CALCULATION OF BEAM QUALITY PARAMETERS FOR X-RAY MAMMOGRAPHY SPECTRA: A MONTE CARLO SIMULATION STUDY

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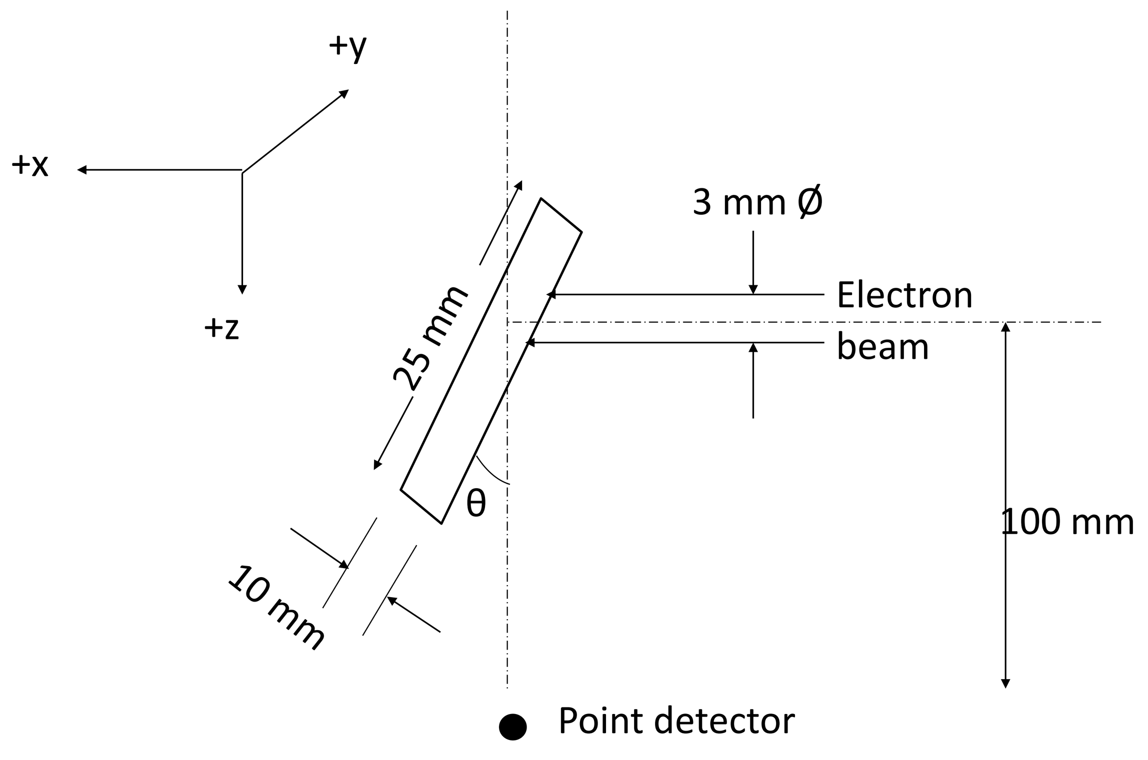
Purpose

Breast cancer is known to be the most malignant type of cancer among women in the world. By x-ray mammographic imaging, the disease can be detected and then an early stage treatment can be started following this. For a reliable imaging, beam quality parameters should be precisely determined. However, measurement of x-ray beam quality parameters necessitates using specific equipment. An efficient way for determining these parameters is to utilize scientifically proven and verified Monte Carlo simulation codes

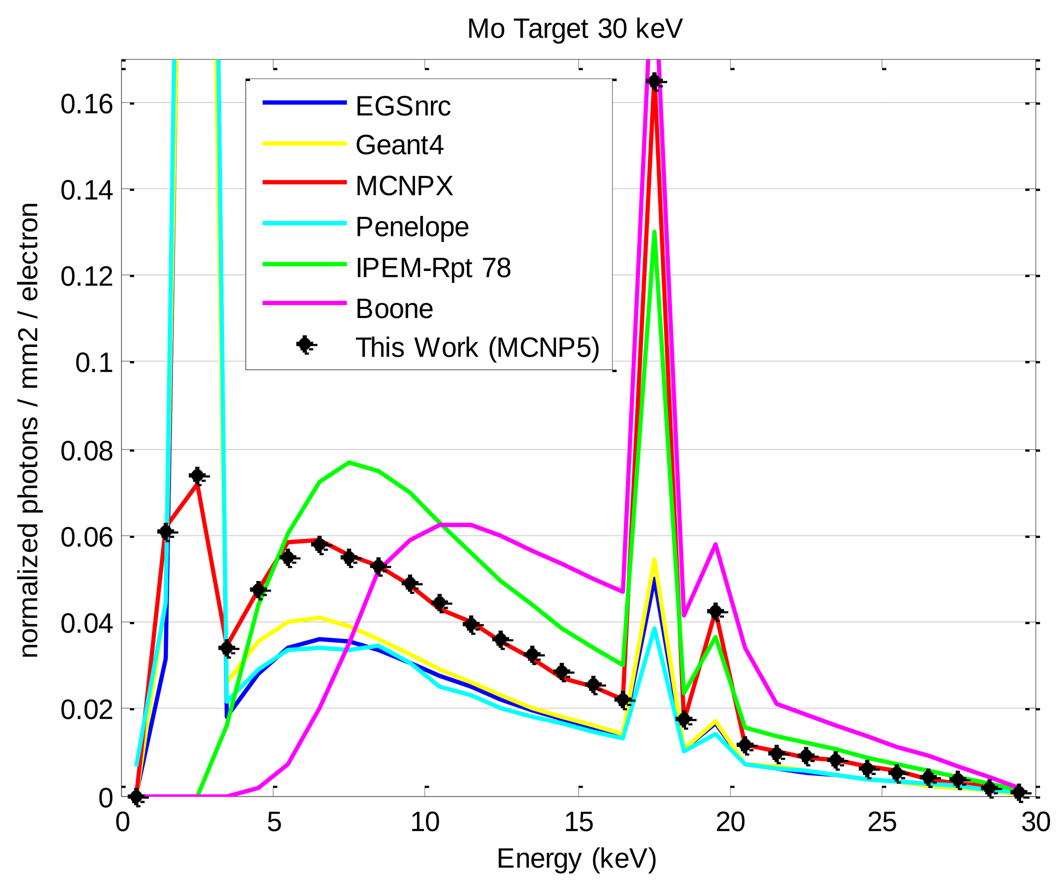
Methods

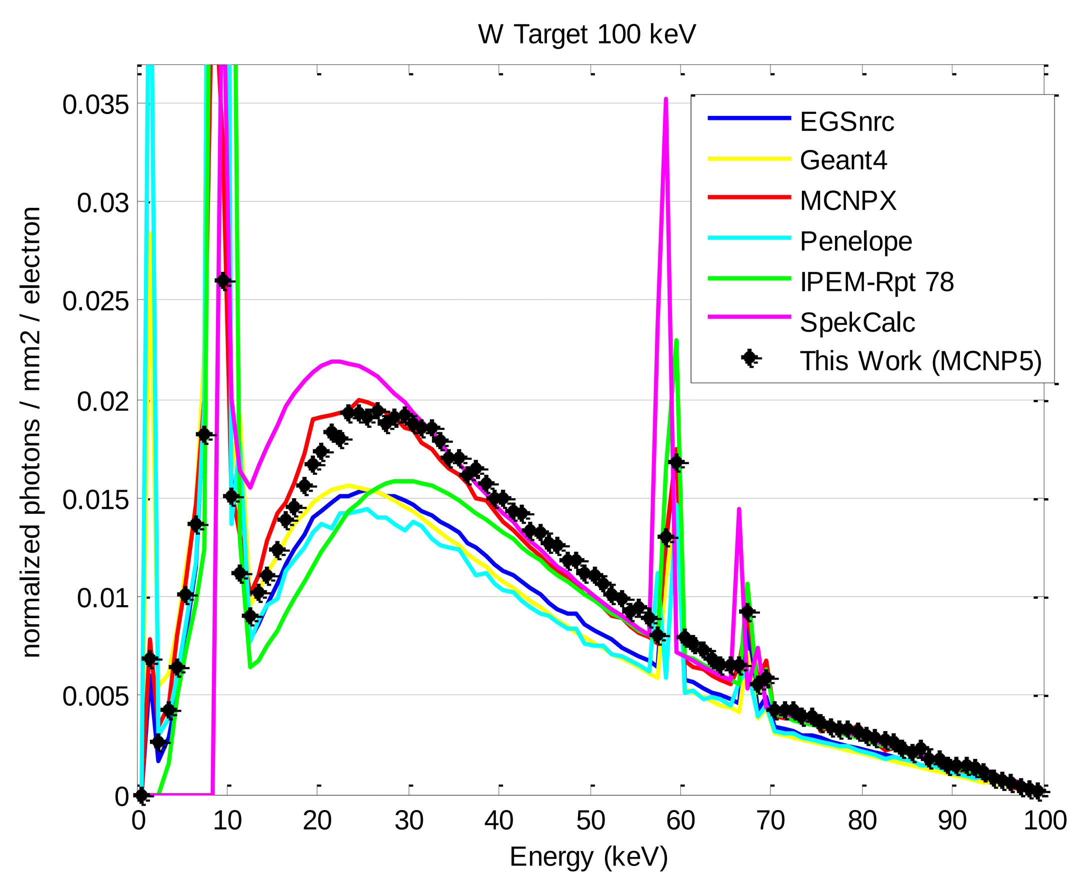
Monte Carlo simulations are widely used in digital mammography imaging research. In this work, MCNP5 was used for simulating generation of x-ray spectrum including both bremsstrahlung and characteristic X-rays. Electron beam and target (anode) were modelled as specified in the Report of AAPM Task Group 195: Monte Carlo Reference Data Sets for Imaging Research.

Target setup given in [1] we remodeled in MCNP5 [2]



Comparison of our simulated spectrum with those given in AAPM Report





Simulation parameters for x-ray spectra generation

Target Material	Incident Electron Kinetic Energy Range(kVp)	Anode Angle (deg)
Mo	25-40	15
Rh	25-40	15
W	25-40	11

Surface Fit function

$$Parameter(kVp, th) = A + B.kVp + C.th + D.kVp^2 + E.kVp.th + F.th^2$$

$$Parameter = HVL, Eeff, Eavg, Kerma$$

$$kVp = Energy$$

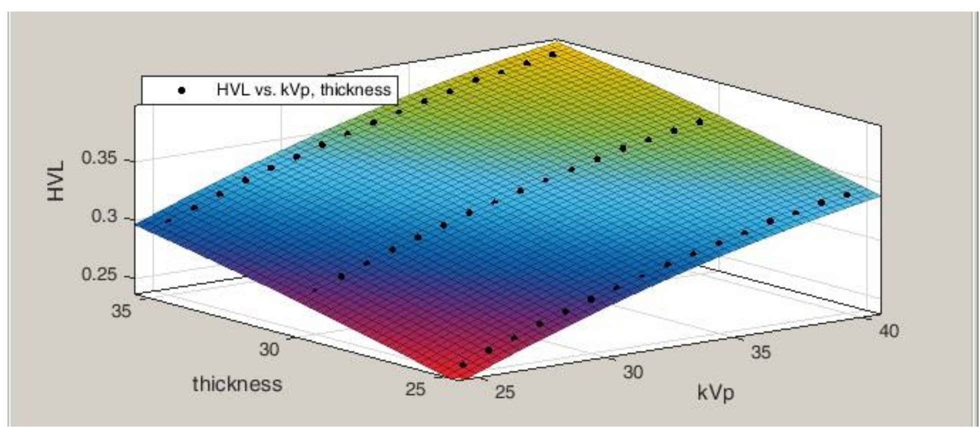
$$th = filter\ thickness\ in\ micrometers$$

Surface Fit parameters

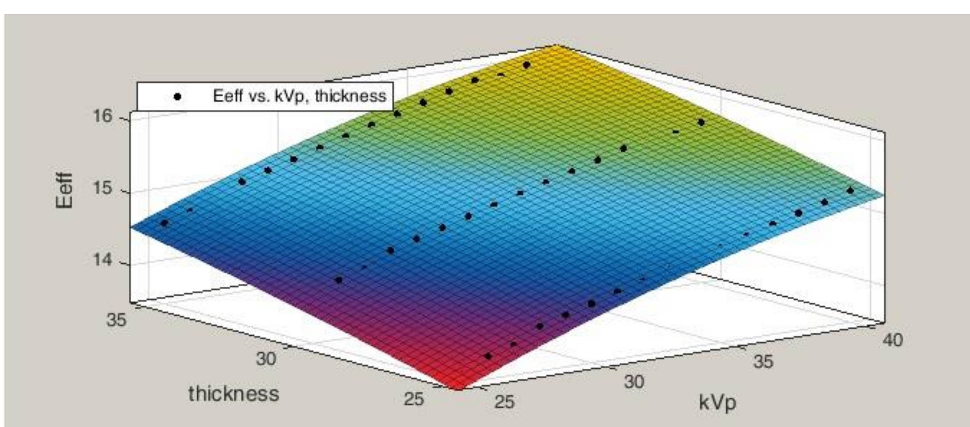
Filter	Mo/Mo				Mo/Rh				Rh/Rh			
Coe./Par.	HVL	E_{eff}	E_{avg}	Kerma	HVL	E_{eff}	E_{avg}	Kerma	HVL	E_{eff}	E_{avg}	Kerma
A	-0.2944	3.977	10.62	-6.597	-0.4323	2.568	10.69	-10.51	-0.5912	-2.382	1.945	-6.793
B	0.01641	0.2962	0.1232	1.386	0.02401	0.3948	0.1683	1.355	0.03231	0.6191	0.6398	1.14
C	0.01162	0.2186	0.1102	-0.5761	0.01982	0.3512	0.1781	-0.4884	0.01357	0.3433	0.238	-0.5665
D	-0.0001476	-0.002509	0.001169	0.002735	-0.0002346	-0.003787	0.0002095	0.002637	-0.0003752	-0.00688	-0.005582	0.0019
E	-2.132e-05	-0.001015	-0.001319	-0.02429	-8.838e-05	-0.00225	-0.002244	-0.02838	0.0001335	-0.0005441	-0.003122	-0.02265
F	-9.125e-05	-0.001625	-0.0006625	0.01444	-0.0001837	-0.003375	-0.00125	0.01764	-0.00015	-0.003625	-0.001487	0.01679

Filter	W/Rh				W/Ag				W/Al			
Coe./Par.	HVL	E_{eff}	E_{avg}	Kerma	HVL	E_{eff}	E_{avg}	Kerma	HVL	E_{eff}	E_{avg}	Kerma
A	-0.2283	6.385	16.66	0.146	-0.518	4.616	9.688	-1.935	-0.07479	4.218	2.276	0.1215
B	0.0124	0.2149	-0.2692	0.5028	0.02766	0.4438	0.1787	0.6405	0.004265	0.2699	0.5241	1.06
C	0.01172	0.1928	0.1299	-0.1949	0.01231	0.1082	0.1416	-0.1968	0.0001936	0.01145	0.008112	-0.04173
D	-3.14e-05	-0.00115	0.009457	-0.001807	-0.0002561	-0.004161	0.002501	-0.002915	-4.243e-05	-0.002509	-0.002246	-0.004294
E	-2.779e-05	-0.0007206	-0.00226	-0.004476	1.176e-05	-0.0009265	-0.002179	-0.004872	2.593e-05	0.000164	6.368e-05	-0.000564
F	-5.875e-05	-0.001125	-0.0003375	0.002325	-6.75e-05	-0.000125	-0.0004	0.002388	-3.937e-07	-8.437e-06	-5.062e-06	3.931e-05

HVL surface fit for Mo/Mo



E_{eff} surface fit for Mo/Mo



Results

X-ray quality parameters such as **Aluminum (Al) equivalent half-value layer (HVL), Al equivalent effective energy, average energy, and air kerma** of the simulated polyenergetic X-ray beams were calculated and tabulated for a wide range of commercially available mammographic x-ray tube voltage (kVp) and target /filter material and thickness combinations(molybdenum/molybdenum, molybdenum/rhodium, rhodium/rhodium, tungsten/rhodium, tungsten/silver, and tungsten/aluminum). All calculated parameters were then **fitted to second-degree polynomial surface equations** as a function of kVp and filter thickness for each target/filter combination.

Conclusions

This work is essential and flexible in the sense that it **provides a reliable and quick look-up database** for those performing mammographic patient dose and image quality calculations. In addition, it could be taken as **a starting point for generation of quality data for entire diagnostic x-ray energy range, e.g. 20-140 kVp**, for any combination of target/filter. On the other hand, with this study, it can be deduced that **important mammographic parameters can be precisely calculated with Monte Carlo methods**, which would otherwise need for expensive and complicated experimental equipment and much more time.

References

[1] Sechopoulos I., et al. (2015), Monte Carlo reference data sets for imaging research: Executive summary of the report of AAPM Research Committee Task Group 195. Med. Phys., 42: 5679–5691. doi:10.1118/1.4928676

[2] J.J. Briesmeister, "MCNP5- A General Monte Carlo N-Particle Transport Code, Version 5 Los Alamos National Laboratory", March, 2005