EXOTIC FILTER MATERIALS FOR DIAGNOSTIC X-RAY EQUIPMENT - ARE THEY SUPERIOR TO COMMONLY AVAILABLE MATERIALS?

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ABSTRACT

Measurements and computer simulations were carried out to evaluate the suitability of various elements for use in X-ray filters. Filter thicknesses were selected to give approximately identical absorbed doses to the image receptor for all elements under consideration. The results suggest that elements in the ranges of atomic numbers from approximately 22 to 42, and above 68 perform about equally well in terms of affecting the phantom dose and image contrast under the conditions used in measurements and simulations. In some specialized applications, exotic filters may have advantage in matching the X-ray spectrum to the image receptor response. These special cases are not considered here.

INTRODUCTION

In diagnostic radiography, filters are used to modify the spectral distribution of photons in an X-ray beam in order to reduce the number of photons that would contribute to the patient dose but not to the acquisition of diagnostic information. Aluminum and, less frequently, copper have been traditionally used in equipment designed for diagnostic procedures other than mammography. In recent years, several less common elements, typically metals from either the rare earth or the fifth period group, have been proposed and tested as filter materials. Adding such filters to the basic filtration, e.g. 2.5 mm Al, results in decreasing both the X-ray dose to the patient and image contrast. Filters tested by the Bureau of Radiation and Medical Devices performed as advertised. An obvious question is whether adding an equivalent thickness of other, more common and less expensive materials, would result in similar changes in the patient dose and image contrast as does adding a more exotic filter.

To evaluate the behaviour as X-ray filters of a large number of elements under various conditions, we developed a computer simulation of the basic X-ray imaging chain. We found good agreement between results of computations and data obtained by actual measurements of film densities and exposures.

COMPUTER SIMULATION AND COMPARISON WITH EXPERIMENT

Figure 1 shows the simulated arrangement. The spectrum calculated according to [1] is filtered through a 1 mm thick glass window and 2.5 mm Al basic filter before reaching the additional filter under evaluation. The filtered beam is attenuated by a phantom, simulating the patient, and two contrast test objects. It passes through the patient support and antiscatter grid, and is finally absorbed by the image receptor.

Mass attenuation coefficients are calculated from the parametrization method developed in Ref. [2], while mass energy absorption coefficients are interpolated from Ref. [3]. Attenuation calculation uses the standard exponential formula

$$E = \int \{E(e)*\exp(-\mu(e)*d)\}de \qquad (1)$$

where E is the beam energy fluence, e is the photon energy, E(e) is the spectral distribution of the fluence, and $\mu(e)*d$ is the product of attenuation coefficient and attenuator thickness

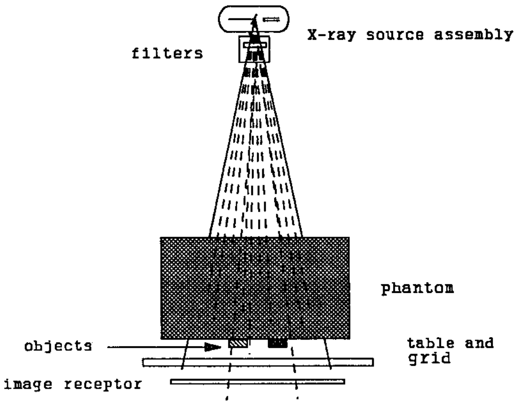
while the integral dose uses the formula for thin absorbers [4],

$$D = \int \{E(e)*\nu(e)/\mu(e)*[1-\exp(-\mu(e)*d)]\}de \qquad (2)$$

where $\nu(e)$ is the mass energy absorption coefficient, and the other symbols have the same meaning as in (1).

Derivation of Eq. (2) in Ref. [4] can be applied also to thick absorbers, such as phantoms, in a narrow beam geometry.

Fig. 1. Simulated experimental arrangement



Since we use the model to compare the behaviour of different filters under identical conditions, we are interested only in relative values. In this case, it is not necessary to include any correction to account for the grid factor. Similarly, we have used the inverse square law to facilitate the comparison with experimental data, but its omission would not influence the results of comparison of individual filter materials. The computer model does not take into account the scattered radiation. For comparisons between calculated and measured values, we corrected the measured values by subtracting the estimated contribution of scattered radiation from the reading of the probe used to measure the exposure at the phantom exit and image receptor entrance. We did not use any patient support or grid in this particular case.

Table 1 summarizes the results of comparison. The data are presented in pairs consisting of figures for the filter under consideration and an approximately equivalent copper filter.

Tab.1. Computed and Measured Film Contrasts and Phantom/Phosphor Dose Ratios

			obj.1 contr.		obj.2 contr.		dose ratio	
kVcp	elem	mm	calc	meas	calc	meas	calc	meas
60	Pd	0.025	0.29	0.31	0.43	0.45	28.3	33.8
	Cu	0.1	0.29	0.32	0.43	0.46	25.7	30.6
	Nb	0.03	0.29	0.29	0.44	0.44	28.9	33.9
	Cu	0.075	0.29	0.28	0.44	0.43	28.1	33.3
	Er	0.1	0.28	0.29	0.42	0.45	27.2	30.2
	Cu	0.175	0.28	0.33	0.42	0.44	20.6	24.0
80	Pd	0.025	0.32	0.31	0.49	0.49	37.1	36.5
	Cu	0.125	0.32	0.31	0.48	0.46	31.9	37.7
	Nb	0.03	0.33	0.32	0.49	0.49	37.0	40.7
	Cu	0.075	0.33	0.31	0.49	0.48	35.6	38.5
	Er	0.1	0.33	0.33	0.49	0.47	33.2	33.4
	Cu	0.275	0.30	0.30	0.46	0.46	26.2	28.3
	Mo	0.03	0.33	0.29	0.49	0.43	36.1	32.1
	Cu	0.175	0.31	0.29	0.47	0.44	29.4	31.1
100	Pd	0.025	0.27	0.26	0.40	0.42	28.3	30.4
	Cu	0.125	0.27	0.26	0.40	0.39	25.7	27.5
	Nb	0.03	0.27	0.28	0.41	0.46	28.9	30.5
	Cu	0.075	0.27	0.28	0.41	0.41	28.1	30.0
	Er	0.1	0.27	0.31	0.41	0.47	27.2	27.2
	Cu	0.375	0.25	0.27	0.37	0.39	20.6	21.6

Fig.2. Computed Values of Dose Ratios and Contrasts

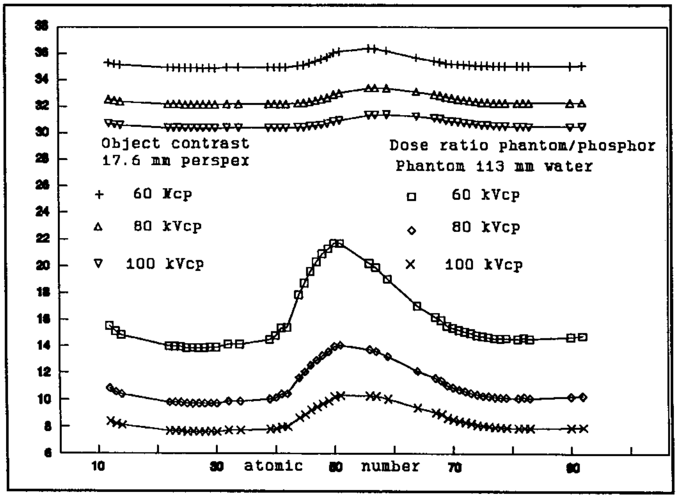


Figure 2 shows the calculated values of object contrasts and relative doses for several simulated situations, with filter materials and thicknesses listed in Table 2.

Conditions simulated in Table 1 and Figure 2: X-ray tube voltage 60, 80 and 100 kVcp (approximated by a three phase generator operating at low X-ray tube current), phantom 113 mm H_2O, objects 11.8 (not shown in Fig.2) and 17.6 mm polymethylmethacrylate.

Tab.2. Filter Thicknesses in Fig.2 Computations

elem.	mm	elem.	mm	elem.	mm
12 Mg	3.2	41 Nb	0.03	69 Tm	0.028
13 Al	1.75	42 Mo	0.026	70 Yb	0.0375
14 Si	1.7	44 Ru	0.017	71 Lu	0.0265
22 Ti	0.295	45 Rh	0.016	72 Hf	0.0195
23 V	0.2	46 Pd	0.015	73 Ta	0.015
24 Cr	0.145	47 Ag	0.017	74 W	0.0133
25 Mn	0.128	48 Cd	0.02	75 Re	0.0123
26 Fe	0.105	49 In	0.0225	76 Os	0.0108
27 Co	0.085	50 Sn	0.023	77 Ir	0.0108
28 Ni	0.075	51 Sb	0.025	78 Pt	0.0109
29 Cu	0.068	56 Ba	0.054	79 Au	0.0117
30 Zn	0.079	57 La	0.031	81 Tl	0.018
32 Ge	0.088	59 Pr	0.031	82 Pb	0.018
34 Se	0.085	64 Gd	0.029	83 Bi	0.0205
39 Y	0.075	67 Ho	0.0275	90 Th	0.0145
40 Zr	0.042	68 Er	0.027	92 U	0.008

The filter thicknesses listed in Table 2 result in approximately identical doses absorbed in the image receptor under conditions shown for Table 1 and Figure 2. Calculations of the solid bone contrast (not shown) result in the same pattern of dependence on the atomic number of the filter as found for polymethylmethacrylate. Some of the elements listed in Table 2 may not be suitable for X-ray filters because of their mechanical or chemical properties, radioactivity, or cost.

CONCLUSION

The results of measurements and computations suggest that, under the conditions used in this work, there is no noticeable difference in performance as filter materials for elements in the ranges of atomic numbers from approximately 22 to 42, and above 68. Advantages of special filters designed for matching the X-ray spectrum with image receptor response are not treated in this paper.

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