BIOEN 6401 Medical Imaging Systems
Homework #4
Due Monday, November 18, 2019

State all assumptions and show all your work

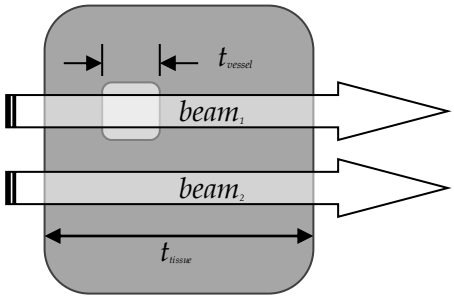
1. Suppose an unnamed element with electron K, L, M-shell binding energies of 25.0, 3.0, and 0.6 keV, respectively, is being used as the anode target in an x-ray source:

   (a) Sketch a clearly labeled the emission spectrum of the x-ray source operating at 30 keV. You may assume that x-ray less than 10 keV is filtered out.

   (b) Moreover, suppose a thin layer of the same element is placed at the exit port of the source for additional filtering. Sketch the spectrum for the newly filtered x-ray.

2. Digital subtraction angiography acquires x-ray images before and after injection of contrast agent, then "subtracts" the two to obtain a blood vessel-only image:

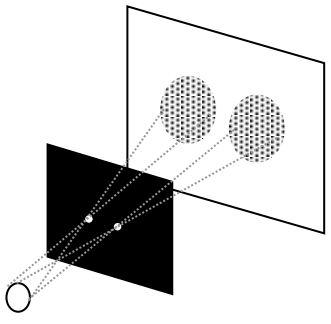
   (a) Suppose a vessel of t_{vessel} thickness is embedded inside a tissue with t_{tissue} thickness, as shown to the right, and that the linear attenuation coefficients are μ_{vessel} and μ_{tissue}, respectively. Write expressions for intensities of x-ray beams passing through only the tissue, and through both tissue and the vessel.



   (b) Repeat the above for the post-contrast scan, where μ_{vessel} now becomes μ_{contrast}.

   (c) How can the pre- and post-contrast intensities be mathematically manipulated to remove any contribution from the tissue? Show that your answer works for both tissue-only and tissue-with-vessel intensities.

3. Refer to the figure to the right. An x-ray imaging system has a uniform circular source of radius r_s and the impulse response of the detector is a uniform circle of radius r_d. As target object, a lead sheet with two pinholes separated by a distance s is placed at a distance z from the source. Derive an expression for the resolution of the system (i.e., the minimum s at which the images of the two holes do not overlap). What ratio of r_s / r_d is needed to make the resolution independent of z?



4. Suppose a chest x-ray is to be taken using a 50 keV source and that the exposure at distance d = 1.0 cm from the source is 10R. Ignore tissues other than the lung, how far should the patient be positioned from the source if the dose equivalent is to be kept below 10 mrems? Repeat the calculation for a 20 keV source. (Hint: The National Institute of Standards and Technology keeps tables of mass attenuation coefficients.)

For the following problem, you'll test parts (b) and (c) on 3 different persons (i.e., subjects) other than yourself and your classmates.

5. Use the provided `gen_im` function to create a 256 × 256 attenuation image that contains a circle of radius $r = 6$ with intensity $I = 0.2$ inside, against a background of 1.0 intensity.

   (a) What is the contrast of the circle?

   (b) Use the provided `poissrnd` function to simulate x-ray exposure, starting with a mean fluence $\lambda = 10$ (i.e., average of 10 counts per pixel). Repeat the procedure several times, each time with differently placed location of the circle and progressively smaller λ. Without disclosing the location of the circles, show your exposed images to each of your test subject. What is the minimum λ that the subject can still confidently detect the circle? Compute the corresponding SNR at this minimum λ.

   (c) Repeat above parts (a) and (b) for $I = 0.4, 0.6$, and 0.8. In each case, report the contrast value, minimum fluence and corresponding SNR for detection, and show the minimum-exposure image. Organize and present your data and results in, for example, a table.