HLTH 204 Radiographic Physics and Protection

Assignment 1 – Radiation Physics

Model Answers 2008

Instructions: Answer the questions below in the spaces provided. Attach a completed cover sheet and turn in to the HLTH 204 assignment box in the ELS Centre (Room 101).

An x-ray exposure is taken for 0.15 s at 140 kV_p. During the exposure the step-up transformer supplying the high-voltage part of an x-ray tube draws a current of 150 A from the 240 V mains supply. Assume that the combined transformer and rectification circuit are 95% efficient and produce negligible ripple.

1. What is the mA of the exposure? [2 marks]

"95% efficient" means that the power dissipated in the tube is 95% of that drawn from the mains, so $0.95\,V_{mains}I_{mains} = V_{tube}I_{tube}$. *Here* V_{tube} *is the accelerating voltage between the filament and anode, i.e. 140 kV, and* I_{tube} *is the current carried by the electrons striking the anode. Thus*

$$I_{tube} = \frac{0.95V_{mains}I_{mains}}{V_{tube}} = \frac{0.95 \times 240\,\mathrm{V} \times 150\,\mathrm{A}}{140\,000\,\mathrm{V}} = 0.244\,\mathrm{A} = 244\,\mathrm{mA}$$

2. What is the resistance of the tube in the circuit? [2 marks]

$$R = \frac{V_{tube}}{I_{tube}} = \frac{140\,000\,\mathrm{V}}{0.244\,\mathrm{A}} = 5.73 \times 10^5\,\Omega$$

3. How much energy is used by the tube during the exposure? [2 marks]

Power is the energy used or generated per unit time, so the energy consumed is

$$140\,000\,\mathrm{V} \times 0.244\,\mathrm{A} \times 0.15\,\mathrm{s} = 5\,130\ \ \mathrm{J/C} \times \mathrm{C/s} \times \mathrm{s} = 5\,130\,\mathrm{J}$$

4. What is the kinetic energy of the electrons just before striking the anode? Express your answer both in keV and in joules. [3 marks]

An electron crossing a potential difference of 1 V loses or gains 1 eV of energy, depending on the direction it crosses in. During the exposure the electrons crossing from the filament to the anode in the tube gain 140 keV of kinetic energy before reaching the anode. In joules, we have

$$140\,000\,\mathrm{eV} \times 1.60 \times 10^{-19}\,\mathrm{J/eV} = 2.24 \times 10^{-14}\,\mathrm{J}$$

5. What is the speed of an electron – as a fraction of the speed of light – just before striking the anode? (Hint: use KE= $\frac{1}{2}mv^2$, even though the relativistic formula might be more appropriate). [3 marks]

Here you have to look up the mass of an electron, i.e. $m = 9.11 \times 10^{-31}\,\mathrm{kg}$, *and the speed of light,* $c = 3.00 \times 10^8\,\mathrm{m/s}$. *Then*

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2 \times 2.24 \times 10^{-14}\,\mathrm{J}}{9.11 \times 10^{-31}\,\mathrm{kg}}} = 2.22 \times 10^8\,\mathrm{m/s}$$

So $v/c = 0.739$. *That's pretty fast! The relativistic formula gives* $v/c = 0.62$.

7. How many electrons strike the anode during the exposure? [3 marks]

A tube current of 0.244 A means that 0.244 C of charge passes through the tube each second. Each electron carries a charge of $1.60 \times 10^{-19}\,\mathrm{C}$*, so the total number is*

$$\frac{0.244\,\mathrm{C/s} \times 0.15\,\mathrm{s}}{1.60 \times 10^{-19}\,\mathrm{C/electron}} = 2.29 \times 10^{17}\,\text{electrons}$$

8. What is the maximum energy of the x-ray photons that are produced at the anode? [2 marks]

The photons are produced by the interactions of individual electrons in the anode, therefore the photon energy is limited by the electron kinetic energy. In other words, the maximum energy is 140 keV.

9. Estimate the total energy of the x-rays produced during the exposure. [2 marks]

On average, about 1% of the electron kinetic energy is converted to x-rays. Thus the total energy of all of the x-rays produced during the exposure is

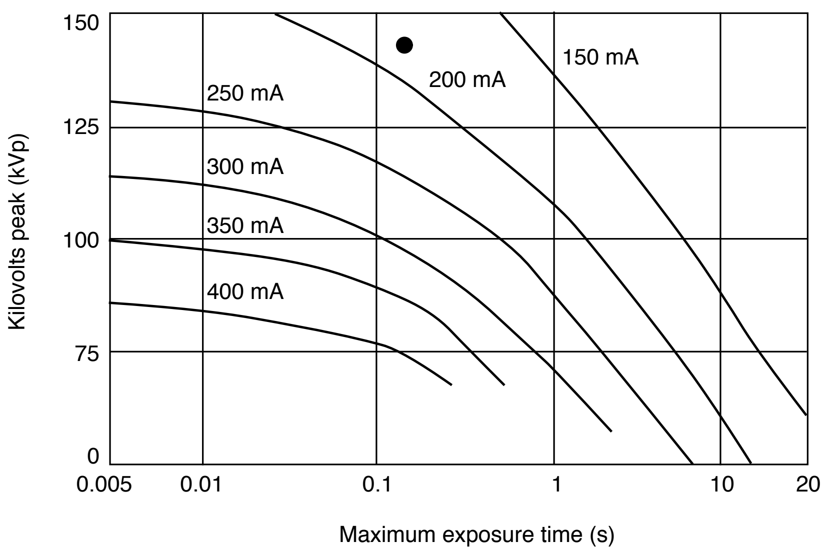
$$0.01 \times 5130\,\mathrm{J} = 51.3\,\mathrm{J}$$

10. If the average energy of the x-ray photons is 10 keV, estimate the total number of x-ray photons produced during the exposure. [3 marks]

The average x-ray energy is $10^4\,\mathrm{eV} \times 1.60 \times 10^{-19}\,\mathrm{J/eV} = 1.60 \times 10^{-15}\,\mathrm{J}$. *Thus the number of photons produced during the exposure is*

$$\frac{51.3\,\mathrm{J}}{1.60 \times 10^{-15}\,\mathrm{J/photon}} = 3.21 \times 10^{16}\,\text{photons}$$

11. The tube rating chart is shown below. Is the exposure likely to damage the tube? Explain your reasoning. [3 marks]



We just broke the anode. The black dot on the chart corresponds to our exposure settings of 140 kV$_p$ *and 0.15 s. The curves tell us that the limiting current for these settings is between 150 and 200 mA (closer to 200 mA). Higher currents for the same kV*$_p$ *and duration generate more heat, so 244 mA is very bad.*