On field Spectrometry for Diagnostic X-ray Beams: a Comparison Between two Innovative Devices

[1]P.L. Rossi, [1]L. Andreani, [1]M. Bontempi, [1,2] S. Cappelli, [2]M. Zuffa, [2]A. Margotti, [3]C. Labanti, [1,2]G. Baldazzi , IEEE Member

[1] Dep.t of Physics, University of Bologna, Viale B. Pichat 6/2, I-40127, Bologna, Italy
[2] INFN - National Istitute for Nuclear Physics, Viale B. Pichat 6/2, I-40127, Bologna, Italy
[3]INAF/IASF Bologna, Via Gobetti 101 I-40129, Bologna, Italy

University of bologna
Dep.t of Physics

Section of Bologna

Abstract

The knowledge of X-ray beam spectrum would be important for the optimization of diagnostic procedures, allowing to reduce the patient dose and improving the image quality. In fact, only the spectrometric analysis permits a complete characterization of the photonic beam both under qualitative and quantitative aspects enabling attenuation studies and quality parameters evaluation.

Usually the spectrometry of the available diagnostic X-rays beam is not feasible on-site because the anode brilliance is always too great for any spectrometric detector. To overcome this difficulty, we have built up and tested a portable spectrometric system based on the Compton scattering effect: the X-ray spectrum, scattered by a suitable graphite target inside the chamber at a specific angle, is collected and reconstructed by the inversion of scattering matrices. To optimize the performance of tis instrument, we have tested many kind of detectors and the reconstruction algorithm takes into account the detector efficiency and performs a parametric description of the bremsstrahlung in the diagnostic energy range (15 keV -150 keV).

The second instrument is a real-time detector system capable to measure some parameters from the X-ray beam and the high-voltage generator. A PC runs the reconstruction of the spectrum starting from of such experimental parameters.

Experimental results obtained with these two devices will be shown and compared each other, but also with spectra acquired with a nitrogen cooled HPGe detector in a laboratory facility (the gold standard not suitable for on site measurements). Aim of this work is to present, characterize and compare these two innovative devices that can be simply implemented in every X-ray imaging machine to test, optimize but also control the performances.

Corresponding author: giuseppe.baldazzi@unibo.it

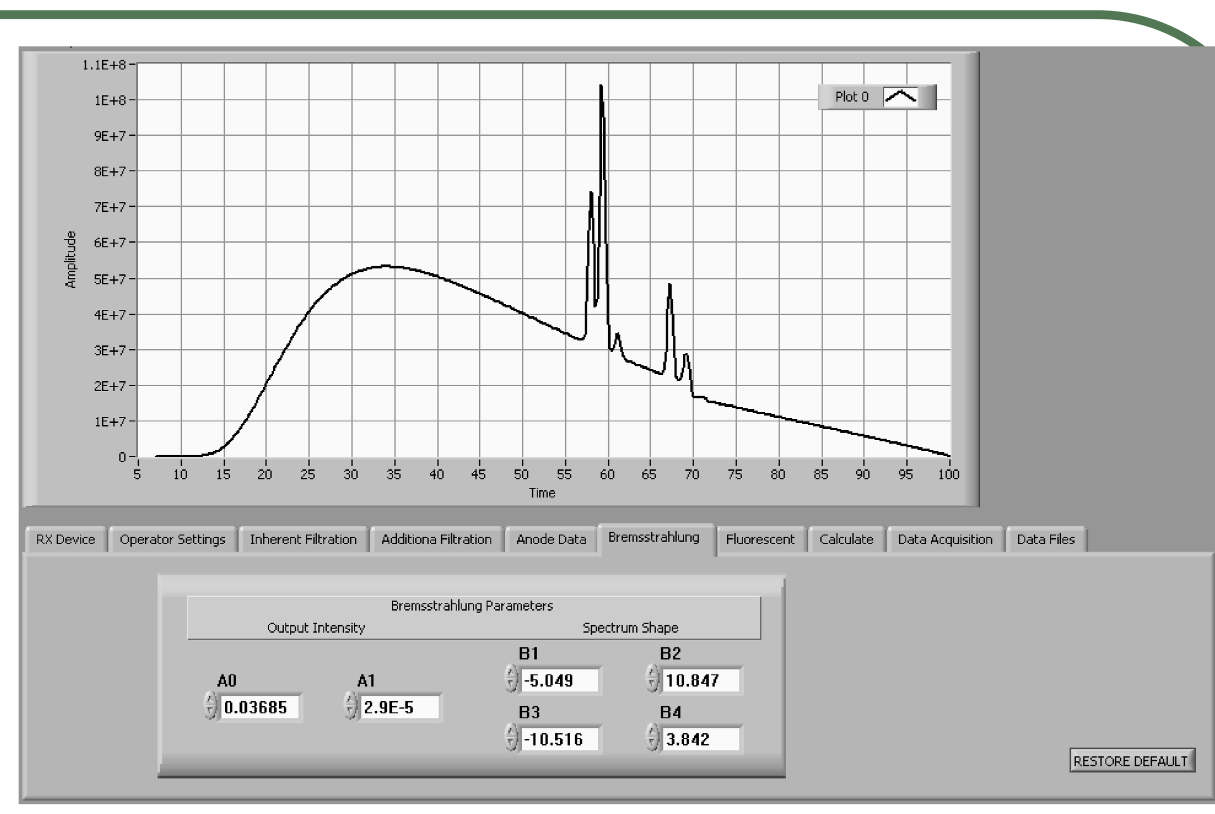
Introduction

Many attempts of computing theoretical x-ray spectra was developed and enhanced in time. These models satisfactory fits bremsstrahlung experimental data but the radiation emitted by each individual apparatus differs for efficiency, anode angle and composition, inherent and additional filtration, technical characteristics of the focusing electronics. Therefore, the models cannot replace the on-field measurements of the quality parameters of each radiological equipment for diagnostic use.

The most significant models have been realized by:

- Birch and Marshall (B&M) (1979) [1]; this is still the fastest and the most accurate model;
- Tucker et al. (1991) [2]; uses the same empirical model as B&M adjusting the exponent value according to G&C (1961) theoretical predictions [7] and adding the term studied by Vignes and Dez (1968) [8] to take into account the depth of production of the characteristic x-rays and the consequent attenuation by the anode;
- Poludniowski (2007) [3]; this model uses calculations based on probability rules and empirical adjustments to obtain satisfactory results to simulate characteristic radiation.

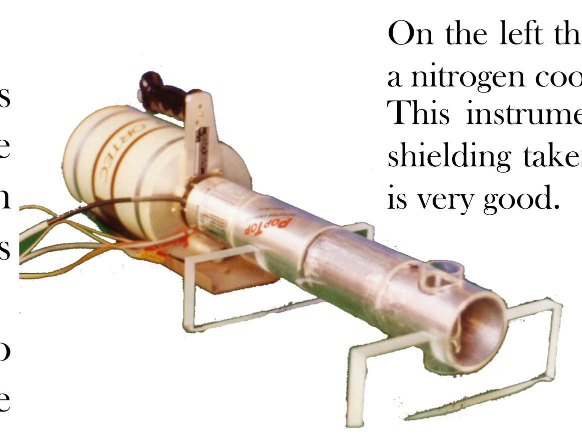
All this models are *parametric semiempirical* attempts to reconstruct the bremstrahlung continuum and characteristic emission from tungsten and molybdenum anodes X-rays tubes. We make use of these models to fit experimental points, obtained with some kind of innovative instruments, by adjusting the parameters by means of a least squares technique.



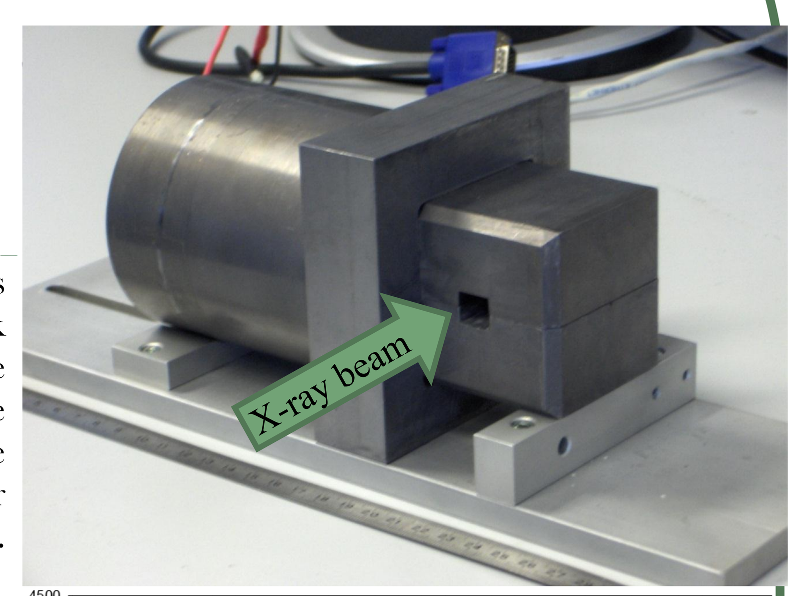
Simulation program of bremmstralhung and fluorescence lines for tungsten anode. Beam at 100 kvp. The spectrum area must meet the photon fluence measured on-field and be consistent with the instantaneous values measured of the anode current. The model is a modified Birch-Marshall and parameters Bi control the shape of the spectrum, the Ai parameters control the total fluence (area).

The Compton scattering method for X-ray Spectrometry

It isn't possible to make spectrometry directly on the available diagnostic beam, in fact the anode's brilliance is always too great (at least of 9th order of magnitude) for any spectrometric system. To overcome this difficulty we have developed, built up and tested few portable spectrometers based on the Compton scattering: the primary X-rays beam impinge on a target and photons scattered inside a narrow cone around a 90° angle are detected. Leaving intensity is of a $10^9 \div 10^{11}$ factor lower with respect to that of the primary beam and the spectrometric analysis is now possible.
A dedicated software algorithm was studied to reconstruct the scattered spectra. The deconvolution method was also experimentally tested using a cooled HPGe detector with strong collimation placed at a great distance (5m) from the focal spot.



On the left the Compton spectrometer built around a nitrogen cooled HPGe is shown.
This instrument is not useful because its alignment and shielding takes very long time but the X-ray spectrometry is very good.

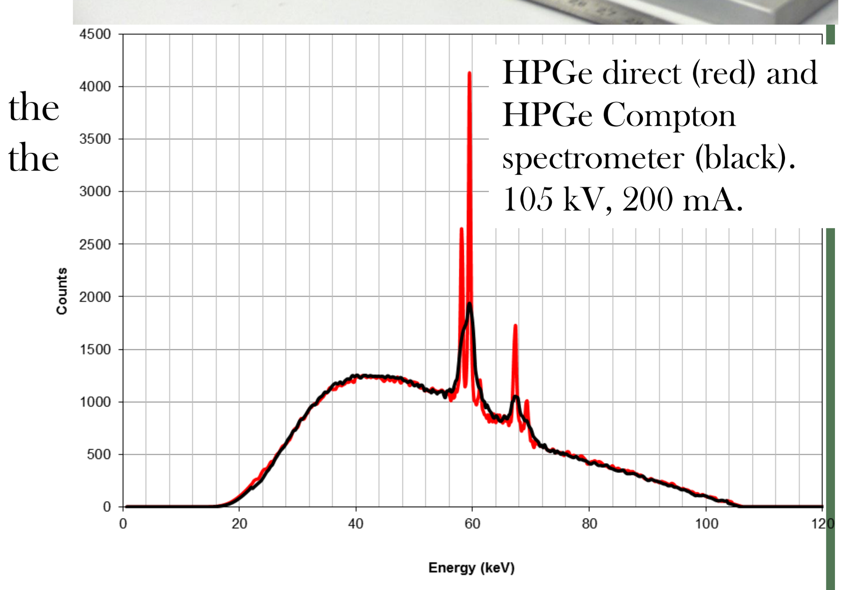


Different Compton spectrometers with different kind of detectors (thick Si, YAP and $LaBr_3$ scintillator) have been developed and tested. On the right you can see the last prototype made to accommodate a detector based on $LaBr_3$ scintillator .

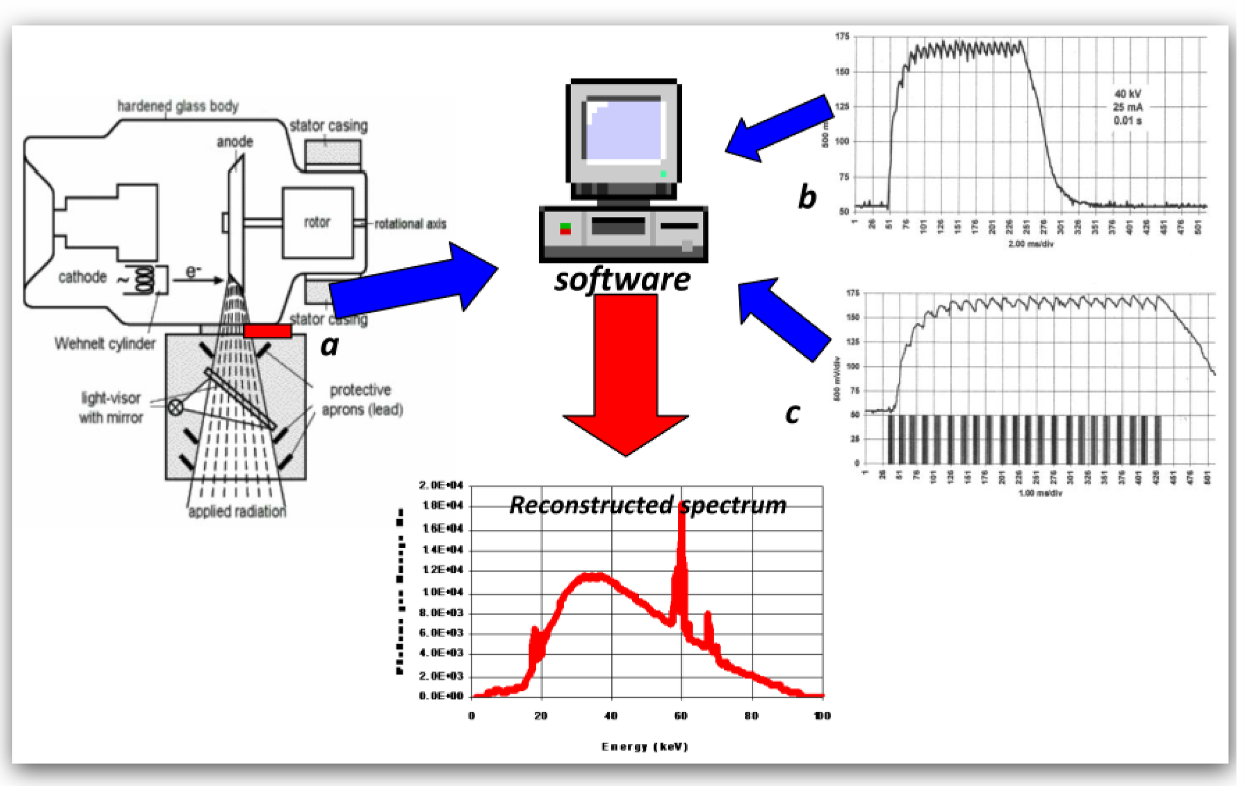
The simulation with measured parameters method for real-time X-ray Spectrometry

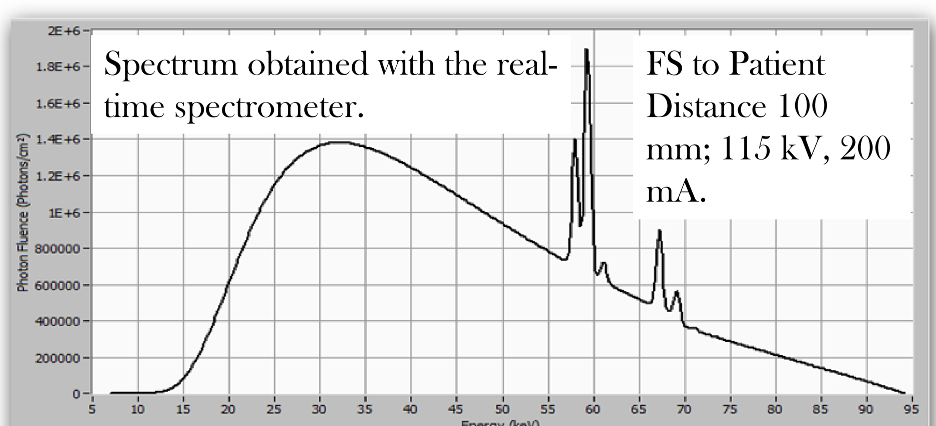
To measure the X-ray spectrum in real-time during a diagnostic examination, the information coming from three sources are needed: *a)* a specially developed exposure meter system which is mounted between the X-ray tube and the collimators group, and intercepts a little outer section of the beam; *b)* the waveforms of voltage and *c)* of the anode current taken out from the inverter of the radiological system. Such information is used to calculates parameters for a photon fluence spectrum simulation software. The method is completely operating and working, at an experimental level, at the Dep.t of Physics of the University of Bologna.

The system can implement a *patient dosemetric card*, equipped with a microchip, in which the interested anatomic district, the FOV dimension and the focal spot-patient distance (that could be automatically measured to calculate the skin air KERMA) can be automatically registered together with the photon fluence spectrum. Such collection of information guarantee the patient dosimetry and a precise repeatability of the diagnostic exam.



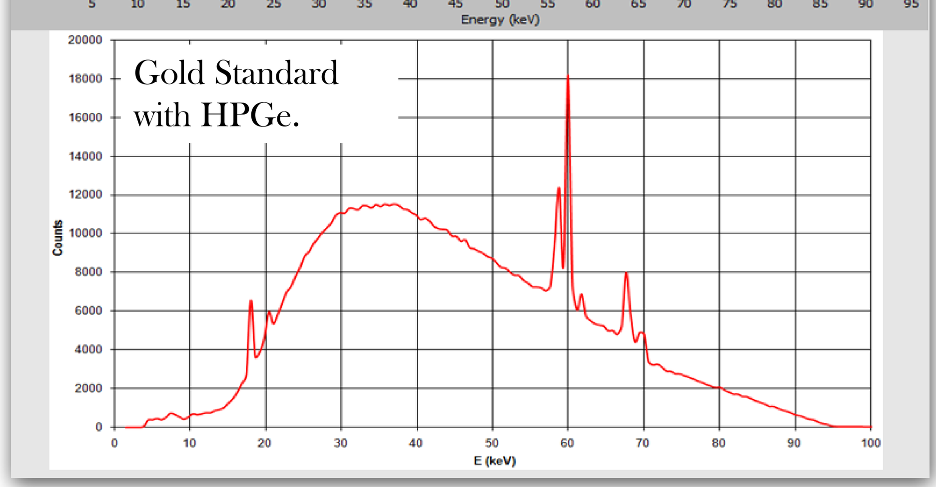
HPGe direct (red) and HPGe Compton spectrometer (black). 105 kV, 200 mA.



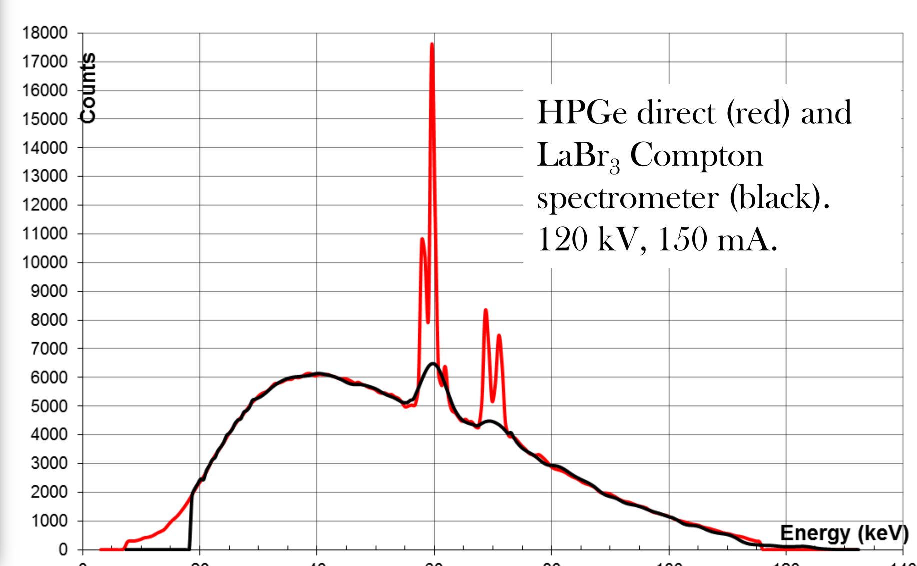


Spectrum obtained with the real-time spectrometer.

FS to Patient Distance 100 mm; 115 kV, 200 mA.



Gold Standard with HPGe.



HPGe direct (red) and $LaBr_3$ Compton spectrometer (black). 120 kV, 150 mA.

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