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LAMINOGRAPHIC EXCITATION CAMERA FOR THYROID IMAGING

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Summary

We describe a camera for the laminographic imaging of the thyroid without administration of radiopharmaceuticals to the patient. An external source of gamma-rays is used to excite the characteristic x-rays of natural iodine in the patient's thyroid, source geometry limiting excitation to well-defined planes. The camera consists of a parallel hole collimator and a xenon-filled proportional wire chamber with digitized readout of coordinates. Pulse height selection is provided to limit events in the image display to a selected energy range.

We estimate that the system will obtain high resolution laminography for local exposures on the order of 1 to 5 rad, with exposure times of a few minutes for each laminogram.

Introduction

We describe a special purpose imaging system that combines the advantages of well-established and new techniques to obtain high resolution laminographic images of the thyroid.

The camera for thyroid imaging employs a technique developed by Hoffer et al, at the University of Chicago,[1] which uses characteristic x-ray excitation and a scanning device. Their scanner contains an ^{241}Am source which excites the natural iodine in the thyroid. The characteristic x-rays are detected by a solid state silicon crystal which scans the thyroid region in a raster pattern with a focused collimator. The detected density of characteristic x-rays is recorded as in a conventional radioisotope scan.

Our proposed instrument also employs the excitation principle in order to provide thyroid imaging at extremely low patient exposures, which are limited to the region of interest. Instead of using a scanning device with the source moving in unison with the detector, as is done in Hoffer's device,[1] we activate only a well-defined and selected plane within the patient's neck for each image of the thyroid. By exciting characteristic x-rays from a series of such planes high resolution tomograms may be obtained. The x-rays are detected by a xenon-filled multi-wire proportional chamber with delay-line readout of coordinates.[2] A parallel hole multichannel collimator limits detection of x-rays to those with perpendicular orientation to the plane of the chamber. (Figure 1).

The laminar excitation thyroid imaging device is expected to offer large improvements in quality and information content of thyroid images.

1. Increased spatial resolution in images to about four millimeters (FWHM) with ultimate capability of about 1 mm FWHM.
2. Reduced patient exposure to radiation by limitation of radiation exposure to specific thyroid regions and duration of the image formation.
3. Laminographic thyroid imaging evaluation of palpable nodules without interference by superimposed thyroid tissue with different functional characteristics from the nodule.
4. Ability to image suppressed thyroids: This method of thyroid imaging will depend upon tissue content of iodide rather than the functional activity of that tissue. Thus, thyroids whose function is fully suppressed will still be susceptible to imaging by examination of their iodide content (principally hormone stores). The method will thereby offer several types of information which are inherently different from those obtained by conventional thyroid imaging with radioactive iodide or pertechnetate.
5. Low system cost: The proposed instrumentation may be constructed for a total system cost which would be acceptable for a special purpose instrument that provides the listed advantages and improvements over existing techniques.

The Laminographic Excitation Camera

A line ^{241}Am source, collimated to irradiate a plane, is used to activate the volume of interest. The 60 keV gamma-rays from this source excite the emission of 28.6 keV rays that can be detected with the collimated wire chamber imaging system. (Fig. 2). Scintillation cameras cannot be used in this application because of their poor energy and position resolution at iodine fluorescent energies.

Multi-Wire Proportional Chamber

The detector consists of three wire planes with an active area of 11 X 13 cm^2. The two outside planes have their wires at 90 degrees to each other and are made of 127μm gold-coated molybdenum wire, stretched on 1 cm thick frames of Nema G-10 fiberglas epoxy with a pitch of 24 wires per inch. The ends of the wires are soldered to printed circuit boards which terminate outside the chamber volume. Wires are connected in pairs to a common bus bar through 200kΩ resistors. The central plane consists of 30μm gold-coated tungsten wires with a pitch of 12 wires per inch. The ends of these wires are soldered to a common high voltage terminal.

A 130μm Mylar window with a 25μm aluminum coat on it seals the front of the chamber, while a steel plate is used as the back window. The chamber is filled with a 90% Xe - 10% CO_2 gas mixture. (Fig. 3).

During operation the windows are held at ground, with the outside and center planes held at +250V and +5400V respectively, thus allowing the volume between the windows and outside planes to be used as drift regions. With this configuration the chamber has a 13% efficiency for detection of the 28.6 keV characteristic x-rays of iodine.

The principle of operation is as follows: Some of the x-ray photons reaching the active volume of the chamber convert their energy to an electron through the photoelectric effect. The electron ionizes the gas, and due to the electric field these secondary electrons will drift towards the anode wires and undergo multiplication in the region immediate to these wires, producing a voltage pulse on them. Simultaneously, an induced pulse of the opposite polarity will be generated on the cathode wires by the initial motion of the positive ions.

Electromagnetic delay-lines[3] are coupled capacitatively to the outside wire planes by placing each delay-line over the external portion of the printed circuit boards.

A prompt signal that indicates the detection of an ionizing event is obtained from the center plane. Pulse-height discriminators select for processing only those events within a desired energy window. The pulses are processed by a zero-crossing technique which produces a narrow signal corresponding in time to the peak of the detected pulse. This signal is used to start two time-to-height convertors. Similarly processed signals are obtained from the delay-lines and used to stop the converters, one each for the X and Y coordinates. Figure 4 shows the schematics of this technique and typical signals obtained from the center plane and delay lines. The output of the converters is used to drive the XY deflection plates of a Tektronix 602 Oscilloscope. The electronics provide for pile-up rejection, area of interest selection and image magnification. The individual points on the scope are integrated by a Polaroid camera left with its shutter open during the exposure. Presently this system yields a 17% FWHM energy resolution, a spatial accuracy of location of 2 mm FWHM, and can be operated at rates of 10^5/sec with a rejection rate of 30%.

Collimator

We use a High Resolution (trademark) parallel hole collimator supplied by the Nuclear-Chicago Corporation.

This collimator has an area of 10 X 12 cm^2 and allows for a geometric resolution of 0.3 cm and 0.5 cm for objects on the collimator surface and 2.5 cm away respectively (these numbers include effects due to the finite thickness of the detector). The efficiency of the collimator is estimated at $G = 2.9 \times 10^{-4}$, where G is the fraction of gamma-rays emitted by the subject that reaches the chamber.

Source

We have chosen ^{241}Am for the purpose of exciting the characteristic line of iodine. The 60 keV gamma-ray used will allow for a quite uniform irradiation, and the general availability and long lifetime of this radioisotope make ^{241}Am a very attractive choice. We favor a symmetrical arrangement of two "line" sources (fig. 1), since this maximizes uniformity of excitation. Each source consists of a 0.3 cm X 15 cm^2 - area container with 9 Ci of ^{241}Am. As shown in figure 5, the isotope will be shielded and collimated by lead plates so that the source will be approximately 20 cm away from the patient. Self absorption decreases the effective source strength to about 2.5 Ci.

Figure 6 shows the estimated counting rate along two cuts, AA' and BB', of a typical thyroid with an iodine content of 5×10^{-4} g/cm^3. The pair of sources is located symmetrically about the patient, yielding about 650 counts/cm^3/min. Radiation exposures (limited to the excited area) will be of the order of 1.3 rad/min. This is equivalent to a sensitivity of about 500 counts/cm^3/rad. These rates will make possible the acquisition of high quality laminograms in a few minutes. For instance, for a 0.5 cm thick cut along AA', one will obtain about 400 counts/cm^2/min. This will allow for collection of 1600 counts/cm^2 in four minutes, yielding a contrast of about 12% over a distance of 0.5 cm. By use of a variable aperture, laminograms of 0.1 to 2 cm depth are possible.

Preliminary Results

Figure 7 shows energy spectra obtained with various sources. The energy resolution is of the order of 17% FWHM, and the deviation from linearity is less than 500 eV in the energy range from 20 to 60 keV. To check the over-all performance of the system near iodine fluorescent energies we injected ^{125}I - labelled albumin in a rat and imaged its distribution by detecting the 27.5 keV Tellurium K_α line. Figure 8 shows a comparison of the images obtained by our camera and a conventional scintillation camera. Count rates were of the order of 20 counts/min/μCi. Although the 9 Ci ^{241}Am sources are not yet available for use, we have used a 500mCi source with a 1 cm - diameter area for initial tests of the ability of the system to discriminate among different iodine concentration levels. Figure 9 shows a fluorescent image obtained from five 1-cc vials, each with a 1 cm - diameter area. For comparison purposes one vial is filled with distilled water, while the others contain from 0.1 to 3.1 mg I/cc solutions of non-radioactive iodine. Clinical testing will be initiated upon completion of the excitation sources.

Acknowledgements

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3. R. Grove, I. Ko, B. Leskovar, and V. Perez-Mendez, "Phase Compensated Electromagnetic Delay Lines for Wire Chamber Readout", UCRL-20255 (March 1971). Submitted to Nuc. Inst. Meth.

Figure Captions

Figure 1. Schematics of the laminographic imaging technique. The 60 keV gamma-rays from two collimated ^{241}Am line sources irradiate a well-defined plane within a subject. The natural iodine is excited and yields 28.6 keV characteristic x-rays that are collimated and then detected by the multi-wire proportional chamber.

Figure 2. Schematics of the excitation camera. The two ^{241}Am are placed on opposite sides of the patient's neck, with the detector system placed above it. Only photons within the energy band corresponding to the iodine K_α excitation line are displayed in the image.

Figure 3. Wire-chamber assembly. The wires are stretched on Nema G-10 fiberglas epoxy frames and soldered to printed circuit boards. The outside planes are made of 127μm wires with a pitch of 24 wires per inch. The center plane is made of 30μm wires with a pitch of 12 wires per inch.

Figure 4. Schematic of the readout technique. The delay lines are placed on the external portions of the printed circuit boards. The signals (shown in the insert photographs) are amplified and those within selected energy windows are processed by a zero-crossing technique. The timing pulses thus obtained from the center plane and the delay-lines are used to start and stop respectively, two time-to-height converters.

Figure 5. Shows the lead collimators (a), source holders (b), variable aperture tungsten shutters (c), and encapsulated source (d).

Figure 6. Estimated counting rates along two cuts, AA' and BB' of a typical thyroid with an iodine content of 5×10^{-4}g/cm^3, using two symmetrically located planar sources with an effective strength of 2.5 Ci of ^{241}Am each.

Figure 7. Energy apectra obtained with the MWPC. (a) ^{109}Cd, (b) ^{241}Am, (c) Fluorescent spectrum from a 10% I solution. The energy resolution is of the order of 17% FWHM.

Figure 8. Rat labelled with I^{125} - albumin. A 300μCi dose was injected in the caudal vein of a rat: we show images obtained with our camera with (a) 4,000 counts, (b) 20,000 counts, (c) 80,000 counts, and (d) image obtained with a high resolution scintillation camera a day later. Labelling of the thyroid has occurred at this latter time (100,000 counts).

Figure 9. Fluorescent image obtained from five 2-cc vials with a 1 cm - diameter area containing (from left to right) distilled water, 0.1, 0.78, 1.56 and 3.12 mg I/cc. This exposure contains 10,000 counts in the area of interest.

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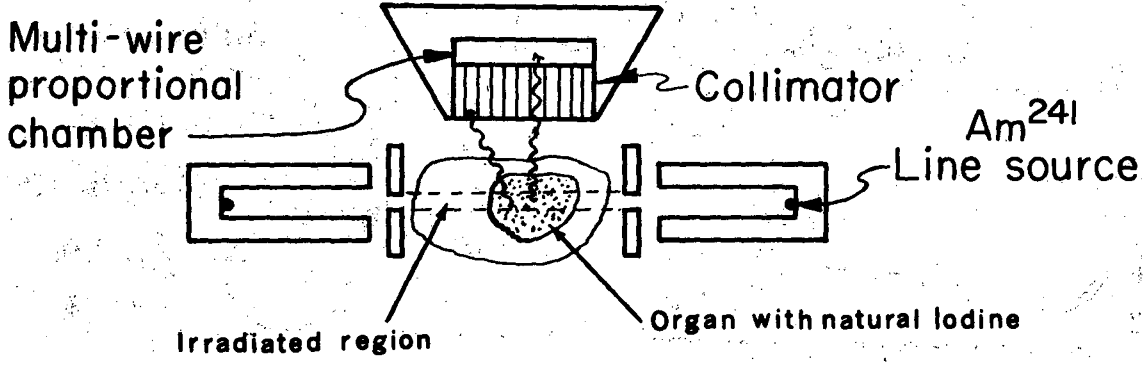

XBL 7110-1540

Figure 1

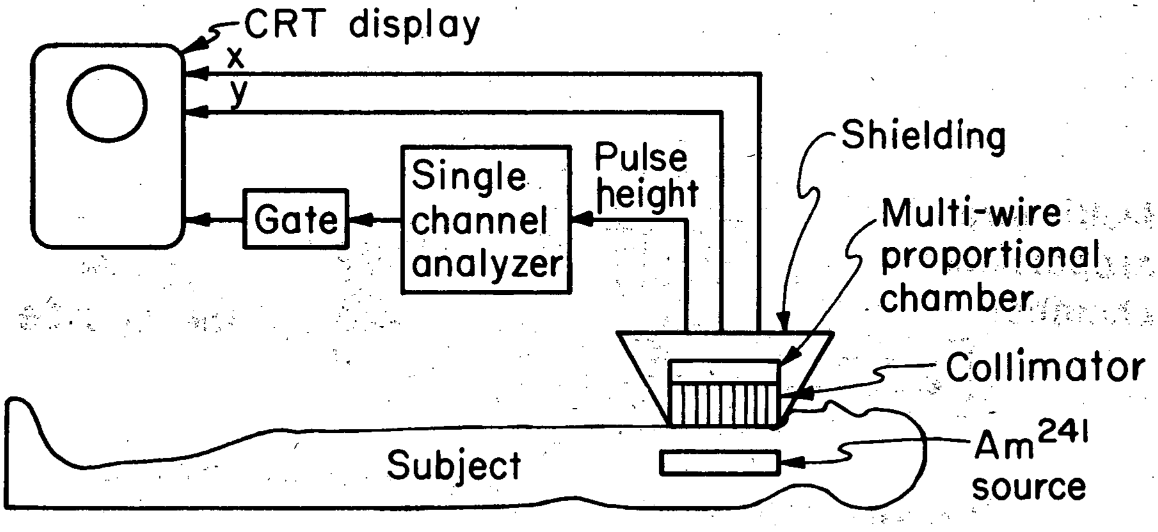

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Figure 2

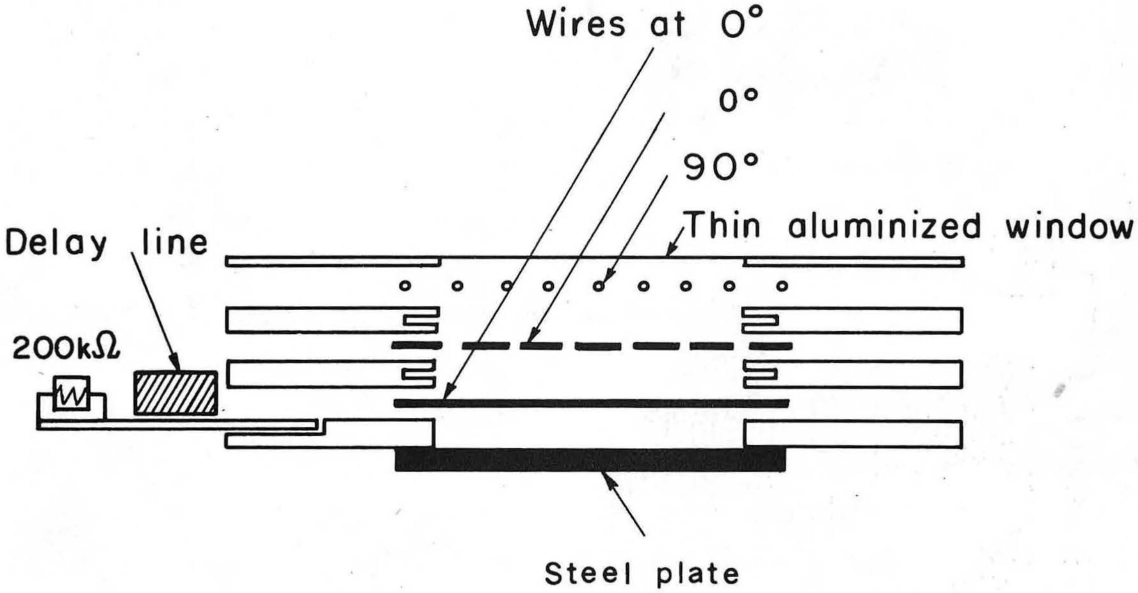

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Figure 3

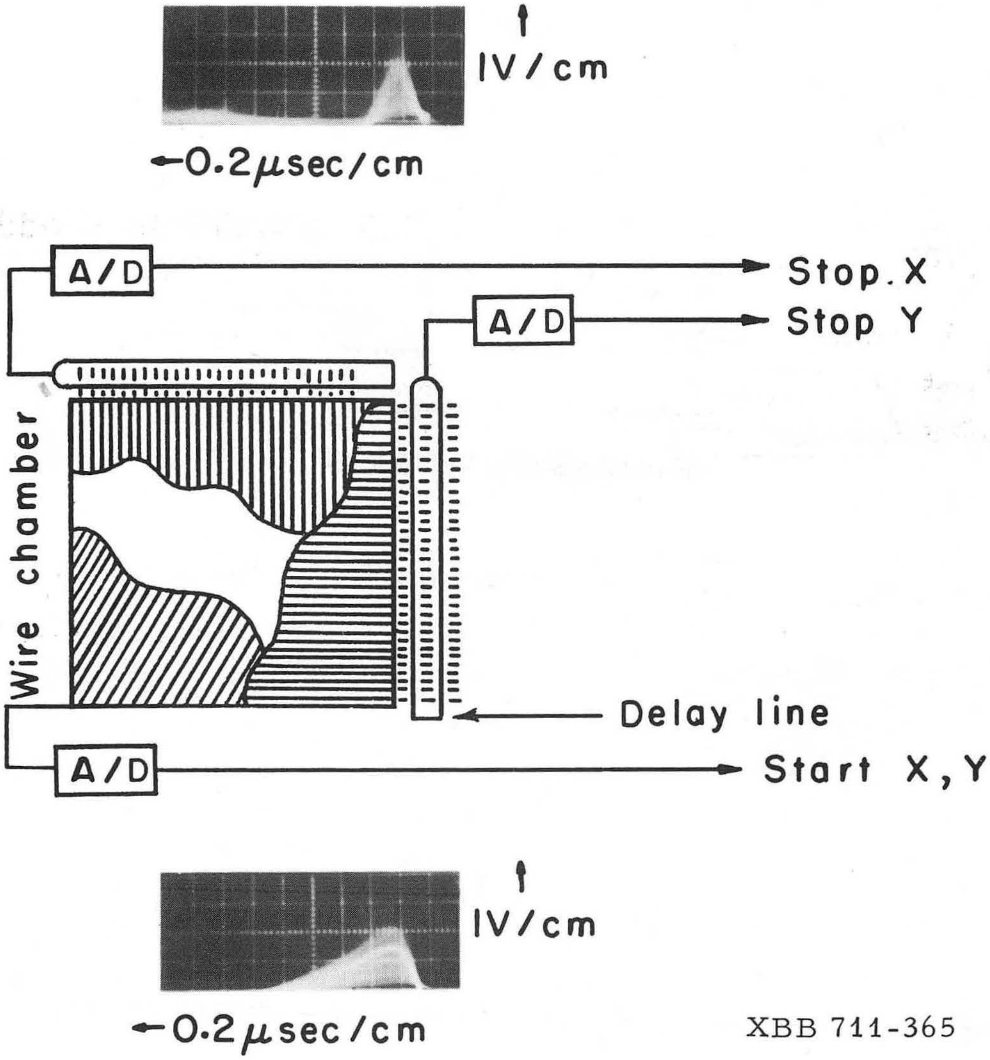

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Figure 4

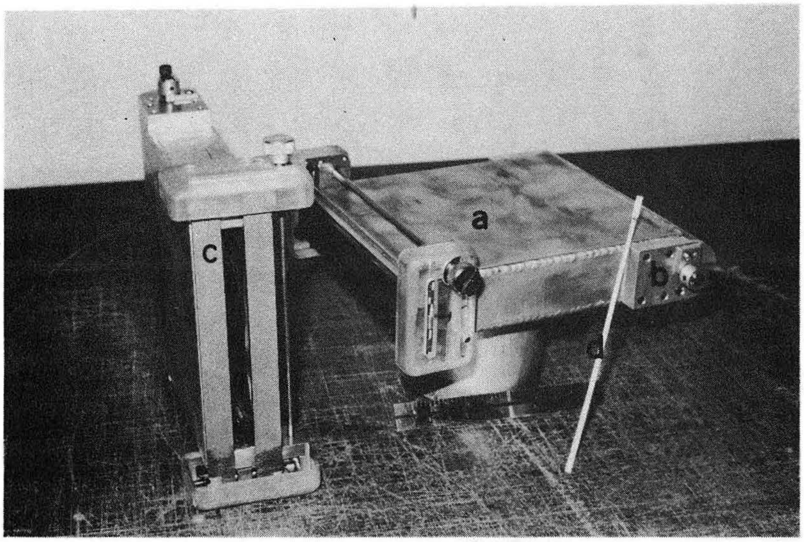

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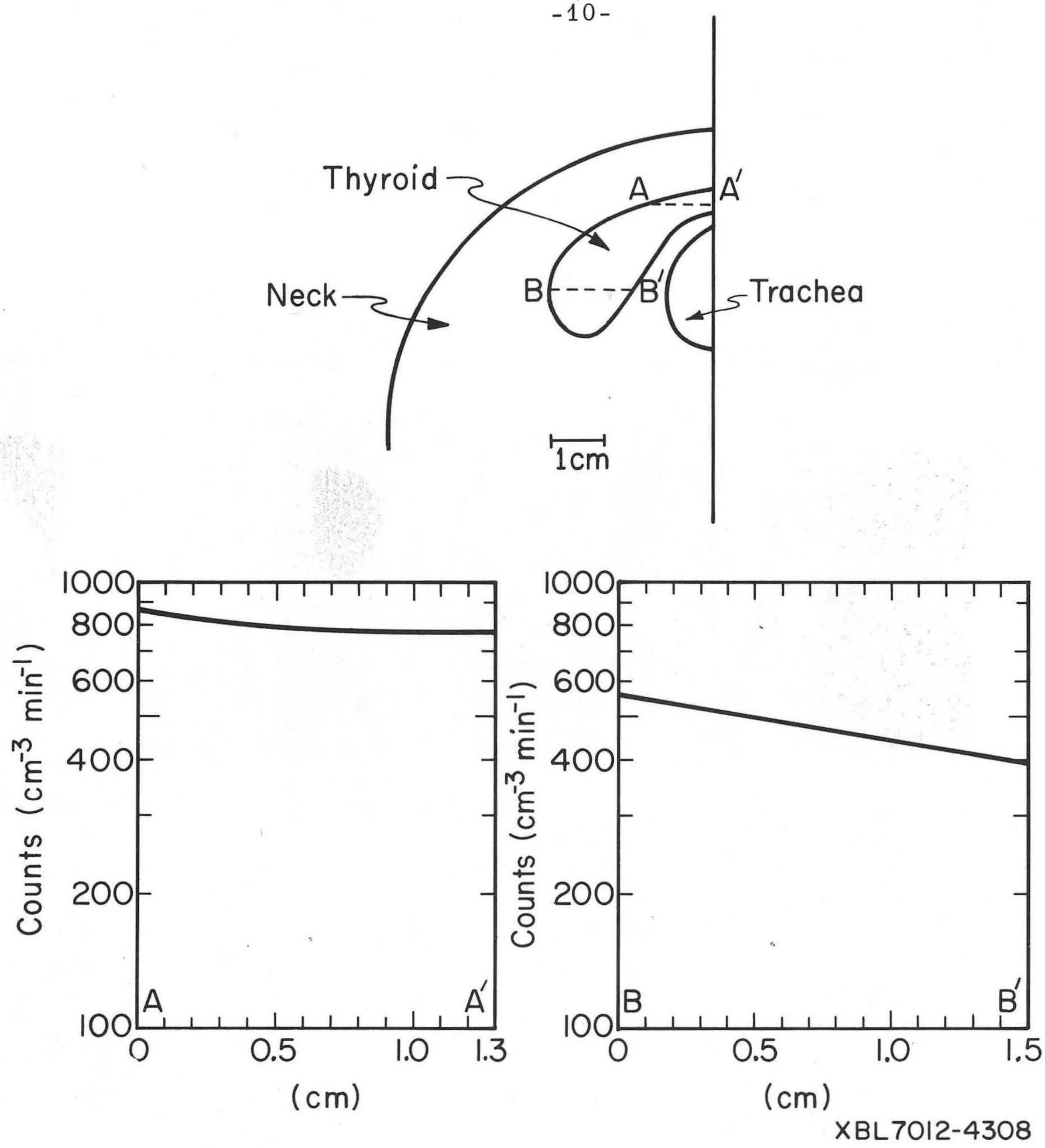
Figure 5


Thyroid
Neck
Trachea
A
A′
B
B′
1cm
1000
800
600
400
200
100
Counts (cm^{-3} min^{-1})
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A′
0
0.5
1.0
1.3
(cm)
B
B′
1.5
XBL7012-4308

Figure 6

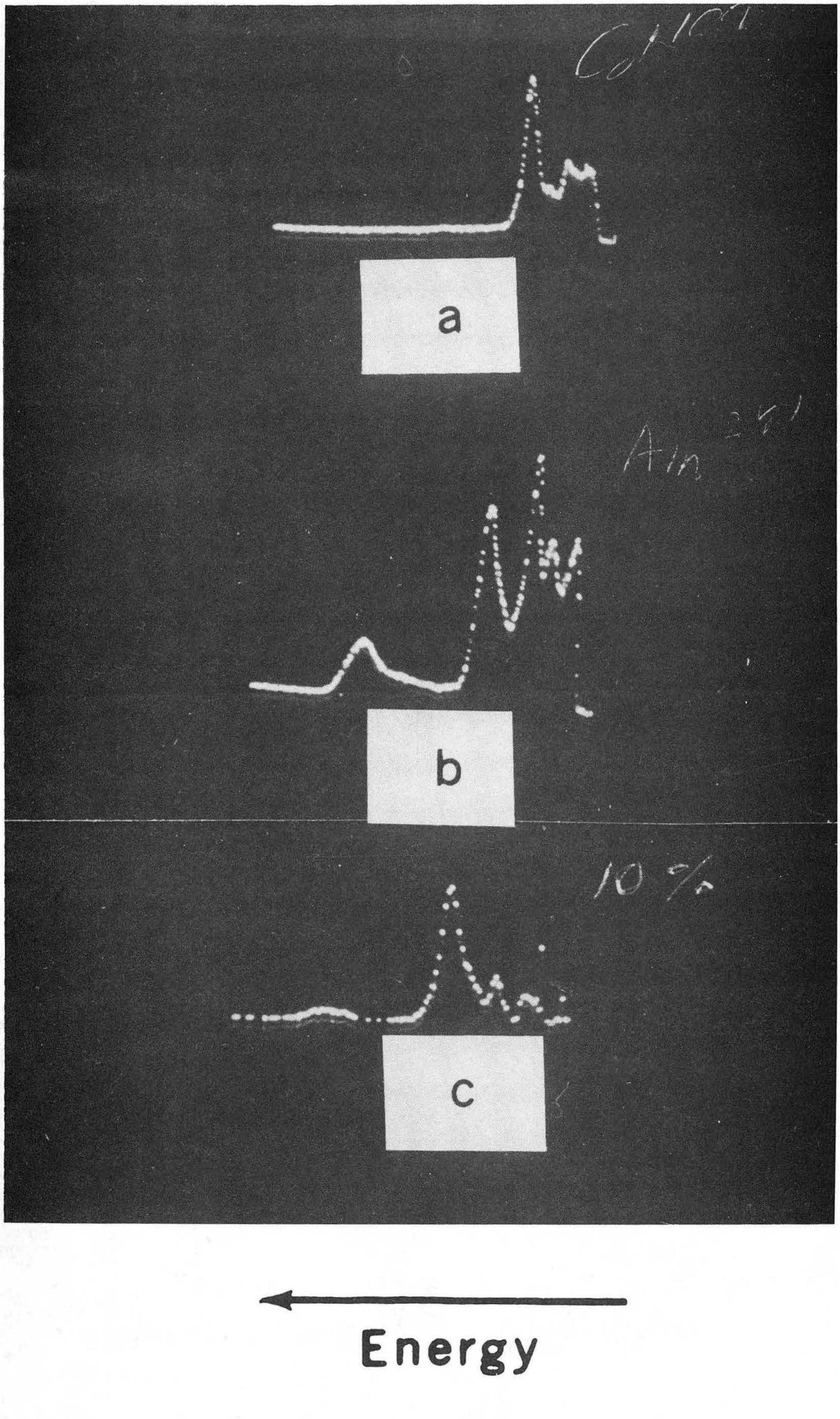

Figure 7

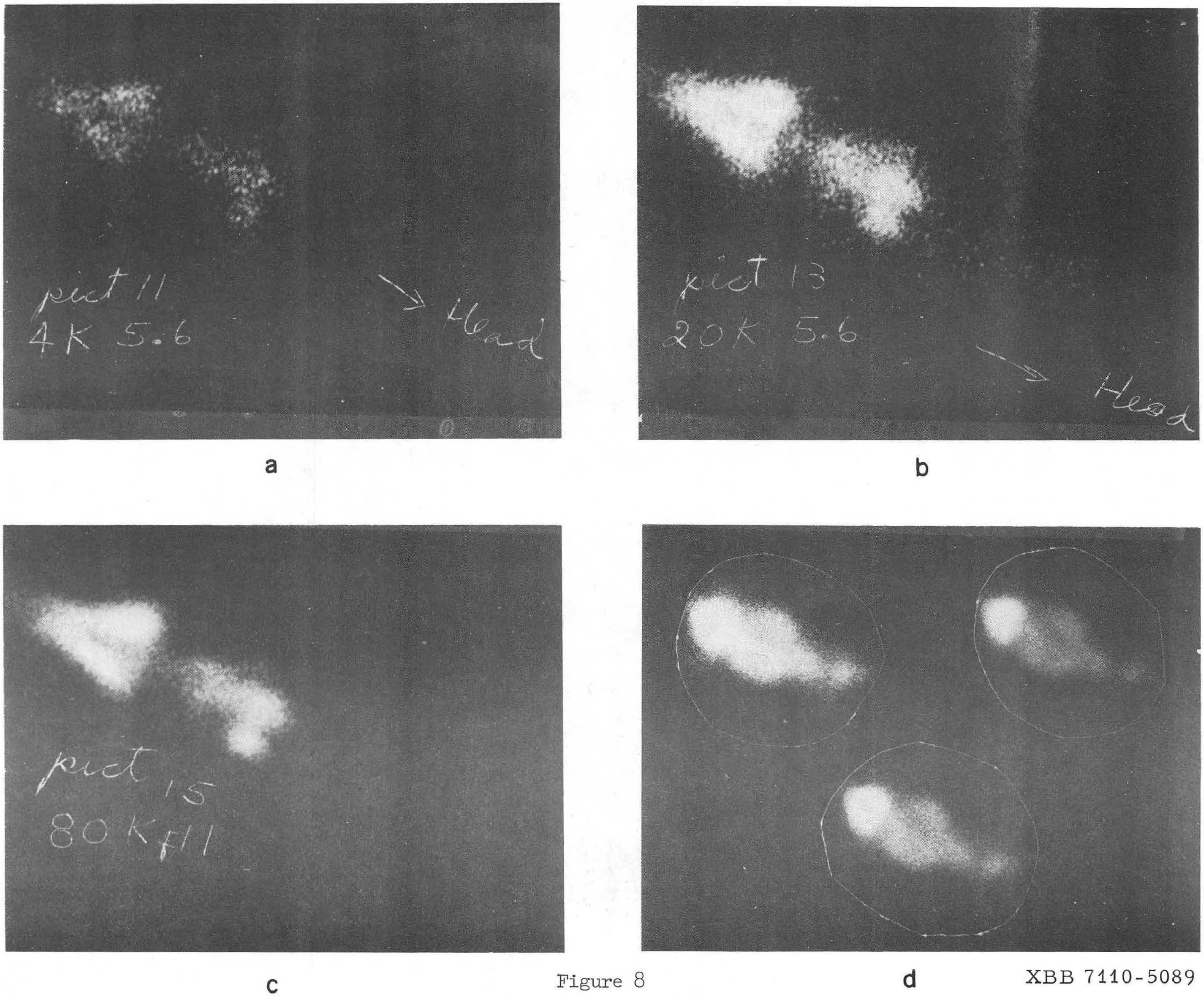

Figure 8

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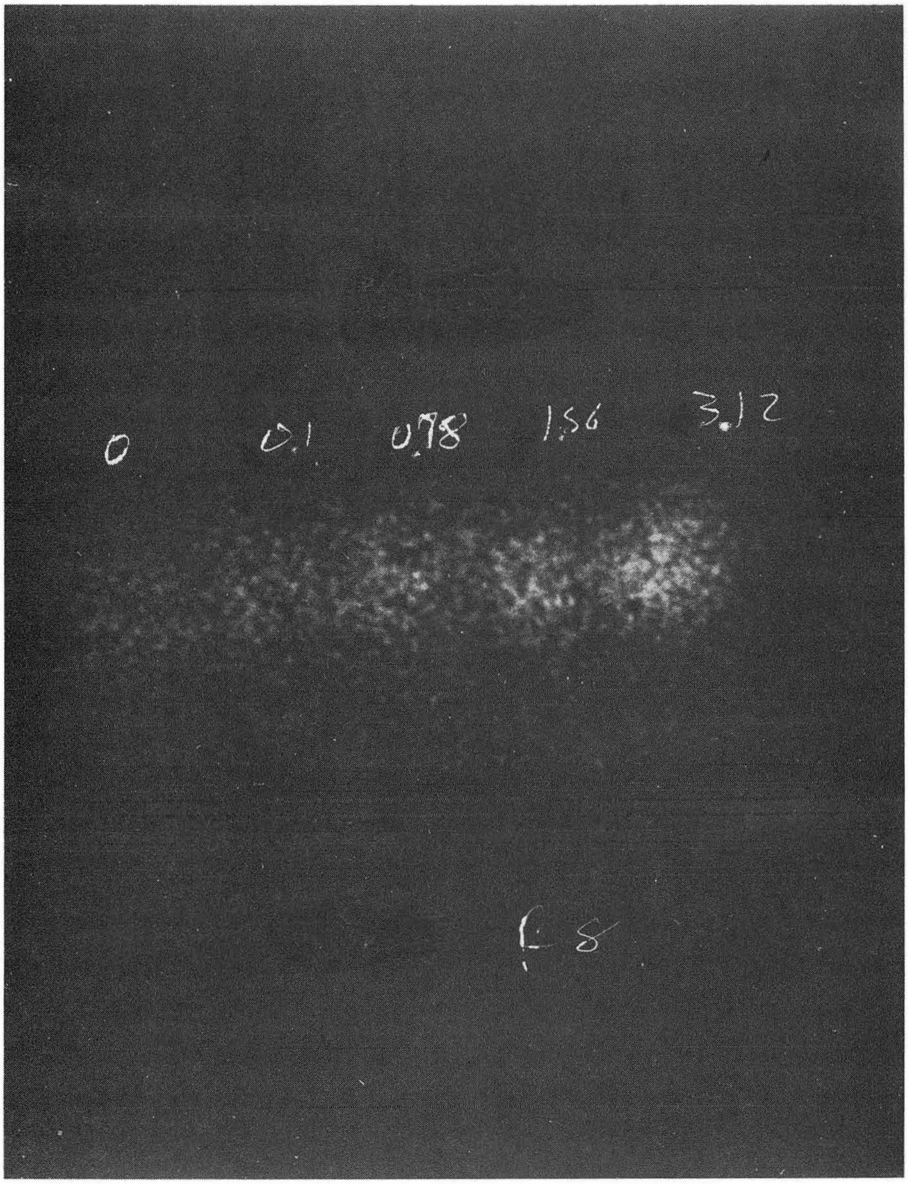

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Figure 9

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