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DIGITAL X-RADIOGRAPHY FOR MEASURING SMALL DENSITY VARIATIONS

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Small abnormalities in soft-tissue are not readily detected by standard x-ray diagnostic techniques. Such techniques depend ordinarily on significant differences in atomic absorption coefficients and are normally not effective in distinguishing small "depth-density" [$\int\rho(x)dx$] differences between regions having similar atomic composition.

Recently energetic heavy charged particles[1,2] have been used effectively to determine depth-density differences in soft tissue. A monoenergetic beam of such particles will penetrate a particular absorber to a precisely known depth, the particle range. For sample thicknesses approximately equal to this range, small thickness differences yield large differences in relative penetration and may therefore be distinguished with high photographic contrast.

It is also possible, however, to distinguish small density variations in soft tissue by using monoenergetic x-rays if digital-imaging and contrast-enhancement techniques are employed. To detect a depth-density difference between two picture elements it is only necessary that there be a statistically significant difference between the respective numbers of detected x-rays.

For example, for each picture element, if μ is the x-ray attenuation coefficient and Δx is a variation in sample thickness, then the variation in the number of x-rays detected,

$$\frac{\Delta N}{N} = (1-e^{-\mu\Delta x})$$

must be larger than the statistical uncertainty in the total number of detected x-rays. For an average of N x-rays detected per picture element, a one-standard-error thickness uncertainty would be limited by counting statistics to

$$\Delta x_1 = -\frac{1}{\mu} \ell n \left(1-\frac{1}{N}\right) .$$

The x-ray fluence required for such a picture would be

$$I = \frac{N}{\epsilon \ell^2} e^{\mu x} ,$$

where x is the thickness of the object, ℓ is the width of a picture element, and ϵ is the detector efficiency. The average radiation dose absorbed by the object is then

$$D = \frac{1.6x10^{-5}\ EN}{x\epsilon\ell^2}\ (e^{\mu x} - 1) \qquad \mu rad$$

if E, the x-ray energy, is expressed in keV.

Figure 1 shows, as a function of x-ray energy, the number of counts required to distinguish 1% thickness differences in a water absorber. Also shown is the average absorbed dose under these irradiation conditions. We see from the figure that there are regions of suitable x-ray energy where the required number of counts per resolution area and the absorbed radiation dose are both quite low.

Some preliminary experimental measurements have been made to confirm these calculations. Figure 2 shows a sample image taken with a Xe-filled multiwire proportional chamber.[3] The test object was a 6 x 6 in. lucite block contining five 1-in.-diameter holes of depth 1, 0.5, 0.2, 0.1, and 0.05 cm respectively. The image data were collected as a 64x64 array in a pulse-height analyzer and very simply processed by computer for image enhancement and display. The source used was the 22 keV x-ray from ^{109}Cd. As can be seen in the figure the counting statistics were just adequate to detect the 0.1 cm hole, which corresponded to a 1.6% decrease in absorber thickness.

These first results, while preliminary in the sense of not fully exploring longitudinal and depth resolution capabilities, do demonstrate the potential of such an x-ray detection and imaging scheme for discerning small depth-density differences in soft tissue at sub-mrem delivered doses.

References

1) V. W. Steward and A. M. Koehler, Radiology, 110, 217 (Jan. 1974).

2. E. V. Benton, R. P. Henke, and C. A. Tobias, Science, 182 (Nov. 1973).

3) S. Kaplan, L. Kaufman, V. Perez-Mendez and K. Valentine, Nucl. Inst. and Meth., 106, 397 (1973).

Figure Captions

Figure 1 - Detector counts (---), and average relative dose to a water absorber (———), vs x-ray energy, for resolving 1% $\Delta x/x$ with one standard error. The dose-curve data must be divided by $\epsilon \ell^2$ to obtain absorbed dose in μrem. Results are plotted for x equal to a) 5 g/cm^2, b) 10 g/cm^2, and c) 20 g/cm^2.

Figure 2 - Samples of a processed digital radiograph of test object described in text.

a) uniform distribution of grey shades

b) high contrast image made by showing as black all picture elements having counts $1.03\bar{N} \leq N \leq 2.00\ \bar{N}$

c) similar to a) with $1.06\bar{N} \leq N \leq 2.00\ \bar{N}$

d) similar to a) with $1.30\bar{N} \leq N \leq 2.00\ \bar{N}$.

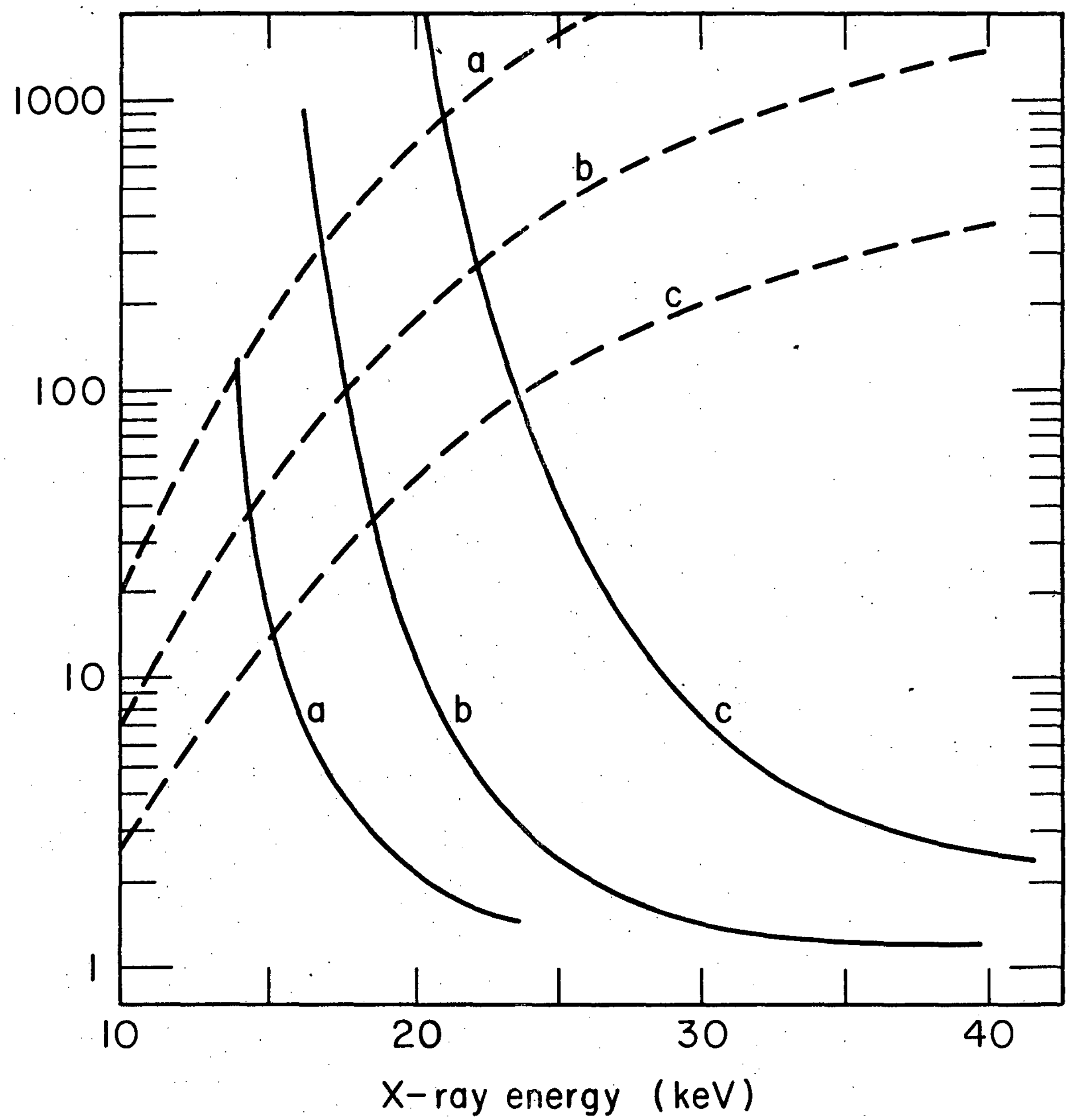

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Fig. 1

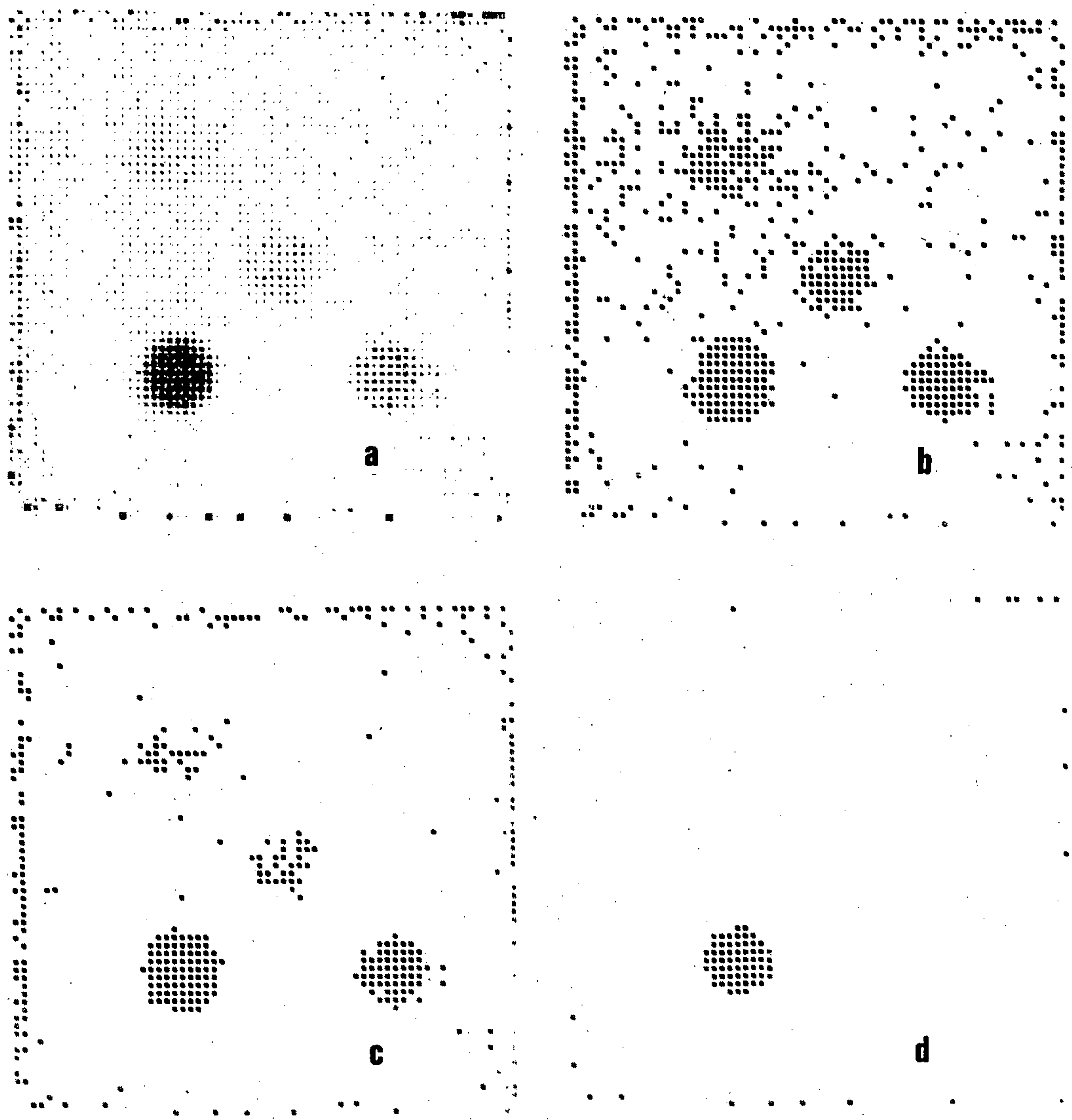

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Fig. 2

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