table 2 summarizes this moderator configuration.

Proton Energy	1 GeV
Pulse Rate	60 Hz
Average Power	2 MW
Energy per pulse	34 kJ
Proton Beam Shape	rectangular
Proton Beam Size	200x70 mm^2
Proton Pulse	$\delta(t)$
Target	Hg
Inner Reflector	Be
I.R. Coolant	D_2O
Outer Reflector	Pb
O.R. Coolant	D_2O

Table 1: Target station parameters used in calculations. All normalizations are performed per 34 kJ-pulse.

The top upstream moderator is cadmium-decoupled hydrogen at 20 K and has curved viewed surfaces. The moderator material has a maximum thickness of 65 mm, and an average thickness of about 55 mm. The moderator is poisoned with gadolinium at the centerline and is viewed from both sides.

Beam-line	Moderator Location	Moderator Material	Temperature (K)	Decoupling Material	Poison Material	Poison Depth (mm)
2	TU	H_2	20	Cd	Gd	27
5	TD	H_2	20	–	–	–
8	BU	Composite	–	Cd	Gd	30
11	TU	H_2	20	Cd	Gd	27
14	BD	H_2O	300	Cd	Gd	27
17	BU	Composite	–	Cd	Gd	30

Table 2: Moderator summary. Hydrogen is 20–27 K supercritical, modeled as 20 K liquid. Water is 300 K liquid.

The top downstream moderator is fully coupled unpoisoned hydrogen at 20 K, and is viewed from one side only. This moderator also has a curved viewed surface, with maximum thickness of 65 mm, and an average thickness of about 55 mm. This moderator also has approximately 20 mm of light water surrounding it as premoderator.

The bottom upstream moderator is a hydrogen-water composite, viewed from both sides, in which a 12.5 mm layer of hydrogen at 20 K forms each viewed surface, as shown in Figure 1. Each hydrogen layer is closely backed by a central layer of water 37.5 mm thick at 300 K. The moderator is decoupled with cadmium. In the base POI5 configuration, the moderator is poisoned with gadolinium in the center of the water layer. Other configurations have been studied; comparisons between different poison scenarios for the composite moderator appear elsewhere.

The bottom downstream moderator is cadmium-decoupled, gadolinium-poisoned water at 300 K, and has a curved viewed surface. The moderator material has a maximum thickness of 65 mm, and an average thickness of about 55 mm. The moderator is poisoned with gadolinium at the centerline and is viewed from both sides.

2 Calculational Techniques

The simulations reported are the results of calculations using the MCNPX code from LANL (version 2.1.5). The spectral intensities shown result from calculations using point detector tallies located 5 m from the viewed surface of the moderator. The emission time distributions (pulse shapes) come from current tallies on the viewed surface of the moderator material, and are averaged over 2π steradians. Weight windows to accelerate the pulse shape calculations were generated by separate iterative runs using MCNP 4B in parallel mode on a large cluster of machines with a neutron-only source term. MCNPX runs using these weight windows produced the reported results, which have further been scaled (from the point detector calculations) to correspond to the peak intensity coming off of the moderator face in the normal direction, rather than the average over 2π steradians. Each moderator nominally requires a unique set of weight windows, and thus a unique set of runs, although in some runs, the results for moderators other than the one for which the weight windows were optimized are adequately sampled.

3 Parametric Descriptions

The calculated spectra, as shown in Section 6, can be described moderately well by the function

$$i(E) = I_{\rm epi} \left(R \frac{E}{(kT)^2} e^{-E/kT} + \Delta(E) \frac{1}{E^{1-\alpha}} \right), \tag{1}$$

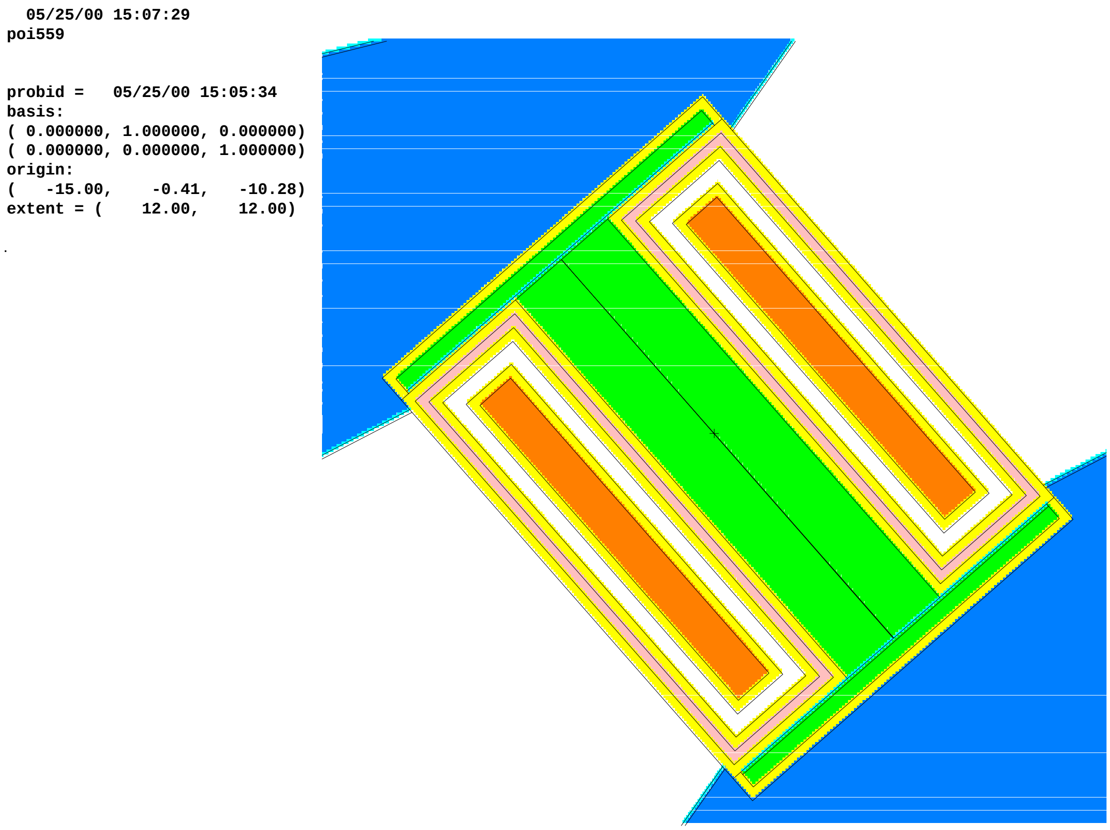


Figure 1: Composite moderator configuration. The viewed layers are supercritical hydrogen, the central region is liquid water. The central line shows the poison location.

a combination of a slowing-down spectrum and a Maxwellian, using a generalized Westcott joining function $\Delta(E)$,

$$\Delta(E) = \frac{1}{1 + (E_{\rm co}/E)^s}. \tag{2}$$

Parameters resulting from such fits are shown in Table 3. The most important parameters include the characteristic energy kT of the Maxwellian and the thermal flux ratio R, which define the shape of the spectra, and the moderator coupling $I_{\rm epi}$, which serves as an overall intensity factor. It should be noted that R is the ratio of the thermal flux integral to the flux per unit energy at unit energy.

The parametric fits to the spectral intensities appear in Figure 2. As mentioned above, the quality of the fits is only moderate, but can certainly be trusted to better than a factor of two over the given energy range.

ID	Beam-lines	Moderator	I_{epi} (n/ster/eV/pulse)			kT (meV)			R		
source_poi264_bd_14_03	15BD	Water	8.6×10^{11}	$\pm$	3.7%	35	$\pm$	1.7%	4.9	$\pm$	4.2%
source_poi503_bu_17_03	9/17BU	Composite	1.6×10^{12}	$\pm$	1.5%	8.5	$\pm$	5.6%	1.4	$\pm$	8.3%
source_poi203_td_05_03	5TD	Coupled H_2	9.5×10^{11}	$\pm$	4.0%	5.6	$\pm$	2.2%	9.2	$\pm$	5.2%
source_poi203_tu_11_03	2/11TU	Decoupled H_2	9.1×10^{11}	$\pm$	3.7%	4.3	$\pm$	4.3%	1.2	$\pm$	6.0%

Table 3: Spectral parameterizations of moderator performances. Uncertainties quoted are percentages (1σ) and reflect only the statistical precision of the Monte Carlo calculation and the quality of the fit.

4 Extrapolation

The results of the various simulations are reported, both here and in the source files, over a broad range energies. In the event that results for energies outside this range are desired, certain extrapolations are reasonable. Spectra can be extrapolated to higher energies by using a simple power law, as they are very nearly, but not exactly, $1/E$ up to energies of approximately 100 keV. Emission time distributions can in general be assumed to be invariant as a function of vt (velocity multiplied by time), equivalent to t/λ. However, the proton pulse at SNS is not actually a delta function in time, but rather has a width of a few hundred nanoseconds. Neutron pulse shapes for energies above 10 eV or so will be influenced by this proton pulse shape, while neutron pulse shapes for energies above 300 eV or so will be completely dominated by the proton pulse shape, and thus will be invariant as a function of time.

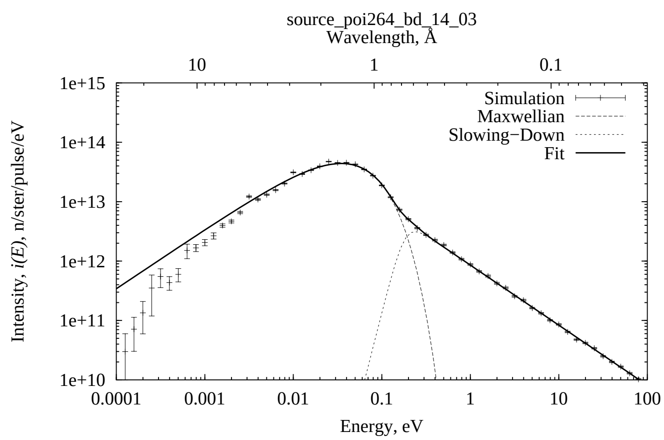
At low energies, the spectral intensity from the water moderator (Figure 2(a)) can be assumed to follow a Maxwellian distribution. The points shown below 1 meV are extremely undersampled, as indicated by the large error-bars, and thus can be assumed to be underestimated. The low-energy intensity from the remaining moderators can be extrapolated with a power law relationship from the data shown, and will likely not correspond to Maxwellians with parameters from Table 3.

5 Data Availability

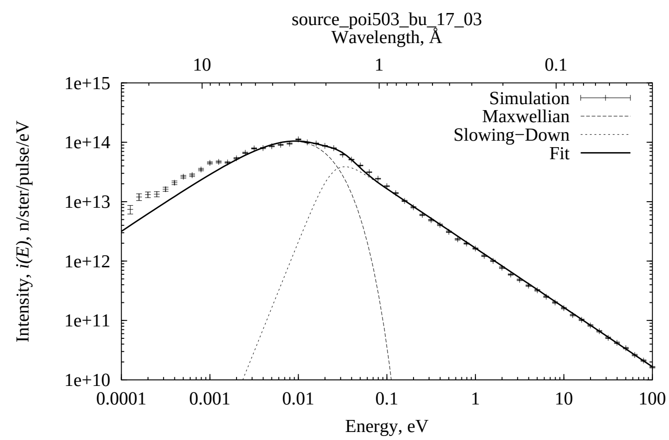
These results are available electronically as “source files;” ASCII files containing the spectra and emission time distributions, with comments showing the file format. Each moderator is represented by a single source file. These source files can be downloaded from http://www.sns.anl.gov under “R&D Projects.”

6 Detailed Spectra and Pulse Shapes

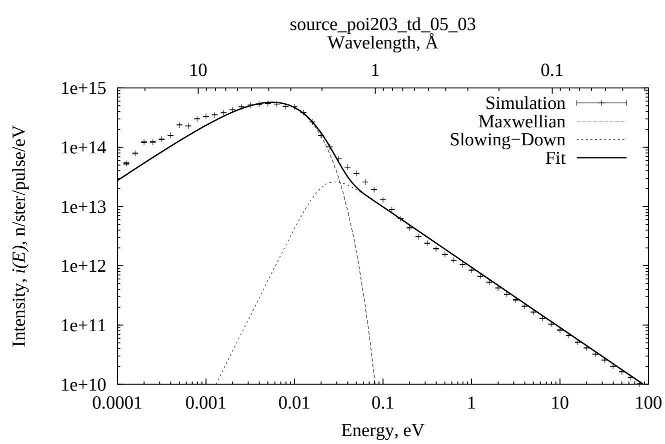
The detailed spectra and pulse shapes as produced by the simulation appear below. These data are completely unprocessed, and appear exactly as they result from the calculations. The results for beamlines 2 and 11 are nominally identical; only results for beamline 11 are reported. Similarly, results for beamline 17 should be used for beamline 8. Pulse widths (from Figure 3(b)) are poorly estimated at low energies, as the pulse shapes themselves are statistics-limited.



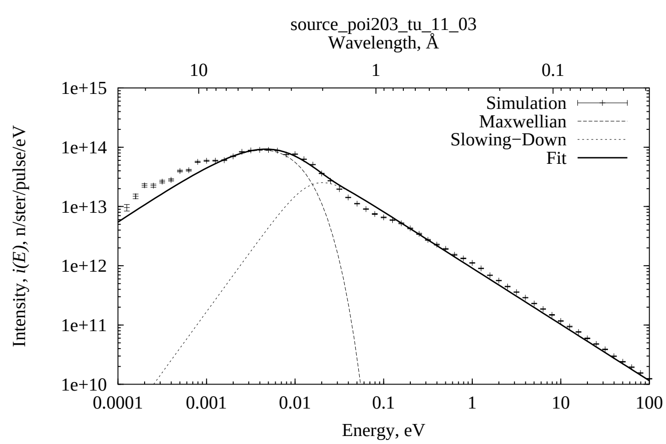
(a) Water



(b) Composite

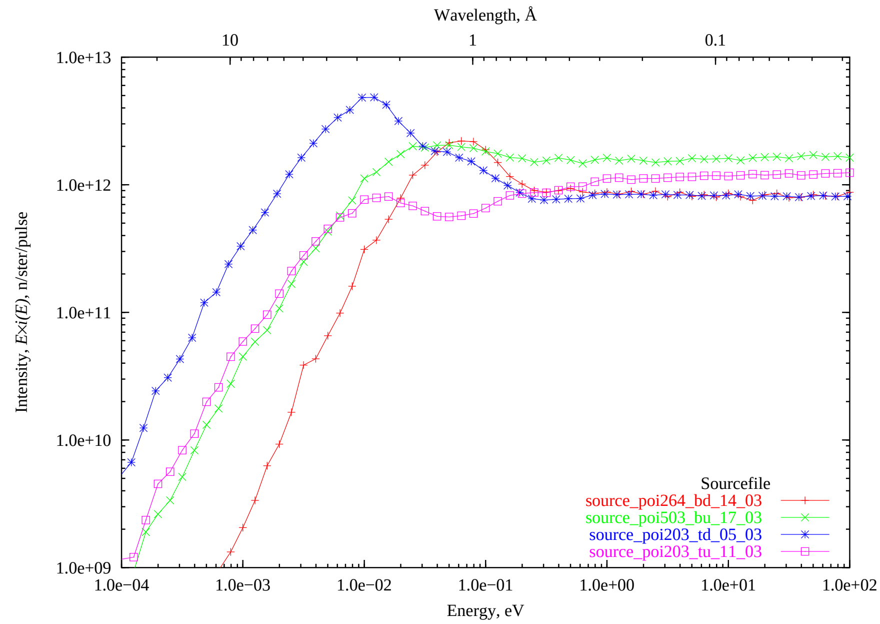


(c) Coupled Hydrogen

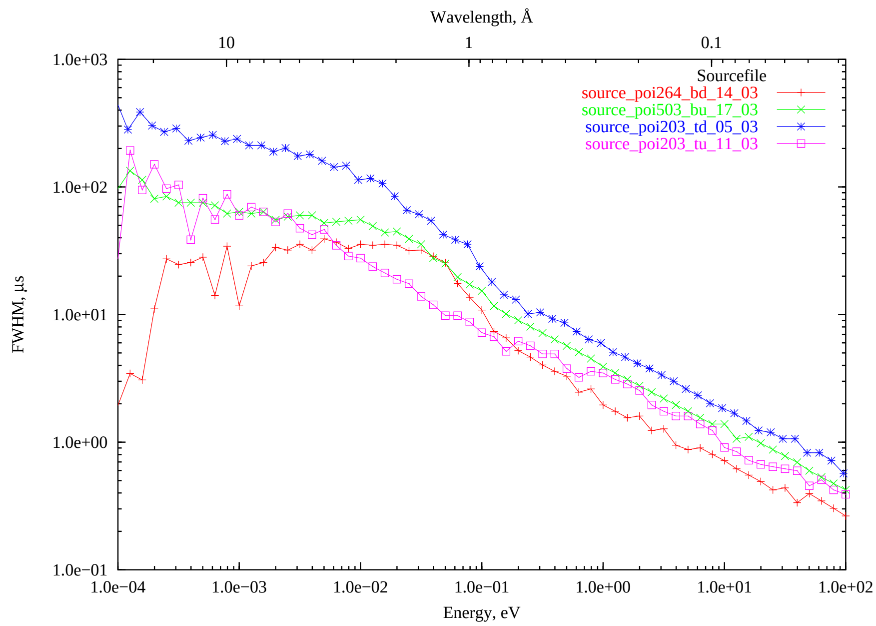


(d) Decoupled Hydrogen

Figure 2: Parametric fits to the spectral intensities.



(a) Intensity



(b) Pulse Width

Figure 3: Intensity (per unit lethargy) and pulse widths as functions of energy for all moderators. The water moderator is denoted source_poi264_bd_14_03, the composite source_poi503_bu_17_03, the coupled hydrogen source_poi203_td_05_03, and the decoupled hydrogen source_poi203_tu_11_03.

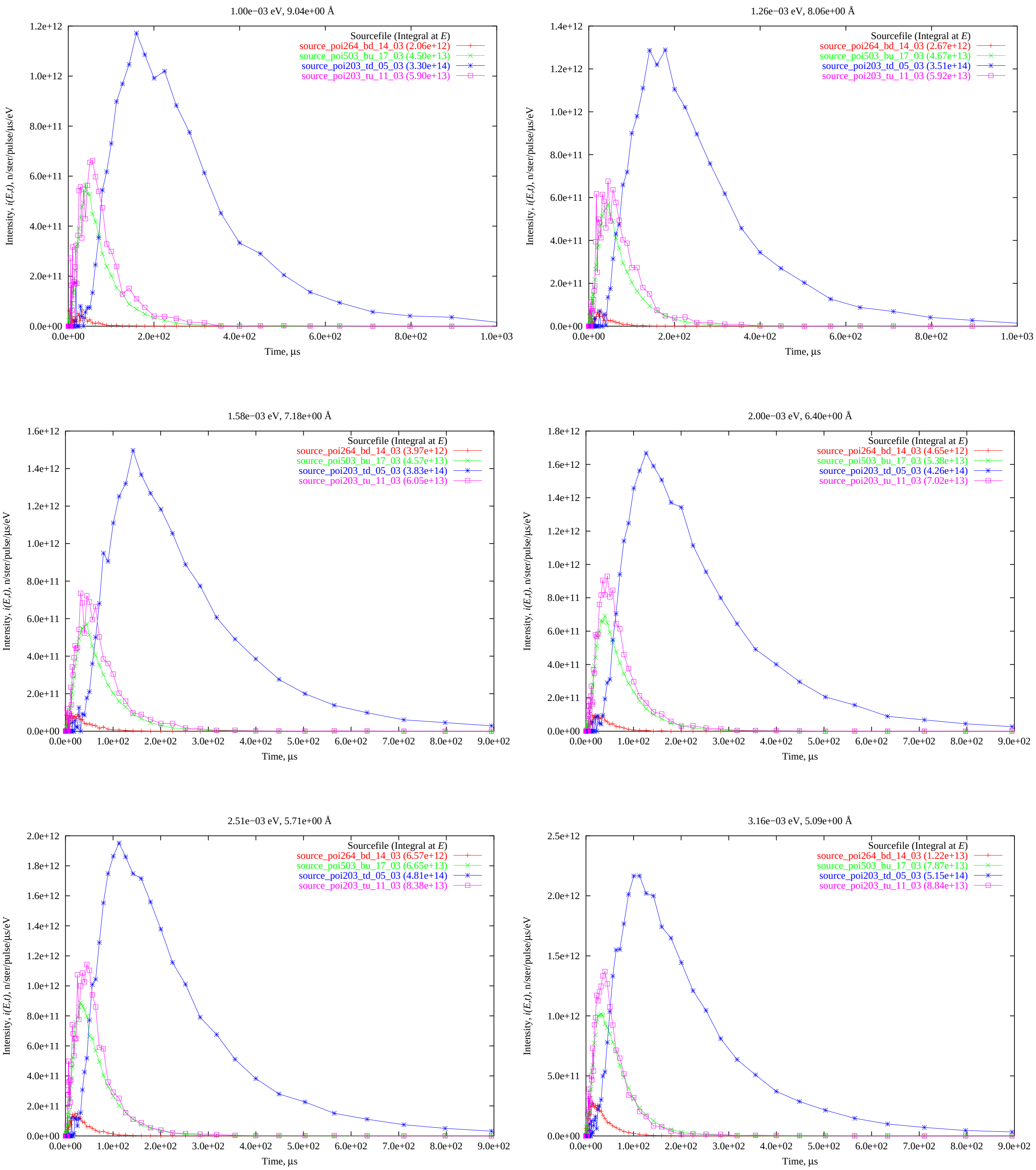


Figure 4: Emission time distributions. The water moderator is denoted source_poi264_bd_14_03, the composite source_poi503_bu_17_03, the coupled hydrogen source_poi203_td_05_03, and the decoupled hydrogen source_poi203_tu_11_03.

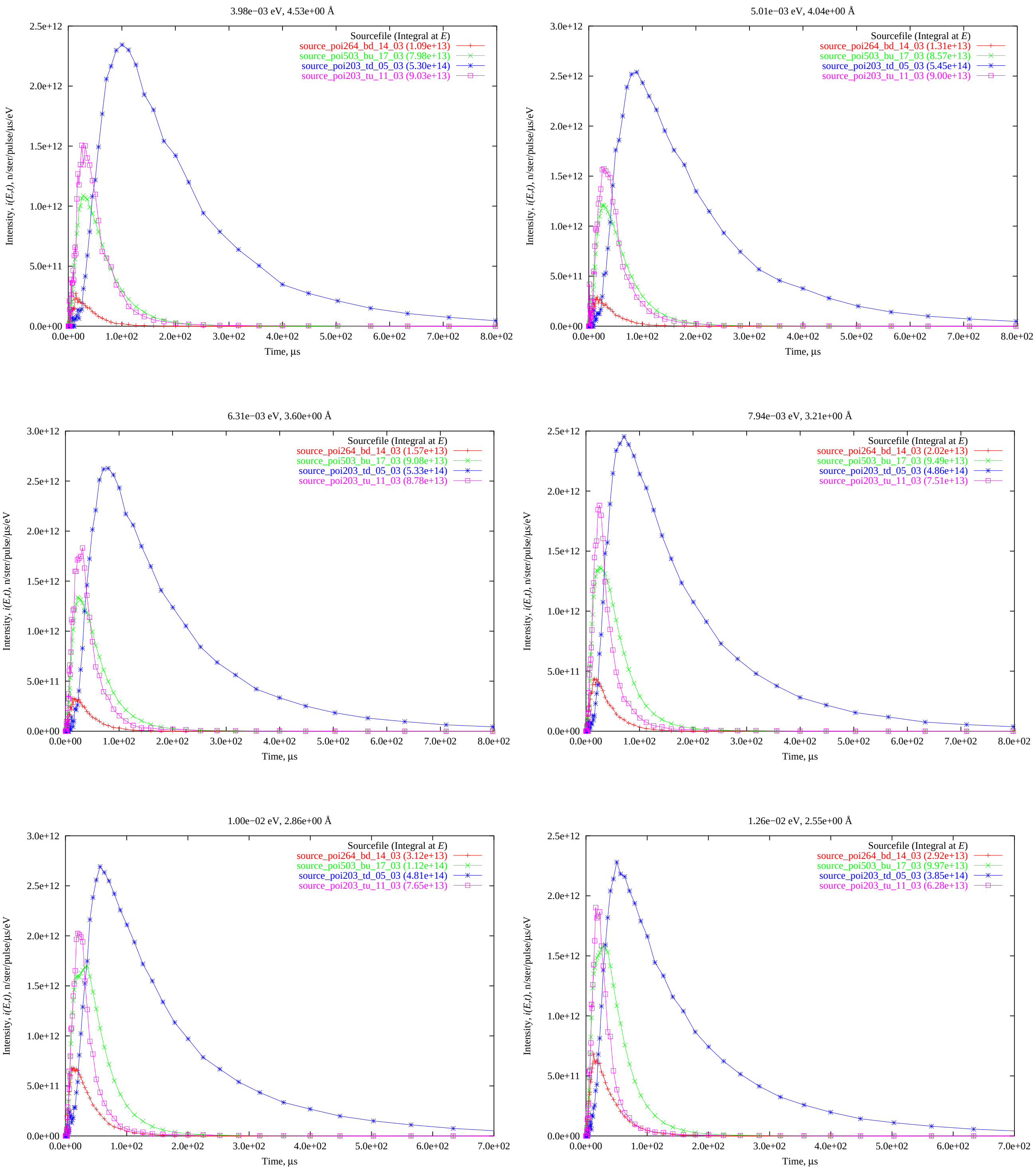


Figure 5: Emission time distributions. The water moderator is denoted source_poi264_bd_14_03, the composite source_poi503_bu_17_03, the coupled hydrogen source_poi203_td_05_03, and the decoupled hydrogen source_poi203_tu_11_03.

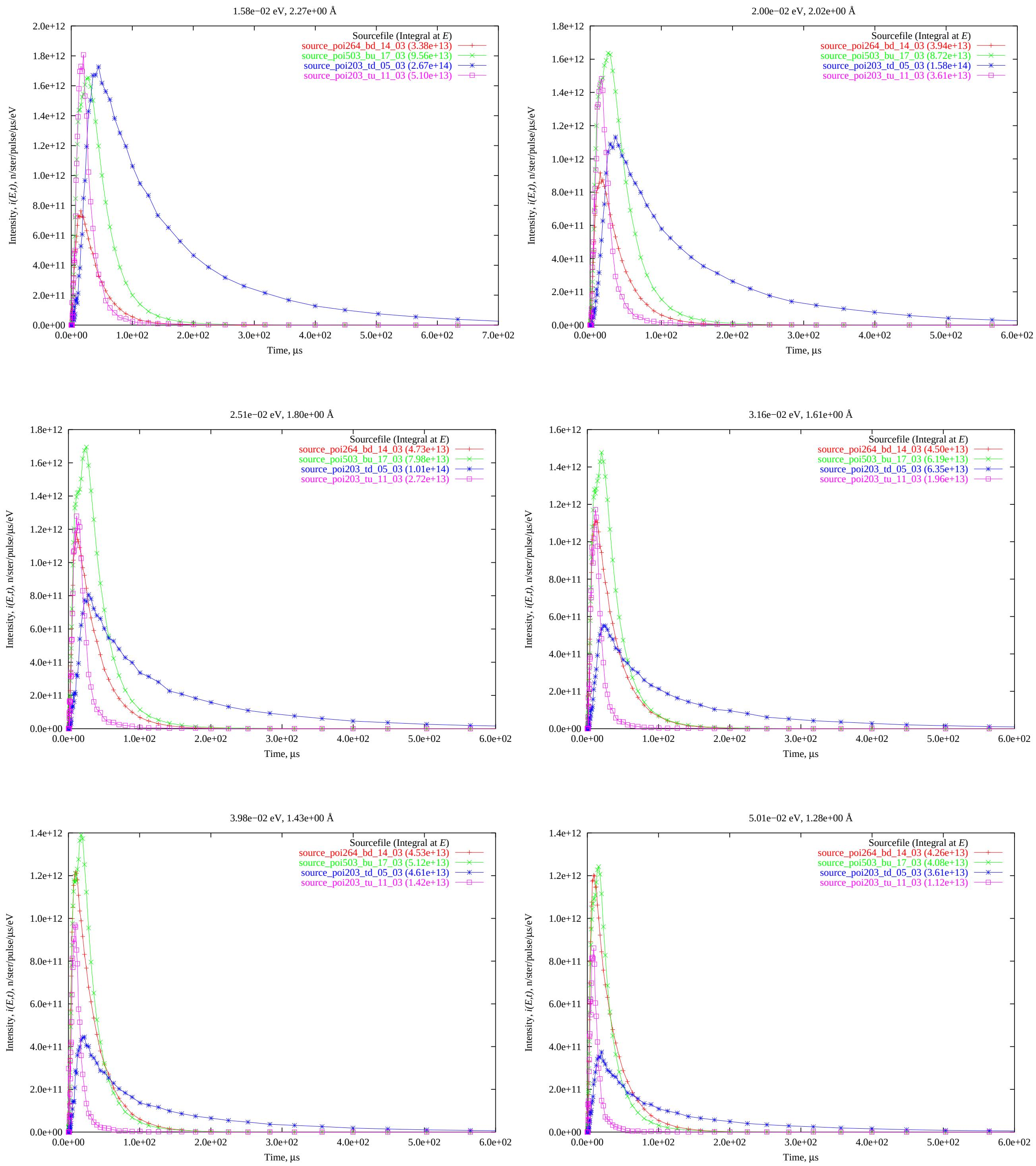


Figure 6: Emission time distributions. The water moderator is denoted source_poi264_bd_14_03, the composite source_poi503_bu_17_03, the coupled hydrogen source_poi203_td_05_03, and the decoupled hydrogen source_poi203_tu_11_03.

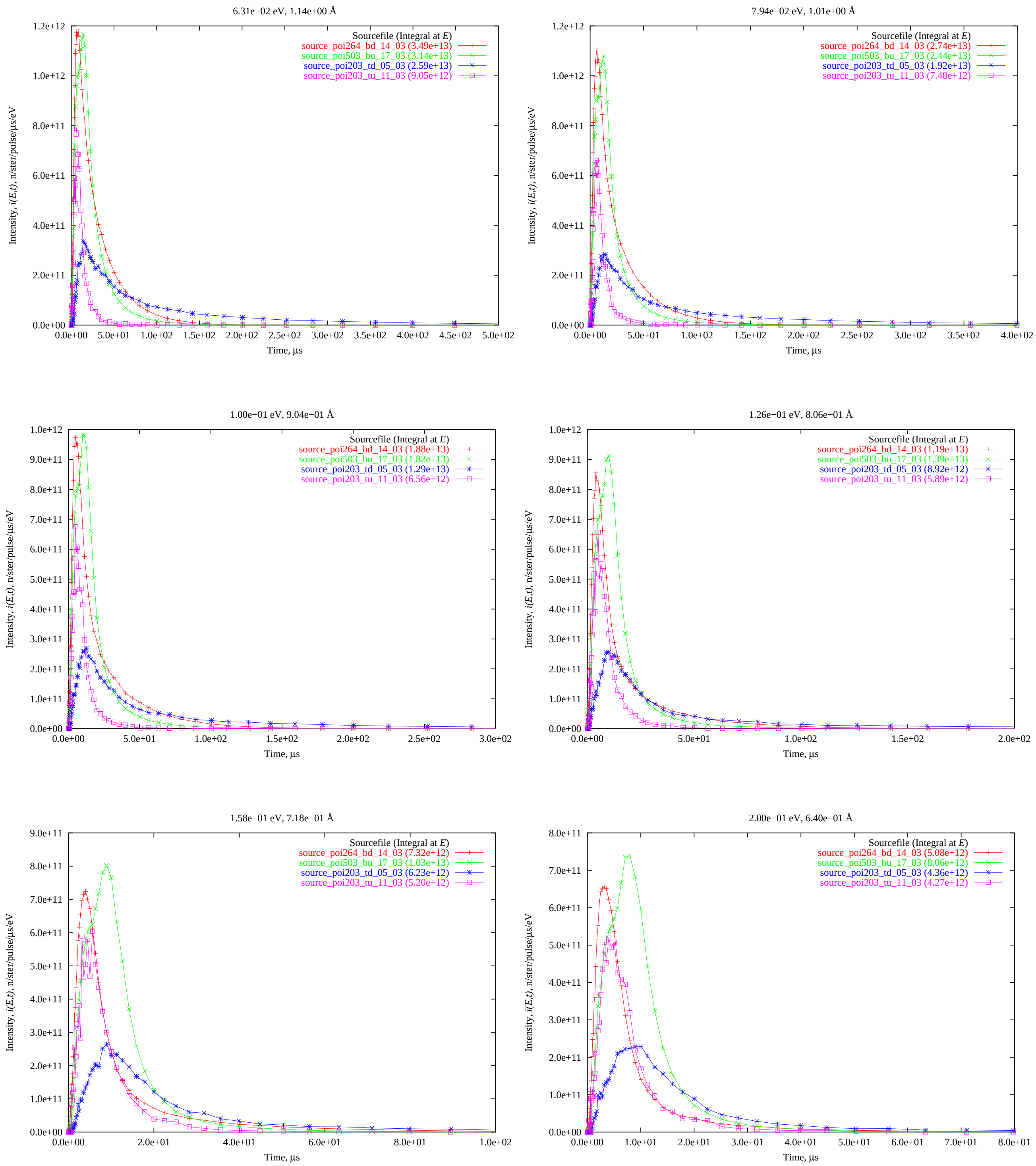


Figure 7: Emission time distributions. The water moderator is denoted source_poi264_bd_14_03, the composite source_poi503_bu_17_03, the coupled hydrogen source_poi203_td_05_03, and the decoupled hydrogen source_poi203_tu_11_03.

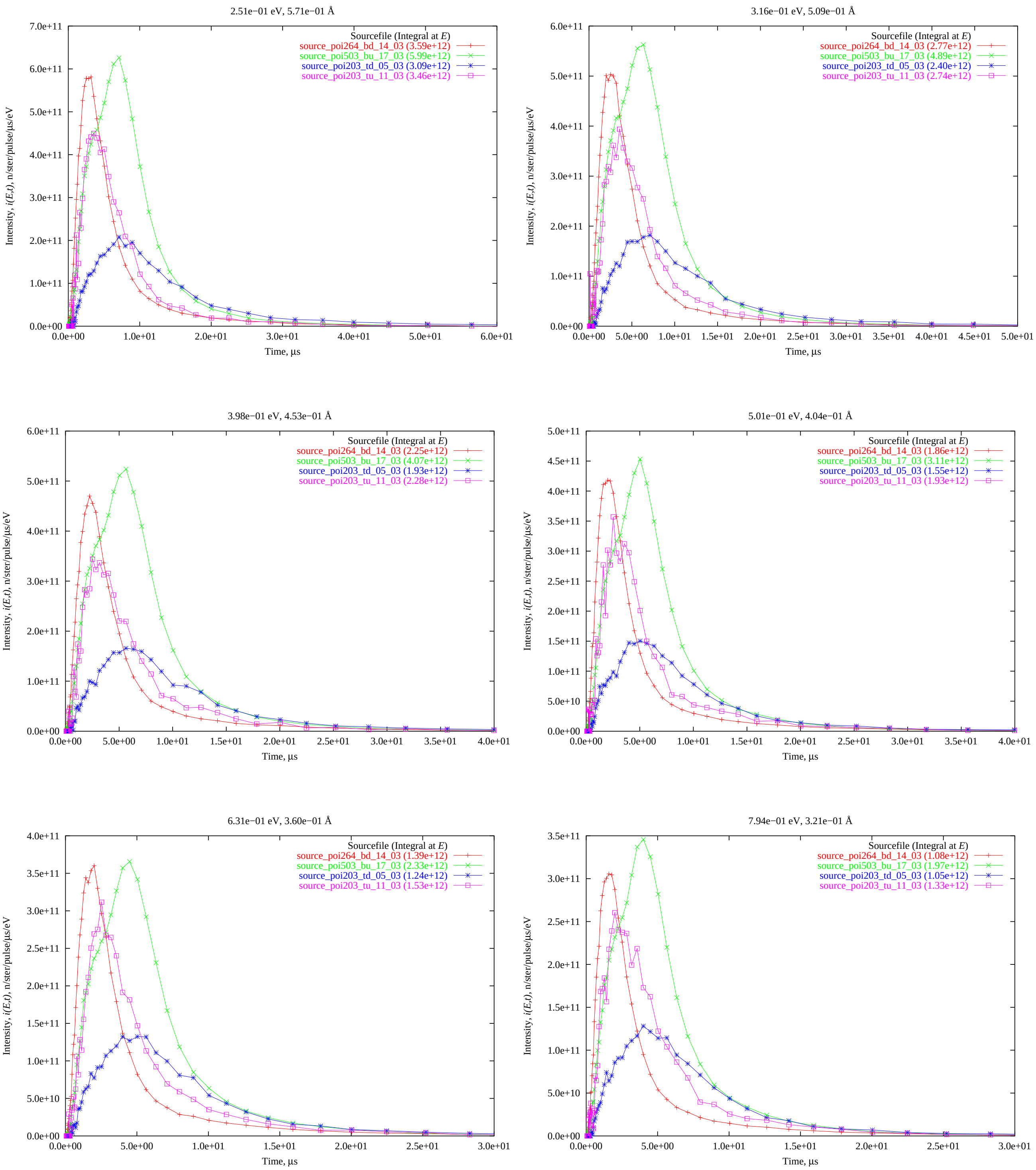


Figure 8: Emission time distributions. The water moderator is denoted source_poi264_bd_14_03, the composite source_poi503_bu_17_03, the coupled hydrogen source_poi203_td_05_03, and the decoupled hydrogen source_poi203_tu_11_03.

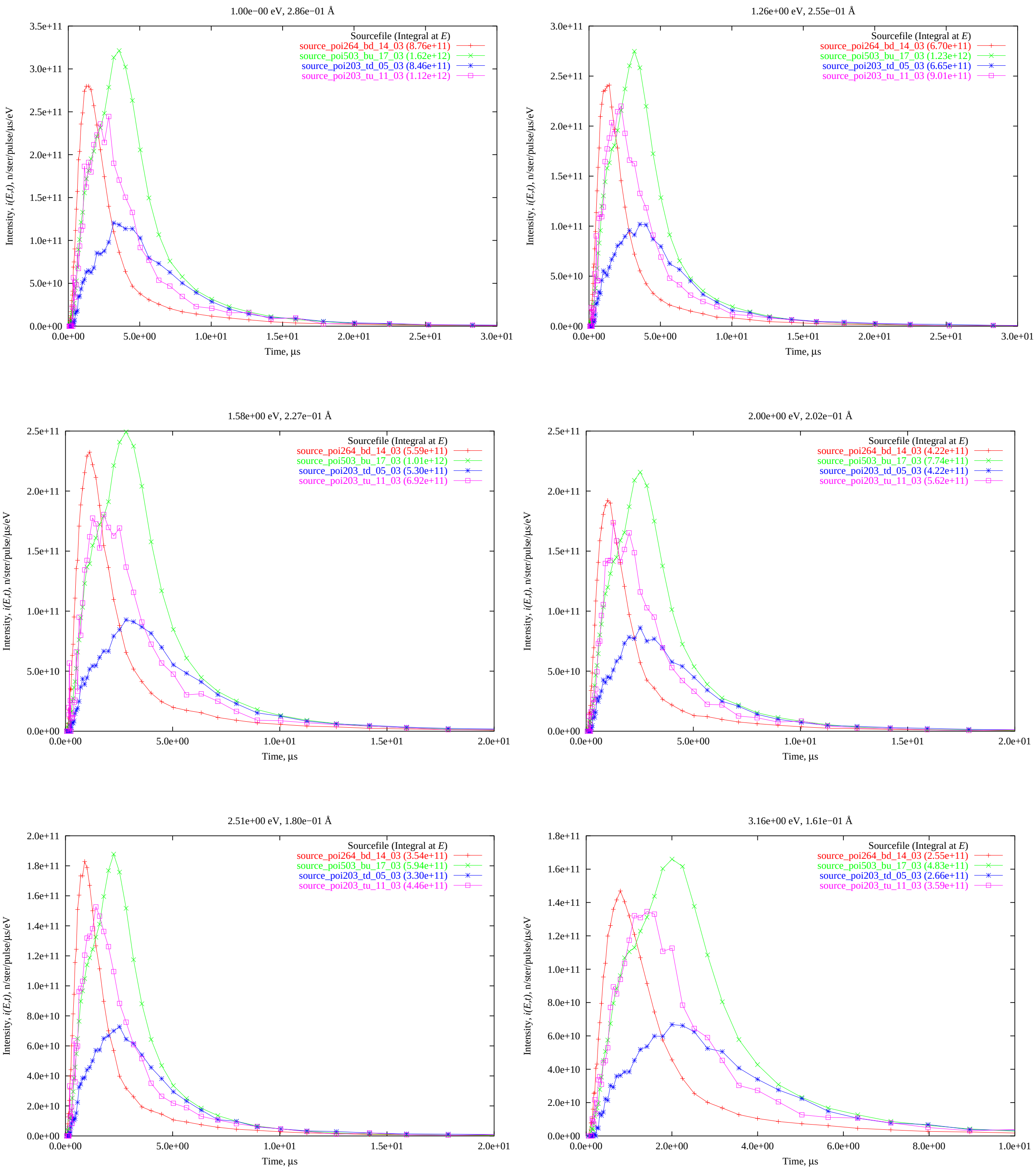


Figure 9: Emission time distributions. The water moderator is denoted source_poi264_bd_14_03, the composite source_poi503_bu_17_03, the coupled hydrogen source_poi203_td_05_03, and the decoupled hydrogen source_poi203_tu_11_03.

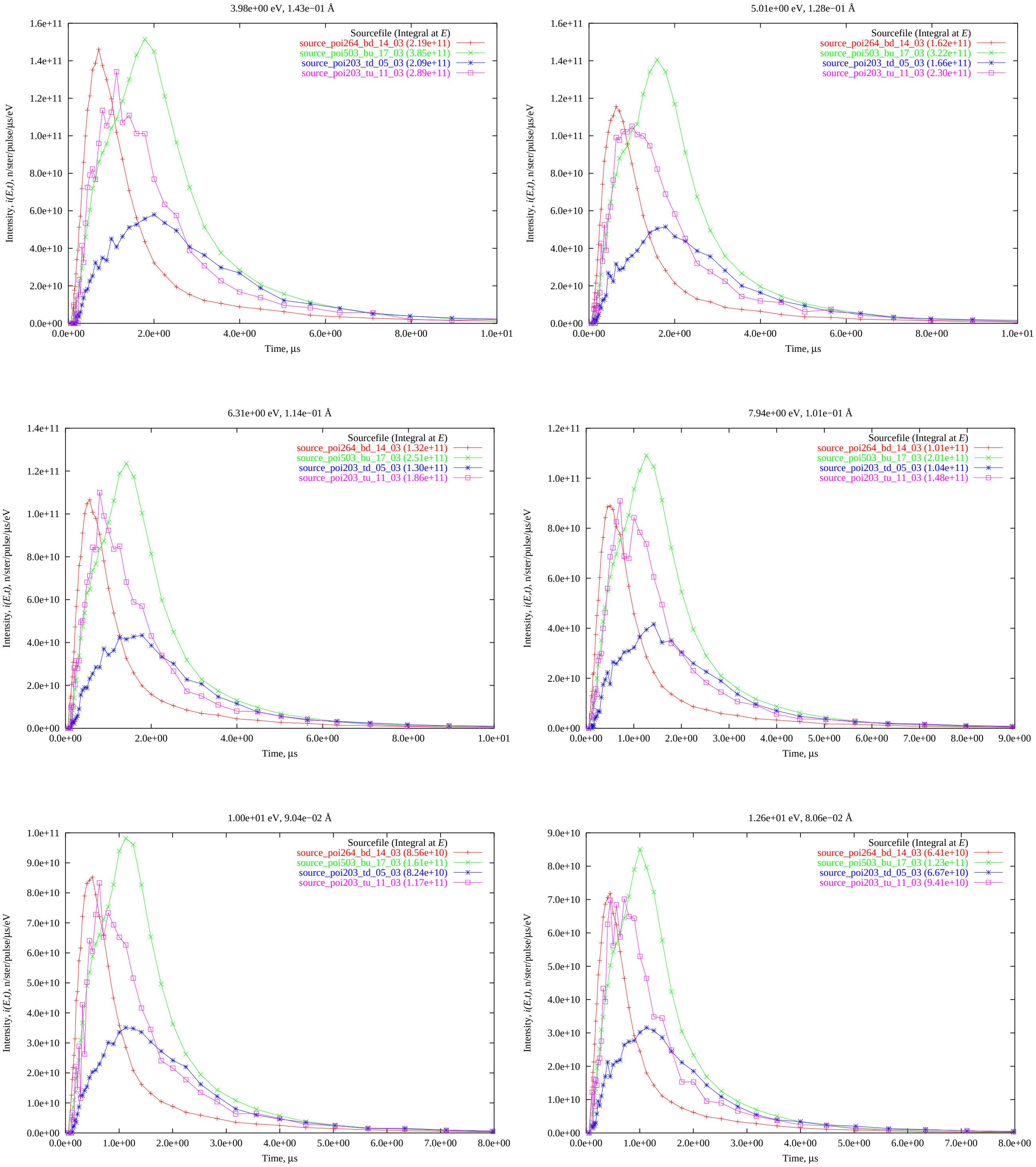


Figure 10: Emission time distributions. The water moderator is denoted source_poi264_bd_14_03, the composite source_poi503_bu_17_03, the coupled hydrogen source_poi203_td_05_03, and the decoupled hydrogen source_poi203_tu_11_03.

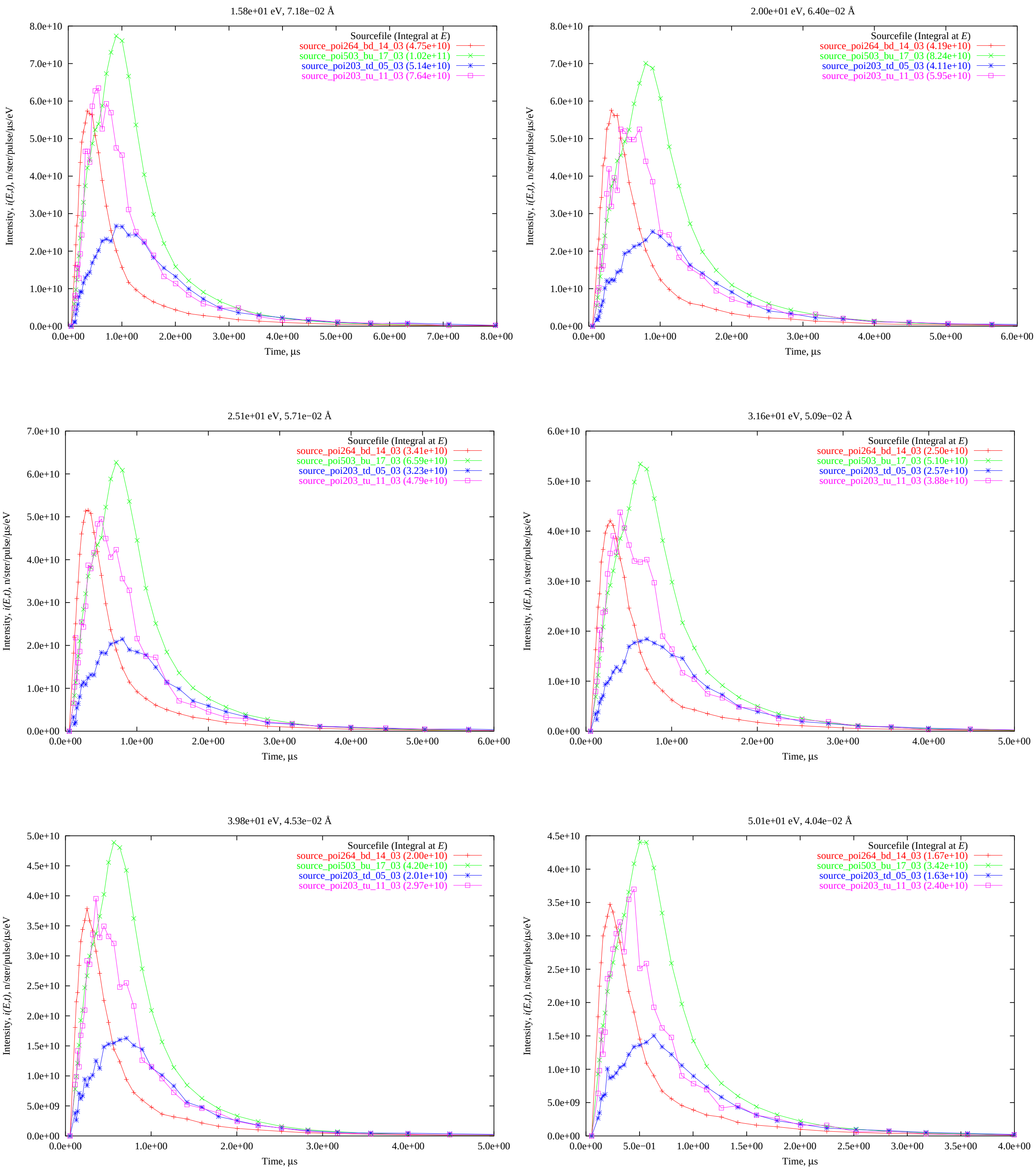


Figure 11: Emission time distributions. The water moderator is denoted source_poi264_bd_14_03, the composite source_poi503_bu_17_03, the coupled hydrogen source_poi203_td_05_03, and the decoupled hydrogen source_poi203_tu_11_03.