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HEALTH PHYSICS DIVISION

SEMIANNUAL PROGRESS REPORT

FOR PERIOD ENDING JANUARY 31, 1956

OAK RIDGE NATIONAL LABORATORY
U.S. ATOMIC ENERGY COMMISSION

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HEALTH PHYSICS DIVISION SEMIANNUAL PROGRESS REPORT

APPLIED RADIOBIOLOGY

E. G. Struxness

DISTRIBUTION AND EXCRETION OF URANIUM IN MAN

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In a continuation of the study[1] of the distribution and excretion of uranium in man, all the urine, blood, and feces samples from patients VII and VIII, who were injected with uranium tetrachloride (UCl_4), have been analyzed. In addition, the analyses of autopsy samples taken from patients III and VIII have been completed.

Detailed statistical analyses of the distribution and excretion data on the patients (I through VI) injected with U(VI) were started during this period in order to obtain the best set of parameters to represent the data. One of the statistical methods used is the regression test of linearity[2] applicable to data such as decay curves when several measurements are taken at a given time. The test is simple; the variance within measurements is compared to the variance between the data and the best fitting regression curve by the F ratio test, and, if this variance is significantly different, the data are said to depart significantly from a regression curve. When this procedure was applied to excretion data of patients I, II, III, IV, V, and VI where the linear version of the power function $At^b (b < 0)$ was assumed, it was concluded that the data were not best described by this function. It is interesting to know that when the same test was applied to plutonium urinary excretion data[3] there was no significant departure from linear regression.

The per cent of injection dose per 10^4 g of bone (autopsy samples) for patients I, II, III, V, and VI is plotted in Fig. 1. The graph, which includes all the individual analyses, shows a wide range of concentrations. If a single exponential is assumed to be representative of these data and if the linearity test (*vide supra*) is applied, the data depart significantly from this function. The value of the intercept is 3.8×10^{-4}% of injected dose per gram and the half life is 241 days. Functions other than the single exponential term, for example, $(a + bt)^{-2}$, were similarly tested without success.

It is suggested that these data can be represented by letting λ in the function $\epsilon^{-\lambda t}$ vary with time. The following procedure shows that this is true: (1) assume a single exponential term; (2) calculate the half life from bone biopsy and autopsy values for each patient; and (3) plot this calculated half life vs the time of expiration. The calculated half lives of step 2 are listed in Table 1. Note the significant difference between

[1] S. R. Bernard *et al.*, *HP Semiann. Prog. Rep. July 31, 1955*, ORNL-1942, p 1.

[2] W. J. Dixon and F. J. Massey, *Introduction to Statistical Analysis*, p 160–161, McGraw-Hill, New York, 1951.

[3] W. H. Langham *et al.*, *Distribution and Excretion of Plutonium Administered Intravenously to Man*, LA-1151 (Sept. 20, 1950), p 24–25.

TABLE 1. BIOLOGICAL HALF LIVES OF U(VI) IN BONE – BIOPSY AND AUTOPSY SPECIMENS

	Patient Number				
	I	VI	II	V	III
	Expiration Time (days)				
	2.5	18	74	139	566
Biological half life and standard deviation (days)	2.3 ± 0.56	15.1 ± 6.24	17.1 ± 6.89	44.4 ± 6.83	222.1 ± 68.3

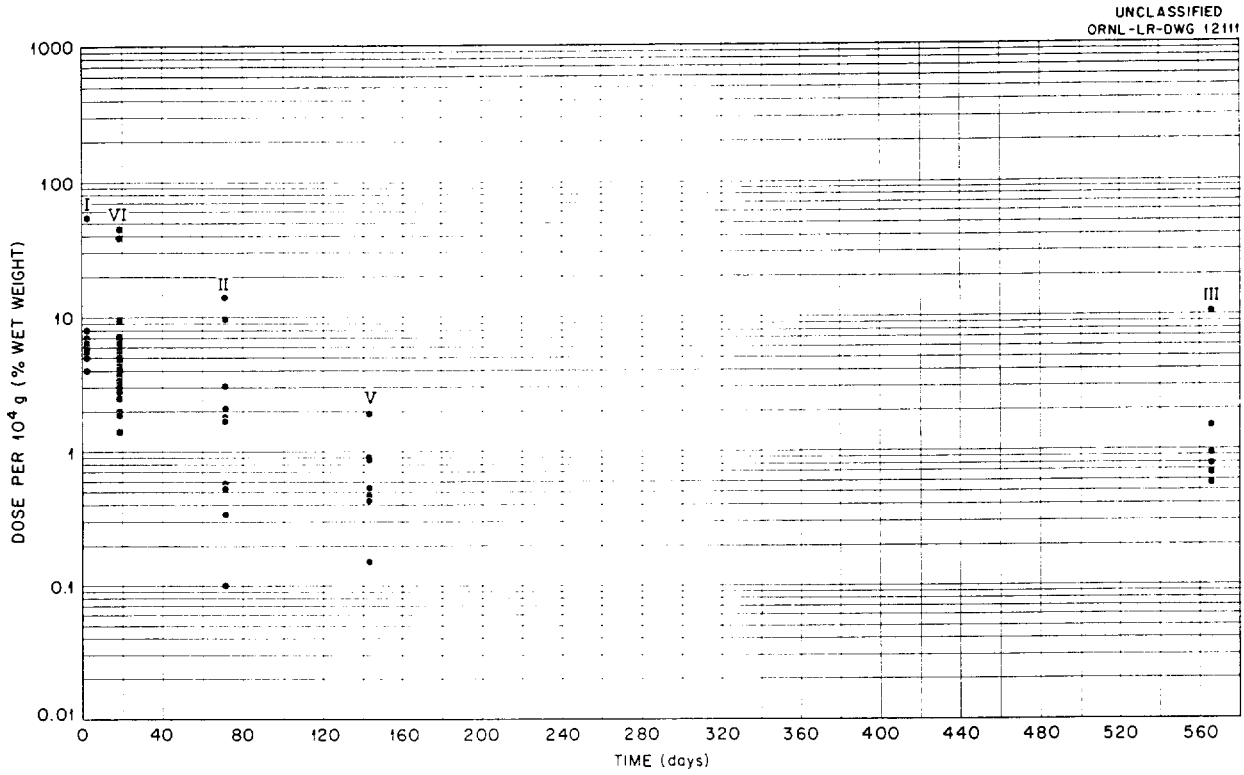

Fig. 1. Plot of Individual Bone Autopsy Results for Five Patients Injected with U(VI).

the patients. The graph of step 3 is shown in Fig. 2, where the half life is seen to increase in proportion to $t^{4/5}$.

Other data which have important application to the calculations of maximum permissible concentrations (MPC) for uranium are those contained in Tables 2 and 3 and Fig. 3. Table 2 shows that (1) the different samples of bone reflect different mean concentrations; (2) the U(IV) autopsy bone concentrations are very similar to U(VI); and (3) the samples of the femur are the lowest in concentration, while the vascular bone, rib, is highest in the early stages after injection and the skull concentration is highest at later stages. Figure 3 is a diagram of the uranium concentrations in a longitudinal plane sectioned from the distal end of the femur. The section, approximately ¼ in. thick, was cut into smaller sections and each section was analyzed for uranium. The numbers in each section are the concentrations in counts per minute per gram of bone. In general, it may be said that the concentrations decrease in the direction of the shaft.

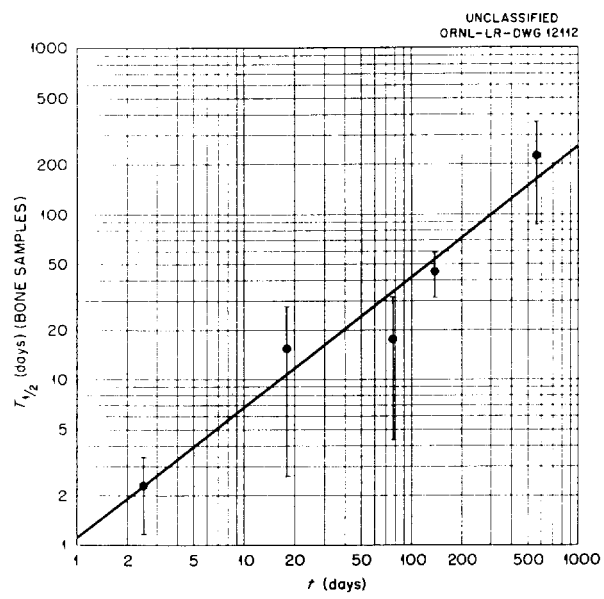

Fig. 2. Plot of Biological Half Life of U(VI) in Bone Determined from Femur Autopsy and Biopsy Samples vs Time of Autopsy.

TABLE 2. BONE AUTOPSY DATA – PER CENT OF INJECTED DOSE PER 7000 g

Patient No.*	Postinjection Time (days)	Sample					Mean
		Femur	Rib	Skull	Sternum	Vertebra	
		Injection: $UO_2(NO_3)_2 \cdot 6H_2O$					
I	2½	4.1	13.8	5.5		37.7	14.0
VI	18	3.3	29.5				16.3
II	74	0.4	1.8	8.3	0.4	1.3	2.4
V	139	0.4	0.6	1.3			0.8
III	566	0.6	0.6	7.4	1.1	0.4	2.0
		Injection: UCl_4					
VIII	21	0.6	27.5			15.1	14.4

*No autopsy data obtained for patients IV and VII.

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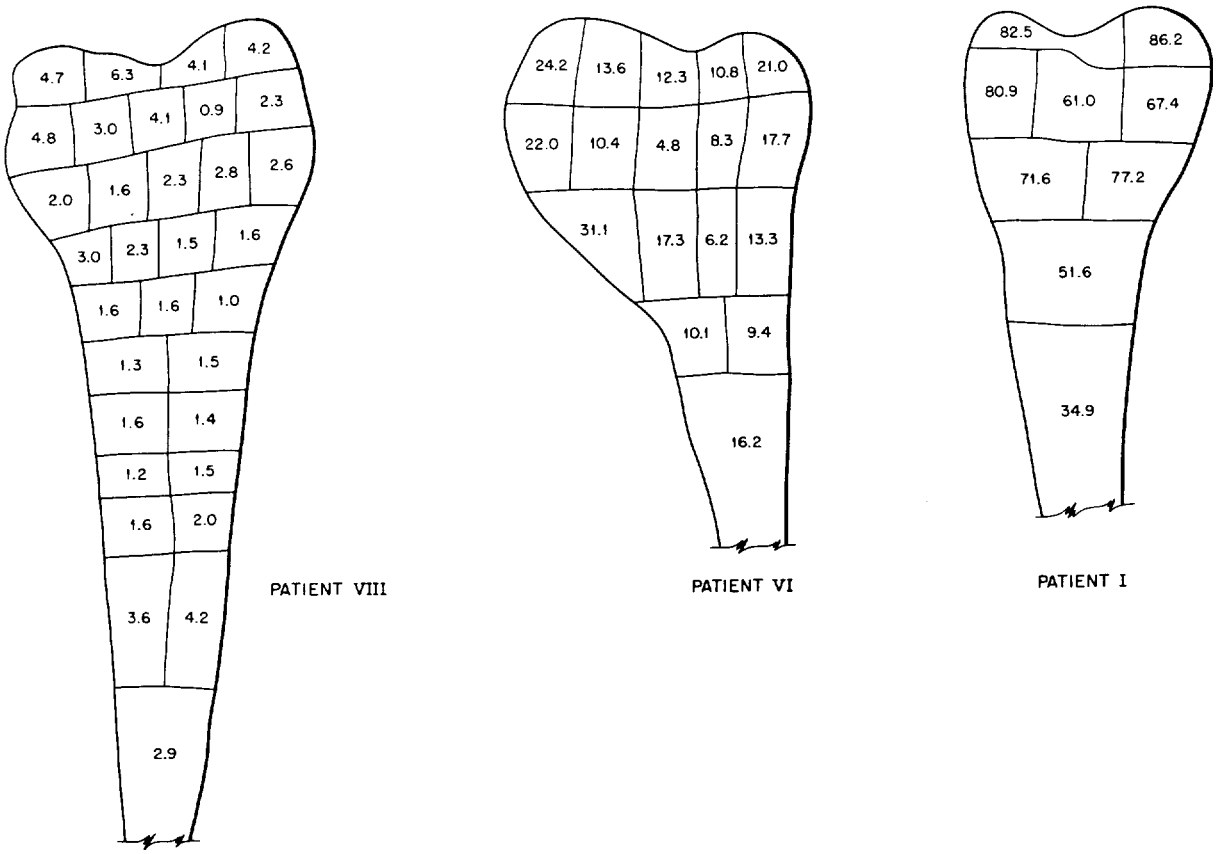

Fig. 3. Diagram of Concentration of Uranium in Longitudinal Section of Distal End of the Femur. Numbers in each section represent counts/min/g.

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TABLE 3. PER CENT OF INJECTED DOSE PER STANDARD MEAN ORGAN OR TISSUE FOR SIX TERMINAL BRAIN TUMOR PATIENTS

Patients I, VI, II, V, and III injected with $UO_2(NO_3)_2 \cdot 6H_2O$
Patient VIII injected with UCl_4

Organ or Tissue	Sample Amount (g)	Patient Number					
		I	VI	II	V	III	VIII
		Expiration Time (days)					
		2.5	18	74	139	566	21
Kidney	300	16.6	7.2	0.7	1.2	0.4	1.1
Muscle	30,000	1.2	2.1	0.9	0.3	0.06	0.4
Skin and subcutaneous tissues	6,100	1.8	1.0	0.1	0.06		
Fat	10,000	0.6	0.6			0.04	
Red marrow	1,500			0.02	0.03	0.1	
Yellow marrow	1,500						
Blood	5,400	1.0	0.2	0.005	0.002	0.004	0.08
Lower large intestine	150						
Stomach	250	0.08	0.02	0.003	0.001	0.001	
Small intestine	1,100	0.2	0.2	0.03	0.01	0.006	0.1
Upper large intestine	135						
Liver	1,700	1.8	1.1	0.2	0.2	0.05	9.2
Brain	1,500						
Lungs	1,000	0.5	0.4	0.03	0.02	0.008	0.3
Lymphoid tissue	700						
Heart	300	0.06	0.02	0.003	0.006	0.002	0.004
Spleen	300	0.6	0.2	0.1	0.02	0.006	5.6
Urinary bladder	150	0.03		0.002	0.001	0.0003	0.06
Pancreas	70	0.7	0.008	0.008	0.0006	0.0004	
Salivary glands	50						
Testes	40		0.01	0.008	0.002	0.002	0.008
Spinal cord	30						
Eyes	30						
Thyroid gland	20		0.003	0.0002	0.0001	0.0002	0.0009
Teeth	20						
Prostate gland	20		0.003	0.0004	0.0004	0.0001	0.003
Adrenal gland	20	0.02	0.01	0.003	0.001	0.0004	0.02
Thymus	10						
Miscellaneous tissues (blood vessels, cartilage, nerves, etc.)	390	0.3	0.2	0.04	0.002	0.002	0.04

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Some interesting observations can be made of the distribution and excretion of tetravalent uranium. Table 3 shows that U(IV) favors deposition in the reticulo-endothelial tissues of the liver and spleen in direct contrast to U(VI), which concentrates in the kidney. Figures 4, 5, and 6 show the disappearance of U(IV) from blood, feces, and urine, respectively. There appears to be little difference between the urinary excretion of U(VI) and U(IV); however, in excretion via the gastrointestinal tract, the data in Fig. 5 for U(IV) show some time relationship not seen in the data for the fecal excretion of U(VI). Only 0.1% of the injected dose had accumulated in feces of patient VII at 430 hr. The rate of disappearance of U(IV) from the blood is only slightly different from that of U(VI).

ECOLOGY

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Soil Fertility and the Uptake of Strontium by Plants

Strontium and calcium have been related chemically in both soils and plants. Variations in the uptake of these elements have been attributed to the amount and kind of clay minerals occurring in soils and to the rate of plant growth.

Since soils may serve for the disposal of nuclear wastes containing strontium, an evaluation is required to determine the degree to which this element may replace calcium on soil colloids.

In the studies reported here the nonradioactive isotope of strontium and the normal plant nutrients have been adsorbed on Conasauga shale, and the amounts of the isotope and the nutrients taken up by bean plants at various stages of maturity have been determined. In addition, each series of soils received equal amounts of radioactive Sr^{90}.

Occurring naturally as the subsoil of Armuchee silt loam, the Conasauga shale was taken from the Four-Acre Site at ORNL. Preliminary studies indicate this material to be 87% silt (0.006 to 0.002 mm) and 12% clay (0.002 mm and less). It has a total exchange capacity of 20 milliequivalents (meq) with 4.26 meq Ca^{++}, 1.08 meq Mg^{++}, 0.19 meq Na^{+}, and 0.47 meq K^{+} per 100 g of soil. It contains 0.009% nitrogen, 0.0055% sulfur, 0.064% carbon, and 0.53% strontium. About 0.82 ppm of phosphorus is extractable with 0.1 *N* HCl. Results from the x-ray powder photographs, electromicrographs, and differential-thermal-analyses patterns of the colloidal fraction indicate that the exchange surface is composed of a mica-type mineral with some quartz and a little halloysite present. Little or no kaolin was detectable. The soil was brought to the laboratory, air-dried, and ground to pass through an 8-mesh screen.

Seven ratios of calcium to strontium were established so that the soils of each series had a cation composition of 5% potassium, 15% magnesium, and 80% calcium and strontium. The latter two elements were varied so that their sum remained constant. For each Ca-Sr ratio, triplicate cultures, consisting of 3 kg of oven-dried soil, were prepared for each of the four stages of bean plant maturity at which the plant will be analyzed for Sr. Each culture received 360 mg of nitrogen, 300 mg of phosphorus, and 240 mg of sulfur.

An aliquot of soil material of particle size less than 175 μ in diameter and representing approximately 5% by weight of the total soil to be contaminated was obtained by mechanical dry sieving. To the aliquot, $Sr^{90}CO_3$ was added to give a 1:1 ratio by weight of soil to water suspension which was maintained by agitation for 30 min and then dried at 70°C. These dried fine fractions and the nutrients to be added were pulverized and incorporated into the soil for each plant series by mechanical batch- or barrel-type mixing. The specific activity was adjusted to about 2.7 μc per 100 g of soil.

The cultures were kept moist for at least five days to allow each soil nutrient complex to reach a possible equilibrium. Five seeds of the garden bush bean *Phaseolus vulgaris*, variety Top Crop, were seeded in each pot and covered with ½ in. of white quartz sand. Plants from each calcium-strontium series were harvested at 12-day intervals.

The upper portions of the plants were removed by cutting the stem 1 in. above the soil. The individual plant parts were separated and weighed and then dried at 70°C for 24 hr. The entire material was digested by the nitric-perchloric acid method of Piper. Aliquots were removed for counting and for making chemical determinations of calcium, strontium, magnesium, and potassium.

One object of this experiment was to determine the effect of high concentrations of calcium and

[4]Research participant.
[5]Temporary summer employee.

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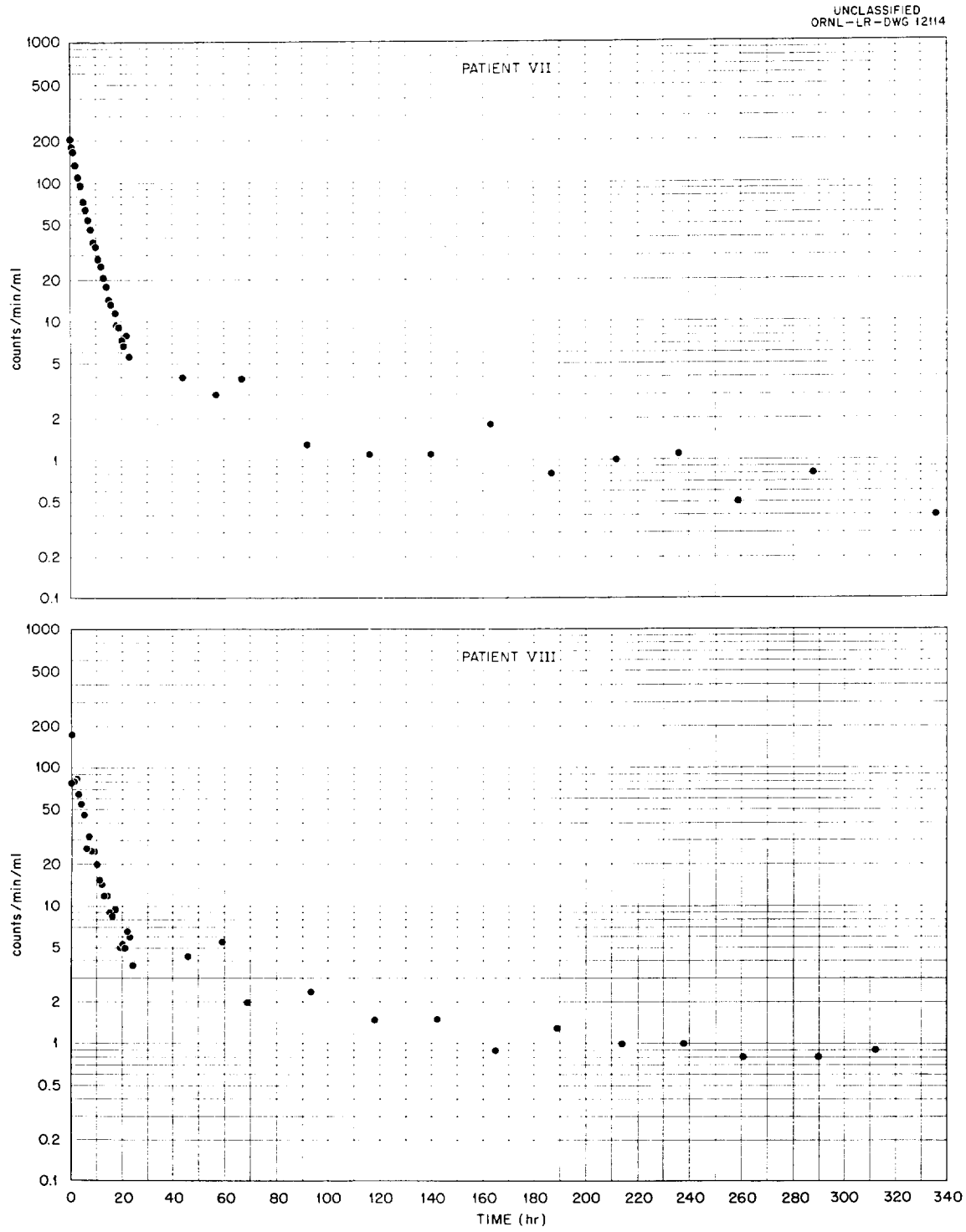

Fig. 4. Disappearance of U(IV) from Blood of Patients Injected Intravenously with UCl_4.

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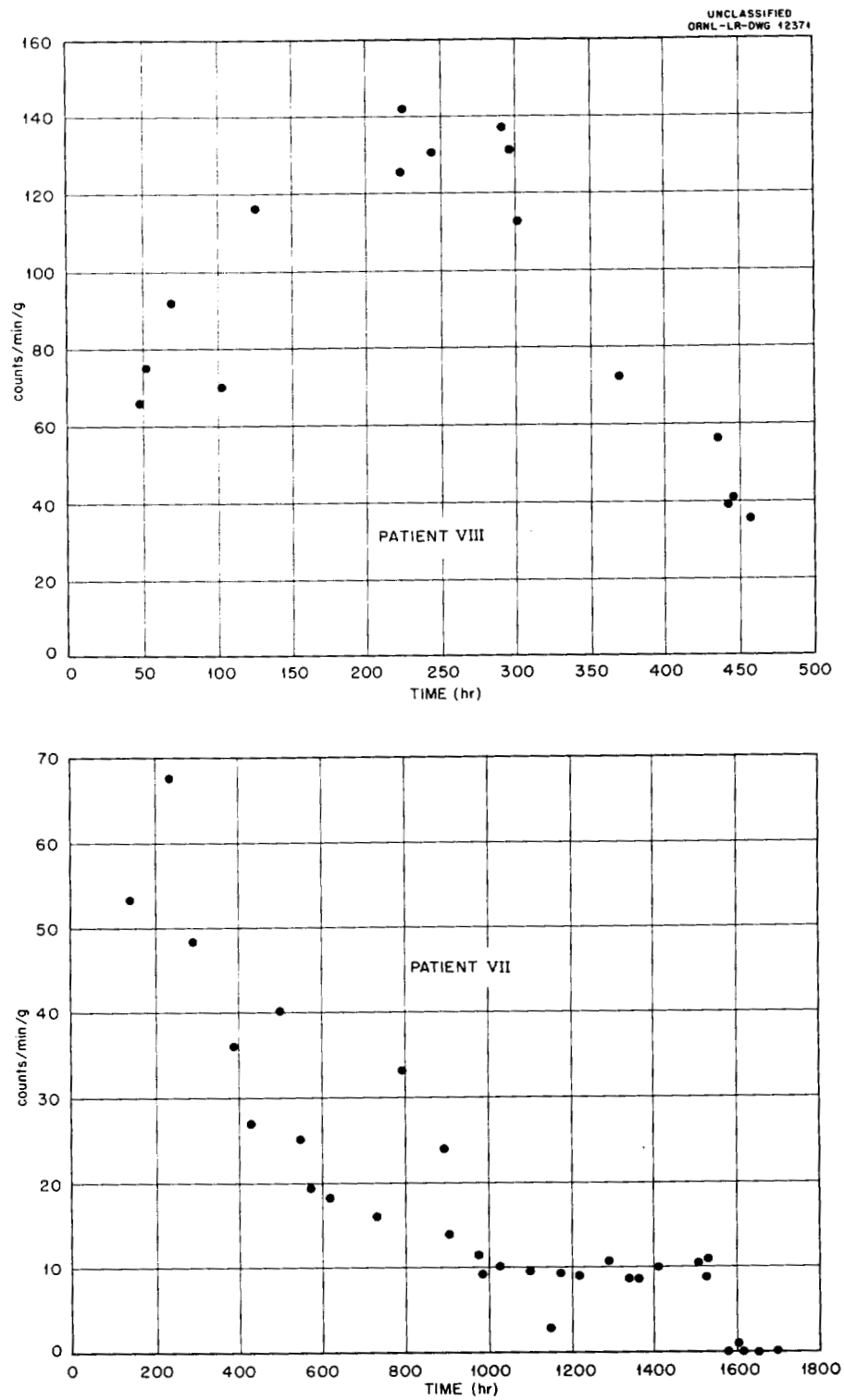

Fig. 5. Excretion of Uranium Via Feces Following Intravenous Administration of UCl_4.

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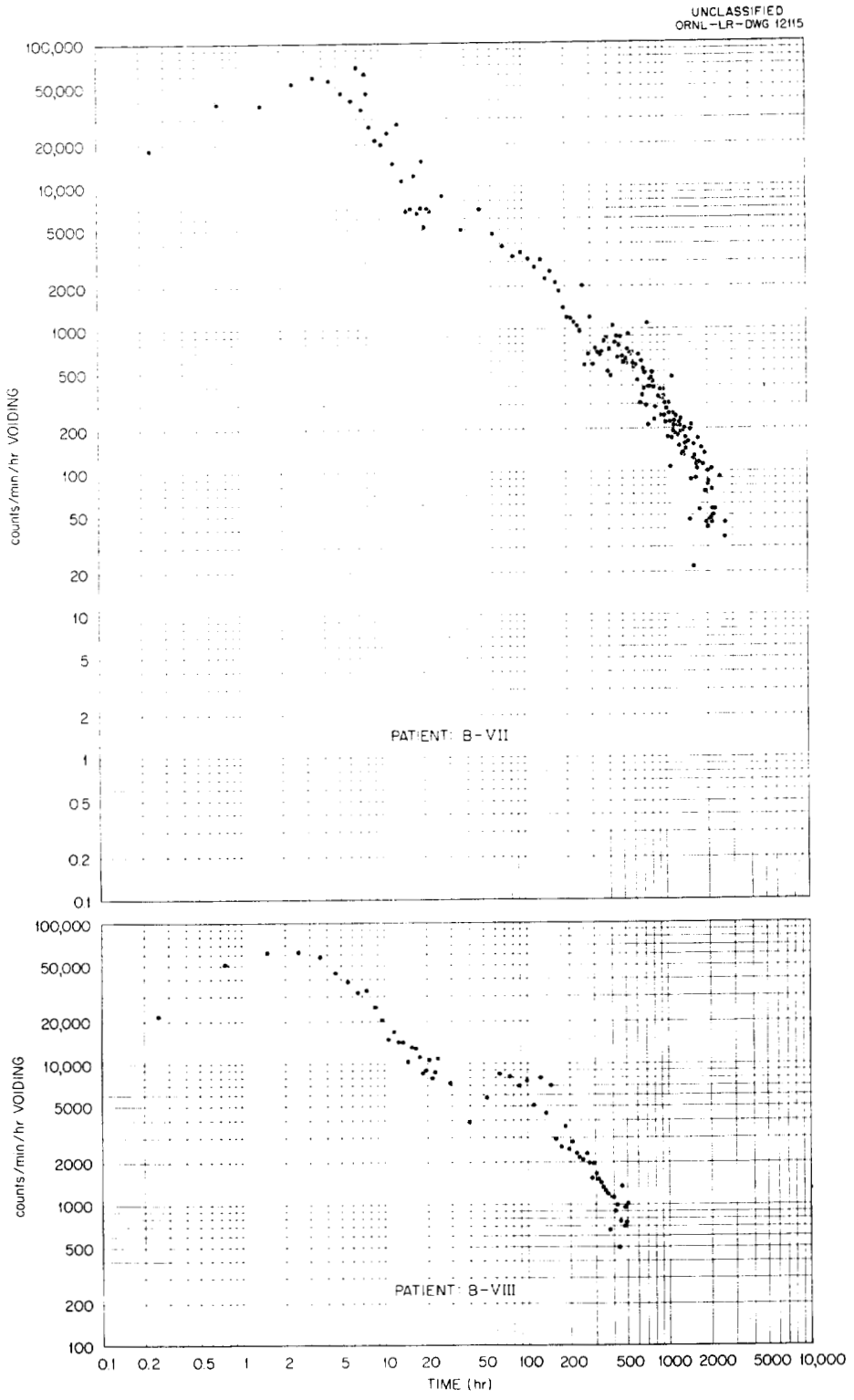

Fig. 6. Urinary Excretion of Uranium Following Intravenous Administration of UCl_4.

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strontium in the soil on the uptake of Sr^{90} by the bean plants. There appears to be a gradual decrease in the concentration factor

$$\frac{\text{counts/min per gram of leaf}}{\text{counts/min per gram of soil}}$$

as the per cent of strontium in the cation composition of the soil increases, as indicated by the data in Table 4.

The distribution of the Sr^{90} activity in the various parts of the plant with respect to soil treatment is well illustrated by the data in Table 5. A general decline of activity in the stems, leaves, and pods with increasing amounts of carrier strontium available was noted. The seeds seem to accumulate more of the activity as more carrier strontium and less calcium are available in the soil. In each series the leaves contained more activity than the corresponding stems, pods, or seeds.

TABLE 4. CONCENTRATION OF Sr^{90} IN 12-DAY-OLD BEAN LEAVES ACCORDING TO SATURATION OF SOIL WITH CALCIUM AND STRONTIUM CARRIER

Degree of Soil Saturation (%)		Concentration Factor
Sr	Ca	
10	70	8.19
20	60	6.71
30	50	6.48
40	40	5.38
50	30	3.99
60	20	3.91

TABLE 5. Sr^{90} ACTIVITY IN BEAN PLANT PARTS ACCORDING TO CALCIUM AND STRONTIUM IN THE SOIL

Degree of Saturation of Soil Colloids (%)		Activity (counts/min/mg)			
Sr	Ca	Stems	Leaves	Pods	Seeds
10	70	48.7	60.9	30.4	4.8
20	60	38.3	54.0		5.1
30	50	39.9	53.5	30.5	5.7
40	40	37.6	50.7	25.6	8.1
50	30	33.8	38.0	25.7	9.6
60	20	27.6	35.4	19.2	11.4

Tables 6 and 7 indicate the magnitude of the decline of the Sr^{90} activity of the leaves and stems. It is notable that the decline occurs at all stages of growth. This is in agreement with the theory of isotope dilution.

By increasing the degree of saturation of the soil with carrier strontium, the uptake of this element by all plant parts was enhanced, although the concurrent decrease of calcium in the soil was not always accompanied by a proportionate decrease of the calcium concentration in the plants. The data in Table 8 indicate that only after 36 days of growth do the plants begin to show a definite dependence on the soil calcium. Determination of the magnesium and potassium concentration in the plant parts indicated that these elements had been supplied in adequate amounts and that they were freely available from the soil colloids used in this study.

The growth of the plants did not show evidence of injury from either the activity or high concentration of strontium in the soil. Definite decreases in seed yield became evident as less calcium and more strontium were available in the soils.

It appears reasonable to conclude from the experiments conducted that (1) the uptake of Sr^{90} from natural soils will be concentrated to a higher degree in the leaves than in the other parts of the bean plant, and (2) the concentration factor will be approximately sixfold and that this factor may depend on the total amounts of strontium available in the soil. The amount per unit weight of active strontium absorbed and translocated to leaves declines as more carrier strontium is available in the soil. Uptake of calcium from the soil appears to be almost independent of soil saturation with calcium, at least in the earlier stages of plant growth.

Strontium can replace calcium on the soil colloid to make adequate amounts of potassium and magnesium available for plant growth.

Effects of Gamma Radiation on *Onthophagus texanus* Schaeffer (Coleoptera, Scarabaeidae)

A species of soil-inhabiting beetle, *Onthophagus texanus*, was subjected to gamma radiation from a

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Co^{60} source. *Onthophagus* beetles were used because they have a short, continuous life cycle, can be easily handled and sexed, and are readily reared in earth-filled flower pots.

Female beetles, when supplied with day-old cow dung, construct 3 to 7 in. burrows, each with a wad of dung at its terminus. A single egg is placed in each wad; the larva develop within the wad. Since the larvae could not complete development without this food supply furnished by the adult beetles, not only doses which produce sterility but any radiation effect on adult activity must be considered. The dry wads containing the larvae were easily removed from the pots, irradiated,

TABLE 6. CONCENTRATION OF CARRIER* AND RADIOACTIVE STRONTIUM** IN BEAN LEAVES OF DIFFERENT STAGES OF GROWTH

Degree of Saturation of Soil Colloids (%)		Growth Stage							
		12 Days		24 Days		36 Days		48 Days	
Stable Sr	Ca	Sr^{90}	Total Sr	Sr^{90}	Total Sr	Sr^{90}	Total Sr	Sr^{90}	Total Sr
0	80	0.8	0.025	0.7	0.014	0.7	0.023	0.7	0.034
10	70	79.3	0.179	112.2	0.635	53.7	0.439	60.9	0.375
20	60	76.4	0.597	105.7	1.288	65.2	0.927	54.0	0.637
30	50	62.6	1.031	98.4	1.986	64.4	1.394	53.5	1.127
40	40	56.3	1.143	79.2	2.848	48.6	1.796	50.7	1.260
50	30	56.2	1.203	64.6	2.534	53.0	2.160	38.0	1.613
60	20	47.5	1.304	59.1	2.634	52.7	2.405	35.4	1.910

*Total Sr given as per cent dry weight.

**Sr^{90} given as counts/min per mg of dry leaf corrected to 10% geometry. Each value is the average of three determinations on independently grown cultures of five plants each.

TABLE 7. CONCENTRATION OF CARRIER* AND RADIOACTIVE STRONTIUM** IN BEAN STEMS HARVESTED AT DIFFERENT STAGES

Degree of Saturation of Soil Colloids (%)		Growth Stage							
		12 Days		24 Days		36 Days		48 Days	
Stable Sr	Ca	Sr^{90}	Total Sr	Sr^{90}	Total Sr	Sr^{90}	Total Sr	Sr^{90}	Total Sr
0	80	0.6	0.062	1.0	0.011	0.4	0.027	0.9	0.019
10	70	122.9	0.500	69.3	0.354	56.5	0.415	48.7	0.314
20	60	72.3	0.609	69.1	0.935		0.788	38.3	0.547
30	50	71.2	1.018	70.1	1.495	45.7	0.971	38.0	0.884
40	40	57.5	0.953	59.6	1.752	41.1	1.385	37.6	1.064
50	30	53.3	1.113	55.0	1.629	41.6	1.653	33.8	1.251
60	20	51.9	4.89	44.9	1.825	41.5	1.733	27.6	1.324

*Total Sr given as per cent dry weight.

**Sr^{90} given as counts/min per mg of dry stem corrected to 10% geometry. Each value is the average of three determinations on independently grown cultures of five plants each.

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TABLE 8. Sr-Ca COMPOSITION OF BEAN PLANTS AT VARIOUS STAGES OF GROWTH ACCORDING TO TREATMENT OF THE SOIL WITH CALCIUM AND STRONTIUM

Degree of Saturation of Soil Colloids (%)		Leaves		Stems		Roots	
Sr	Ca	Total Sr	Ca	Total Sr	Ca	Total Sr	Ca
			12-Day-Old[a]				
0	80	0.035	0.981	0.062	0.916	0.079	0.328
10	70	0.179	0.540	0.500	1.132	0.147	0.325
20	60	0.597	1.160	0.609	1.169	0.230	0.264
30	50	1.031	1.102	1.018	0.941	0.309	0.262
40	40	1.143	0.728	0.953	0.546	0.294	0.229
50	30	1.203	0.577	1.113	0.446	0.416	0.239
60	20	1.304	0.536	4.89	0.284	0.448	0.232
			24-Day-Old[b]				
0	80	0.014	1.447	0.011	0.9842	0.217	0.6259
10	70	0.635	1.583	0.354	0.6531	0.365	0.6118
20	60	1.288	1.692	0.935	0.8981	0.604	0.6117
30	50	1.986	1.342	1.495	0.9850	0.862	0.6619
40	40	2.848	1.587	1.752	0.9184	0.756	0.6066
50	30	2.534	1.514	1.629	1.0023	0.423	0.4310
60	20	2.634	1.352	1.825	0.8192	0.787	0.5224
			36-Day-Old[a]				
0	80	0.023	2.635	0.027	1.618	0.020	0.971
10	70	0.439	2.203	0.415	1.604	0.095	0.910
20	60	0.927	2.385	0.788	1.699	0.176	0.644
30	50	1.394	2.012	0.971	1.008	0.228	0.628
40	40	1.796	1.755	1.385	1.231	0.326	0.723
50	30	2.160	1.720	1.653	1.146	0.416	0.719
60	20	2.405	1.220	1.733	0.962		

Degree of Saturation of Soil Colloids (%)		Leaves		Stems		Pods		Seeds	
Sr	Ca	Total Sr	Ca	Total Sr	Ca	Total Sr	Ca	Total Sr	Ca
				48-Day-Old[a]					
0	80	0.034	2.405	0.019	1.6030	0.004	0.681	0.002	0.084
10	70	0.375	1.783	0.314	1.2054	0.144	0.583	0.014	0.084
20	60	0.637	1.605	0.547	1.2007	0.334	0.551	0.023	0.097
30	50	1.127	1.765	0.884	0.9009	0.354	0.562	0.030	0.115
40	40	1.260	1.495	1.064	0.9001	0.408	0.444	0.056	0.115
50	30	1.613	1.300	1.251	0.8063		0.406	0.066	0.139
60	20	1.910		1.324	0.7037	0.465	0.376	0.073	

[a]Each value is an average of three cultures representing a total of 15 plants. Values given in per cent of dry weight.
[b]In the determination of strontium in the roots, there was some contamination from soil.

and then kept in metal salve boxes, where their development could be observed.

Adult beetles were given a dose of 5000 r at a dose rate of 26 r/sec. Second-stage larvae in the dung wads were given total doses of 2000 and 4000 r at the same dose rate.

The number of dung wads placed at the ends of the burrows by the adults was considered as one criterion of activity, while the lack of eggs within the wads was considered as an indicator of sterility. With doses of 3000 to 5000 r the adult beetles formed fewer egg cells than the controls, and in no case did the treated adults produce fertile eggs. Table 9 summarizes this portion of the work.

The second-stage larvae were divided into three lots of 30 cells each, which were in turn divided into sublots of 10 cells. One lot of 30 cells was left untreated, one lot received a dose of 2000 r, and one lot of 30 received 4000 r. Table 10 summarizes the results. No developmental differences could be noted between the controls and those cells given the 2000-r dose. With 4000 r there was a high mortality and the few beetles reaching the adult stage were badly deformed. The crumpled elytra, shortened antennae with the antennal clubs fused, tarsal segments fused or missing, and the deformed clypeus were a few of the more obvious deformities produced. While radiation-induced deformities have been noted in *Drosophila* and *Habrobracon*, they have not been previously recorded for beetles.

The adults resulting from the treated larvae were placed in rearing pots. The deformed adults from the larvae given the 4000-r dose were too abnormal to burrow and were therefore incapable of reproduction even if they had been fertile. The adults from the 2000-r larval treatments, while normal in appearance, produced few cells and no fertile eggs, as is indicated in Table 11. Whiting and Bostian[6] found that some *Habrobracon* adults

[6] A. R. Whiting and C. H. Bostian, *Genetics* 16, 659–680 (1931).

TABLE 9. REPRODUCTION OF *ONTHOPHAGUS* CONTROLS AND IRRADIATED ADULTS

Number of Pairs	Dose (r)	♂ Life Span (days)	♀ Life Span (days)	Number of Egg Cells Formed	Number of Egg Cells Viable
			Irradiated		
1	5000	19	8	4	0
1	5000	14	16	4	0
3	5000	7, 8, 15	7, 17, 13	0	0
3	5000	9, 14, 14	14, 14, 16	1	0
1	3000	17	21	0	0
3 ♂	♂ – 5000	9, 9, 14			
			Controls		
1 ♀	♀ – 0		14	1	0
1	0	15	25	5	3
2	0	15	18	8	8
2	0	av for	av for	7	6
2	0	males	females	8	7
2	0	15	18	13	12
2	0	15	18	23	22
2	0	15	18	8	8
2	0	15	18	4	4

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TABLE 10. DEVELOPMENT OF ADULT *ONTHOPHAGUS* FROM CONTROL AND IRRADIATED SECOND INSTARS

	Number of Cells	♂	♀	Number Unsuccessful	Average Development Time (days)
				Control	
	10	4	2	4	35–51, 39 median
	10	5	2	3	
	10	3	4	3	
Total	30	12	8	10	
				Irradiated	
				2000 r	
	10	1	6	3	35–44, 38 median
	10	4	2	4	
	10	7	0	3	
Total	30	12	8	10	
				4000 r	
	10	1	0	9	42–49, 42 median; all adults deformed
	10	0	2	8	
	10	0	0	10	
Total	30	1	2	27	*

*1 ♂, 3 ♀ dead in cells.

emerging from larvae which had been subjected to doses as low as 730 r failed to reproduce. The number of failures increased as the dose was increased. These investigators suggested that this was not entirely due to sterilization but to lessened vigor, which resulted in early death. In the *Onthophagus* from the 2000-r treatment there was no evidence of shortened life span, but, since they produced considerably fewer cells, it is possible that their vigor was affected as well as (or instead of) their fertility.

Delayed Effects of Gamma Radiation on Tree-Hole Arthropods

A single beech tree hole from the Laboratory environs was completely excavated, and part of the removed substrate was subdivided into 100-g samples. These samples were grouped into three series, each series consisting of eight samples divided into the following doses of gamma radiation from a Co^{60} source: 3×10^3, 8×10^3, 1.5×10^4, 2.5×10^4, 5×10^4, 7.5×10^4, 1×10^5, and 1.25×10^5 r, at a dose rate of 26 r/sec. Five control samples were set up as a part of each series. After irradiation each sample was transferred to a sterile red-clay flower pot covered with cellophane. The pots were stored in chambers where the temperature was kept at 75 ± 3°F and the relative humidity ranged from 65 to 85%. At the end of 30 days a series, consisting of eight experimental and five control samples, was removed and processed through Berlese-type funnels to extract the surviving arthropods. Of the remaining two series, one was processed after 60 days and the other after 90 days. All samples were counted in a gridded evaporating dish under a dissecting microscope. Total counts were made in all cases.

Preliminary analysis of the data indicates differences in response to irradiation under these conditions for Acarina, Collembola, Isopoda, and Chilopoda. In the case of the Acarina and Collembola there is evidence of difference even between species which are morphologically closely

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TABLE 11. REPRODUCTION OF *ONTHOPHAGUS* FROM CONTROLS AND ADULTS IRRADIATED AT SECOND INSTAR

Number of Pairs	Dose (r)	♂ Life Span (days)	♀ Life Span (days)	Number of Cells Formed	Number of Cells Viable
		Irradiated			
2	2000	18, 20	14, 14	0	0
2	2000	12, 13	16, 38	3	0
2	2000 (+3000 as adults)	13, 14	16, 18	1	0
1	4000	6	6	0*	
		Control			
1	0	15	25	5	3
2	0	15	18	8	8
2	0	av for	av for	7	6
2	0	males	females	8	7
2	0	15	18	13	12
2	0	15	18	23	22
2	0	15	18	8	8
2	0	15	18	4	4

*Adults unable to burrow.

related. At the higher taxonomic category levels, differences appear to be even more pronounced. Most of the Acarina showed relatively high resistance to radioactivity for the entire period of the experiment, but the Isopoda and Chilopoda were adversely affected (as measured by survival) by much lower doses of radiation. The Collembola, both at the species and family level, showed greater resistance to the irradiation under these conditions than did either the isopods and chilopods but less resistance than did the mites. A more detailed statistical analysis of the data is currently in progress.

Studies of the Uptake of Fission Products by Earthworms

Uptake of Sr^{89} by *Allolobophora caliginosa* (Savigny). – To investigate further the ability of earthworms to concentrate Sr^{89} present in the soil, an experiment was conducted which was similar to the one used for *Eisenia foetida* (Savigny)[7] except that *Allolobophora caliginosa* (Savigny)[8] was used in place of *Eisenia foetida*. *Allolobophora caliginosa* is believed to be the most abundantly represented and most widely distributed of the North American earthworms.[9]

The design of this experiment differed somewhat from the previous experiment.[7] Two soil series were used. In one series the same type of soil as in the previous experiment was used without modification. In the second series the soil was enriched with certain inorganic constituents considered to be of importance in soil fertility. The

[7] S. I. Auerbach *et al.*, *HP Semiann. Prog. Rep. July 31, 1955*, ORNL-1942, p 7.

[8] The authors are indebted to Dr. W. Murchie, Thiel College, Greenville, Penn., for supplying the worms.

[9] F. Smith, *Proc. U. S. Nat. Museum* 52, 157–182 (1917).

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analyses of these two soils[10] are given below:

	Soil	
	I	II
Organic matter, %	4.1	4.4
P_2O_5, ppm	29	45
K, ppm	12	28
Mg, ppm	13	13
Ca, ppm	100	160
pH	5.3	6.2
Total hydrogen, meq/100 g	6.0	2.5
Cation exchange capacity, meq/100 g	12	12
Base saturation, %	50	79

Six red-clay flower pots were used for each series. Each series was divided into five experimental pots and one control pot. Each of the five pots was brought up to a different activity level of Sr^{89}. The activities (in microcuries per gram of soil) were as follows: 1.88×10^{-3}, 3.77×10^{-3}, 5.65×10^{-3}, 7.54×10^{-3}, 9.43×10^{-3}. These activities were the same in both series. The isotope was added to the soils in the same manner as before.[7] Six adult worms were added to each pot. The pots were weighed twice a week to determine the water loss, and water was added as needed.

After 30 days the pots were examined for the surviving worms; 69 of an initial 72 specimens were found to have survived. All the specimens were placed between sheets of moistened filter paper for three days while they emptied their intestinal tracts of soil.

Fifty per cent of the individuals from each pot were cut in half. The two halves were analyzed separately to determine any gross difference in the distribution of the radionuclide in the body of the worm. All the remaining worms were then weighed individually and sacrificed. Preparation of the worms for counting and the counting procedures were the same as before.[7]

The radionuclide uptake, as determined from the whole worms in each series, is presented in Table 12, together with the activity of the soil at the time that the worms were removed. The ratio of worm to soil (in $\mu c/g$) is given. The results indicate that although there is some uptake of the fission product Sr by this species of worm there is no concentration under the conditions of this experiment. Furthermore, as shown in the enriched soil series, it is evident that the addition of calcium to the soil served to depress the uptake of Sr^{89}.

In Table 13 these ratios for *A. caliginosa* are compared with those for *E. foetida*. The data indicate that *A. caliginosa*, even when the diluting effect of calcium is present, has a greater affinity for the radionuclide than does *E. foetida*. The reason for this is probably related to the fact that *A. caliginosa* is a true soil-feeding species whereas *E. foetida* prefers humus and other decomposing organic matter both as food and as a niche.

In Table 14 the uptake ratios and the specific activity for the anterior and posterior sections of *A. caliginosa* under both soil conditions are

[10]Soil analyses were made by the Department of Soils, College of Agriculture, University of Missouri, Columbia.

TABLE 12. ANALYSIS OF Sr^{89} ACTIVITY IN EARTHWORM, *ALLOLOBOPHORA CALIGINOSA* (SAVIGNY)

Pot No.	Activity of Soil at End of Experiment ($\mu c/g$)	Number of Individuals	Untreated Soil Series: Activity ($\mu c/g$ of worm)	Untreated Soil Series: Ratio ($\frac{\mu c/g \text{ of worm}}{\mu c/g \text{ of soil}}$)	Number of Individuals	Enriched Soil Series: Activity ($\mu c/g$ of worm)	Enriched Soil Series: Ratio ($\frac{\mu c/g \text{ of worm}}{\mu c/g \text{ of soil}}$)
I	1.25×10^{-3}	3	2.39×10^{-4}	0.191	3	0.963×10^{-4}	0.077
II	2.51×10^{-3}	2	3.23×10^{-4}	0.128	3	1.64×10^{-4}	0.065
III	3.76×10^{-3}	3	5.22×10^{-4}	0.138	3	3.37×10^{-4}	0.089
IV	5.02×10^{-3}	3	5.58×10^{-4}	0.111	3	4.63×10^{-4}	0.092
V	6.27×10^{-3}	3	7.16×10^{-4}	0.114	3	4.17×10^{-4}	0.066
Control	0	3	0		3	0	

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TABLE 13. COMPARISON OF WORM UPTAKE–SOIL ACTIVITY RATIOS OF Sr^{89} IN THE CASE OF *EISENIA FOETIDA* AND *ALLOLOBOPHORA CALIGINOSA*

Pot No.	*Eisenia foetida*		*Allolobophora caliginosa*		
	Activity of Soil at End of Experiment ($\mu c/g$)	Ratio $\left(\frac{\mu c/g \text{ of worm}}{\mu c/g \text{ of soil}}\right)$	Activity of Soil at End of Experiment ($\mu c/g$)	Untreated Soil Ratio $\left(\frac{\mu c/g \text{ of worm}}{\mu c/g \text{ of soil}}\right)$	Enriched Soil Ratio $\left(\frac{\mu c/g \text{ of worm}}{\mu c/g \text{ of soil}}\right)$
I	0.937×10^{-3}	0.030	1.25×10^{-3}	0.191	0.077
II	1.87×10^{-3}	0.057	2.51×10^{-3}	0.128	0.065
III	2.81×10^{-3}	0.043	3.76×10^{-3}	0.138	0.089
IV	3.75×10^{-3}	0.046	5.02×10^{-3}	0.111	0.092
V	4.69×10^{-3}	0.049	6.27×10^{-3}	0.114	0.066
Control	0	0	0	0	0

TABLE 14. ANALYSIS OF ACTIVITY IN ANTERIOR AND POSTERIOR PORTIONS OF *ALLOLOBOPHORA CALIGINOSA*

Pot No.	Number of Individuals	Anterior Portions ($\mu c/g$ of tissue)	Ratio $\left(\frac{\mu c/g \text{ of tissue}}{\mu c/g \text{ of soil}}\right)$	Posterior Portions ($\mu c/g$ of tissue)	Ratio $\left(\frac{\mu c/g \text{ of tissue}}{\mu c/g \text{ of soil}}\right)$
			Untreated Soil		
I	3	1.90×10^{-4}	0.152	0.89×10^{-4}	0.071
II	3	4.77×10^{-4}	0.190	2.27×10^{-4}	0.090
III	3	8.10×10^{-4}	0.215	3.27×10^{-4}	0.086
IV	3	8.33×10^{-4}	0.166	3.89×10^{-4}	0.077
V	3	10.30×10^{-4}	0.164	2.49×10^{-4}	0.040
Control	3	0	0	0	0
			Enriched Soil		
I	3	1.82×10^{-4}	0.145	0.95×10^{-4}	0.076
II	2	2.35×10^{-4}	0.093	1.16×10^{-4}	0.046
III	3	4.17×10^{-4}	0.111	3.78×10^{-4}	0.100
IV	3	7.07×10^{-4}	0.141	2.69×10^{-4}	0.053
V	3	6.98×10^{-4}	0.111	1.98×10^{-4}	0.031
Control	3	0	0	0	0

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presented. In both series at each level of soil activity the anterior portions contained more radionuclide than did the posterior portion. The explanation for this phenomenon may be due to the presence of the calciferous glands in the anterior segments of the worm. Recent work[11] on some other species of earthworms has demonstrated that these glands are concerned with the extraction and storage of calcium. This would account for their affinity for strontium and for the higher activity in the nontreated soil series.

URINALYSIS RESEARCH

L. B. Farabee

Although there are several complicated techniques in general use for the determination of radioactive cesium in biological materials and in water, none of them are entirely satisfactory. There is a need for a simple, reliable procedure. The recently reported[12] precipitation of potassium as its tetraphenylboron salt provides a simple method for the separation of potassium from a wide range of ions associated with it. Potassium and cesium form very insoluble tetraphenylboron compounds in dilute mineral acids, whereas the sodium salt is very soluble.

Preliminary tests with procedures for separating Cs^{137} from biological materials with the use of sodium tetraphenylboron give excellent recovery as well as good separation from the other fission products. However, potassium, which is present in large amounts in such samples, coprecipitates with the cesium and makes the sample rather bulky for counting. Also, K^{40} contributes to the radioactivity of the sample.

In the analysis of muscle tissue of fish as well as in urinalysis the radioactive cesium can be concentrated by a precipitation of the potassium in the sample as potassium cobaltinitrite. The cesium can be separated subsequently from potassium by precipitating cesium silicotungstate. The cesium is finally precipitated as cesium tetraphenylboron.

DISTRIBUTION OF RADIOISOTOPES IN ANIMAL TISSUE

M. J. Cook F. G. Karioris[13]
K. Z. Morgan

It is extremely important to test experimentally the mathematical relation used (in publications by the National Committee on Radiation Protection[14] and the International Commission of Radiological Protection[15]) in employing single-exposure data to determine the MPC of radionuclides in air and water for continuous exposure. A pilot experiment on Co^{60} was computed,[16] and the indication is that the mathematical relations used in the handbooks on internal dose are correct within a factor of 2 for Co^{60}. A study with mice was initiated to check this relationship for other radionuclides.

Each mouse was given a single dose of 10 μc of $Sr^{90} + Y^{90}$ by stomach tube. In groups of 10, the mice were sacrificed at the following intervals: 4 and 24 hr; 3, 5, and 7 days; 2, 3, 4, 5, and 7 weeks. The animals that were sacrificed at the periods of from 4 hr through 2 weeks were dissected into 16 parts. In the 2-week group, only a trace of Sr^{90}-Y^{90} remained in the soft tissue; therefore, the mice sacrificed after 2 weeks are dissected only into soft tissues, femur, and carcass. Other mice will be sacrificed at 3, 6, 12, and 18 months.

As a second part of the experiment mice will be subjected continuously to a fixed concentration of $Sr^{90} + Y^{90}$ in the drinking water. In order to know the exact amount of water containing the radioisotope which the mice drink *ad libitum*, a capillary drinking fountain was designed and is pictured in Fig. 7. The critical factor in this device is the height of the liquid in the drinking pool, which must remain within narrow limits to be available to the animals and to prevent spills. Within less than 24 hr, the mice learn to drink from the fountain. Now that this fountain has been

[11] H. V. Kashyap and M. R. Ranade, *Proc. Zool. Soc. Bengal* 5, No. 1, 1–9 (1952).

[12] G. Wittig and P. Raff, *Ann. Chem., Justus Liebigs* 573, 195 (1951).

[13] Summer research participant from the Physics Department of Marquette University, Milwaukee, Wisconsin.

[14] United States National Bureau of Standards, *Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water*, Handbook 52 (1953), Superintendent of Documents, Washington 25, D.C.

[15] International Congress of Radiology, "Recommendations of the International Commission of Radiological Protection," *Brit. J. Radiol.* Suppl. 6 (revised Dec. 1, 1954).

[16] M. J. Cook, K. Z. Morgan, and A. G. Barkow, "An Experiment Designed to Test the Validity of the Current Practice of Using Single-Exposure Data to Calculate Maximum Permissible Concentration in Water for Continuous Exposure to Radioisotopes." Accepted for publication in *Am. J. Roentgenol., Radium Therapy Nuclear Med.*

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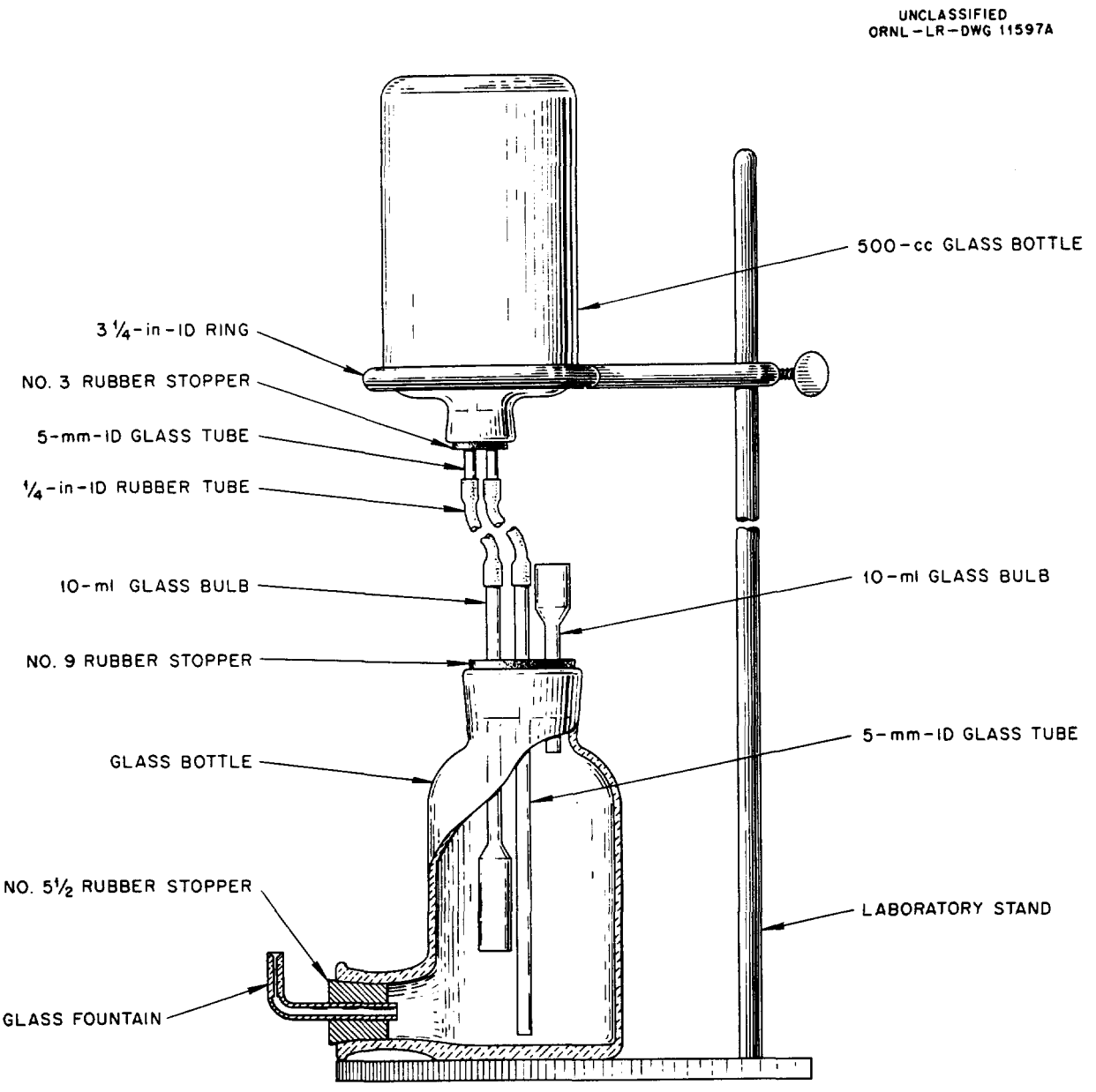

Fig. 7. Measuring Capillary Fountain.

developed and tested, the second part of this experiment is getting under way.

ISOTOPIC DISTRIBUTION IN MAN

Internal Dose

K. Z. Morgan M. J. Cook
M. R. Ford

The tables of maximum permissible concentrations for continuous exposure to radioisotopes[14,15] are being revised. The revision will include new biological data, additional elements, additional isotopes, and additions to the bibliography.

Spectrographic Analysis of Human Tissue

I. H. Tipton D. K. Bowman
M. J. Cook K. K. McDaniel

During the period from July 1, 1955, through December 31, 1955, the collecting of normal human tissue was extended to four more cities in the

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United States, making a total of eight cities distributed in seven states. Tissues from 57 adult autopsies, with an average of 26 tissues per autopsy, were received.

In addition to the tissues from adult autopsies the program is being expanded to include analyses of tissues from fetuses, still births, babies, children, and teen-agers. From each city where adult tissues are being received, it is hoped that the following tissues may be received in order to compare the elements found in the tissues of adults with those in the tissues of younger people:

Fetus (6 to 9 months)	2 whole
Birth to 6 months	1 autopsied
3 to 6 years	1 autopsied
14 to 18 years	1 autopsied

Invitations have been extended by pathologists in four additional cities in the United States, and arrangements will be made at a later date to extend the program to these cities.

Perhaps the most difficult tissue to obtain is the eye. Fifteen eyes have been secured from fetuses and still births or from infants whose bodies were left at the hospital for disposal.

The tissues are packed in dry ice and shipped via air express to this laboratory, where they are stored in the deep-freeze unit until time for ashing. From shipment until arrival, the time in all instances has been less than 24 hr.

The tissues are dry-ashed as follows:

1. Tissues are trimmed, weighed, and then washed in ion-exchange water.
2. Tissues are placed in the oven and the temperature is gradually brought to 300°C, where it is held for 20 hr.
3. At the end of 20 hr the tissues are cooled and reweighed in order to obtain the dry weight.
4. Tissues are placed in the oven and the temperature is gradually brought to 450°C, at which temperature the tissues remain for 24 hr or longer if necessary.
5. The tissue ashes are cooled and reweighed.
6. The ash is transferred to a polyethylene bottle and ground for 30 min.

During the past six months 806 tissues have been dry-ashed and sent to the Physics Department of the University of Tennessee, where over 30,000 spectrographic determinations have been made.

The analytical method is essentially the same as that described in earlier reports except that two internal standards are employed: indium for the elements boron, zinc, gallium, silver, cadmium, tin, lead, gold, and bismuth; and palladium for the elements manganese, iron, cobalt, nickel, copper, cesium, strontium, molybdenum, barium, lanthanum, and gold. The upper and lower limits of sensitivity in parts per million in ash and the precision of the method expressed as coefficients of variation in per cent are given in Tables 15 and 16. The coefficients of variation were determined from 16 replicate analyses of a single standard sample.

The improved techniques of collection and ashing make the analyses more meaningful, since there is

TABLE 15. SPECTROGRAPHIC DETERMINATIONS OF DRY-ASHED SOFT TISSUE FOR LIMITS OF SENSITIVITY AND COEFFICIENTS OF VARIATION

Element	Limits of Sensitivity (ppm in ash)		Coefficient of Variation (%)
	Upper	Lower*	
Boron	400	10	
Aluminum	4,000	2	15
Titanium	1,000	10	15
Vanadium	1,000	10	
Chromium	1,000	0.1	10
Manganese	1,000	1	10
Iron	100,000	1,000	
Cobalt	400	5	
Nickel	1,000	10	10
Copper	1,000	25	5
Zinc	10,000	400	5
Gallium	20	1	
Strontium	40	1	15
Molybdenum	1,000	10	10
Silver	400	1	15
Cadmium	5,000	75	4
Tin	1,000	10	20
Cesium	3,000	100	
Barium	400	0.2	20
Lanthanum		100	
Gold	400	20	
Lead	1,000	10	15
Bismuth	400	10	

*Other elements with lower limits include: beryllium (3), arsenic (300), zirconium (30), niobium (100), ruthenium (10), antimony (100), and thallium (10).

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TABLE 16. SPECTROGRAPHIC DETERMINATIONS OF DRY-ASHED BONE FOR LIMITS OF SENSITIVITY

Element	Limits of Sensitivity (ppm in ash)	
	Upper	Lower*
Boron		30
Aluminum	100	4
Titanium		40
Vanadium		20
Chromium		5
Manganese	100	2
Iron	4000	100
Cobalt		10
Nickel		30
Copper	100	2
Zinc	3000	700
Gallium		5
Strontium	1000	10
Molybdenum		15
Silver	100	1
Cadmium		200
Tin	400	10
Cesium		400
Barium	200	4
Lanthanum		400
Gold		15
Lead	400	10
Bismuth		20

*Other elements with lower limits include: arsenic (1000), zirconium (400), niobium (150), ruthenium (?), antimony (100), and thallium (20).

considerably less cross-contamination. The elements beryllium, arsenic, zirconium, niobium, ruthenium, antimony, and thallium are sought in every sample. However, except for traces of ruthenium in two spleen samples, none have been detected. Part of the results of the analyses of tissues collected from one city are presented in Table 17, which does not include all the tissues received from the autopsies but only the tissues analyzed spectrographically as of December 31, 1955. All the elements were sought, and a blank space means that nothing was detected within the limits of sensitivity. Table 17 presents data which indicate the specific tissues in which the various elements are found. Gallium was found in three specimens of lung only (average value of 0.03 $\mu g/g$) and is not included in the table. Tables are available on request giving the element distribution in each tissue.

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TABLE 17. CONCENTRATIONS OF ELEMENTS IN SPECIFIC WET TISSUES

Tissue	Number of Samples: Analyzed	Number of Samples: Containing Element*	Average Value for Samples Containing Element (μg/g)	Number of Samples: Analyzed	Number of Samples: Containing Element*	Average Value for Samples Containing Element (μg/g)
	Aluminum			**Bismuth**		
Adrenal	3	3	0.70	3		
Aorta	12	12	0.87	12	3	0.40
Bladder	13	13	1.1	13		
Bone	23 (5)	13	0.53	23		
Brain	21	21	0.40	21 (1)		<0.15 T
Esophagus	8	8	1.4	8 (1)	1	>>4
Heart	19	19	0.43	19 (1)		<0.10 T
Intestine						
Duodenum	7	7	0.76	7	1	>>4
Jejunum and ileum	20	20	0.80	20 (2)	1	>>4
Large	22	22	1.0	22 (3)	1	0.07
Kidney	24	24	0.67	24	6	1.1
Liver	24	24	0.70	24	3	0.90
Lung	24	24	23	24 (1)		<0.11 T
Muscle	18	18	0.50	18		
Pancreas	21	21	0.70	21 (1)	2	0.36
Prostate	8	8	0.75	8 (2)		<0.13 T
Spleen	22	22	2.2	22	2	0.36
Stomach	20	20	0.53	20 (1)	1	>>4
Thyroid	8	8	1.40	8 (1)		<0.11 T
	Barium			**Boron**		
Adrenal	3	3	0.03	3 (1)	2	0.17
Aorta	12	12	0.11	12	1	0.40
Bladder	13 (1)	10	0.03	13 (1)	1	0.30
Bone	23	23	1	23		
Brain	21	9	0.04	21	3	0.18
Esophagus	8	8	0.04	8		
Heart	19 (2)	15	0.02	19		
Intestine						
Duodenum	7	7	0.03	7	2	0.08
Jejunum and ileum	20	20	0.05	20 (2)	2	0.22
Large	22	22	0.06	22 (4)	1	0.12
Kidney	24 (3)	16	0.06	24 (1)	1	0.16
Liver	24 (2)	2	0.04	24 (5)	3	0.30
Lung	24	24	2.6	24 (3)	2	0.14
Muscle	18 (1)	12	0.02	18		
Pancreas	21 (2)	14	0.06	21 (2)	4	0.17
Prostate	8 (1)	6	0.08	8 (1)	1	0.24
Spleen	22 (1)	14	0.04	22 (1)	1	0.20
Stomach	20	19	0.03	20 (2)	4	0.13
Thyroid	8	8	0.34	8		

*The numbers in parentheses indicate the number of samples with a trace.

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TABLE 17 (continued)

Tissue	Number of Samples			Average Value for Samples Containing Element (μg/g)	Number of Samples			Average Value for Samples Containing Element (μg/g)
	Analyzed		Containing Element*		Analyzed		Containing Element*	
	Cadmium				Chromium			
Adrenal	3		2	0.41	3		3	0.08
Aorta	12		1	0.87	12	(2)	4	0.07
Bladder	13				13		5	0.06
Bone	23				23	(1)		<0.8 T
Brain	21				21	(2)	2	0.02
Esophagus	8				8	(1)	5	0.03
Heart	19				19	(1)	8	0.03
Intestine								
Duodenum	7	(2)		<0.60 T	7		2	0.03
Jejunum and ileum	20	(5)	5	0.92	20	(4)	6	0.02
Large	22				22	(2)	11	0.04
Kidney	24		24	31	24	(2)	4	0.04
Liver	24	(1)	22	3.3	24	(7)	4	0.03
Lung	24	(4)	7	1.1	24		23	0.14
Muscle	18				18	(1)	3	0.06
Pancreas	21	(7)	9	1.6	21	(2)	2	0.04
Prostate	8	(1)		<1.0 T	8	(1)	2	0.30
Spleen	22		1	1.3	22	(8)	5	0.05
Stomach	20	(2)		<0.64 T	20	(4)	6	0.03
Thyroid	8	(1)	2	1.9	8	(2)	3	0.06
	Cesium				Cobalt			
Adrenal	3				3		2	0.05
Aorta	12				12		2	0.12
Bladder	13	(1)	1	1.7	13			
Bone	23				23			
Brain	21				21			
Esophagus	8				8			
Heart	19				19		1	0.20
Intestine								
Duodenum	7				7			
Jejunum and ileum	20				20			
Large	22				22		1	0.12
Kidney	24	(2)		1.1 T	24	(1)		<0.11 T
Liver	24				24	(2)	4	0.12
Lung	24		12	3.1	24	(1)	3	0.22
Muscle	18				18			
Pancreas	21				21			
Prostate	8				8			
Spleen	22				22			
Stomach	20				20			
Thyroid	8		1	2.8	8		2	0.26

*The numbers in parentheses indicate the number of samples with a trace.

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TABLE 17 (continued)

Tissue	Number of Samples: Analyzed	Number of Samples: Containing Element*	Average Value for Samples Containing Element (μg/g)	Number of Samples: Analyzed	Number of Samples: Containing Element*	Average Value for Samples Containing Element (μg/g)
	Copper			Iron		
Adrenal	3	3	1.1	3	3	28
Aorta	12	12	1.1	12	12	30
Bladder	13	13	1.1	13	13	19
Bone	23	23	0.69	23	23	95
Brain	21	21	4.8	21	21	44
Esophagus	8	8	1.3	8	8	32
Heart	19	19	3.1	19	19	46
Intestine						
Duodenum	7	7	1.5	7	7	48
Jejunum and ileum	20	20	3.0	20	20	32
Large	22	22	1.4	22	22	29
Kidney	24	24	2.9	24	24	76
Liver	24	24	5.7	24	24	170
Lung	24	24	1.4	24	24	210
Muscle	18	18	0.90	18	18	31
Pancreas	21	21	1.8	21	21	43
Prostate	8	8	1.9	8	8	25
Spleen	22	22	1.3	22	22	280
Stomach	20	20	1.5	20	20	24
Thyroid	8	8	1.2	8	8	69
	Gold			Lanthanum		
Adrenal	3	(1) 2	0.24	3		
Aorta	12	(2) 1	0.24	12		
Bladder	13	(1)	<0.16 T	13		
Bone	23			23		
Brain	21			21		
Esophagus	8	(2)	<0.19 T	8		
Heart	19	(1) 1	0.33	19		
Intestine						
Duodenum	7			7		
Jejunum and ileum	20	(1)	<0.18 T	20		
Large	22			22		
Kidney	24	(1)	<0.22 T	24		
Liver	24			24	(1)	<1.2 T
Lung	24			24	(3)	<1.1 T
Muscle	18			18		
Pancreas	21			21		
Prostate	8			8		
Spleen	22			22	(6)	<1.3 T
Stomach	20			20		
Thyroid	8			8		

*The numbers in parentheses indicate the number of samples with a trace.

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TABLE 17 (continued)

Tissue	Number of Samples			Average Value for Samples Containing Element (μg/g)	Number of Samples			Average Value for Samples Containing Element (μg/g)
	Analyzed		Containing Element*		Analyzed		Containing Element*	
	Lead				**Molybdenum**			
Adrenal	3		3	0.08	3	(1)	2	0.17
Aorta	12	(1)	11	0.87	12			
Bladder	13	(1)	8	0.23	13			
Bone	23		23	4.2	23			
Brain	21	(5)	4	0.85	21		1	0.30
Esophagus	8	(2)	5	0.09	8			
Heart	19	(7)	4	0.68	19		1	0.30
Intestine								
Duodenum	7		5	0.10	7			
Jejunum and ileum	20		15	0.38	20			
Large	22	(6)	10	0.12	22		1	0.07
Kidney	24		24	0.94	24		24	0.33
Liver	24		24	1.5	24		21	1.1
Lung	24		24	0.63	24			
Muscle	18	(3)	2	0.09	18			
Pancreas	21		21	0.63	21			
Prostate	8	(5)	1	2.6	8		1	0.13
Spleen	22		21	0.38	22			
Stomach	20	(4)	14	0.14	20			
Thyroid	8	(2)	6	0.14	8			
	Manganese				**Nickel**			
Adrenal	3		3	0.15	3		3	0.50
Aorta	12		12	0.10	12		3	0.35
Bladder	13		11	0.10	13	(1)	3	0.29
Bone	23	(1)		<0.35 T	23		1	1.8
Brain	21		21	0.26	21		1	0.15
Esophagus	8		8	0.14	8		1	0.09
Heart	19		19	0.18	19	(1)	3	0.17
Intestine								
Duodenum	7		7	0.3	7	(1)		<0.08 T
Jejunum and ileum	20		20	0.43	20	(2)	4	0.34
Large	22		22	0.23	22	(2)	9	0.18
Kidney	24		24	0.56	24			
Liver	24		24	0.76	24		2	0.26
Lung	24		24	0.19	24		8	0.33
Muscle	18		18	0.06	18			
Pancreas	21		21	0.73	21		1	0.36
Prostate	8		8	0.30	8			
Spleen	22		22	0.13	22			
Stomach	20		20	0.25	20			
Thyroid	8		8	0.26	8		1	0.23

*The numbers in parentheses indicate the number of samples with a trace.

1026253

TABLE 17 (continued)

Tissue	Number of Samples: Analyzed		Number of Samples: Containing Element*	Average Value for Samples Containing Element (μg/g)	Number of Samples: Analyzed		Number of Samples: Containing Element*	Average Value for Samples Containing Element (μg/g)
	Lead				**Molybdenum**			
Adrenal	3		3	0.08	3	(1)	2	0.17
Aorta	12	(1)	11	0.87	12			
Bladder	13	(1)	8	0.23	13			
Bone	23		23	4.2	23			
Brain	21	(5)	4	0.85	21		1	0.30
Esophagus	8	(2)	5	0.09	8			
Heart	19	(7)	4	0.68	19		1	0.30
Intestine								
Duodenum	7		5	0.10	7			
Jejunum and ileum	20		15	0.38	20			
Large	22	(6)	10	0.12	22		1	0.07
Kidney	24		24	0.94	24		24	0.33
Liver	24		24	1.5	24		21	1.1
Lung	24		24	0.63	24			
Muscle	18	(3)	2	0.09	18			
Pancreas	21		21	0.63	21			
Prostate	8	(5)	1	2.6	8		1	0.13
Spleen	22		21	0.38	22			
Stomach	20	(4)	14	0.14	20			
Thyroid	8	(2)	6	0.14	8			
	Manganese				**Nickel**			
Adrenal	3		3	0.15	3		3	0.50
Aorta	12		12	0.10	12		3	0.35
Bladder	13		11	0.10	13	(1)	3	0.29
Bone	23	(1)		<0.35 T	23		1	1.8
Brain	21		21	0.26	21		1	0.15
Esophagus	8		8	0.14	8		1	0.09
Heart	19		19	0.18	19	(1)	3	0.17
Intestine								
Duodenum	7		7	0.3	7	(1)		<0.08 T
Jejunum and ileum	20		20	0.43	20	(2)	4	0.34
Large	22		22	0.23	22	(2)	9	0.18
Kidney	24		24	0.56	24			
Liver	24		24	0.76	24		2	0.26
Lung	24		24	0.19	24		8	0.33
Muscle	18		18	0.06	18			
Pancreas	21		21	0.73	21		1	0.36
Prostate	8		8	0.30	8			
Spleen	22		22	0.13	22			
Stomach	20		20	0.25	20			
Thyroid	8		8	0.26	8		1	0.23

*The numbers in parentheses indicate the number of samples with a trace.

1026254

TABLE 17 (continued)

Tissue	Number of Samples: Analyzed	Number of Samples: Containing Element*	Average Value for Samples Containing Element (μg/g)
Silver			
Adrenal	3	3	0.03
Aorta	12	(2) 7	0.06
Bladder	13	(5) 3	0.008
Bone	23	1	0.4
Brain	21	(3) 17	0.03
Esophagus	8	(1) 6	0.01
Heart	19	(7) 8	0.01
Intestine			
Duodenum	7	(3) 4	0.01
Jejunum and ileum	20	(6) 13	0.02
Large	22	(7) 10	0.01
Kidney	24	(5) 15	0.02
Liver	24	(7) 17	0.03
Lung	24	(11) 8	0.02
Muscle	18	(5) 3	0.02
Pancreas	21	(7) 10	0.02
Prostate	8	(2) 4	0.05
Spleen	22	(9) 5	0.06
Stomach	20	(4) 11	0.02
Thyroid	8	(2) 5	0.06
Strontium			
Adrenal	3	3	0.03
Aorta	12	12	0.20
Bladder	13	13	0.12
Bone	23	23	20
Brain	21	21	0.07
Esophagus	8	8	0.13
Heart	19	19	0.07
Intestine			
Duodenum	7	7	0.12
Jejunum and ileum	20	20	0.15
Large	22	22	0.13
Kidney	24	24	0.08
Liver	24	24	0.04
Lung	24	24	0.13
Muscle	18	18	0.04
Pancreas	21	21	0.08
Prostate	8	7	0.14
Spleen	22	22	0.06
Stomach	20	20	0.11
Thyroid	8	7	0.17
Tin			
Adrenal	3	3	0.24
Aorta	12	(1) 10	0.30
Bladder	13	11	0.20
Bone	23	(1) 1	3
Brain	21	(1)	<0.15 T
Esophagus	8	7	0.22
Heart	19	(2) 11	0.18
Intestine			
Duodenum	7	(1) 5	0.56
Jejunum and ileum	20	(1) 16	0.66
Large	22	21	0.78
Kidney	24	(2) 21	0.27
Liver	24	(1) 23	0.56
Lung	24	24	1.1
Muscle	18	(1) 1	0.12
Pancreas	21	(5) 6	0.20
Prostate	8	(2) 6	0.26
Spleen	22	(4) 15	0.27
Stomach	20	15	0.24
Thyroid	8	7	0.35
Titanium			
Adrenal	3	2	0.16
Aorta	12	(1) 2	0.48
Bladder	13	(1) 3	1.1
Bone	23		
Brain	21		
Esophagus	8	(2) 1	0.17
Heart	19		
Intestine			
Duodenum	7	1	0.08
Jejunum and ileum	20	(1) 2	0.46
Large	22	(1) 4	0.34
Kidney	24	(2) 5	0.67
Liver	24	2	0.50
Lung	24	24	2.8
Muscle	18		
Pancreas	21	(3) 3	0.36
Prostate	8	2	0.41
Spleen	22	(1) 4	1.0
Stomach	20	(2)	<0.08 T
Thyroid	8	4	1.20

*The numbers in parentheses indicate the number of samples with a trace.

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TABLE 17 (continued)

Tissue	Number of Samples		Average Value for Samples Containing Element (μg/g)	Number of Samples		Average Value for Samples Containing Element (μg/g)
	Analyzed	Containing Element*		Analyzed	Containing Element*	
	Vanadium			Zinc		
Adrenal	3			3	3	7.8
Aorta	12	(1)	<0.10 T	12	12	16
Bladder	13			13	13	21
Bone	23			23		
Brain	21			21	21	14
Esophagus	8			8	8	23
Heart	19			19	19	29
Intestine						
Duodenum	7			7	7	16
Jejunum and ileum	20	(1)	<0.09 T	20	20	22
Large	22	1	0.34	22	22	19
Kidney	24	(1)	<0.11 T	24	24	48
Liver	24	(2)	<0.12 T	24	24	48
Lung	24	(4) 12	0.27	24	24	17
Muscle	18			18	18	53
Pancreas	21			21	21	31
Prostate	8			8	8	80
Spleen	22	(2)	<0.13 T	22	22	21
Stomach	20			20	20	19
Thyroid	8			8	8	28

*The numbers in parentheses indicate the number of samples with a trace.

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