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#10-110 Ultra-short/Ultra-high X-ray pulse spectrometry based upon FDS/OSL spectrometer and Bayesian unfolding algorithms: spectrometer design and online X-ray source qualifications

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X-ray spectrometry is routinely performed with fast scintillators associated with Pulse Height Analyzers (PHAs). A PHA discretizes the signal amplitude (proportional to the energy of the incoming photon) and counts the number of pulses incoming in each register, thus generating a pulse-height energy spectrum. In practice, the combination of scintillator and electronics imposes a dead time between successive pulses (period during which no counting is possible). Although 100-MHz count rates are achieved with the fastest electronics and scintillators (rise & fall times of several tens of nanoseconds), significant pile-up occurs under ultra-high-count rate situations, thus hindering routine PHA spectrometry.
X-ray spectrometry already proves difficult with conventional Linear Accelerators (LINACs) delivering peak dose rates of about 10 kGy/s (mean dose rate ~ 10 mGy/s). It is an even more challenging task with dedicated LINACs delivering ultra-high dose rates of about 1 MGy/s (mean dose rates of some Gy/s), e.g. for Flash Therapy, fast X-ray imaging, etc.
Conversely, ultra-short pulses are encountered with femtosecond (fs) laser-based X-ray sources. An intense laser power (~ TW (1012 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. PHAs are not appropriate because the dead time of counting electronics is at least three orders of magnitude larger than the time width of the X-ray pulse, similar to the laser pulse duration (several 10 fs, i.e. 10-14 s).
In the context of the European MULTISCAN 3D Project, CEA List designed and qualified an online X-ray FDS (Filter-Detector Stack) spectrometer for assessing the spectral behavior of X-ray beams generated by fs-LPA processes. The spectrometer consists in a cradle hosting 16 OSL/FO (Optically Stimulated Luminescence/Fiber Optics) sapphire detectors alternating with metal filters of increasing density. Light elements (stainless steel, molybdenum) are placed at the front part and are used to cut the low energy part of the spectrum. Heavier ones (tantalum, tungsten) are placed at the rear part and provide medium- and high-energy discrimination. After irradiation, laser light remotely stimulates each OSL/FO probe and the OSL light is transported back to the readout unit by the same optical fiber. Laser stimulation also leads to OSL erasure so that the spectrometer may be irradiated again (no disassembly is required). The 16 OSL/FO probes provide 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 –MAP-EM). Such algorithms involve an inversion matrix whose coefficients are determined by Monte-Carlo modeling (MCNP6, PHITS) to account for both probe/filter attenuation and internal/external build-up. We provide a complete description of the basics and performance of ML-EM and MAP-EM algorithms in another paper of the same conference.
The X-ray FDS/OSL spectrometer has been qualified in the range of 10 MeV with radionuclides sources (192Ir, 60Co and 137Cs) and a Varian LINAC (6 MV, 9 MV). The reconstructed spectra compared favorably to expected ones. Final tests are planned with a fs Ti-Sa laser (SHERIL installation) in order to fully characterize the fs-LPA process for X-ray generation.

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