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STATISTICAL ANALYSIS OF A LOS ALAMOS SCIENTIFIC LABORATORY STUDY OF PLUTONIUM IN U.S. AUTOPSY TISSUE*

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Abstract—The Autopsy Tissue Program at the Los Alamos Scientific Laboratory was begun in 1959. To date, tissues from 900 or more persons in 7 geographic regions throughout the U.S. have been collected and analyzed for plutonium content. The tissues generally consist of lung, liver, kidney, lymph node, bone, spleen, thyroid and gonadal tissues for each individual. The present objective of the program is to determine the level of plutonium in human tissues due solely to fall-out from weapons testing. The baseline thus established is to be used to evaluate future changes. Geographical comparisons are made, but require adjustment because of outliers, and time and age trends present in the data.

I. INTRODUCTION

PLUTONIUM IS extremely rare in nature, hence non-occupational exposure to ^{239}Pu is usually a result of fallout from atmospheric weapons testing. Occupational exposures may occur in facilities producing or using plutonium. Exposures may result from accidental ingestion, inhalation, or wounds. Data on exposed populations have been collected at several laboratories but on a less extensive scale than at Los Alamos.

The autopsy tissue program at Los Alamos Scientific Laboratory (LASL) was established in 1959. Its original objective was to validate urine bioassay estimates of plutonium in occupationally exposed laboratory employees and to determine the pattern of plutonium deposition in the body. A second objective which developed from the first is that of establishing baseline concentrations of plutonium in tissues of the non-occupationally exposed general population in various geographic areas. Once established, such baselines will be useful in monitoring changes related to the growth of the nuclear industry. It should be emphasized that the total amounts of plutonium found in tissue samples of an individual in this study are 3–4 orders of magnitude smaller than the ICRP recommended maximum permissible body burden of 40 nCi of plutonium for occupational exposures (ICRP72).

Tissues from seven geographic regions are collected. These regions include (1) Los Alamos, New Mexico (2) New Mexico (other than Los Alamos) (3) Colorado (4) New York (5) Pennsylvania (6) Illinois (7) Georgia–South Carolina. The tissues collected include bone (rib and/or sternum and/or vertebral wedge), kidney, liver, lung, lymph node, rib, spleen, thyroid and gonadal tissue. Pathologists from around the country provide these tissues as permitted by their local and state autopsy laws.

When these tissues are received, they are

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ashed and dissolved in acid. A fraction of the solution is analyzed, the remainder being retained as an archival sample.

The samples are passed through an ion-exchange column and the isolated plutonium electrodeposited on stainless steel planchets. For samples analyzed before 1972, ^{236}Pu tracer was added (just prior to ion-exchange) to estimate the fraction (R) of plutonium recovered. Since June 1972, ^{242}Pu has been the tracer of choice because of its longer half-life and lower energy of alpha decay. Beginning in 1976, the tracer has been added to the wet tissue prior to ashing in order to give an indication of the recovery for the entire analytical procedure. The α-activity of the ^{239}Pu spectrum is measured for 50,000 sec. The measured activity is divided by an efficiency factor (E) which is the fraction of the total activity reaching the detector. The result is given in disintegrations per minute (D),

$$D = (S/t_1 - B/t_2)RE$$

where S is the sample count, B the average background count, and t_1 and t_2 the respective times (in minutes) for which the sample and backgrounds are counted. One disintegration per minute of ^{239}Pu is approximately equivalent to 7.14×10^{-12} g of ^{239}Pu.

The data gathered to date (approx. 900 cases) were reported in *Health Physics* (Mc79). The data consist of the measured concentrations on each sample and an indication of whether the measurement is significantly greater than zero. Two methods were used to assess the significance of the sample count. In the first method a minimum detection limit (the 99th percentile of the net background for reagent blanks) was set up and samples whose net count fell below the detection limit were declared not to be significantly different from zero, i.e. nothing was detected. This method did not, however, take into account the recovery of the internal tracer, efficiency of the detector for measuring alpha activity, or the count rate for the sample. The second method consisted of constructing an approximate 95% confidence interval on the concentration (D) of each sample, based on propagation of error formulae. If the confidence interval included zero, the activity in the sample was judged not to be significantly different from zero. With the published data there is an expanded account of the history of the program, the measurement process, and the quality control program.

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2. STATISTICAL NATURE OF THE SAMPLE

It is important to realize that autopsy samples do not, in general, constitute random samples from *all* deaths. The reason for this is that some causes of death are more heavily represented in autopsy cases than in a sample of all deaths. Traumatic deaths or deaths from unknown causes (including unattended deaths) are more likely to require autopsy, although practices vary from place to place. As long as the "reason" for autopsy has nothing to do with the plutonium concentration in the tissue, the sample may be treated as a random one. Traumatic deaths and deaths from unknown causes are not *believed* to have anything to do with exposure to fallout. In order to verify this belief, we present in Tables 1 and 2 some common causes of death in our sample along with the associated plutonium concentration in lung and liver tissue. A χ^2 test of independence was used to measure association between cause of death and plutonium concentration. Values of 32.5 and 36.4 with 28 degrees of freedom indicate no detectable association. We conclude from this that our sample may be treated as a random sample with respect to plutonium concentration.

Many autopsies are done because the pathologist has obtained consent of the person or his next of kin. If a person knew that he had been (occupationally) exposed to plutonium other than fallout, he or his next of kin may have been more likely to give consent for autopsy. This might have caused us concern in the analysis, but if there was even the slightest evidence of occupational exposure, the sample was classified as such and does not appear in

Table 1. Lung Tissue: Number of persons in each cause of death category

	Plutonium concentration (dis/min per kg)					
Cause Of Death	.2	.2 -.4	4-.8	.8-2	>2	Totals
Homicide	2	8	9	7	4	30
Accident	7	2	4	3	2	18
Injury	3	5	4	3	4	19
Heart	14	23	13	6	8	64
Pneumonia	8	8	2	4	1	23
Cancer	6	8	3	4	3	24
Alcohol, Drugs	3	7	8	2	0	20
Other	16	21	23	13	3	76
Totals	59	82	66	42	25	274

$\chi^2 = 32.53$ with 28 d.f.

the published data with which we are dealing here.

Table 3 gives the number of samples in each geographic tissue-sex category. The age distributions for each geographical region are shown in Fig. 4. (The number of cases shown in Fig. 4 and Table 3 do not agree because the age was not known for every subject in the data base.) These may or may not be typical of the general population (New York is not), but the effect of age will be dealt with in section 6.

The years during which the data was collected is given in Table 4. The effect of time is discussed in section 5.

3. DATA EDITING

In every large set of data one finds outliers (observations which do not appear to be a part of the bulk of the data). These may result from errors in observation, transcription, or keypunching or a failure to measure what was intended (such as contaminated or misclassified samples). In our data, the plutonium concentration is near background, and even slight contamination may have a significant effect. Some contamination from natural uranium and thorium has been observed in freshly purchased reagents and on new stainless steel planchettes. The amount of contaminant analyzed with the autopsy specimen during the analysis may have been equal to the activity in the sample, thus causing the measurement process to give erroneously high results. Outliers may also occur as a result of processing a sample with high activity along with other samples.

We show later that measurements using small aliquots and small tissue samples are much more variable than samples from larger aliquots and larger tissues, and this fact plays a part in creating outliers. A third contributor to outliers is improperly prepared samples con-

Table 2. Liver Tissue: Number of persons in each cause of death category

	Plutonium concentration (dis/min per kg)					
Cause of Death	.4	.4-1	1-2	2-3	>3	Totals
Homicide	3	6	10	6	5	30
Accident	1	3	5	3	6	18
Injury	7	3	5	2	4	21
Heart	4	12	20	13	9	58
Pneumonia	4	6	11	3	4	28
Cancer	3	6	3	6	7	25
Alcohol, Drugs	9	7	4	2	4	26
Others	10	10	25	16	8	69
Totals	41	53	83	51	47	275

$\chi^2 = 36.40$ with 28 d.f.

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Table 3. Estimates of central tendency (dis/min *per* kg wet *tissue*)

GEOGRAPHIC REGION* -SEX-TISSUE	WEIGHTED MEAN	UNWEIGHTED MEAN	MEDIAN	N
LA F GONAD	.3141	.7551	0.0000	11
LA M GONAD	.7240	.6629	.5685	10
LA F KIDNEY	.4310	.6610	.1240	56
LA M KIDNEY	.3808	.7130	.3700	39
LA F LIVER	1.5547	1.7574	1.5850	62
LA M LIVER	2.3421	2.0875	1.9755	38
LA F LUNG	1.2257	1.7679	1.0240	63
LA M LUNG	1.0745	1.5398	.9860	36
LA F LYMPH NODE	18.2887	23.6345	8.3330	53
LA M LYMPH NODE	16.7592	20.2821	6.9285	34
LA F THYROID	.2063	.7210	.8110	15
LA M THYROID	3.2724	4.3034	1.6580	14
LA F VERTEBRAE	1.0091	.9759	.4320	32
LA M VERTEBRAE	.8280	1.3463	.7730	18
NM M GONAD	.0728	.1453	.0525	26
NM F KIDNEY	.2141	.3514	.0810	39
NM M KIDNEY	.2250	.4381	.1095	86
NM F LIVER	1.6310	1.7476	.7210	33
NM M LIVER	2.0498	2.0487	1.7645	84
NM F LUNG	1.5873	1.4863	.9540	33
NM M LUNG	1.0337	1.0035	.6135	84
NM F LYMPH NODE	12.5212	14.6945	6.6670	31
NM M LYMPH NODE	8.5974	12.7800	5.4285	82
NM M RIB	1.0588	1.2274	.9580	19
NM M SPLEEN	.1856	.2081	.1510	23
NM M THYROID	1.0785	.9864	.5380	25
NM F VERTEBRAE	1.0219	1.5089	.5560	21
NM M BERTEBRAE	1.0787	1.6225	.7730	63
CO F BONE	1.2260	1.3576	.8800	17
CO M BONE	1.8941	1.9441	1.5055	32
CO F GONAD	.4942	.2784	.0470	14
CO M GONAD	.3755	.4144	.1110	74
CO F KIDNEY	.2266	.4897	.1400	49
CO M KIDNEY	.1693	.3877	.1010	92
CO F LIVER	1.5338	1.6215	1.4010	72
CO M LIVER	1.8423	2.0132	1.7350	129
CO F LUNG	.5252	.4950	.4005	68
CO M LUNG	.5886	.6093	.4360	125
CO F LYMPH NODE	4.6883	13.2410	7.0495	42
CO M LYMPH NODE	4.4788	20.2237	3.0385	88
CO F RIB	.7936	.6645	.7430	10
CO M RIB	.4742	.4488	.4145	22
CO F SPLEEN	.1420	.1488	.1075	18
CO M SPLEEN	.1071	.1130	.1190	31
CO F THYROID	.2681	.2545	.4365	12
CO M THYROID	.8503	.8813	.3330	14
CO F VERTEBRAE	.5834	.6641	.4590	27
CO M VERTEBRAE	.9400	1.0822	.7225	44
NY M GONAD	1.1291	1.4324	1.0000	29
NY M LIVER	1.5789	1.7680	1.5000	27
NY M LUNG	.9426	1.0999	.6290	31
NY M VERTEBRAE	1.4080	2.8785	1.5395	26
PA F GONAD	.6732	.7051	.7665	12
PA M GONAD	.6531	.8522	.3135	108
PA F KIDNEY	.1496	.1523	.0990	51
PA M KIDNEY	.1419	.1671	.1115	150
PA F LIVER	1.3121	1.4467	1.4970	41
PA M LIVER	1.3644	1.4988	1.2900	121
PA F LUNG	.4494	.5017	.3025	42
PA M LUNG	.3532	.3729	.2540	117
PA F LYMPH NODE	6.9043	6.8241	4.0630	19
PA M LYMPH NODE	2.2742	3.9771	1.6160	73
PA F RIB	.9732	1.0404	.9270	13
PA M RIB	.5062	.5604	.4310	68
PA F SPLEEN	.2007	.2318	.1520	42
PA M SPLEEN	.1966	.2839	.1645	148
PA F THROID	1.2062	1.9023	.9620	20
PA M THYROID	1.2326	1.5684	.5750	101
PA F VERTEBRAE	.3772	.3892	.3630	11
PA M VERTEBRAE	.4571	.4556	.3650	67
GA M GONAD	.1455	.1362	.1050	21
GA F KIDNEY	.0835	.1004	.0520	49

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Table 3. (Contd)

GEOGRAPHIC REGION* -SEX-TISSUE	WEIGHTED MEAN	UNWEIGHTED MEAN	MEDIAN	N
GA M KIDNEY	.1451	.1853	.1155	62
GA F LIVER	1.6440	1.7958	1.5270	57
GA M LIVER	2.1169	2.2240	2.1470	76
GA F LUNG	.3188	.3454	.2985	56
GA M LUNG	.5994	.6252	.3325	76
GA F SPLEEN	.2047	.2362	.1730	47
GA M SPLEEN	.1667	.1854	.1635	48
GA F VERTEBRAE	.5651	.6083	.6075	28
GA M VERTEBRAE	.4081	.3870	.4000	43
IL F LIVER	1.4967	1.5170	1.4430	22
IL M LIVER	1.6514	1.7810	1.7445	14
IL F LUNG	.1358	.1568	.1170	23
IL M LUNG	.1023	.1128	.0975	14

*LA = Los Alamos
NM = New Mexico (other than Los Alamos)
CO = Colorado
NY = New York
PA = Pennsylvania
GA = Georgia and South Carolina
Il = Illinois

taining undissolved solids that interfere with the measurement process. Finally, there is a possibility that, despite all efforts to prevent it, some occupational cases have crept into the data base. Frequently the only indication that an observation is an outlier is its magnitude. If it is much larger than the bulk of the data, we suspect the measurement process. We did not look for outliers on the low side since we were mainly interested in contamination. Undissolved solids and erroneous tissue weights can lead to outliers on the low side, but they are much harder to detect.

Large erroneous observations can seriously impair the statistical analysis of the data. They can bias the mean upward, increase variances, cause tests of hypotheses to fail. For these reasons, we have omitted observations which have been identified as outliers by a standard statistical test. We believe such omissions will give more realistic estimates of means, standard deviations and percentiles. We have used the Grubbs' statistic as a test for single outliers and the Tietjen–Moore test (Ti72) as a test for multiple outliers.

In Table 5, we present the results of our outlier testing. For each geographic location, sex and tissue type, the number of observations in that set (n) and the number of outliers detected (k) is given. Suspected observations are declared to be outliers only when found to be significant at the $\alpha = 0.05$ level. Also presented are the case number, the concentration, and the percentile (percentage of observations less than) corresponding to the concentration.

The case against an outlier cannot be proven absolutely with statistical methods. There may be statistical evidence that the observation does not belong with the bulk of the data, but there is always some chance (however remote)

Table 4. Years during which data were collected

GEOGRAPHIC REGION	YEARS
LOS ALAMOS	1959-1963, 1967-1977
NEW MEXICO	1960-1963, 1965-1976
COLORADO	1970-1977
NEW YORK	1967-1968
PENNSYLVANIA	1974-1977
GEORGIA-SOUTH CAROLINA	1972, 1974-1976
ILLINOIS	1973-1977

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Table 5. Results of outlier testing

GEOGRAPHIC REGION-SEX-TISSUE	n	k	CASE NO.	dpm/kg	OUTLIER PERCENTILE	ALIQUOT SIZE (%)	WET WEIGHT (KG)	BONE	GONAD	KIDNEY	LIVER	LUNG	LYMPH NODE	RIB	SPLEEN	THYROID	VERTEBRAE
LA-F-Kidney	58	2	3-38	11.055	98	10	.199				66	80	32				92
			1-142	7.647	97	10	.170				58	53	66				
LA-M-Kidney	40	1	3-36	17.651	98	10	.315				67	69	75				
LA-F-Liver	64	2	11-82	43.904	98	25	1.00		27	40		19	55		27	69	
LA-F-Lung	64	1	11-18	8.783	98	25	.475				34		84		36	6	25
LA-M-Lung	38	2	3-62	14.081	97	2.5	.767			95	54		60				86
			1-88	7.655	95	20	.307			71	38		80				
LA-F Lymph Node	56	3	7-114	857.692	98	40	.0013			5	65	60			92	44	58
			7-2	369.512	96	40	.0041			12	81	22					61
			5-2	290.00	95	20	.003			41	25	50					47
LA-M-Lymph Node	39	5	1-60	1093.182	98	40	.0022			12	64	3					18
			3-124	327.5	95	20	.002			56	36	18					9
			11-128	293.33	93	50	.0009		55	90						93	
			1-60	227.273	90	10	.0066			12	64	3					18
			11-150	218.947	88	50	.0019			34	92					20	
LA-F-Spleen	11	2	7-114	3.554	92	10	.171			5	65	60	98			44	58
			11-86	2.857	83	50	.217		81	62	66	61	38	71		81	33
LA-F-Thyroid	16	1	11-138	8.000	94	50	.004		36		30	13	70				
LA-F-Vertebrae	36	4	2-146	23.256	97	2	.215			71	25	47	80				
			2-102	20.974	95	4	.267			38	41	94	93				
			3-38	9.559	92	4	.170			98	66	80	32				
			5-56	9.143	89	10	.070			67	13	56	5				
LA-M-Vertebrae	21	3	3-76	49.80	95	10	.050			78	3	28	70				
			3-82	19.737	91	10	.038			29	74	49	23				
			3-62	18.750	86	4	.088			95	56	97	60				
MM-M-Gonad	28	2	7-128	5.385	97	50	.013			42	36	6	65	20	78	40	38
MM-M-Kidney	41	2	1-82	25.937	98	10	.320					82	38				
			1-84	4.701	95	10	.234					59					
MM-M-Kidney	87	1	7-50	5.761	99	50	.309				6	12	42				85
MM-F-Liver	35	2	7-92	120.705	97	25	.596			52		41	14				69
MM-F-Lung	36	3	2-104	46.626	97	10	.163			14	19		14				7
			3-64	9.653	92	2.5	.750			67	44		57				88
MM-M-Lung	85	1	3-94	231.82	99	2.5	.665			14	27		68				31
MM-F-Lymph Node	36	5	5-12	400.00	97	20	.001			60	50	27					58
			3-52	385.00	95	20	.002			79	25	62					92
			7-94	256.667	92	40	.0015			10	14	51					73
			5-88	188.750	89	40	.002			67	31	68					54
			11-56	142.00	86	50	.001			90	69	11					62
MM-M-Lymph Node	85	3	11-112	305.714	99	50	.007		70	68					43	46	
			2-32	277.50	98	20	.004			78	76	75					
			3-92	141.25	97	20	.004			10	18	68					78
MM-M-Rib	21	2	11-8	7.000	95	50	.012		67	53	55	30	39		22	65	26
MM-M-Spleen	24	1	11-76	1.182	96	50	.022			34	49	38	69			12	53
MM-M-Thyroid	27	2	11-120	18.00	96	50	.004		7						74		
			11-140	10.667	93	50	.003		63	7			30				
MM-F-Vertebrae	25	4	3-56	125.796	96	4	.063			88	83	65	46				
			3-52	60.00	92	4	.070			79	25	62	95				
			3-64	52.00	88	4	.050			57	44	92	57				
			5-46	14.643	85	25	.115			71	78	78	43				
MM-M-Vertebrae	69	6	3-30	77.00	99	4	.075			60	93	76	48				
			3-42	35.769	97	4	.130			91	58	92	76				
			3-50	33.857	96	4	.175			84	51	70	45				
			2-148	17.368	94	4	.321			81	95	96	69				
			7-10	16.842	93	5	.076			91	57	25	62				
			2-150	12.556	91	4	.223				72	85	37				
CO-M-Bone	33	1	8-12	16.667	97	2	.300			24	99	98					
CO-F-Kidney	53	4	8-38	56.711	98	10	.076				96	26		17			7
			6-134	9.115	96	10	.113				57	59	98				93
			8-2	7.719	95	10	.114				86	71	4	67			48
			6-174	7.213	93	10	.122				11	23	76				66
IL-M-Lung	35	1	13-24	0.471	94	25	.200										

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Table 5. (*Contd*)

GEOGRAPHICAL REGION-SEX-TISSUE	n	k	CASE NO.	dpm/kg	OUTLIER PERCENTILE	ALIQUOT SIZE (%)	WET WEIGHT (KG)	BONE	GONAD	KIDNEY	LIVER	LUNG	LYMPH NODE	RIB	SPLEEN	THYROID	VERTEBRAE
CO-M-Kidney	94	2	6-126	30.357	99	10	.196				69	41	51				32
			8-66	10.972	98	10	.072				45	91	4	48			
CO-M-Liver	131	2	8-12	10.824	99	25	.306	97		24		98					
			8-116	10.611	98	25	.286		28	18			33				
CO-F-Lung	69	1	6-4	3.372	99	50	.325	50			84		84				
CO-M-Lung	128	3	8-24	67.533	99	25	.890		28	55	78		73	24			
			8-12	15.951	98	25	.163	97		24	99						
			6-10	4.950	98	50	.404	35			97		59				
CO-F-Lymph Node	44	2	6-134	76.136	98	40	.0022			96	52	59					93
			8-44	73.333	96	40	.0015			76	41	17		83			
CO-M-Lymph Node	89	1	6-150	537.50	99	40	.002		97	77	86	88					
CO-F-Rib	11	1	8-64	8.235	92	50	.017			35	67	7					
CO-M-Rib	24	2	8-18	2.429	96	20	.140				93	69	63				
			8-68	2.203	92	20	.227			86	42	11					
CO-M-Spleen	33	2	8-136	1.321	97	50	.268		44	46	25	95		84			
			22-4	1.087	94	50	.046		61	46	35	60	47			50	
CO-F-Thyroid	13	1	8-130	3.412	93	50	.017		33	52	14	4	2		16		
CO-M-Thyroid	17	3	16-36	21.684	94	50	.019		45	36					59		
			16-42	20.824	89	50	.017		15						50		
			8-128	5.500	83	50	.004		28	65	28	9	16		68		45
CO-F-Vertebrae	28	1	8-16	12.620	97	20	.271			63	18	64	13	50			
CO-M-Vertebrae	46	2	6-150	18.156	98	20	.282		97	77	86	88	99				
			8-4	6.549	96	20	.142			95	21	93	84	16			
NY-M-Gonad	32	3	4-16	214.25	97	20	.020				97	71					69
			4-52	45.50	94	20	.030				83	12					17
			4-6	10.60	91	20	.025				27	68					83
NY-M-Liver	29	2	4-16	6.618	97	5	.550		97			71					69
			4-10	6.579	93	5	.456		61			79					97
NY-M-Lung	33	2	4-8	10.958	97	5	.480		76		20						77
			4-2	8.000	94	5	.615		79		73						73
NY-M-Vertebrae	29	3	4-10	23.529	97	4	.170		61		93	79					
			4-30	19.583	93	4	.180		52		13	76					
			4-46	19.112	90	4	.242		64		7	15					
PA-F-Gonad	15	3	19-64	13.714	94	50	.007				93	14	5		29		
			19-110	9.000	88	50	.002			62	61	26			4		
			14-22	7.333	81	30	.005			88	86	67	45		62	83	
PA-M-Gonad	110	2	19-96	81.111	99	50	.018				86	54	28	83	63	86	
			15-70	13.714	98	50	.021			8				1		42	53
PA-F-Liver	43	2	15-2	61.394	98	25	1.004			17		49					
			19-42	6.506	95	25	.482					72					
PA-M-Lung	120	3	19-92	20.714	99	25	.336		82		84		86	56	69	63	62
			20-94	13.674	98	25	.356			16	8		51		72	64	94
PA-M-Lymph Node	77	4	14-26	150.00	99	60	.002			83	52	33			85	89	
			15-92	123.33	97	50	.006		85	17	42						
			14-24	56.25	96	60	.008			92	13	84			95	69	
			15-36	55.00	95	50	.004		41	2						93	
PA-F-Rib	14	1	14-2	9.60	93	25	.01			98	80	35	20		96	88	
PA-M-Rib	70	2	14-32	8.571	99	50	.028		54	98	36	34			29	22	
			14-58	4.300	97	50	.02		39	88	46	11			45	22	
PA-F-Spleen	44	2	15-76	3.059	98	50	.017		13	37			55	7		13	
			14-2	2.175	96	25	.057			98	80	35	20	99		88	
PA-M-Spleen	149	1	19.150	6.674	99	50	.170			95	62	7		34			3
PA-F-Thyroid	23	3	14-54	26.500	96	50	.004		38	8	64	40			58		
			19-6	13.000	92	50	.008		31	19	77	72			84		
			14-2	12.50	88	30	.004			98	80	35	20	99	96		
PA-M-Thyroid	104	3	15-56	137.00	99	50	.008						82		83		
			19-98	69.867	98	50	.015		28		89	64			65		
			15-64	26.588	97	50	.017		96	38			27	25	49		10
GA-F-Kidney	52	3	9-14	30.00	98	10	.062				22	54					93
			17-86	1.747	96	50	.079				29	83			53		97
			17-52	1.505	94	50	.101				56	42			63		10
GA-M-Kidney	64	2	9-28	83.633	98	10	.245				85	1					
			9-12	3.75	97	10	.184				22	91					
GA-F-Liver	58	1	9-150	6.957	98	25	.445					86			78		23
GA-M-Liver	77	1	17-138	8.035	99	25	.458			69		64			92		73
GA-F-Lung	58	2	25-12	15.323	98	25	.372				59						
			25-10	4.014	97	25	.573				64						
GA-M-Lung	77	1	9-10	73.016	99	25	.425		77	94	35						82
GA-F-Spleen	48	1	9-126	1.650	90	50	.000			49	73	59					
GA-M-Spleen	49	1	17-32	1.244	98	50	.045			62	95	78					

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that the measurement in question may not be erroneous. To assist in deciding the case against an outlier, we give some related information which, in many cases, supports the evidence that the observation is indeed erroneous. Since small aliquot fractions and small wet weights can lead to high apparent concentrations, aliquot size and wet weight of the tissue involved are reported. It is expected that when one tissue of a given individual shows a relatively high concentration of plutonium, other tissues from that individual will also be high. If this is not the case, the high tissue value is suspect. We have, therefore, presented the percentiles of related tissues for the same individual. Altogether we detected and omitted 133 outliers in the 4373 observations (3%). For the most part, the outliers were obvious (from their magnitude) even without statistical tests; frequently they were several orders of magnitude larger than the next closest observation.

4. ESTIMATES OF CENTRAL TENDENCY

After the outliers have been identified and removed, it is appropriate to estimate central tendencies (i.e. means, medians, etc.). Each geographic region, sex and tissue combination is examined separately. For each of these sets the 10, 25, 50, 75 and 90th percentiles are calcu-

Table 6. Percentiles by geographic region, sex and tissue type (dis/min *per* kg *wet tissue*)

GEOGRAPHIC REGION -SEX-TISSUE	10	25	50	75	90
LA F GONAD	-4.4572	-.2500	0.0000	3.6670	5.7056
LA M GONAD	-1.0951	-.1128	.5685	1.1055	2.9242
LA F KIDNEY	-.0453	0.0000	.1240	1.0790	2.3750
LA M KIDNEY	0.0000	.0550	.3700	.9200	2.4750
LA F LIVER	.1585	.7573	1.5850	2.5870	3.9052
LA M LIVER	.3117	.8913	1.9755	2.8468	4.2868
LA F LUNG	.2120	.4770	1.0240	2.3300	5.3882
LA M LUNG	.1423	.3930	.9860	2.1145	4.3154
LA F LYMPH NODE	-.3156	0.0000	8.3330	20.8845	93.7775
LA M LYMPH NODE	-.3815	1.2260	6.9285	22.5000	81.0715
LA F THYROID	-1.1000	0.0000	.8110	1.3330	2.7602
LA M THYROID	-.3215	.6670	1.6580	8.1968	14.5000
LA F VERTEBRAE	0.0000	.1633	.4320	1.5450	2.4326
LA M VERTEBRAE	-.2801	.3010	.7730	2.0645	4.2714
NM M GONAD	-.2589	-.0833	.0525	.3873	.7632
NM F KIDNEY	-.0320	0.0000	.0810	.5140	1.2400
NM M KIDNEY	-.0015	0.0000	.1095	.4608	1.5343
NM F LIVER	.0570	.4605	.7210	2.2690	5.5270
NM M LIVER	.2625	.7353	1.7645	2.8770	4.1410
NM F LUNG	.1634	.3650	.9540	2.4625	3.5846
NM M LUNG	.1855	.3973	.6135	1.2460	2.3010
NM F LYMPH NODE	-2.8302	0.0000	6.6670	18.1250	42.4286
NM M LYMPH NODE	-.2800	.6045	5.4285	18.5415	40.2292
NM M RIB	.3230	.6150	.9580	1.7780	3.0910
NM M SPLEEN	.0148	.0710	.1510	.3540	.5502
NM M THYROID	-1.4666	0.0000	.5380	1.7915	5.0356
NM F VERTEBRAE	0.0000	.0140	.5560	1.8330	5.2882
NM M VERTEBRAE	0.0000	.2720	.7730	1.8750	5.7600
CO F BONE	0.0000	.1665	.8800	2.0465	4.5890
CO M BONE	0.0000	.7105	1.5055	3.2240	7.2166
CO F GONAD	-4.7500	-1.3998	.0470	2.8268	4.1395
CO M GONAD	-.3750	-.0445	.1110	.5185	1.7370
CO F KIDNEY	-.0500	.0215	.1400	.5115	2.4240
CO KIDNEY	-.0785	.0205	.1010	.5600	2.0381
CO F LIVER	.1512	.6718	1.4010	2.2913	2.9874
CO M LIVER	.1900	.8380	1.7350	2.9210	3.6240
CO F LUNG	.1153	.2013	.4005	.6408	1.0741
CO M LUNG	.1308	.2570	.4360	.7145	1.2698
CO F LYMPH NODE	-2.2977	0.0000	7.0495	26.1493	46.0000
CO M LYMPH NODE	-1.3148	0.0000	3.0385	13.4375	70.6365
CO F RIB	-.5706	.1875	.7430	1.0500	1.7058
CO M RIB	-.0749	.1615	.4145	.7560	.9564
CO F SPLEEN	-.0469	.0315	.1075	.2518	.3428
CO M SPLEEN	0.0000	.0190	.1190	.1740	.2868

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Table 6. (Contd)

CO F THYROID	-.9639	.2855	.4365	.7980	1.1617
CO M THYROID	-.0770	0.0000	.3330	1.5093	3.3445
CO F VERTEBRAE	.1018	.2130	.4590	.8700	1.8276
CO M VERTEBRAE	.1195	.3133	.7225	1.4653	2.9385
NY M GONAD	-.5130	.2105	1.0000	2.6015	3.5900
NY M LIVER	.2722	1.0440	1.5000	2.4040	3.2960
NY M LUNG	.0562	.2040	.6290	1.3570	3.1858
NY M VERTEBRAE	.0140	.5650	1.5395	4.0785	8.9797
PA F GONAD	-.3400	.0555	.7665	1.1875	1.8668
PA M GONAD	-.4305	-.0165	.3135	.8655	2.6067
PA F KIDNEY	-.2464	-.0440	.0990	.2670	.7156
PA M KIDNEY	-.0299	.0298	.1115	.2080	.4183
PA F LIVER	.1386	.6250	1.4970	2.1315	2.6090
PA M LIVER	.3096	.6135	1.2900	2.0160	3.2548
PA F LUNG	.0877	.1663	.3025	.6453	1.3316
PA M LUNG	.0548	.1380	.2540	.4045	.7262
PA F LYMPH NODE	-25.0000	0.0000	4.0630	18.0000	32.5000
PA M LYMPH NODE	-1.3135	.0985	1.6160	4.4485	14.8182
PA F RIB	-.0402	.5360	.9270	1.0690	3.0088
PA M RIB	.0669	.2323	.4310	.7228	1.4072
PA R SPLEEN	-.0399	.0278	.1520	.3183	.7521
PA M SPLEEN	-.0010	.0655	.1645	.3298	.6814
PA F THYROID	-.7906	0.0000	.9620	2.5748	8.0000
PA M THYROID	-.3974	0.0000	.5750	1.3810	3.8428
PA F VERTEBRAE	.1344	.1880	.3630	.5000	.7744
PA M VERTEBRAE	.1108	.1810	.3650	.6600	.9248
GA M GONAD	-.2178	-.0870	.1050	.3310	.7222
GA F KIDNEY	-.0400	-.0085	.0520	.1380	.4290
GA M KIDNEY	-.0218	.0258	.1155	.2150	.3949
GA F LIVER	.3780	.7675	1.5270	2.8585	3.5688
GA M LIVER	.3516	1.1203	2.1470	3.0433	4.3378
GA F LUNG	.0346	.1240	.2985	.4545	.7456
GA M LUNG	.1457	.2158	.3325	.7815	1.1691
GA F SPLEEN	-.0478	.0620	.1730	.4030	.6166
GA M SPLEEN	-.0379	.0843	.1635	.2905	.4292
GA F VERTEBRAE	.1736	.3123	.6075	.8378	1.1105
GA M VERTEBRAE	-.0218	.2400	.4000	.8000	.9242
IL F LIVER	.6396	.9330	1.4430	1.9470	2.5894
IL M LIVER	.6975	.9813	1.7445	2.4965	3.2505
IL F LUNG	-.0222	.0520	.1170	.3140	.3958
IL M LUNG	.0200	.0558	.0975	.1360	.2865

lated. These give a good idea of the spread of the data and are shown in Table 6. The 50th percentile is the median.

Shown in Table 3 are the median and two means: unweighted and weighted. The unweighted mean is the arithmetic mean of the data. The weighted means are related to aliquot sizes and wet weights. Measurements derived from small aliquot sizes and small wet weights are more variable than those from larger aliquots and larger tissues. The reason for this is that count data are considered to have a Poisson distribution with a parameter λ which is the average count/time interval. For a Poisson distribution both the mean and variance are equal to λ. A 25% aliquot would yield a sample with an average count (or variance) of $\lambda/4$. For such an aliquot, the measured activity x is multiplied by 4, hence the quantity of interest is the variance of $y = 4x$. The variance of y is $4^2(\mathrm{Var}(x)) = 16\ \mathrm{Var}(x) = 16(\lambda/4) = 4\lambda$, so that the variance of a 25% aliquot is four times that of the undivided sample. In other words, a 25% aliquot has twice the standard deviation of a 100% aliquot. The same is true of a tissue with small wet weight. The weighted means in Table 3 use inverse variances as weights so that small tissues and small aliquots get less weight.

5. TIME TRENDS

B. G. Bennett of the Environmental Measurements Laboratory has estimated that 320 kCi of ^{239}Pu were dispersed globally dur-

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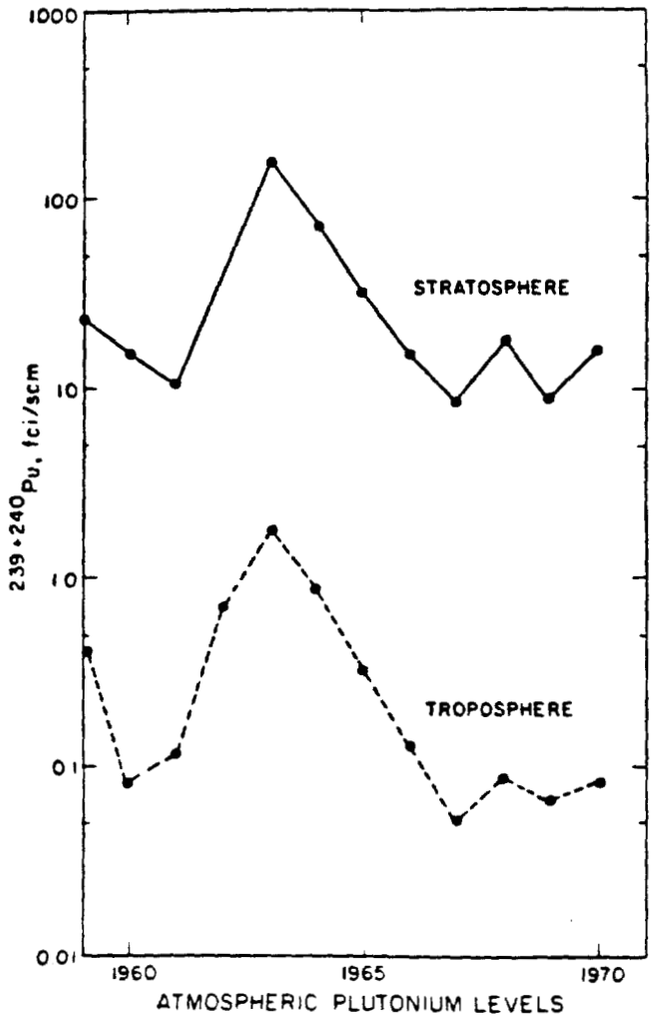

FIG. 1. Atmospheric plutonium levels.

ing atmospheric weapons testing (Be74). Beginning in 1965, levels of ^{239}Pu in surface air were measured on a monthly basis at a number of localities throughout the world (En 79). Annual averages, as calculated at McClellan Air Force Base, appear in Fig. 1, which shows that the levels of plutonium in the stratosphere began rising sharply about 1961, reached a peak about 1963, then fell off to the former levels in about 1967. Unfortunately, the localities at which the measurements were made do not coincide with those at which the autopsy tissues were taken (except NYC), but a study of the data for 1966–77 for three widely separated localities in the U.S. (New York City, Miami, Florida and Sterling, VA) indicates that these localites do not differ significantly in the total amount of ^{239}Pu received, despite the fact that some localities lag others by a month. However, surface air data for Salt Lake City (the closest station to the Colorado, New Mexico and Los Alamos sites) differs considerably from that on the east coast, so that fallout patterns across the country might have been quite different and could account for some geographical differences seen later. Harley (Ha79) has attributed part of this difference to testing at the Nevada Test Site.

There are also highly significant differences in the amounts of ^{239}Pu in the air from month to month within a year for a given station. In Table 11 are given the annual total amounts of ^{239}Pu collected by one air sampler at the given stations. These data show sizeable year-to-year differences.

As a result, some *time* trends in the data are to be *expected*, particularly since people are still inhaling plutonium which has retention half-times in the lung of 100–1000 days and in the liver and bone of 40 and 100 yr respectively (Ic72).

The form of the fallout was most probably PuO_2 and inhalation is believed to be the only significant pathway into the body (Be74). Bennett used a compartmental model for the plutonium intake and resulting burdens in the lung, liver, and bone, basing his estimates on the ICRP Task Group on Lung Dynamics model and observed levels of fallout in soil and air samples in New York City.

In Fig. 2 and 3 we have plotted (as squares) the annual median lung and liver concentrations for the New Mexico cases, since it is the earliest data available. The plots also show the results of Bennett's calculations as a solid line. The *shape* of his curves agrees with the autopsy data, and it is surprising that the agreement in magnitude is as good as it is. It is quite conceivable that a refinement in Bennett's parameters or our data could produce even better agreement. The autopsy data, then, does lend support to the theoretical model and does show that there are definite trends with time. The implication from these time trends is that

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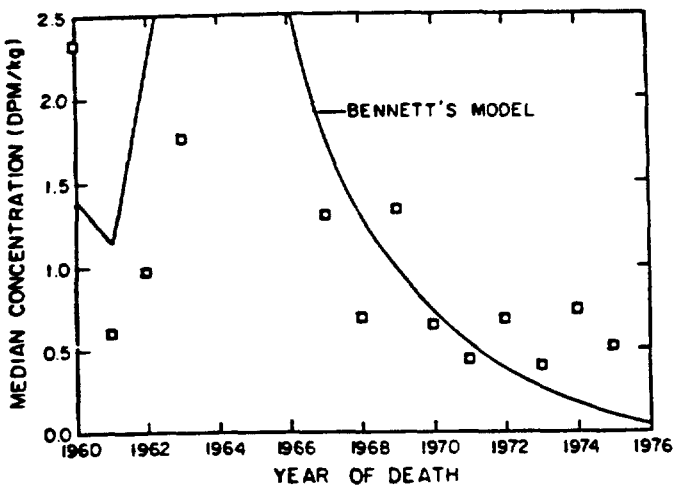

FIG. 2. Median concentration of New Mexico lung data 1960–75.

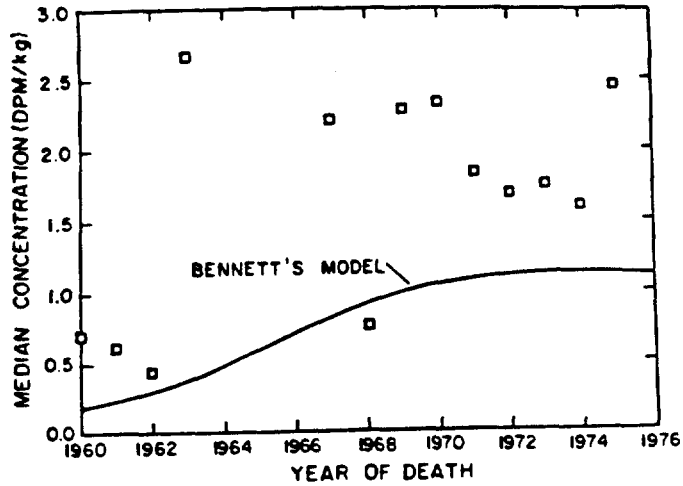

FIG. 3. Median concentration of New Mexico liver data 1960–75.

reporting a single mean or median for a given locality is not sufficient; a summary for *each year* is necessary for future work.

6. AGE TRENDS

The age at death of the persons considered in this report was an uncontrolled variable, and the observed age distributions might not be typical of the population at large. The age distributions over the entire time period are shown by locality in Fig. 4. While the distributions resemble each other generally, the New York data are a clear exception: the individuals from that population are much younger than those from other areas. This difference may be due to the fact that the New York samples are largely from unclaimed bodies and traumatic deaths which occur more frequently in younger males.

It has been suggested (Mc73) that, for a given exposure, the amount of plutonium in the liver increases with age. The same effect, to a far lesser degree, was noted for lung tissue. If age trends are present, it is important to adjust for them before making geographical comparisons. Separate regressions indicate no dependence between age and geography. In order to test for such trends with the autopsy tissue data presently available, we selected four very short segments of time (1968–69; 1970–71;

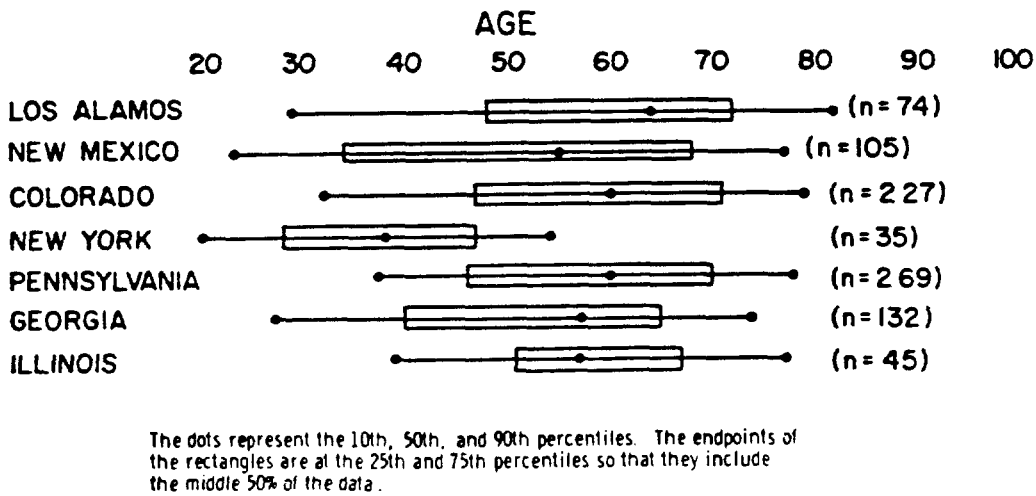

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FIG. 4. Age distributions.

1972–73; 1974–75) during which time trends should be nearly constant. For liver and lung tissue data (over all ages and localities), the plutonium concentration vs age at death was fitted to a linear relationship by least squares for each of the four short time periods. Another line was fitted to the data (for each tissue separately) over the whole time period (1968–75). Tests of whether the slope of the line is significantly different from zero were made. For the liver, the slopes are consistently different from zero, but a single line fits as well as separate lines for each time period. We conclude from this that the linear relationship, $(C) = 0.91356 + 0.01682 \times (\text{age})$, where C is the concentration of Pu (dis/min per kg) in the liver, best represents the effect of age on liver concentration. Over an 80 year lifetime, an increase of about 1.3 dis/min per kg could be expected in the liver. From ages 40 to 80, the increase would be about 0.67 dis/min per kg due to age alone.

For lung tissue, the evidence of a trend with age is not convincing.

For kidney, tracheobronchial lymph node, rib and male gonadal tissue, there is no detectable effect of age for any of the time periods.

For vertebrae, the slope (of concentration vs age at death) is significantly different from zero for the 1974–75 data and the 1968–75 data. More importantly, the slopes for the vertebrae data are negative (or near zero), and this supports the hypothesis that due to skeletal remodeling, plutonium is being transferred from trabecular bone to liver and (possibly) cortical bone. Moreover, the slopes do not seem to differ from each other, particularly if the 1968–69 data is omitted. An estimate of the slope (from the 1970–75 data) is −0.0073. A single regression line is not adequate; the age effect is affected by the year of death (i.e. the biological effect of aging on the deposition and retention of plutonium in the body is also a function of atmospheric concentration). This makes it necessary to report both year of death and age at death when reporting means or medians.

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Table 7. Sex comparisons in Colorado

Tissue	Female†	Male†	P-value*
Bone	17	32	.1151
Kidney	49	92	.7096
Lymph Node	42	88	.4351
Rib	10	22	.1932
Spleen	18	31	.5611
Thyroid	12	14	.3031
Vertebrae	27	44	.1356
Lung	60	120	.3594
Liver	64	124	.1528

*Significant if less than .05
†Number of cases

7. SEX DIFFERENCES

There are roughly twice as many males in this study as females. To test the hypothesis of sex differences, we used all the Colorado 1970–77 data adjusted for age trends. The results are presented in Table 7. The Mann–Whitney Test shows that there are no significant differences due to sex.

8. GEOGRAPHICAL COMPARISONS

We now wish to compare levels of plutonium concentration in the various geographical regions. Since the data depend upon age at death and year of death, we attempt to eliminate these factors by considering only very short segments of time (i.e. year of death) (1974–75 and 1967–68) and subtracting out the age trends found during those time periods. Almost all of the subjects in this sample were born before 1945, hence had nearly equal exposure times.

These periods of time were selected because they include the major portion the data and because they are the only periods where data is available from certain geographical locations. Plots of median plutonium concentration vs age at death for lung and liver tissue for 1974–75 are given in Figs. 5 and 6.

For the above time periods and across all locations, there is no evidence that the concentrations are normally distributed in any of the tissues. The kidney, vertebrae and gonadal tissues are the only tissues in which the concentrations appear to be lognormally distributed.

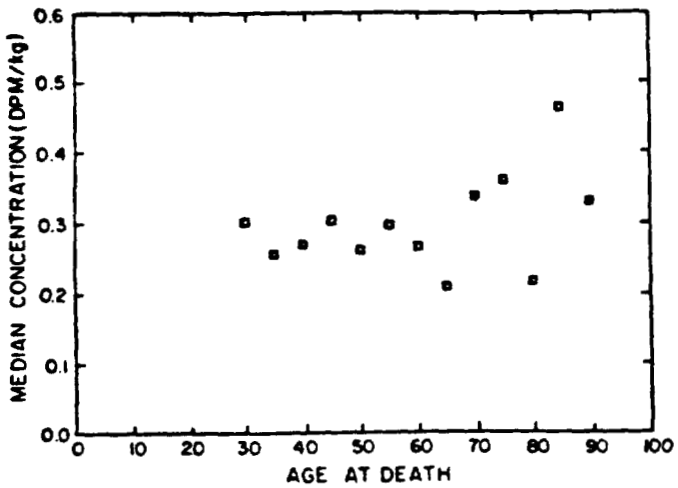

FIG. 5. Median concentrations of lung data vs age at death.

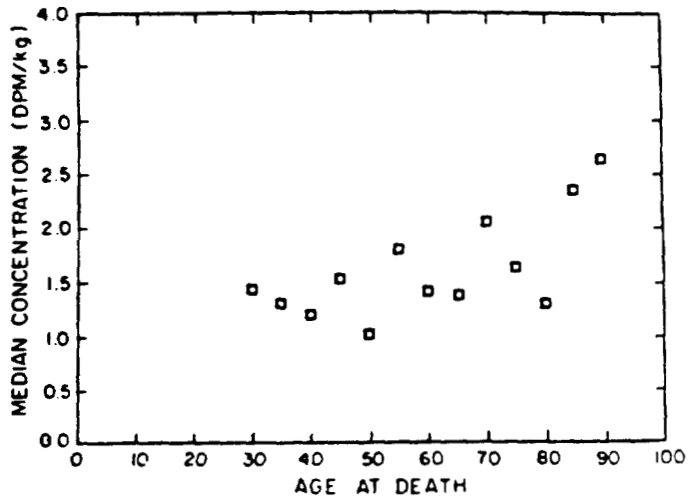

FIG. 6. Median concentrations of liver data vs age at death.

The *W*-test (Sh75) was used to establish this conclusion.

As a result of the above testing, we have chosen to use a non-parametric procedure recommended by Lin and Haseman (Li78) and Conover (Co71). This procedure consists of a Kruskal–Wallis test of the significance of among-region differences at the α-0.05 level. If this test indicates overall significance, Mann–Whitney tests are performed for all pairwise comparisons of the geographic regions (at the $\alpha = 0.05$ level). If the Kruskal Wallis test is not significant, then all pairwise comparisons are declared not significant.

In Table 8 we present a ranking of the medians adjusted for age trends. This table indicates which geographic regions have consistently large medians.

Table 9 presents the results of the Kruskal Wallis tests. For those tissues in which the *p*-value exceeds 0.05 no significant differences among regions are indicated. For the other

Table 8. Medians adjusted for age effects

	MEDIANS ADJUSTED FOR AGE EFFECTS largest					smallest
1974-75						
Kidney	PA	LA	GA	CO	NM	
Liver	LA	NM	GA	IL	PA	CO
Lung	NM	LA	GA	CO	PA	IL
Lymph Node	NM	LA	CO	PA		
Rib	LA	NM	PA			
Vertebrae	NM	CO	GA	PA	LA	
Female Gonad	CO	LA	PA			
Male Gonad	LA	PA	GA	CO	NM	
Spleen	LA	PA	GA	NM	CO	
Thyroid	LA	PA	CO	IL	GA	NM
1967-68						
Liver	LA	NM	NY			
Lung	LA	NM	NY			
Vertebrae	NM	NY	LA			

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Table 9. Results of Kruskal-Wallis tests for geographic differences

1974-75	p-value
Kidney	.5764
Liver	.0000
Lung	.0000
Lymph Node	.0247
Rib	.0072
Vertebrae	.0560
Female Gonad	.9507
Male Gonad	.0077
Spleen	.0969
Thyroid.	.0110
1967-69	
Liver	.8001
Lung	.1277
Vertebrae	.1202

tissues, there is an overall effect, and we proceed to test pairwise differences with the Mann–Whitney test.

Table 10 summarizes the results of the Mann–Whitney testing. For each tissue, those regions underlined with the *same* line do not differ significantly. Median values are given in parentheses. Even in the cases where there are significant differences, however, the differences in median are quite small—on the order of one disintegration per min per kg of tissue—so that the *practical* significance is uncertain.

For example,

Tissues	*Interpretation*
Kidney, vertebrae, female gonad, spleen, all 1967–68 tissues	No significant differences
Liver	LA, NM, GA not sig. diff. IL, PA, CO not sig. diff. LA, NM, GA sig. greater than IL, PA, CO
Lymph node	NM, LA, CO not sig. diff. PA sig. lower than NM, LA, CO
Rib	LA, NM not sig. diff. PA sig. lower than LA, NM
Male gonad	LA, PA not sig. diff. GA, CO, NM not sig. diff. LA, PA sig. greater than GA, CO, NM
Thyroid	LA, PA, CO, IL not sig. diff. GA, NM not sig. diff. LA, PA, CO, IL sig. greater than GA, NM.
Lung	IL sig. lower than other tissue. The remaining tissues divide into two groups: NM, LA, GA, CO on the high end and GA, CO, PA on the low end; with GA and CO belonging to both groups.

Table 10. Results of hypothesis testing for geographic differences

1974-75	
Kidney	PA(.114) LA(.108) CO(.081) GA(.075) NM(.063)
Liver	LA(2.399) NM(2.123) GA(1.942) IL(1.461) PA(1.398) CO(1.276)
Lung	NM(.535) LA(.447) GA(.316) CO(.301) PA(.271) IL(.104)
Lymph Node	NM(6.500) LA(6.553) CO(2.917) PA(1.923)
Rib	LA(1.125) NM(.966) PA(.460)
Vertebrae	NM(.673) CO(.631) GA(.400) PA(.363) LA(.213)
Female Gonad	CO(2.769) LA(0.667) PA(1.000)
Male Gonad	LA(.568) PA(.319) GA(.042) CO(.063) NM (.053)
Spleen	LA(.350) PA(.164) GA(.160) NM(.147) CO(.101)
Thyroid	LA(1.303) PA(.749) CO(.363) IL(.286) GA(-.194) NM(0.00)
1967-68	
Liver	LA(1.823) NM(1.730) NY(1.500)
Lung	LA(1.272) NM(1.165) NY(0.668)
Vertebrae	NM(4.557) NY(1.539) LA(0.769)

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Table 11. Total Pu concentrations in surface air for years 1966–77 (atto Ci/c m^3)

	New York City	Sterling, Va.	Miami	Salt Lake City
1966	1475.10	1195.50	1014.79	
1967	611.40	402.86	593.43	
1968	965.70	829.00	848.80	
1969	652.70	629.90	550.80	
1970	774.05	659.00	752.20	
1971	719.80	629.10	728.74	1326.10
1972	326.29	276.60	327.90	727.50
1973	160.69	125.24	202.11	255.54
1974	464.91		534.20	690.30
1975	240.53		256.24	
1976	74.40		85.87	
1977	251.49		270.18	

9. RELATIONSHIPS BETWEEN LIVER CONCENTRATION AND CONCENTRATION OF OTHER TISSUES OF THE SAME INDIVIDUAL

We wish to investigate the relationship between plutonium concentration in the liver and plutonium concentration in selected other tissues (lung, vertebrae, gonad) of the same individual.

Combining the data for all geographic regions, we selected those individuals who had measurements for both liver and the related tissue in question.

For each of the three selected tissues, we ran a linear regression of the related tissue concentrations on liver concentration. The results were as shown in Table 12.

We conclude that knowledge of liver concentration is of little use in predicting the concentration in other tissues in the same individual. The explanation for the lack of relationship is that both the liver tissue and the lung tissue concentrations, for example, are changing with time and age, but at vastly different rates (both are increasing with age, but the liver is increasing with time while the lung is decreasing with time). It is, therefore mathematically impossible for these ratios to be constant.

10. SUMMARY AND CONCLUSIONS

Tissues collected at autopsy from over 900 nonoccupationally exposed individuals from seven geographic areas in the U.S. have been analyzed for their ^{239}Pu content. The objective was to establish baselines of plutonium concentration, possibly differing by region, age and sex. The causes of death were examined and it was concluded that this sampling could be treated as a random sample of the U.S. population with respect to plutonium concentrations in the tissues.

Time trends in the retention of plutonium in the lung and liver were observed and related to the changing atmospheric inventory of fallout

Table 12. Linear Regressions: liver vs other tissues

		(males only)	
Related tissue:	Lung	Vertebrae	Gonad
number of observations	712	352	199
intercept	0.618	1.12	0.912
slope	0.074	-0.021	-0.04
correlation coefficient	0.1	-0.02	-0.045
R^2*	0.01	0.0004	0.002

*Amount of variability in the related tissue concentration explained by the regression on liver concentration.

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plutonium. Comparison of the annual median ^{239}Pu concentrations in these tissues with the projected concentrations based upon the ICRP lung model parameters showed very good agreement.

The data from the analyses of 4373 tissues were tested for the presence of outliers which may have resulted from possible errors in analysis, transcription of data, contamination of a sample, small sample sizes, etc. Confirmation of such statistically identifiable outliers was attempted by intercomparison of all tissue concentrations of plutonium in a suspect case, theorizing that if one tissue had a high concentration value, other tissues would reflect this. In this manner, approx. 3% of the data were identified as outliers and omitted from consideration of the estimates of central tendency (means, medians) of the data.

The effects of analyzing aliquots of the tissues on the variance of the measured result was examined. The variance was shown to increase as the size of the sample analyzed decreased. Weighted means (using inverse variances as weights), unweighted means and medians were presented as estimates of central tendency which serve as baselines for plutonium concentration.

The data show an increase in liver concentrations of plutonium with age and a corresponding decrease in skeletal concentrations, suggesting that remobilization of the bone mineral is releasing plutonium from the skeleton for eventual deposition in the liver.

No significant differences in tissue deposition of plutonium due to sex were evident.

An examination of the data for geographic differences was made, using short time segments to eliminate any influence of the year of death, and subtracting out the age trends found in these time periods. For the time span 1967–68, no geographic differences in any of the tissue concentrations of plutonium was observed. Individuals dying in 1974–1975 (the bulk of our data) had no regional differences in plutonium concentrations in the vertebrae, kidney, spleen and female gonads. Small regional differences were identifiable in all other tissues.

It was believed at the beginning of the study that a single average plutonium concentration over the entire U.S. population would suffice. The data show a much more complex structure, making it impossible to pool autopsy data over long periods of time, wide age ranges, or geographical regions. As a result, we have established numerous baselines, and each will have to be monitored separately in order to establish changes.

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