QUALITY ASSURANCE OF RADIOTHERAPY USING SCATTERED X-RAY

Students: Tatiana Kashtanova, Samuel Ydenberg

Mentors: Dr. Xun Jia, Dr. Lin Su (JHH)
Dr. Yujie Chi (UT Arlington); Dr. Youfang Lai, Dr. Xiaoyu Hu (JHH)

BACKGROUND

- **Radiation Therapy (RT)** is a type of cancer treatment where a high radiation dose is delivered to a tumor with a goal of destroying it while minimizing the damage to the surrounding normal tissue
- **Quality Assurance (QA)**[1,2] are the procedures ensuring the precise and safe delivery of the prescribed dose to the target volume while sparing the normal tissue and minimizing personnel exposure:

Image source: https://images.app.goo.gl/Y4493cVg6LhvWzEC7

- **Treatment planning**
  - Contour delineation
  - Dose calculation

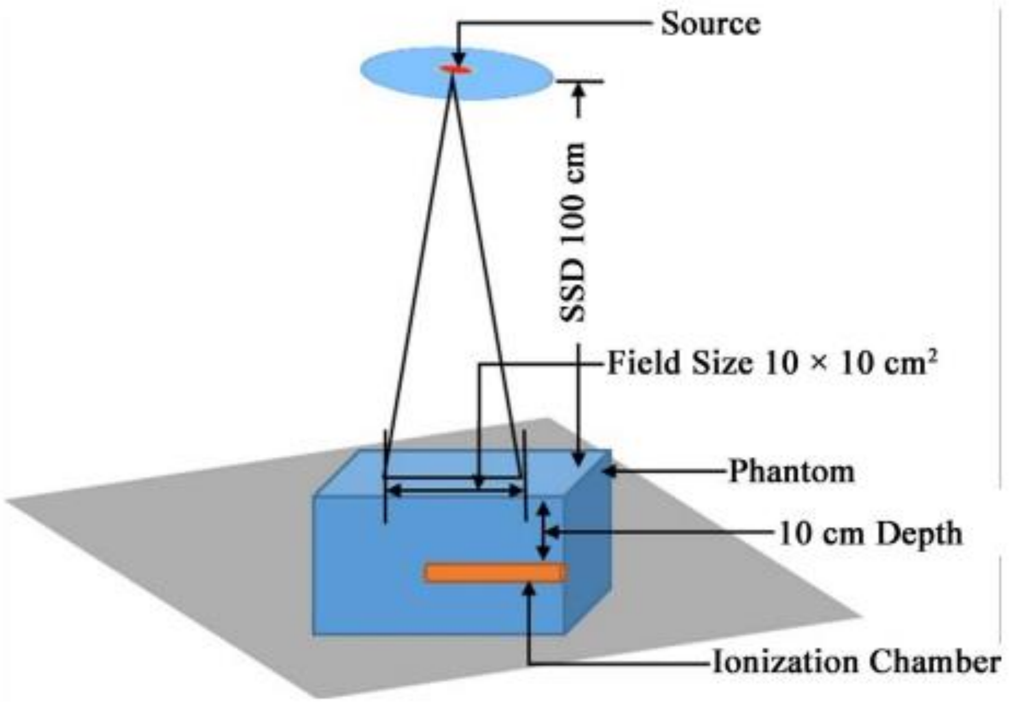
- **Treatment verification**
  - Simulations (MC, SC)
  - Tests (dosimeters, phantoms)

- **Treatment delivery**
  - Equipment calibration
  - Patient positioning (4DCT, CBCT)
  - Motion management

CLINICAL MOTIVATION

Radiation dose distribution verification

- Prior to treatment:
  - Absolute dosimetry[3,4] using ionization chambers and slab phantoms
  - Reference dosimetry[5] using radiochromic films
- *In vivo* dosimetry[3] using thermoluminescent dosimeters or diodes (dose at surface only)



Absolute dose measurement[4]

A need for a technology[6] allowing to verify dose distribution in a medium OUTSIDE of a phantom/patient, ideally in real time.

QUALITY ASSURANCE OF RADIOTHERAPY USING SCATTERED X-RAY

GOAL: To implement a new quality assurance method for radiation therapy using scattered x-ray registration

DELIVERABLES

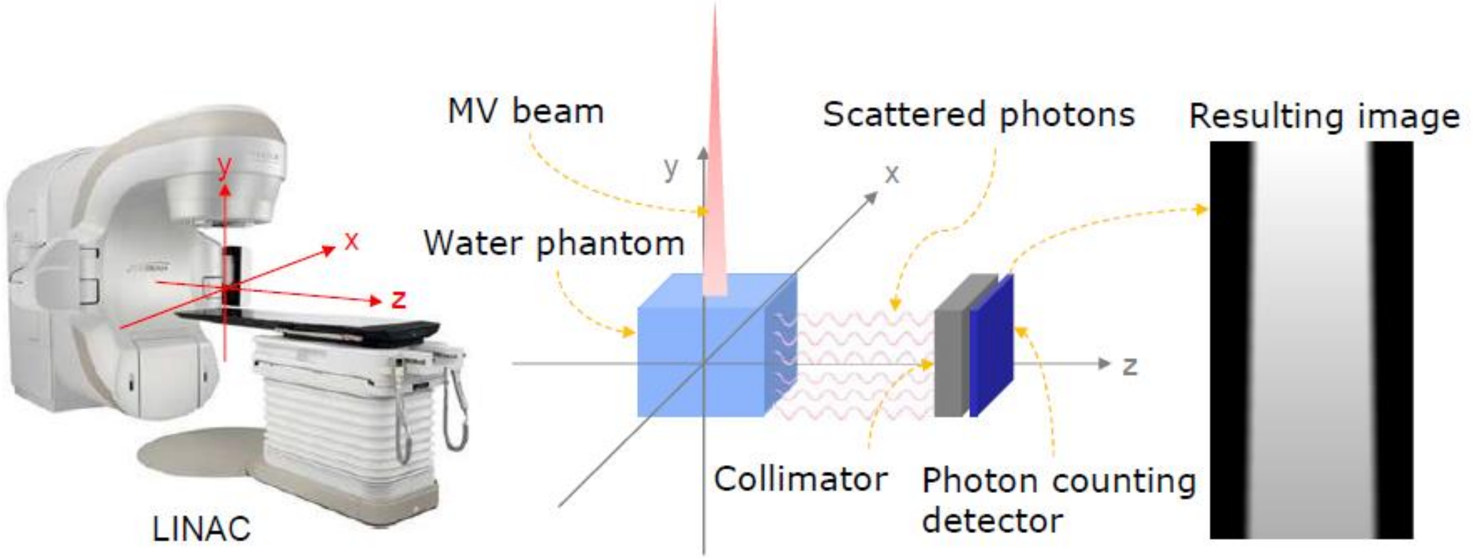
Minimum: Incorporation of the detector section into the existing Monte Carlo radiation transport simulation package[7,8] (the gDPM)

Expected:
1. Detector performance verification
2. Depth dose profile simulation

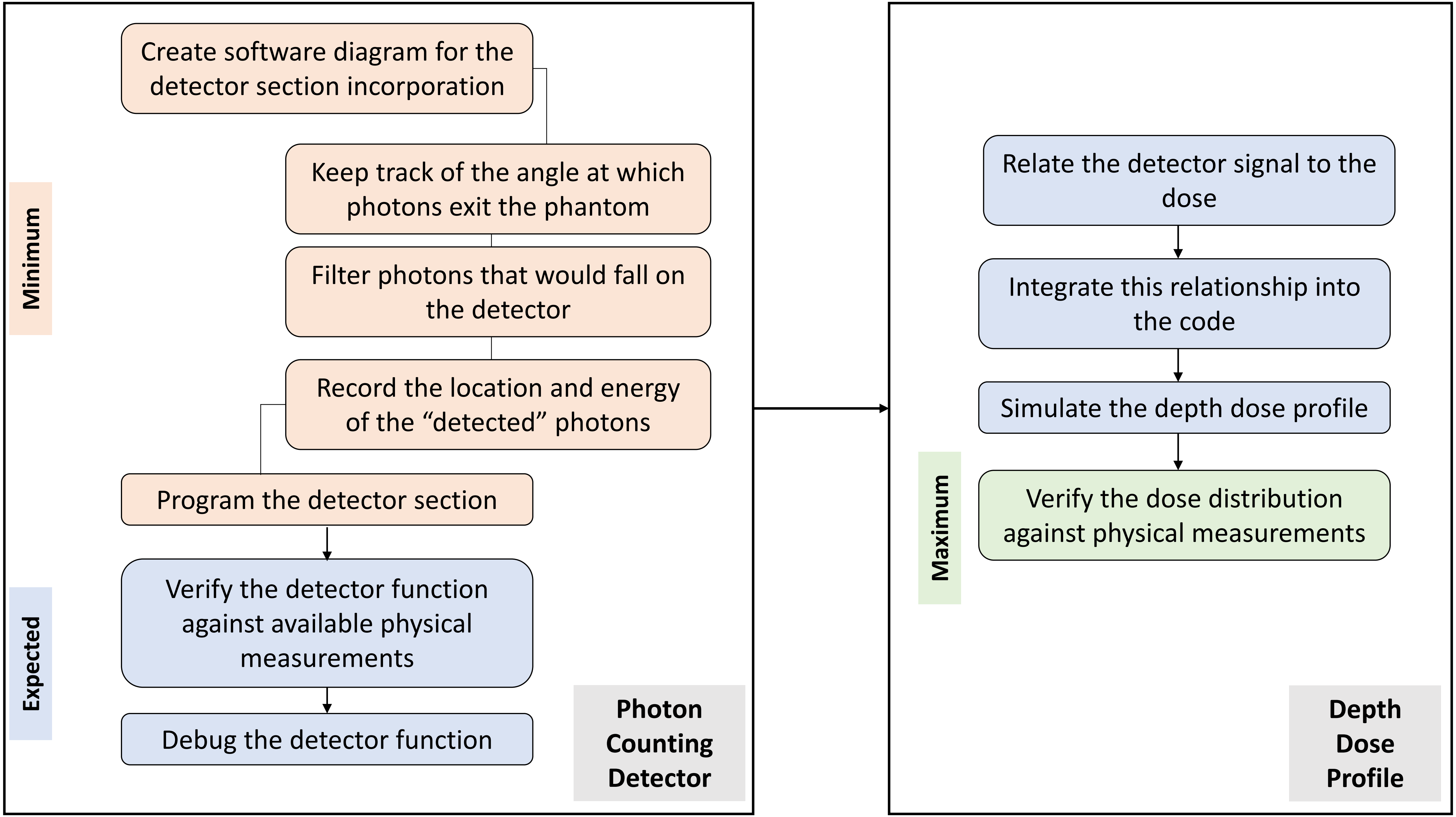
Maximum: Simulated depth dose profile verification

TECHNICAL APPROACH

Work environment: Monte Carlo Simulation of MV radiation transport into a medium[9,10]



The diagram of RT QA method using scattered x-ray registration[6]


Create software diagram for the detector section incorporation
Keep track of the angle at which photons exit the phantom
Filter photons that would fall on the detector
Record the location and energy of the "detected" photons
Program the detector section
Verify the detector function against available physical measurements
Debug the detector function
Minimum
Expected
Photon Counting Detector
Relate the detector signal to the dose
Integrate this relationship into the code
Simulate the depth dose profile
Verify the dose distribution against physical measurements
Maximum
Depth Dose Profile

KEY DATES & RESPONSIBILITIES

Project Deliverable		Activities	Output (submit in the team's chat)	Deadline Soft (Hard)	Status
Minimum	Incorporation of the detector section into the existing MC radiation transport simulation package[7,8] (the gDPM)	1. Perform literature review on QA, Cherenkov Imaging, and Photon counting; study the gDPM package documentation	A written 1-1.5-page summary to use in the final project report	02/20 (02/23)	Done on 02/17
		2. Address the corresponding dependences and make sure that CUDA drivers are installed correctly	Screenshots of successful runs of the first two examples in CUDA samples	02/20 (02/23)	Done on 02/15
		3. Compile the gDPM on our machine	Statistical comparison of our and our mentors' simulation results with the same input parameters	02/24 (02/27)	Done on 02/21
		4. Create a plan for incorporating the detector into the gDPM code	A block diagram of the desired code structure	03/10 (03/12)	In progress
		5. Program the detector section based on the designed block diagram	C code with comments, a plot of the registered scattered x-rays	03/17 (03/19)	Not started
		6. Document the code	PDF document	03/20 (03/21)	Not started

Project Deliverable		Activities	Output (submit in the team's chat)	Deadline Soft (Hard)	Status
Expected	Detector performance verification	1. Adjust the simulation to match the setup of the previous kV x-ray scattered photon registration experiments[11,12]	C code with comments	03/28 (03/29)	Not started
		2. Document the setup parameters	PDF document	03/28 (03/29)	Not started
		3. Compare the simulation and experimental data	MATLAB code with comments and data visualizations	03/29 (03/30)	Not started
		4. Debug the detector section code until the simulation data match the experimental data with 5-8% accuracy	Refined detector code	04/06 (04/07)	Not started
		5. Document the data comparison methodology and the discussion of the results	PDF document	04/07 (04/08)	Not started
	Depth dose profile simulation	1. Relate the detector signal to the delivered dose based on the mentor's guidance	Mathematical expression(s)	04/20 (04/21)	Not started
		2. Integrate the relationship into the simulation code	C code with comments, a plot of the depth dose profile	04/24 (04/25)	Not started
		3. Document the relationship and the code	PDF document	04/24 (04/25)	Not started

KEY DATES & RESPONSIBILITIES (continued)

Project Deliverable		Activities	Output (submit in the team's chat)	Deadline Soft (Hard)	Status
Maximum	Simulated depth dose profile verification	1. Adjust the simulation to match the setup of the prospective MV x-ray QA experiments following the mentor's guidance	C code with comments	04/25 (04/26)	Not started
		2. Document the setup parameters	PDF document	04/25 (04/26)	Not started
		3. Compare the simulation and experimental data	MATLAB code with comments and data visualizations	04/27 (04/28)	Not started
		4. Document the data analysis methodology and the discussion of the results	PDF document	04/27 (04/28)	Not started
CIS II	Fulfillment of the final class requirements	1. Make the project poster presentation	Poster presentation in PDF	Exam date in May	Not started
		2. Write the final project report	Project report in PDF		

DEPENDENCIES

Need	Dependencies	Source	Responsible	Deadline Soft (Hard)	Status	Contingency Plan
General	Computer with a CUDA-capable GPU	Dr. Mohammad Rezaee	Tatiana	02/03 (02/07)	Done on 01/31	NA
	Remote access to the computer for Samuel	JHU IT	Tatiana	02/10 (02/13)	Done on 02/08	NA
The gDPM compilation	The gDPM simulation package	Dr. Youfang Lai, Dr. Yujie Chi	Dr. Lin Su	02/10 (02/13)	Done on 02/09	NA
	Google Colab	Google	Samuel	02/13 (02/15)	Done on 02/13	NA
Comparison of the simulated depth dose profile with physical measurements	Physical measurements	Dr. Xun Jia, Dr. Lin Su		04/20 (04/25)	Not started	Do in summer if possible

MANAGEMENT

Samuel and Tatiana's work:

- Meetings on Monday, Wednesday, and Friday for 2-3 hours via Zoom or at JHH
- Meetings on Tuesday and Thursday on JHU Homewood for 1.5 hours before or after the class
- Individual remote connection to the computer when needed

Communication with mentors (weekly):

- Correspondence via JHU email and Microsoft Teams group chat
- Meetings via Microsoft Teams

File sharing:

- JHU OneDrive, JHU email and Microsoft Teams group chat

READING LIST

- QA[1,2,3,4]
- Cherenkov imaging:
  - Miao, T., Bruza, P., Pogue, B. W., Jermyn, M., Krishnaswamy, V., Ware, W., Rafie, F., Gladstone, D. J., & Williams, B. B. (2019). Cherenkov imaging for linac beam shape analysis as a remote electronic quality assessment verification tool. *Medical Physics*, *46*(2), p. 811–821. doi: 10.1002/mp.13303
  - Pogue, B.W., Zhang, R., Glaser, A., Andreozzi, J.M., Bruza, P., Gladstone, D.J., & Jarvis, L.A. (2017). Cherenkov Imaging in the Potential Roles of Radiotherapy QA and Delivery. *Journal of Physics: Conference Series, 847*, p. 012046. doi: 10.1088/1742-6596/847/1/012046
- Photon counting[10,11]:
  - Huang, Y., Hu, X., Zhong, Y., Lai, Y., Shen, C., & Jia, X. (2021). Improving dose calculation accuracy in preclinical radiation experiments using multi-energy element resolved cone-beam CT. *Physics in Medicine and Biology*, *66*(24), p. 245003. doi: 10.1088/1361-6560/ac37fc
- gDPM Simulation package[6,7]

REFERENCES

1. World Health Organization. (1988). Quality Assurance in Radiotherapy: a Guide Prepared Following a Workshop Held at Schloss Reisensburg, Federal Republic of Germany, 3-7 December1984. Geneva.
2. Glide-Hurst, C.K., & Chetty, I.J. (2014). Improving radiotherapy planning, delivery accuracy, and normal tissue sparing using cutting edge technologies. *Journal of Thoracic Disease*, *6*(4), p.303–318.doi:10.3978/j.issn.2072-1439.2013.11.10
3. Gurjar, O.P., Mishra, S.P., Bhandari, V., Pathak, P., Patel, P., & Shrivastav, G. (2014). Radiation dose verification using real tissue phantom in modern radiotherapy techniques. *Journal of Medical Physics*, *39*(1), p.44–49.doi:10.4103/0971-6203.125504
4. Kumer, T., Das, P., Khatun, R., Rahman, Md., Akter, S., & Kumar Roy, S. (2021). Comparative Studies of Absolute Dose in Water Phantom, Solid Water Phantom and MatriXX with MULTICube Phantom. *International Journal of Medical Physics, Clinical Engineering and Radiation Oncology, 10*(4), p. 169-177. doi: 10.4236/ijmpcero.2021.104014
5. Khachonkham, S., Dreindl, R., Heilemann, G., Lechner, W., Fuchs, H., Palmans, H., Georg, D., & Kuess, P. (2018). Characteristic of EBT-XD and EBT3 radiochromic film dosimetry for photon and proton beams. *Physics in Medicine and Biology*, *63*(6), 065007. doi: 10.1088/1361-6560/aab1ee
6. Jia, X. (2023). Quality assurance of radiotherapy treatment using scattered x-ray. Presentation slides for CIS II

REFERENCES (continued)

7. Jia, X. & Jiang, S.B. (2011). gDPM v2.0. A GPU-based Monte Carlo simulation package for radiotherapy dose calculation. The Center for Advanced Radiotherapy Technologies (CART), UCSD.
8. Jia, X., Ziegenhein, P., & Jiang, S. B. (2014). GPU-based high-performance computing for radiation therapy. *Physics in Medicine and Biology, 59*(4), p. R151–R182. doi: 10.1088/0031-9155/59/4/R151
9. The Netherlands Commission on Radiation Dosimetry. (2006). Monte Carlo treatment planning. An introduction. Report 16.
10. Hall, E.J. (2000). Radiobiology for the radiologist. 5th edition. Philadelphia, PA: Lippincott Williams & Wilkins.
11. Hu, X., Zhong, Y., Lai, Y., Shen, C., Yang, K., & Jia, X. (2022). Small Animal Photon Counting Cone-Beam CT on a Preclinical Radiation Research Platform to Improve Radiation Dose Calculation Accuracy. *Physics in Medicine and Biology, 67*(19), p. 195004. doi:10.1088/1361-6560/ac9176
12. Hu, X., Zhong, Y., Yang, K., & Jia, X. (2022). Photon Counting Detector-Based Multi-Energy Cone Beam CT Platform for Preclinical Small Animal Radiation Research. *Proc. SPIE 12304, 7th International Conference on Image Formation in X-Ray Computed Tomography*. doi: 10.1117/12.2647036