QUESTION: We are producing a new material based on tungsten/rubber. We tested the material in the energy range of 60-140 kVa. I would like to know if it is possible to extrapolate the radiation shielding properties, attenuation, and lead equivalency to higher energies and if it is possible to predict the behavior of the material in between the different energies by creating a behavior formula.

ANSWER: I am not sure that I have fully understood your question. Let me rephrase it. You have developed a material that is some kind of tungsten-loaded rubber which you intend to use for shielding of low-energy x rays. I am assuming that you tested the attenuation properties of this material using various x-ray spectra (does kva stand for kilovolt accelerating potential?). You want to know whether you (a) can predict the attenuation and lead equivalency of the material in between the different energies, by fitting the data with some kind of model, and (b) extrapolate the attenuation and lead equivalency to higher energies.

(a) Archer et al. (Archer 1983) have described the transmission of broad x-ray beams, B, through various shielding materials by a mathematical model:

$$B = \left[\left(1 + \frac{\beta}{\alpha} \right) e^{\alpha\gamma x} - \frac{\beta}{\alpha} \right]^{\frac{1}{\gamma}} \qquad 1)$$

Where x is the thickness of the shielding material and α, β, and γ are the fitting parameters at a given accelerating potential (kVp).

The above equation may be solved for the thickness x as a function of the transmission, B:

$$x = \frac{1}{\alpha\gamma} \ln \left(\frac{B^{-\gamma} + \frac{\beta}{\alpha}}{1 + \frac{\beta}{\alpha}} \right) \qquad 2)$$

At any accelerating potential, there is a correlation between the transmission provided by different materials (Sutton 2000). It is possible to fit polynomial equations to the data and therefore relate the different materials required to produce the same transmission. Thus the lead equivalency of the material can be determined at each accelerating potential.

Equation 2 can be rewritten as:

$$\ln(B) = -\alpha x - \left[\frac{1}{\gamma} \ln \left(1 + \frac{\beta}{\alpha} \right) \right] \qquad 3)$$

At large values of x, the second term in Equation 3 becomes insignificant and the equation reduces to:

$$\ln(B) = -\alpha x \qquad 4)$$

Integrating the above equation yields:

$$B = e^{-\alpha x} \qquad 5)$$

where the Half Value Layer, that is, the thickness of the material required to reduce the intensity by a factor of 2, is given by

$$\text{HVL} = (\ln 2)/\alpha \qquad 6)$$

Thus, if the material is thick enough to provide sufficient attenuation and hardening of the x rays, then a conservative assumption would be to treat the x rays as being of a constant HVL. The HVL could then be plotted as a function of the accelerating potential and fitted with an appropriate model.

(b) The answer to the second part of the question is not that straightforward. Suffice it to say that it is not a good scientific practice to extrapolate the data to higher energies unless there is some way of validating the extrapolation. I suspect that at the higher energies, the attenuation of the tungsten will be the dominant factor. A better approach would be to perform Monte Carlo calculations at both the low energies where measurements were made and at higher energies where no measurements were made. If you could validate the Monte Carlo calculations with the measurements at the low energies, then you could have confidence in the calculations at the higher energies.

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References

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