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CURRENT STATUS OF INFORMATION OBTAINED FROM PLUTONIUM CONTAMINATED PEOPLE

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from Plutonium Contaminated People

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Abstract

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There has been no recorded incidence of cancer or serious biological damage in man resulting from occupational exposures to internally deposited plutonium. However, we must consider the relatively short time since exposure in some cases. Because of industrial accidents in early Manhattan Project exposures, a number of individuals have been exposed to plutonium. Some have maintained multiples of the maximum permissible body burden (MPBB) for almost three decades. Although the exact levels of contamination are uncertain, it is clear that this body of information represents a valuable resource for study. Data have been reported for specific groups (Manhattan Project workers), and other studies are accruing data for future use as the populations age. Another source of particularly valuable information, 18 people who received plutonium during the late 1940's, provided the basis of the human excretion equations derived by Langham. The injected levels range from about 0.25 to about 5.8 microcuries and, in one case, was retained for 21 years. Other information exists in the form of virtually the entire world's population which has accumulated plutonium, although somewhat inefficiently, from detonations of nuclear weapons and burn-up of one thermoelectric generator (plutonium 238) in the atmosphere. Information obtained from these and other sources will be summarized. (This work is being performed under the auspices of the U. S. Atomic Energy Commission.)

Key words:

Plutonium

Man

Contamination

Internal emitters

INTRODUCTION

Earlier in this Congress Dr. Alvin Weinberg asked the following question, "Can man learn to live with fission." Perhaps another way of phrasing this important question would be to ask if man can learn to live with plutonium and other actinide elements. There has been much interest and concern expressed about the potential toxicity and effects of plutonium and the actinide elements on man. Although there exists a considerable data base on the biological effects of plutonium on experimental animals, there is a relative paucity of data existing for exposed human subjects. Therefore, we are placed in a situation in which we must extrapolate or project in some manner the effects of plutonium on experimental animals to man. Nevertheless we do have some information concerning human subjects who were exposed to plutonium through occupational exposures. I shall attempt to review this information for you today. We should keep in mind that this kind of information, even though very limited, is human experience of the most relevant kind for establishing value judgments where inadequate data exist for formulating risk evaluations.

There have been no recorded substantiated incidents of cancer production in man from the internal deposition of any plutonium isotope in the nuclear energy industry, even though internal depositions have occurred. This excellent record has resulted from effective control measures. Although some exposures occurred 30 years ago, we must keep in mind the relatively short time since exposure for many of these cases. There has been a reasonable number of individuals exposed to quantities of plutonium at or near the maximum permissible lung or body burden. Although the exact levels of internal contamination are uncertain, it is clear that this body of information represents a valuable resource for current and future study. Some work has been done on specific groups and other studies are in the process of gathering pertinent data for future use as these populations age.

Another source of information on the effects (or lack thereof) is a group of persons who received plutonium during the mid-1940's. These are particularly interesting as data accrued for these persons provided the basis for the human excretion equations derived by Langham at Los Alamos. In addition, the injected levels were reasonably high and retained in one case for 21 years. Still another source of information exists in the form of virtually the entire world's population, which has accumulated plutonium, although rather inefficiently, from previous and present atmospheric detonations of nuclear weapons. Past and current autopsy programs involving both occupationally and non-occupationally exposed persons will also furnish useful information on the uptake and concentration of plutonium in various body tissues. These data provide us with some insight on the efficiency of the human organism for incorporating plutonium and on its distribution among body tissues. In the case of occupational exposures, this data base will also allow us to make comparisons of the body burden with estimates based on bioassay data obtained during the life of the subjects in question.

The message I would like to leave with you is that we have not observed any serious biological consequences in man from occupational exposure to plutonium. The next logical question is, "how do you know," or "have you looked." We have indeed looked and the record to date is quite reassuring. However, I would like to point out that the past is not always prologue, cheerful as that thought might be. Although the final answers are not in, I would hasten to add that we now have information on people which has spanned almost three decades so that the argument of latency for certain late effects (how long does it take to produce a tumor) is losing impact in at least some of the cases I will discuss.

MANHATTAN PROJECT EXPOSURES

Since the discovery of plutonium over three decades ago,[1] some personnel exposures have occurred. Some have been studied and reported on in varying degree, both during life and after death.[2-9] One of the most interesting groups, because of both time since exposure and level of exposure, is that of the Manhattan Project plutonium workers.[10]

Twenty-five male subjects who worked with plutonium during World War II under very crude working conditions, as judged by today's standards, have been followed medically for the intervening years. Within the past several years, 21 of these men have been examined at the Los Alamos Scientific Laboratory. In addition to physical examinations and laboratory studies (complete blood count, urine chemistry profiles and urine analysis), roentgenograms were taken of the chest, pelvis, knee and teeth. Chromosomes of lymphocytes cultured from peripheral blood and cells shed from the pulmonary tract were also studied. Urine specimens assayed for plutonium yielded calculated body burdens which ranged from 0.005 to 0.42 μCi. These estimates of body burden, on the average, are higher than earlier estimates based on radioassay of urine samples collected in the past, perhaps reflecting uncertainties in the models used to estimate body burden from excretion data. Table I indicates the kinds of information obtained from the Manhattan Project plutonium workers. Most, but not all, of these tests have been conducted every four to five years since the group has been studied. This appears to be a very healthy group of men in their early to mid-fifties. There are no adverse biological effects that have been detected that can be attributed to the radiation exposure. Except for the ailments that one would expect in a group of men of this age, all subjects examined were in remarkably good health. One man had a coronary occlusion but had recovered and was well compensated, and another of the original group died in 1959 of a coronary at age 38. Another had a hamartoma of the lung surgically removed without complication in 1971. A third had a melanoma of the chest wall (regional lymph nodes were negative). A fourth had a partial gastrectomy free-bleeding ulcer. Several had mild hypertension and moderate obesity and one had gout. All men were actively working, mostly as successful executives. More detailed information on this particular group of workers has been published.(11-12) It is important to realize that these men worked under very crude working conditions as judged by today's standards. Figure 1 shows the building in which these men worked in 1944 and 1945 as part of the program to make the first nuclear weapons. I can assure you that there is probably a factor of 115,000 between safety constraints in this building and those modern facilities now used for working with plutonium. Things have changed quite dramatically with the goal of providing more protection for the worker and more complete containment of the plutonium within the facility. The health protection record of plutonium workers has been quite good and I think it is clear that if we stick to our controls and regulations as regard plutonium, we are not destined to repeat the kinds of things that happened with the use of radium earlier in this century.

Table II shows the current status of several LASL plutonium study groups. Group 2, which is now in the early stages of study, will expand the size of the original cohort by perhaps 40 people. Twenty-five of the 40 men who have been identified have been located and have responded to questionnaires. Groups 1 and 2 collectively represent the creme de la creme of the early plutonium exposures. Once again, these are extremely important subjects to study intensively as approximately three decades have elapsed since their exposures. Group 3 will include a larger spectrum of exposures including more recent accidents and exposures to plutonium 238. All are estimated to have systemic plutonium burdens of 4 or more nanocuries. Table III shows the current systemic body burden estimates based on urine excretion for some of the men in the Manhattan Project plutonium worker group. Only those with more than three maximum permissible body burdens (or 120 nCi) in 1972 are shown. Again, the original exposures were in the early 1940's so that Case 3, who now has approximately 10 times the allowable occupational bone burden, has carried this estimated 410 nCi of plutonium for approximately three decades. The selected cases shown in Table III represent systemic plutonium burdens ranging from 0.13 to 0.42 μCi, which correspond to annual bone doses of approximately 2 to 6 rad. I won't dwell on the earlier estimates for 1953 and 1962 other than to point out that these are somewhat uncertain. The model that is used to estimate body burden from the urine analysis data does contain some uncertainty(13) and cannot be applied accurately to each individual. It is also true that some of the body burden estimates are based on relatively few data points. Table IV contains information which is detailed in an earlier publication.(10) The data are for the plutonium 239-240 content for some tissues that were removed from Case 2 who developed a non-malignant growth (hamartoma) in the lung. This particular medical condition, which was found as part of the medical follow-up study, afforded an opportunity to obtain some hamartoma tissue, lymph node tissue, rib tissue and normal lung tissue for radiochemical analyses.

The concentration of $^{239-240}$plutonium was approximately the same in both the tumor and normal lung tissue. The lowest plutonium concentration was found in a rib sample and the highest in the lymph node tissue consistent with experimental findings in dogs exposed to plutonium dioxide by inhalation.

If one assumes a total lung weight of 1000 grams, a respiratory lymph node weight of 20 grams, and a homogeneous distribution of plutonium throughout these tissues, the total plutonium burden is approximately 8 nCi, roughly equally divided between the lung and lymph node. Estimates of the chest burden of plutonium in Case 2, based on chest counting procedures, are in reasonable agreement (a factor of about 2) with the estimate based on extrapolation from analysis of lung and lymph node tissue.

Figure 2 is a photomicrograph of an autoradiograph of a plutonium particle in a lymph node section removed from Case 2 in May 1971. Observations of other plutonium particles in the lymph node tissue examined suggested a very non-uniform radiation dose distribution from the plutonium particles. Attempts have been made to estimate the number of particles inhaled by the Manhattan Project plutonium workers. By making certain assumptions for the mass median diameter, geometric standard deviation of the distribution and the particle density, one can show that the mass fraction for plutonium dioxide particles larger than 0.6 micron diameter in the distribution is approximately 15%. Further calculations indicate that approximately 10^7 particles larger than 0.6 micron diameter could have been retained by the 25 subjects during their exposures in 1944 and 1945.[14] If the lung cancer risk for such "hot particles" were 5×10^{-4} per particle, as suggested by the National Resources Defense Council Report,[15] then the 10^7 particles should yield about 5000 lung cancers for this group of men. The observed lung cancer incidence after almost 30 years since exposures is zero.

PLUTONIUM ADMINISTRATION STUDIES IN HUMAN SUBJECTS

In an attempt to determine relationships between urinary excretion, total excretion, and body content of plutonium, 18 persons received plutonium parentally in 1945 and 1946.[16-17] Fifteen of the 18 were older than age 45, and all but two of the 18 were given ^{239}Pu only (one received ^{238}Pu and ^{239}Pu and another received only ^{238}Pu). The amounts of plutonium administered ranged from about 0.3 to about 6 μCi. For comparison, the current occupational maximum permissible body burden for ^{239}Pu is 0.04 μCi.

Although these subjects were thought to be hopelessly ill, four of the group were alive in November 1973, almost three decades after receiving the plutonium. Excretion data from some of the survivors was presented earlier at this symposium.(18) This particular situation represents the unique opportunity to check on the validity of the excretion data equations that are used currently by radiation protectionists to estimate body burdens. It is of considerable interest that much of the data used to establish the excretion equations came originally from this group of 18 subjects during the relatively short time (several months in most cases) they were studied. To establish the unique excretion curves, Langham used additional data obtained over a five-month period from three of the plutonium recipients and additional excretion data from several Los Alamos occupational exposure cases for about 300 days and one for about 1700 days. These retention equations have proved extremely useful for over several decades and appear to be somewhat conservative in most instances when estimated body burdens can be checked with data obtained at postmortem. When initially reported in 1950,(16) Langham and coworkers reported, "Admittedly the observations made during this study provide no evidence of what may happen in 10-30 years. It may be said, however, that these studies and those of other investigators indicate that the intravenous injection of a single dose of 5 to 100 microgram of plutonium was without acute subjective or objective clinical effects."

One of the original 18 plutonium recipients is of particular interest. He was a white 58 year old male who was suffering from gastric carcinoma and gastrointestinal hemorrhage when he received 5.19 µCi of ^{238}Pu and 0.12 µCi of ^{239}Pu as $PuO_2(NO_3)_2$ by intravenous injection on 14 May 1945. He later received a total gastrectomy and a splenectomy but did not die until 9 January 1966, some 21 years later, from cardiovascular disease. We can obtain a very rough estimate of the bone dose by assuming 40% deposition in the skeletal tissues with no subsequent loss. Under these circumstances, the skeletal dose over the 21-year period would be approximately 900 rad. The annual dose rate to the skeletal tissues would be approximately 40 rad, a factor of approximately 70 higher than the annual skeletal dose rate of 0.6 rad delivered by the maximum occupational bone burden of 40 nCi of ^{239}Pu.

U. S. TRANSURANIUM REGISTRY (USTR)

During the summer of 1968, the United States Atomic Energy Commission authorized the establishment of the National Plutonium Registry which was later renamed as the United States Transuranium Registry. The Registry is part of the organizational structure of the Hanford Environmental Health Foundation in Hanford, Washington, and functions as a repository for all pertinent available information that may be used to identify any radiation hazard to the worker that may exist from exposure to transuranium elements.[19-21] Major AEC contractors and some licensees using plutonium and other transuranium elements have agreed to endorse the program and to recommend that their affected employees support this program. Cooperation with the USTR is completely voluntary on an individual basis and includes release of medical and health physics data. Permission is also obtained on a voluntary basis for postmortem analyses of certain organs.

The employees remain under the health physics and medical programs of the AEC contractor until termination of employment, at which time the USTR assumes responsibility if the employee has authorized postmortem examination.

The major criterion used by the USTR to determine inclusion of an individual into the Registry is as follows: persons for whom the employer has provided a routine surveillance program because of a reasonable probability that a deposition could occur. This rather broad criterion allows for the different methods used to estimate the extent of contamination (e.g., urine analysis, chest counting, or air concentration data) and for uncertainties in estimating burdens under certain conditions (e.g., chronic inhalation of insoluble plutonium). It also removes the emphasis on the larger contamination cases.

At autopsy, comparisons can be made between estimates of the body burden based upon tissue analyses and estimates made previously on the basis of health physics and operational data. In addition to a medical history of a disease or abnormal conditions, employees can often provide information on their work history, smoking habits, exposure to toxic materials, and other pertinent data.

In addition to AEC contractors, the USTR receives health physics information from the AEC's Health and Mortality Study and from the Assistant for Workman's Compensation and Radiation Records of the AEC.

Preliminary findings for the first fourteen autopsy cases reported by the USTR appear in the proceedings of the 12th Hanford Biology Symposium.(22) To date, information obtained by the USTR indicates that estimates of the plutonium systemic burden based on urine analysis have been on the conservative side, that is, higher than those estimates based on analysis of tissue obtained at autopsy.(22) Workers in the United Kingdom have also found this to be true.(23) In addition, the USTR reports that, "to our knowledge, no employee has ever sustained serious harmful effects due to the internal deposition of any of the transuranium elements."(24)

Table VI i licates the status of the USTR as of June 1974. To date, most of the USTR activities have been confined to Hanford, Los Alamos, and Rocky Flats. The interested reader is directed to a recent USTR publication for details of the level of cooperation between the USTR and the other AEC contractors shown in Table VI.[25]

ACCIDENT CASES

A considerable amount of information has been obtained from accidental occupational exposures to plutonium. However, the total number of accident cases has been relatively small. Information obtained from the AEC's Division of Operational Safety as shown in Table VII indicates that during the period 1957 to 1970 there have been on the order of 200 contractor personnel exposed to 25% or more of the maximum permissible body burden (MPBB) for plutonium. These data also indicate that inhalation is the major portal of entry and that more than half the exposure cases represent plutonium burdens that are less than 50% of the MPBB. Table VII also shows that of the 203 accidental depositions, approximately 18% were treated by chelation therapy and 54% were related to production activities. Eighteen percent of the 203 exposures shown in Table VII were associated with plutonium activities greater than one occupational permissible body burden. It may be instructive to look at a specific instance of an industrial accident which was reported in the open literature. A fire in a plutonium fabrication plant resulted in a large-scale spread of plutonium oxide on October 15, 1965.[3] Following the accident, the Rocky Flats body counter was used to measure the plutonium in the lungs of all employees working in the area at the time of the accident. Of the approximately 400 employees counted, 25 were found to have enough plutonium in their lungs to deliver a dose of 15 rem/year or greater. These data are shown in Table VIII. Estimates of the plutonium were obtained by using two scintillation detectors placed in contact with the subject's chest. A 60 KEV photon peak from ^{241}Am was used. The ^{241}Am content of the material released during the fire was determined and the amount of plutonium in the subjects was then determined from calibrations done on a chest phantom containing material with a similar ^{241}Am to ^{239}Pu ratio.

The plutonium consisted of "high fired" PuO_2 and particle size measurements made on air samples collected after the fire indicated a mass median diameter of 0.32 microns with a geometric deviation of 1.83. On the average, about 30% of the material initially deposited in the lungs was cleared in two to three months. Subsequent lung measurements indicate a much slower clearance. All of the 25 individuals shown in Table VIII have one or more maximum permissible lung burdens for occupational workers. The quantities of plutonium for this group of 25 individuals range from 16 to 272 nCi. It is not clear how many individuals received measurable body burdens less than 16 nCi ^{239}Pu. Hopefully, these cases will ultimately be studied by the U. S. Transuranium Registry. One would also think that this particular cohort of individuals should be carefully studied and followed throughout their lives in a manner similar to the Manhattan Project workers mentioned earlier.

Another example of accidental exposure of workers is of interest because the isotope involved was ^{238}Pu.[2] This particular evaluation deals with three personnel who were contaminated as a result of an explosion inside a glove box at Mound Laboratory which resulted in significant inhalation exposures. Chest counting measurements made at another laboratory indicated that the employees had lung burdens of 134, 141, and 91 nCi. Radiochemical analysis of urine samples obtained from these three individuals during the first half-year following exposure suggested elimination patterns which differed from those observed following previous inhalation exposures to ^{238}Pu.

The long-term systemic body burdens were estimated to be 290, 210, and 30 nCi. Because of the isotope involved and the relatively high levels of contamination, these individuals might also represent useful additions to long-term biomedical follow-up investigations.

One case of contamination resulting from a puncture wound is extremely interesting as it has been interpreted by some as being an example of cancer produced in man by plutonium. The lesion was first described in the open literature more than ten years ago[26] and was also included with other information on plutonium wounds at a later time.[4] The radiation dose around the plutonium implanted in the palmar skin was estimated to be 75 million rads. However, this kind of dose estimate is probably meaningless as we do not know which cells were exposed or for what time periods. The entire lesion was very small, being on the order of 2.8×10^{-5} cm^3. The author stated, "Although no malignancies of the skin of man have ever been shown autoradiographically to be associated with such alpha-emitting foreign bodies, the changes here would seem to indicate that the development of such a lesion is possible." The lesion is shown in Figure 3. The 5 nCi particle of plutonium was surgically excised from the individual's palm approximately four years after the accident. The pathologist involved in the study carefully described the cell changes as having "a similarity to known precancerous epidermal cytologic changes."[26] More recently, Tamplin and Cochran correctly acknowledged this wording when they first refer to it in their report. However, as pointed out by Dr. Dolphin[1], in the second reference the wording is altered slightly to "pre-cancerous changes in human tissue," and in the third reference another word change is made and it becomes "particle induced cancer."[15] This particular lesion appears to be about the most severe insult that we have seen to date in terms of potential harm to man from plutonium.

TISSUE ANALYSIS PROGRAMS

For many years the Los Alamos Scientific Laboratory[27] and several other AEC contractor laboratories[28-31] have conducted tissue analysis programs to determine plutonium levels in various tissues of the both exposed occupational personnel and in individuals of the general population who are not engaged in work with plutonium. These programs were started in the 1940's in the Hanford complex and at the Los Alamos Scientific Laboratory. One report contains information on approximately 350 autopsies.[28] Other reports from these and other groups are available.[32-34] Table IX shows plutonium concentrations as determined for lung, liver, lymph nodes, kidney, and bone for the period 1959-1971 for non-occupationally exposed persons from several parts of the United States and for occupationally exposed persons.[35] Data for the plutonium concentration of gonadal tissue which appears in the original publication is not included in Table IX, as errors associated with a change in the analytical procedures were detected by the authors subsequent to its original publication. Similar data shown in Table X have been obtained for non-occupationally exposed persons and represent analyses made during the period 1972-1973.[35] The average lung concentration for the data shown in Table X is about 0.3 pCi for a 1000 gram lung, and the lymph node concentration is about 11 pCi/kg. No special concentration of plutonium in gonadal tissue has been observed in this particular study. Recent analysis of the gonadal data suggest plutonium concentrations of about 0.12 pCi/kg for non-occupationally exposed persons.

The higher plutonium concentrations and lymph node tissue in Table X as compared with those in Table IX for non-occupationally exposed individuals are not thought to represent real increases, but rather an improvement in the dissection techniques used to separate lymph node tissue from lung.

The AEC's Health and Safety Laboratory (HASL) recently has used information obtained from the International Commission on Radiological Protection to model the intake and body burden from fallout plutonium and to estimate the radiation dose to man from this source.[36] The cumulative lung and bone dose for the period 1954-2000 is 16 and 34 mrem respectively. The HASL group has also compared the body burden based on their model with that actually obtained from the tissue sampling programs. The agreement between the Colorado-New Mexico tissue data and the model predictions as shown in Table XI for 1970-1971 is quite good. The comparison based on the New York tissue sampling data is not as good and probably represents the fact that only about 24 autopsies were included in the analysis.

Plutonium is present in extremely small quantitites in various organs of contemporary humans. Although most of the plutonium was produced from atmospheric testing of nuclear weapons by several countries prior to the 1963 limited test treaty ban, some material from contemporary atmospheric weapons testing by France and the People's Republic of China adds to the total human burden. The current lung burden estimated for persons in the United States is about 0.3 pCi, $^{239,240}Pu$, and a very rough estimate of the total amount in the body is perhaps 5 pCi as shown in Table XII. Estimates of the total amount of plutonium produced via nuclear weapons testings vary, but a value of about 0.5 megacurie probably is quite reasonable. If, of this amount, 0.4 megacurie has returned to the biosphere, then very little (about 10^{-8}) has found its way into the earth's population (3×10^9 people). Another way of looking at this is to simply divide the estimated average human burden (5×10^{-12} curies) by the estimated amount in the biosphere (0.4×10^6 curie); in this instance the average accumulation per person is about 10^{-17}.

Results of the tissue sampling programs for occupationally exposed plutonium workers has also given us the opportunity to compare the body burden founded autopsy with that estimated during life on the basis of bio-assay data. Almost without exception, workers in the USA and United Kingdom have found less plutonium by a factor of approximately 10 at autopsy as compared with that amount predicted by bioassay data. Thus it would appear that estimates of the body burden made during life are conservative in that they predict more plutonium than is actually present in the body. Because a considerable amount of data on this subject is now available, it might be profitable for responsible persons in the radiation protection areas to evaluate this finding in terms of current radiation protection practices and guides followed in the nuclear energy industry.

Recently several researchers have examined the United Kingdom experience in terms of the medical aspects of radiological protection of workers handling plutonium. They conclude that the information to date cannot conclusively show that the presently accepted working levels for plutonium are adequate but they do allow for a certain amount of cautious optimism. They also state, "It is true to say that after 30 years' experience in the USA and 22 years' in this country, no disease attributable to plutonium toxicity has been diagnosed in any worker concerned in the production or manipulation of plutonium."(23)

It is important to realize that none of the information presented in this paper means that we will never see an adverse biological effect of plutonium in man. Nevertheless, the record of human experience with plutonium to date is reassuring in the sense that the radiation protection standards which have been followed for many years are very probably quite adequate and do not misrepresent the potential risk by many orders of magnitude, as has been suggested.

TABLE I

BIOMEDICAL WORK RELATED TO MANHATTAN PROJECT PLUTONIUM WORKERS
Medical History and Examination
Radiology
Karyology
Pulmonary Cytology
Urine Radiochemistry
Chest Counting (Uranium L X-Rays)
Blood Chemistry Profiles
Hematology

TABLE II

LOS ALAMOS SCIENTIFIC LABORATORY PLUTONIUM STUDY GROUPS
Group 1[a]
25 men exposed during 1944-1945
Periodic biomedical follow-up for three decades
Reports available in literature[b]
Group 2
42 men also exposed during Manhattan Project
25 located and responded to questionnaires
Group 3
190 early and current plutonium workers
175 identified by Social Security Number
2 identified by military service number

[a]Manhattan Project Plutonium Workers

[b]References 10-12

TABLE III

PLUTONIUM SYSTEMIC BODY BURDEN ESTIMATES FOR SELECTED MANHATTAN PROJECT PLUTONIUM WORKERS AT THREE DIFFERENT TIMES[a]

CASE CODE	$^{239-240}Pu$ (nCi) 1953	1962	1972
1	30-60	10	210
3	80	130	420
4	80	140	260
5	80	140	180
6	60	70	140
7	60	80	150
17	40	90	130

[a]persons with more than 120 nCi $^{239-240}Pu$ systemic burden in 1972.

TABLE IV

$^{239-240}$PLUTONIUM CONTENT OF TISSUES REMOVED FROM CASE #2 IN MAY 1971

Tissue	Wet Weight (g)	$^{239-240}$Plutonium dpm/g	$^{239-240}$Plutonium pCi/g
Lung	70.85	8.48	3.85[a]
Lymph node	1.25	451.00	205.00
Hamartoma	0.77	7.47	3.40
Rib	20.00	3.55	1.61

[a]Contemporary level from weapons detonations is about 0.0004 pCi/g.

TABLE V

PLUTONIUM RECIPIENTS[a]

- Eighteen persons received plutonium in 1945 and 1946.
- Fifteen of the 18 were older than age 45.
- All but 2 given ^{239}Pu; one received ^{238}Pu only and one received ^{238}Pu and ^{239}Pu
- Amounts ranged from ~0.3 to ~6 μCi (current maximum permissible occupational body burden is 0.04 μCi)
- Data from group provided basis for plutonium excretion functions
- One male received 5.2 μCi ^{238}Pu and 0.12 μCi ^{239}Pu and $PuO_2(NO_3)_2$. Later had total gastrectomy and splenectomy. Died 21 years later of cardiovascular disease.
- Some of original group still alive three decades later.

[a]Reference 17

TABLE VI

CURRENT STATUS OF UNITED STATES TRANSURANIUM REGISTRY[a]

AEC CONTRACTOR	WORKERS IDENTIFIED	RECORD RELEASES[b]	AUTOPSY AGREEMENTS	AUTOPSIES PERFORMED	AUTOPSY REPORTS COMPLETED
Hanford	2199	2132	525	12	8
Los Alamos	259	259	127	1	0
Rocky Flats	1504	1489	167	30	21
Savannah River	1559	0	0	0	0
Mound Laboratory	322	0	0	1	1
Oak Ridge	0	0	0	1	1

[a]Reference 25

[b]Health Physics and Medical Records

TABLE VII

INTERNAL PLUTONIUM DEPOSITIONS EXCEEDING 25% OF THE OCCUPATIONAL MAXIMUM PERMISSIBLE BODY BURDEN AMONG AEC CONTRACTOR PERSONNEL DURING THE PERIOD 1957-1970

By Year	
1957	12
1958	6
1959	10
1960	10
1961	16
1962	20
1963	9
1964	29
1965	22
1966	27
1967	10
1968	8
1969	6
1970	3
??	15
Total	203

By Activity	
Research	25
Production	109
Maintenance	17
Development	4
Health Physics	18
Construction	2
Analytical	1
Recovery	5
Unknown	22

By % of Permissible Body Burden	
25 to 50%	118
50 to 75%	35
75 to 100%	13
100 to 200%	15
200 to 500%	15
500 to 1000%	7

By Route of Entry	
Inhalation	131
Wound	48
Both	8
Unknown	16

By Therapy Employed	
Chelate	37
Excision	21
Both	10
None	135

TABLE VIII

ROCKY FLATS ^{239}Pu INHALATION EXPOSURES FROM A SINGLE ACCIDENT[a]

NUMBER OF WORKERS	MULTIPLES OF OCCUPATIONAL MAXIMUM PERMISSIBLE LUNG BURDENS
1	17
1	10
1	7
3	3-5
19	1-2

[a]Reference 3

[b]Derived MPLB is 0.016 μCi

TABLE IX

50TH PERCENTILE DISTRIBUTION OF PLUTONIUM IN HUMAN TISSUE (1959-1971)

	Plutonium Disintegrations per Minute per Kilogram									
	Lung		Liver		Lymph Node		Kidney		Bone	
Nonoccupationally Exposed:										
Los Alamos	1.3	(57)[2]	1.1	(58)	5.0	(52)	0.1	(54)	0.4	(35)
New Mexico and U.S.	1.0	(76)	0.9	(73)	4.0	(66)	0.2	(66)	0.5	(41)
Colorado	0.5	(66)	1.7	(60)	2.0	(46)	1.4	(45)	0.9	(65)
New York	0.4	(26)	1.7	(26)	b		b		2.0	(25)
All Populations	0.8	(217)	1.4	(217)	3.0	(164)	0.6	(163)	0.6	(166)
Occupationally Exposed:[c]										
Potential	4.0	(44)	1.0	(41)	15.0	(42)	0.1	(42)	0.3	(25)
High Potential	100.0	(15)	100.0	(15)	700.0	(14)	10.0	(13)	50.0	(11)

[a]Number of samples (in parentheses)

[b]Samples not requested

[c]Data cannot be compared as a group because of differences in type and duration of exposure

TABLE X

50TH PERCENTILE DISTRIBUTION OF PLUTONIUM IN HUMAN TISSUE (1972-1973)

	Plutonium Disintegrations per Minute per Kilogram									
	Lung		Liver		Lymph Node		Kidney		Vertebrae	
Nonoccupationally Exposed:										
Los Alamos	0.8	(8)[a]	1.6	(5)	35	(4)	0.2	(5)	1.6	(5)
New Mexico and U.S.	0.4	(17)	0.7	(10)	20	(15)	1.2	(10)	0.4	(16)
Colorado	0.7	(29)	1.8	(25)	15	(22)	3.0	(25)	1.1	(25)
New York[b]	0.3	(34)	1.4	(31)	c		c		0.7	(32)
Savannah River	0.4	(20)	1.2	(14)	40	(6)	2.2	(11)	0.7	(12)
All populations[d]	0.6	(74)	1.5	(54)	25	(47)	1.5	(51)	0.7	(58)

[a] (n) number of samples (in parentheses)

[b] New York data for 1972 include all data analyzed

[c] Samples not requested

[d] All population data for 1972 do not include the New York data analyzed during 1972

TABLE XI

PLUTONIUM-239 IN MAN[a]

	Concentration (dpm/kg)	Burden (pCi)	Computed Burden (pCi)
Colorado-New Mexico (1970-1971)			
Lung (1.0 kg)	0.6 (96)[b]	0.30	0.3
Lymph (0.015 kg)	5.0 (73)	0.03	0.6
Liver (1.7 kg)	1.8 (88)	1.40	0.8
Kidney (0.3 kg)	1.1 (73)	0.10	-
Bone (5.0 kg)	0.6 (96)	1.40	0.9
		3.20	2.6
New York (1968)			
Lung (1.0 kg)	0.4	0.20	0.6
Liver (1.7 kg)	1. 7	1.30	0.7
Bone (5.0 kg)	2.0	4.50	0.8
Lymph (0.015 kg)	-	-	0.7
		6.00	2.8

[a]Reference 36

[b]Number of samples (in parentheses)

TABLE XII

PLUTONIUM IN MAN FROM ATMOSPHERIC NUCLEAR WEAPONS TESTS

A. PLUTONIUM PRODUCED FROM ATMOSPHERIC WEAPONS TESTS ~0.5 MCi

B. PLUTONIUM NOW ON EARTH'S SURFACE ~0.4 MCi

C. PLUTONIUM IN CONTEMPORARY MAN

	$dpm \cdot kg^{-1}$	$pCi \cdot kg^{-1}$	kg	$pCi \cdot organ$
Lung	0.8	0.4	1.0	0.4
Liver	1.4	0.6	1.7	1.0
Bone	0.6	0.3	10.0	3.0
Other	-	-	-	0.6
		Total		~5.0 pCi

D. EACH PERSON ON EARTH ACCUMULATED ABOUT 10^{-17} OF B

$$\frac{5 \times 10^{-12}\ Ci \cdot person^{-1}}{0.4 \times 10^{6}\ Ci}$$

E. ABOUT 10^{-8} OF THE EARTH'S INVENTORY FOUND ITS WAY INTO THE 3×10^{9} PERSONS ON EARTH

$$\frac{(3 \times 10^{9}\ persons)\ (5 \times 10^{-12}\ Ci \cdot person^{-1})}{0.4 \times 10^{6}\ Ci}$$

FOOTNOTE

[1] G. W. Dolphin, Hot Particles, National Radiological Protection Board, Radiological Protection Bulletin #8, pp. 8-10, 1974.

FIGURE LEGENDS

Fig. 1 Original wooden D Building which housed the chemists and metallurgists who worked with plutonium at Los Alamos in 1944-45.

Fig. 2 Photomicrograph of an autoradiograph of a lymph node section removed from early Manhattan Project plutonium worker (Case #2).

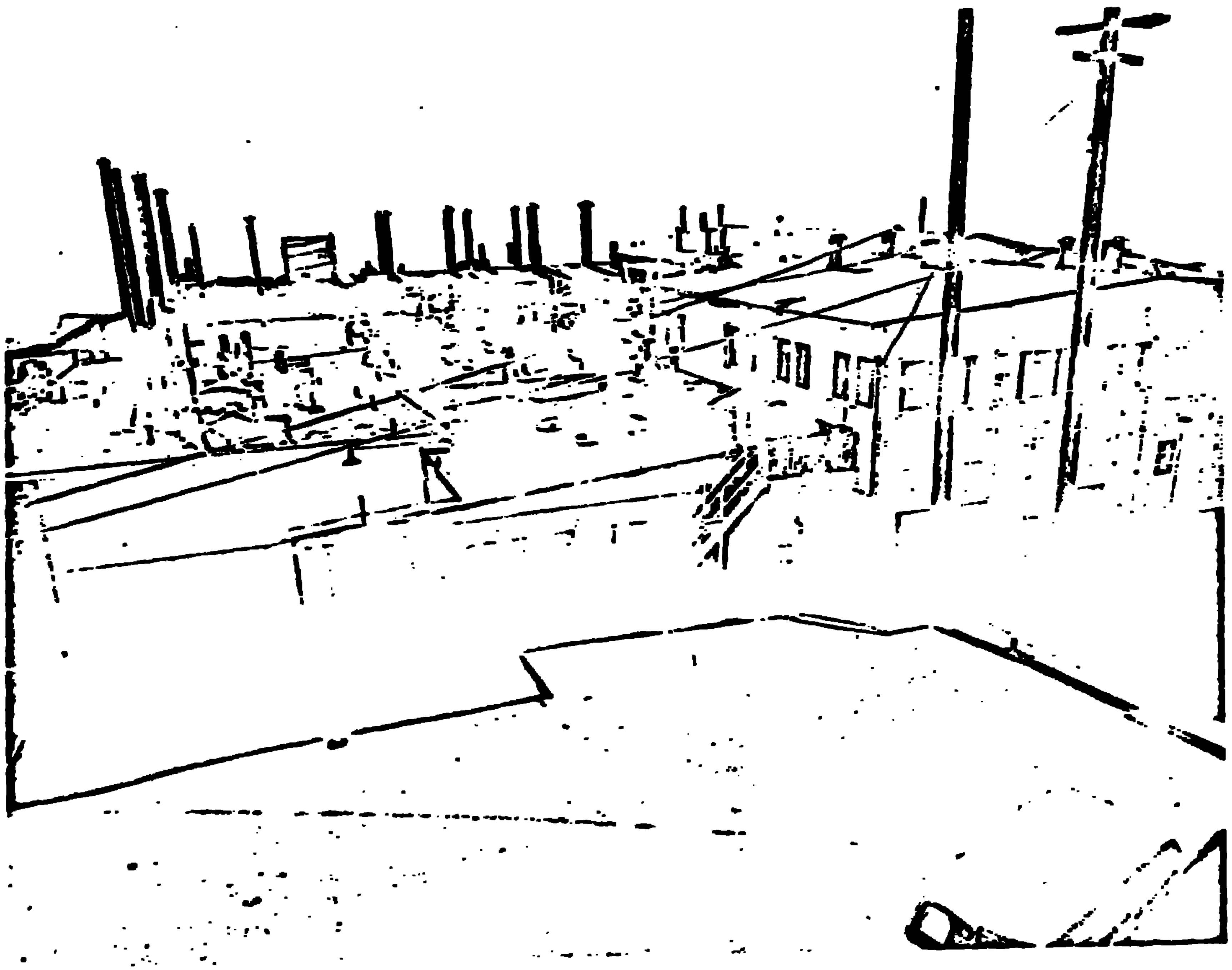
Fig. 3 a Photomicrograph of skin section removed from palmar surface of plutonium worker's hand about four years after accident.
b Photomicrograph of autoradiograph prepared from tissue close to that shown in a.

Note for file copy:

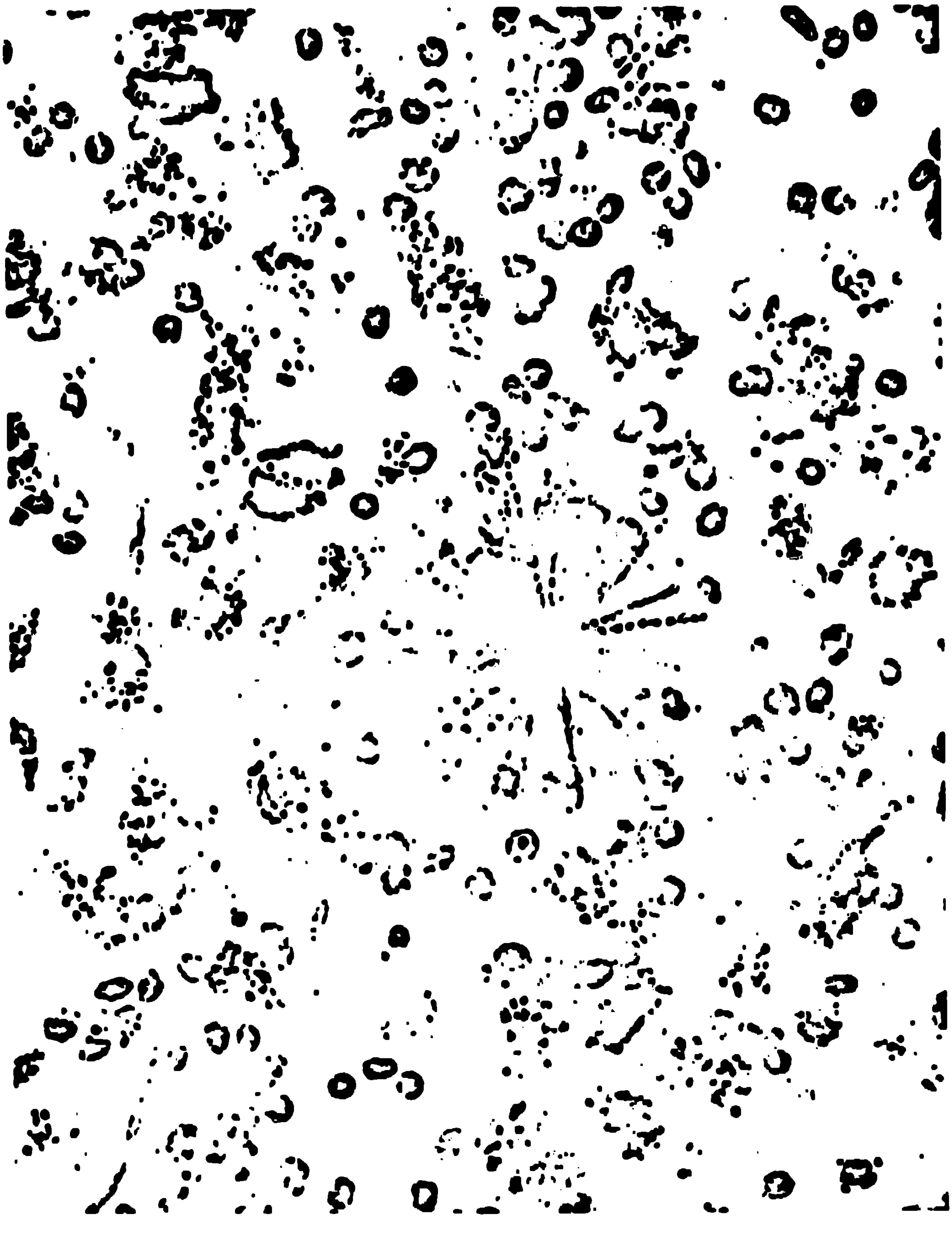
Fig 1 = LASL neg. # 6163

Fig 2 = Med. Res. Lab neg #155-71

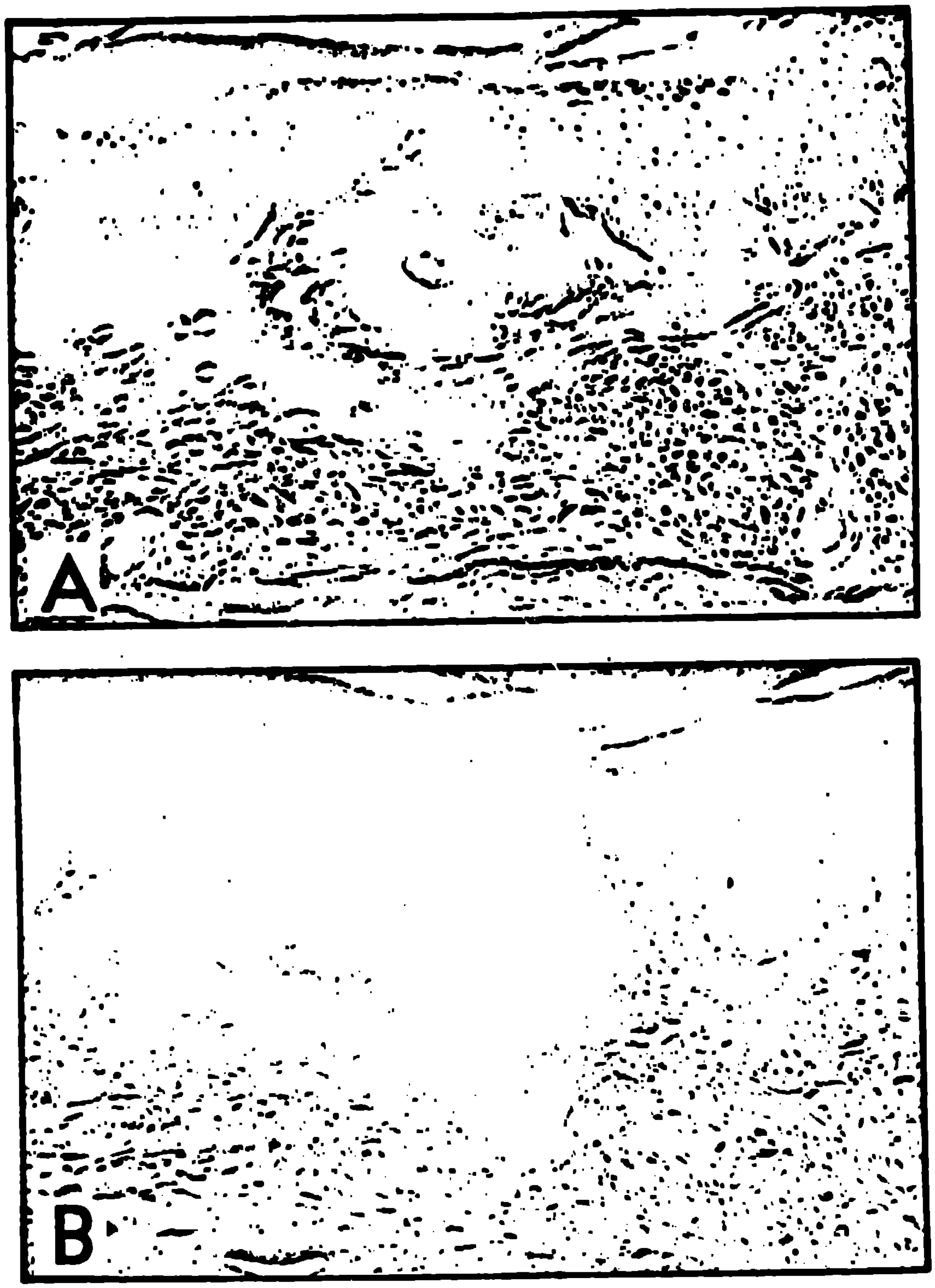
Fig 3 = LASL neg # 63156



Radiation Research, C. R. Richmond
Fig. 1



Radiation Research, C. R. Richmond
Fig. 2



Radiation Research
C. R. Richmond
Fig. 3

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