BNWL-SA-5037

712569

IN-VIVO DETECTION OF PLUTONIUM IN THE TRACHEOBRONCHIAL LYMPH NODES WITH A FIBER OPTIC COUPLED SCINTILLATOR*

K. L. Swinth, J. F. Park
Battelle
Pacific Northwest Laboratory
Richland, Washington 99352

G. L. Voelz
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

J. H. Ewins
Laboratory of Nuclear Medicine
and Radiation Biology
Los Angeles, California

REPOSITORY PNL
COLLECTION Intraesophageal
BOX No. K Swinth
FOLDER N/A

* This paper is based on work performed under United States Atomic Energy Commission Contracts AT(45-1)-1830, AT(04-1)GEN-12 and W-7405-ENG-36.

1084056

IN-VIVO DETECTION OF PLUTONIUM IN THE TRACHEOBRONCHIAL LYMPH NODES WITH A FIBER OPTIC COUPLED SCINTILLATOR

K. L. Swinth, J. F. Park, G. L. Voelz and J. H. Ewins

A principal route of internal contamination for workers exposed to plutonium is via the respiratory tract from which deposited material will be translocated to other portions of the body including the thoracic lymph nodes. Over an extended period of time (several years) 50% of the alveolar deposited plutonium in dogs may be translocated to thoracic lymph nodes resulting in concentrations in the nodes which are 50 to 100 times that in the lungs.[1]

Results on autopsy samples from workers and the general population show similar concentration phenomena. Selection of subjects with a high potential for exposure to plutonium show a median concentration for the lymph nodes which is about seven times that of the lungs.[2] These subjects were not selected for route of administration and along with the fact that sampling of tracheobronchial lymph nodes is representative of only a portion of the lymph nodes draining the lungs, one would expect actual ratios to be higher. In terms of plutonium concentration, complete analysis of the respiratory nodes and lung tissues gave concentration differentials of over 1000 to 1 when comparing lymph nodes and lung parenchyema.[3] Many inhaled materials show this concentration phenomena and various aspects of lymphatic drainage of the lung and concentration phenomena have been reviewed by Morrow[4] and others.[5]

Because of this translocation and concentration phenomena, the highest radiation doses delivered to any tissue are often received by the thoracic lymph nodes. This redistribution will affect the dosimetric evaluation of inhalation depositions and will also affect the interpretation of whole-body counts. This paper describes a probe built to evaluate lymph node depositions and thus aid in the interpretation of inhalation exposures. Application of the probe to experimentally exposed animals and to an accidental exposure case are described.

1084057

In-vivo measurement of plutonium is performed by counting the L x-rays of the uranium daughter and radiations from ^{241}Am, the daughter of ^{241}Pu. The x-rays (13.6, 17.0 and 20.2 keV) plus the 60 keV gamma of ^{241}Am are of low intensity[6] and rapidly attenuated by tissue.[7] Typically, fewer than 30 x-rays per minute will escape from the body of a subject with alveolar deposited plutonium representing one Maximum Permissible Lung Burden (16 nCi) and only a fraction of these will be intercepted by a detector of practical dimensions. Variations in tissue absorption due to changes in tissue mass,[8] differential translocation of ^{241}Am and ^{239}Pu,[9] and the low count rates make it impractical to correct for sensitivity of external counting[10] or to determine the relative distribution of the translocated material.

Because of the high doses delivered to the lymph nodes and the changing dose pattern with time[5] it is valuable to have a technique for estimating the amount deposited in the nodes. Figure 1 shows a typical lymph node geometry from which it is apparent that the nodes are accessible for counting by a probe placed in either the esophagus or the trachea. The esophagus is the preferred site due to lessened chance of infection, reduced interference with breathing, subject comfort and ease of the probe insertion procedure. The figure shows only the nodes in the region of the bifurcation; mediastinal, pulmonary, paratracheal, etc., nodes are not shown. Little detail is known about the distribution of translocated material among nodes and the distribution of nodes by weight or size. Measurements by Pochin[11] indicate an average mass of 16 g for the tracheobronchial nodes in nine adults with a range of 10-30 g. The concentration between lymph nodes can vary widely;[3] and more information is needed in this area. Since the tracheobronchial node at the carina is generally the largest, the greatest activity would be expected at this point.

1084058

For dogs the tracheobronchial node groups are smaller and show less variation than in humans;[12] their mass is 0.548 ± 0.016 g.[13] Data from dogs indicate a fairly uniform distribution of the material among the tracheobronchial nodes on the basis of concentration.

The Intraesophageal Probe

Previous efforts with solid-state avalanche detectors demonstrated the feasibility of counting plutonium in the tracheobronchial lymph nodes using an intraesophageal radiation detector.[14] The low efficiency (5-10%) of these detectors, their temperature drift, their angular sensitivity, and the presence of high voltage limited their clinical usefulness and hindered achievement of the low detection limits desired (∿2 nCi).

Early efforts at coupling scintillators to photomultipliers with fiber optics[14] indicated that this could be a useful technique if the background count rate could be suitably reduced. Since efforts with the avalanche diode had reached a plateau short of required goals, efforts were directed toward the fiber-optic coupled scintillator.

Coupling a scintillation crystal to a photomultiplier with fiber optics causes an 80-90% loss in the scintillation intensity reaching the photomultiplier. At low energies this is serious becuase it causes a loss of resolution and moves the scintillation spectra into the noise region of the phototube. For low background counting and an improved signal to noise ratio, one must reduce the background from the photomultiplier. This was done by selecting a low-noise, high-gain phototube, magnetically limiting the active area of the photocathode and by reducing the number of fast rise time pulses by a pulse-shape discrimination technique.[15] Use of these techniques reduces the background count rate in the energy range from 6.5-40 keV by a factor of 50 or more.

1084059

Figure 2 shows background spectra before and after noise reduction techniques were applied. A coincidence technique[15] leads to even lower background rates; however, the small reduction in detection limit did not justify the added expense at this stage.

Figure 3 shows a photograph of the assembled probe with the detector and photomultiplier; a preamplifier can be encased in the housing with the phototube. This unit uses a 2.5 cm long by 4.7 mm diameter crystal coupled to the photomultiplier by 60 cm of fiber optics. The NaI(Tl) scintillation crystal is packed in MgO in a thin aluminum shell (0.25 mm) with an outside diameter of 7 mm. Three other probes using a 90 cm fiber optic coupling have been built and resulted in performance comparable to the present unit.

The completed assembly is coated with a pure polyurethane resin and cured slowly at room temperature and high humidity. This material protects the probe from the caustic fluids within the digestive tract and softens the edges and corners of the probe. Due primarily to the thermal sensitivity of the NaI(Tl) crystal the probe cannot be autoclaved; however, gas sterilization has been used without degrading the performance or longevity of the probe.

The calculated absorption in the detector for normally incident photons is 100% below 80 keV; however, at low energies attenuation in the aluminum encapsulation becomes important. For example, the intensity of the uranium L x-rays emitted in the decay of plutonium (13.6, 17.0 and 20.2 keV) is reduced 38% by the 0.25 mm thickness of aluminum encapsulation. Above 80 keV the efficiency begins to fall and is reduced to 65% at 150 keV. Measured resolution at 59.6 keV with the probe directly coupled to the photomultiplier is 17%; however, with the fiber optics the resolution is reduced to 54%. The poor resolution is caused by light losses resulting from the fiber optic coupling of the crystal.

1084060

Compared to an avalanche probe the sensitivity (cpm/nCi) for plutonium x-rays is over 25 times greater for the scintillation probe. The probe was also evaluated for other biomedical applications[16] and had higher sensitivity than solid-state probes such as CdTe and GaAs.

RESULTS

Dog Counting

Dogs from a low-level PuO_2 inhalation experiment[1] were used for testing of the probe. Four dogs exposed to $^{239}PuO_2$ and one exposed to $^{238}PuO_2$ were counted. When count rates were high enough to warrant it, scans were taken to determine count rate as a function of position. When count rates were low, timed counts were taken at locations expected to correspond to maximum and minimum count rates. Timed counts were also performed at selected positions in the higher level dogs.

Figure 4 shows a typical scan in one of the dogs. Peak count rate was shown to correlate with the position of the tracheal bifurcation by radiographs as shown in Figure 5. Previous counts with avalanche probes on dogs showed a sharper peak in count rate on scans. This was caused by two factors. First, the sensitive length of the scintillation probe is longer leading to poorer spatial resolution. Second, since these were gross counts (no energy discrimination) the 60 keV photons from ^{241}Am would degrade the spatial resolution due to their longer mean free path in tissue. Energy discrimination was not used with the avalanche probe but the sensitivity of the scintillation probe is approximately 100% at 60 keV compared to 0.5% for the avalanche probe.

Table 1 shows the estimated sensitivity for lymph node counting in four ^{239}Pu dogs and one ^{238}Pu dog. The average sensitivity for the ^{239}Pu dogs, 1.2 cpm/nCi, is close to the sensitivity estimated from the relative sensitivity of the avalanche and scintillation probe and previous dog

1084061

counts with the avalanche probe 1.0 cpm/nCi. The large range in sensitivities is not surprising considering that measured deposition in the lymph nodes can vary by over a factor of two in different dogs at the same time since exposure. Also, the lymph node burdens estimated from whole body counts and observed translocation rates in other dogs include all the thoracic lymph nodes, not just the tracheobronchial nodes. An accurate calibration will require post-mortem analysis of lymph nodes.

The net count rate at the position of interest in these animals was determined by subtracting count rates taken at a position a few centimeters further down the esophagus (caudad). This procedure corrects for counts contributed by material deposited in the lungs. Based on the average sensitivity and a five-minute counting period the Minimum Detectable Amount (MDA) at the 84% confidence level is 4.8 nCi compared to about 10 nCi with the avalanche diode probe. The MDA does not change in direct proportion to the sensitivity because of the higher background of the scintillation probe. If the counting had been performed in a shield the MDA would have been about 2.4 nCi for the scintillation probe, but would not have changed significantly for the avalanche probe.

Human Measurements

A phantom consisting of an esophagus and tracheobronchial tree fabricated of silicon rubber and suspended in water were used to simulate the human geometry for calibration purposes. The phantom is based on the best available anatomical information and employs sources positioned at the carina and at each side of the trachea to simulate the geometry depicted in Figure 1. Figure 6 shows a scan in the phantom illustrating the change in count rate as the lymph node region is passed. Again the peak in count rate is not as well defined as for the case of the avalanche diodes [14] as discussed in the section on dog counting. The peak sensitivity at

1084062

x-ray energies is 0.807 cpm/nCi. This yields an MDA of 3.0 nCi compared to 34 nCi with an avalanche diode as shown in Table II. This is at the 90% confidence level with a 20-minute counting period.

Activity in the lungs will contribute to the count rate particularly at 60 keV. To correct for this activity counts away from the lymph nodes are taken and subtracted from the lymph node region counts. Phantom lungs containing plutonium and located in a phantom were used to calibrate the probe for lung activity. At x-ray energies (17 keV) the sensitivity was 0.025 cpm/nCi while at γ-ray energies (60 keV) it was 0.072 cpm/nCi. This calibration will depend on isotopic composition of the counted material. It is clear that the sensitivity for lung deposited material is much less than that for lymph node activity.

The procedure developed for using the probe on human volunteer test subjects was based on a combination of experience from counting the dogs and standard medical endoscopic procedures. Briefly, after explaining the procedure to the subject to assure informed consent his throat is lightly anesthetized and the probe inserted by a physician to the approximate location of the bifurcation. Next radiographs (or fluoroscopy) are used to adjust the probe so that the detector is just below the bifurcation. The subject is then placed in a whole body counter shield where two 10-minute counts are taken at the bifurcation, one 10-minute count is taken 4 cm below (caudad) this location and one 10-minute count is taken 5 cm above the bifurcation region (cephalad).

The first counts measure the activity in the tracheobronchial lymph nodes, the second measures primarily lung contribution and the third measures activity from mediastinal and paratracheal nodes.

1084063

Two volunteer subjects were counted at Los Alamos Scientific Laboratory. One was a background or control subject while the second was an individual accidentally exposed to an aerosol of $^{239}PuO_2$ 14 years prior to our counting. His lung burden is estimated at 8 nCi of ^{241}Am for in-vivo counting since the L x-rays of ^{239}Pu are no longer detectable.

Figure 6 is an x-ray showing the probe properly positioned for the first set of counts. The probe is just below the bifurcation. Table III shows counting results at the three positions. The errors shown are based on statistical variations and represent the precision of the measurement. Accuracy is limited by errors in calibration and our lack of knowledge concerning variability of lymph node sizes and interlymph node activity. Accuracy is difficult to estimate, but a factor of two error is not inconceivable. The high count rates at position 3 (5 cm cephalad of bifurcation position, 1) are probably due to a combination of paratracheal nodes, mediastinal nodes and a higher contribution from the lungs.

Conclusions

Experimental results have shown that it is possible to count plutonium in the tracheobronchial lymph nodes using a relatively safe and simple procedure. The new scintillation probes have greater sensitivity, less positional dependence and do not require placing high voltages within the body. The probe itself is completely passive. With a minimum detectable amount (MDA) of approximately 3.0 nCi, the probe can be used to perform counts on many occupationally exposed plutonium workers. With refinements the MDA could be reduced by a factor of two.

1084064

The probe is not meant to replace whole-body counting techniques for plutonium, but will allow one to determine the partitioning of dose from translocation materials and to continue counting plutonium when it "disappears" due to increasing attenuation of the x-rays as the material becomes more centrally located in the thorax (lymph nodes).

The probe technique is not limited to plutonium counting. The intra-esophageal technique could be used for studying lymph node build-up of various materials tagged with low energy photon emitters. Similarly, the fiber optic coupling of a scintillator provides a biomedical probe which is passive and could be used for many studies.[16]

1084065

Table 1: Estimated Sensitivity for Counting Procedure

Dog	Initial Alveolar Burden (nCi)	Count* Rate (cpm)	Estimated Sensitivity+ (cpm/nCi)
759	802	121 ± 7	0.61
753	2450	272 ± 11	0.45
764	140	59 ± 4	1.7
781	44	21 ± 3	1.9
1042F (^{238}Pu)	2900	530 ± 13	0.61

* Net count rate at x-ray energies.

\+ Based on estimated thoracic lymph node burden using initial alveolar deposition and previously observed translocation rates.

1084066

1084061

Table 2

Comparison of Probe Sensitivities for Material in Tracheo-Bronchial Lymph Nodes in a Phantom

Probe	Background, B† (cpm)	Sensitivity, S (cpm/nCi)	Minimum Detectable Amount (nCi)*
Avalanche 1	5.05	0.025	52
Avalanche 2	5.56	0.039	34
Fiber Optics:			
X-Ray Energies (17 keV)	18.4 (9.20)†	0.807	3.0
-Ray Energies (60 keV)	38.7 (3.06)†	1.22	2.9

* Calculated at 90% confidence level with a 20 minute counting period (i.e., $MDA = \frac{2.56}{S} \frac{B}{20}$).

† Values in parentheses are for shielded detector.

1081068

Table 3

Preliminary Results from Intraesophageal Probe Counts

Position	Net Counts (per 10 min)		Approximate Activity (nCi)*	
	X-Ray (12-40 keV)	γ-Ray (41-95 keV)	X-Ray	γ-Ray
1a	88 ± 37	80 ± 17	10 ± 4	6 ± 1
1b	63 ± 28	53 ± 16	7 ± 3	4 ± 1
2	---	81 ± 11	---	110 ±15#
3	155 ± 26	204 ± 21	17 ± 3	16 ± 2

* Based on phantom calibration with ^{239}Pu for activity in simulated lymph node geometry.

\# Activity in "lungs" based on lung calibration using phantom.

REFERENCES

(1) J. F. Park, W. J. Bair and R. H. Busch, "Progress in Beagle Dog Studies with Transuranium Elements," Health Physics 22: 803-810 (1972).

(2) E. E. Campbell, M. F. Milligan, W. O. Moss, H. F. Schulte and J. F. McInroy, USAEC Report LA-4875, Los Alamos Scientific Laboratory, 1973.

(3) I. C. Nelson, K. R. Heid, P. A. Fuqua and T. D. Mahony, "Plutonium in Autopsy Tissue Samples," Health Physics 22: 925-930 (1972).

(4) P. E. Morrow, "Lymphatic Drainage of the Lung in Dust Clearance," Annals of the New York Academy of Sciences 99: 46 (1969).

(5) K. L. Swinth and G. C. Huth, "The Role of the Lymph Nodes in Inhalation Exposures," ANS Transactions on Nuclear Science 18:385 (1974).

(6) K. L. Swinth, "A Solid State X-Ray Alpha Coincidence Counter," IEEE Trans. On Nucl. Sci. NS-18:125 (1971).

(7) J. Rundo, K. Rudram and B. T. Taylor, "Effective Tissue Thicknesses for External Counting of Low Energy Emitters in Lung," Health Physics 17: 155 (1969).

(8) K. L. Swinth and B. I. Griffin, "A Developmental Scintillation Counter for Detection of Plutonium In-Vivo," Health Physics 19: 543 (1970).

(9) L. J. Johnson, R. L. Watters, C. R. Lagerquist and S. E. Hammond, "Relative Distribution of Plutonium and Americium Following Experimental PuO_2 Implants," Health Physics 19: 743 (1970).

(10) K. L. Swinth, In: Diagnosis and Treatment of Deposited Radionuclides (Edited by H. A. Kornberg and W. D. Norwood), pp 208-221, Excerpta Medica Foundation, Amsterdam (1968).

(11) E. E. Pochin, "The Mass of the Tracheobronchial Lymph Glands," Health Physics, 12: 563 (1966).

(12) M. H. Ratzlaff, In: The Beagle as an Experimental Dog (Edited by A. C. Anderson), pp 246-260, Iowa State University Press, Iowa (1970).

(13) J. F. Park, W. J. Clarke and W. J. Bair, In: The Beagle as an Experimental Dog (Edited by A. C. Anderson), pp 285-293, Iowa State University Press, Iowa (1970).

(14) K. L. Swinth, J. F. Park and P. J. Moldofsky, "Counting Plutonium in the Tracheobronchial Lymph Nodes," Health Physics, 22: 899 (1972).

1084069

REFERENCES (Cont'd)

(15) K. L. Swinth, "Photon Counting with Fiber-Optic Coupled Scintillators," IEEE Trans. on Nuc. Sci., NS-21: 119 (1974).

(16) K. L. Swinth and J. H. Ewins, "A Biomedical Probe Using a Fiber Optic Coupled Scintillator," presented at meeting of Radiological Society of North America, Chicago: November 1973.

1084070

FIGURE CAPTIONS

Figure 1: Lymph nodes located near tracheal bifurcation on a human cadaver. Although this represents a typical geometry it does not represent an average.

Figure 2: Spectra for the background of a phototube with and without reduction of the background noise. Magnetic limitation of the photocathode area and pulse-shape discrimination were used to lower the background count rate.

Figure 3: Photograph showing the probe employed in these studies. The detector is shown at the end of the fiber optics bundle while the phototube is in the large housing at the opposite end.

Figure 4: Count rate vs. position for probe in a dog.

Figure 5: X-ray showing probe located at position of maximum count rate in dog. This is the location of the tracheobronchial lymph nodes.

Figure 6: Scan in phantom showing variation in sensitivity with position.

Figure 7: X-ray showing probe properly positioned in human subject.

1084071

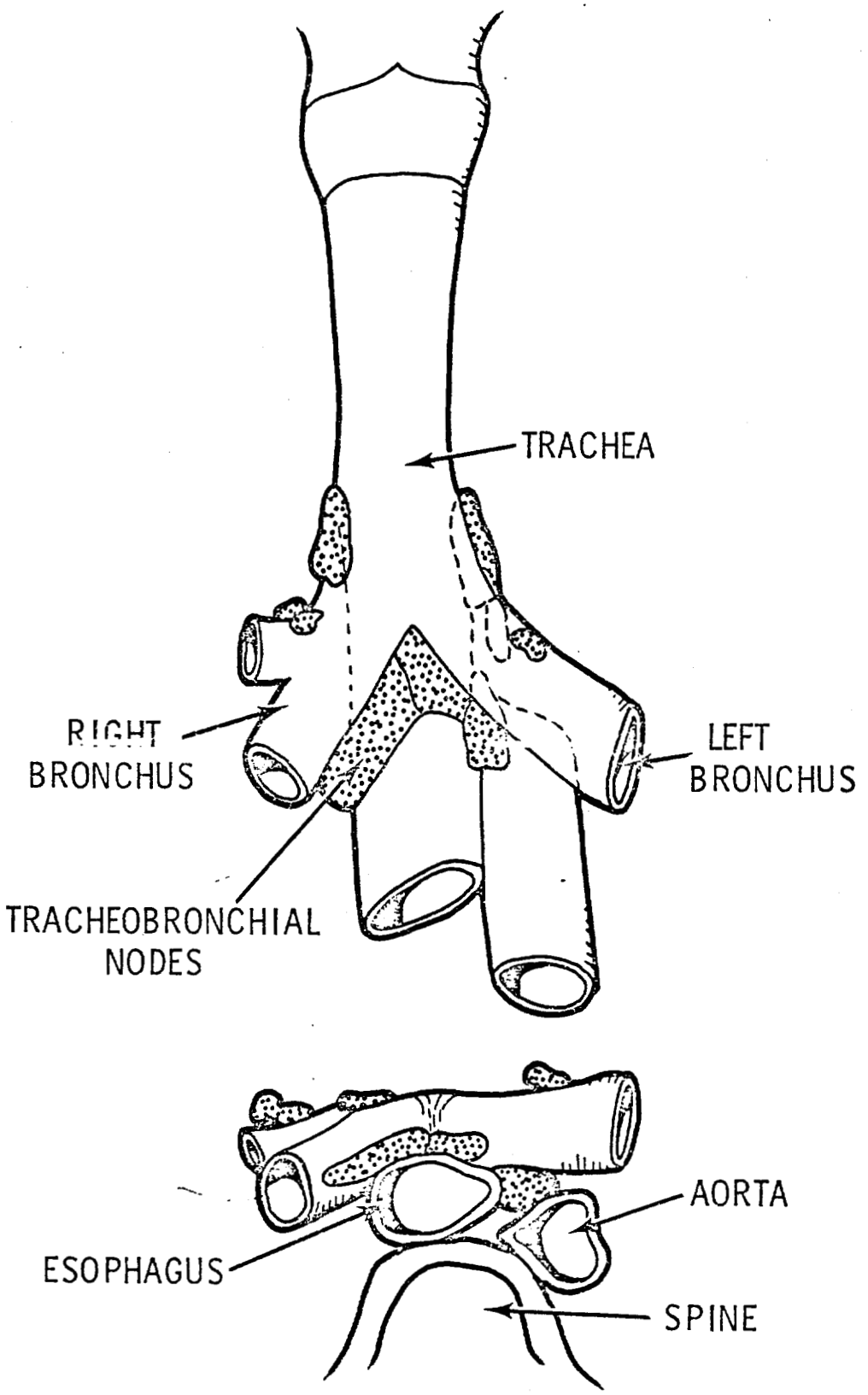


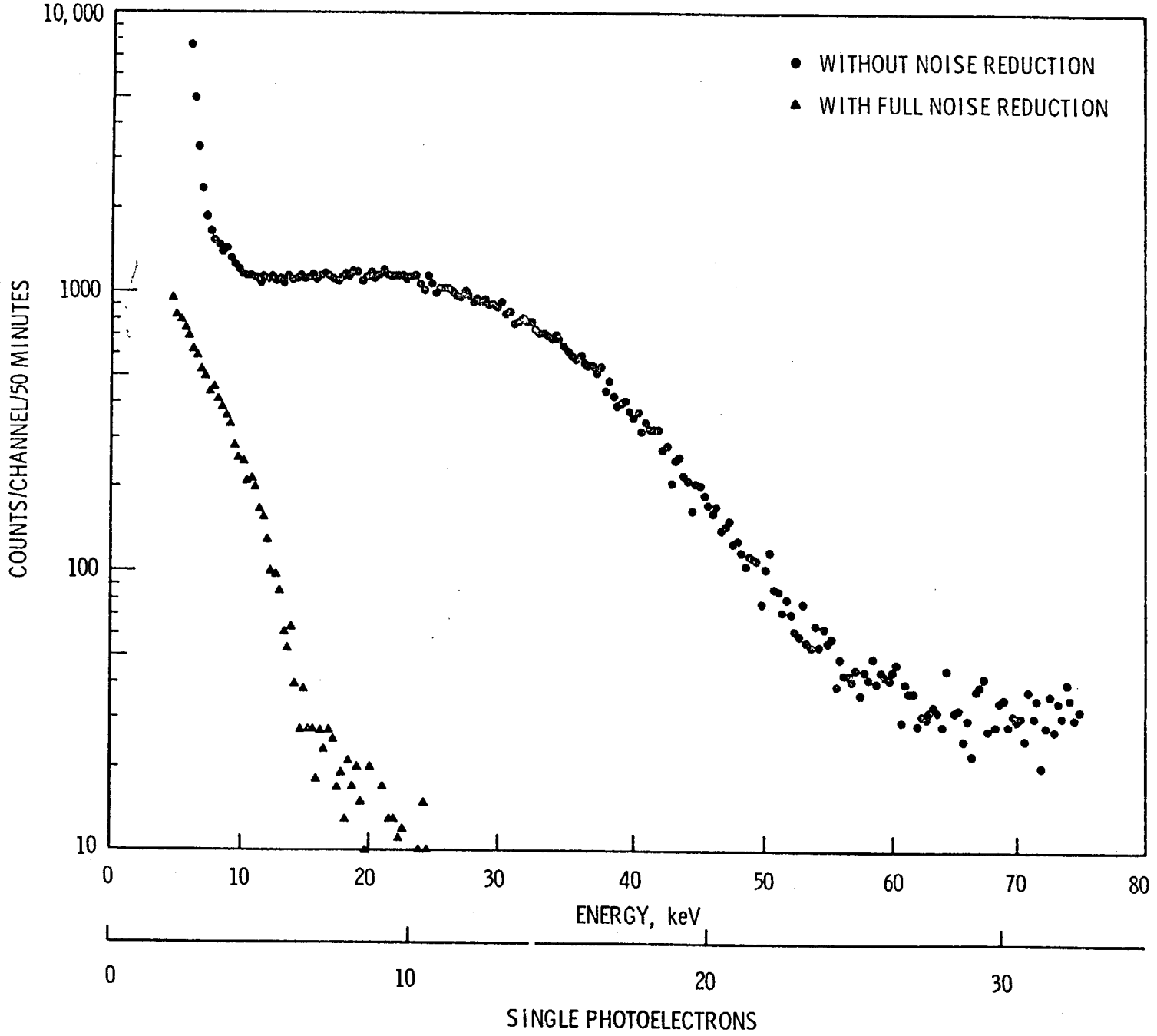
FIGURE 1

LYMPH NODES LOCATED NEAR TRACHEAL BIFURCATION ON A HUMAN CADAVER

1084072

FIGURE 2

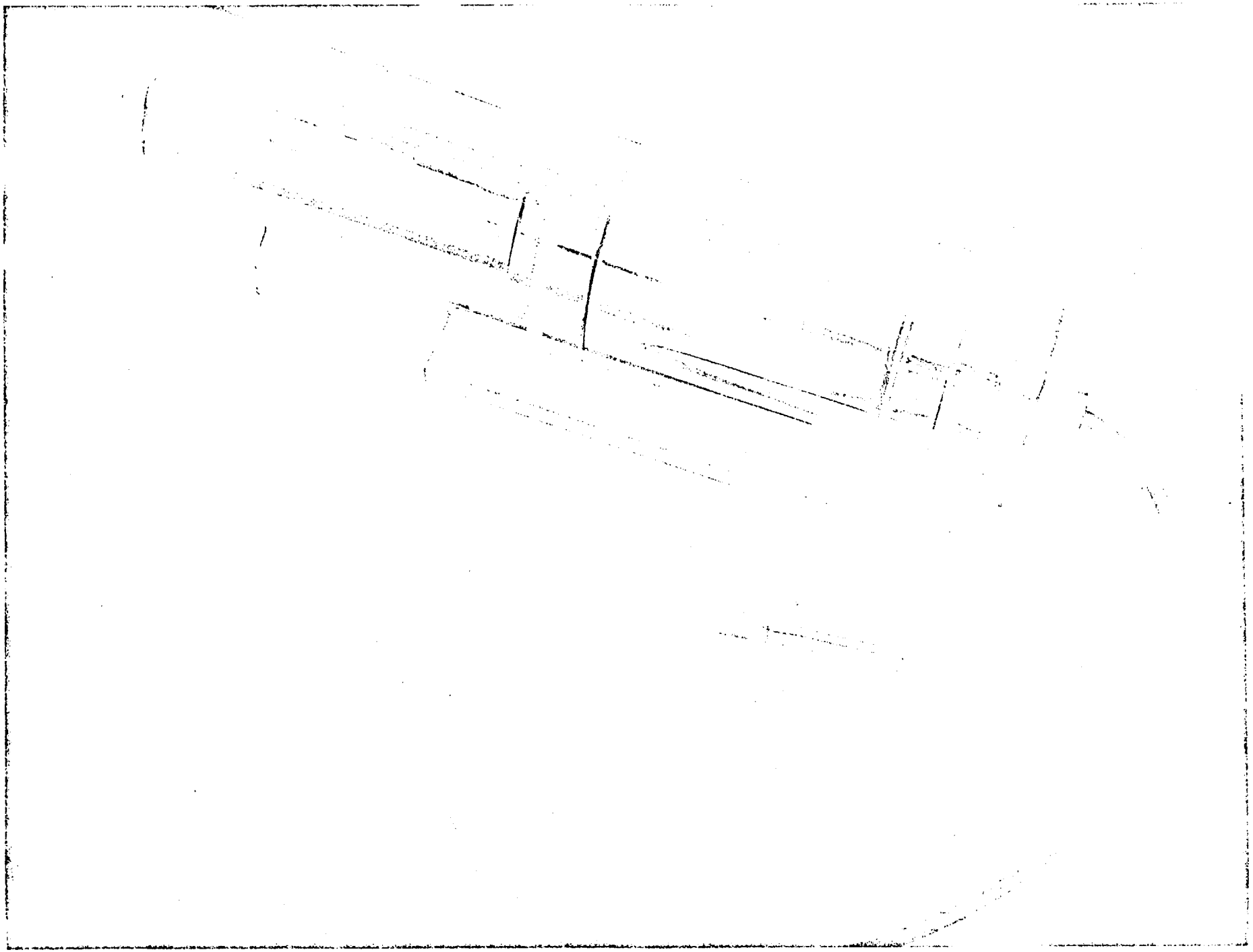
SPECTRA FOR THE BACKGROUND OF A PHOTO TUBE WITH AND WITHOUT REDUCTION OF BACKGROUND NOIS



1084013

FIGURE 3

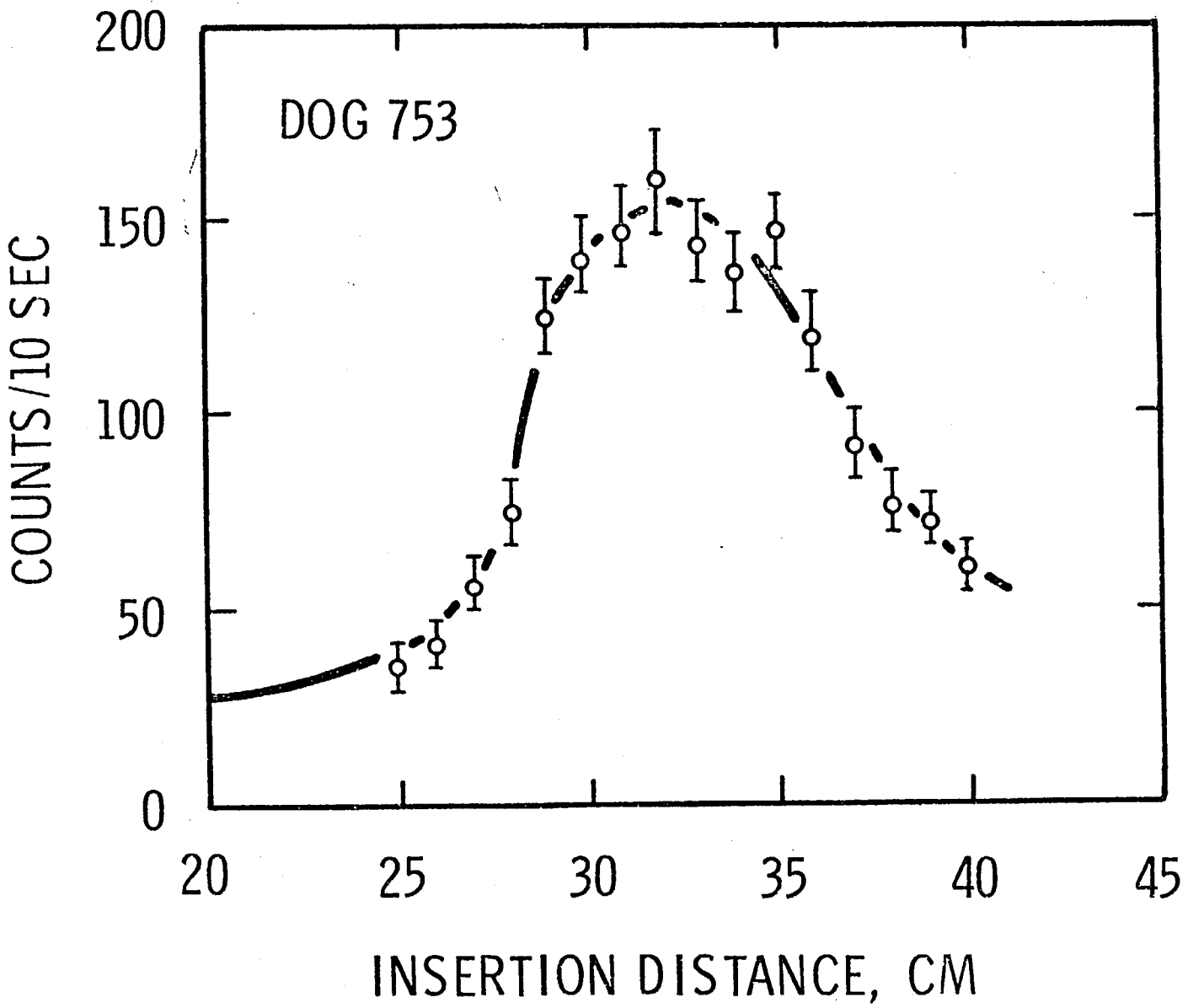
PHOTOGRAPH C. PROBE EMPLOYED IN STUDIES



1084014

FIGURE 4

COUNT RATE VS. POSITION FOR PROBE IN DOG



1084015

5

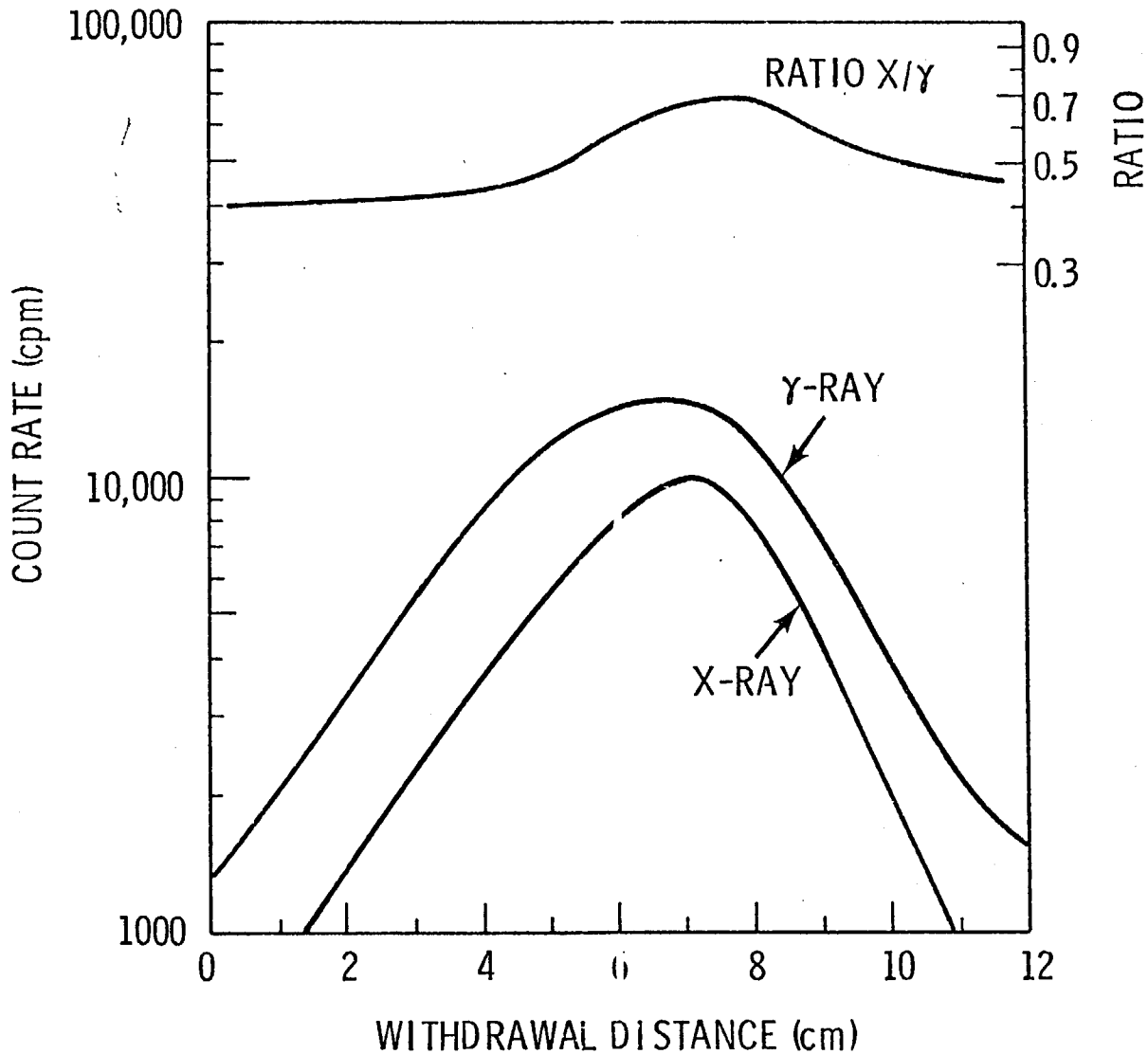
FIGURE 5

X-RAY SHOWING PROBE LOCATED AT POSITION OF MAXIMUM COUNT RATE IN DOG

1084076

FIGURE 6

SCAN IN PHANTOM SHOWING VARIATION IN SENSITIVITY WITH POSITION



1084071

Richards

FIGURE 7

X-RAY SHOWING PROBE PROPERLY POSITIONED IN HUMAN SUBJECT

1084078