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The HEALTH EFFECTS of PLUTONIUM and RADIUM

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THE LOS ALAMOS SCIENTIFIC LABORATORY'S HUMAN AUTOPSY TISSUE ANALYSIS STUDY*

J.F. McInroy**

ABSTRACT

Since 1959, the Health Division, Los Alamos Scientific Laboratory has analyzed the tissues from 81 former employees of the Laboratory for plutonium. Additionally, approximately 700 autopsy cases from the general population have also been analyzed for plutonium resulting from fallout.

The variation in the distribution of plutonium in the bodies of the occupationally exposed individuals suggest that each exposure incident is unique and must be evaluated on the basis of the chemical form, solubility, particle size, mode of entry, and duration of exposure.

Particle size distribution of plutonium in a lymph node of a long-term chronic exposure case has been estimated to have a mass median diameter of 0.32 μm with a geometric standard deviation of 1.5.

The baseline concentrations of environmental plutonium have been estimated for the general population and the tissue distributions compared with the occupationally exposed cases.

INTRODUCTION

The tissue analysis program at the Los Alamos Scientific Laboratory (LASL) began in 1959. The primary objective, at that time, was the measurement of plutonium in the tissues obtained at autopsy from occupationally exposed workers. The program was expanded to include not only the determination of plutonium distribution within the body, but also the establishment of baseline levels of environmental plutonium in the non-occupationally exposed general population. With the interest and financial support of the Division of Biomedical and Environmental Research (DBER), Energy Research and Development Administration (ERDA), the

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program has been expanded to sample tissues from seven geographic areas in the United States in addition to occupational exposure cases.

MATERIALS AND METHODS

Autopsy specimens, including lung, tracheobronchial lymph nodes, liver, kidney and bone were requested from every case provided by the cooperating pathologists in each community. The unknown microdistribution in organs and the low concentrations observed in the tissues of the general population suggested that, for lung, liver and kidneys, whole organs be collected for analyses. In the case of bone, 200-300 g of vertebral wedge from the lumbar or thoracic region and/or ribs and sternum were usually supplied. Recent interest in plutonium deposition in other tissues has prompted an increase in the number of tissues sampled to include the thyroid, spleen and gonadal tissue. Because of the difficulty encountered by some pathologists in releasing whole organs, smaller quantities (≈ 500 g) of lung and liver must now be accepted.

Insulated shipping containers, plastic bags for each tissue or organ collected, an instruction guide and a pathology information sheet are provided. The samples are frozen immediately after their collection and stored until it is convenient for the pathologist, or his representative, to pack them in dry ice and ship them to us by air express. Five to ten kilograms of dry ice preserve the tissues over three to four days delivery time.

Each autopsy kit contains a Pathology Information Sheet for the pathologist to provide the pertinent background information concerning the deceased. Except for occupational exposure cases, the individual's name is not requested, and the case is identified by autopsy number only. The date of death, age at death, body weight, sex and race are identified. The residential and occupational histories are requested as well as information concerning smoking habits, use of drugs, alcohol and other relevant personal habits. The primary and secondary causes of death are identified and the gross weights of the wet tissues are recorded. Locally, those cases identified as having worked at LASL are treated separately from the general population cases. Their medical, work and exposure histories are reviewed and the pertinent data recorded in addition to the information provided by the pathologist.

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The legality of the pathologist sending tissues has been investigated and has been found to be within the limitations included in the Autopsy Consent Form used by most hospitals. Although these consent forms vary from hospital to hospital, forms similar to the ones suggested by the Law Department, American Medical Association (Form 44 in "Medico-legal Forms with Legal Analysis," A.M.A., Chicago, Illinois, 1961) are used. Form 44, Authorization for Autopsy, states ".... I (we) authorize the removal and retention or use for diagnostic, scientific, or therapeutic purposes of such organs, tissues, and parts as such physicians and surgeons deem proper." This authority is granted subject to any special restrictions by the next-of-kin but generally provides for the release of tissues for a scientific study, such as ours. In practice, the burden of responsibility is placed upon the pathologist, since he is the one most familiar with his state and/or local legal restrictions in such matters. The number of autopsy cases received from the various communities is shown in Table I. Approximately 700 cases have been analyzed to date.

Table I. Autopsy cases received since inception of program.

Area	Number of Autopsies (1959-1975)
Colorado	307
Georgia	100
Illinois	36
Pennsylvania	219
New Mexico	372*
New York	36
Tennessee	2
Total	1072

*Includes 90 former employees of LASL. Not all of these have been analyzed.

The frozen tissue, when received at LASL, is gamma-scanned to detect the presence of medical isotopes the patient may have received prior to death. Figure 1 is a flow chart showing the general steps in the analysis of each tissue. The gamma-scan will alert the analyst of the presence of ^{131}I, ^{60}Co, ^{137}Cs, ^{57}Fe, etc. As an item of interest, ^{134}Cs

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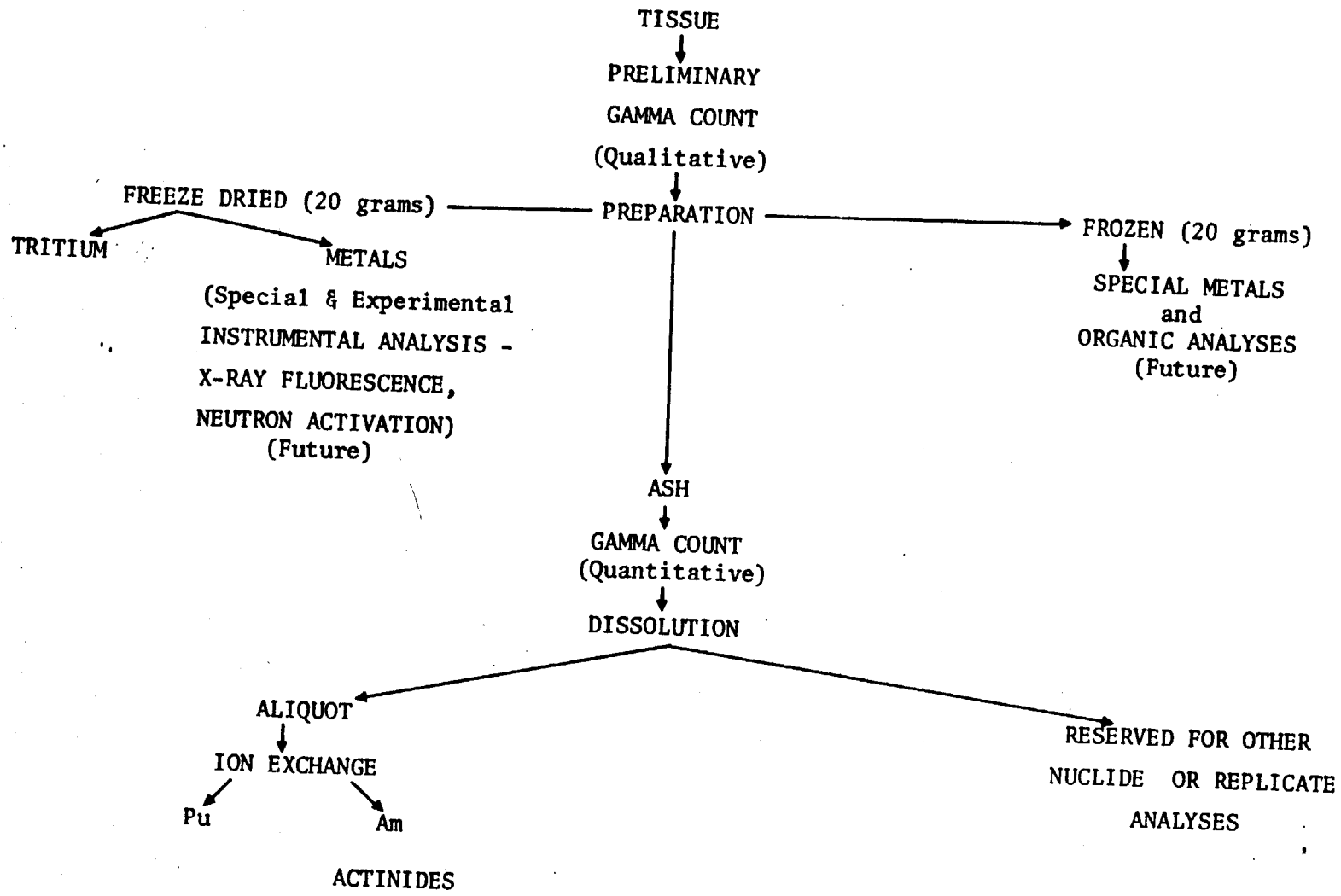

Figure 1. Flow chart of tissue analysis procedure.

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has been detected in about 40 of the autopsies received. Evidence to suggest that it is a contaminant in ^{99m}Tc used for brain and liver scans has been reported (Ide and McInroy 1975).

Following the first gamma-scan, the tissues are taken to our preparation laboratory where two 20-g samples are removed from the larger tissues, the lung, liver and kidney. One of the 20-g samples is freeze dried and the extracted water has been analyzed for tritium in a few cases. The other 20-g sample is frozen and also preserved for future analyses. The dried residue is preserved for future trace metal analyses. At the present time approximately 1500 such tissues are in our "tissue library". The remainder of the organ is muffled to drive off most of the organic material leaving the mineral ash. This ash is whitened with nitric acid and the residue recounted on the gamma counter if the first scan gave any evidence of radioactivity present. The reduction of the volume of the tissue by the ashing procedure improves the geometry factors and allows for a more satisfactory quantitative measurement of any gamma-emitting isotopes present. The first gamma measurement was simply qualitative to warn of any radionuclides present and to detect those more volatile isotopes.

The ashed residue is then dissolved in nitric acid so that a uniform solution of the tissue salts and plutonium is obtained. An aliquot of this solution is spiked with ^{242}Pu and put through an anion exchange column to isolate the plutonium. The remainder of the solution is preserved for replicate or other analyses at a future date. The eluate from the ion exchange procedure containing the plutonium is converted to the chloride and is electroplated onto stainless steel planchets. The alpha activity of the plutonium is measured by alpha pulse height analysis that is capable of distinguishing the different energies of the various plutonium isotopes. The lower limit of detection (sensitivity) is 0.03 dis/min per sample analyzed.

To determine the efficiency of the chemical recovery of plutonium from the analysis, a small known amount of a plutonium isotope (^{242}Pu) not used in the nuclear industry is added as an internal tracer to the sample at the time of aliquoting. The alpha pulse height analysis can identify the alpha energy of this isotope and enables us to measure the amount of added "spike" recovered. This efficiency is used to adjust

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the amounts of ^{238}Pu and ^{239}Pu measured, thus accounting for any plutonium lost during the ion exchange and electroplating steps of the analytical procedure. For many years, ^{236}Pu was used as the internal tracer. This isotope has the disadvantage that the half life of ^{236}Pu is only 2.8 years, resulting in an ingrowth into the stock solution of daughter products (uranium and thorium), thus necessitating the frequent purification and recalibration of the stock solution. In 1972, another isotope, ^{242}Pu, became available and is now used as the tracer. This isotope has a relatively long half life ($\simeq 4 \times 10^5$ years) and does not require the purification and frequent standardization characteristic of the ^{236}Pu.

RESULTS AND DISCUSSION

Occupationally Exposed Workers. Autopsy tissues from 90 former employees at LASL have been received and, of these, 82 cases have been analyzed for plutonium concentrations. Not all of the cases received had direct exposures to plutonium, since many were secretaries, clerks, truck drivers, and other support personnel. On the basis of medical, employment, and monitoring data, 30 of the 82 cases were classified as having a potential for exposure. This group of 30 "potential exposures" have been further subdivided into a high potential group of plutonium workers with documented exposures and a low potential group that may have had possible exposures incidental to their normal work assignments. The measured concentrations in the lung, lymph node, liver, kidney, and bone are shown in Table II for potentially exposed workers.

1. Lung and Tracheobronchial Lymph Node (TBLN) Concentrations of ^{239}Pu.

The TBLN concentrations were the highest concentrations measured in 77% of the potential exposure cases; the lung was highest in 10% of the cases (see Table II). The high lung and TBLN concentrations are indicative of the most probable mode of exposure, inhalation. It is interesting to note the long residence time of the plutonium in these tissues. In many cases, the only recorded exposures were 20 to 30 years prior to their death.

In one dase (7-138), the lymph node concentrations were high enough to enable the estimation of particle size distribution by autoradiographic techniques (Leary 1951). The particles were assumed to be $^{239}PuO_2$ and the

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Table II. Concentration of plutonium in autopsy tissues of potentially exposed workers.

Case No.	Date of Death	Time from possible first exposure to death[a]	Concentration of ^{239}Pu in Tissues				
			Lung	TBLN[b]	Liver	Kidney	Bone[c]
			(dis/min)/kg				
1-039	1959	13	6334	85096	9836	47	2389
1-094	1960	5	51	139	16	<MRL[d]	NA[e]
1-128	1961	6	8	10	3	<MRL	NA
1-130	1961	8	273	512	23	8	NA
2-004	1961	15	2522	46000	4343	50	NA
2-014	1961	15	33	<MRL	6	2	NA
2-030	1962	15	8538	150896	2866	71	612
2-058	1962	11	55	841	21	14	<MRL
2-064	1962	16	29	208	10	1	6
2-068	1962	14	9	239	12	1	5
2-100	1962	13	18	172	2	11	64
2-126	1962	8	4	95	1	4	107
2-130	1962	8	473	294	263	294	178
3-014	1965	22	10	46	216	10	1904(rib)
3-016	1965	19	377	26845	702	<MRL	34
3-028	1966	9	1	<MRL	4	<MRL	<MRL
3-088	1968	15	2	24	3	1	<MRL
5-064	1970	15	19	<MRL	7	<MRL	<MRL
5-076	1970	24	21	49	3	<MRL	16
5-080	1970	18	16	61	7	<MRL	1
5-114	1970	25	NA	8572	59	NA	87
5-138	Living[f]	31	8465	563750	NA	NA	3550(rib)
5-150	1971	22	7	227	2	<MRL	<MRL
7-006	1971	14	<1	<MRL	2	<MRL	1
7-054	1972	27	297	2298	<1	1	12
7-066	1972	29	375	10352	538	10	85
7-072	1972	28	79	1105	15	<MRL	12
7-074	1972	14	33	1808	5	<MRL	<MRL
7-084	1972	20	290	3678	74	1	18
7-138	1973	25	69955	787949	3846	57	1117

[a]Time from first exposure to death is the year from hire to death where n no exposures were recorded.

[b]TBLN = Tracheobronchial lymph nodes.

[c]Bone = Vertebrae unless otherwise noted.

[d]MRL = Minimum reporting level.

[e]NA = Tissues not available

[f]Specimens from biopsy.

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distribution was determined to have a count median diameter of 0.20 μm and a calculated activity or mass median diameter of 0.32 μm with a geometric standard deviation of 1.5 (McInroy et al. 1974). Ninety-five percent of the particles in the node were estimated on this basis to contain less than 0.22 pCi of ^{239}Pu per particle. Similar studies are currently in progress on lung sections from this same case to determine the distribution of $^{239}PuO_2$ particles. Because of the lower concentrations of plutonium in the lung, the number of particles detected by autoradiography is greatly reduced and the number of tissue sections processed to give statistically significant results must be proportionally increased.

Also included in the study above were histological sections of tracheobronchial lymph nodes from 13 other cases where the lymph node concentrations of plutonium ranged from 0.11 to 4000 (dis/min)/g. Microscopic examination revealed no abnormalities other than those directly attributable to the basic disease or condition that caused the death of the persons in the study.

Pleural and parenchymal lung concentrations have been measured in two cases, one an acute exposure shortly before death in an auto accident and the other with a chronic exposure over a period of 26 years. The distribution of plutonium between the pleura, sub-pleura and lung parenchyma was measured from the apex to about the middle of one lobe from each case. The distribution of plutonium was fairly uniform for the recent acute exposure case. The long-term exposure case had concentrations from 10 to 30 times higher in the pleura and sub-pleural tissue than in the parenchyma. Similar partitioning of plutonium in the lung of a long-term exposure case has been reported by Nelson et al. (1971). Other analyses of lung have not observed this effect (Norwood and Newton 1975).

2. Bone Concentration of Plutonium.

The estimation of total skeletal deposition is very difficult due to the relatively small sample sizes obtainable from most autopsies and also to the observed variability in the distribution of plutonium in different bones. As mentioned in the previous paper at this meeting (Durbin), wide variations in plutonium concentrations have been measured in different bones of the body as well as different parts of the same bone. It

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therefore seems obviously inaccurate to assume a uniform distribution of plutonium throughout the skeleton for the purpose of extrapolating skeletal burdens but this is the best method presently available.

Another problem in the calculation of the skeletal burden is the estimation of the mass of the skeleton itself and whether or not the marrow should be included in the total weight. Values for a 70 kg standard man are 10 kg for the total skeleton and 7 kg without bone marrow (ICRP 1959). For our extrapolations, the 10 kg skeletal mass is used since the marrow is not separated from the bone.

A better method for this calculation has been suggested by Durbin and others, in which one adjusts for the individual variations in body weight and the bone analyzed (Durbin, 1972). In this "Ponderal" method, the total skeletal mass is estimated as a fraction of the body weight and the skeletal burden of plutonium is adjusted for the fraction of total skeletal mass analyzed and the fraction of the skeletal burden contributed by that particular bone. However, no data are available on bone distributions of plutonium in the normal human skeleton. Lack of the latter data negates the advantage gained by making the other adjustments in the estimation.

3. Muscle Concentrations of Plutonium.

Muscle has been received in three cases, two of which were participants in the U.S. Transuranium Registry. In one case (systemic body burden < 1nCi), the activity in the muscle was below our minimum detection level (0.03 (dis/min)/sample analyzed) in replicate samples analyzed. The other two cases had a total extrapolated muscle content (assuming that muscle comprises 40% of total body weight) of approximately 1% of the systemic body burdens of 10 and 18 nCi.

4. Gonadal Concentrations.

Gonadal tissue has been analyzed in five occupational cases, all males. Only two cases had plutonium concentrations above the minimum detection level (see Table III). The fraction of the systemic burden of plutonium found in the testes of 8×10^{-4} and 1×10^{-4} in cases 7-066 and 7-138, respectively, compare favorably with data reported by Richmond and Thomas (1975). In their work, the fraction of administered burden of plutonium to the gonads in five non-human mammalian species was about

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3×10^{-4}. Richmond and Thomas further stated that for data accumulated on gonadal tissue concentrations in humans, an average retention value of about 10^{-4} of the administered dose for injected plutonium in soluble form would appear to be a reasonable estimate to use for human males. It appears that the translocation of plutonium to gonadal tissue once taken up by the blood stream, whether injected as a soluble compound or solubilized from the lung deposition, is the same.

Table III. Gonadal concentrations of plutonium.

Case No.	Sex	Age at Death	Years Since First Possible Exposure	Systemic Body Burden (dis/min)	Gonadal Burden (dis/min)/ Organ	Ratio Gonad/ Systemic Body Burden
7-066	M	61	28	1672	1.4 ± 0.2*	0.0008
7-138	M	46	26	20611	2.1 ± 0.3	0.0001

*One standard deviation

5. Liver and Kidney Concentrations of Plutonium.

The concentration of plutonium in the liver was generally the highest of all systemic tissues measured (Table II). The liver to vertebrae concentration ratios had a range of < 1 to 21 with a median value of two. A liver to bone ratio of about 10 based on mean plutonium concentration values was reported by Magno et al. (1969) in human tissue due to fallout. Similarly, Campbell et al. (1973) reported a median ratio of two for approximately 200 autopsy cases having no known occupational exposure to plutonium. Our data seem to confirm that the concentration of plutonium in the liver is generally two to ten times the average concentration (including marrow) in the vertebrae. No attempt has been made in this study to identify the deposition mechanisms or sites in the liver.

Kidney concentrations were among the lowest concentration of all tissues measured in 21 of the 28 cases in Table II containing kidney specimens. Three of the cases in which it was not the lowest in concentration had additional soft tissues analyzed including muscle. In one case, the muscle concentration was below the detection level. The other two cases had muscle to kidney concentration ratios of 0.17 and 0.12, respectively.

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6. Whole Body Burdens.

Table IV shows the percent of whole body burden of plutonium contributed by each tissue analyzed and lists only those cases where a complete set (lung, TBLN, liver, kidney, bone) of tissues was obtained and the analyses were greater than the minimum detection level for almost all tissues. In a few cases, the kidney concentration in the aliquot analyzed was below detection limits but the cases were included if all other tissue results were positive since the kidney contributes a relatively small portion of the total body burden (less than 1% in most cases). The lung and tracheobronchial lymph nodes contained an average of 28 and 5 percent, respectively, of the total burden. The liver contained 18%, the kidney 0.5% and the skeleton 48% of the total burden. The frequency distributions of plutonium in each tissue for this group are shown in Figure 2. The large variation associated with each tissue distribution is likely due to the numerous factors influencing each exposure. These include the solubility of the plutonium, the particle size distribution, mode of exposure (inhalation, ingestion, wound, etc.) and the length of time from exposure to death. Figure 2b (percent in TBLN) indicates a precaution that must be taken when deriving mean values for data of this type. The average of 4.7 clearly does not represent the contribution of the lymph node burden in most of the cases. Clearly, one must examine the distribution before assigning much confidence to reported mean values of this type.

7. Systemic Body Burden.

Table V and Figure 3 show the distribution of the plutonium that has reached the blood and been transported to the liver, kidney and skeleton. Note that three of the cases had additional tissues analyzed and that in two of these, the contribution to the systemic burden was less than 4%. The third case, 7-066, had in addition to muscle and spleen specimens, a blood sample which contributed significantly to the 26% contribution of the "other" tissues. Norwood and Newton (1975) have reported much lower concentrations observed in blood from 23 employees with estimated systemic burdens from 6 to 4000 nCi and the high blood concentrations observed in case 7-066 may represent an artifact. Blood has not normally been collected at autopsy because of the problems associated with the

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Table IV. Whole body distribution of plutonium in tissues of occupationally exposed workers.

Case No.	Percent of Total Whole Body Burden					
	Lung	TBLN	Liver	Kidney	Skeleton	Other*
1-039	11.4	2.7	40.4	0.03	44.9	0.6
2-030	42.3	11.2	25.6	0.11	20.8	---
2-064	29.1	3.1	17.2	0.20	50.5	---
2-068	13.8	5.2	26.9	0.57	53.6	---
2-100	3.1	0.4	0.8	0.48	95.1	---
2-126	0.6	1.1	0.3	0.16	97.8	---
2-130	21.3	0.3	18.3	4.4	55.8	---
3-014	0.1	0.0	3.6	0.0	96.3	---
3-016	16.2	17.3	54.2	**	12.3	---
5-076	15.8	0.7	3.5	**	80.0	---
5-080	35.1	2.0	30.1	**	32.8	---
7-016	41.7	2.9	18.2	**	37.2	---
7-054	65.2	8.9	0.2	0.05	25.6	---
7-066	17.0	7.0	31.3	0.05	25.1	19.5
7-072	32.7	6.9	11.6	**	48.9	---
7-084	57.3	6.9	16.7	0.04	19.0	---
7-138	77.0	3.0	8.2	0.02	11.2	0.6
Mean	28.2	4.7	18.1	0.51	47.5	6.9
Standard Deviation	22.6	4.6	15.3	1.24	29.3	10.9
No. Cases	17	17	17	12	17	3

*Other tissues included heart, muscle, spleen in case 1-039; muscle, gonad, thyroid, blood, spleen in case 7-066; muscle, gonad, brain, fat, spleen and thyroid in case 7-138.

**Results are less than our minimum reporting level (MRL)

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Table V. Fractional distribution of plutonium in systemic tissues.

	Fraction of Systemic Burden (%)			
Case No.	Liver	Kidney	Skeleton	Other
1-039	47.1	0.03	52.2	0.7
2-030	54.9	0.23	44.8	---
2-064	25.3	0.29	74.4	---
2-068	33.2	0.71	66.1	---
2-100	0.8	0.50	98.7	---
2-126	0.3	0.16	99.5	---
2-130	23.3	5.57*	71.2	---
3-014	3.6	0.02	96.4	---
3-016	81.5	**	18.5	---
5-076	4.2	**	95.8	
5-080	47.9	**	52.1	---
7-006	32.9	**	67.1	---
7-016	32.9	**	67.1	---
7-054	0.7	0.20	99.1	---
7-066	41.2	0.06	33.0	25.7
7-072	19.2	**	80.8	---
7-084	46.7	0.10	53.2	---
7-138	40.9	0.09	55.8	3.2
Average	29.8	0.22	68.1	
Standard Deviation	22.5	0.21	24.0	
Number of Cases	18	11	18	

*Omitted from average.

**Analytical results were < MRL

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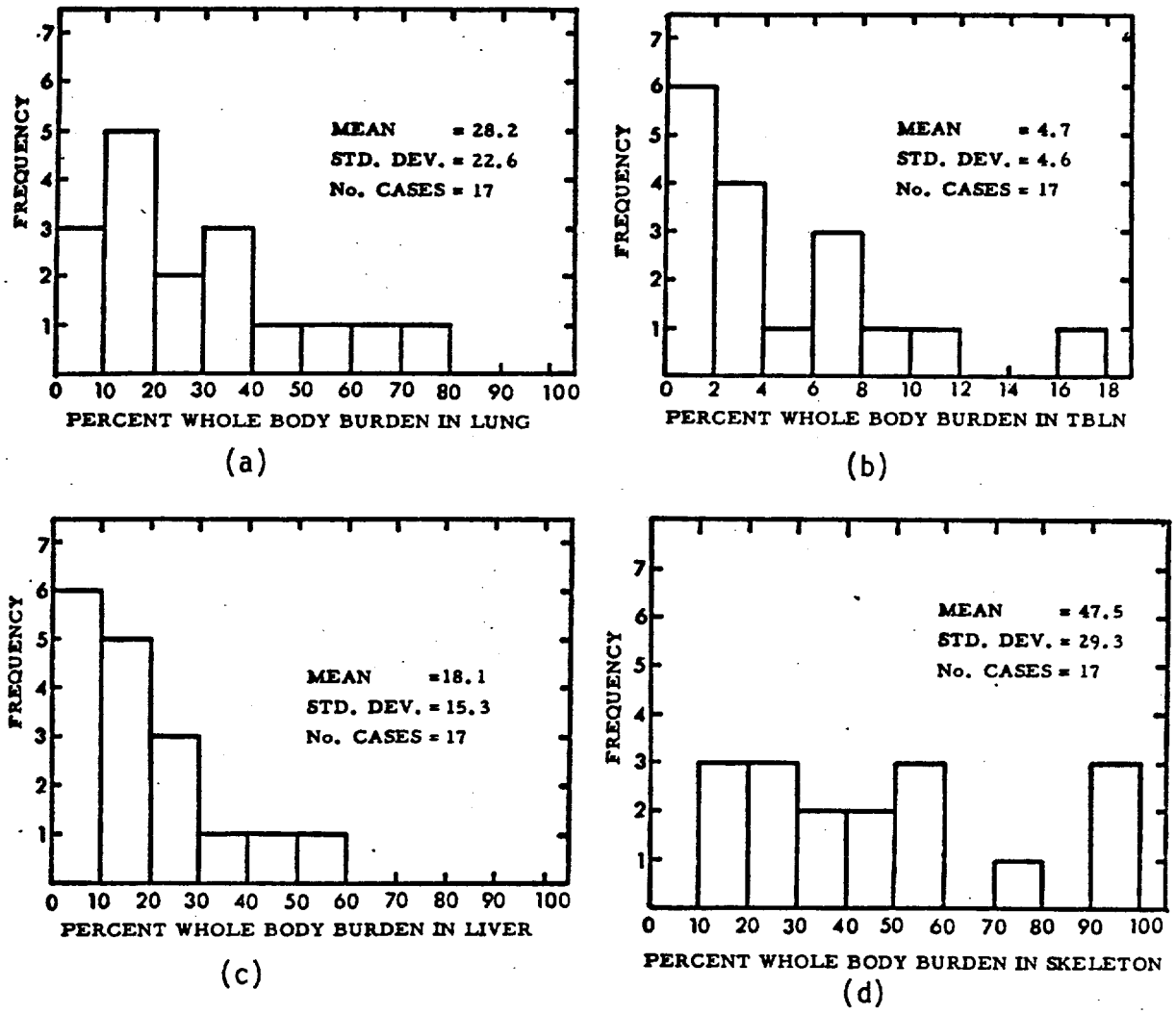

Fig. 2. Distribution of whole body burden of plutonium in tissues of 17 occupationally exposed workers.

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methods of collection, but perhaps further attempts need to be made to establish the contribution of this tissue to the total systemic burden.

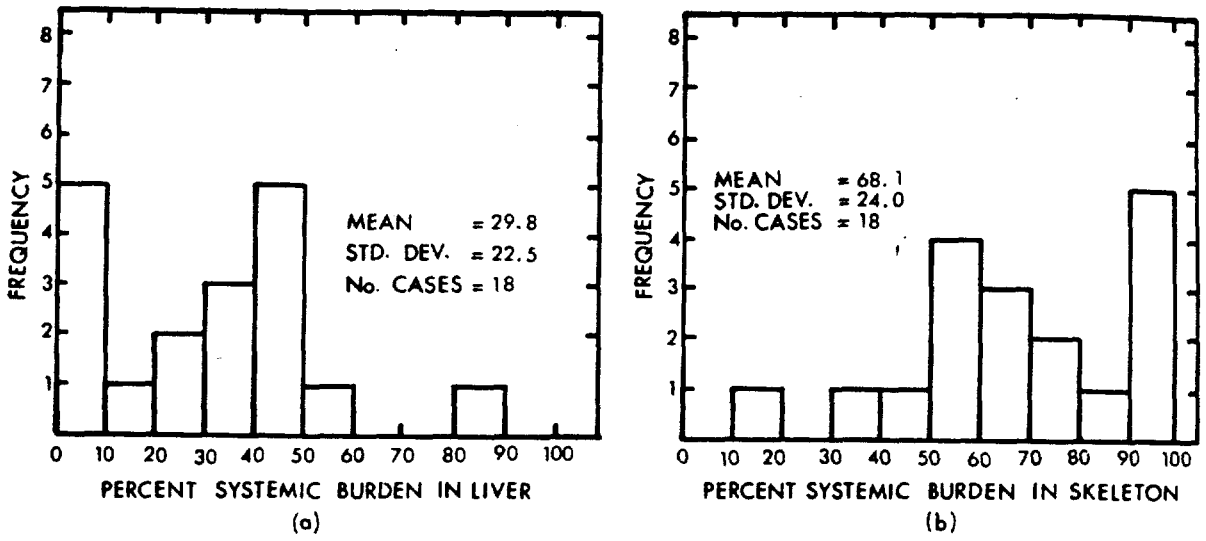

Figure 3. Distribution of systemic burden of plutonium in the tissues of 18 occupationally exposed workers.

The estimates of systemic burdens by tissue analyses have been used to compare with ante-mortem estimates by other techniques, particularly urine analysis. The uncertainties of the skeletal extrapolations have been pointed out earlier in this paper. Table VI shows the comparison of systemic plutonium content extrapolated from tissue analysis and that extrapolated from urine assay, using the PUQFUA computer code used at LASL (Lawrence 1960, 1975). The computer program estimates are based upon the power function curves developed by Langham (1956). Only those cases having measurable concentrations in the body and for which a reasonable number of urine samples were analyzed are listed.

The variation observed between the tissue and urine estimates is similar to those reported by others (Lagerquist et al. 1973, Norwood and Newton 1975). The urine estimate, generally, tends to be high by factors up to five or more. A discussion of the problems associated with this technique for the assessment of plutonium deposition are the subject of a paper to be presented at an IAEA Symposium later this year (Voelz et al. 1975).

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Table VI. Comparison of urine and tissue analysis estimates.

Date of Death	Time of First Exposure to Death (years)	Number of Urine Samples	Body Burden (nCi)			Ratios	
			Urine	Tissue Estimate			
			Estimate	Systemic	Lung	Urine/ Systemic	Urine/ Total
1959	13	71	26.	18.4	3.0	1.4	1.2
1961	15	49	12.	3.5*	1.9	3.4	2.2
1962	15	58	10.	4.2	4.9	2.4	1.1
1962	11	26	2.4	0.02	0.03	120	48
1962	13	13	2.5	0.25	0.01	10	9.6
1962	8	23	1.8	0.4	0.01	4.3	4.2
1962	8	18	2.2	0.9	0.25	2.4	1.9
1965	19	40	5.4	0.7	0.35	7.7	5.1
1972	29	42	7.2	0.75	0.24	9.6	7.3
1973	25	149	31	9.3	37.1	3.3	0.67

*No bone sample was obtained. This estimate does not include the skeleton.

• Plutonium in the Non-Occupationally Exposed General Population. Data are being accumulated to identify the baseline concentrations of environmental plutonium in the general population of various geographic regions throughout the United States. This information is essential for the assessment of risk parameters associated with the nuclear industry. The evaluation of the first 100 autopsy cases from one area has been completed. This was the number of cases judged necessary for analyses to give statistically reliable estimates of the baseline concentration for a given variable such as geographic area of residence. Tissues will be collected from this area on a reduced scale (15 to 20 cases/year) to permit monitoring of the established plutonium baseline levels.

The levels of plutonium measured in the general population tissues present special problems in the analytical procedure and the interpretation of the data that are not associated with the relatively high levels of activity found in occupational exposures. Extreme precautions are observed to maintain a laboratory where the possibility of contamination is minimized. To evaluate the statistical significance of these data, a study was initiated to determine the minimum level of detection for our instrumentation and, also, to identify the statistical error associated

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with each measurement and establish the level of confidence with each analysis. The lower limit of detection, or the minimum alpha activity that can be measured and identified as being statistically different from zero is a function of the background of the counting system. Evaluation of a large number of background measurements for each detector has indicated that, at the 99% level of confidence, any measurement greater than 0.03 dis/min will be considered significant.

The uncertainty associated with chemical analyses and alpha activity measurement involve the variations associated with 1) the chemical recovery; 2) the accuracy of transfer of the tracer spike; 3) the efficiency of the detector for measuring the true alpha activities; and 4) the background of the detector. A propagation of error calculation using each of the above variances is calculated for each measurement of plutonium activity. If the measured value minus approximately two standard deviations is equal to or less than zero, the activity found cannot be distinguished from zero at the 95% level of confidence.

The plutonium concentrations in the general population tissue data have been examined statistically and have been found to be log-normally distributed (Tietjen 1975). One way of representing these data is shown in Figure 4 indicating the distributions of plutonium concentration in the general population lung tissue. These data represent all measurements of plutonium concentrations in the lung of non-occupationally (to the best of our knowledge, based upon the pathology report) exposed persons collected from the locations mentioned previously. One problem associated with the interpretation and evaluation of these data concerns the measurements that are either below the minimum detection level or are determined to be not statistically different from zero. For the purpose of graphing and interpretation, we have included the number of all the samples in this category in determining the cumulative frequency up to the first point above the minimum detectable level but have not included the lower values on the graph. This is necessary since the values below the minimum detectable level are part of the overall sample and eliminating them would distort the statistics. Therefore the first point on the graph is the first positive measurement. In the case of the general population lung, for example, 303 of the 373 lung specimens measured had plutonium concentrations greater than "MRL".

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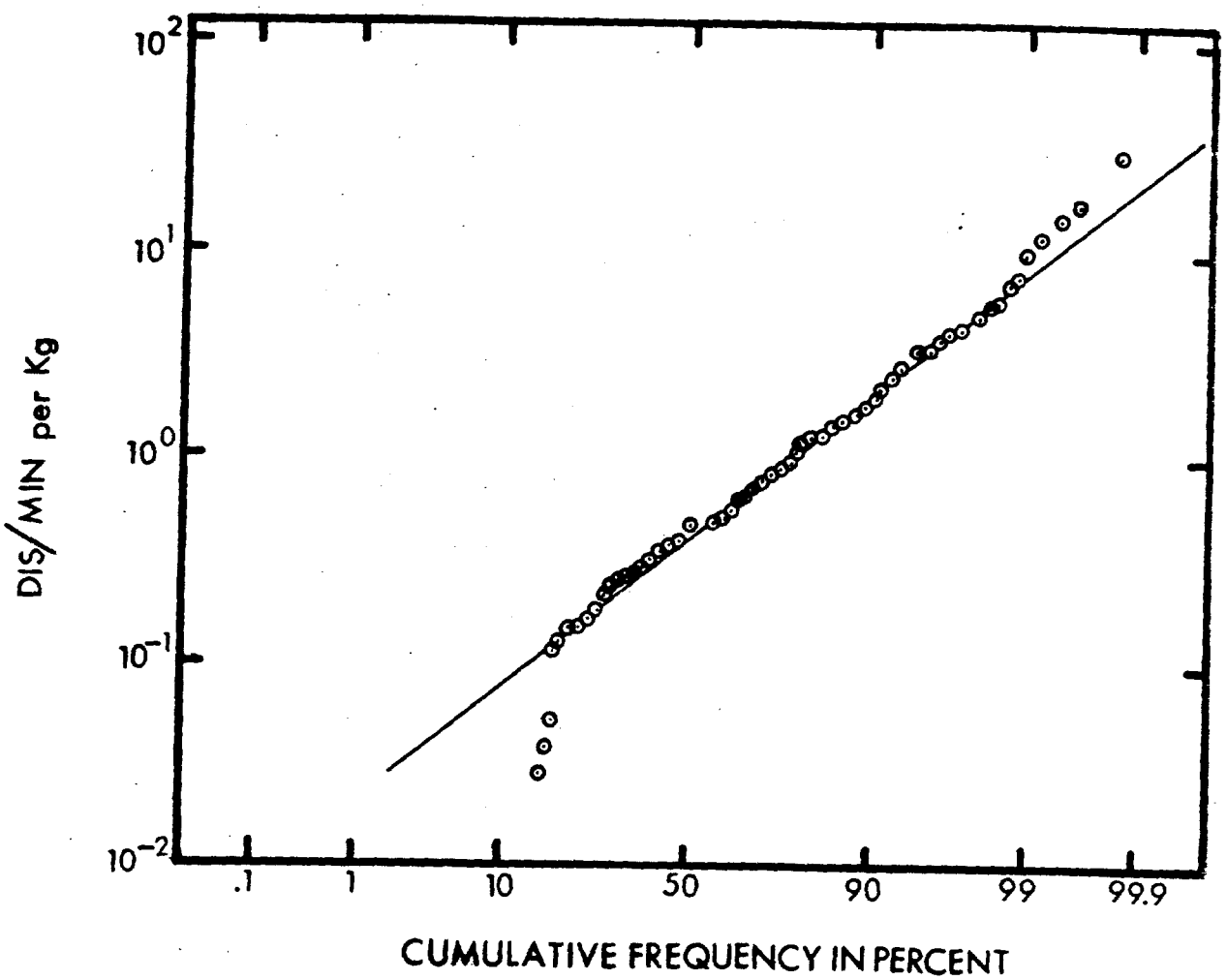

Figure 4. Log-probability plot of plutonium in lung of general population.

The line shown on the graph is a least squares fit of the positive data. Also calculated by this same statistical program are the 5th, 50th and 95th percentile values of the data. All data analyzed to date are represented in Table VII. The 50th percentile, or median value, can be used to approximate the baseline levels of environmental plutonium in the various geographical areas. The tissues collected from Pennsylvania represent the most recent deaths (all died in 1974). The lower median concentrations in the lungs and lymph nodes may be the result of decreasing environmental levels of plutonium due to the restrictions on atmospheric testing of nuclear weapons.

SUMMARY

The distributions of plutonium in the tissues of occupationally exposed workers shows great variability. The mode of exposure (inhalation,

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Table VII. 50th Percentile distribution of plutonium in human tissue for the non-occupationally exposed (1959-1975).

Location	Picocuries per Kilogram					
	Lung	Liver	Lymph Nodes	Kidney	Vertebra	Gonad
Los Alamos	0.60(66)[a]	0.56(60)	1.51(62)	0.12(64)	0.22(41)	d
New Mexico and United States[b]	0.36(100)	0.46(86)	1.07(93)	<MRL[f](91)	0.18(66)	<MRL(9)
Colorado	0.25(111)	0.77(90)	0.56(84)	<MRL(76)	0.19(45) 0.39(73)[e]	<MRL(61)
New York	0.30(36)	0.62(32)	c	c	0.37(32)	0.34(33)
Georgia and S. Carolina	0.25(20)	0.53(14)	d	<MRL(12)	<MRL(13)	d
Pennsylvania	0.13(40)	0.54(39)	<MRL(21)	<MRL(39)	<MRL(18)[e]	<MRL(18)
All populations	0.27(373)	0.57(321)	1.35(260)	<MRL(281)	0.23(197)	<MRL(121)

[a]Number of samples analyzed.

[b]Nonresidents of Los Alamos that died and/or were autopsied at the Los Alamos Medical Center.

[c]Samples not requested and/or not received.

[d]Insufficient number analyzed for statistical significance.

[e]Rib specimens (not included in All Population data).

[f]Minimum reporting levels.

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ingestion, wound, etc.), solubility and particle size of the plutonium particulates, the length of time from exposure to death all play a role in the kinetics of distribution. In general, the highest concentrations of plutonium in the tissues of occupationally exposed individuals are found in the tracheobronchial lymph nodes, the lungs, the liver and the bone, in decreasing order. Skeletal burdens are very difficult to extrapolate reliably because of the relatively small bone samples available for analysis and the known, but not defined, non-uniform distribution of plutonium within the skeletal system.

The tissue distributions in the general public are slightly different than those observed in the plutonium workers. The highest concentrations are observed in the tracheobronchial lymph nodes, the liver, lung, and bone. Concentrations in the kidneys and gonadal tissue of the general population are very difficult to measure because of the small size of the organs and the low concentrations of plutonium. More than half of the analyses of these latter tissues are below our minimum detection level of 0.03 (dis/min)/sample analyzed.

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