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# Monte Carlo modeling of a FDS/OSL spectrometer and reconstruction of laser-based bremsstrahlung source spectrum with Bayesian unfolding algorithm

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## *[Background]*

Detection technologies have long played an important role in customs border checks, by making it easier to detect dutiable, prohibited/controlled goods and materials. For instance, X-ray Computed Tomography (CT) is widely used by online inspection portals, *e.g.* in airports, ports and all critical infrastructures. However, as cargo fret and passenger flux is rising every year, there is a need to improve the performance in CT reconstruction in terms of both spatial resolution and speed. Customs control must indeed be quick, effective to avoid disrupting trade flow in a fast-moving economy. Current CT techniques rely upon the use of LINear ACcelerators (LINACs) as X-ray source. However, they still lead to inconclusive or even faulty results, partly due to loading complexity or to the sophistication of smuggling methods.

With the aim of improving the inspection of large dimension cargo, the European Commission has funded the Horizon 2020 European Project MULTISCAN 3D. The objective is to design and test an innovative 3D high-energy CT system capable of illicit material detection, relying upon the use of laser-plasma based X-ray sources as substitutes to LINACs. An intense femtosecond (fs) laser beam is focused onto a gas jet, thus generating a plasma and contributing to accelerate free electrons. High-energy electrons (tens of MeV) eventually hit a tungsten target, producing Bremsstrahlung X-rays emission. The control of this new source technology and associated instrumentation is therefore a real technological breakthrough. It would allow a greater number of point sources to be used leading to improved 3D resolution in CT images while optimizing both cost and compactness issues.

## *[Problem statement]*

Laser-based X-ray sources require dedicated instrumentation, especially because of the ultrashort duration of the X-ray pulse, of same order as that of the laser beam. Conventional MultiChannel Scaling (MCS) based on Pulse-Height Analysis (PHA) involving active detectors is not appropriate to fs pulse detection because the dead time of counting electronics (nanosecond) is much larger than the pulse width. Therefore, a spectrometric analysis must rely upon passive dosimeters and filter methods. CEA LIST designs a dedicated photon spectrometer based on the Filter-Detector Stack (FDS) concept for use with laser-based X-ray source (below 10 MeV, due to regulation constraints).

## *[Methodology]*

The FDS-based spectrometer consists in successively stacking metallic filters (of increasing Z and density) and passive detectors. Light filter elements are positioned at the front part of the FDS and are used to cut the low energy part of the spectrum. Heavier ones are placed at the rear part and provide high-energy discrimination. OSL (Optically Stimulated Luminescence) is used as detector technology. Coupled with fiber optics, it enables online monitoring. 16 OSL sapphire pellets, provided by Landauer Co (USA), are used as OSL detectors. Electron traps and recombination centers are present within the sapphire crystal. The traps are filled under irradiation and emptied by laser stimulation. The electrons stored within the OSL crystal then recombines onto recombination centers and the observed OSL light is proportional to the dose absorbed between two successive laser stimulations.

The process of spectrum reconstruction relies upon an underdetermined matrix formalism. The coefficients of the response matrix are obtained with the help of a Monte Carlo transport code. The input and output vectors are the dose and energy spectrum respectively. Usual matrix inversion calculation often leads to non-physical solutions. A solution is found by successive iterations based upon a Bayesian relationship. We used the ML-EM (Maximum Likelihood-Expectation Maximization) algorithm to retrieve the distribution in energy of the X-ray source. The algorithm starts from a flat spectrum and converges towards a spectrum of maximum likelihood.

### *[Results]*

We describe a preliminary architecture of a FDS-OSL spectrometer involving sapphire pellet and aluminum, molybdenum, tantalum and tungsten filter disks. The matrix size is typically 16x100 and matrix coefficients are obtained with the help of the MCNP6 Monte Carlo code (Los Alamos, USA), by increment of photon energy, between 100 keV and 10 MeV. We successfully retrieve the equally spaced distribution in energy of several X-ray sources (Bremsstrahlung and radionuclide sources ( $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ )) using the ML-EM algorithm. More details will be given during the conference.

### *[Conclusion]*

A FDS-OSL spectrometer is designed for the spectrum monitoring of laser-based ultrashort laser-based X-ray source. Such design may find other applications in high intensity X-ray radiation field. The algorithm for spectral reconstruction makes use of both a Monte-Carlo transport code (MCNP6) to build the response matrix and a ML-EM algorithm to estimate the spectrum from input dose data.

Preliminary tests with simulated sources (radionuclides, LINAC) give satisfactory results. Experiments are planned to validate the design of the FDS spectrometer and the ML-EM algorithm in real conditions.

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