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# #10-111 Ultra-short/Ultra-high X-ray pulse spectrometry based upon FDS/OSL spectrometer and Bayesian unfolding algorithms: assessment of ML-EM and MAP-EM algorithms for spectrum reconstruction

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The spectrometry of X-ray pulses is hindered whenever ultra-high dose rate or ultra-short pulses are involved because of electronics dead time and pile-up phenomena occurring in PHAs (Pulse Height Analyzers). Ultra-High dose rates (i.e. 1 MGy/s) are produced by dedicated Linear Accelerators (LINACs) for Flash Therapy or fast X-ray imaging purposes, for instance. Ultra-Short X-ray pulses are encountered with femtosecond (fs) laser-based X-ray sources. An intense laser power (~TW ($10^{12}$ W)) is achieved by focusing the light from a fs titanium-sapphire (Ti-Sa) laser in a gas, leading to plasma generation and wakefield electron acceleration (Laser Plasma Acceleration –LPA). The electron bunch is eventually projected onto a metal target (most often tungsten) to generate Bremsstrahlung.
In the context of the European MULTISCAN 3D Project, CEA List designed and qualified an online X-ray spectrometer for assessing the spectral behavior of X-ray beams generated by fs-LPA processes. The Filter-Detector Stack (FDS) spectrometer consists in alternating metal filters (stainless steel, molybdenum, tantalum and tungsten) with passive OSL/FO (Optically Stimulated Luminescence/Fiber Optics) sapphire detectors. We describe its complete design in another paper of the same conference. The X-ray spectrometer hosts 16 OSL/FO detector probes providing an experimental dose vector from which we reconstruct the X-ray spectrum with the help of Bayesian unfolding algorithms: Maximum Likelihood Expectation Maximization (ML-EM), Maximum A Posteriori Expectation Maximization (MAP-EM). Such algorithms involve an inversion matrix (16x25) whose coefficients are determined by Monte Carlo modeling (MCNP6, PHITS) to account for both probe/filter attenuation and build-up within the spectrometer body (including 5-cm-thick lateral lead shield and a 10-cm-thick lead collimator). Those algorithms are well suited to ill-posed inversion problems like spectrum reconstruction, as they allow the incorporation of a priori information and constraints. For continuous spectra such as Bremsstrahlung, a guess spectrum (associated with the assumption of spectral smoothness) facilitates the convergence process. Compared to other inversion techniques, these algorithms offer the advantage of both noise and uncertainties management, leading to more stable and accurate solutions.
The resulting energy spectrum is divided in 25 energy bands. In the low-energy part of the spectrum (up to 1.5 MeV), the energy bin is 100 keV, whereas it is 500 keV in the range [1.5 MeV- 3 MeV] and 1 MeV up to 10 MeV. We applied variance reduction techniques, including the Weight-Window (WW) generation method provided in PHITS, to improve statistical convergence and simulation efficiency.
The X-ray FDS spectrometer has been qualified up to 10 MeV using radionuclide sources ($^{192}$Ir, $^{60}$Co, and $^{137}$Cs) and a Varian LINAC (6 MV, 9 MV). The reconstructed spectrum of the iridium source was consistent with simulations, with a mean energy deviation within an acceptable range. However, for cobalt and cesium, additional environmental factors were considered in the simulations, as these sources are housed in a steel casing with an aperture, which affects the spectra received by the spectrometer. Final tests are planned with a fs Ti-Sa laser (SHERIL installation) to fully characterize the LPA process for US X-ray generation.
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