NTNU – Trondheim
Norwegian University of
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Department of Physics

Examination paper for TFY4320 Physics of Medical Imaging

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Examination date: **Friday June 10th 2016**
Examination time (from-to): **09:00-13:00**
Permitted examination support material: **Code C**

- **Karl Rottmann: Matematisk Formelsamling.**
- **Barnett and Cronin: Mathematical Formulae.**
- **Øgrim og Lian: Størrelser og enheter i fysikk og teknikk.**
- **A specified, simple calculator is permitted.**

Other information: **Each sub-question (1a, 1b, etc) carries equal weight in the evaluation. Exam might be answered in English or Norwegian.**

Language: **English**
Number of pages: **4**
Number of pages enclosed: **0**

Checked by:

Date Signature

Some expressions that might become useful:

I = Number of photons per unit area multiplied with the photon energy E.

$$I(x) = I_0 exp(-\int \mu(x)dx)$$

$$S = \varepsilon A(I_P + I_S)$$

$$C = \frac{I_1 - I_2}{I_1}$$

$$k = \frac{S_1 - S_2}{STD_S}$$

$$D = EN_0\left(\frac{\mu_{en}}{\rho}\right)$$

$$\varepsilon = \frac{N_{out}}{N_{in}}$$

$$p(s,\theta) = -ln\frac{I}{I_0} = \int_A^B \mu(s,t)dt$$

$$HU = 1000 * \frac{\mu - \mu_w}{\mu_w}$$

$$R_c = \frac{d(L+z)}{L}$$

$$g = \frac{d^2}{4\pi L^2} \cdot \frac{d^2}{(d+t)^2}$$

$$t = \frac{6d}{\mu L - 3}$$

$$S = S_0(1 - e^{-TR/T1})e^{-TE/T2}$$

$$S = \frac{S_0(1 - e^{-TR/T1}) sin\theta e^{-TE/T2}}{1 - cos\theta e^{-TR/T1}}$$

$$f\lambda = c$$

$$c = c_0 + v\beta, \quad \beta = 1 + B/2A$$

$$f_d = \frac{\pm 2 f_0 v cos\theta}{c}$$

Energy	Linear Attenuation Coefficient [1/cm]						
keV	Water	Soft Tissue	Bone	Aluminum	Lead	CsI	NaI
20	0,81	0,87	7,68	9,29	980	121	52
40	0,27	0,28	1,28	1,53	163	104	58
60	0,21	0,22	0,60	0,75	57,0	35,7	20
80	0,18	0,19	0,43	0,54	27,5	16,6	8,5
100	0,17	0,18	0,36	0,46	63,0	9,18	5,1
140	0,15	0,16	0,29	0,38	27,3	3,91	2,5
511	0,10	0,10	0,17	0,23	1,77	0,43	0,32

Problem 1

1a)

- Sketch the principal construction and working principle of an X-ray tube designed for diagnostic imaging.
- With the help of filters that are inserted into the X-ray beam, the energy distribution of the photons can be altered. Why is such filtration wanted?
- Show an example X-ray spectrum before and after filtration. State your choice of anode material, acceleration voltage and filter material.

1b) Assume you perform a dual energy CT exam, where the effective X-ray energy in the two acquisitions are 60 and 100 keV respectively. In the 60 keV image, two different voxels have identical Hounsfield unit values HU = 1857 at 60 keV. You are told that one of the voxels contains pure bone, the other is a mixture of aluminum and soft tissue, but from one image you cannot distinguish between the two voxels. The effective linear attenuation coefficient of a mixture of two materials *1* and *2* is given by

$$\mu_{eff} = f \cdot \mu_1 + (1 - f)\mu_2$$

where *f* is the volume fraction of material *1.*

- Calculate the volume fraction of Aluminum in the voxel.
- Calculate the expected HU values for the two voxels in the 80 keV image.
- Can you now determine which of the voxel is pure bone?

Problem 2

2a) Assume a Tc-99m source located at 10 cm depth inside soft tissue and with an activity of 300 MBq. The gamma camera is place at 5 cm distance from the body and is using a parallell hole collimator with hole length 40 mm, hole diameter 2.5 mm and septal thickness of 0.3 mm. The holes are square-shaped.

- Calculate the geometric efficiency of the gamma camera.
- Calculate the number of expected number of counts in the gamma camera, given that the NaI-scintillator is 4 cm thick. Assume 100% photofraction for simplicity.

2b) Explain one method used for scatter correction in SPECT.

2c) Write a computer program (in pseudo-code) for attenuation correction in PET. Assume that your starting-point is a single slice reconstructed, but uncorrected, PET-image, named *im(x,y)*. In addition you have access to a mu-map (image of linear attenuation coefficients) of the exact same slice, *mu(x,y)*.

Problem 3

3a) Calculate the expected signal change (in %) if T2 increase from 60 to 70 ms in a spin-echo-sequence with TE = 70 ms. What will be your choice for TE if you want to obtain a T1-weighted image?

3b) Explain why blood-vessels appear brighter than the background tissue in a socalled time-of-flight MRI sequence.

3c) Draw the extended phasegraph for a 3-pulse MR-experiment, where the delay between rf-pulses 2 and 3 is longer than the delay between between rf-pulses 1 and 2. Identify the twice-refocused spin-echo and the stimulated echo.

Problem 4

4a) Derive an expression for the depth at which the propagating pressure-wave reach a "sawtooth"-shape due to non-linear effects. Neglect the effect of attenuation.

4b)

- In CW-Doppler, calculate the Doppler-shift for a blood flow of 2 m/s oriented at 30 degrees with the ultrasound beam at 2 MHz. Velocity of sound = 1540 m/s.
- Explain what is meant by transit time broadening.
- From the expression of the axial resolution: $FWHM_{sphere} = 1.2\lambda n_f$, derive an expression for the value of the transit time broadening Δf_d. Calculate Δf_d for the above blood flow, given $n_f = 10$.