135

A BIO-ASSAY METHOD FOR DETECTING INTERNAL CONTAMINATION FROM BETA-GAMMA RADIOACTIVITY

Dissertation
by
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A BIO-ASSAY METHOD FOR DETECTING INTERNAL CONTAMINATION FROM BETA-GAMMA RADIOACTIVITY

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PREFACE

The work presented by this paper is an investigation of a bio-assay method for detecting internal body contamination from beta-gamma radioactivity. The objective of the work was to determine a quick and easy method that would serve to establish rapidly if personnel involved in an incident with a pressurized water reactor had become contaminated with a biologically significant amount of radioactivity. The radioactivity used in the experiments was reactor coolant from a pressurized water reactor and the experimentation was performed on living animals.

The procedure developed consisted of vacuum filtering the urine with 800 millimicron filter paper and counting the filter paper with a Geiger-Mueller Counter. The results indicate that it is possible to detect less than 1% of a body burden of the mixed radionuclides contained in reactor coolant during the first day after the incident.

Acknowledgement is due (a) CDR. R. Skow of the Bethesda Naval Medical Center for his assistance with the counting equipment, (b) Mr. F. G. Steiner of the General Electric Company for his technical advice, (c) Mr. M. Miles of the

United States Atomic Energy Commission for his technical advice regarding the application of the experiment and (d) Dr. E. P Rubacky, Georgetown Medical School, Department of Pathology, my mentor, for his guidance and assistance in performance of the work.

Since both background (B) and sample plus background rates (S + B) must be determined, the total error in the net sample count $[(S+B)-(B)]$ is the square root of the sum of the squares of the errors of each.

$$\sigma_B = \sqrt{B\,t}$$

$$\sigma_{S+B} = \sqrt{(S+B)\,t}$$

$$\sigma_S = \sqrt{(\sigma_B)^2 + (\sigma_{S+B})^2}$$

For the Poisson Distribution Law, (15), 1σ is 68.27% confidence level, 2σ is 95.45% confidence level, 3σ is 99.73% confidence level and 4σ is 99.99%.confidence level.

APPENDIX III

Calculation of Minimum Sensitivity of System

Using the following parameters,

a) Filter paper of 800 mu pore size

b) Sample counting time of twenty-five minutes

c) Urine sample volume of 20 cc

d) Greater than 3σ confidence level

e) Background count rate of $15 \pm .77$ counts per minute

the minimum activity that can be measured by the system is

$$A = (17.9 \pm .85 - 15 \pm .77) \times \frac{1}{20} \times 4.5 \times 10^{-7} \times 3.88 \text{ uc/cc}$$

$$A = 2.5 \times 10^{-7} \text{ uc/cc} \qquad \text{where } \sigma_s = \pm .96$$

Then, using a filtering efficiency of 10% for samples collected between the sixth and twelfth hours (see Table 8), the minimum urine activity that can be detected by the reference system is

$$A_{min} = \frac{A}{10\%} = 2.5 \times 10^{-6} \text{ uc/cc}$$

Appendix IV

Data from Second and Third Animal Experiments

Item	Sample	Counting Time -min.	Total Counts -c	Activity -c/m	Confidence Level - U	Filtering Time	Activity - uc/cc
1	Background - 3/24/61	5	71	14.2	-	-	-
2	Background of 2cc evaporated animal urine	5	74	14.8	-	-	-
3	Background of 20cc filtered animal urine - 800mu filter	5	76	15.2	-	-	-
4	01-2cc evaporated	5	338	67.6	>4 ~~10.1~~	-	4.61×10^{-5}
5	02-2cc evaporated	5	320	64.0	>4 ~~9.5~~	-	4.29×10^{-5}
6	01-6.5cc filtered - 800mu filter	5	91	18.2	1.16 ~~0.85~~	-	8.0×10^{-7}
7	02-13cc filtered - 800mu filter	5	101	20.2	1.83 ~~1.35~~	-	6.70×10^{-7}
8	P1-2cc evaporated	5	1104	220.8	>4 ~~24.4~~	-	1.79×10^{-4}
9	P2-2cc evaporated	5	853	170.6	>4 ~~21~~	-	1.36×10^{-4}
10	P1-8.5cc filtered - 800mu filter	5	142	28.4	>4 ~~3.26~~	-	2.69×10^{-6}
11	P2-9cc filtered - 800mu filter	5	190	38	>4 ~~5.05~~	-	4.40×10^{-6}
12	L1&L2-2cc evaporated	5	1136	227.2	>4 ~~25.2~~	-	1.85×10^{-4}
13	L1&L2-12.5cc filtered - 800mu filter	5	227	45.4	>4 ~~4.4~~	-	3.47×10^{-6}
14	refilter of 6.5cc of P1 (10) -800mu filter	5	150	30	>4 ~~3.6~~	-	3.95×10^{-6}
15	refilter of 12cc of L1&L2(13)-800mu filter	5	152	30.4	>4 ~~2.7~~	-	2.20×10^{-6}

Data from Second Animal Experiment

Item	Sample	Counting Time -min.	Total Counts -c	Activity -c/m	Confidence - σ	Filtering Time	Activity -uc/cc
16	Background - 3/25/61	5	75	15	-	-	-
17	03- 2cc evaporated	5	281	56.2	>4	-	3.6×10^{-5}
18	P3- 2cc evaporated	5	357	71.4	>4	-	4.94×10^{-5}
19	L3- 2cc evaporated	5	328	65.6	>4	-	4.43×10^{-5}
20	03- 9.5cc filtered - 800mu filter	5	161	32.2	>4	7min	3.06×10^{-6}
21	P3- 10cc filtered - 800mu filter	5	188	37.6	>4	4min	3.90×10^{-6}
22	L3- 10cc filtered - 800mu filter	5	173	34.6	>4	10sec	3.38×10^{-6}
23	L3- 10cc filtered - 300mu filter	5	190	38	>4	6min	3.97×10^{-6}
24	5cc of coolant - 800mu filter	5	1897	379.4	-	5sec	1.27×10^{-4}
25	5cc of coolant - 800mu filter	5	1914	382.8	-	5sec	1.28×10^{-4}
26	5cc of coolant - 300mu filter	5	2015	403	-	7sec	1.35×10^{-4}
27	5cc of coolant - 300mu filter	5	2571	514.2	-	7sec	1.74×10^{-4}

Data from Second Animal Experiment

Item	Sample	Counting Time -min.	Total Counts -c	Activity -c/m	Confidence Level - σ	Filtering Time	Activity -uc/cc
1	Background 6/27/61	5	60	12	-	-	-
2	Background of 2cc evaporated animal urine	5	54	10.8	-	-	-
3	Background of 10cc filtered animal urine - 800mu filter	10	106	10.6	-	-	-
4	01-2cc evaporated	5	86	17.2	~~1.94~~ 2.71	-	5.59×10^{-6}
5	P1-2cc evaporated	5	113	22.6	~~3.3~~ >4	-	1.03×10^{-5}
6	L1-2cc evaporated	5	94	18.8	~~2.94~~ 3.3	-	7.02×10^{-6}
7	01-14cc filtered - 800mu filter	10	246	24.6	~~5.53~~ >4	3min	1.74×10^{-6}
8	P1-10cc filtered - 800mu filter	10	521	52.1	~~10.4~~ >4	12min	7.21×10^{-6}
9	L1-17cc filtered - 800mu filter	10	346	34.6	~~8.24~~ >4	12min	2.46×10^{-6}
10	02-2cc evaporated	5	87	17.6	~~2.95~~ 2.87	-	5.94×10^{-6}
11	P2-2cc evaporated	5	80	16	~~1.92~~ 2.26	-	4.54×10^{-6}
12	L2-2cc evaporated	5	62	12.4	~~0.62~~ 0.75	-	1.4×10^{-6}
13	02-7cc filtered - 800mu filter	10	123	12.3	~~0.71~~ 1.13	29min	3.68×10^{-7}
14	P2-6.5cc filtered - 800mu filter	10	126	12.6	~~0.84~~ 1.32	23min	4.83×10^{-7}
15	L2-10cc filtered - 800mu filter	10	125	12.5	~~0.76~~ 1.26	25min	2.96×10^{-7}

Data from Third Animal Experiment

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF APPENDICES

SECTION I

INTRODUCTION

A. Historical Review

In 1895, Wilhelm Roentgen discovered x-radiation in a laboratory experiment. The following year, Antoine Becquerel accidentally exposed a photographic plate to uranium salts and discovered their radioactive property (1). Madame Curie, during her celebrated experiments with uranium minerals, isolated the radioactive elements polomium and radium in 1898. These events were the beginning of a new era in which man was required to develop techniques to measure radiation and to be able to protect himself from it.

It was many years before experimenters realized the full implications of radiation. The important characteristic of radiation is that its absorption by matter causes atoms to ionize (2). This accounts for its biological significance. It now became paramount to be able to measure all forms of radiation so as to protect personnel.

At the Second International Congress of Radiology, held in Stockholm in 1928, the International Commission on Radiological Protection (ICRP) was organized to deal initially with problems of x-ray protection and later with radioactivity protection. In 1929, an Advisory Committee on X-Ray and Radium Protection was organized in the United States under the sponsorship of the National Bureau of Standards. In 1946, this committee was reorganized as the National

Committee on Radiation Protection and Measurements(NCRP). The NCRP through its various subcommittees publishes information concerning all aspects of radioactivity protection. Information concerning internal exposure to radioactivity, which is of concern in this report, is contained in National Bureau of Standards Handbook 69 (3). The handbook lists permissible concentrations of radionuclides in air and water and permissible amounts of radionuclides in the body. This information is applicable to all cases of internal contamination whether it be from a single radioisotope used in nuclear medicine and scientific research, or from the many radioisotopes constituting the fission products and by-products of nuclear fission in BOMBS and reactors.

B. Statement of the Problem

The handling of radioactive substances must be done under controlled conditions to safeguard personnel. Constant surveillance of the working areas must be maintained. However strict and thorough the precautions may be, large exposures cannot be eliminated. But exposures are not limited

to only those persons knowingly handling radioactivity. Contamination of food, water or air, affecting a few or many people, can occur due to radioactivity from reactor accidents, fallout from weapons or gross negligence in the handling of radioisotopes being used in industry, medicine and research. After an exposure does occur, immediate evaluation of the external and internal exposure of personnel must be accurately made (4). The methods presently in use for evaluating internal contamination consist of performing detailed radiochemical analyses of the feces or the urine for a specific nuclide (4, 5 & 6) or counting the radioactivity that remains in the body with "whole-body" counters (4&7).

With the advent of the nuclear reactor, the assessment of the internal exposure became more complicated. The majority of reactors are pressurized water reactors where the water acts as both moderator and coolant. The coolant of these reactors contains many radionuclides due to wear and corrosion and subsequent activation of the materials of which the plant is constructed. In addition, the number of radionuclides and their concentrations vary among reactors, and the concentrations in each reactor

will vary with time depending on the prior operating history and the chemistry conditions.(8).

Most reactor plants whether they be located in an isolated area or aboard a ship do not contain elaborate and expensive equipment, such as "whole-body" counters or multichannel analyzers to perform an immediate, detailed analysis for possible internal contamination. In addition, the necessity of maintaining the habitability in a closed environment such as aboard a ship would not permit using such toxic substances as hydrochloric acid, nitric acid or even the boiling of large quantities of human urine to determine internal contamination. The use of chelates to remove the radioactivity from the body for subsequent evaluation would necessitate its use by only skilled personnel because of the medical effects. The use of ion-exchanging resins to remove the radioactivity from the urine would require detailed chemical processes to dissolve the resin and concentrate the radioactivity. The procedures presently available for determining internal body contamination are restricted in their use because of their complexity, cost, or toxic reagants.

The problem then is to determine a physical method for

counting internal body contamination of gross beta-gamma radioactivity which is simple and does not require the use of elaborate equipment or toxic substances. Since the accuracy of the method will suffer because of the above restrictions, it should be a rapid method which can be performed shortly after the exposure has occured when the largest amount of radioactivity is still available in the persons affected.

SECTION II

THEORY

A. Internal Contamination

Internal contamination refers to radiation exposure from radionuclides that have entered the body. The nuclides may enter the body by inhalation, ingestion or absorption through a wound. Permissible concentrations of radionuclides in air and water are derived from experiments on and estimates of their somatic and genetic effects. The NCRP has recommended such limits in National Bureau of Standards Handbook 69 (3). The basis for these limits is that no significant biological effects would be expected from continuous exposure throughout life to concentrations of radionuclides at these limits. The calculation of the permissible concentrations of radionuclides involves the following factors:

1. The initial body retention of the radionuclide.
2. The effect of the radionuclide on the specific organs which accumulate the

radionuclide (for example, Strontium 90 accumulates in the bone.)

3. The fraction going from the blood and gastro-intestinal tract to the specific organ.
4. The size of the specific organ.
5. The sensitivity of the tissue of the specific organ to radiation.
6. The energy of the radiation produced by the radionuclides.
7. The specific ionization and attenuation of energy in the tissue of the critical organ.
8. The effective half-life in the body of the nuclide (equal to the geometric mean of the physical half-life of the isotope and the biological half-life.)
9. The limiting dose rates established for the various body organs.

Limiting dose rates mentioned in 9. above have been determined from medical experience with x- and gamma rays, from experiments on animals, and by comparison with natural background exposures or those that have been encountered

during past radiation accidents.

The permissible body burden of a nuclide is the number of microcuries of a nuclide in the body that will give a limiting dose rate as described above. The permissible concentrations of radionuclides in air and water can then be calculated as the concentrations which through normal inhalation of air or ingestion of water will produce and maintain one body burden throughout a period of 50 years.

B. Coolant Activity

National Bureau of Standards Handbook 69(3) presents the body burdens for specific radionuclides. For radioactivity from a nuclear reactor or other sources containing many nuclides, a gross detection method must be based on the most limiting nuclide. Table 1 contains a tabulation of the major nuclides which are present in the reactor coolant of a typical pressurized water reactor (8) such as the one for which samples were obtained for these experiments. For either case in Table 1. cobalt 60 is the nuclide which is highest relative to its Handbook 69 limit for permissible concentration in air. ~~Hence, the body burden for cobalt 60~~

~~is the nuclide which is highest relative to its Handbook 69 limit for permissible concentration in air.~~ Hence, the body burden for cobalt-60 of 10 microcuries (3), or some fraction thereof, should be the minimum detertable limit to consider a bio-assay method useful for its intended purposes. From the information presented in Table 1, it is also apparent that cobalt 60 is the most limiting nuclide for large variations in the concentrations of the radionuclides and for long times after reactor shutdown, which is equivalent to long times after an internal exposure. Based on the above information, the reactor coolants used during this project were considered to consist predominantly of cobalt-60 activity and the body burden of coolant was considered to be 10 uc.

C. Proposed Method

Bio-assay studies of internal contamination with zinc-65 (9) have shown that it is possible to make a very sensitive estimate of the actual body burden in terms of the permissible body burden of 60 microcuries (uc). Using very large scintillation detectors and the lowest urine excretion

		COLUMN A	COLUMN B	COLUMN C	COLUMN D
NUCLIDE	HALF-LIFE	Typical Concentration in Reactor Coolant during Operation uc/cc	Typical Concentration in Reactor Coolant 48 hours after Shutdown uc/cc	NBS Handbook 69 Permissable Concentration in air uc/cc	Relative Amount $\frac{\text{Col.A}}{\text{Col.C}} 10^{-3}$
Mn-56	2.6 hours	$5x\ 10^{-3}$	$6x\ 10^{-10}$	$2x\ 10^{-7}$	30
Na-24	15 hours	$5x\ 10^{-4}$	$2x\ 10^{-4}$	$5x\ 10^{-8}$	10
W-187	24 hours	$5x\ 10^{-4}$	$6x\ 10^{-5}$	$8x\ 10^{-7}$	5
Fe-59	45 days	$5x\ 10^{-5}$	$5x\ 10^{-5}$	$2x\ 10^{-8}$	3
Hf-181	46 days	$5x\ 10^{-5}$	$5x\ 10^{-5}$	$1x\ 10^{-8}$	5
Co-58	71 days	$8x\ 10^{-5}$	$8x\ 10^{-5}$	$2x\ 10^{-8}$	4
Ta-182	112 days	$4x\ 10^{-5}$	$4x\ 10^{-5}$	$7x\ 10^{-9}$	6
Mn-54	300 days	$7x\ 10^{-5}$	$7x\ 10^{-5}$	$1x\ 10^{-8}$	7
Co-60	5.2 years	$3x\ 10^{-4}$	$3x\ 10^{-4}$	$3x\ 10^{-9}$	100
Total		1x 10	1x 10		170

Table 1.

Activity of Reactor Coolant from a Typical Pressurized Water Reactor

value obtained, it was concluded (9) that it would be possible to detect about 0.1 percent of the maximum permissible body burden of zinc 65 by urine bio-assay.

The radionuclides contained in the reactor coolant from a typical pressurized water reactor vary in size and solubility in water, in the physical definition of the term (10). Hence, it may be possible to filter out a measurable percentage of the activity which would be excreted in the urine. The beta-gamma activity could be counted by a standard scaler and Geiger-Mueller tube assembly. Therefore, a bio-assay procedure consisting of filtering urine and counting the activity deposited on the filter paper was investigated.

SECTION III

MATERIALS AND EQUIPMENT

A. Filtration Equipment

The filtration equipment used in the experiment is shown in figure 1. and consisted of the following items:

1. High vacuum oil diffusion vacuum pump "Hy-Vac" driven by General Electric, 60 cycles per second, 115 volt, motor.
2. Stainless steel precipitation apparatus, manufactured by Tracerlab Company, Model # E-8B. The chimney was designed for filter paper 24 mm in diameter.
3. Filter papers with pore sizes of 300 and 800 millimicrons, manufactured by the Millipore Filter Corporation.
4. Miscellaneous rubber tubing and 2 liter flasks.

B. Counting Equipment

The counting equipment used in the experiment consisted

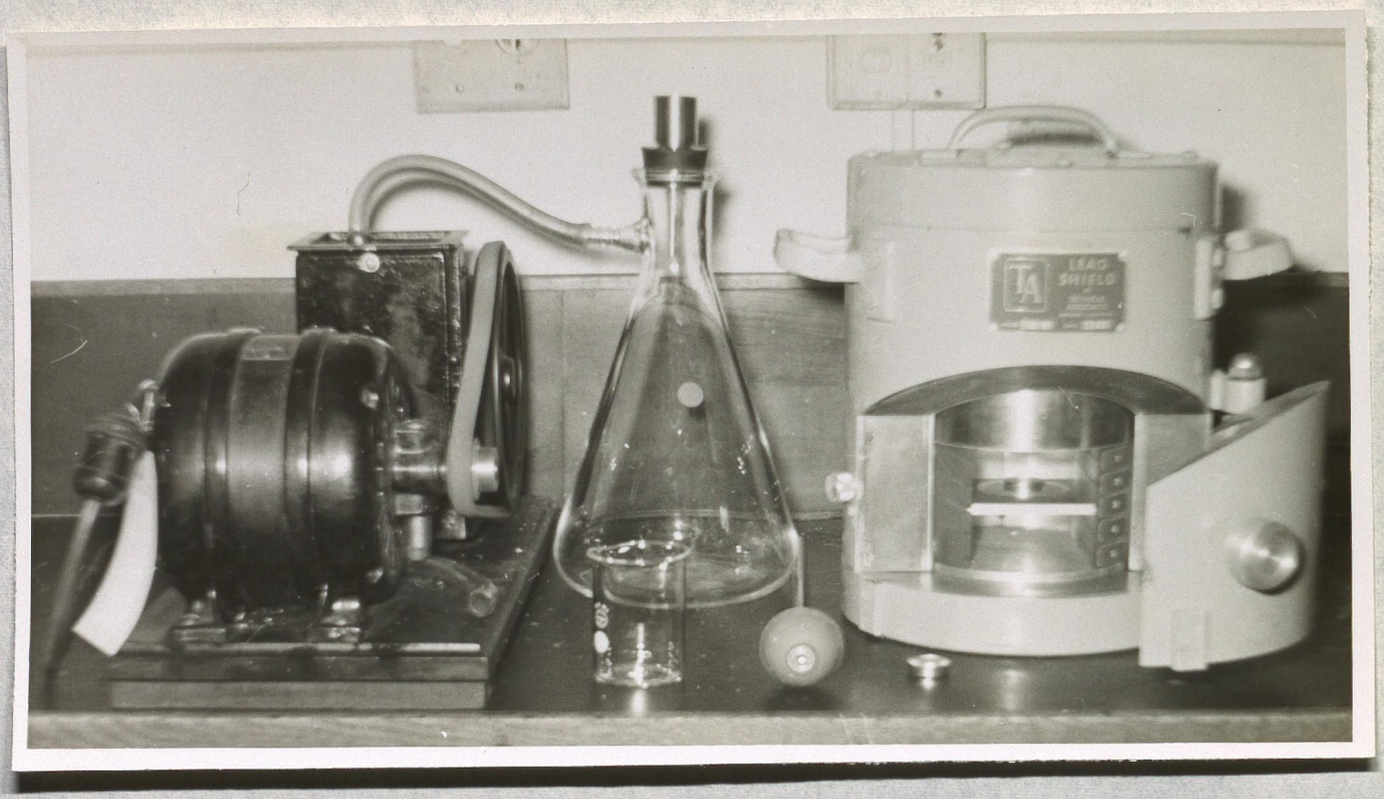


Figure 1. Filtration Equipment

of the following:

1. Radiac Computer Indicator, Model CP-297 (XN-2)/UD ~~,~~ manufactured by Nuclear Chicago Corporation shown in Figure 2. This is the standard Navy beta-gamma scaler (11). The operating characteristics of this counter are designed for radionuclides with end-point energies in the range of 0.25 to 2.5 Mev.
2. Lead Shield, Model LS-6, manufactured by

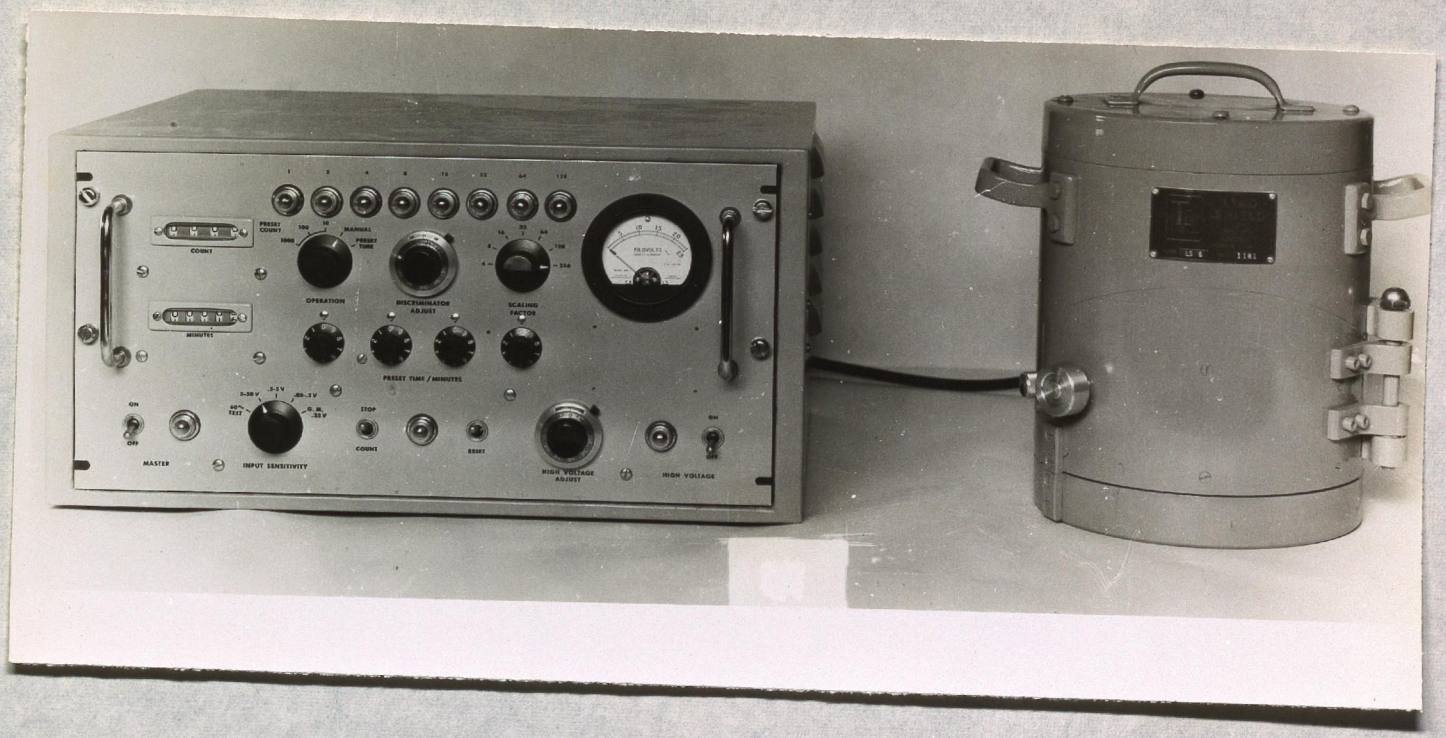


Figure 2. Radiac Computer Indicator and Lead Shield

Technical Associates, shown in Figure 2. The lead shield houses the tube mount assembly, the detecting element and the samples when being counted. The shield is constructed of $1\frac{3}{8}$ inches of lead to shield the detecting element from extraneous radiation fields including background.

3. The general counting equipment consist-

ing of the tube mount assembly, the Geiger-Mueller detecting element, aluminum absorbers, radioactive calibration sources and miscellaneous hardware is shown in Figure 3.

C. Animals and Sampling Equipment

The animals used in the experiment were albino rats of the Spraque-Dawley strain whose size ranged from 200 to 240 grams. These animals were chosen because of their well-established use in biological studies related to man. The sample collecting equipment consisted of a series of glass funnels 10 inches in diameter which were supported by a sample-collecting rack. Below each funnel was placed a 150 cc sample-collecting jar and inside each funnel was placed a plastic cage which contained all the animals that received the radioactivity by the same mode of internal contamination. Each cage was also fitted with a small-mesh wire screen to separate the feces from the urine. The urine volume was measured with an automatic 10 cc ($\pm$ 0.1cc) pipette. Animal injection volumes were accurately controlled through the use

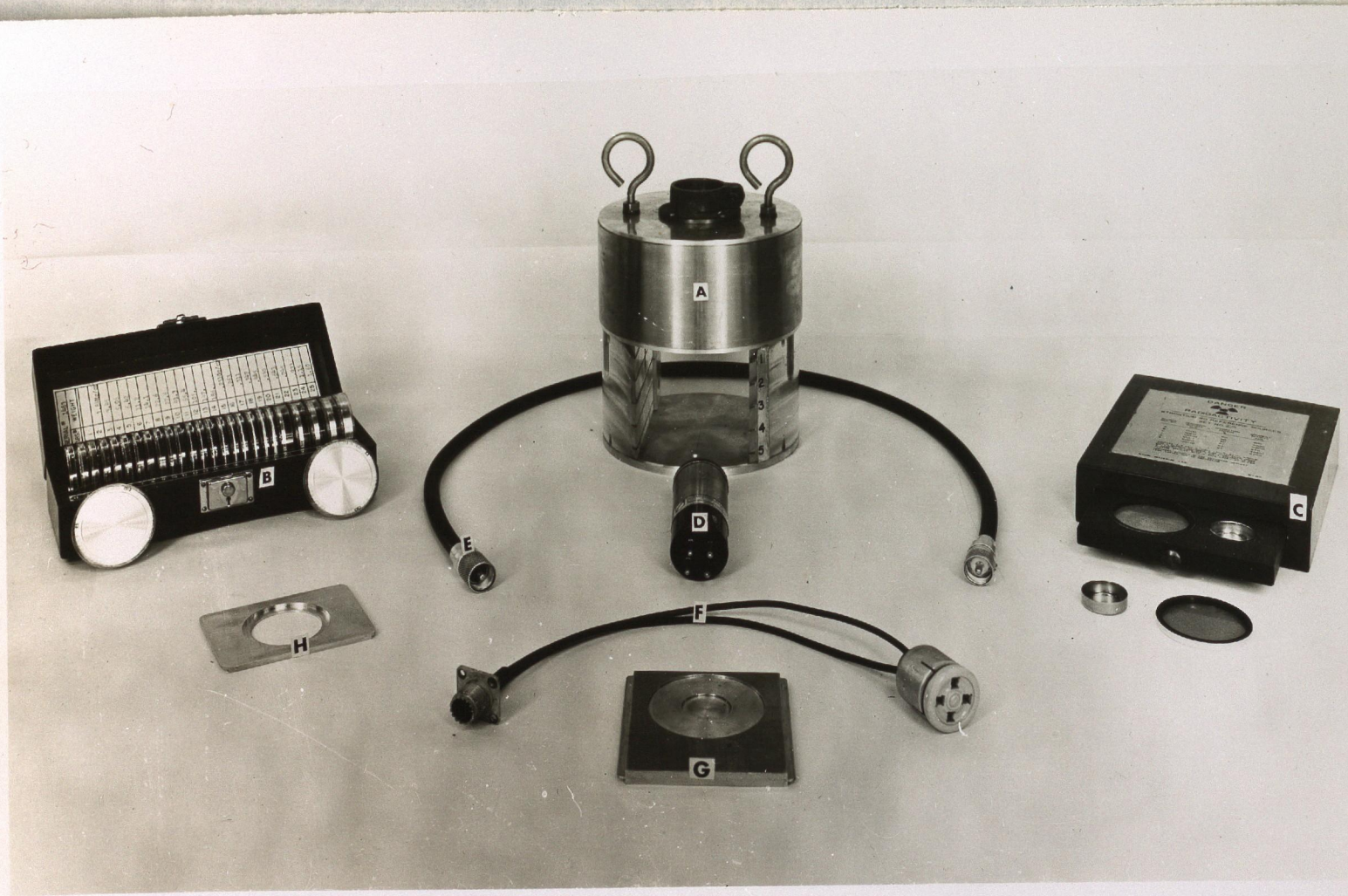


Figure 3 - Components of General Counting Equipment

A. Tube Mount Assembly
B. Aluminum Absorber Set
C. Sr 90-Y90 Reference Source Set
D. G-M Tube, Type 220T ($\frac{1}{2}$ Inch)
E. 3-Ft. Coaxial Cable
F. 1-Ft. Connecting Cable
G. Sample Positioning Shelf
H. Aluminum Absorber Shelf

of a calibrated (NBS certified) Luer-Lok 1.0 cc ($\pm$ .01cc) tuberculin syringe (#I2924) to which was affixed a #25 guage disposable 3/4 inch hypodermic needle.

SECTION IV

DEVELOPMENT AND PROCEDURES

A. Filter Evaluation

Filter papers with pore sizes of 300 mu and 800 mu were evaluated for their effectiveness and possible use in the system. The two sizes chosen represent the limits of what was considered practicable and useful by the manufacturer and by previous work in the filtering of reactor coolant (10). The efficiency of the filters for removing radioactivity from the reactor coolant and the average time to filter human and animal urine was determined and the results are summarized in Table 2. Although the 300 mu paper has a 40% higher filtering efficiency than the 800 mu paper, the long filtering times associated with the former was the basis for choosing the 800 mu paper as the reference size. The filtering efficiencies were shown in the actual experiments to be less, probably due to the fact that the body membranes and organs act as filters for the larger particles in the reactor coolant.

Test	Filter Size	
	300mu	800mu
Average Filtering Efficiency for Reactor Coolant - %	68.4	49.5
Average Filtering Time for 10 cc of Animal Urine - sec	170	75
Average Filtering Time for 10 cc of Human Urine - sec	795	163

Table 2. Preliminary Filter Evaluation

B. Mammalian Processes

The objective of the work was to evaluate a method for determining internal body contamination by counting the activity that could be filtered out of the urine. Preliminary investigations of filtering activity out of reactor coolant and reactor coolant mixed with human urine indicated that the method may be feasible. However, these investigations were only tests of the counting equipment and the filtering equipment under controlled conditions; they were not a test of the method for determining internal body contamination. An evaluation of the complete method would have to consist of filtering urine from mammals that had been contaminated with beta-gamma radioactivity from reactor coolant. This would be the only way to perform a true evaluation since the chemical and physical reactions of the body affect the injected radioactivity. These body effects may vary with the size, type, concentration and route of entry of the radionuclides and would affect the amount of the radioactivity excreted and filtered by the proposed method. Albino rats were chosen to simulate the body reactions discussed above.

It was considered impracticable to construct an air-tight room into which radioactive vapors could be introduced for the animals to breathe. Likewise, it was considered impracticable to prepare contaminated food for the animals to ingest. Therefore, it was decided to simulate the actual conditions by which the radioactivity from reactor coolant could enter the body by using the following methods:

a) Injecting the radioactivity intrapulmonarily to simulate inhalation.

b) Injecting the radioactivity by stomach intubation to simulate ingestion.

c) Injecting the radioactivity intraperitoneally, as a control because it is known to be a more highly absorptive membrane which would not be a normal method of internal body contamination.

These three mammalian processes which are referred to as L (lungs-intrapulmonary), O (orally-stomach intubation) and IP (intraperitoneally) are shown schematically in Figure 4. The use of injections to contaminate the animals gave as a distinct advantage the ability to determine the exact amount

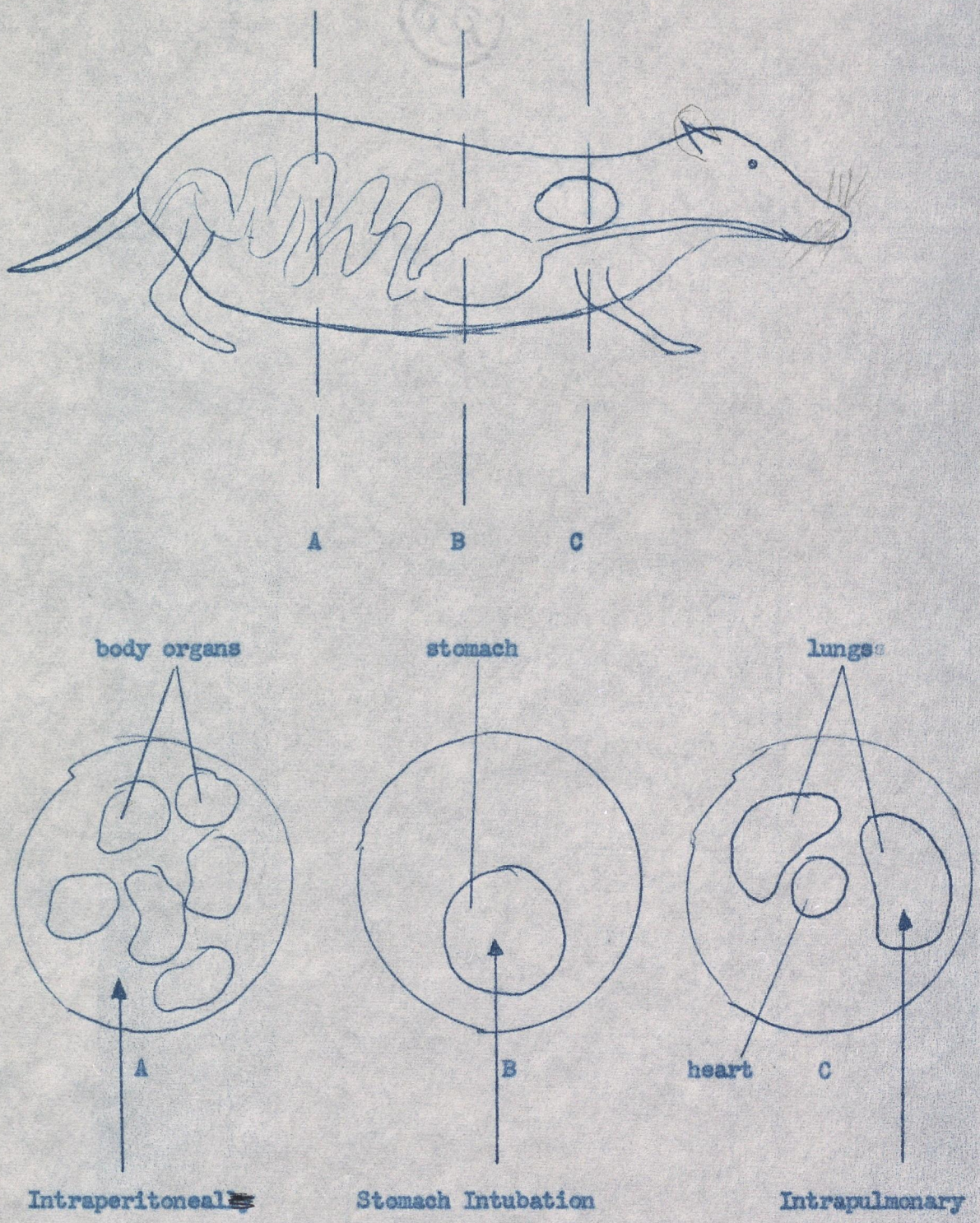


Figure 4. Mammalian Processes

of the radioactivity introduced and therefore eliminated this variable in determining if the body reacted differently to each mammalian process.

Special treatment of the animals was performed prior to and during the experiments. This treatment consisted of a) elimination of food intake for eight hours prior to and during the experiments,

b) hydration during the experiments and

c) regulated environmental conditions in an air-conditioned room. The animals were hydrated to maintain their normal urinary excretion rate and were fasted to provide a favorable condition for OPTIMUM AND MORE UNIFORM absorption of the radioactivity into the body fluids (activity that is not absorbed would be excreted in the feces and would be of ~~only slight~~ less biological concern).

C. Reference Method

The animals were combined in groups of three for each method used, orally, intraperitoneally and intrapulmonarily. In this manner, the volumne of the samples collected would be larger and the difference in the biological processes

between animals would be minimized.

From each of the pooled samples, 2 cc was removed for evaporation in a planchet under a hood and then counted by the counting system. The ratio of the total activity counted in an evaporated sample (product of the activity per unit volume times the total volume of the sample) to the total injected activity was designated the biological efficiency (E_B). This is a measure of the percentage of the injected radioactivity from reactor coolant that is excreted in the urine in a given time period. The remainder of the pooled sample was filtered and then the filter was placed in a planchet and counted by the counting system. The ratio of the total activity counted in a filtered sample to the total activity counted in an evaporated sample was designated the filtering efficiency (E_F). Finally, the ratio of the total activity counted in a filtered sample to the total injected activity (which is also the product of E_B and E_F) was designated as the overall efficiency (E_0) of the system under investigation. The process flow sheet for the system is outlined in Figure 4.5.

All counting and the calibration of the counting equipment was performed in accordance with reference 11.

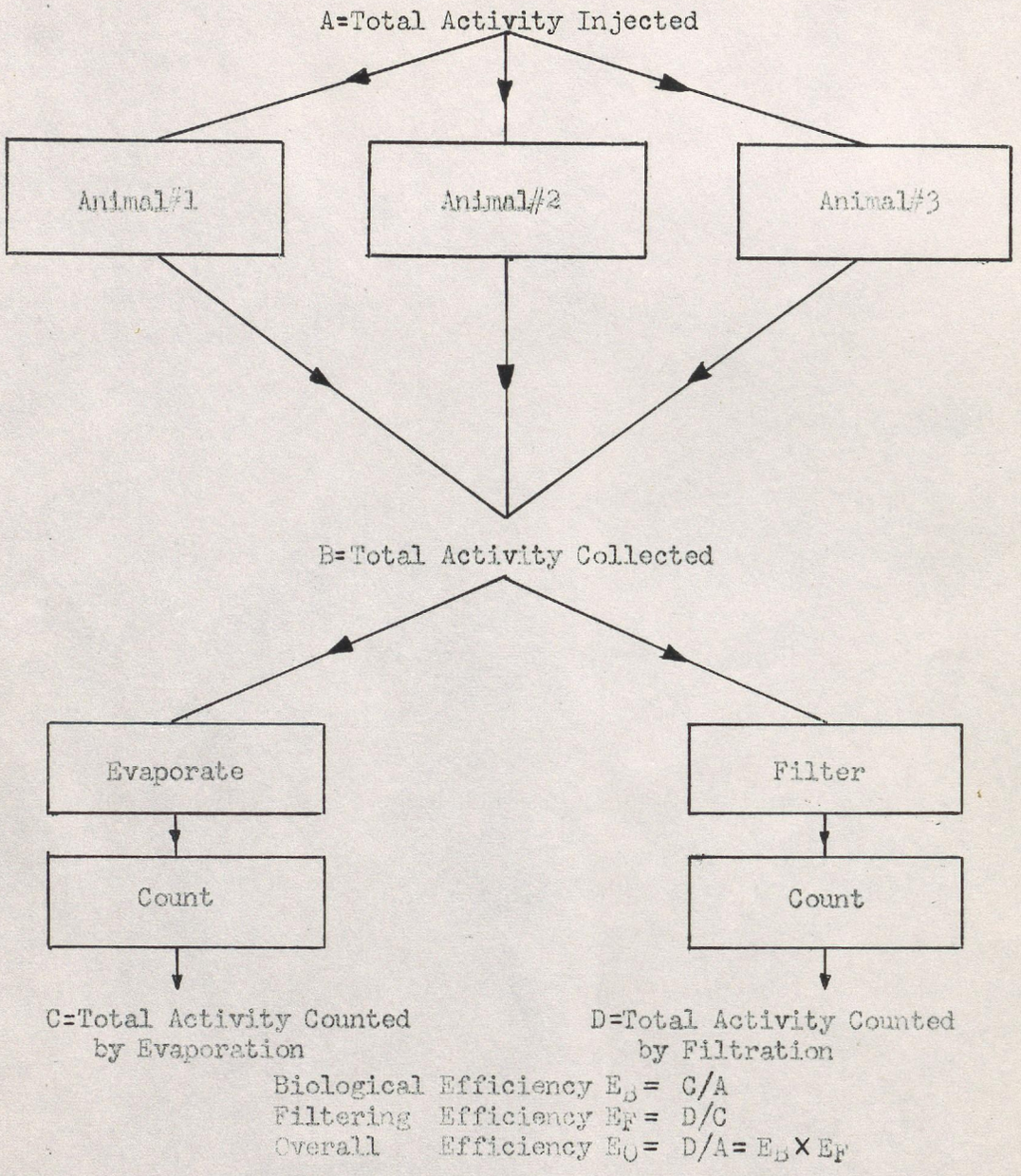


Figure 5.-Process Flow Sheet

The method of calculating the measured activities from the evaporated and filtered samples is contained in Appendix I and the summary of the Statistical Analysis used to determine the significance of the measured activities is contained in Appendix II.

D. Experimental Runs

The first experimental animal run consisted of injecting three animals intraperitoneally with a total volume of 25 cc of reactor coolant. A pooled sample of 22 cc of urine was collected after four and one half hours. These animals were fasted for eight hours prior to and during the experiment and were hydrated prior to the experiment which was performed in an air-conditioned room.

The second and third animal experiments consisted of nine animals each; three in each experiment contaminated intraperitoneally, intrapulmonarily and orally. These animals were fasted for eight hours prior to and during the experiment, were hydrated prior to and during the experiment and were restricted to an air-conditioned room. The complete schedule (body weights, isotope doses, hydrating

times and sampling times) for the second and third animal experiments are contained in Tables 3 and 4 respectively.

Time			0830	1100	1100	1130	1330	1330	1700	1100
Animal	Body-Weight gms	Isotope Mode	Water Dose cc	Collect Bkgd	Water Dose cc	Isotope Dose* cc	Water Dose cc	Sample	Sample	Sample
1	200	0	4.0		4.0	0.5	4.0	01	02	03
2	240	0	4.8		4.8	0.6	4.8	01	02	03
3	235	0	4.7		4.7	0.59	4.7	01	02	03
4	240	IP	4.8		4.8	0.6	4.8	P1	P2	P3
5	235	IP	4.7		4.7	0.59	4.7	P1	P2	P3
6	240	IP	4.8		4.8	0.6	4.8	P1	P2	P3
7	240	L	4.8		4.8	0.6	4.8	L1	L2	L3
8	200	L	4.0		4.0	0.5	4.0	L1	L2	L3
9	200	L	4.0		4.0	0.5	4.0	L1	L2	L3

Table 3.

*$\bar{A} = 9.34 \times 10^{-3}$ uc/cc

Procedure for Second Animal Experiment

Time			0930	1000	1030	1630	2030	2145	0830	1030
Animal	Body-Weight gms	Isotope Mode	Water Dose cc	Collect Bkgd	Isotope* Dose cc	Water Dose cc	Sample	Water Dose cc	Water Dose cc	Sample
1	240	0	7.2		1	7.2	01	7.2	4.8	02
2	240	0	7.2		1	7.2	01	7.2	4.8	02
3	210	0	6.3		1	6.3	01	6.3	4.2	02
4	240	IP	7.2		1	7.2	P1	7.2	4.8	P2
5	220	IP	6.6		1	6.6	P1	6.6	4.4	P2
6	240	IP	7.2		1	7.2	P1	7.2	4.8	P2
7	210	L	6.3		0.83	6.3	L1	6.3	4.2	L2
8	220	L	6.6		1	6.6	L1	6.6	4.4	L2
9	230	L	6.9		1	6.9	L1	6.9	4.6	L2

*$\bar{A} = 3.08 \times 10^{-3}$ uc/cc

Table 4.

Procedure for Third Animal Experiment

SECTION V

EXPERIMENTAL RESULTS

A. First Animal Experiment

The results of the first animal experiment are presented in Table 5. The overall efficiency (E_O) of the system for a sample collecting time of four and one half hours after the radioactivity had been injected intraperitoneally was measured to be 0.53%. The initial injected activity for this run was approximately 2.5×10^{-3} uc. The results were based on a confidence level higher than $\Delta\sigma^4$ as calculated by the statistical analysis summarized in Appendix II. The measured biological efficiency (E_B) was 9.05% and the measured filtering efficiency (E_F) was 5.84% for the 800 mu filter paper.

Item	Sample	Counting Time -min.	Total Counts -c	Activity -c/m	Confidence Level -σ	Filtering Time	Activity -uc/cc
1	Background	5	51	10.2	-	-	-
2	Background of 2 cc evaporated animal urine	5	74	14.8	-	-	-
3	Background of 20cc filtered animal urine-800mu filter	20	372	18.6	-	4 min	-
4	2cc evaporated sample	20	531	26.6	4.1	-	1.01×10^{-5}
5	20cc filtered sample-800mu filter	20	509	25.5	3.4	35 sec	0.59×10^{-6}

IP injected activity - uc	2.45×10^{-3} ($25cc@0.98 \times 10^{-4}$)	Sample Volume - cc	22
Evaporated Activity - uc	2.21×10^{-4}	Filtered Activity - uc	1.3×10^{-5}

E_B	9.05%	E_F	5.9%	E_O	0.53%

Table 5.

Results of First Animal Experiment

B . Second Animal Experiment

A summary of the results of the second animal experiment is presented in Table 6. and the data is contained in Appendix IV. The measured overall system efficiencies(E_O) were in decreasing order; 1.21% for IP, 0.91% for L and 0.365% for O. The measured biological efficiencies (E_B) followed the same order and were; 29.7% for IP, 24.7% for L and 8.75% for O. The measured filtering efficiencies were approximately the same for the three methods, 3.95% $\pm$ .30%.

Curves of the measured total activity (in microcuries) and the measured concentration of activity (in microcuries per cubic centimeter) as a function of time after contamination are shown in Figures 6. and 7.

Isotope Mode	Oral			IP			Lung		
Injected Activity - uc	1.58×10^{-2}			1.67×10^{-2}			1.49×10^{-2}		
Sample	01	02	03	P1	P2	P3	L1	L2	L3
Volume - cc	8.5	15	14.5	10.5	11	32	-	14.5	25
Evaporated Activity - uc/cc	$4.61_5 \times 10^{-5}$	$4.29_5 \times 10^{-5}$	$3.61_5 \times 10^{-5}$	$1.79_4 \times 10^{-4}$	$1.36_4 \times 10^{-4}$	$4.94_5 \times 10^{-5}$	-	$1.85_4 \times 10^{-4}$	$4.43_5 \times 10^{-5}$
Evaporated Activity - uc	$3.92_4 \times 10^{-4}$	$5.58_4 \times 10$	$5.22_4 \times 10^{-4}$	$1.88_3 \times 10^{-3}$	$1.5_3 \times 10^{-3}$	$1.58_3 \times 10^{-3}$	-	$2.58_3 \times 10^{-3}$	$1.11_3 \times 10^{-3}$
Filtered Activity - uc/cc	$8.01_7 \times 10^{-7}$	$6.70_7 \times 10^{-7}$	$3.06_6 \times 10^{-6}$	$2.69_6 \times 10$	$4.4_6 \times 10^{-6}$	$3.9_6 \times 10^{-6}$	-	$3.47_6 \times 10^{-6}$	$3.38_6 \times 10^{-6}$
Filtered Activity - uc	$6.8_6 \times 10^{-6}$	$8.7_6 \times 10^{-6}$	$4.55_5 \times 10^{-5}$	$2.83_5 \times 10^{-5}$	$4.84_5 \times 10^{-5}$	$1.25_4 \times 10^{-4}$	-	$5.03_5 \times 10^{-5}$	$8.42_5 \times 10^{-5}$
E_B	2.48%	3.52%	3.31%	11.2%	8.97%	9.45%	-	17.3%	7.46%
E_F	1.73%	1.51%	8.72%	1.5%	3.23%	7.9%	-	1.95%	7.6%
E_O	0.043%	0.05%	0.29%	0.16%	0.29%	0.75%	-	0.34%	0.57%
E_B	8.75%			29.7%			24.7%		
E_F	4.15%			4.06%			3.65%		
E_O	0.365%			1.21%			0.91%		

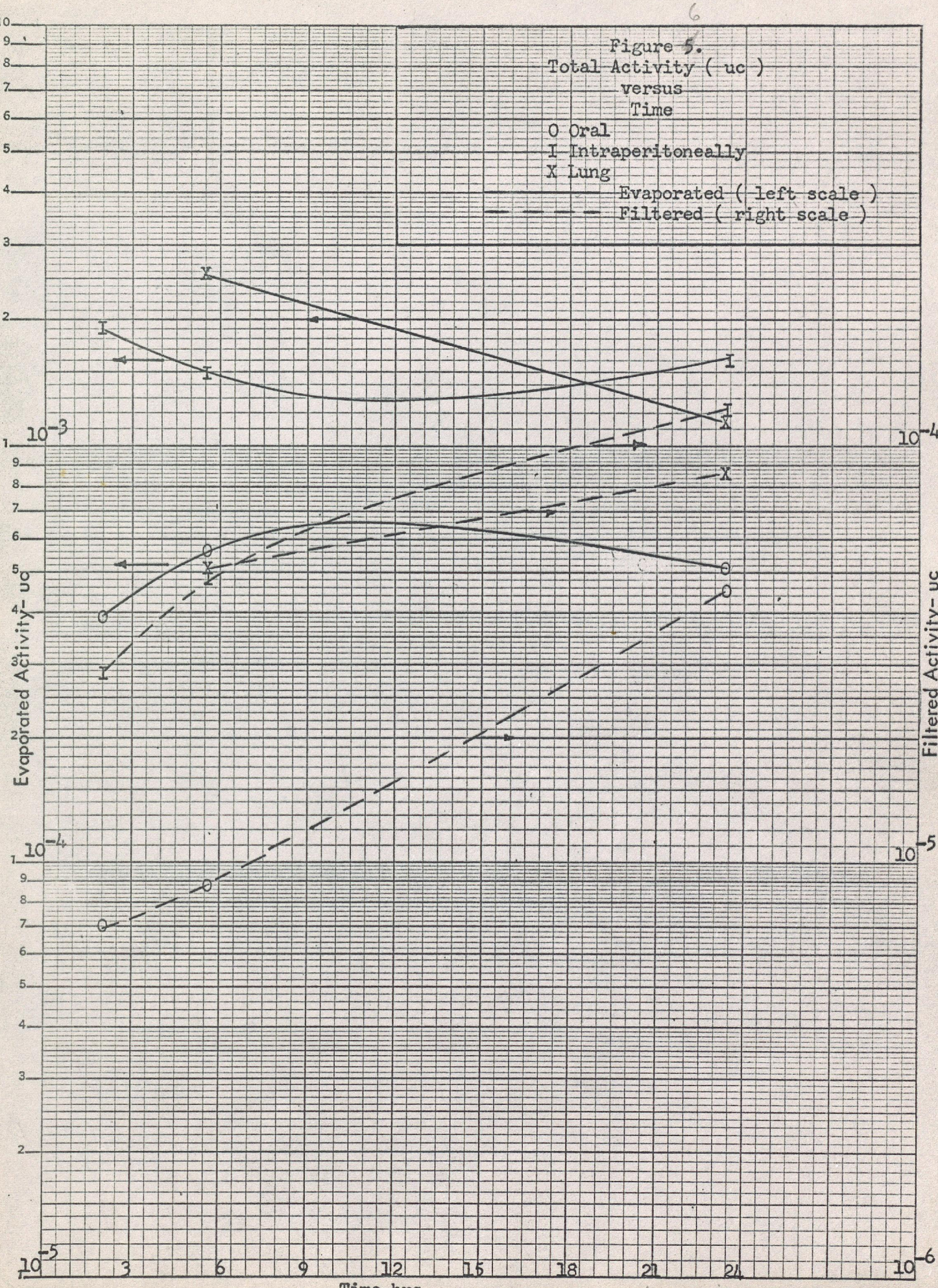
Table 6.

Results of Second Animal Experiment

Figure 5.
Total Activity (uc)
versus
Time

O Oral
I Intraperitoneally
X Lung

——— Evaporated (left scale)
— — — — Filtered (right scale)



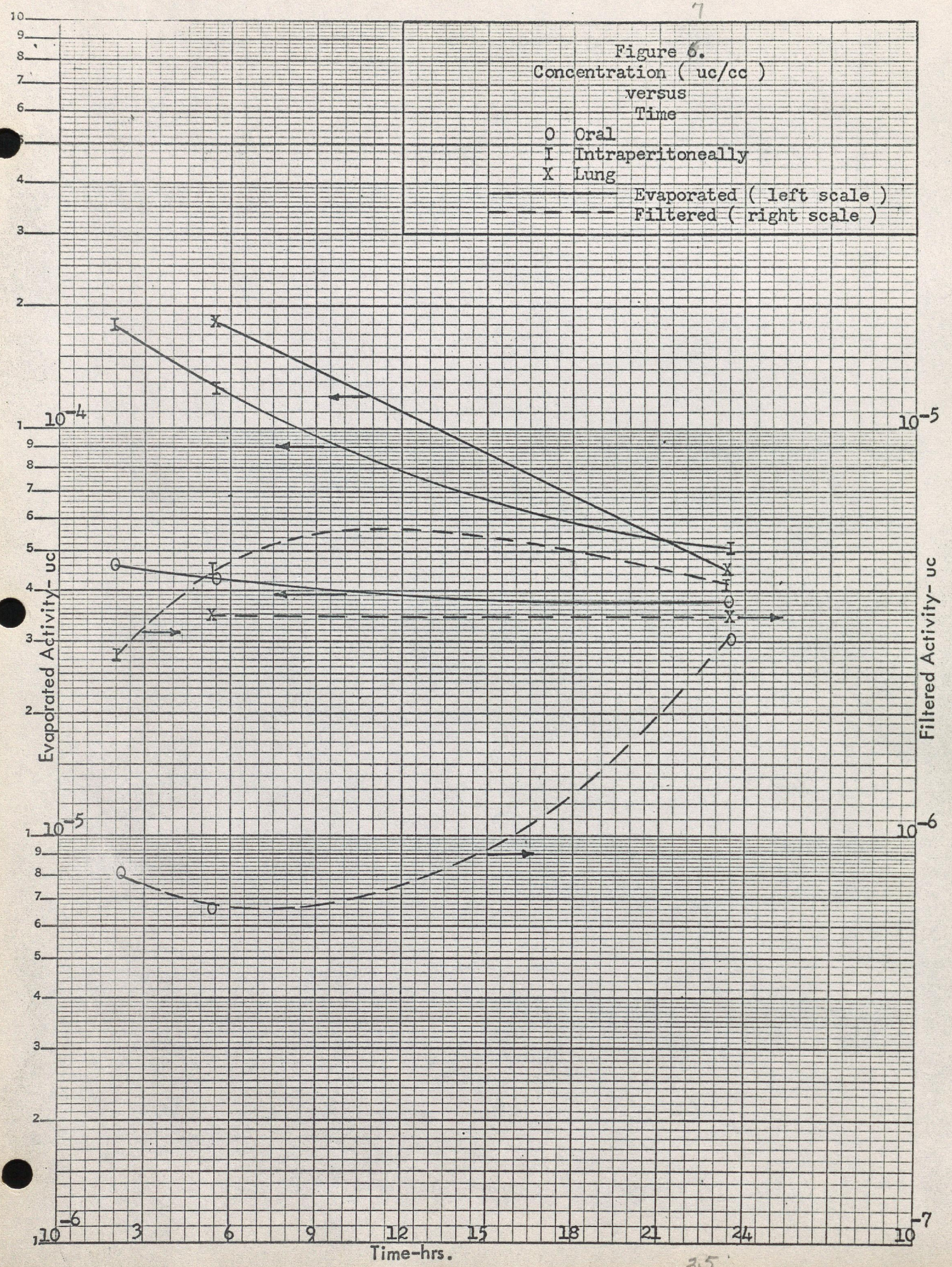


Figure 6.
Concentration (uc/cc)
versus
Time
O Oral
I Intraperitoneally
X Lung
Evaporated (left scale)
Filtered (right scale)
Evaporated Activity- uc
Filtered Activity- uc
Time-hrs.
10^-4
10^-5
10^-6
10^-7
3
6
9
12
15
18
21
24

C. Third Animal Experiment

A summary of the results of the third animal experiment is presented in Table 7. and the data is contained in Appendix IV. The measured overall system efficiencies (E_O) were in decreasing order; 2.45% for IP, 0.66% for L and 0.396% for O. The measured biological efficiencies (E_B) were; 5.13% for IP, 2.08% for L and 2.51% for O. The measured filtering efficiencies(E_F) varied by as much as a factor of 1.5 from the mean of 32% and were; 48% for IP, 31.4% for L and 15.7% for O.

Isotope Mode	Oral		IP		Lung	
Injected Activity- uc	9.24×10^{-3}		9.24×10^{-3}		8.7×10^{-3}	
Sample	O1	O2	P1	P2	L1	L2
Volume- cc	16	24	29	38.5	19	33
Evaporated Activity -uc/cc	$5.59_6 \times 10^{-6}$	$5.94_6 \times 10^{-6}$	$1.03_5 \times 10^{-5}$	$4.54_6 \times 10^{-6}$	$7.02_6 \times 10^{-6}$	1.4×10^{-6}
Evaporated Activity - uc	$8.94_5 \times 10^{-5}$	1.43×10^{-4}	3.0×10^{-4}	1.75×10^{-4}	1.34×10^{-4}	$4.62_5 \times 10^{-5}$
Filtered Activity - uc/cc	$1.74_6 \times 10^{-6}$	$3.68_7 \times 10^{-7}$	$7.21_6 \times 10^{-6}$	$4.83_7 \times 10^{-7}$	$2.46_6 \times 10^{-6}$	$2.96_7 \times 10^{-7}$
Filtered Activity - uc	$2.78_5 \times 10^{-5}$	$8.83_6 \times 10^{-6}$	2.1×10^{-4}	$1.86_5 \times 10^{-5}$	$4.68_5 \times 10^{-5}$	$9.75_6 \times 10^{-6}$
E_B	0.97%	1.55%	3.2%	1.89%	1.54%	0.53%
E_F	31%	6.1%	70%	10.6%	34.2%	21%
E_O	0.3%	0.096%	2.24%	0.2%	0.54%	0.12%
E_B	2.51%		5.13%		2.08%	
E_F	15.7%		48%		31.4%	
E_O	0.396%		2.45%		0.66%	

Table 7.

Results of Third Animal Experiment

SECTION VI

DISCUSSION AND CONCLUSIONS

A. First Animal Experiment

The first animal experiment, which was designed as a test of the effectiveness of the proposed method, consisted of contaminating three animals intraperitoneally (IP). IP was chosen because it was considered that it would give the largest excretion of radioactivity and thereby determine quickly if the method had merit.

The results of the experiment which are presented in Table 5 showed that the method was practicable and effective. The overall efficiency (E_O) of the system was measured to be 0.53% based on an initial injected activity of 2.45×10^{-3} uc, a sample collecting time of four and one-half hours and a statistical confidence level of greater than 4 σ.

The measured biological efficiency (E_B) which represents the percentage of the injected activity that is excreted in four and one-half hours was 9.05%. The measured filtering efficiency (E_F) of 5.84% for the 800 mu paper was considerably less than the average filtering efficiency

of 49.5% (Table 2.) for straight reactor coolant. This result proves, as postulated in Section IV B., that the proposed bio-assay method could not be evaluated by merely mixing reactor coolant with urine and that the reactor coolant would have to be injected into mammals to account for the actual effects of the body. The reason for the low filtering efficiency may be due to the fact that a high percentage of the large-sized particles which are easiest to filter were retained in the body.

Even though the filtering efficiency was not very large, the method was able to conclusively detect excreted activity from an injected activity of 2.45×10^{-3} uc which is considerably less than a body burden of 10 uc for cobalt 60.

B. Second Animal Experiment

The second animal experiment consisted of contaminating three animals by each of the three methods, intraperitoneally (IP), intrapulmonarilly (L) and orally (O). The results which are presented in Table 6. show that the mammals excreted radioactivity in decreasing order of activity from the IP, L and O methods of contamination. This confirms an a priori evaluation of the three methods which have an

increasing number of body membranes for the radioactivity to pass through for the IP, L and O processes.

The overall filtering efficiencies (E_F) for the twenty-four hour period were measured to be approximately the same (3.95% $\pm$ .25%) for the three processes. This may indicate that the body assimilated and treated the radioactive particles in the same manner according to the particle size regardless of the mode of cantamination, even though each mode exhibited a different rate of excretion (E_B). The filtering efficiency of each method increased with time after the simulated exposure. This implies that the smaller-sized particles tend to be absorbed faster and therefore excreted sooner from the body than the larger-sized particles. The latter, of course, have a higher filtering efficiency due to the small pore size of the filter paper.

The overall efficiencies (E_O) follow the same pattern as the biological efficiencies (E_B) and each process has a measured overall efficiency (E_O) that is different, namely 1.21% for IP, 0.91% for L and 0.365% for O. Although the overall system efficiencies are not large, these must be evaluated realizing that the total injected activity was only about 1.5×10^{-2} uc which represents much less than 1.0%

of a body burden (10uc) of cobalt 60 for a human.

Curves of the measured total activity (in microcuries) and the measured concentration (in microcuries per cubic centimeter) for the three processes as a function of time are shown in Figures 6. and 7. Both these curves show that the total activity and the concentration of activity measured by the evaporation method decrease with time; but, more significantly, since the filtering efficiency increases with time, the total activity and the concentration of activity measured by the filtration method increases with time. Therefore, the filtration method according to the times measured in this second experiment (Table 3) is most efficacious when the urine samples to be analyzed consist of the voids from 5 1/2 to 23 1/2 hours after the exposure.

C. Third Animal Experiment

The third animal experiment also consisted of contaminating three animals by each of the three methods, intraperitoneally (IP), intrapulmonarilly (L) and orally (O). The results, which are presented in Table 7., confirmed the determination in the second animal experiment that the mammals excreted radioactivity in decreasing order of ac-

tivity from the IP, L and O processes.

The overall efficiencies (E_O) measured during this experiment were, 2.45% for IP, 0.66% for L and 0.396% for O. The biological efficiencies (E_B) varied in approximately the same ratio as the overall efficiencies (E_O). The filtering efficiencies (E_F) however, varied by as much as a factor of 1.5 from the mean value of 32%.

This experiment which consisted of collecting samples from different time intervals than the first experiment showed that the bio-assay method is most efficacious when the samples are collected during the first ten hours after the exposure.

D. Combined Results

A summary of the results of all the animal experiments is contained in Table 8. The reproducibility of the overall system efficiencies (E_O) for comparable sample collecting times appears to be quite good. The overall efficiency of the first IP experiment of 0.53% for a four and one-half hour sample compares very well with the overall efficiency of the second IP experiment of 0.46% for a combined five

	Mode	0-4½ hr. sample									Totals		
Expt. #1		E_B	E_F	E_0							E_B	E_F	E_0
	IP	9.05%	5.84%	0.53%							9.05%	5.84%	0.53%
	Mode	0-2 hr. sample			2-5½ hr. sample			5½-23½ hr. sample					
		E_B	E_F	E_0	E_B	E_F	E_0	E_B	E_F	E_0	E_B	E_F	E_0
Expt. #2	IP	11.2%	1.5%	0.17%	8.97%	3.23%	0.29%	9.45%	7.9%	0.75%	29.7%	4.06%	1.21%
	O	2.48%	1.73%	0.04%	3.52%	1.51%	0.05%	3.31%	8.72%	0.29%	8.75%	4.15%	0.365%
	L	-	-	-	0-5½ hr. sample 17.3%	1.95%	0.34%	7.46%	7.6%	0.57%	24.7%	3.65%	0.91%
	Mode		0-10 hr. sample			10-24 hr. sample							
			E_B	E_F	E_0		E_B	E_F	E_0		E_B	E_F	E_0
Expt. #3	IP		3.2%	70%	2.24%		1.89%	10.6%	0.2%		5.13%	48%	2.45%
	O		0.97%	31%	0.3%		1.55%	6.1%	0.096%		2.51%	15.7%	0.396%
	L		1.54%	34.2%	0.54%		0.53%	21%	0.12%		2.08%	31.4%	0.66%

Table 8. Combined Results

and one half hour sample. The overall efficiencies based on the total activity measured in the two twenty-four hour experiments were 1.83% $\pm$ .62% for IP, 0.78% $\pm$ .12% for L and 0.38% $\pm$ .02% for O. These results confirm that there are distinct differences in the body's reaction to activity injected by the three processes and that the contamination process can be easily identified.

Although the overall efficiencies (E_O) compared very well, there were large differences in the biological (E_B) and filtering (E_F) efficiencies between the second and third experiments. These differences are probably not due to the differences in concentration of the radioactivity used in the two experiments (approximately 1×10^{-2} uc/cc and 3×10^{-3} uc/cc for the second and third experiments, respectively) because the body's reactions should proceed in the same manner for each concentration. The most probable reason for the differences in E_B and E_F is that the chemistry control of the reactor plant, from which the samples were obtained, was modified between the time the samples were obtained for the second and third experiments. The change consisted of operating the reactor with higher pH chemistry control (10) which would result in more

insoluble but less total corrosion and wear products. This change probably resulted in a higher percentage of large-sized particles in the third experiment than the second experiment.[10] Hence, in the second experiment the measured biological efficiencies (ΔB) were large while the measured filtering efficiencies (ΔF) were small because of the high percentage of small-sized particles. However, for the third experiment, the measured biological efficiencies (ΔB) were small, because it is not as easy for the large-sized particles to pass through the body, while the measured filtering efficiencies (ΔF) were high. It was not possible to evaluate these changes in detail, but more important it was not necessary because the overall efficiencies of the processes were very reproducible even with the differences in particle size due to the changes in chemistry control and the differences in concentration of the coolant. This is very important because all pressurized-water reactor plants would have different operating histories and variations in chemistry control prior to an accident. Since these factors had very little effect on the limited amount of experimentation performed, the method was shown to be effective and practicable for performing a quick and accurate determination

of the significance of any internal contamination.

The results of the second experiment show that the overall efficiencies for all the three processes were greatest for the samples collected between 5 1/2 and 23 1/2 hours after the exposure. Since the third experiment had the highest overall efficiencies for the samples collected during the first 10 hours, the combined results indicate that the method would be most effective if the samples were collected during the period approximately 6 to 12 hours after the incident. Although the experiments were only performed during the first day, the above conclusion is considered valid since the literature (9, 12) does not contain cases where the activity excreted per unit time increases beyond the first day and a half.

E. Filter Evaluation

The reference method used in all the three experiments consisted of the 800 mu filter paper. During the second animal experiment, the 300 mu filters were measured to be 27% more efficient for straight coolant than the 800 mu filters. However, measurements made during the second animal experiment

using radioactive urine (lung method only) showed that the 300 mu filters were only 17% more efficient than the 800 mu filters. These slight differences in filtering efficiencies are not considered significant enough to justify the longer filtering times associated with the 300 mu filters not to compare with the large biological differences to which the system is inherently subjected.

The filtering efficiencies measured during the experiments cannot be interpreted to mean that the same percentage of the activity consists of particles of greater than 800 mu size. Rather, it should be considered that the filter is trapping some insoluble activity that consists of particles greater than 800 mu size, and other soluble and insoluble material by methods such as surface tension effects, absorption, adsorption, electrical effects causing repulsive and attractive forces, and mechanical reductions in the pore sizes due to the sediments contained in urine.

F. Evaluation of Results

The results of all the experiments performed showed that it was possible, using the reference method for sampling periods during the first twenty-four hours after a reactor

incident, to detect approximately 0.5% to 2.5% of the total activity injected. The total activity in the cases tested varied between 2.5×10^{-3} uc to 1.5×10^{-2} uc. Hence, it can be concluded that it is possible to detect less than a body burden of radioactivity based on assuming that cobalt-60 which has a body burden of 10 uc, is the predominant radionuclide in reactor coolant. To determine exactly what percentage of a body burden can be detected by the system is not amenable to rigorous analysis. However, the following two approaches are possible.

First, we can determine the minimum sensitivity of the system or the activity in human urine which can be counted by the reference method and considered statistically significant. This calculation is performed in Appendix III and the minumum activity in urine which can be detected with $3\sqrt{}$ confidence by the system is 2.5×10^{-6} uc/cc. Now, the literature (12) contains a single case of cobalt 60 contamination which was completely evaluated. It was determined by whole-body counting that the two persons contaminated had each inhaled 0.5 uc of cobalt 60. During the first day after the incident the activity in the urine was 2 to 3 $\times 10^{-5}$ uc/cc. Since the body burden

for cobalt 60 is 10 uc, our minimum system sensitivity of 2.5×10^{-6} uc/cc is equivalent to being able to detect 0.5% of a body burden. This conclusion is independent of any relationship between the mammals used in the experiments and man since it is based on the physical limitations of the counting system and actual human results from the literature.

Secondly, we can determine an approximate relationship between man and the mammals used in the experiment. The dosage required to give the same number of uc/gm would be an inverse ratio to the weights of the two species. The ratio of the volumes of urine excreted in a day from each of the two species, would form a dilution factor. The above two items combined with the biological correlation factor (13) between Sprague-Dawley rats and man of approximately six to seven will form our relationship factor.

Hence, $\frac{\text{rat}}{\text{man}} = \frac{200\text{gms(rat)}}{60{,}000\text{gms(man)}} \times \frac{2000\text{ cc(man)}}{40\text{ cc(rat)}} \times 6$ [illegible].

Therefore, the foregoing calculation suggests that the relationship between rats and man is approximately one. Since our system was able to detect a total injected activity (O or L) of approximately 1.0×10^{-2} uc, this is equivalent to being

able to detect approximately 0.1% of a body burden. This rough estimate then compares favorably with the previous determination. As is the case in all biological studies, the method should be tested in humans if practicable.

SECTION VII

SUMMARY

The bio-assay method evaluated in this project consists of vacuum filtering urine samples obtained during the first twenty-four hours after an internal body exposure to beta-gamma radionuclides in the reactor coolant from pressurized water reactors. The filters are 800 mu pore size which are counted in a Geiger-Mueller counting system that includes a lead-shielded detecting element. The method was evaluated by contaminating mammals with reactor coolant from a pressurized water reactor and assuming that the coolant consisted primarily of cobalt 60.

The major conclusions of the work are summarized as follows:

1. The reproducibility of the overall efficiency of the method (1.83% ± .62% for activity injected intraperitoneally, 0.78% ± .12% for activity injected intrapulmonarilly, and 0.38% ± .02% for activity injected orally) for a period of 24 hours after the exposure appeared to be quite good. This was true for the three animal runs which accounted for different animals different

concentrations of the reactor coolant and different distribution of particle sizes in the reactor coolant. The latter condition affected the biological and filtering efficiencies but not the overall system efficiency; that is, the coolant with a high percentage of large-sized particles resulted in lower biological efficiency but a higher filtering efficiency than the coolant with a high percentage of small-sized particles.

2. The overall system efficiencies were measured to be highest during the time interval approximately six to twelve hours after the similated internal body exposure. The system would therefore be most efficacious if the samples were obtained during that time interval.

3. The 800 mu filter paper was determined to be the most useful since it permitted larger sample volumes to be filtered many times faster and showed only approximately 17% less filtering efficiency than the 300 mu filter paper.

4. The minimum concentration of radioactivity in urine that can be detected by the counting system (Appendix III) is 2.5×10^{-6} uc/cc. Based on the cobalt 60 body burden of 10 uc, the bio-assay method is

capable of detecting approximately 0.5% of a body burden.

Because the method was devised to provide a rapid method for initially evaluating possible significant amounts of internal contamination, detailed studies to improve all aspects of the method are not warranted. It is considered to be practical and useful in its present form for initially evaluating cases of possible internal contamination. However, some aspects might be studied further. An additive or "wetting" agent that will allow faster filtering may be helpful since the filtering times will vary considerably. In conjunction with this a higher vacuum filtering system might be investigated. Also, more studies with animals could be performed to determine the exact time after the incident when the filtering efficiency and biological efficiency produce the highest overall system efficiency. As is the case in all biological studies, the method should be tested in humans if practicable.

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APPENDIX I

Calculation of Activities

For activity counted by the Geiger-Mueller system (11)

$$A = (C - B) \times \frac{1}{V} \times 4.5 \times 10^{-7} \times \frac{S_o}{S_1 - B}$$

where A = measured activity in uc/cc

B = background in c/m

C = measured activity (sample plus background) in c/m

S_o = activity of calibrated source in d/m

S_1 = measured acyivity of calibrated sources in c/m

$\frac{S_o}{S_1 - B}$ = counting efficiency of G-M system = 3.88 d/m per c/m

4.5×10^{-7} = uc per d/m (1C = 3.7×10^{10} d/s)

V = volume of sample in cc

For 2cc evaporated samples:

$$A = (C - B) \times \frac{1}{2} \times 4.5 \times 10^{-7} \times \frac{S_o}{S_1 - B} \text{ uc/cc}$$

$$A = (C - B) \times 8.73 \times 10^{-7} \text{ uc/cc}$$

For filtered samples:

$$A = (C - B) \times \frac{1}{V} \times 1.74 \times 10^{-6} \text{ uc/cc}$$

APPENDIX II

SUMMARY OF STATISTICAL ANALYSIS

The fundamental problem of low level counting is to obtain the desired degree of statistical precision in a minimum period of time. Low-level counting can be defined as the determination of such small amounts of radioactivity that the counting statistical error is the factor limiting the attainable precision. This usually implies that the net count rate obtainable from the sample is smaller than the background rate, or at least, not greatly larger than it. Since the background and the sample counting rates are random processes, they obey the usual random error law, that is the Poisson Distribution Law (14). According to this law, fundamental to all calculations of counting errors, the standard deviation of a count is given by the square root of the total number of events observed.

$$\sigma = \sqrt{N} = \sqrt{r\,t}$$

σ = the standard deviation

N = total events recorded

r = average rate

t = counting time