THE EFFECT OF PARTICLE SIZE ON THE REGIONAL DEPOSITION OF INHALED AEROSOLS IN AN AVIAN RESPIRATORY TRACT

by

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CHAPTER I

INTRODUCTION

As early as 1556 Agricola [1] wrote,

> ....some mines are so dry that they are entirely devoid of water, and this dryness causes the workman even greater harm for the dust which is stirred and beaten up by digging penetrates into the windpipe and lungs and produces difficulty in breathing.

Although subsequent studies elucidated the physiological effects of dust on man, little research has been conducted on the direct effects of air pollutants on animals.

Only recently has the need been recognized for controlled environments to improve the health and production efficiency of domestic animals [35,40]. Modern, high density poultry houses have definite need for such controlled environments.

Damaging Effects of Dust Within Poultry Units

Airborne particulates not only serve as allergen-carrying vehicles [6, p. 17], but also transport infectious pathogens [27,29,52,53] -- concentrations as high as 4×10^5 viable organisms/ft^3 have been reported [7]. Airborne bacteria contacting eggs reduces egg hatchability [39]. Severe dust pollution of the air may significantly affect the incidence of airsacculitis in turkeys [52], or serve directly as a mechanical irritant [6, p. 17]. Odor transport has been attributed to airborne particulates. In poultry houses where dust concentrations are minimized, broiler performance, body weight, and feed conversion have improved [35]. There also

appears to be a direct correlation between mortality of chicks and hatchery sanitation [25].

Knowledge of the regional deposition of inhaled aerosols in the respiratory tract will allow for the characterization of the toxicity of the airborne contaminants [36].

Character of Poultry House Dust

Dust concentration and particle size within poultry houses is a function of the age and density of the bird population; ventilation rate; relative humidity; temperature; litter moisture content; operation of overhead feeding equipment (if used); and activity levels (a function of light:dark cycles)[6, p. 92; 42]. During light periods--where greatest activity is observed--only 25 percent of the airborne particles are 10 microns or less in diameter, whereas 50-55 percent of the particles are smaller than 10 microns when birds are at rest [6, p. 92]. Likewise, dust concentrations as high as 1.16 mg/ft^3 are reported by Anderson [6, p. 42] during periods of high activity with a drop to 0.025 mg/ft^3 during low activity [6, p. 92; 16].

Two distinct types of particulates were noted by Koon et.al. [32] in poultry house dust. The majority was flat, flaky, and cellular in structure, with diameters from 1 to 450 microns. Its origin was thought to be primarily skin debris and feed particles. The second type was long and cylindrical, with nodes and internodes. This was thought to be feather barbules with a diameter of 4 microns. Chemical analyses show the dust to contain 88-92 percent dry matter, of which 60-64 percent is crude protein [6, p. 103; 45], the remainder is fat, cellulose, ash, and hydrocarbon.

The analysis of poultry house dust is a complex matter. The values mentioned above should not be accepted nor interpreted as absolute since dust

concentration levels, size, composition etc., depend on a variety of variables. The characterization of an all inclusive representative sample is extremely difficult.

Objectives

The objective of this study is twofold. The first goal is to determine whether regional deposition of particles varies as a function of particle size; the second to trace deposition of monodispersed particles within the respiratory system.

CHAPTER II

REVIEW OF INHALATION STUDY TECHNIQUES

Dust is associated with diseases in man such as silicosis, tuberculosis, fibrosis, etc. [20, p. 31-35; 42, p. 357-411], and as a carrier of harmful pathogens such as bacteria and virus [53]. Research techniques used in aerosol inhalation studies have progressed from the early use of light microscopes to a complete tracing of dust activity during respiration using radioactively tagged isotopes [28, 36].

Aerosol Deposition in Mammals

In 1955 Albert [3] attempted to develop procedures for predicting permissible periods of exposure by miners to radioactive dust, and reported a method for tracing the radioactive dust within the human respiratory system. His subjects were allowed to inhale radioactively tagged iron powder of a given size range. The localized activity was measured using a scintillation counter placed against the subject's chest. Clearance rates were then determined for periods up to 33 hours. At the time, no means existed for investigating the effect of particle size on the deposition and clearance of insoluable radioactive dust.

Whitby [50] described the development and use of a homogeneous aerosol generator. Based on the principle of a spinning disc, liquid droplets containing the material of interest are centrifugally thrown from a spinning disc; the liquid eventually evaporates leaving a residue of the particle in the size of interest. The size of the particle is controlled by the con-

centration of the solute, disc speed, disc diameter, and liquid density.

In 1964 Albert [5] reported the use of such a generator to create monodispersed radioactively tagged particles. The next year, in cooperation with Lippmann [4] he showed the benefit of the generator in investigating the clearance of radioactively tagged particles from the human lung as a function of particle size.

Lippmann and Albert [36] showed a definite relationship between particle size and regional deposition, with larger particles having greater deposition in the upper respiratory tract. Dautrebande [17] stated that primarily only particles below 1 micron will penetrate the lower pulmonary depths. Of these, in excess of 90% will eventually reach the alveolar spaces in man.

Although a considerable amount of knowledge exists concerning particle deposition in the mammalian respiratory system, direct analogies to the avian system would be extremely difficult if not impossible due to the profound anatomical and gaseous pathways differences (Appendix A). However, the methods developed in investigating particle deposition in mammals may be employed in studying deposition in the avain system.

Aerosol Deposition in the Avain Respiratory System

In 1929, Dotterweich [19] allowed pigeons, ducks, and ground finches to breath soot from an oil lamp for periods of a few minutes to several hours. Following inhalation, the birds were euthanized and dissected. The posterior sacs were heavily laden with soot, with only a few soot particles deposited in the anterior sacs[1]. In addition, Dotterweich also reported some soot deposition in the trachea, primary bronchi, the entrance region of the dorsobronchi,

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[1] Soot size range; 0.03 to 1.0 microns [10, p. 79].

and on some projecting tissue parts of the parabronchi. Little or no soot was reported in the ventrobronchi and anterior sacs.

Hazelhoff [26] in 1943 achieved similar results using powdered charcoal. The results of Dotterweich and Hazelhoff tended to confirm the work of Bethe [12, pp. 22-27]. Hazelhoff's results have been questioned since the charcoal was injected into posterior sacs of dead birds to achieve unidirectional flow through the bird. Nevertheless, his data did confirm the work of Dotterweich. The pathways taken by respired gas result from the respiratory anatomy and not the physical opening or closing of valves [45]. A unidirectional flow applied through the posterior sacs of dead birds would, therefore, closely simulate that of live birds, and Hazelhoff's conclusions would be acceptable. To date, additional studies on aerosol deposition are minimal. To understand its effects, continued investigation is necessary.

CHAPTER III

MATERIAL AND METHODS

Apparatus

Particles. This study incorporated five particle sizes or ranges. The median size selected was 0.3 micron diameter, as it is least affected by mechanical collection mechanisms [49]. Particles approximately one-fourth and one-half this size provided a study of diffusion effects in the system. Studies on particle size dependence in mammalian systems influenced the choice of particles approximately 1 micron and 6 microns diameter for deep system deposition and upper tract deposition, respectively.

The non-availability of an aerosol generator required the purchase of monodispersed polystyrene latex aerosols from the Dow Chemical Company[1].

Table 1

Particle Sizes Used and Standard Deviation

Average Diam. in Microns	One Standard Dev. in Microns	Material
0.091	0.0058	Polystyrene
0.176	0.0023	Polystyrene
0.312	0.0022	Polystyrene
1.1	0.0055	Polystyrene
5.7	Range 4-7 microns	Polystyrene

[1] Diagnostics Products, The Dow Chemical Company, P.O. Box 1156 Indianapolis, Indiana 46206.

Polystyrene, a pure hydrocarbon, cannot be radioactively labeled. Polymerizing iodine on the surface of the particle provides a means for labeling. Bogen [14] reported a ± 1% to ± 5% agreement between radiochemical and optical counting using the iodine polymerization procedure for labeling polystyrene spheres. This study used a modification of his procedures (Appendix C). Only 5% of the particles were found to be multiplets (Appendix E).

Neutron bombardment for 1 1/2 hours at full power (TRIGA MK II-Reactor-neutron flux of 10^{11} neutrons/cm^2 sec, approximately 250 KW) activated two 5 ml samples prior to each test. This reactor time gave approximately 87.5% of the maximum radioactivity possible from the iodine128. Shorter reactor times did not provide sufficient activity when later inhaled by the bird.

Aerosol Dispersion Equipment. Figures 1,2,3 and 4 show the arrangement of the air handling equipment. Dried and prefiltered (Sporlan filter-dryer[1]) air from the compressor (Maintained between 45 and 80 psig) flowed through an electrically operated solenoid valve. Routed through an absolute filter[2], air passed to a pressure regulator set to maintain a pressure of 10 psig for optimum nebulizer performance [23]. A Vaponephrine[3] nebulizer was the primary instrument for atomizing the liquid-dispersed aerosol.

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1 Sporlan Catch-All Filter-Dryer, Type c 969 2 core

2 Environmental Research Corporation, 3725 North Dunlap Street, St.Paul, Minnesota 55112

3 No longer available. For an explanation of operation reference Fraser et.al. [23, p. 30].

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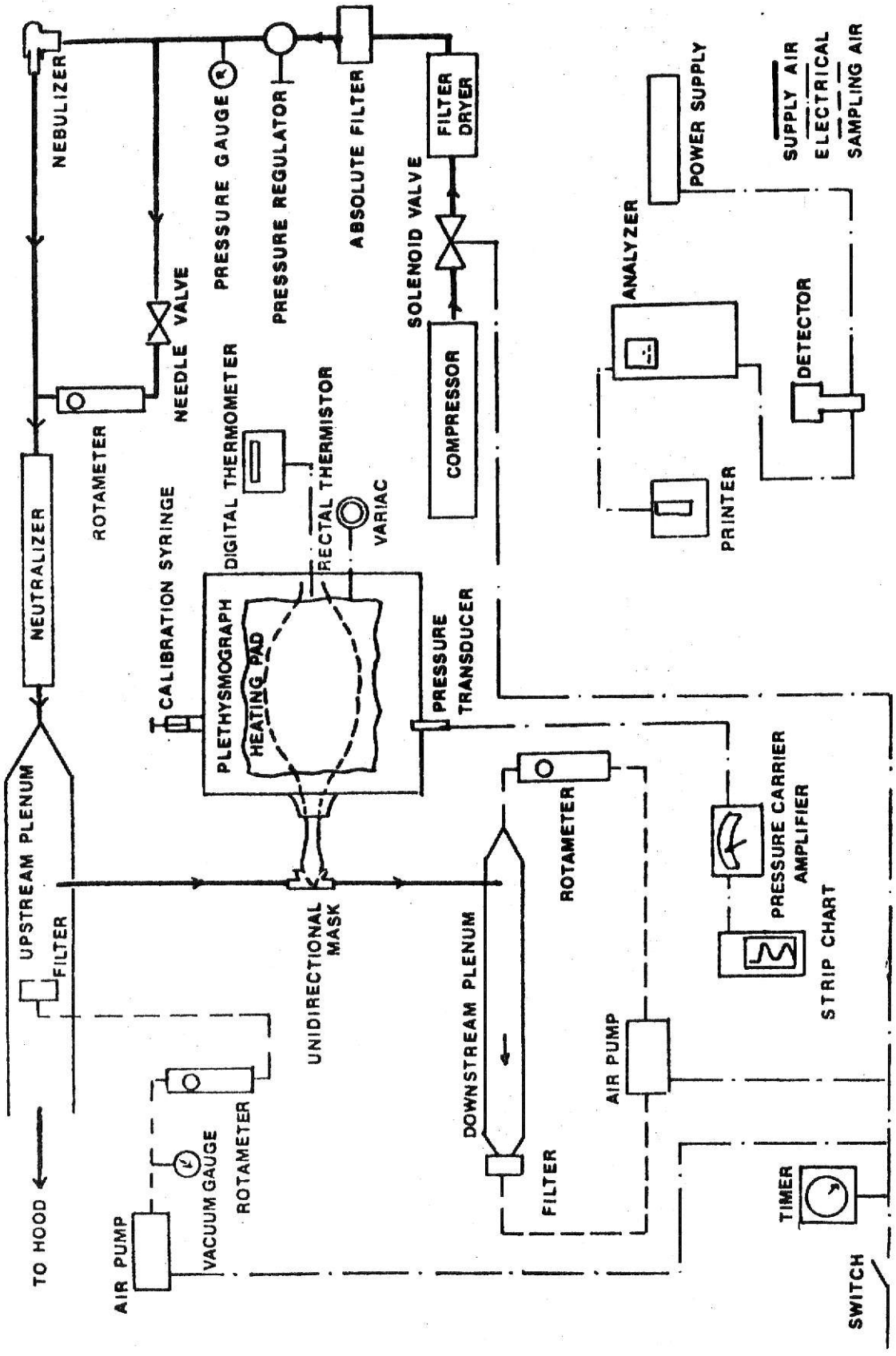

Figure 1. Schematic of Test Equipment

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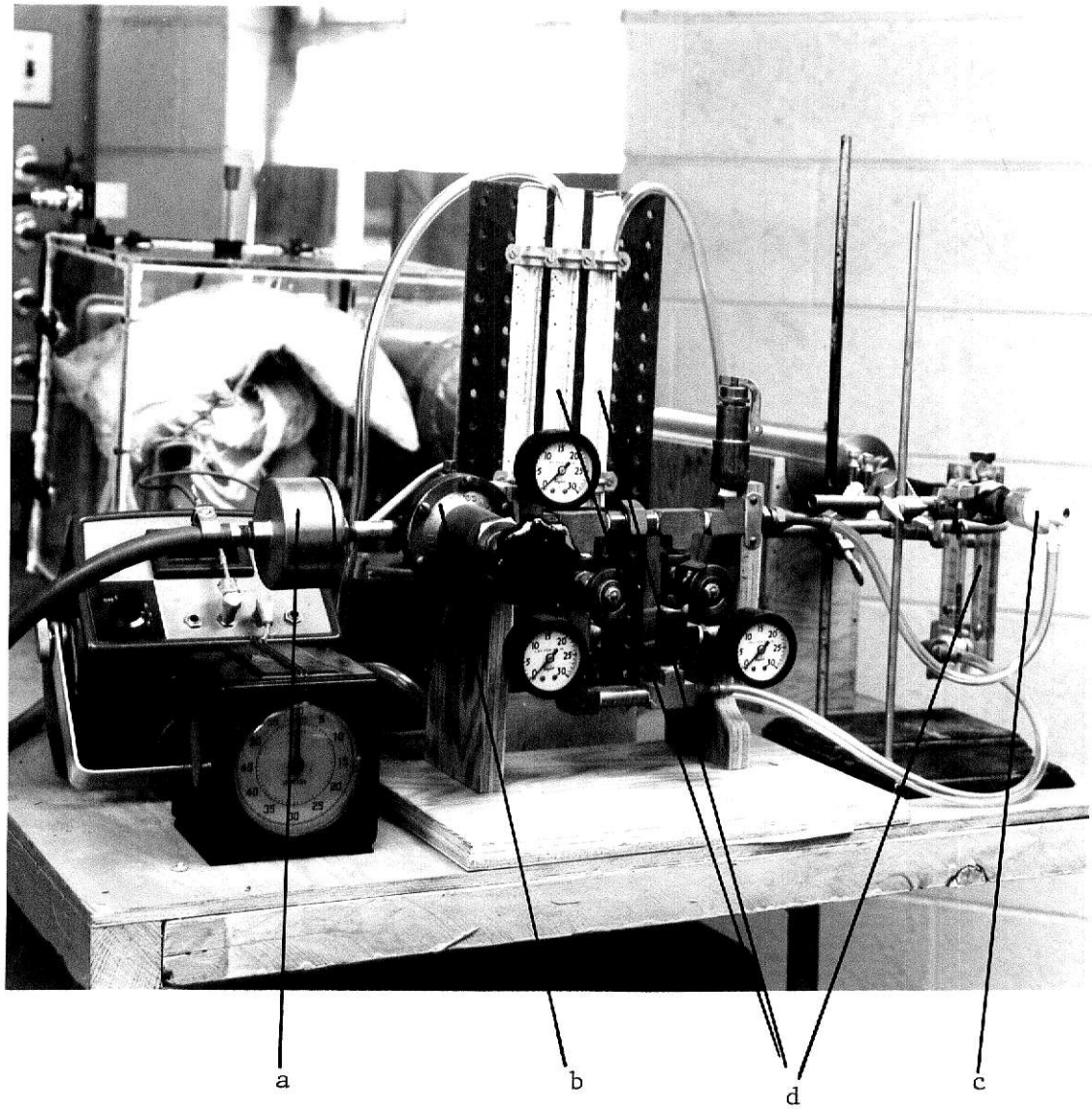

Figure 2. Air Handling Equipment

(a) absolute filter, (b) pressure regulating apparatus, (c) nebulizer and (d) rotameters.

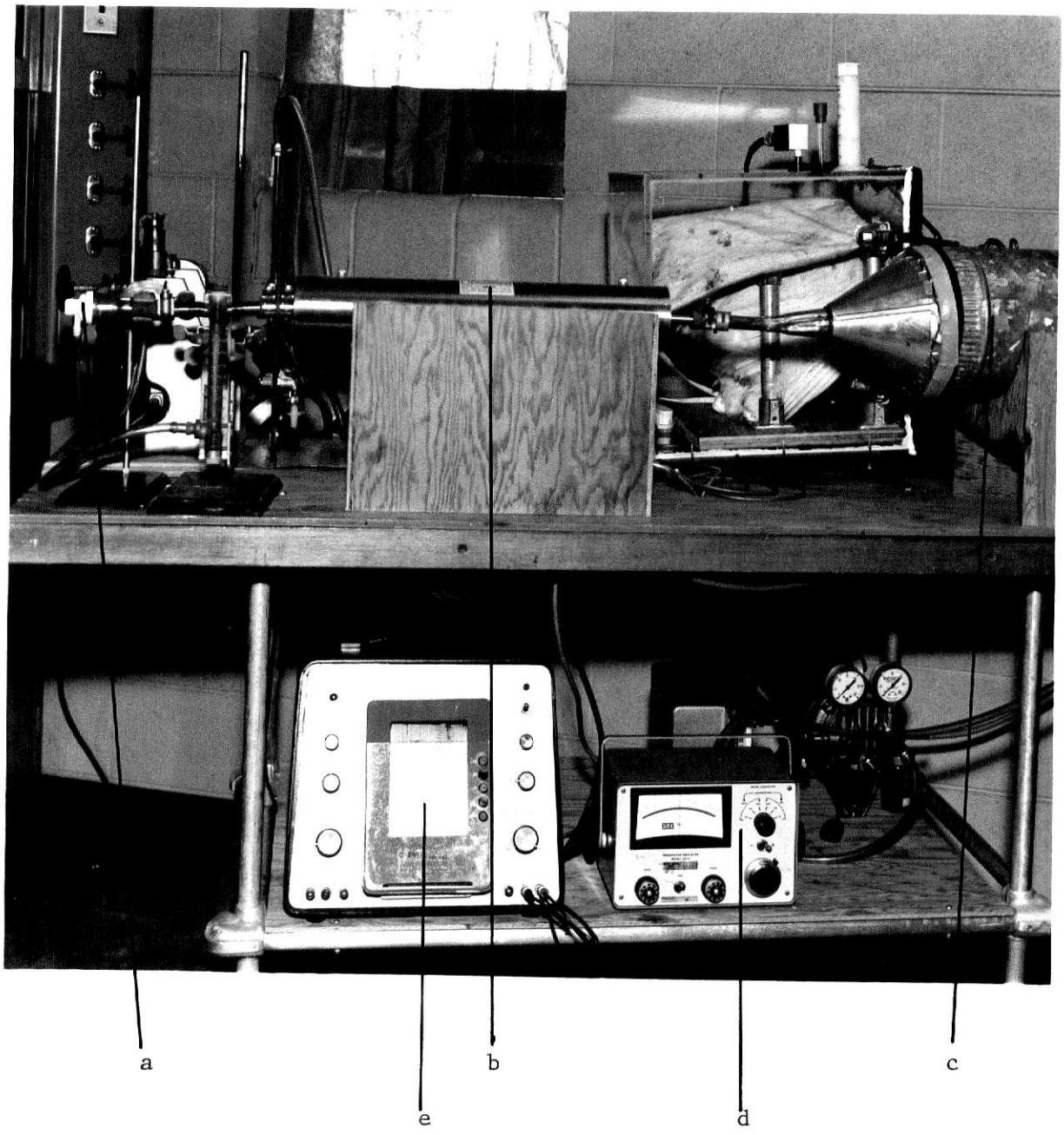

Figure 3. Air Handling Equipment and Spirograph Equipment

(a) nebulizer, (b) $^{85}_{Kr}$ charge neutralizer, (c) upstream plenum, (d) pressure carrier amplifier and (e) strip chart recorder.

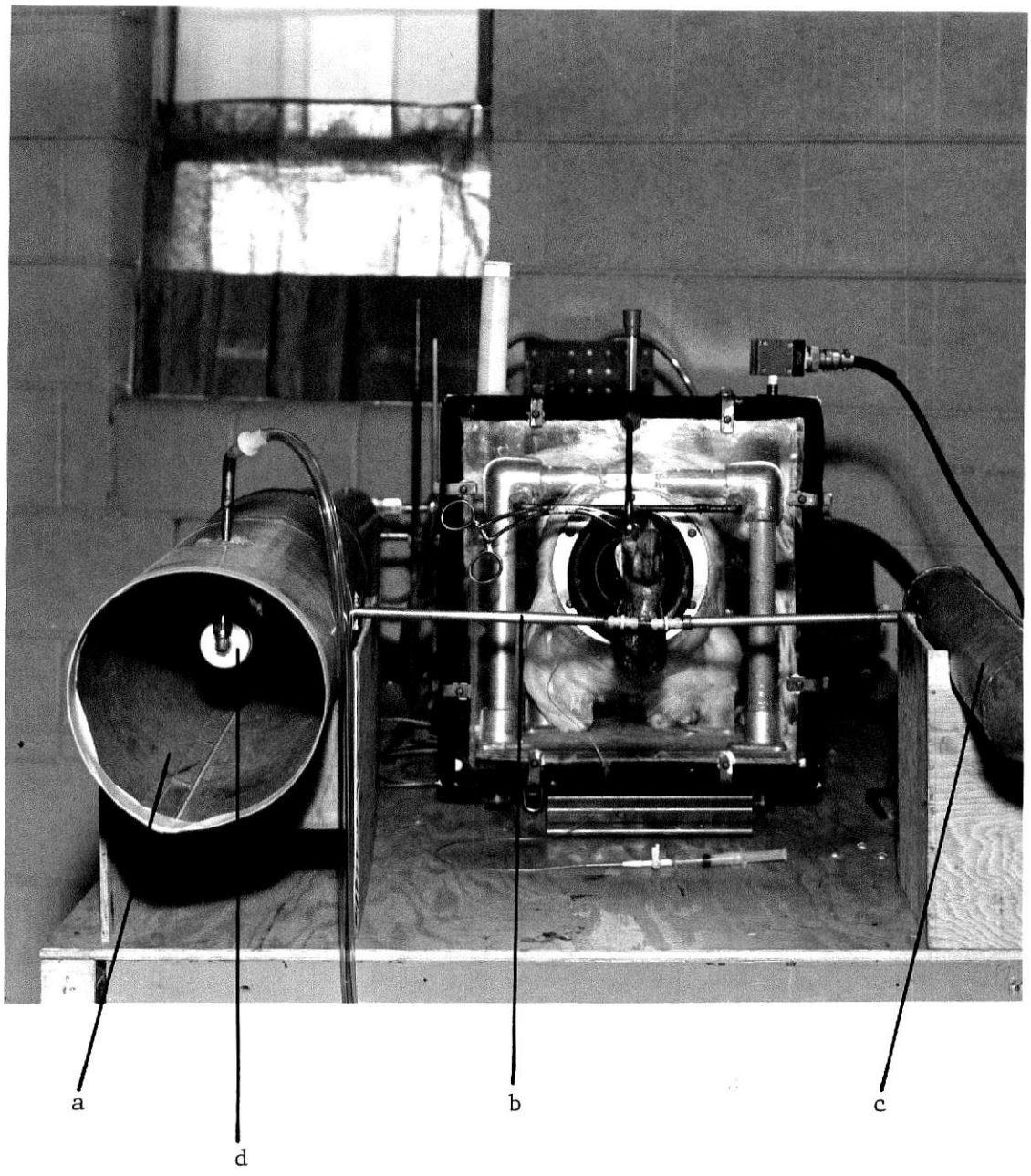

Figure 4. Air Handling Equipment

(a) upstream plenum, (b) bird respiration tubing, (c) expiration plenum and (d) air filter sampling holders.

Sixty liters/minute[1] by-passed the nebulizer and mixed with the atomized particles to evaporate the water enveloping the spheres.

Extreme electrostatic charges are carried by particles after atomizing [48]. Neutralization of these charges is necessary to prevent agglomeration and electrophoresis to the walls of the air handling equipment and respiratory tract of the bird.

A ^{85}Kr (half-life 10.3 years) neutralizer de-ionized the statically charged aerosol by producing bipolar ions [48]. The de-ionized air passed into a 7-in. diameter, 26-in. long plenum--completely open downstream to maintain pressures as low as possible. No pressure difference between plenum and ambient existed (to 0.001 in. w.g.). A Millipore plastic filter holder containing a Millipore type AA, 47 mm plain, white (0.8 micron) filter paper[2] sampled the air in the large plenum at midstream approximately 1 1/2 diameters downstream from inhalation point. The contaminated air exhausted through a chemical hood containing a HEPA filter.

The bird breathed at will through a demand activated unidirectional mask shown in Figure 5. The mask was connected to the plenum by a 1-cm diameter brass tube inserted to midstream in the upstream plenum (Figure 4).

The bird exhaled through a unidirectional valve into a 3-in. diameter, 20-in. long downstream plenum (Figure 4). A filter similar to the millipore above captured all the expired particles at the outlet of the small plenum. Air flowing at 1300 ml/min continually washed down the walls of the small plenum by recirculating the air exhausted through the filter. This minimized any particle capture on the walls. A 1/4-in. bleed tube submerged 2 mm or less

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1 0-80 LPM Rotometer, Gelman Instrument Company

2 Millipore Corporation, Bedford, Mass.

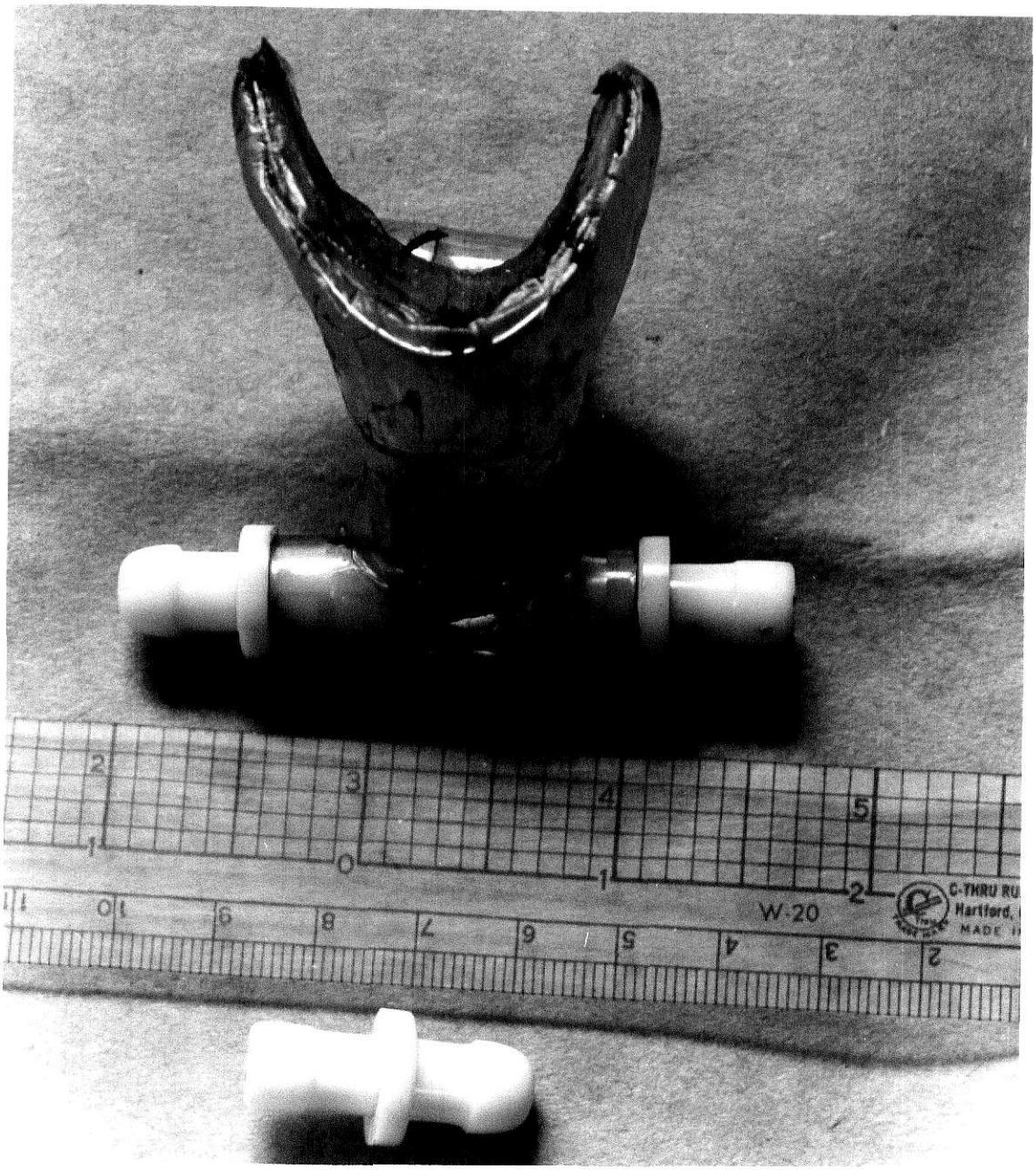

Figure 5. Bird Respiratory Mask and Unidirectional Valve.

below the surface of water contained in a vial maintained the small plenum at or below 2 mm of water gage pressure.

An MSA model #79810 diaphram air pump drew air at 50 ml/min flow (measured by an Ace 1A-15-1 rotameter[1]) through the large plenum sampling filter, and a Gast model 0211-P45 air pump recirculated the air through the downstream plenum (Ace 4-15-2 rotameter)[2].

Bird Apparatus. A pliable silicon rubber mask (Figure 5) with light pliable wire molded in the rubber for shaping minimized or eliminated excess dead space problems experienced in earlier masks of fiber glass, plastic, etc. Valves from a double action air bulb[3] provided the least resistance to flow with little particle loss through them (Appendix E). A heavy grade wheel bearing grease, flexible enough to not constrict the head, provided a positive seal in the mask about the bird's face.

The measurement of the quantity of respired air during exposure with the upstream plenum sample filter gave a means for verification that all the activity--hence particle deposition--had been accounted for in the bird (Appendix F). Tidal volume and respiratory rate was measured through use of a whole body plethysmograph [13]--constructed of 1/4-in. Plexiglas with inside dimensions of 14 in. x 14 in. x 14 in. as shown in Figure 6. This provided needed information to determine total respired air. Silicone rubber sealed the joints and a gasket of rubber foam tape 1/4-in. thick sealed the front opening. Suit case latches provided a positive locking mechanism for the front opening. A model KP 15 Whittaker pressure trans-

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1 Flow as measured by a rotameter in combination with a diaphram pump is subject to some question as to accuracy [9].

2 Ace Glass Company Inc., Vineland, New Jersey 08360

3 85 ml Double Acting Air Bulb, Van Waters and Rogers Scientific Co., 4300 Holly Street, Denver, Colorado 80217

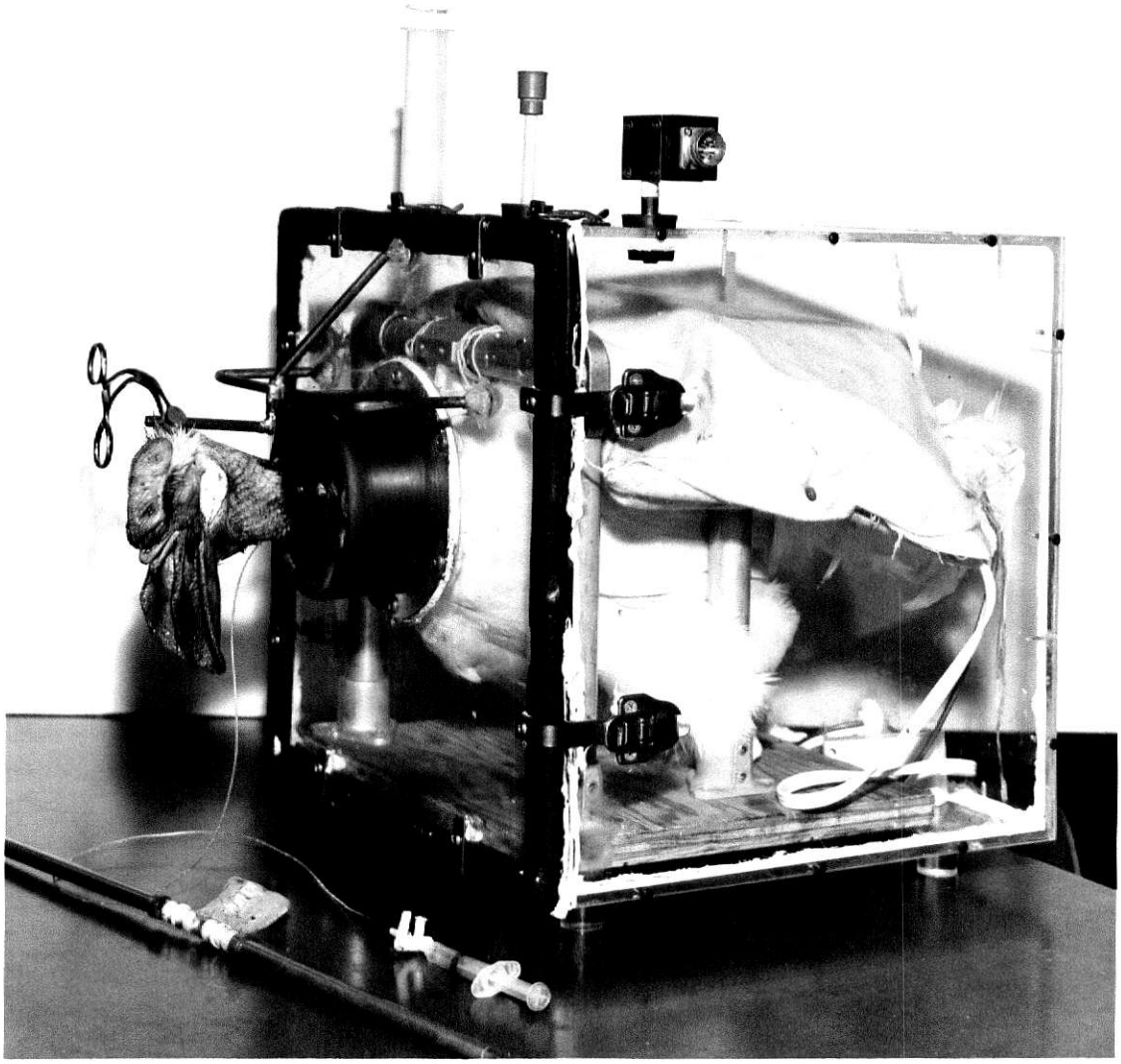


Figure 6. Whole Body Plethysmograph

ducer, with a 1-psi diaphram placed in a hole in the top of the plethysmograph, measured pressure changes resulting from volume changes. Also, a 60-ml syringe sealed in the top of the plethysmograph provided a means for individual calibration.

The bird's head and neck protruded through a rubber collar attached to the front of the plethysmograph. Grease sealed the collar and the bird's neck. A 1/8-in. diam. steel bar attached to the front of the plethysmograph supported the bird's head by attaching a fold of skin just posterior of the comb to the bar with a large hemostat. A thermistor probe sealed through the plethysmograph monitored rectal temperature. An electric heating pad located in the box maintained the core temperature of the bird (Figure 6).

The change in specific volume of air as it became saturated and elevated in temperature upon entering the respiratory tract required a correction in the plethysmograph volumetric readings [22]. For correction, it was assumed that the air was saturated in the bird and at core temperature (the ratio of ambient specific volume to the specific volume at the elevated condition multiplied by the volume measured).

Shutting off the pad when dust exposure started prevented considerable baseline drift in pressure measurement [13]. No appreciable change in core temperature existed during the 30 minute exposure period. A transient in the location of the baseline of approximately five minutes existed following the shut down of the heating pad. Spirogram readings began after this transient period.

By individually calibrating for each bird, variations in bird size did not affect the volume measurements of each spirogram. However, occasional erratic tracings occured when doors were opened or closed in various parts of the building. Heavier Plexiglas may have alleviated this problem.

Securing the wings and tail in a metal frame of 1" aluminum pipe (Figure 6), allowed the bird to breath naturally by maintaining him in an upright posture without restraining chest movements [31, p. 365].

Five major areas divide the bird's respiratory system (Appendix A): the nasopharyngeal, tracheobronchi, the lung, the posterior air sacs and the anterior air sacs. The total deposition within the bird was accounted for by radioactively counting each of seven, 2.5 in. sections along the median plane, shown in Figure 7 and 8. The trends of regional deposition were still apparent even though considerable overlap of sacs and lungs occurred in section 5.

A fiberglass and resin mold, made from a plaster cast of a 4.75 lb chicken supported the bird for counting (Figure 8). The surface of the mold had the approximate sac and lung positions marked on it. The markings were located by individually placing five dissected birds in the mold. Following some minor corrections using the second bird, it was not necessary to change the sac/lung position for the three subsequent birds. A latex cast of the respiratory system provided through the courtesy of the USDA Avian Anatomy Project, Michigan State University, confirmed the relative size and position of the sacs and lung.

A Plexiglas frame supported the mold so that the lower extremities of each air sac, trachea, head section etc. formed a baseline equidistant from the base of the frame.

Radioactive Detection Appartus. A collimated detector in a fixed position shown in Figures 1 and 9 externally measured, radiochemically, particle concentration within a given region of the bird. The scintillation counter (Harshaw, NaI(T_1) Integrated Line Scintillation Detector, type 12SW12W4)

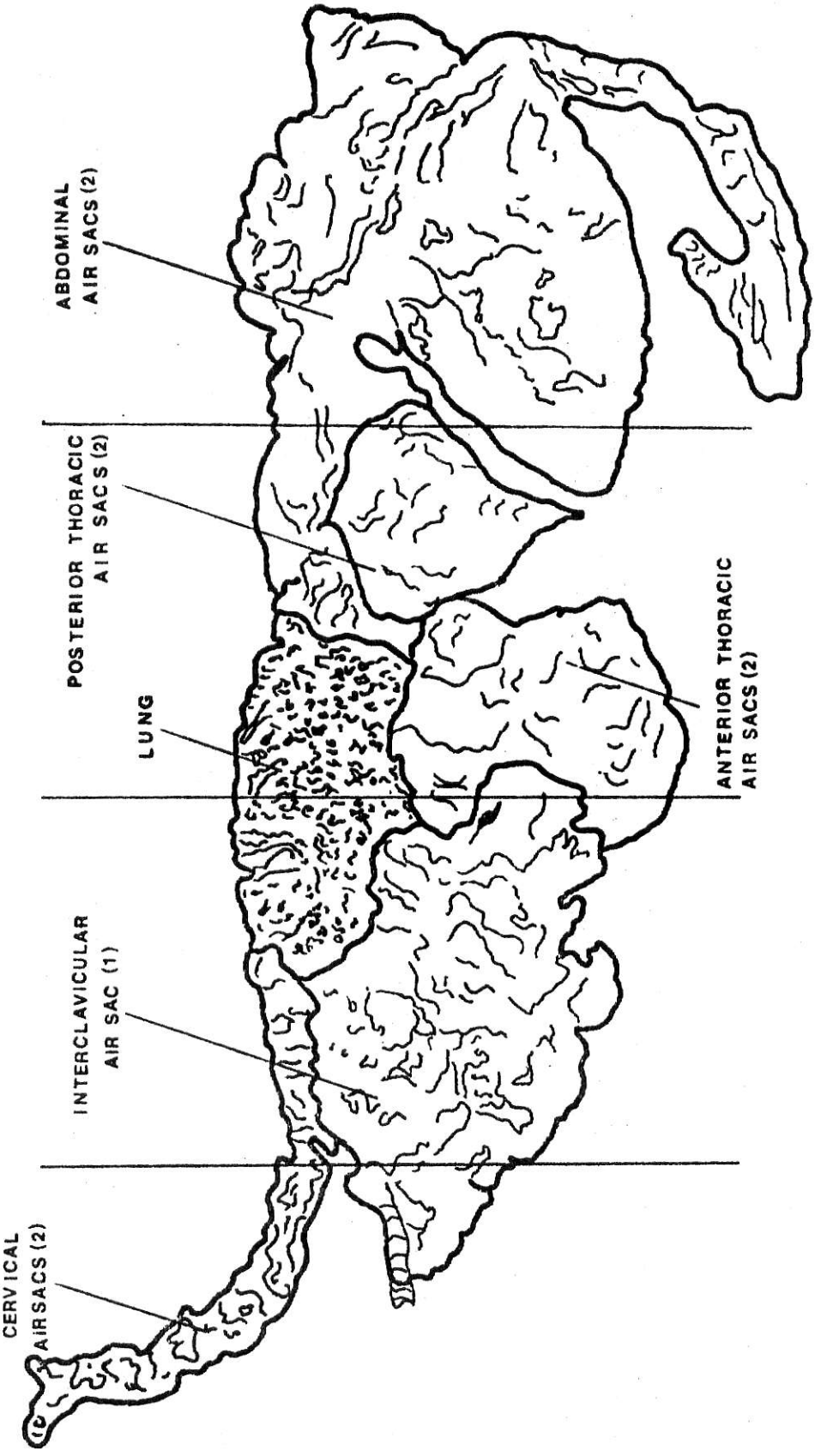


Figure 7. Air Sacs and Lung Locations And Caudal Division Markings.

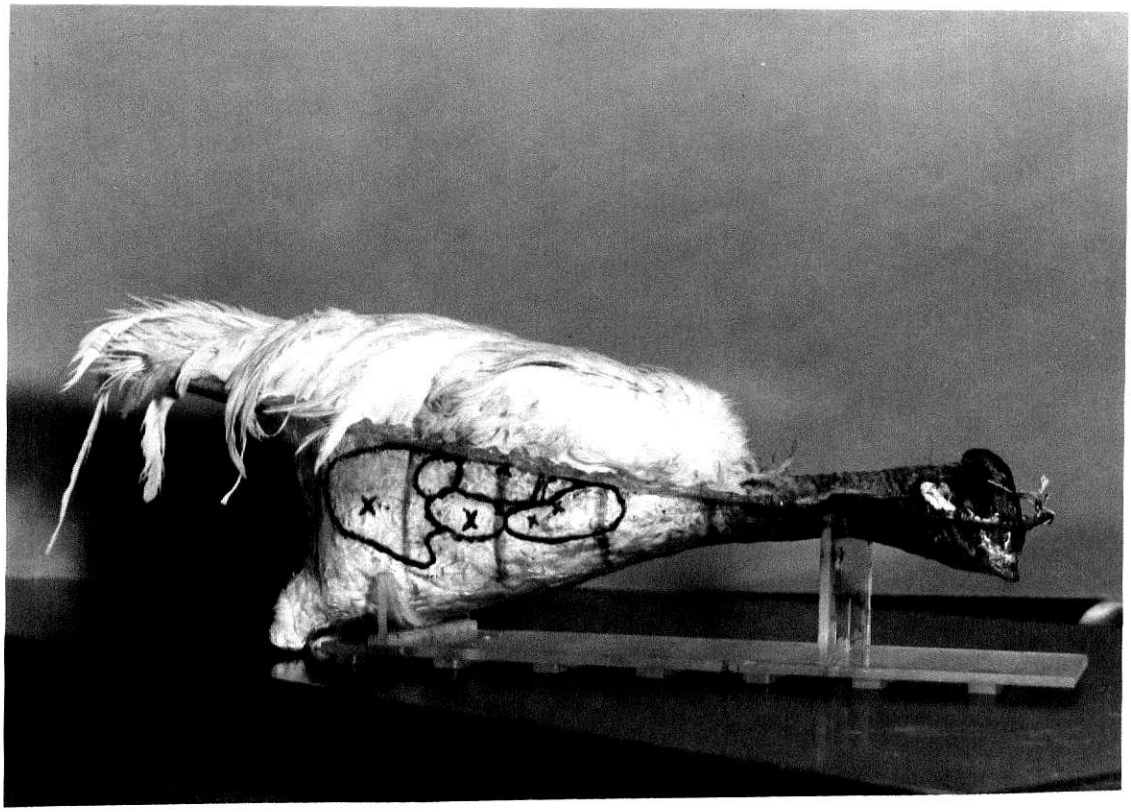


Figure 8. Resin Mold and Counting Support

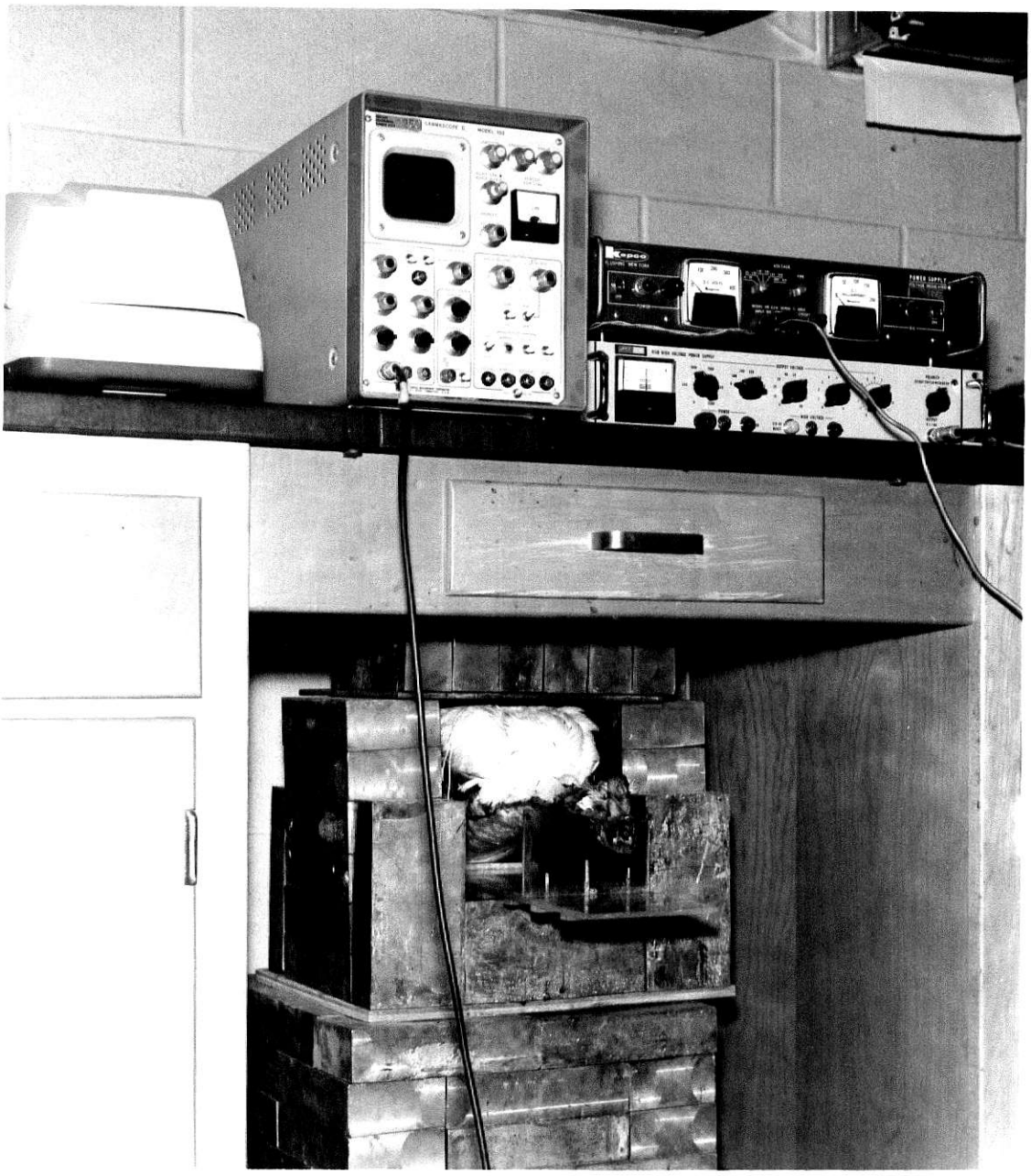
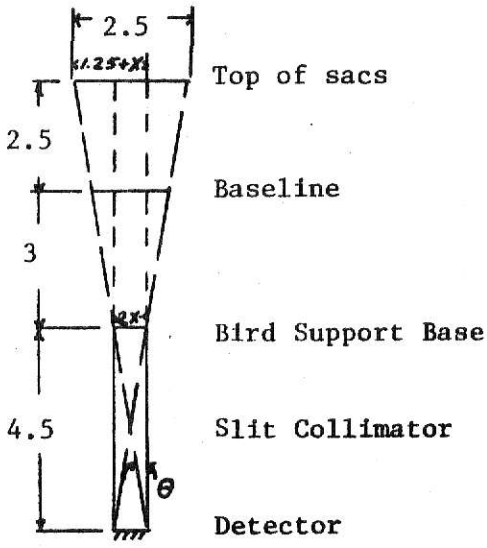


Figure 9. Radiation Measurement Apparatus

contained a 3 in. x 3 in. NaI crystal. A 1000-v power supply operated the photo-multiplier tube (Fluke, 415 High Voltage Power Supply) and a low voltage (Kepco Power Supply Model HB-2AM) supplied the preamplifier. A 100-channel pluse height analyzer (Gammascope II model 102, gain 32 KV per channel) counted the pulses from the signal of the scintillator. A paper tape printer (Monroe model 011F11) gave the activity output, determined by summing the counts within the energy band of the source.

A slit, lead brick collimator, designed to provide as vertical a cross sectional area (small solid angle) as possible to prevent counting overlap, surrounded the scintillator. Activity read included that in the solid angle formed from the top of the detector to the slit at the top of the collimator. The base of the solid angle included the full width of the bird, 6.6 in. and 2.5 in. axially along the bird. The baseline measured from the resin mold and latex cast was approximately 2.5-in. below the top portion of the sacs. An optimum distance for counting while providing a minimal solid angle was 4.5-in. from the top of the detector to the base of the support with an additional 3-in. to the base line. The bird divided into seven 2.5-in. sections gave a slit width determined as follows:



Width of Slit

$$\text{Tan } \theta = \frac{2x}{4.5} = \frac{1.25 + x}{10}$$

$$x = 0.3630$$

$$2x = 0.726$$

Figure 10. Collimator dimension determination.

A small sheet metal curb, built up 0.25 in. above the edge of the slit assured that the birds were positioned the same for each section. The base of the bird support had 0.725-in. wide, 0.25-in. thick Plexiglas strips attached to the underside, centered on each section (Figure 3). These strips fit into the curb and the remainder of the support rested on the top of the collimater.

Low activity levels made shielding paramount. Four inches of lead completely enclosed the collimator and bird (Figure 9) except for the opening where the bird was inserted. This shielding around and over the bird cut the background to 1/3 the original activity measured without shielding.

Procedure

The birds were Single Comb White Leghorn type (Babcock strain) male chickens approximately six months of age, weighing an average of 4.5 lb. The birds were fasted 24 hours before the experiment to avoid regurgitation of food and to stabilize metabolic rate, [15, p. 338]. Their weight was recorded and the anesthesia, sodium phenobarbital (0.162 gm/cc, 0.295 cc/oz body weight), intravenously injected into the tarsometatarsul region. An overdose of sodium pentobarbital through a cutaneous ulnar venous cannula later euthanatized the chicken.

Plucking the feathers from the neck provided a better seal with the grease in the plethysmograph collar. The bird was clamped in an upright position, the rectal tamperature probe inserted 4 in., and the heating pad placed over the bird and frame. Prior to applying the mask, a spirogram tracing assured detection of any marked respiratory effects. Lastly, the mask was fitted to the bird's face and sealed with grease.

Simultaneouly with bird preparation, the reactor activated the particles. Decay time started when the reactor was shut down to retrieve the activated particles. One of the two 5-ml vials was counted for 1 minute to obtain the relative activity of the sample. Approximately 2 1/2 ml of aerosol solution was placed in the nebulizer. Opening the solenoid valve simultaneously started the exposure timer and sampling pumps, and particle atomization began.

To avoid transients, spirogram tracings started five minutes after heating pad shut-down. Core temperature was recorded, as well as barometric pressure, sampling vacuum pressure, room air temperature, and internal plethysmograph temperature. (Reference Figure 15 for sample data sheet.)

At the end of a 15 minute period the solenoid valve was closed thus stopping the timer and sampling pumps. The nebulizer was refilled and the equipment restarted for a second 15 minute exposure.

The bird was euthanized by injecting approximately 2.5 cc of sodium pentobarbital. Calibration of the plethysmograph was performed simultaneously with 4-minute live time counts of the upstream and downstream filter samples placed at the baseline in the resin mold. Clamping off the trachea with a large rubber footed hemostat, injections of 20, 30, 40, and 50 ml of air were placed in the plethysmograph and simultaneously recorded on the strip chart.

Removing the bird from the plethysmograph, and amputating his feet to facilitate handling in the collimator, the bird was placed in the resin mold. To avoid biasing, counting began on opposite ends with each succeeding bird. The seven sections were each counted for 4 minutes and the results recorded. A background count was taken upon completion of counting.

CHAPTER IV

RESULTS

Physiological Observations

The respiratory activity based on 30 observations was as follows: mean tidal volume, 32.73 ± .66 ml/breath; respiratory frequency, 18.03 ± 0.39; minute volume, 591.03 ± 12.95 ml/min. The body weight was 2.030 ± 0.048 Kg; body temperature, 101.8 ± 0.2°F.

Regional Deposition

The radioactivity of inhaled particles for a given region was determined by summing the counts within the energy band of the source for that region (Appendix F), subtracting background and correcting for time decay. Dividing this corrected radioactivity for a given region by the sum of all regions and the activity expired provided a relative indication of the per cent of total deposition for that region. A complete summary of the data taken including physiological, inspired activity, percent deposition and estimated inspired activity for each bird is presented in Table 6 of Appendix F.

A three-way analysis of variance (Table 2) and a multiple comparison of means (Table 3 and 4) using the least significant difference method ($P<0.05$) was made using the "AARDVARK"[1] computer program.

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[1] "AARDVARK" Numerical Analysis Program
Statistical Laboratory
Iowa State University, Ames, Iowa, 1968
Revised by the Dept. of Statistics and Computer Science
Kansas State University

Table 2. Three Way Analysis of Variance

Source of Variation	D.F.	Sum of Squares	Mean Square	F
Particle Size (P)	4	0.0007271	0.00018	0.000007
Section (S)	7	1520.2661133	217.18086	7.855667*
Bird	25	0.0020272	0.00008	0.000003
P x S	28	4430.3828125	158.22895	5.723276*
Error	175	4838.1210938	27.64639	
Total	239	10788.78.2500		

* Indicates significance at the 5% level.

Testing birds within particle size ($F_{4, 25} = 2.22$), it was not found ($P<0.05$) that the birds were unequally exposed. Although significant differences ($P<0.05$) existed for deposition by site only (combined particle size), inferences from this statistic is not possible without first weighting each particle size based on particle size distribution frequences in poultry environments. Significant differences ($P<0.05$) also existed when observing site deposition for each particle size, the objective of this study. Tables 3 and 4 exhibit this site deposition size dependence in greater detail.

Comparing the total activity within the bird plus that expired with the estimation of upstream sampling showed the upstream sample to read consistently low (2.59 ± .78%). This difference may be explained by the isokinetic sampling error discussed elsewhere (Appendix E).

Table 3. Means for Regional Deposition by Particle Size in Order of Decrease Magnitude Showing Non Significant Difference Groupings (By Line) at the 0.5 Protection Level (Significance Range 5.95).

Part. size μ	0.091							
Section	7	6	5	4	1	3	2	EXP.
% Deposition	21.75	18.97	17.43	12.18	10.30	8.62	7.51	3.95
Non-significant Groups	———		———	———	———	———	———	

Part. size μ	0.176							
Section	4	6	3	7	5	2	1	EXP.
% Deposition	19.69	16.84	13.30	12.40	12.31	11.21	7.30	6.95
Non-significant Groups	———	———		———	———	———	———	

Part. size μ	0.312							
Section	1	3	2	4	5	7	6	EXP.
% Deposition	20.72	17.12	16.37	13.12	10.03	8.21	7.59	6.82
Non-significant Groups	———	———	———	———	———	———		

Part. size μ	1.1							
Section	5	7	6	2	4	1	EXP.	3
% Deposition	19.55	19.38	16.89	10.80	9.52	9.45	7.39	6.99
Non-significant Groups	———	———	———		———	———	———	———

Part. size μ	5.7							
Section	1	2	6	3	4	5	7	EXP.
% Deposition	22.94	17.90	11.98	11.46	11.07	9.28	8.42	6.93
Non-significant Groups	———	———	———	———	———	———	———	———

Table 4. Means for Regional Deposition of Particle Size Grouped by Section in Order of Decreasing Magnitude Showing Non Significant Difference Groupings (by line) at the 0.5 Protection Level (Significance Range 5.95).

Section 1					
Part. Size μ	3.7-7	0.312	0.091	1.1	0.176
% Deposition	22.94	20.03	10.30	9.45	7.30
Non-signif. Groups	———	———	———	———	———
Section 2					
Part. Size μ	3.7-7	0.312	0.176	1.1	0.091
% Deposition	17.90	16.37	11.21	10.80	7.51
Non-signif. Groups	———	———	———	———	———
Section 3					
Part. Size μ	0.312	0.176	317-7	0.091	1.1
% Deposition	17.12	13.30	11.46	8.62	6.99
Non-signif. Groups	———	———	———	———	———
Section 4					
Part. Size μ	0.176	0.312	0.091	3.7-7	1.1
% Deposition	19.69	13.12	12.18	11.07	9.52
Non-signif. Groups	———	———	———	———	———
Section 5					
Part. Size μ	1.1	0.091	0.176	0.312	3.7-7
% Deposition	19.55	17.43	12.31	10.03	9.28
Non-signif. Groups	———	———	———	———	———
Section 6					
Part. Size μ	0.091	1.1	0.176	3.7-7	0.312
% Deposition	18.97	16.90	16.84	11.98	7.59
Non-signif. Groups	———	———	———	———	———
Section 7					
Part. Size μ	0.091	1.1	0.176	3.7-7	0.312
% Deposition	21.75	19.38	12.40	8.43	8.21
Non-signif. Groups	———	———	———	———	———
Expired					
Part. Size μ	1.1	0.176	3.7-7	0.312	0.091
% Deposition	7.39	6.95	6.93	6.82	3.23
Non-signif. Groups	———	———	———	———	———

CHAPTER V

DISCUSSION

Physiological Responses

The respiratory volumes and rates are similar to those previously reported (Appendix A). Although a portion of the trachea and head were outside the plethysmograph, this apparently did not measureably affect tidal volume readings because the volume of the entire trachea is less than one percent of the total respiratory volume (Appendix A).

Site Deposition for Each Particle Size

A schematical summary for each particle size or range is given in Figures 11 a-e. An analogy to mechanisms in fiber filters will be made by referring to Whitby's [49] paper on the "Mechanics of Air Cleaning".

3.7-7 Microns. Roughing filters are described as being constructed of relatively large fibers whose primary function is to remove large particles. Fiber shape, material, and arrangement appear to have little effect on the efficiency since the principle filtration mechanisms are interception (for larger particles) and inertial impaction (for particles larger than 2 microns). Diffusion contributes little to the collection of small particles in a roughing filter. To prevent reintrainment of particles larger than 5 microns an adhesive is occasionally used.

The anatomy of the nasopharyngeal area may be compared to the roughing filter. The small feathered flap within the nares, the turbinate bodies,

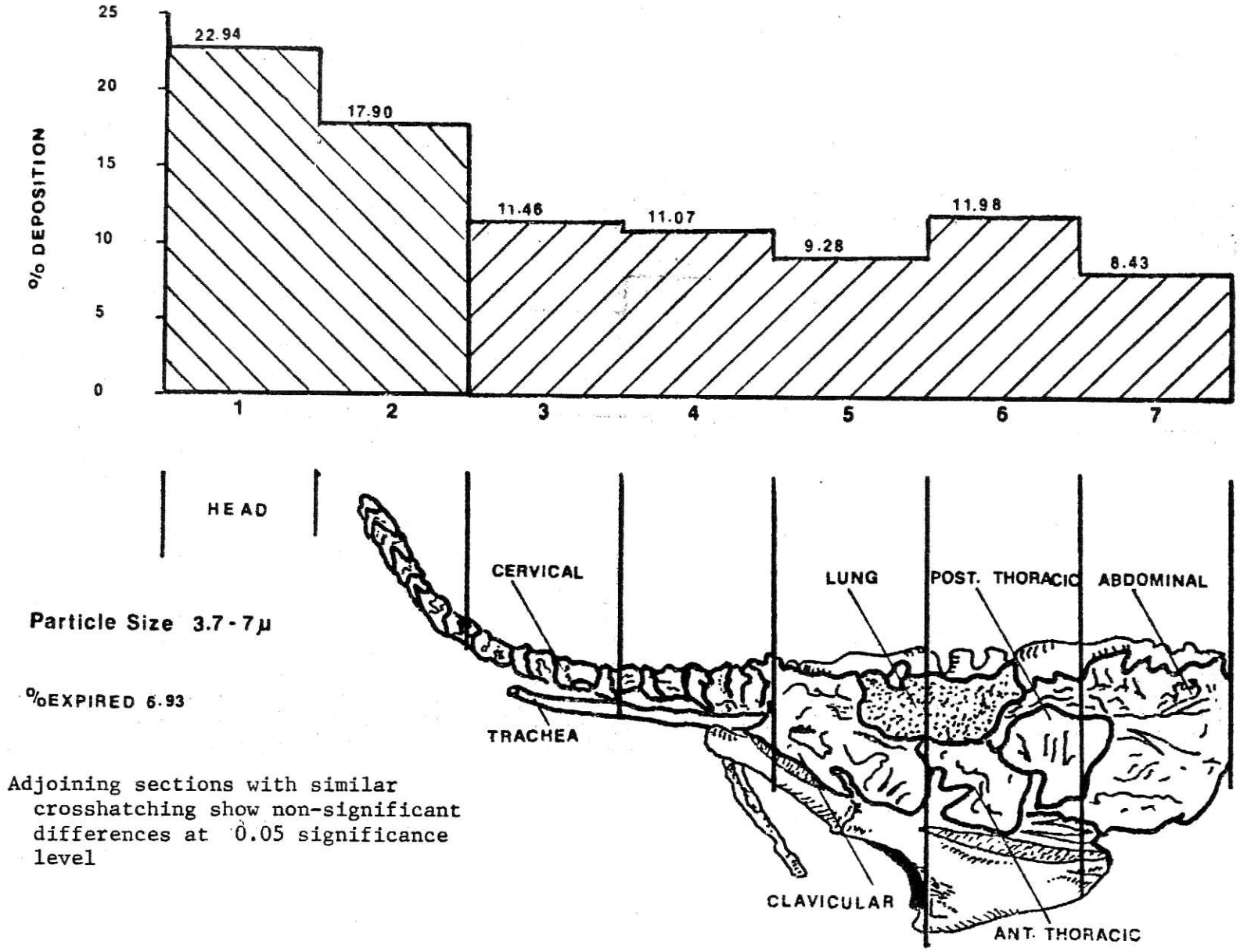


Figure 11 a. Regional Deposition in % by Particle Size 3.7 - 7 microns

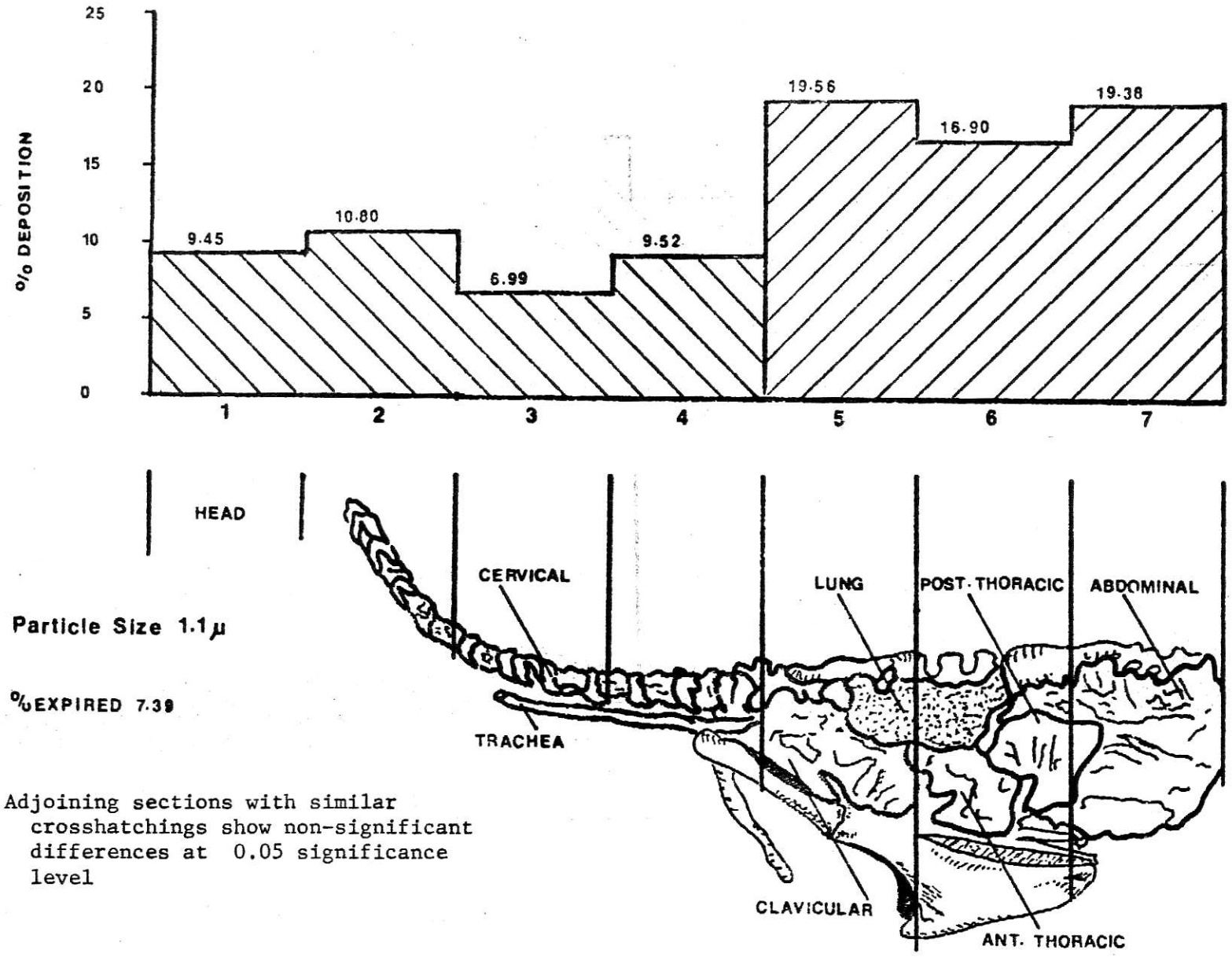
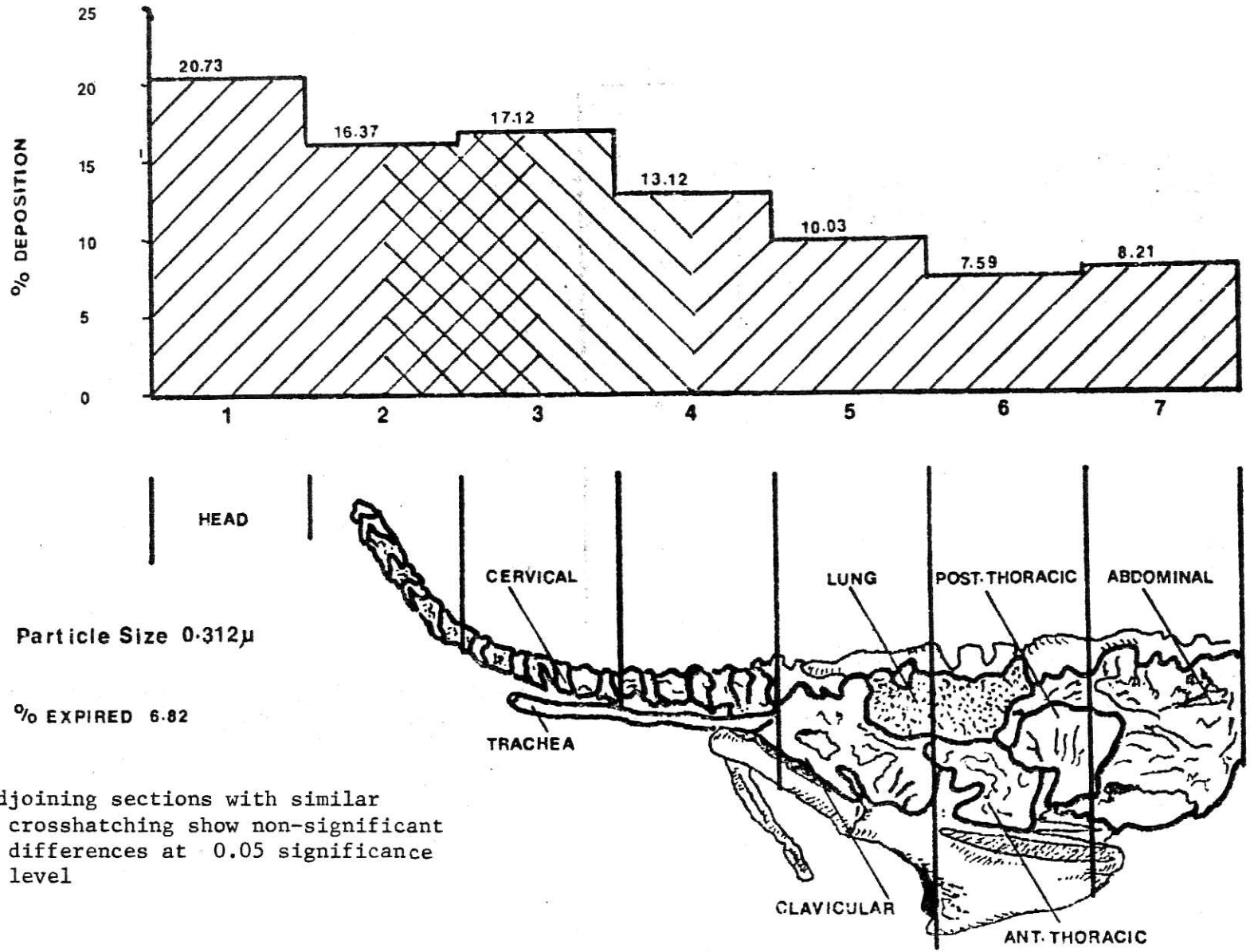


Figure 11 b. Regional Deposition in % by Particle Size, 1.1 microns



Adjoining sections with similar crosshatching show non-significant differences at 0.05 significance level

Figure 11 c. Regional Deposition in % by Particle Size, 0.312 microns

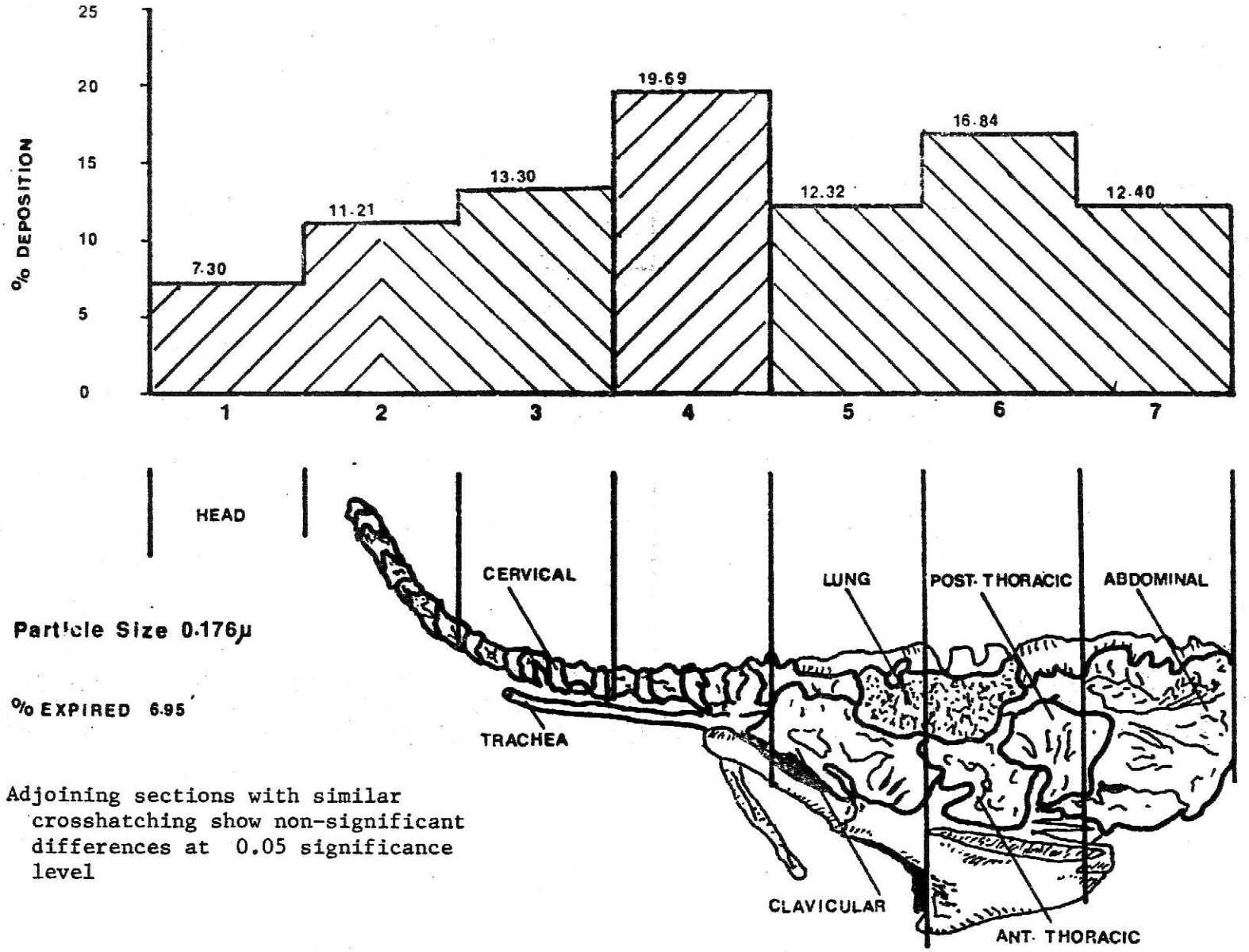
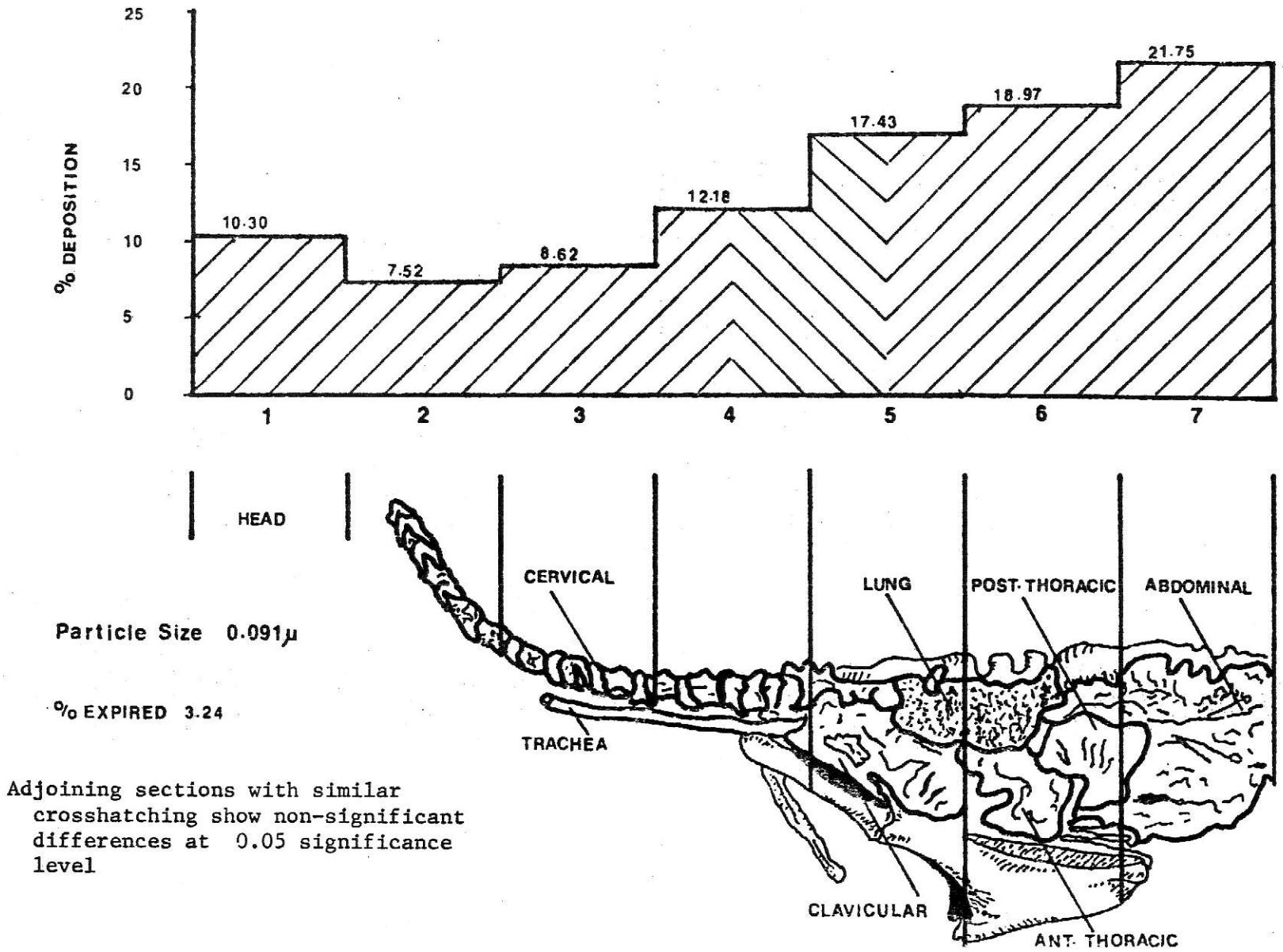


Figure 11 d. Regional Deposition in % by Particle Size, 0.176 microns



Adjoining sections with similar crosshatching show non-significant differences at 0.05 significance level

Figure 11 e. Regional Deposition in % by Particle Size, 0.091 microns

and the valving mechanism of the cranial larnyx all would contribute to the mechanisms of inertial impaction and interception. To prevent deeper inhalation of these already captured particles, this nasopharyngeal area is coated with mucus acting as the adhesive on the roughing filter. Thus one would expect to find a significant percentage of the large particles (especially those above 2 microns) to be captured in this area.

Those particles not captured would then pass down the trachea, and those particles having greater inertia would tend to impact the walls of the trachea or any bend in the bronchi (Appendix B). Those particles which avoided impaction probably would be trapped as they entered the caudal regions of the bird (posterior air sacs).

Table 4 appears to confirm that the anterior portion of the bird acts as an effective roughing filter. Sections 1 and 2 account for approximately 40% of the particles deposited, with the remainder equally deposited throughout the rest of the system.

1.1 Microns. The theoretical fractional efficiency curves for the mechanisms in a roughing filter show that a comparatively low efficiency could be expected with particles 1.0 micron or below. Therefore, a lower percentage of particles this size would be expected to be captured in the upper tract (Table 4). If this is true, the various pathways of the aerosol contaminated gas must be traced in the lung region. It is likely that as the trachea bifurcates from the primary bronchi, capture of particles would increase because of impaction and interception.

The lung may be compared to both a medium and a high performance filter. Medium performance filters generally are more densely packed with fibers

(higher soliderity factor) than roughing filters. The lower media velocity to maintain the pressure drop through them requires a large face filter area. Impaction and interception contribute about equally to provide a reasonably high efficiency on particles 1 micron and larger. The relatively low velocity of air passing through is due to the number of secondary and tertiary bronchi. This may explain why the lung acts as the described filter.

Those particles bypassing the lung probably pass to the posterior and prethoracic air sacs. As the gas is forced to reverse direction--from inspiration to expiration--their inertia may cause them to leave the airstream and impact the walls of the sacs. The 1.1 micron particles apparently followed this route with the majority reaching the caudal areas of the bird (Figure 11-b).

0.312 Microns. Particles of 0.3 micron diameter are the least affected by the mechanical collection mechanisms. Thus, it is difficult to predict respiratory capture of these particles. Capture of these particles must be analyzed by studying the gas pathways.

Some degree of deposition should occur in each region during inspiration. About 35% of the inspired gas passes through the lung, with the remainder going to the posterior sacs. Because of the size dependence on capture, the 0.3-micron particles are not necessarily trapped in these regions. Upon expiration, the posterior sacs empty primarily through the lung, and partially through the primary bronchi (Appendix A). The lung gas empties into the anterior sacs; the anterior sacs through the ventro bronchi into the primary bronchi to the trachea and out the nostrils and mouth.

Particles not captured in the posterior sacs may be captured in the lung. If not, they may then be washed into the anterior sacs. With the many intricate channelings and pathways in these sacs compared to posterior sacs, the residence time in portions of these sacs may be greater than in the posterior sacs, thereby increasing the probability of capture. As air from the posterior sacs is mixed in the primary bronchi with air from the anterior sacs, it may contain uncaptured particles. The remaining airborne particles have greater opportunity for capture as they exit through the trachea.

The deposition shown in the histogram (Figure 11-c) may be interpreted as follows: a higher deposition in the trachea is explained by the bidirectional flow through it as well as the long cervical sac paralleling it. Deposition in the mid section is the sum of that in the lung and anterior sacs. Caudally from the lung, deposition is solely that of capture in the posterior sacs and possibly anterior thoracic.

0.176 Micron. Diffusion appears to be the primary collection mechanism. As the particles pass through the trachea, diffusion increases to a maximum where the velocity has been greatly reduced as the trachea bifurcates at the syrinx (Figure 11-d).

Further diffusion occurs in a reduced amount. As the concentration of the aerosol is reduced the percent of deposition is equally reduced and the remainder of the aerosol is deposited in the lung and posterior sacs. Although some migration could be expected, it is theorized that the majority of the particles are captured during the inspiratory phase.

0.091 Micron. Diffusion appears to affect the particles to an even greater extent. They tend to follow the streamlines about the obstacles in the rela-

tively high velocity areas of the upper respiratory tract. As they flow posteriorly the decrease in the velocity in the lower trachea and even lower velocity through the lung cause some increased capture of the aerosol.

Since 65 percent of the air passes directly to the large posterior sacs, at very low relative velocities, it would be expected that a large quantity of small particles would diffuse to the walls of the sac where they would be deposited (Table 4). Few of the particles are deposited in the anterior sacs (Figure 11-c). Because of the high percentage of particles in section 6, it may be assumed that the majority of captured particles are not re-intrained. To reach the calvicular and prethoracic sacs the particles first pass through the lung. Because of the anatomy of the lung, particles in it could be assumed to be captured, and not free to pass on to other sacs.

CHAPTER VI

SUMMARY

Summary of this Study

Radio-chemical labeling has provided a means for determining the regional deposition of particles of known size in the respiratory tract of chickens.

The theories of particle collection mechanisms in mechanical filters can aid understanding of respiratory tract capture. The larger particles are primarily removed by impaction and interception as they pass through the relatively course filter properties of the head and upper trachea. Particles of 1.0 micron, less affected by impaction and interception and too large for diffusion influence, reach the lower regions of the system.

Particles of 0.3 micron diameter are least influenced by the capture mechanism. This is demonstrated by what may be a migration of the particles through the system, eventually trapped in the anterior sacs and trachea during the expiratory phase.

Diffusion becomes more important as the particle sizes decrease. The smallest reach the most caudal areas of the bird, and are deposited on the walls of the posterior air sacs.

Areas for Further Study

Portions of the respiratory anatomy should be excised and counted to increase knowledge of deposition. This would require an isotope of greater

half life (^{131}I) which would also permit clearance studies and reduce the variance experienced in this study. Size frequency distributions from poultry house environments would benefit the interpretation of this study, and provide needed information for air cleaning commercial poultry units.

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APPENDIX A

AVIAN RESPIRED GAS PATHWAY AND RELATED ANATOMY

The following terminology, or variations thereof, will be used in describing the avian respiratory system anatomy.

Ventral - The surface of the body or some part of organ which is directed toward the plane of support (the ground).

Dorsal - The surface of the body or some part of the body which is directed away from the plane of support.

Median plane - An imaginary plane perpendicular to the plane of support which divides the body, so nearly as possible, into similar halves.

Medial - A structure or structures facing the median plane.

Lateral - A structure or structures facing away from the median plane.

Anterior or Cranial - The head end of the body or facing toward the front.

Posterior or Caudal - The rear end of the body or facing toward the rear part of the body.

Two distinct theories attempt to describe the pathway of respired gas in birds. Zeuthen [54] maintains that all parts of the air sacs/lung apparatus have a bidirectional tidal ventilation, whereas Hazelhoff [26] alleges that gas flow is unidirectional through the parenchymal parabronchi during both inspiration as well as expiration.

Anatomy of the Respiratory System

The respiratory system of birds differs considerably from that of mammals. Avian lungs do not dead-end in the alveoli, instead respired gas passes through relatively rigid parabronchi where gas exchange by diffusion occurs through the walls of the parabronchi and pulmonary capillaries.

Nasopharyngeal. The nostrils of the chicken are located about halfway between the eyes and the point of the beak. A membrane flap carrying a number of small feathers reduces the skeletal opening of the nostril. Also within the nostril are turbinate bodies covered with a mucous secreting membrane with a large surface area relative to that of the nostril [37, p. 47].

Tracheobronchial. A complex valvular apparatus, the cranial larnyx, is located on the cranial end of the trachea. It tends to regulate the flow of air, and also prevents some foreign body inspiration [37, p. 48].

The trachea, lined with mucous membranes and ciliated epithelium is about six inches in length and is composed of a series of semi-rigid cartilaginous rings [41, p. 366]. It terminates with the caudal larnyx or syrinx, which forms the cranial portion of the primary bronchi [37, pp. 48-49].

Lung. The right and left primary bronchus (mesobronchus), about 3 to 5 mm in diameter just caudal to the syrinx, terminate in the abdominal air sac where the bronchus diameter reduces to about 1 mm [31, pp. 179-180]. They, too, are lined with ciliated epithelium [41, p. 367]. In addition, a connection is made through the laterobronchus to the posterior thoracic sac [21].

Branching from the primary bronchus are great numbers of secondary bronchi. The first are the ventrobronchi (about 4 to 5 mm in diameter); the second the dorsobronchi (about 2.5 to 3.5 mm). All the secondary bronchi tend to be constricted at their orgins [31, p. 18].

Directed from the internal ventro and dorsobronchial surfaces are the parabronchi which eventually anastomose with one another, thereby interconnecting all the secondary bronchi. Although subject to some discussion, the diameter of the parabronchi are approximately 1 mm in diameter [31, p. 194]. These parabronchi are the hub of the respiratory unit of the lung [41, p. 371]. Radiating from the parabronchus are the air capillaries which provide the means for gas exchange with the pulmonary blood. A diameter of 6 to 12 microns has been given for these air capillaries, although this is subject to some disagreement [21, 31, p. 196].

Air Sacs. Connected to these air passages are nine large, thin walled chambers commonly known as air sacs. There are four paired sacs that constitute the anterior air sacs, which include the two cervicals, and two anterior thoracics, as well as the single unpaired interclavicular sac. The paired posterior thoracic sacs, and the paired abdominals make up the posterior sacs [26].

All of the anterior sacs communicate with the primary bronchus through the ventrobronchus [21]. The posterior sacs are connected to the primary bronchus as previously mentioned. Figure 7 schematically gives the approximate anatomical location of the air sacs and lungs.

Capacities of the Lung Air Sac System. Numerous attempts have been made to determine the volume of air in the lungs and air sacs. Using various materials such as cocoa butter, latex, molten paraffin, etc., injection casts

were made of the respiratory system [46]. The researchers making the casts acknowledged that this would cause certain distention, particularly in the abdominal sacs, so they made attempts to correct for their error [31]. Dunker [21] presented the following volumes as a percentage of the whole: trachea, 1.0%; cervical, 3%; intercalavicular, 9%; anterior thoracic, 18%; ling 11.0%; posterior thoracic, 14%; abdominal, 44%.

Respired Gas Pathway

Bidirectional. Using gas analysis techniques employing hydrogen as a foreign gas, Zeuthen [54, pp. 11-21] attempted to prove his theory that a bidirectional flow through the lung occurs, implying that flow through the lung is considerable during both respiratory phases. The posterior sacs are filled partially with gas passing through the lungs during inspiration, and emptied partially through the lung during expiration through a reverse order of bronchi.

Undirectional. Possibly a more popular theory, as would be assumed by the many recent papers supporting it, is that flow is undirectional through the lung during both inspiration and expiration.

Hazelhoff [26] maintained that air passes through the dorso-,para-, and ventrobronchi, in that order, during both inspiration and expiration. As did Zeuthen [54, pp. 11-21], Hazelhoff agreed that the posterior sacs received air from both the outside and that which had passed through the lung, and that the anterior sacs were filled only from air that had passed through the dorso-, para-, and ventrobronchi.

Supporting this theory of unidirectional flow, Schmidt-Nielsen [45] attempted to further explain the pathways and associated breathing mechanics. It was first agreed that the filling and emptying of sacs was not antagonistic

(i.e. both the anterior and posterior sacs filled on inspiration and emptied on expiration) [45].

On inhalation, air flows through the primary bronchus partially through the lung, but mainly into the posterior sacs. Initally, the air reaching the posterior sacs is that which remained in the trachea from the previous breath, thus being higher in CO_2 than fresh air. Secondly, but still during the inspiration phase, fresh outside air reaches the posterior sac. The posterior sacs are now filled with a mixture of exhalation air and fresh air.

On exhalation, the air from the posterior sacs passes primarily through the lung. This air then fills the anterior sacs on the next inhalation, being released from the anterior sacs through the ventro and primary bronchi and out the trachea on the following exhalation [45].

A summary of this is presented by Scheid and Piiper [43] and is as follows:

Inspiration:

trachea→primary bronchus → dorsobronchi→parabronchi→ventrobronchi
trachea→primary bronchus → posterior air sacs

Expiration:

dorsobronchi→parabronchi→ventrobronchi→primary bronchus→trachea

Schematically Scheid, Slama and Piiper [44] represented the flow in a simplifed diagram based on flowmeter direction measurements as follows:

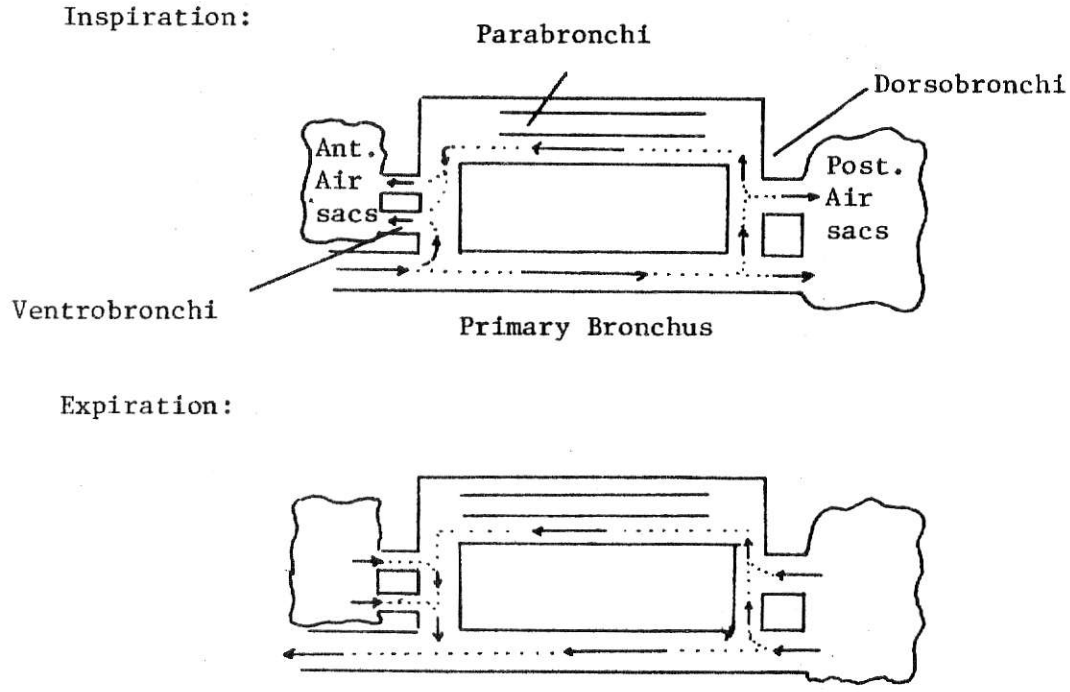


Figure 12 Respiratory Pathways

Zeuthen [54, p. 38] estimated that approximately 35% of the total inspiratory volume passes through the lungs, and approximately 65% of the expiratory volume passes through the lungs. The percentage of inspired gas in each of the sacs was reported to be as follows: cervical and interclavicular, negligible; prethoracic, 6%; postthoracic, 8%; abdominal, 80%; [41, p. 380]. These values must not be taken as absolute, but do indicate a definite difference in levels of ventilation within the bird.

Respiration Rate and Volume

Exercise, heat stress, hormonal state, sex, body size, and rectal temperature affect the respiratory activity in birds [41, 46]. Respiratory rates for chickens under "normal" conditions range from 12 to 37 breaths/minute [15, 46, p. 158]. Tidal and minute volumes range from 25.3 ml/breath and 323 ml/min. to 35 ml/breath and 644 to 760 ml/min. respectively [34,15].

APPENDIX B

THE MECHANICS OF PARTICLE ENTRAPMENT AS RELATED TO RESPIRATION

To rationalize particle capture within the respiratory tract, one must in addition to understanding the respiratory system have a basic knowledge of the mechanics of air filtration and its relationship to the respiratory system.

Collection Mechanisims

Whitby [44] has categorized four filtration mechanisms. Principles of these mechanisms will be shown to apply to the respiratory system as well.

1. Inertial impaction involves heavier particles. Due to their inertia, they tend to leave the airstream (which has been deflected around an obstacle) and impact with the obstacle.
2. Interception primarily involves the larger diameter particles that in following the airstream around an obstacle pass within a distance less than one radius from the obstacle.
3. Diffusion affects the smaller particles that due to their size are continually diverted by the bombardment of gas molecules. If their random path causes the particle to come into contact with an obstacle, it is said to be influenced by diffusion.
4. Electrical attraction influences the particle when the particle, obstacle, or both carry an electrical charge, and the charge tends to affect the motion of the particle.

Of much lesser importance for smaller particles is the mechanism of straining, whereby the physical size of the particle prevents it from passing through the smaller size opening between obstacles.

Least affected by these mechanisms are 0.3 microns particles (49). This is due not only to the relatively minor influence of impaction and interception because of the small size of the particle, but also because it is too large to be significantly affected by diffusion. Below 0.3 micron diameter, the capture efficiency will increase with decreasing particle size.

It cannot be assumed that upon contact with an obstacle, the particle will adhere. Annis [8] has demonstrated the effect of particle bounce, whereby a relatively large particle striking a dry fiber filter will not necessarily adhere to the fiber, but will be reintrained into the airstream. As indicated by Whitby, the effect of particle bounce can be reduced by using an adhesive coating on the fibers [51, p. 40].

Particle Collection as a Function of Anatomy

Within the external nares of the nasal cavities is a membrane flap carrying a number of small feathers (Appendix A). This tends to prevent large dust and foreign matter from entering the system by the mechanisms previously mentioned. A lining of mucous secreting membrane in the nostril tends to act as an adhesive coating thereby causing particles larger than 5 micron coming in contact with the membrane to adhere. In addition, any hygroscopic particles entering the humidifying apparatus of the nose may increase in size, thereby altering the probability of capture.

Because the airstream is somewhat diverted as it passes through the cranial larynx a certain degree of inertial impaction and interception would be expected. Lining the trachea are myriads of cells with whip-like appendages known as cilia. As particles contact this mucous covered beating cilia, they are gradually transported up the trachea clearing the walls of foreign matter [20, p. 33]. Charged ions, such as electrically charged particles,

significantly affect the beat frequency of the cilia [33]. The degree of deposition is also influenced by ionic charges. Fraser and Hill [24] showed that for extremely highly charged unipolar particles, a marked increase in retention occurred. They attributed this to the image force between the particle and vessel wall.

As the particles enter the bronchial area, the larger particles will be captured at the branching points of the bronchi [2, p.113]. The lungs with its tortuous path of bronchi and capillaries ever reducing in size, tends to provide a good filter media for the particles reaching it.

Those smaller particles that enter the sacs are subject to the influence of diffusion due to the reduced velocity within the sac compared to that of the bronchi. As the particle diameter decreases, one would expect a higher degree of capture of those particles reaching this area.

APPENDIX C

PREPARATION OF RADIOACTIVE-LABELED POLYSTYRENE LATEX MONODISPERSED SPHERES

Preparation of the particles followed the general procedure as established by Bogen [14]. The non-availability of certain compounds and handling and storing of the particles made certain modifications necessary. Iodine-127 (non radioactive) was substituted for iodine-131 (8.05 day half line) as the labeling substance. Upon neutron bombardment iodine-127 becomes iodine-128 with 25 minute half life.

Catalytic reagents and heat initiated the emulsion polymerization. Dialysis removed the free iodine remaining as well as any other contaminants.

Preparation

The equipment and apparatus was primarily the same as Bogen's [14]. Here 2 cc of the 10% (W/V) concentration of the monodispersed spheres were placed in a 60 ml screw-top bottle. To this was added 0.2 ml of styrene monomer, 4 mg of sodium dodecyl sulfate, and 8 mg of potassium persulfate. Lastly, the bottle was filled with a 0.1 normal solution of iodine-128 in benzene. The entire mixture was purged with helium and the screw top sealed to maintain an inert atmosphere.

The bottle was wrapped with heating tape (1/2 in. by approximately 24 in., 36 watts at 115 v.). The solution was maintained at 70 C (precalibrated), and shaken for 24 hours on a wrist-action shaker.

The mixture was then transferred to a presoaked (1/2 in. diameter) dialysis membrane bag. The bag was placed in a container with approximately 5 liters of demineralized water. Placed on a rotating shaker table, the container with bags was allowed to shake for seven days with the water changed every 12 hours.

At the end of the week, the solution (now essentially free of excess iodine, and other contaminates) was transferred to the 60 ml bottle where 5 drops of ARLATONE T[1], a surfactant to minimize agglomeration, were added to the solution. The estimated dilution was approximately 500:1.

Storing

The leaching of iodine from the aerosol of 0.2 to 0.3 percent per week as reported by Bogen also occurred in the samples above. For this reason, particles were used for a maximum of two weeks following polymerization.

---

1 Atlas Chemical Industries, Inc.
Wilmington, Delaware 19899

APPENDIX D

TIME CORRECTION FOR RADIOACTIVE DECAY

As in conventional first order systems, radiation decay occurs as $e^{-\lambda t}$ where λ is the decay constant [38, p. 56].

Since the half life of an isotope is known [16], the decay constant can be determined as follows:

$$\frac{N_{1/2}}{N_o} = \frac{1}{2} = e^{-\lambda t_{1/2}}$$

$$\lambda = \ln \; 2/t_{1/2}$$

where $N_{1/2}$ = radioactivity at one half life

N_o = initial radioactivity

$t_{1/2}$ = half life time of isotope

From the Chart of the Nuclides [11], the half life for ^{128}I is given as 25 minutes.

Substituting this into the above equation gives a decay constant of 0.027726.

The measured radioactivity can now be normalized back to time zero knowing the lapsed time between time of measurement and time zero.

$$N_o = N_t \; e^{\lambda t}$$

where N_t = measured radioactivity at some know lapsed time

t = lapsed time in minutes

assume $t = 63.0$ minutes

$N_t = 122$

The corrected radiation to time zero is:

$$N_o = 193\ e^{(0.0277)(63.0)}$$

$$N_o = 698.6$$

APPENDIX E

CALIBRATION MEASUREMENTS

Rotameter Calibration Curves

The rotameters were calibrated with a spirometer as recommended by the Ace Glass Company, and shown in Figure 13.[1]

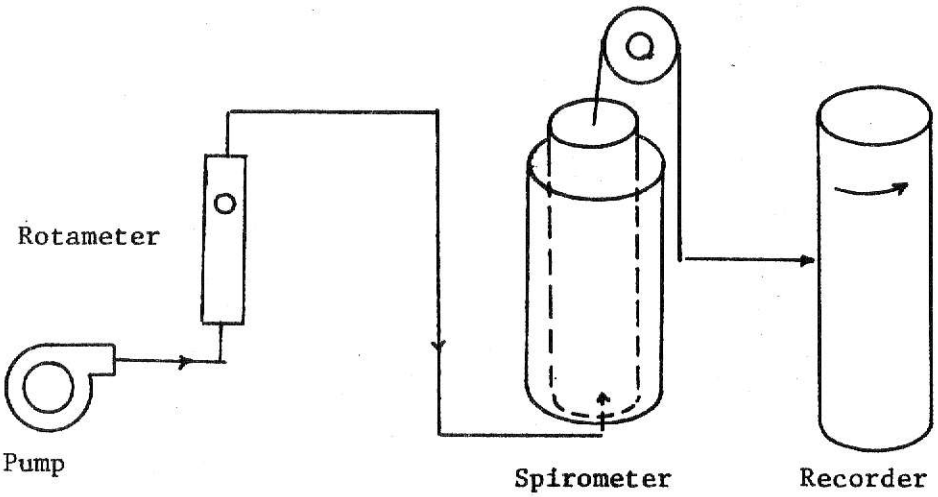


Figure 13. Rotameter Calibration Apparatus

Using a Gast Model 0211-p45 air pump, various flows were passed through the rotameter (12 data points equally spaced over the range of interest). Air flowed into a Collins[2] 9-1 respirometer with the output traced on a chart revolving at 3 min/rev.

The gage and barometric pressures were recorded for volume flow rate corrections. Midpoint float heights were recorded and spirometer flow rates

---

1 "Laboratory Calibration of Rotameters," supplied with Instruction sheets for Ace Rotameters, p. IV 10.

2 Warren Collins Inc., Braintree, Mass. 02184

corresponding to the float heights and corrected for pressure differences were plotted. Little difference between the calibration curves supplied by the Ace Glass Company and those drawn as a result of the above calibration occurred.

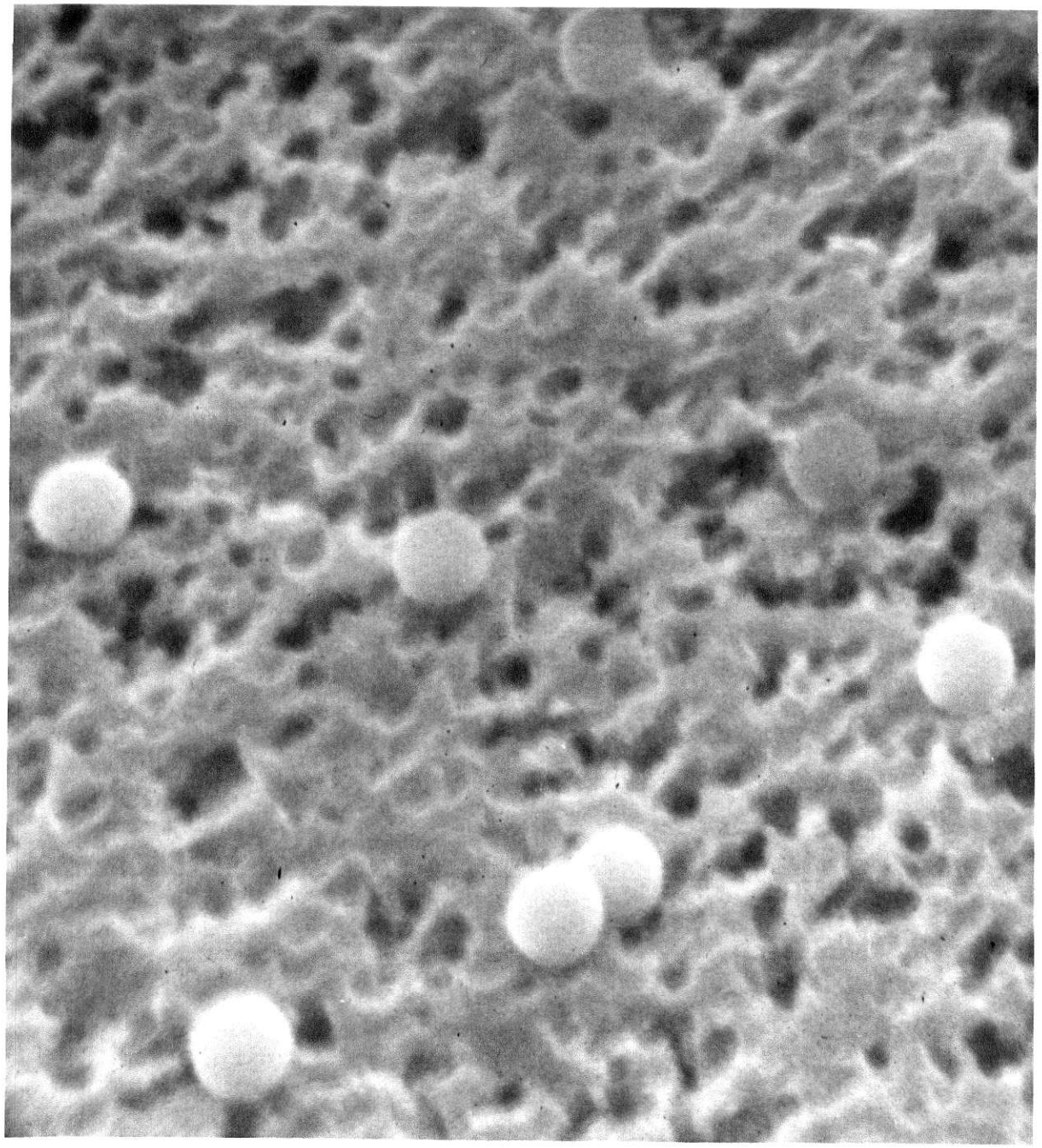
Discrete Particle Test

Impaction within the nebulizer and charge neutralization minimized agglomeration as seen in Figure 14. Here at 0.1% concentration, the particles were nebulized, neutralized and collected on 0.4 micron pore size Nuclepore filter. A maximum of 10% doublets occurred, with most samples showing approximately 5%.

Wall and Mask Losses

The 1 cm diameter brass tubing was inserted in the upstream plenum, as explained under Material and Methods, and connected directly to the downstream plenum, bypassing the unidirectional mask. Air was prevented from recirculating through the downstream plenum by capping the inlet of the plenum, thereby allowing only air drawn from the upstream plenum to enter the downstream plenum. This assured that the most extreme wall loss condition would be measured in the downstream plenum. A sampler was located in the upstream and downstream plenum (Figure 2). The downstream filter sampled at 600 ml/min, drawing approximately the same quanitity of aerosol through the tubing as the bird would during respiration.

Table 5 gives losses determined by correcting the sampling rates of the upstream and downstream samplers, and adjusting to standard pressure. It must be realized that these are the most extreme values. Air at 1300 ml/minute constantly flushed the walls of the downstream plenum during actual bird exposures. No detectable losses in the tubing were found when the downstream filter was attached directly to the outlet of the tubing.



0.5 micron

Figure 14. Electron Micrograph of a 1.1-micron Radioactive-labeled Polystyrene Latex Aerosol. 5KX Power

Table 5

Maximum Wall Losses

Particle Diameter *Microns*	Activity Difference between Upstream and Downstream Samplers (%)
0.091	4.0
0.176	6.0
0.312	6.2
1.1	5.3
5.7	3.7

To determine losses in the unidirectional mask and its valves, the mask and valves were measured for activity following an actual bird exposure. The loss measured was approximately 6% of the total bird activity, of which 72% was lost in the upstream valve and 28% in the downstream valve.

Filter Sampling Error

A sampling velocity that differs from the gas stream is said to be anisokinetic. The quantity of particles entering the filter nozzle differ from that under isokinetic conditions because of the disturbed gas streamlines causing some of the particles to be deflected from their original direction of motion. Particle sedimentation, particle inertia, the geometry and orientation of the sampling head and the speed and direction of the main air stream affect sampling accuracy [18].

Davies [18, p. 924 Table I] presented sampling criteria to accomplish accurate sampling within a small per cent with a small tube sampler[1]. The sampling parameters of this exposure study fall within that criteria for accurate sampling under "calm" conditions (rate of suction, 0.92 cm^3/sec; orifice diameter 0.4 mm). These conditions apply when wind velocity *Uo* is less than or equal to 1/5 the dynamic sampling velocity Vo.

Vo is defined by Davies as:

$$Vo = (F/4\pi T^2)^{1/3}$$

where F = volume rate of sampling

and $T = m/6\pi\alpha\eta$

where m = mass of a particle

α = particle radius

η = viscosity of the fluid

For a 1-micron polystyrene latex aphere (density 1.05 gm/cc) the value of T is as follows:

$$m = (1.05 \text{ gm/cc}) \quad \frac{\pi x(1 \text{ micron} \times 10^{-4} \text{cm/micron})^3}{6}$$

$$= 0.55 \times 10^{-12} \text{ gm}$$

$$\alpha = 0.5 \times 10^{-4} \text{ cm}$$

$$\eta \text{ @ } 71°F = 1.821 \times 10^{-4} \text{ gm/cm} \cdot \text{sec}$$

$$\text{or} \quad T = \frac{0.55 \times 10^{-12} \text{ gm}}{(6)(\pi)(0.5 \times 10^{-4}\text{cm})(1.821 \times 10^{-4}\text{gm/cm sec})}$$

$$T = 3.2 \times 10^{-6} \text{ sec}$$

$$\text{therefore} \quad Vo = \left(\frac{55 \text{ cm}^3/\text{sec}}{4\pi(3.2 \times 10^{-6} \text{ sec})^2}\right)^{1/3}$$

$$Vo = 7.53 \times 10^3 \text{ cm/sec}$$

---

1 Davies also states that limits shown in his Table 1 also apply to a small orifice in a large suction head.

The velocity within the plenum can be estimated as follows:

Flow through plenum approximately

1.082×10^3 cc/sec

Area of the plenum approximately

248.5 cm^2

$$Uo = \frac{1082 \text{ cc/sec}}{248.5 \text{ cm}^2} = 4.35 \text{ cm/sec}$$

or $Uo \leq 1/5$ Vo thus sampling is within Davies criteria.

Using a hybrid computer Vitols [47] was able to predict certain anisokinetic sampling errors for given types and sizes of particles. A plot of sampled-to-true concentration ratios versus sampled-to-free stream velocity curves matched closely with empirical data. Although his data was for larger particles and higher free stream velocities than those used in this study, it is apparent that for a ratio of sampling velocity to free stream velocity of greater than 1 that the ratio of sampled concentration to true concentration was less than one.

In this exposure study the ratio of sampling velocity to free stream velocity was approximately 1.67. Because the particles in this study are smaller, their inertia would not be as great as those used by Vitols and therefore, concentration ratio errors would not be as great as those presented by Vitols.

In this study, one would expect the sampled concentrations to be lower than true plenum concentrations. To confirm this, the orifice plate on the upstream side of the sampler was removed exposing the entire filter paper (3.3 cm diam.) to the free stream. Although this would reduce the sampling velocity to near isokinetic conditions, it could not be assumed that

sampling velocity was uniform across the face of the filter paper due to the construction of the holder.

The results showed a positive difference of approximately 5% between the samples with the orifice plate removed, and with it in place.

APPENDIX F

SUMMARY OF INHALATION TEST DATA

A set of sample calculations showing manipulation of the data are given below. The data used is that from the sample data sheet, Figure 15. Table 6 presents the raw data for each bird.

Time as listed below is the lapsed time from reactor shutdown to time-of-counting for the particular item. Radiation is the total activity count within the energy bands of the source with background subtracted. Time-corrected radiation is the activity count corrected for time decay as explained in Appendix D.

Sample flow rate corrected:

$$\dot{M}ac = \dot{M}a \left(\frac{Pa}{Ps}\right)$$

where:

$\dot{M}ac$ = corrected sample flow rate

$\dot{M}a$ = measured sample flow rate

Pa = sampling pressure, absolute

Ps = standard atmospheric pressure

or:

$$52.90 \text{ ml/min} = 55 \text{ ml/min} \times \frac{28.78 \text{ in. Hg}}{29.92 \text{ in. Hg}}$$

Tidal volume corrected:

$$\dot{V}_{TC} = \dot{V}_T \times \frac{V_s}{V_b}$$

where:

$\dot{V}_{TC}$ = tidal volume corrected

$\dot{V}_T$ = tidal volume measured

v_s = specific volume at standard conditions

v_b = specific volume of saturated air in bird at core temperature.

or:

$$32.0 \text{ ml/breath} = 35.5 \text{ ml/breath} \times \frac{13.7 \text{ ft}^3/\text{lbm}}{15.2 \text{ ft}^3/\text{lbm}}$$

Minute volume corrected:

$$\dot{V}_E = \dot{V}_{TC} \times F_R$$

where:

$\dot{V}_E$ = minute volume corrected

F_R = respiratory frequency

or:

$$576.0 \text{ ml/min} = 32.0 \text{ ml/breath} \times 18$$

Estimated inspired radiation:

$$R = R_s \times r$$

where:

R = radioactivity counts

R_s = radioactivity counts from upstream sample

$$r = \frac{\dot{V}_E}{\dot{M}ac}$$

or:

$$5445.0 = 495.90 \times 10.90$$

The average room temperature was 74.3°F with the plenum temperature approximately 3°F above room. The upstream sampling pressure held at 0.4 in. Hg gage.

Particle Size 1.1

Date 2/7/73 Time 1330

Exposure Time 30

Bird Weight 70.5

Bird Temp. 101.3

Room Air Temp. 76.8

Plethy. Temp. 78.0

Bara Press. 29.18

Vacuum Samp. Press. 0.4

Sample Flow Rate Meas. 55

Sample Flow Rate Correct. 52.90

Resp. Freq. 18

Tidal Vol. Meas. 35.5

Tidal Vol. Correct. 32.0

Minute Vol. Correct. 576.0

Ratio Inspired to Sampled Flow Rates 10.90

Estimated Inspir. Radiation 5445.0

Meas.	Time	Radiation	Time Correct. Radiation	% of Total
5 Ml. Sample	9.25	67,324	86,985.5	
Up Str Sample	49.75	125	495.9	
Down Str Sample	45.5	67	236.3	4.13
Position 1	57.5	57	280.3	4.90
2	63.0	122	698.6	12.20
3	68.0	62	407.8	7.12
4	73.0	69	521.2	9.11
5	77.75	137	1180.5	20.62
6	83.25	76	762.6	13.32
7	88.0	143	1636.7	28.59
Sum			5724.0	

Figure 15 Sample Data Sheet

Table 6. Test Inhalation Data Summary

Bird No.	Part. Size μ	Bird Wt. Oz.	Core Temp. 0_F	Resp. Freq. R/min	Tidal Vol L/min	Min Vol L	Expos. Time Min.	Item Meas.	Time Corrected Activity	% of Total Act.	Up Str. Sample ml/min	Est. Inspired Activity
1	0.091	81.5	103.5	20	32.54	651	30				44.4	4867.4
								Vial	254363			
								U.S.	332.4			
								D.S.	189.8	3.58		
								1	692.6	13.07		
								2	46.5	.88		
								3	794.7	15.00		
								4	574.1	10.84		
								5	952.3	17.97		
								6	1195.8	22.57		
								7	852.5	16.09		
								Total	5298.3			
2	0.091	77	102.0	22	35.09	774	28				44.7	9912.8
								Vial	235849			
								U.S.	572.2			
								D.S.	155.4	1.44		
								1	1022.1	9.50		
								2	727.4	6.76		
								3	244.6	2.27		
								4	381.8	3.55		
								5	2531.6	23.53		
								6	3005.5	27.94		
								7	2688.7	24.99		
								Total	10,757.1			

Table 6 --continued

Bird No.	Part. Size	Bird Wt. Oz.	Core Temp. 0_F	Resp. Freq. R/min	Tidal Vol L/min	Min Vol L	Expos. Time Min.	Item Meas.	Time Corrected Activity	% of Total Act.	Up Str. Sample ml/min	Est. Inspired Activity
3	0.091	67	101.0	16	31.8	509	35				44.7	8656.9
								Vial	316472			
								U.S.	760.1			
								D.S.	429.2	4.75		
								1	484.1	5.36		
								2	386.2	4.27		
								3	1007.6	11.15		
								4	1475.9	16.33		
								5	1034.9	11.45		
								6	1121.0	12.40		
								7	3099.7	34.29		
								Total	9039.4			
4	0.091	73	102.1	18	36.2	652	29				44.7	6548.0
								Vial	145430			
								U.S.	448.7			
								D.S.	504.4	7.63		
								1	1049.6	15.88		
								2	1130.5	17.11		
								3	961.4	14.55		
								4	956.7	14.48		
								5	746.2	11.29		
								6	753.1	11.40		
								7	506.4	7.66		
								Total	6608.3			

Table 6 --continued

Bird No.	Part. Size μ	Bird Wt. Oz.	Core Temp. 0_F	Resp. Freq. R/min	Tidal Vol L/min	Min Vol L	Expos. Time Min.	Item Meas.	Time Corrected Activity	% of Total Act.	Up Str. Sample ml/min	Est. Inspired Activity
5	0.091	73.75	101.0	19	28.33	591	30				46.6	4795.8
								Vial	166905			
								U.S.	413.8			
								D.S.	22.6	0.47		
								1	312.0	6.52		
								2	235.5	4.92		
								3	312.6	6.54		
								4	982.6	20.55		
								5	1014.3	21.21		
								6	847.1	17.72		
								7	1055.2	20.07		
								Total	4781.9			
6	0.091	76.5	102.0	18	32.99	6.60	30				47.9	5864.5
								Vial	322810			
								U.S.	425.5			
								D.S.	87.2	1.54		
								1	648.7	11.45		
								2	630.9	11.13		
								3	126.6	2.23		
								4	416.8	7.35		
								5	1083.5	19.12		
								6	1235.8	21.81		
								7	1438.4	25.38		
								Total	5667.2			

Table 6 --continued

Bird No.	Part. Size μ	Bird Wt. Oz.	Core Temp. ^0_F	Resp. Freq. R/min	Tidal Vol L/min	Min Vol L	Expos. Time Min.	Item Meas.	Time Corrected Activity	% of Total Act.	Up Str. Sample ml/min	Est. Inspired Activity
7	0.176	100.5	101.0	20	33.63	672	25				53.2	8134.1
								Vial	252863			
								U.S.	643.8			
								D.S.	597.7	6.93		
								1	1189.2	13.79		
								2	1249.0	14.48		
								3	859.7	9.97		
								4	1720.9	19.96		
								5	1214.3	14.08		
								6	960.2	11.14		
								7	831.8	9.65		
								Total	8622.8			
8	0.176	65.5	101.3	19	31.53	600	30				52.6	5440.0
								Vial	102037			
								U.S.	476.2			
								D.S.	431.7	8.00		
								1	408.0	7.56		
								2	729.4	13.50		
								3	855.2	15.84		
								4	1121.2	20.78		
								5	881.9	16.33		
								6	690.6	12.79		
								7	281.1	5.21		
								Total	5399.7			

Table 6 --continued

Bird No.	Part Size	Bird Wt. Oz.	Core Temp. $^{0}_{F}$	Resp. Freq. R/min	Tidal Vol L/min	Min Vol L	Expos. Time Min.	Item Meas.	Time Corrected Activity	% of Total Act.	Up Str. Sample ml/min	Est. Inspired Activity
9	0.176	59	102.1	20	31.99	642	14				51.9	2375.3
								Vial	61069			
								U.S.	191.96			
								D.S.	115.7	4.60		
								1	96.0	3.82		
								2	43.3	1.72		
								3	298.7	11.88		
								4	556.1	22.19		
								5	398.9	15.85		
								6	614.6	24.40		
								7	394.0	15.68		
								Total	2517.3			
10	0.176	59.5	101.0	16	29.61	475	30				47.9	2220.0
								Vial	191108			
								U.S.	223.7			
								D.S.	178.0	7.83		
								1	43.0	1.89		
								2	472.4	20.77		
								3	354.3	15.58		
								4	424.7	18.68		
								5	95.4	4.20		
								6	268.2	11.79		
								7	438.4	19.28		
								Total	2274.0			

Table 6 --continued

Bird No.	Part. Size μ	Bird Wt. Oz.	Core Temp. 0_F	Resp. Freq. R/min	Tidal Vol L/min	Min Vol L	Expos. Time Min.	Item Meas.	Time Corrected Activity	% of Total Act.	Up Str. Sample ml/min	Est. Inspired Activity
11	0.176	70	101.8	17	34.00	577	30				44.0	4533.8
								Vial	192413			
								U.S.	345.5			
								D.S.	302.9	6.71		
								1	397.2	8.80		
								2	346.2	7.67		
								3	528.4	11.70		
								4	1033.7	22.89		
								5	251.0	5.56		
								6	928.4	20.56		
								7	727.5	16.11		
								Total	4515.3			
12	0.176	77.5	102.6	16	35.09	565	30				44.3	3047.3
								Vial	170597			
								U.S.	239.1			
								D.S.	247.4	7.64		
								1	257.7	7.96		
								2	296.0	9.14		
								3	481.0	14.85		
								4	442.8	13.67		
								5	578.9	17.87		
								6	660.3	20.38		
								7	275.2	8.52		
								Total	3239.3			

Table 6 --continued

Bird No.	Part. Size μ	Bird Wt. Oz.	Core Temp. 0_F	Resp. Freq. R/min	Tidal Vol L/min	Min Vol L	Expos. Time Min.	Item Meas.	Time Corrected Activity	% of Total Act.	Up Str. Sample ml/min	Est. Inspired Activity
13	0.312	83.5	100.9	18	33.06	592	30				48.8	8192.3
								Vial	499218			
								U.S.	675.7			
								D.S.	588.9	7.06		
								1	715.1	8.58		
								2	1000.1	12.00		
								3	1480.6	17.76		
								4	1502.8	18.03		
								5	969.7	11.63		
								6	1142.9	13.71		
								7	934.9	11.22		
								Total	8335.1			
14	0.312	61.0	100.3	22	25.22	555	30				48.1	5788.7
								Vial	129776			
								U.S.	501.7			
								D.S.	412.5	6.82		
								1	1103.8	20.73		
								2	1064.5	16.37		
								3	1234.0	17.12		
								4	791.1	13.12		
								5	592.8	10.03		
								6	397.1	7.59		
								7	589.1	8.21		
								Total	6184.9			

Table 6 --continued

Bird No.	Part. Size μ	Bird Wt. Oz.	Core Temp. ^0_F	Resp. Freq. R/min	Tidal Vol L	Min Vol L	Expos. Time Min.	Item Meas.	Time Corrected Activity	% of Total Act.	Up Str. Sample ml/min	Est. Inspired Activity
15	0.312	74	101.0	18	38.08	685	30				50.2	8341.7
								Vial	152222			
								U.S.	611.5			
								D.S.	337.0	3.95		
								1	2189.2	25.69		
								2	1814.3	21.29		
								3	1196.3	14.04		
								4	1072.4	12.59		
								5	1256.8	14.75		
								6	175.1	2.05		
								7	480.1	5.63		
								Total	8521.2			
16	0.312	80	103.3	16	34.27	548	30				44.5	7461.3
								Vial	171599			
								U.S.	606.5			
								D.S.	429.7	5.36		
								1	2075.8	25.90		
								2	1178.9	14.71		
								3	1344.6	16.78		
								4	976.5	12.18		
								5	743.0	9.27		
								6	486.7	6.07		
								7	778.8	9.72		
								Total	8014.0			

Table 6 --continued

Bird No.	Part. Size μ	Bird Wt. Oz.	Core Temp. $^{0}_{F}$	Resp. Freq. R/min	Tidal Vol L/min	Min Vol L	Expos. Time Min	Item Meas.	Time Corrected Activity	% of Total Act.	Up Str. Sample ml/min	Est. Inspired Activity
17	0.312	53.25	100.7	16	36.46	583	30				48.0	7535.0
								Vial	197082			
								U.S.	620.5			
								D.S.	542.4	6.75		
								1	1738.4	21.64		
								2	1049.0	13.06		
								3	1342.7	16.72		
								4	953.6	11.87		
								5	1050.8	13.08		
								6	801.9	9.98		
								7	553.4	6.89		
								Total	8032.2			
18	0.312	72	102.3	15	31.99	480	30				61.2	3728.5
								Vial	183235			
								U.S.	475.4			
								D.S.	411.5	11.15		
								1	911.3	24.69		
								2	736.1	19.94		
								3	645.3	17.48		
								4	415.9	11.27		
								5	68.9	1.87		
								6	269.2	7.29		
								7	232.7	6.30		
								Total	3690.9			

Table 6 --continued

Bird No	Part. Size μ	Bird Wt. Oz.	Core Temp. $^{0}_{F}$	Resp. Freq. R/min	Tidal Vol L/min	Min Vol L	Expos. Time Min.	Item Meas.	Time Corrected Activity	% of Total Act.	Up Str. Sample ml/min	Est. Inspired Activity
19	1.1	72.25	102.6	16	38.20	614	20				75.0	4742.6
								Vial	140123			
								U.S.	579.1			
								D.S.	347.1	7.53		
								1	538	11.66		
								2	485.9	10.53		
								3	444.3	9.63		
								4	683.0	14.81		
								5	879.1	19.06		
								6	508.9	11.03		
								7	726.0	15.74		
								Total	4612.3			
20	1.1	65	100.9	18	30.06	541	30				50.2	10251.0
								Vial	155607			
								U.S.	951.0			
								D.S.	631.2	5.85		
								1	889.9	8.24		
								2	713.0	6.61		
								3	608.7	5.64		
								4	662.8	6.14		
								5	1514.7	14.03		
								6	1994.3	18.48		
								7	3779.7	35.02		
								Total	1079.43			

Table 6 --continued

Bird No	Part. Size μ	Bird Wt. Oz.	Core Temp. 0_F	Resp. Freq. R/min	Tidal Vol L/min	Min Vol L	Expos. Time Min.	Item Meas.	Time Corrected Activity	% of Total Act.	Up Str. Sample ml/min	Est. Inspired Activity
21	1.1	70.5	101.3	18	32.0	576	30				52.9	5445.0
								Vial	86986			
								U.S.	495.9			
								D.S.	236.3	4.13		
								1	280.3	4.90		
								2	698.6	12.20		
								3	407.8	7.12		
								4	521.2	9.11		
								5	1180.5	20.62		
								6	762.6	13.32		
								7	1636.7	28.59		
								Total	5724.0			
22	1.1	70.5	100.2	18	26.94	485	30				48.2	5564.8
								Vial	132711			
								U.S.	553.4			
								D.S.	514.5	8.65		
								1	269.4	4.53		
								2	500.3	8.41		
								3	291.3	4.90		
								4	400.2	6.73		
								5	1128.8	18.98		
								6	1603.8	26.97		
								7	1238.1	20.82		
								Total	5946.4			

Table 6 --continued

Bird No	Part. Size μ	Bird Wt. Oz.	Core Temp. $^{0}_{F}$	Resp. Freq. R/min	Tidal Vol L/min	Min Vol L	Expos. Time Min.	Item Meas.	Time Corrected Activity	% of Total Act.	Up Str. Sample ml/min	Est. Inspired Activity
23	1.1	64.5	102.8	15	33.81	507	35				48.2	7372.7
								Vial	113464			
								U.S.	701.5			
								D.S.	668.9	9.06		
								1	918.7	12.44		
								2	553.4	7.49		
								3	615.3	8.33		
								4	1048.5	14.20		
								5	1400.4	18.96		
								6	1568.1	21.23		
								7	611.9	8.29		
								Total	7385.2			
24	1.1	56.75	101.5	18	31.53	568	35.5				47.9	4933.9
								Vial	103453			
								U.S.	415.8			
								D.S.	468.8	9.14		
								1	766.9	14.95		
								2	1003.4	19.55		
								3	325.5	6.34		
								4	315.4	6.15		
								5	1317.9	25.68		
								6	531.7	10.36		
								7	401.7	7.83		
								Total	5131.3			

Table 6 --continued

Bird No.	Part. Size μ	Bird Wt. Oz.	Core Temp. $^{0}_{F}$	Resp. Freq. R/min	Tidal Vol L/min	Min Vol L	Expos. Time Min.	Item Meas.	Time Corrected Activity	% of Total Act.	Up Str. Sample ml/min	Est. Inspired Activity
25	5.7	79	102.5	18	32.17	579	25				52.2	6240.0
								Vial	295236			
								U.S.	562.2			
								D.S.	426.8	6.68		
								1	544.2	8.52		
								2	1322.08	20.69		
								3	744.5	11.65		
								4	507.3	7.94		
								5	1090.3	17.06		
								6	774.3	12.12		
								7	981.4	15.36		
								Total	6390.9			
26	5.7	76.5	103.6	23	30.84	706	25				45.6	5132.9
								Vial	368695			
								U.S.	331.4			
								D.S.	338.6	6.02		
								1	1765.1	31.39		
								2	678.8	12.07		
								3	677.8	12.05		
								4	847.9	15.08		
								5	285.9	5.08		
								6	495.7	8.82		
								7	533.0	9.48		
								Total	5622.8			

Table 6 --continued

Bird No.	Part. Size μ	Bird Wt. Oz.	Core Temp. 0_F	Resp. Freq. R/min	Tidal Vol L/min	Min Vol L	Expos. Time Min	Item Meas.	Time Corrected Activity	% of Total Act.	Up Str. Sample ml/min	Est. Inspired Activity
27	5.7	72.5	101.6	16	40.21	644	29				52.5	9117.4
								Vial	318579			
								U.S.	743.2			
								D.S.	722.3	8.08		
								1	1977.3	22.11		
								2	1994.0	22.30		
								3	1267.8	14.18		
								4	838.5	9.38		
								5	563.2	6.30		
								6	271.9	10.87		
								7	606.0	6.78		
								Total	8941.0			
28	5.7	81	100.9	18	33.32	600	30				52.9	5959.9
								Vial	328881			
								U.S.	525.7			
								D.S.	281.9	4.75		
								1	1841.4	31.05		
								2	1266.7	21.36		
								3	650.3	10.97		
								4	232.6	3.92		
								5	493.3	8.32		
								6	951.4	16.04		
								7	212.9	3.59		
								Total	5930.5			

Table 6 --continued

Bird No.	Part. Size μ	Bird Wt. Oz.	Core Temp. 0_F	Resp. Freq. R/min	Tidal Vol L/min	Min Vol L	Expos. Time Min.	Item Meas.	Time Corrected Activity	% of Total Act.	Up Str. Sample ml/min	Est. Inspired Activity
29	5.7	73	102.4	21	23.99	504	25				48.0	5021.3
								Vial	270283			
								U.S.	478.2			
								D.S.	348.4	6.67		
								1	1073.6	20.56		
								2	949.8	18.19		
								3	459.4	8.80		
								4	919.7	17.61		
								5	421.6	8.07		
								6	660.7	12.65		
								7	388.9	7.45		
								Total	5222.1			
30	5.7	62.75	102.0	16	36.56	585	30				44.3	5673.6
								Vial	346919			
								U.S.	430.1			
								D.S.	565.6	9.40		
								1	1445.1	24.02		
								2	768.8	12.78		
								3	669.4	11.13		
								4	752.2	12.50		
								5	652.2	10.84		
								6	686.2	11.41		
								7	475.7	7.91		
								Total	6015.2			

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VITA

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THE EFFECT OF PARTICLE SIZE ON THE REGIONAL DEPOSITION OF INHALED AEROSOLS IN AN AVIAN RESPIRATORY TRACT

by

RICHARD BROWNING HAYTER

B. S., South Dakota State University, 1965

AN ABSTRACT OF A MASTER'S THESIS

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MASTER OF SCIENCE

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1973

ABSTRACT

Regional deposition of inhaled aerosols, as a function of particle size, in an avian respiratory tract was investigated. Thirty anesthetized, male White Leghorn chickens, approximately six months of age (average body weight of 2.030 $\pm$ 0.048 Kg) were exposed, individually, to radioactive (I-128) inhaled aerosols (monodispersed polytyrene latex particles). Six birds each were exposed to one of five particle sizes (0.091 μ; 0.176 μ; 0.312 μ; 1.1 μ; and 3.7 to 7 μ). During exposure, the respiratory rate and tidal volume were monitored employing a whole body plethysmograph. Detection of the inhaled aerosol was determined externally for each of seven, equal length sections along the axis of the body. Calculations of the percent deposition for each section were made from the corrected time-decay activity.

Significant differences were found for regional deposition as a function of particle size. The largest particles (3.7 - 7 μ) were captured by impaction and interception mechanisms in the head and anterior trachea with distribution of deposition being uniform throughout the remainder of the system. The 1.1-micron size generally avoided capture in the anterior sections of the bird, and was impacted or intercepted on the walls of the bronchi of the lung and posterior air sacs. Particles of 0.3-micron size, having weak interception, impaction and diffusion mechanisms, to a greater extent passed through to the anterior sacs (assuming the Hazelhoff - Bethe gas pathway theory). This accounts for their high degree of anterior and anterior mid-section deposition. The smallest particles, 0.176 micron and 0.091 micron, were highly influenced by diffusion, and were captured in the caudal regions of the bird in the posterior air sacs.