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ROLLER COASTER

PROJECT OFFICERS REPORT—PROJECT 4.1

PLUTONIUM UPTAKE BY ANIMALS EXPOSED TO A NON-NUCLEAR DETONATION OF A PLUTONIUM-BEARING WEAPON SIMULANT

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R. H. Wilson, Project Officer

J. L. Terry, Lt. Col., USAF VC

University of Rochester
Atomic Energy Project
Rochester, New York 14620

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This publication is the author(s) report to Director, Defense Atomic Support Agency; Director, Division of Military Application, Atomic Energy Commission; and Director, Atomic Weapons Research Establishment, United Kingdom Atomic Energy Authority, of the results of atomic weapons experimentation sponsored jointly by the United States - United Kingdom. The results and findings are those of the author(s) and not necessarily those of the Department of Defense, Atomic Energy Commission, or United Kingdom Atomic Energy Authority. Accordingly, reference to this material must credit the author(s). This document is under the control of the Department of Defense and, as such, may only be reclassified or withdrawn from circulation as appropriate by the Defense Atomic Support Agency; Atomic Energy Commission, Division of Operational Safety; or the Atomic Weapons Research Establishment.

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Research was conducted according to the principles enunciated in the "Guide For Laboratory Animal Facilities and Care," prepared by the National Academy of Sciences-National Research Council.

ABSTRACT

Eighty-four dogs, 132 sheep, and 84 burros were allowed to breathe from the cloud generated by the high-explosive detonation of a plutonium-bearing nuclear weapon simulant. No nuclear yield was present in the explosion. Animals were sacrificed serially from H + 1 hour to D + 2½ years to quantitate initial tissue burdens, to establish lung clearance kinetics, and to determine extent of translocation to other organs. Ten dogs and ten sheep were exposed in a similar trial in which more explosive was used and the weapon simulants were housed in a typical earth-covered high-explosive storage magazine, to establish in a limited way if the admixed earth in any way effected the clearance kinetics. Half of those animals were sacrificed on D + 3, the remainder on D + 7.

Calculated initial depositions in the animals were found to emcompass the deposition postulated for man exposed to a similar aerosol, although the estimate of deposition in animals is somewhat sensitive to the mathematical treatment used in analyzing the data. Clearance in dogs and burros was found to be somewhat more rapid than similar measurements on laboratory dogs exposed to pure PuO_2; clearance in sheep was much more rapid, and the usefulness of this species is questionable. No translocation was observed except in those animals exposed to the largest amounts of plutonium, and in these buildup occurred only in lymph nodes. In burros the species for which results are most reliable, lymph node concentration reached

twenty percent of initial lung concentration in 456 days.

Initial lung concentrations were shown to be quite closely comparable among the three species if exposed to the same cloud integral of respirable aerosol, and it is proposed that these species in particular and probably other large animals can serve as monitors of exposure if sacrificed soon after an accident.

The presence of large amounts of inert dust in the storage magazine trial resulted in a three-fold reduction in lung burden as compared to the dirt-free trial. This may be conservative, but the scarcity of data and the short duration of this phase of the studies preclude any more precise estimate of the benefit of earth-covered storage. It is believed that the altered clearance kinetics are those of the inert dust for which the plutonium serves as a tracer.

PREFACE

In the past four years several reports have been issued which dealt with the findings of the biological studies performed on Operation Roller Coaster. These reports have been both formal and informal and have originated in the United Kingdom as well as in the United States. Close comparison of this report with its predecessors will disclose disparities and discrepancies, and it is appropriate here to explain them.

The biological studies were an undertaking of enormous size and of some importance to the establishment of safety criteria for transport and storage of nuclear weapons. There has, therefore, been a continuing and proper pressure for the release of results almost from the day of exposure. To satisfy this demand, the authors and their UK counterparts have prepared a variety of preliminary reports, some of which were issued even prior to completion of the experiment. Of necessity, then, some of these reports are based on incomplete data. Additionally, meticulous reworking of all the data has shown that in many of the earlier reports inexact interpretations or actual errors crept into its analysis.

The preliminary reports have served a useful purpose in that they afforded guidelines for establishment of criteria, and more important, made it clear that previously established criteria were

not grossly in error. The present report is the fruit of much careful analysis, detailed consideration, and methodical searching for errors, and thus represents a truly final reporting of the biological studies — final in the sense that there will be no need for subsequent reports based on reworking the results. This does not preclude the possibility of later reports which might arise from discovering new ways to interpret the data, in consequence of new laboratory findings or other information not presently available.

A companion report is to be issued from the Atomic Weapons Research Establishment of the UKAEA, and it too may be considered final as far as interpretation of existing data is concerned. The two reports are not interdependent, in the sense that availability of either is not a prerequisite to making use of the other. Active users of this material, however, will probably find that availability of both reports will be helpful.

It is impossible to overstate the importance of the contributions of a number of UK representatives to this work. The relationship between the authors and these people has been most cordial and extremely productive of new and valuable insights to the meaning of this study. It is not possible to give proper credit to all UK persons who contributed; Mr. A. Robson, Mr. R. Carter, and Mr. D.M.C. Thomas were particularly helpful in making sense of a wealth of aerosol data. Much of the merit of this report, however, is the result of the cooperation, criticism, and encouragement of Dr. K. Stewart. His efforts in data analysis,

interpretation, and evaluation would demand his inclusion as co-author if this were other than a Project Officer's Report, and the authors are most grateful to him.

Several persons at the University of Rochester Atomic Energy Project have also made valued contributions. Special recognition is due Dr. T.T. Mercer for his help in aerosol evaluation and Dr. P.E. Morrow, who gave much useful counsel on the meaning of the biological results. Dr. A. M. Dutton was most generous with his aid in the statistical analysis of the data.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

1.1.1. The Problem. Plutonium is generally recognized as one of the most hazardous elements known to man. It is a long-lived alpha-emmitter, its oxide is only slightly soluble in body fluids, and laboratory studies performed to date indicate that when deposited in pulmonary or skeletal tissue it has a long residence time. It is not surprising, then, that the development of nuclear warheads containing plutonium and high explosives among other components gave rise to considerable concern in establishing rules and procedures for reasonably safe transport and storage of such weapons. The hazard associated with the chemical explosive is no different from that of conventional weapons containing like amounts of explosive, but the accidental explosion (and to a lesser extent burning) of a plutonium-bearing weapon will lead to broad dispersal of finely-divided plutonium oxide, much of it in the form of respirable aerosol, in addition to any conventional-explosive effects. The chances of fission in an accident of this kind are vanishingly small, but the wide dissemination of plutonium can be of grave concern in its own right, particularly in populated areas.

Every possible precaution is taken, of course, to minimize the likelihood of accidental detonation, but the probability is not zero,

and the Palomares, Spain, accident in 1966 is a case in point. It remains then to minimize the consequences of an accident since it cannot be eliminated. The only realistic recourse is to limit the amount of plutonium which can become involved in an accidental detonation, since this in turn will limit the amount of respirable aerosol dispersed and thereby limit both the severity of exposure and the area affected. This is the fundamental goal of the transport and storage criteria.

It is evident that there are considerations in addition to those relating solely to safety that affect the criteria. For a variety of reasons, weapons must be transported from one point to another, and they must be stored at their destination, wherever it may be. From a safety standpoint, it is obviously desirable to reduce the amount of plutonium to as small an amount as possible, yet this amount should not be so small as to preclude the movement of weapons, or even seriously to hamper such movement if an adequate defense posture is to be maintained. Thus, it is necessary to achieve a carefully considered balance between public safety on one hand and national defense on the other.

The problem was recognized before such weapons were first placed in the nuclear arsenal, but rational bases for transport and storage criteria were essentially nonexistent. Nothing was known about the physical-chemical properties of the released plutonium or about its aerodynamic behavior in the cloud from explosion or fire, although calculations indicated that the metal would melt and most

of it would be converted to the dioxide. There were disparate points of view as to whether the greater hazard was attributable to plutonium deposited on the ground which might subsequently become resuspended or to the material in the detonation cloud. One of the few areas of agreement was that the hazard, if any, would result from inhalation of the plutonium rather than from any other route of entry into the body.

Since there were no adequate grounds for establishment of criteria, a field trial was held in 1956, in which a plutonium-bearing weapon simulant was detonated under conditions approximating an accident. This effort was rather superficial in scope, but it served to provide initial guidance for drawing up criteria. Much more valuable was the insight it gave to the extent of the problem of gathering knowledge which would permit more realistic criteria to be evolved.

1.1.2 Test Group 57 Studies. With the experiences gained from the 1956 exercise, Test Group 57 was assembled as a part of Operation Plumbbob. This group performed a much more elaborate investigation in an attempt to assay the consequences of an accident, and many areas were studied, including cloud physics, biological uptake, decontamination, and area monitoring (References 1, 2, 3, 4). As in 1956, dispersal was by exploding a weapon simulant, containing plutonium so designed as to ensure no nuclear yield.

This trial was the first in which animals were used to evaluate the biological aspects of an accident. Prior to the trial the

primary hazard was believed to be inhalation of resuspended plutonium, and so a very large effort was expended to determine the extent of respiratory uptake as a function of time and of surrounding contamination. Nearly 100 animals (mostly dogs with some sheep and burros) were placed in locations in the fallout pattern a few days after the detonation where levels of ground contamination were ultimately found to be 2.6, 40, and 560 micrograms per square meter ($\mu g/m^2$). The animals were allowed to remain in place for times ranging from 4 days to 160 days in order to assess lung burden buildup as related to occupancy of a contaminated area. A Casella Mark I cascade impactor was located at each animal site in order to evaluate, at least crudely, the plutonium aerosol presented to the animals.

Although this experimental protocol was expected to provide information on the primary hazard, it was deemed fruitful to place a few animals in the field prior to the detonation so that the relative hazard of cloud-derived respirable plutonium might be assessed. To this end, 24 dogs were placed at distances ranging from 500 to 2000 feet downwind from Ground Zero (GZ). No sampling equipment was available for positioning close to these animals, although there were several Casellas at points broadly encompassing the animal locations.

Biologically, the results of this study were somewhat surprising, although with the deeper insight provided by the overall experiment at least in part fairly reasonably explainable. The dogs exposed at the time of detonation showed generally higher lung burdens than

those placed after it to breathe only the resuspended plutonium. Furthermore, the samplers of other programs indicated that respirable concentrations reached a maximum more than twice as far from GZ as the farthest animals, and the greater hazard was thus shown to result from breathing the cloud generated by the explosion. Paradoxically, the resuspension studies showed essentially no buildup in lung burden as a function of time and very little difference in relation to ground contamination. The air samplers with the animals provided much of the explanation for the latter finding. Even though the ground contamination at the highest animal locations was more than 200 times that at the lowest, the total air concentration was only seven times as high, and gross lung activities were too low and too variable to permit distinguishing such a small difference. Further, it was found that air concentrations decreased relatively rapidly with time ($T_{\frac{1}{2}} = 35$ days) so that the combination of lung clearance mechanisms and decreasing air concentrations meant that instead of a continuous buildup in the lung, as would be expected in a laboratory inhalation study, lung burdens should reach a peak and then decrease, the magnitude of time of maximum lung burden being a function of clearance rate.

The finding that duration of exposure made little if any difference in lung burdens seemed inexplicable except again on the basis of the very low activity levels found in the lungs. As will be discussed later, however, the present work can provide a reasonable explanation for this seemingly unreasonable result.

The TG-57 studies provided much information for guidance in the establishment of transport and storage criteria, although evidently there were still many unanswered questions, in large measure because of the mis-directed emphasis of the biological program. The studies showed that the cloud-borne plutonium was of greater concern, yet they had been wholly inadequate to define the magnitude of the hazard. The lack of instrumentation adjacent to the animals was a serious handicap because it meant that no information was available on the aerosol they had breathed, and the variability of the samplers around them served only to emphasize the riskiness of trying to extrapolate from one location to another.

1.2 OPERATION ROLLER COASTER

Although working criteria were drawn up on the basis of the overall TG-57 results, there was some doubt about their usefulness, particularly on the part of the British. A major UK concern was the disparity of estimates of dose to man as extrapolated from impactor results in comparison to those derived from animal results which were as much as a factor of ten lower than the former. This finding, together with the more restrictive permissible lung dose set by the British Medical Research Council for such a situation (15 REM to the lung), emphasized the animal-instrument discrepancies. The added uncertainties imposed by the recognized shortcomings of the TG-57 biological studies seemed to them justifiable cause for doubt.

A number of U.S.-U.K. discussions were held in an attempt to reconcile differences, and Operations Roller Coaster was an outgrowth of these talks. It was conceived as a joint U.S.-U.K. venture dwarfing in scope the TG-57 work (both physical and biological), one which could be expected to give definitive knowledge of cloud mechanics, particle physics, and biological response so that criteria could be drawn which were based on solid foundations of experimental results and thus could be agreed to mutually.

The field work was performed in Stonewall and Cactus Flats near Tonopah, Nevada. Four tests were fired under the code names Double-Tracks, and Clean Slates I, II, and III. Double Tracks was, in a sense, a standardization shot in that every effort was made to minimize entrainment of non-device constituents into the cloud. A single round was fired on an 8-foot by 8-foot steel plate on a 20-foot by 20-foot concrete pad in the middle of a 100-foot circle of stabilized desert soil, at the apex of an extensively instrumented 78-square-mile array which extended more than nine miles downwind.

Clean Slate I was a simulation of an open-storage or transport accident in which a number of rounds (only one of which contained plutonium) were fired simultaneously. Clean Slates II and III each consisted of a number of rounds (again with only one containing plutonium) fired in typical high-explosive magazines in hopes of verifying an assumption used by the U.S. that earth cover would modify beneficially the dispersal of plutonium. For each event, instrumentation was astonishingly extensive.

The major portion of the biological studies to be reported here was performed on the Double Tracks trial, but availability of time, manpower, and animals permitted a modest involvement in a second trial, and Clean Slate II was selected as offering an opportunity to evaluate in a limited way the biological consequences of the earth cover.

CHAPTER 2

PROCEDURES

2.1 INTRODUCTION

The animal studies undertaken as a part of Operation Roller Coaster constituted the largest inhalation investigation ever performed under field conditions. Although the procedural details have been reported elsewhere (Reference 5), it is appropriate to summarize them here in order that the reader may better appreciate the results to be presented.

In simplest terms, 300 animals (84 dogs, 132 sheep, and 84 burros) were exposed to the explosion cloud of the Double Tracks event and then were sacrificed serially at times ranging from H + 1 hour to D + 2 1/2 years in order to satisfy six objectives:

(1) To expose a large number of animals maximally to the cloud containing plutonium (and uranium) which resulted from firing the single weapon simulant in the Double Tracks event;

(2) To characterize the aerosol to which they were exposed in sufficient detail to permit meaningful animal-sampler comparisons to be made;

(3) To determine the initial lung burdens of plutonium and their kinetics of clearance from the animals' lungs to aid in calculating radiation doses to the lung;

(4) To determine if any significant change occurred with time in the plutonium burdens of certain other tissues which might cause one of them to be considered the critical organ rather than lung;

(5) To compare the results of the animal studies with related parameters published for man; and

(6) To expose a group of animals to the cloud arising from the Clean Slate II event in order to determine whether the respiratory hazard would be altered to any degree by the presence of large amounts of inert dust from the earth cover of the magazine and from the crater dispersed in the cloud by the much larger amount of explosive.

The first objective was intended to compensate for the statistical inadequacies of the TG-57 studies. In that work, the overall emphasis of the trial had been on deposition from the cloud which necessitated firing under broadly distributive wind conditions and in turn meant minimal concentrations of respirable plutonium anywhere on the array. This, together with the limited number of animals exposed during cloud passage, and the lack of samplers close to the animal locations meant that estimates of the maximum hazard, at least as derived from animal results, were questionable to say the least.

The second was intended to broaden the base on which hazard estimates were made by defining in the greatest possible detail the relationships between the measured aerosol and animal tissue burdens. Proper evaluation of these relationships would permit extrapolation to other areas and other events for which aerosol data were available.

Even more important, good animal-sampler data would greatly strengthen the validity of extrapolation to man since there is a fair amount of knowledge of the behavior of aerosols breathed by man.

Fulfillment of the third objection was essential if a realistic assessment of radiation dose to the lung were to be made. The kinetics of clearance are a function both of species and of material. Estimation of dose is in turn a function of the kinetics, with slower clearance rates leading to higher doses. Little is known about clearance of plutonium dioxide in man, but presumably the assortment of species used in the trial would give some indication of species variation for clearance of this material, and further, it was expected that at least one of the three species would show a usably close similarity to man to provide guidance in extrapolation to this species.

A major concern, particularly with radioactive materials, is the ultimate fate of the cleared material. Is it excreted? Is it translocated to other tissues, to accumulate to hazardous levels? The fourth objective was intended to investigate this possibility. As a nearly insoluble dust, plutonium dioxide could be expected to show some translocation to lymph nodes, which in turn could lead to intense irradiation of a localized region. Plutonium is also known to concentrate in bone under appropriate circumstances, and its presense in sufficient quantity can lead to severe consequences. Although calculations clearly indicated that the overwhelming

majority of the metal would be converted to the dioxide, there was no basis for presuming that the aerosol formed by the explosive disruption of the simulant constituents related in other than a general way to laboratory plutonium aerosols. In the latter there are no admixed metals as in the simulant, and it has been shown repeatedly that the response of an organism to inhaled insoluble oxides is much affected by the temperature and mechanism of formation of the oxide. Beryllium oxides (formed at various temperatures but all BeO) demonstrate this to a marked degree.

The fifth objective, comparison with man, is an obvious one. After all, man is the species of concern, and ultimately all conclusions drawn from the animal studies must be related to him.

The sixth amounted almost to an afterthought and resulted from the realization that there might well be subtle differences in the biological response to what would be, almost certainly, an aerosol different in kind from that derived from Double Tracks.

2.2 FIELD OPERATIONS

2.2.1 Exposure. Maximization of exposure required that stringent criteria for short-time meteorological conditions be met, namely, moderate temperature inversion to limit cloud rise, minimal directional shear of winds to limit crosswind dispersal and thus maximize airborne concentrations, and wind velocities less than 15 mph so that the time of cloud passage would be long enough to permit adequate collection by samplers and animals and downwind concentrations would be maximized.

While ideal from the standpoint of maximizing lung doses to the animals, these criteria imposed severe requirements on the conduct of the exposure phase of the animal studies. Almost by definition, such a weather regime limits the predictability of cloud trajectory so that a major problem was to insure that the animals were in the right place at the right time even with a lead time as short as fifteen minutes before H-hour.

To obtain mobility, the animals were placed on farm wagons which were pulled to their assigned locations by jeeps and weapons carriers. The dogs and sheep were in cages built on the wagons, while the burros were secured in milking stalls and stanchions. To minimize external contamination and to simplify decontamination after recovery, each animal was shrouded so that only its head and extremities were exposed. Each wagon was equipped with at least one Casella Mark II cascade impactor operated by a battery-driven pump and mounted in a position comparable to the breathing zone of the animals. In addition, some wagons were equipped with additional Casellas or total air samplers to provide samples to be used for analysis of the particles (as contrasted to the overall aerosol).

In pre-trial exercises, it was found that the wagons provided excellent crosswind mobility. Radioed instructions to relocate the wagons could be accomplished with a time between adjoining stations of only one or two minutes. Comparable downwind mobility was not possible, however, because of the excessive distances involved. Therefore, the wagons were placed at three ranges on the array:

6250 feet, 8750 feet, and 11,500 feet from GZ. The middle range approximated the predicted distance to the maximum airborne concentration at ground level (d_{max}) as projected from the meteorological criteria and more than half the animals and instruments were placed at this range. The other two ranges served to allow for the uncertainties in this estimate in case the actual shot-time conditions of weather were sufficiently different from those specified as to cause d_{max} to be more or less than 8750 feet. The final disposition of the animal array at shot time is shown schematically in Figure 2.1.

2.2.2 Sacrifice and Necropsy. Following the detonation, (which occurred at 0255 MST, 15 May 1963) the exposed animals were recovered, and between H + 1 and H + 2 hours, 54 animals were sacrificed to initiate the serial sacrifice schedule shown in Table 2.1. While the sacrificed animals were being prepared for necropsy, the surviving animals were returned to their holding quarters.

A serious threat to successful accomplishment of the mission was the possibility of inadvertent introduction of plutonium contamination into the tissue samples, and a number of measures were taken to minimize this risk. After careful removal of the shrouds, the sacrificed animals were completely skinned, and the pelts and extremities, which were certain to be contaminated, were discarded. The carcasses were then thoroughly rinsed in clear water which was adequate to leave them contamination-free on the basis of TG-57 findings.

At necropsy, a total of 9 teams (three for each species) followed meticulous anti-contamination procedures which included glove and

instrument changes after each organ dissection which conceivably could have led to contamination. On all necropsies, femur, kidney, liver, lung, and hilar lymph nodes were collected, weighed, bagged in polyethylene, and frozen to await radiochemical analysis. Trachea, nasal mucosa, pharyngeal mucosa, and esophagus, stomach, and the first meter or two of duodenum were also collected from the animals sacrificed on D-day in hopes of achieving a comparison between total animal uptake and total aerosol samples.

2.2.3 Excretion Studies. In order to assess the rate of elimination of plutonium from the body, the ten sheep scheduled for the final sacrifice at D + 2 1/2 years were placed in metabolism cages immediately on their return from the detonation site. For the first eight days, urine and feces were collected daily. At each subsequent sacrifice period, the same sheep were again caged and five-day collections of urine and feces were made.

2.2.4 Clean Slate II. The Clean Slate II effort was far more modest than for Double Tracks. Ten sheep and ten dogs were exposed in the manner described above at 6250 feet from GZ. Each of the two wagons was equipped with two impactors, and both wagons were placed at the same location to enhance the possibility of interspecific comparisons. Half of each species was sacrificed on D + 3, while the remaining animals were sacrificed on D + 7, these times being deemed most likely to yield useful information within the limitations of circumstances since initial depositions relative to air samples would be expected to correspond to Double Tracks results, and three-and

seven-day sacrifices would serve to indicate if significant differences existed in clearance kinetics. Necropsy procedures were identical to those followed for Double Tracks.

2.3 ANALYTICAL PROCEDURES

When a sufficient number of tissues of all kinds had been accumulated and frozen, they were packed in dry ice in insulated shipping containers and transported to the four contracting radiochemical laboratories for analysis. These laboratories have reported in detail on their findings (References 6, 7, 8, 9); here it will suffice to highlight the important attributes of their procedures.

Analysis of biological materials for plutonium content is among the most difficult tasks that can be undertaken by an analytical laboratory. Levels important to the investigation are frequently low, interfering ions are many, yields are variable, and cross-contamination always a specter. In an experiment of this magnitude, sample accountancy is a further burden; for the biological studies alone more than 2000 samples were analyzed, and the total for all programs was nearly 12,000 samples. Both wet and dry ashing served to rid the sample of organic constituents. Sodium carbonate fusion was used to treat insoluble residues. Final separation was by ion exchange.

One step common to all contracting laboratories was of transcendent importance in enhancing reliability of the results. This consisted of adding a known amount of plutonium-236, which has an alpha energy

of 5.76 MeV, to the sample in an amount proportional to the anticipated activity of the sample. The spike was added early in the preparation procedure, and its recovery as determined by alpha spectrometry gave a precise determination of analytical yield. Since it was identical chemically to the $Pu^{239-240}$ in the samples, the yield factor determined for the spike could be applied to the alpha activity measured for the sample at the 5.15 MeV energy of $Pu^{239-240}$, and a high degree of reliance can be placed on the reported results. Difficulties experienced in applying this procedure occurred only when the samples contained markedly less activity than anticipated, since in the alpha spectrometer a small fraction of the Pu^{236} counts could be expected to tail into the $Pu^{239-240}$ channels.

TABLE 2.1 ANIMAL SACRIFICE SCHEDULE FOR DOUBLE TRACKS EXPOSURES

Sacrifice	Arc E			Arc G			Arc I		
Time	D	S	B	D	S	B	D	S	B
D-day*	6	7	6	6	7	6	5	5	6
D + 3	6	4	6	7	6	6	9	5	6
D + 7	6	6	6	6	6	6	5	6	6
D + 14	6	6	6	5	6	6	5	6	6
D + 36		1			9				
D + 99					10				
D + 195				6	10	6			
D + 456				6	10	6			
D + 2 yrs.					9				
D + 2½ yrs.					10				

* These animals sacrificed between H + 1 and H + 2 hours.

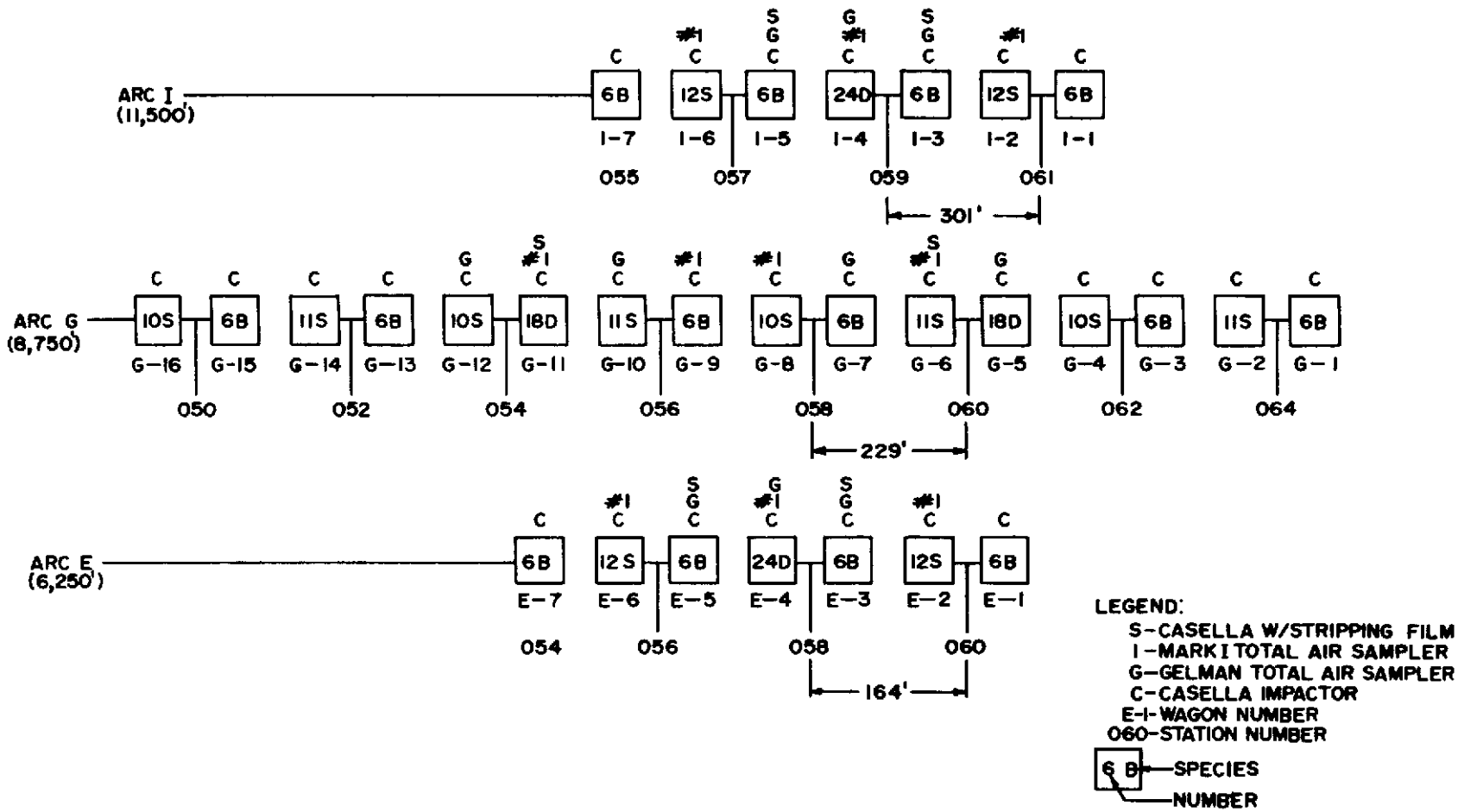

Figure 2.1 Schematic diagram of the animal array.

CHAPTER 3

RESULTS

3.1 INTRODUCTION

As was expected, variability was an overriding characteristic of all Roller Coaster results. Such a finding was inherent in the experiments in view of the method of dispersal of the plutonium, the enormousness of the area to which it was directed (50,000 acres in the case of Double Tracks), the factors controlling this distribution and, in the case of the animal studies, the innate biological variation of the subjects. Other measurements demonstrated that in the first 20,000 feet downwind, the crosswind dispersion of the Double Tracks cloud was small and that the 1600-foot length of the mid-range animal array was only a little less than cloud width at that distance. Ample evidence was found of extremely steep crosswind gradients in plutonium levels, both airborne and deposited on the ground.

Studies showed that the source was comprised of both the stem and the puff, and that the aerosol at any point on the array derived from contributions of both and consisted of particles ranging in size from those large enough to settle with appreciable fall rates under the influence of gravity to those which would disperse almost entirely by the process of atmospheric diffusion. Because of the several-hundred-foot height of the cloud, however, most of the respirable aerosol presented to the animals originated in the lowest

tens of feet of the stem; those particles which reached the breathing zones of the animals from higher in the stem or from the puff were of necessity too large to be respirable.

In projects studying the behavior of the released aerosol, interpretation of the variability of results was in itself a prime area of investigation. In the biological studies variation in the aerosol was a distinct disadvantage, since it meant that the several animal stations received aerosols which differed both in kind and in amount. To have attempted to position all the animals at the same place in order that all might breathe the same aerosol would have been foolhardy; one implication of the steep gradients is that there was a high probability of the entire animal array being incorrectly located. It remained then to evolve ways of normalizing the animal exposures so that in spite of differences in inhaled aerosol, animals sacrificed at the same time could be considered parts of the same population rather than small individual groups of animals.

3.2 THE AEROSOL

3.2.1 The Double Tracks Cloud. Relating the results of the cascade impactors to the animal lung burdens seemed a logical means of inter-relating the exposures of the animals except that the Casellas associated with the animals showed the same extremes of variation observed for samples of other programs. In the worst case (Station E-060), the total alpha activity on the sampler placed with the sheep was found to be more than 26 times as high as that on the burro sampler even though

these two samplers were within 15 feet of each other. Furthermore, as evidenced by Figure 3.1, size distributions of the aerosol were found to be grossly different from those commonly used in laboratory inhalation studies. Mass median diameters (MMD) were in the range 10 to 20 microns*, and although the distribution curves are not log-normal and therefore do not permit determination of σ_g, it can be seen that the slope of the curves is everywhere very steep, and that only a small fraction of the plutonium is encompassed in each increment of size. One highly significant implication of these large geometric standard deviations is that there is only a small difference in probability that a unit parcel of air will contain a particle of one size rather than another, including particles of relatively large size. Friend and Thomas (Reference 10), in an analysis based on the examination of a large number of individual particles ranging in size from 2μm to more than 40μm (real diameter) together with the results obtained from impactors suspended in the cloud, derived the overall size distribution for the Double Tracks aerosol. They found the MMD to be about 45μm and further that σ_g was bi-phasic, being about 6 for particles up to perhaps 30μm and about 2 for particles larger than this. The distribution curve they present indicates that 85 percent of the plutonium is associated with particles larger than 10μm.

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* Throughout this report, unless explicitly stated otherwise, aerosol diameters are expressed as the diameters of spheres of unit density having the same aerodynamic properties as the real particles dispersed by the detonation. For orientation, it may be noted that the equivalent diameter is related to the real diameter by $\rho^{\frac{1}{2}}d$ and that a 1μm PuO_2 particle corresponds roughly to a 3.4μm aerodynamically equivalent particle.

Friend and Thomas also stated that the average particle specific gravity for Double Tracks was 4.9 as contrasted to 11.5 for pure PuO_2. This was based on comparing the diameters of actual particles larger than 2μm real size with the activity measured for each particle and assuming that the balance of the volume was composed of material of 2.6 specific gravity (the average specific gravity of the desert soil). According to Perry (Reference 11), however, there is evidence that the specific gravity of particles smaller than 2μm real size increases with decreasing size and that in all probability, particles less than 1μm real size are very nearly pure PuO_2 or an intermetallic oxide of plutonium and uranium.

The aerosol size distribution developed by Friend and Thomas for Double Tracks serves nicely to explain the enormous variation found in the total impactor samples. Roughly equal amounts of plutonium were present in each size increment in the size range collected by the impactors, and the total number of particles was low. Thus, collection of a particle corresponding to a particular size increment had a low probability of occurrence, and in consequence the presense or absense of the particle would have a marked effect on the distribution curve derived for the impactor and on the total sample collected by it. The effect is especially evident in relation to particles in the larger collectible sizes, many of which carried considerable amounts of plutonium. It is noteworthy that the highest total impactor from the animal array represents the collection from

an aerosol whose average concentration was 270 disintegrations per minute (dpm) per liter, which is equivalent to only four 5-μm particles (real diameter) per liter.

3.2.2 The Respirable Aerosol. Davies (Reference 12) and Stewart (Reference 13) have published curves of deposition in man as a function of particle size. And although Landahl and Tracewell (Reference 14) and Pattle (Reference 15) have shown nasal penetrations of 10μm particles to be as high as 20 percent, Stewart et al. (Reference 16) have proposed that the likelihood of penetration of these particles into the deeper reaches of the lung is low and that therefore it is not unreasonable to assume 10μm as an upper cutoff for the Double Tracks respirable aerosol. Support for this assumption is furnished by considerations of the Task Group on Lung Dynamics (Reference 17) which indicated that particles greater than 10μm will be deposited in the nose quantitatively. Recent work by Stuart (Reference 18) denies this, for he found ceramic spheres as large as 30μm in the alveoli of dogs following inhalation. Further, he calls attention to the radiological significance of the intense, localized radiation from such large particles, expecially since they are apparently immobile once deposited deep in the lung, in contrast to the more diffuse irradiation from a like amount of activity in the form of smaller particles.

For animal-instrument comparisons, however, it is necessary to assume an upper limit for the diameter of respirable particles, and even though the amount of plutonium is roughly constant in each size increment, the number of particles of necessity is not, so the

statistics of collection favor the reliability of results for the smaller sizes. Thus it is prudent for present purposes to consider the fraction of the aerosol <10μm to be respirable, while that >10μm is not, bearing in mind, however, that an occasional particle >10μm may indeed be deposited deep in the lung and is quite likely to remain there indefinitely.

A further justification for selection of the 10μm cutoff arises from the uncertainties associated with the distribution curves at larger sizes. The plotting errors for impactor stage constants greater then 10μm are large, and because particles represented by these sizes carry considerable amounts of activity, a modest error in plotting the distribution curve for the samples collected can lead to a large error in the estimate of the respirable fraction.

If only the fraction of the aerosol less than 10μm is considered, much of the variation found for total impactor samples at the same locations disappears, and the two samplers mentioned earlier which showed a ratio of 26 for total activity now show a ratio of less than 1.5. As evidenced by Table 3.1, not all ratios between pairs of samplers were so dramatically improved, but it is clear that respirable fractions for pairs in most cases compare much more favorably than do totals.

3.3 THE ANIMALS

3.3.1 Lung Burden-Respirable Aerosol Relation. In a general way, animal lung data showed good agreement with sampler results,

although there was ample evidence of biological variation superimposed on the wide range of lung burdens resulting from the differing amounts of aerosol breathed at different locations. Clearly, it would not be meaningful to relate the animals one to another solely on the basis of lung burdens; some normalizing technique was needed which would permit intra-and inter-specific comparisons regardless of the animals' locations and absolute lung burdens.

It was equally clear that any attempt to relate lung burden to impactor results would have to account for the extremes of total impactor samples. If the lung burdens are compared to the fraction of the aerosol less than 10μm in diameter, however, the effect of the widely varying amounts of activity associated with large particles disappears and a better distribution of data results. Even more important, this permits reduction of all lung data to a common basis— the ratio between lung burden and less-than-10μm-fraction. Allowance must be made for relative sampling rates of animals and instruments, and the relationship becomes

$$F = \frac{\text{Pu in lung}}{\text{Pu} < 10\mu\text{m}} \times \frac{\text{Sampling rate}}{\text{Breathing rate}}$$

The most important attribute of F is that it permits a rational grouping of animals sacrificed at the same time regardless of their position on the array because variations in respirable aerosol quantities inherent in the experiment have been normalized. A secondary attribute is that at least for Day 0, F represents the fraction of

the aerosol initially deposited in the animals' lungs. It is important to bear in mind that the deposition so determined is different in kind from that published by Davies and by Stewart. Depositions of <10μm aerosol determined from their curves are limited by definition to an upper limit of 10μm, whereas in enumerating F only the aerosol is limited to <10μm. As has been mentioned earlier, Stewart et al. state that the likelihood of penetration of particles larger than 10μm is small, but it is not zero, and hence it is possible that some of the activity measured in the animals' lungs derives from larger particles. If it is taken that particles larger than 10μm are not likely to be major contributors of activity in the lung, it is reasonable to assume that initial deposition in animals is probably comparable to initial deposition in man as estimated from these published deposition curves.

Log-Normal Distributions. Relating lung burdens to the respirable fraction of the aerosol reduced but did not eliminate the spread of values of the lung results. Such variation is a common characteristic of biological studies, and Stewart et al. have suggested that this is reasonable since each animal is the product of its past experience. They have proposed that because of this, it is appropriate to treat the animals in each sacrifice group as members of a log-normally distributed population. When they are so treated, it is found that in general they do indeed fit such a distribution. Stewart and Wilson (Reference 19) found that when tested

statistically, 95 percent of the groups show fits ranging from good to very good. In 5 percent of the cases, the fit is marginal to poor.

Respiratory Rates. In computing the fraction F, it is necessary to evaluate the ratio of the sampling rate of the Casella to the breathing rate of the animal. Determination of the former was no problem; most of the samplers and pumps had been pre-calibrated, and a few were recalibrated when set in place on the wagons and generally showed satisfactory agreement with the pre-trial measurements. Selection of a suitable respiratory rate for animals, however, poses the same problem as selecting a single value for man. In the latter species, minute volumes may range from less than 5 to more than 50 liters per minute (lpm) wholly in response to oxygen demand at the time of measurement.

Similar extremes can be expected for animals, frequently under much more subtle influences than would affect the respiratory rate in man. Joyce and Blaxter (Reference 20), for example, found that the minute volume in sheep was sensitive to levels of feeding and to temperature and humidity. They noted that under hot, humid conditions the ventilation rate in one sheep increased to nearly 36 liters per minute while at thermoneutrality this fell to 8.4 lpm. With further decrease in temperature, the animal showed an increase in pulmonary ventilation which rose to 12.6 lpm under conditions of wind, cold, and rain.

Many studies have been made of pulmonary ventilation in dogs, but

these are generally performed under laboratory conditions of temperature and humidity and usually on dogs which have undergone sufficient training to remain quiescent during measurement. For the Roller Coaster dogs, a rate of 3 lpm has been selected as representing the best compromise to account for altitude (nearly 5,000 feet), relatively low temperature (about 10° C at the time of exposure), and mild excitement stimulated by the withdrawal of arc personnel, the detonation itself, and bright, noisy photographic flares fired for several minutes after detonation for cloud tracking purposes.

Published respiratory rates for sheep were much less readily available (it should be noted that the work of Joyce and Blaxter was published a year after these studies were performed). A single value of 5.7 lpm was given for a 63-kg sheep in the Handbook of Respiration (Reference 21), but nothing in that source indicated the conditions of measurement. It was decided, therefore, to measure minute volumes of some sheep identical in all respects to the Roller Coaster sheep (the latter were not readily available at the time measurements were made), and it was found that at an elevation of 5,000 feet, a temperature of 18° C, and at about 20 percent relative humidity (RH), mean ventilation rates in sheep averaging 50 kg was 25 lpm. This rate may be compared with Joyce and Blaxter's value of 21.5 lpm under nearly the same conditions except for altitude.

No such definitive studies as theirs have been performed on

burros, so measurements were made on some of the burros remaining from Operation Roller Coaster. Much like the sheep, burros showed a significant temperature dependence of ventilation rate. Although the animals seemed thoroughly quiescent during measurement, at 30° C and less than 10 percent relative humidity but with a high solar input, rates in excess of 100 lpm were obtained. These seemed much too high for resting animals, so two of the most cooperative burros were remeasured under the same conditions as the sheep and a long series of determinations grouped closely around 50 lpm which value was selected for determining F.

It is obvious that F values calculated from lung-sampler data are highly sensitive to the breathing rate selected. This is only of concern, however, when making absolute comparisons among the three species or between the animals and man. Within each species, the breathing rate selected has no effect on conclusions drawn relative to that species (e.g. clearance kinetics). It is important, however, in using the results of these studies to recognize that such things as initial deposition fractions for the animals are no more precise than the values selected for breathing rates.

3.3.2 Deposition and Clearance Kinetics.

Lung Burdens versus Respirable Fractions. In order to estimate radiation dose from inhaled radioactive material, it is essential to know, in as much detail as possible, the kinetics of removal of the material from the lung. Obtaining this knowledge was

a primary objective of the biological studies, since it was not known prior to these studies whether clearance kinetics for the debris from an accidental detonation was relatable to laboratory studies with pure PuO_2 or to some other, perhaps unique, pattern of removal.

An important aim in establishing these kinetics is to achieve a mathematical description of them. Such a description enhances comparisons amongst inhalation studies and, more important, permits operations such as dose estimates to be performed on the data using accepted mathematical procedures.

Commonly, either of two general forms is used to describe lung clearance— single- or multiple-exponential equations, or power equations. While neither form relates necessarily to the physiological processes governing clearance, one or the other nearly always gives a good fit to experimental results. Precedent has favored use of the exponential form, and most clearance studies in the past have been reported in this framework. Exponentials have the merit of being relatively insensitive to early results (up to a few days), but long-term results may have a pronounced effect on the parameters of the equations, and if the magnitude of the results is low or more subject to error than early results, assignment of constants may show considerable uncertainty.

The power function is less sensitive to erratic long-term results but conversely is highly sensitive to early results. In a study lasting 1000 days, the first ten days' results have as much

weight in establishing the clearance curves as do the remaining 990, and it is important to have enough points at these early times to compensate for one or two aberrant results.

Stewart and Wilson (Reference 19) have examined the results for the Roller Coaster animals and determined that the findings for dogs are most appropriately described by a single exponential, while those for sheep and burro correspond more closely to power functions.* The fundamental difference between these two kinds of expressions makes comparisons between them far from simple, and for purposes of this report it seems profitable (though admittedly equivocal) to examine the results both ways, and, such guidance as the authors can afford, the reader may weigh one approach against the other and select for himself that which more readily suits his needs.

Figures 3.2, 3.3, and 3.4 present the medians for each sacrifice day for the three species plotted as power functions.+ Regression lines are also plotted, and these serve the double purpose of providing the line which best fits the data for the function selected (in these figures a power function) and also a relatively unbiased estimate of initial deposition, which for this treatment is taken as H + 1½ hours, or 0.06 day. The merit of this over assuming initial deposition to be that observed is that results for Day 0 sacrifices are not likely to be any more precisely representative of the median

* Most of the statistical treatment of these data was performed by K. Stewart and coworkers at AWRE and by A. M. Dutton at the University of Rochester.

\+ The data from which these figures are derived are presented in Tables 3.2, 3.3, and 3.4.

of a large population than are results for later times. Thus, since the assumption has been made, for present purposes, that clearance obeys a power function, the 0.06-day intercept more truly represents the initial lung burden than the calculated medians for the relatively small Day 0 populations.

The power function for dog may be expressed as

$$LB_t = 20.2\ t^{-0.1273}$$

with an intercept at 0.06 days of 29.0 **percent**. For sheep the expression is

$$LB_t = 3.42\ t^{-0.416}$$

and the 0.06-day intercept is 11.1 **percent**. Burro corresponds to

$$LB_t = 12.1\ t^{-0.242}$$

with the 0.06-day intercept at 24.2 **percent**.

It is evident from the equations and emphasized by the figures that clearance in sheep is markedly more rapid than in the other two species. In the first twenty days, lung burden in relation to respirable aerosol drops by an order of magnitude. It is also evident that variability in this species is generally greater than in the other two. The figures further indicate the difficulty attendant on analyzing low-level samples; with the passage of time and the decrease in lung burdens of all species, the confidence intervals become steadily larger.

The same data are presented in exponential form in **Figures 3.5**, 3.6, and 3.7. As Stewart and Wilson found, it is not reasonable to try to express results **for dogs** with more than a single exponential,

and the equation for dog becomes

$$LB_t = 20.2 \exp\left(\frac{-0.693\ t}{174}\right)$$

which signifies an initial lung burden of 20.2 percent and a clearance half-time of 174 days.

For sheep and burro a double exponential is more appropriate. Regression analysis for sheep data, on the assumption (supported reasonably well by the data) that Day 0 through Day 7 represented largely early clearance and Day 14 through Day 930 represented long-term clearance leads to the expression

$$LB_t = 7.3 \exp\left(\frac{-0.693\ t}{3.3}\right) + 0.73 \exp\left(\frac{-0.693\ t}{399}\right).$$

This expression signifies that the initial deposition is 8.03 percent, that of this amount 7.3 percent is cleared rapidly with $T_{\frac{1}{2}}$ = 3.3 days and 0.73 percent is cleared slowly with T = 399 days.

For burro, Day 0 and Day 3 were assumed to represent short-term clearance and Day 7 through Day 456 related to long-term clearance. These selections were the result of the paucity of data in comparison to sheep and the importance therefore of giving as much weight as possible to the long-term results. This permits regression analysis only of the long-term values, and the short-term part of the equation is determined graphically. The equation for burro thus becomes

$$LB_t = 7.7 \exp\left(\frac{-0.693\ t}{4}\right) + 10.2 \exp\left(\frac{-0.693\ t}{155}\right)$$

for an initial deposition of 17.9 percent of which 7.7 percent is cleared rapidly with $T_{\frac{1}{2}}$ = 4 days and 10.2 percent is cleared with $T_{\frac{1}{2}}$ = 155 days.

From these equations and figures it is again evident that dog and burro compare rather favorably, while sheep show quite different clearance kinetics. Indeed, the kinetics found for this animal are so different from those commonly obtained for other experimental subjects (including man) as to suggest some unusually effective mechanisms for removal of material from the lung, but what these might be cannot here be determined.

In some regards there is a measure of agreement between the two methods of analysis, although in all cases the power function treatment estimates a higher initial deposition than does the exponential approach. The ratios of initial depositions are roughly the same by each method, indicating that there is no aberrant attribute of either method for dealing with the data for any one species. Both methods emphasize the extensive clearance in sheep, although the exponential treatment indicates that the material which remains in the lung is cleared much more slowly than in dog or burro. The effect of this on dose will be treated in a later section.

Lung Concentrations versus Respirable Fractions. Because of the somewhat arbitrary way in which breathing rates were chosen, the lung-sampler correlations were also considered in relation to lung weight, on the assumption that, to some extent at least, ventilation rate would be related to the volume of the lung which in turn is related to its weight. There was no significant change in the kinetics derived from this treatment, nor was there any indication

of improvement in the spread of data for each group of animals. Evidently lung weights and breathing rates are not closely enough related to compensate for the innate biological variations in these two parameters.

One result of this treatment could be of great significance in the event of an accidental detonation. The derived initial lung burdens, expressed as $dpm_{lung}/gm_{lung}/dpm$ presented, are 2.27×10^{-3}, 2.46×10^{-4}, and 1.25×10^{-4} for dogs, sheep, and burros, respectively, or in ratio form, 1.0 : 0.108 : 0.055. If this ratio is multiplied by the ratio of assumed breathing rates, 1 : 8.33 : 16.67, which is equivalent to assuming that the three species breathe the same concentration at the same time, the resultant ratio is 1.0 : 0.900 : 0.917. That is to say, for practical purposes animals exposed to the same air concentrations for the same times will show roughly the same initial lung concentration (dpm/gm). It is perhaps not unreasonable to suppose that man would follow this pattern (in general terms) and that therefore animal lungs collected soon (within a few hours) after an accident could serve as monitors of human lung burdens. Evidently, collection of dog, sheep, or burro lungs would provide the best indications of human exposure, but it is not unlikely that goats and perhaps cattle would also serve, at least to establish the order of magnitude of exposure in man. In this context, it is just as important that animals selected to serve as monitors be close to possibly exposed humans as it was important that samplers be close to animals in the field studies.

Estimation of human lung burdens by extrapolation to Time Zero from later times must be done much more cautiously and is valid only for the three species used in the field exercise. **Figures** 3.8, 3.9, and 3.10 present plots of the medians of lung concentrations in relation to respirable plutonium as a function of time, and regression lines are shown for each set of results. It will be noted that while results for dog are plotted as a single exponential, those for sheep and burros are plotted as power functions. There are two reasons for this selection of functions:

1. Stewart and Wilson have shown that dog results more closely approximate a single exponential expression, while sheep and burro are better represented by power functions.

2. If extrapolations to Time Zero are to be made for periods ranging from a few hours to a few days after an accident (the most likely period for collection of lungs of exposed animals), it is far preferable that it be made along a mathematically derived straight line, in which some confidence can be placed, than along a somewhat intuitively plotted double exponential curve, particularly during the first week where the rate of change in lung burden is rapid and therefore the slope of the early-clearance part of the double exponential is very steep.

Treated in this way, the kinetics for dog can be expressed as

$$LC_t = 2.275 \times 10^{-3} \exp\left(\frac{-0.693t}{187}\right) ,$$

that for sheep as

$$LC_t = 7.94 \times 10^{-5}\ t^{-0.404},$$

and that for burro as

$$LC_t = 7.89 \times 10^{-5}\ t^{-0.164}$$

It is worth emphasizing that extrapolations from these curves should be taken as no more than indicators of deposition in individual human subjects. Unless appreciable numbers of lungs from animals exposed under nearly identical conditions were available, the magnitude of the confidence intervals assumes major importance in estimating median initial depositions in exposed animals. Similar uncertainties exist in estimating deposition in the individual human. In lieu of more precise aerosol data, however, concentrations in lungs of animals can provide estimates within a factor of ten of initial deposition in humans.

3.3.3 Translocation of Plutonium. A major concern following inhalation of Pu aerosol is the extent of translocation of the active material from the lung to other sites in the body. Particularly worrisome is the possibility that some of it will be moved to the bone where deposition is permanent for practical purposes. Morrow et al. (Reference 22), as well as others, have shown that in beagles, following inhalation of massive doses of plutonium oxide as a finely divided particulate, some of the plutonium leaving the lung is indeed found in bone. However, these workers showed that the fraction so relocated

amounts to only 5×10^{-4} (on a per gram basis); kidneys showed a similar uptake, and liver was about a factor of 3 lower. For pulmonary lymph nodes, however, they found tissue concentrations to be equal to lung concentrations and nearly twice as high as lung on the basis of initial lower respiratory tract dose with total pulmonary lymph node burden amounting to about 4 to 5 percent of total lung burden. Furthermore, they observed a buildup in pulmonary lymph node with a time at a rate proportional to $t^{0.42}$.

When tissues of the Roller Coaster animals are expressed as percents of the respirable aerosol, no discernible trend with time is found except in the case of lung as evidenced by Table 3.5. At least in part this must be attributable to the much lower initial lung burdens, and therefore much smaller amounts available for translocation, as compared to Morrow's dogs. A further contributing factor is the normalizing effect of considering all animals; although the advantages of this for examining lung burdens are obvious, so many of the lymph nodes were near background because of the low initial lung burdens they tend to bias the interpretation away from results for individual animals with the highest lung burdens. If lymph node burdens are considered for the highest stations only (G-062, G-064, I-059, and I-061), an increase with time is discernible in lymph nodes of burros and sheep (the only species at these locations) as shown in Table 3.6.

In the case of sheep, the percentages shown are highly sensitive to analytical errors, however. For example, the highest

percentage, that at two years, results from a single animal with a lymph node burden of 1.6 dpm, so that an error of 0.1 dpm corresponds to an error of about 6 percent in estimating the value for the two-year figure.

A similar appraisal of other tissues of animals at these locations substantiates the evidence of Table 3.5. There is no indication of any translocation with time to any tissue except lymph nodes. This is not unexpected; if the G-064 burro sacrificed at 456 days had the same initial lung burden as the burro sacrificed at Time Zero and if the translocation fraction is the same for burro as for dog, then the plutonium moved to the bone would have amounted to less than 2 dpm which would have been undetectable against the background for bone.

3.3.4 Control Animals. At each sacrifice period, each team sacrificed at least one unexposed animal of the same species and necropsied it following the same anti-contamination procedures used for the exposed animals, the intent being to give a measure of cross-contamination control during necropsy. Unfortunately, no tissues were collected from animals which in no way could have been exposed to plutonium for determination of plutonium background of the analytical methods. Therefore, it is not possible to say with confidence and impartiality whence came the activity found in the control tissues. The only insight to be gained is from single samples of three different sheep tissues (lung, liver, and bone) sent to the analytical laboratories. These samples were obtained

from a slaughter house in Rochester and were sent together with a number of spiked samples to the laboratories to be processed as regular Roller Coaster samples. The results (for the blanks only) are shown in Table 3.7. It is evident that the plutonium blank is not zero for these tissues, but the data are too few to serve as any more than indicators of activity in presumably plutonium-free tissues.

Analyses of tissues from control animals show an astonishing range of values. The highest single bone level of all femurs analyzed was found for a control burro. There are, however, a gratifying number of 0 - <1 dpm values for the controls, and it turns out that control activity is largely a function of weight of sample, as shown in Figure 311. The line sketched in this figure is no more than an indicator of trend. It is worth noting, however, that while these data are plotted as weight of tissue versus activity found, the curvature of the line signifies that on a per gram basis tissue activities determined for control animals will go through a minimum, and this minimum occurs at about 500 grams.

The results for the control tissues give no indication of any tissue being more likely to show activity than another except on the basis of tissue weight. The rapid increase in activity levels for heavier tissues is puzzling, the problem attendant on processing several pounds of burro liver notwithstanding. The implications of the control data are that low-level tissues of the order of 10 kg will give meaningless results because background levels will be too

high.

In evaluating the results for the exposed animals, no account was taken of the control values since these were so variable, and there is no appropriate way to consider them in the same sense of deposition as for the exposed animals. For early times this is of little concern since the tissue burdens, at least of the important tissues, are high enough that control background would have little effect. At later times, and particularly at extreme locations, the exposed values are virtually the same as the controls; but since medians of log-normal distributions are used for interpretation of the data, use of exposed animal results without correction for control values tends more to alter the limits of the confidence interval rather than the median value itself.

3.3.5 Excretion Studies. The excretion patterns shown by the ten exposed animals which were kept for 2½ years apparently bear little if any relation to body burdens as indicated in Table 3.8 and Figure 3.12. The highest single day's plutonium level in urine was found in the D + 1 day collection from a sheep exposed to the lowest amount of respirable aerosol of any of the ten. Furthermore, this same highest value is more than 20 times as high as the total body burden of the highest sheep sacrificed on D-day. Plutonium found in feces was a little less extreme although still much too high to relate to measured body burdens of any of the sheep.

These data, rather than throwing light on plutonium metabolism, serve to indicate how difficult is the problem of preventing external

contamination of experimental animals and emphasize the importance of the measures taken to prevent cross contamination during necropsy. The values found for urinary and fecal excretion almost certainly derive from a continual sifting of external contamination from the animals. Two aspects of Figure 3.12 bear out this interpretation:

1. It is reasonable to presume that some plutonium bearing particles would be more firmly trapped in the wool than others. The more loosely attached particles would detach more easily and would appear as sample contamination in the earlier collections. With the passage of time dislodgement would become increasingly difficult, and sample contamination would decrease at a decreasing rate. A situation of this kind is best described by a power equation, and Figure 3.12 indicates that indeed the daily urinary excretion does follow such a function.

2. It will be noted that the mean value for the 456-day collection is somewhat low relative to the plotted line and essentially the same as the two-year value. Not long before the 456-day excreta collections were made, all ten sheep were shorn for the first time after exposure, and it may be presumed that any remaining surface contamination was removed with the wool.

Perhaps of greatest interest in considering these results is their demonstration that shrouding is inadequate to prevent external contamination of animals exposed in the field. The shrouds used consisted of sheets of muslin taped snuggly around the neck, brisket,

and abdomen so that only the head and legs were exposed. To all appearances, careful removal of the shrouds should have left the animals reasonably free from contamination, yet evidently this was not the case.

It is unlikely that this superficial contamination signifies any more to the experiment than an interesting footnote. Most of the activity which was found in the excreta was probably there in association with bits of hair, wool, fat, or other debris. It is most unlikely that it could in any way have made a measurable contribution to the body burdens of any of the sheep since it was probably associated with particles too large to be respirable and if ingested would have passed through the animal unabsorbed.

The problem was probably even less apparent for dogs and burros since these animals shed the entire pelage, and thus in considerable measure, their coats were self-cleaning.

One aspect of Table 3.9 bears additional consideration. It will be noted that the early control values are considerably elevated above values for later times. Because of the abrupt drop to background levels at 36 days, it can only be surmised that control activities are the result of cross-contamination during collection of the samples. Since the sheep were quartered in separate cages in a shelter, there was no possibility of transfer of activity from one cage to another except during the process of sample collection. And, of course, during the first collections, some of the samples were highly active so that inadvertent transfer of contamination is not

impossible.

3.3.6 Total Deposition. Attempts to relate the total sample collected by the impactors to the amount of plutonium in the respiratory tract together with the gastro-intestinal tract were only partially successful. Table 3.9 summarizes the results of this analysis.

Total plutonium in 9 of 11 dogs exceeded the amount of aerosol inhaled as estimated from impactor data. In each of the nine the GI tract burden was the determining factor. It is evident, therefore, that ingestion rather than inhalation was the primary route of entry of the plutonium. This probably resulted from the dogs licking their lips and noses, thus trapping and swallowing large active irrespirable particles which had settled on them. Licking of the feet may also have been a contributing factor since, although the animals were somewhat restrained by collar straps, they were not immobilized, and the front paws in particular were available for cleaning.

Although the sheep data are apparently better, this is a somewhat erroneous impression because for 6 of 14 cases there are no results for pharyngeal mucosa. Generally this tissue was of the same order as nasal mucosa, but the results for both are too scattered to permit any estimate.

The burro data are the best of the three, and it is of interest to note that the highest total deposition was only slightly more than 50 percent. It will be recalled that median Day 0 lung deposition for respirable aerosol in the burro was 17.9 percent, yet the median for

total aerosol is only 10.5 percent. In view of the reasonably good consistency of the total deposition data for burro, this difference in deposition probably should be interpreted as signifying that the burro is a less efficient collector of > 10μm particles than a Casella. It is probably incorrect to assign the lower efficiency to removal of contamination prior to sacrifice by snorting or sneezing. Certainly this does occur, but conditions at time of cloud passage were not such as to induce this reaction in the animals to any appreciable degree. In only two of fourteen cases did nasal mucosa constitute more than 10 percent of the total burden, although for one of these it comprised the major share of total activity found.

Truly important amounts of plutonium were found in the trachea of only one dog and one burro. This perhaps unexpected finding probably resulted from two factors:

1. The earliest sacrifice was an hour after exposure and the latest, nearly two. For purposes of lung burden considerations this time framework constitutes immediate sacrifice. But for a process as rapid as tracheal transport it is a long period. The Task Group on Lung Dynamics, for example, proposes a half-time of 10 minutes for tracheal-bronchial clearance (Reference 17). Unfortunately records were not kept of the time of sacrifice of each animal so it is not possible to relate time to tracheal burdens.

2. Ciliary function does not necessarily end with clinical death. Laboratory preparations of sections of trachea are relatively

simple to maintain active for several hours provided they are kept in a warm, moist environment. Thus, it is reasonable to expect that ciliary action in the trachea may have continued for appreciable times after sacrifice.

The most useful function this analysis of data can perform is to emphasize further the importance of knowing the characteristics of the aerosol in studying inhalation problems. It is evident here that total aerosol is almost unrelatable to any feature of tissue burdens.

3.3.7 Clean Slate II. It will be recalled that ten dogs and ten sheep were exposed on Arc E (6250 feet) to the Clean Slate II cloud in conjunction with two Casella impactors on each wagon in order to determine if there was any detectable difference in biological response to the cloud from an explosion in a typical high-explosives magazine (CS-II) and one in the open with minimal entrainment of debris (DT). Half of the animals were sacrificed on D + 3, the balance on D + 7. It is undeniable that a larger effort on this trial would have been desirable, had it been possible, in order to strengthen comparisons with Double Tracks results. Notwithstanding the relatively small number of experimental subjects and the short duration of this added study, the findings are very interesting and are likely to prove most useful.

The sampler results turned out to be the most consistent found for any of the biological work. The total impactor samples for the sheep wagon were 5825 and 5665 dpm, and the distributions were so similar

as to be indistinguishable. Totals for the dog samplers were 5783 and 5855 dpm, and again the distributions were nearly identical. Of great significance, however, is the fact that these self-consistent pairs of samplers are not in agreement with each other. Even though the total activity found on each of the four samples is within 2 percent of their mean, the respirable fraction determined from the impactors placed with the sheep is more than twice as high as that for dog, or 19 percent for the former and 8 per cent for the latter, thus emphasizing once again that sampling from clouds such as these is highly probabilistic, and unsubstantiated extrapolations to other locations are to be avoided if possible.

In the main, the biological results for this event, limited though they are, show similarly high self-consistency except for two sheep on D + 7 which are a factor of 10 high in relation to all other sheep lung values both for Day 3 and Day 7. The results of considering lung burdens for the Clean Slate II animals in terms of per cent of respiratory aerosol are presented in Table 3.10. Also included are corresponding values as found in Double Tracks for the two species.

These findings may be highly significant in hazard prediction. In all cases except sheep at seven days, the ratio between Double Tracks and Clean Slate II is greater than 3, and as was mentioned, two of the five sheep on this day showed anomalously high values for deposited fraction, while agreement amongst the other three was extremely good. Were there a valid basis for discarding the high

values, the deposited fraction for Day 7 for sheep would be 0.34 percent.

In view of the method used to calculate percent of respirable aerosol in the lung, there is no reason to expect that initial deposition would be different for Clean Slate II than for Double Tracks. Stated another way, since respiratory fractions are based on the amount of aerosol <10μm equivalent aerodynamic diameter, per cent deposition should be insensitive to whether the source was the Double Track cloud or that from Clean Slate II, even though the clouds were admittedly quite different.

On this basis, it is evident that the clearance kinetics for the first seven days are distinctly different for the two events. Some time between Day 0 and Day 3 nearly four times as much of the initially deposited aerosol was cleared from the lungs of animals exposed to the detonation in the CS-II magazine as contrasted to the relatively dirt-free Double Tracks event. The short duration of this experiment obviates any extrapolation beyond seven days except to take what is probably a conservative position by assuming that at later times the ratio DT : CS-II is constant at some value between 3.0 and 4.0. It is not inconceivable that additional animals for longer times might have shown an increase in the ratio with time. It is highly unlikely that a decrease would have occurred. Explanations for these results will

be presented in the Discussion section, but it is clear that a more extensive investigation of response to the Clean Slate II cloud would have been enormously valuable.

3.4 POPULATION SEGMENTS

A particularly useful aspect of treating animal data as the distribution of results for each sacrifice period is that it permits enumeration of the quantity being measured for various fractions of the sample population. In this connotation perhaps the most important single point is the initial deposition. It has been shown that in these studies the data for each point are log-normally distributed, and for each distribution the median has been calculated. The Day 0 median tells us only that half the population will show an initial deposition less than the median, and half will show more. For hazards analysis it is essential to know how much higher depositions larger fractions of the population will show.

Distributions of initial depositions for three experimental species and for man are shown in **Figure 3.13**. Curves for the animals are derived from median initial depositions as determined by the regression analyses on exponential functions and from values for σ observed in the Day 0 animals. The curve for man is taken from **Stewart and Wilson (Reference 19)**. **Several interesting and useful points** may be gleaned from these curves:

1. Initial deposition in sheep is to be expected to show a

very wide range of values.

2. Of the three species, burro shows a distribution of initial depositions that corresponds most closely to man.

3. According to the distribution curves presented here, nearly two percent of exposed dogs and nearly one percent of exposed sheep will show depositions in excess of 100 percent. About 0.1 percent of burros will exceed this value. Depositions of more than 100 percent are patently meaningless and are probably best explained by the small populations represented in estimating σ and by the possibility that a few particles > 10 μm were deposited in the lungs of some of the animals.

4. Deposition in any desired fraction of populations of dogs, sheep, burros or humans may be readily determined. For example, ninety percent of exposed dogs will show depositions of 56 percent or less, of sheep will show 30 percent or less, burros 36 percent or less, and humans 25 percent or less. Because the curves indicate depositions in excess of 100 percent for very large fractions of the populations, extrapolations beyond 98 or 99 percent are probably unwarranted.

It should be noted that the curves in Figure 3.13 represent only one of several ways of presenting initial deposition distributions. Similar sets could have been prepared using observed initial depositions, depositions extrapolated from the power function curves, or as Stewart and Wilson have shown, by referring all animals to Zero Time through the regression relations. Each such treatment leads

to essentially the same interpretation, but values for various population fractions are quite different. For example the 90 percent fraction for dogs, which in this treatment amounted to 56 percent, if considered on the basis of the power function analysis becomes 77 percent. Thus, important though the population fractions are in hazards assessment, evaluation and application of them must be done most judiciously.

TABLE 3.1 CASCADE IMPACTOR RESULTS BY STATION

Sta.	Samp. No.	Species	Gross α	% < 10μm	dpm < 10μm	17.5 lpm Actual Sample Rate	Normalized Activity (dpm)
ARC E							
E-054	9685	B	74	1.5	1.1	1.000	1.1
E-056	9653	S	2456	16.0	393	1.028	404
	9687	B	2066	16.0	331	0.778	258
E-058	9698(1)	D	7932	--	3.4	0.778	2.6
	9689	B	3361	1.0	33.6	0.778	26.1
E-060	9651	S	7316	0.8	58.5	0.833	48.7
	9690	B	279	12.0	33.5	1.000	33.5
ARC G							
G-050	9667	S	41	28.0	11.5	1.093	12.6
	9677	B	1041	4.8	50.0	1.000	50.0
G-052	9666	S	644	11.0	70.8	1.093	77.4
	9678	B	3082	2.5	77.0	1.000	77.0
G-054	9664	S	1424	17.0	242	1.093	264
	9696	D	1163	13.0	151	1.000	151
	9627	D	1251	29.0	363	0.778	282
G-056	9662	S	1716	13.0	223	1.093	244
	9680	B	2942	8.0	235	0.778	183
G-058	9660(2)	S	762	--	100	1.029	102
G-060	9626	S	1311	22.0	288	0.778	224
	9694	D	3827	7.2	276	1.000	276
G-062	9657	S	7241	37.0	2680	0.972	2605
	9683	B	6248	52.0	3250	1.000	3250
G-064	9656(3)	S	15260	39.0	5950	0.972	5783
	9684	B	11802	50.0	5900	1.000	5900
ARC I							
I-055	9647	B	777	22.0	171	0.778	133
I-057	9655	S	2882	17.0	490	1.029	504
	9649(4)	B	1916	49.0	939	0.778	730
	9629(5)	B	2727	25.0	682	0.778	530
I-059	9693(6)	D	583	74.0	431	0.778	335
	9675	B	4322	53.0	2340	0.778	1820
I-061	9668(3)	S	6784	36.0	2440	1.346	3284
	9676	B	9347	43.0	4020	0.778	3127

(1) This sample analysed in two parts: A, Stages 1 and 2, and B, Stages 3, 4, and 5. In general, B is one-half the <10μm fraction. However, for animals at this station, results for 9689 (E-058) were used.
(2) Same as (1) except 9680 (G-056) used.
(3) Values for these samples derived from corrected field counts.
(4) Decimal error assumed for Stage 3, based on corrected field counts.
(5) This sampler had strippable film as trapping medium.
(6) Results suggest this sampler functioned incorrectly. Results for 9675 used instead.

TABLE 3.2 LUNG BURDENS OF DOGS AS PERCENT OF RESPIRABLE FRACTION

Day	Loc.	Animal No.	Lung dpm	Lung Burden (%)
0	E-058	1024	5.4	120
		1040	0.6	13.3
		1050	2.6	57.8
		1054	3.6	80.0
		1069	1.2	26.7
		1150	0.6	13.3
	G-054	1041	13.7	37.0
		1117	4.0	10.8
		1125	3.8	10.3
	G-060	1067	10.5	22.2
		1099	10.9	23.1
		1132	3.2	6.8
	I-059	1022	50.3	16.2
		1029	45.8	14.7
		1035	51.7	16.6
		1081	49.1	15.8
		1087	60.1	19.3
3	E-058	1002	1.3	28.9
		1003	1.2	26.7
		1088	0.6	13.3
		1091	0.9	20.0
		1115	1.1	24.4
		1131	1.9	42.2
	G-054	1052	6.0	16.2
		1101	4.5	12.2
		1107	8.1	21.9
	G-060	1047	8.0	16.9
		1055	9.4	19.9
		1059	10.1	21.4
		1085	5.6	11.9
	I-059	1006	53.0	17.0
		1011	35.3	11.4
		1012	15.5	5.0
		1013	47.0	15.1
		1025	92.3	29.7
		1037	32.2	10.4
		1042	91.8	29.5
		1084	30.4	9.8
		1094	106.0	34.1
7	E-058	1034	2.5	55.6
		1036	10.6	236
		1045	2.9	64.4
		1064	2.6	80.0
		1118	1.9	42.2
		1123	5.4	120
	G-054	1038	3.4	9.2
		1051	1.0	2.7
		1080	12.5	33.8
	G-060	1014	47.6	100.8
		1063	0.8	1.7
		1082	2.8	5.9
	I-059	1007	65.9	21.2
		1015	47.6	15.3
		1028	55.4	17.8
		1061	14.1	4.5
		1103	56.4	18.1
14	E-058	1021	3.7	82.2
		1027	46.2	1028
		1053	0.25	5.6
		1086	0.25	5.6
		1105	0.25	5.6
		1113	0.8	17.8
	G-054	1065	12.5	33.8
		1100	4.4	11.9
		1126	11.1	30.0
	G-060	1077	6.3	13.3
		1109	3.3	7.0
	I-059	1008	18.4	5.9
		1009	46.3	14.9
		1032	37.1	11.9
		1049	59.9	19.3
		1092	70.0	22.5
195	G-054	1056	1.1	5.0
		1057	2.4	11.0
		1083	6.2	28.3
		1129	2.9	13.2
	G-060	1068	5.4	11.4
		1124	3.9	8.3
		1048	5.9	12.5
456	G-054	1072	8.2	37.4
		1090	3.4	15.5
	G-060	1039	4.4	9.3
		1048	5.9	12.5
		1078	0	0.5
		1120	0	0.5

Loc	Casella dpm	Sample Rate, lpm	BR/SR	dpm Presented
E-058	33.6	22.5	.1333	4.5
G-054	151	17.5	.1714	25.8
	363	22.5	.1333	48.3
			Mean	37.0
G-060	276	17.5	.1714	47.2
I-059*	2340	22.5	.1333	311

* Dog sampler apparently malfunctioned; burro sampler (9675) used.

TABLE 3.3 LUNG BURDENS OF SHEEP AS PERCENT OF RESPIRABLE FRACTION

Day	Loc.	Animal No.	Lung dpm	Lung Burden (%)
0	E-056	2003	115	19.9
		2169	57.5	10.0
		2179	58.8	10.2
	E-060	2022	5.6	7.7
		2052	5.4	7.4
		2140	37.2	50.9
		2183	2.3	3.2
	G-052	2126	9.0	8.2
	G-054	2069	50.3	13.3
		2189	5.2	1.4
	G-056	2168	250.6	72.0
	G-058	2034	76.5	23.5
	G-060	2005	24.0	7.5
	G-062	2173	283	7.6
	I-057	2061	41.7	5.8
		2143	134	18.6
	I-061	2116	371	7.9
		2137	424	9.1
		2196	71.9	1.5
3	E-056	2074	16.9	2.9
		2106	9.6	1.7
		2184	8.3	1.4
	E-060	2153	1.6	2.2
	G-050	2190	1.9	10.6
	G-052	2059	1.3	1.2
	G-054	2033	109.9	29.1
	G-060	2029	10.7	3.3
	G-062	2146	2.9	0.1
	G-064	2176	317	3.8
	I-057	2104	25.8	3.6
		2144	22.2	3.1
		2150	22.2	3.1
	I-061	2024	139	3.0
		2047	151	3.2
7	E-056	2015	6.2	1.1
		2091	1.0	0.2
	E-060	2064	3.6	4.9
		2093	1.1	1.5
		2141	1.4	1.9
	G-050	2068	1.6	8.9
	G-052	2194	289	263
	G-056	2076	3.5	1.0
	G-058	2027	10.2	3.1
	G-060	2135	19 5	6.1
	G-064	2009	0.7	0.0
	I-057	2053	31.0	4.3
		2056	8.2	1.1
		2119	5.8	0.8
	I-061	2117	120	2.6
		2121	112	2.4
		2130	125	2.7
14	E-056	2030	5.1	0.9
		2063	1.0	0.2
		2123	7.4	1.3
	E-060	2044	5.5	7.5
		2060	2.6	3.6
		2070	5.4	7.4
	G-050	2148	0.3	1.7
	G-056	2158	1.3	0.4
	G-058	2095	4.4	1.4
	G-064	2013	93	1.1
		2039	218	2.6
	I-057	2094	7.0	1.0
		2105	4.1	0.6
		2193	1.7	0.2
	I-061	2131	65.0	1.4
		2175	64.3	1.4
		2191	40.8	0.9
36	E-060	2026	1.1	1.5
	G-050	2163	1.9	10.6
		2177	0.7	3.9
	G-052	2129	0.9	0.8
	G-056	2021	1.1	0.3
	G-058	2006	1.0	0.3
		2154	1.7	0.5
	G-060	2081	57.3	17.9
	G-062	2124	14.0	0.4
		2128	37.9	1.0
99	G-050	2085	0.4	2.2
	G-052	2166	0.5	0.4
	G-054	2025	0.5	0.1
		2075	0.3	0.1
	G-056	2045	0.3	0.1
	G-060	2035	1.0	0.3
		2182	0.1	0.0
	G-062	2082	3.4	0.1
	G-064	2186	21.9	0.5
195	G-050	2167	3.5	19.6
	G-052	2051	1 1	1.0
		2099	2.2	2.0
	G-054	2042	0.9	0.2
	G-056	2151	0.8	0.2
	G-058	2062	1.4	0.4
	G-060	2187	1.0	0.3
	G-062	2096	3.6	0.1
		2156	7.7	0.2
	G-064	2077	2.8	0.0
456	G-050	2114	0.2	1.1
	G-052	2054	0.2	0.2
	G-054	2017	27.1	7.2
	G-056	2038	0.2	0.1
		2147	6.5	1.9
	G-058	2185	11.2	3.4
	G-060	2072	1.5	0.5
	G-062	2004	1.1	0.0
	G-064	2113	156	3.3
730	G-050	2083	0.3	1.7
	G-052	2145	0	
	G-054	2125	0.7	0.2
	G-056	2088	0.3	0.1
	G-058	2011	0.3	0.1
	G-060	2098	0.3	0.1
	G-062	2023	1.3	0.0
	G-064	2067	2.4	0.0
913	G-050	2157	0.1	0.6
	G-052	2036	1.3	1.2
	G-054	3078 (B)	0.8	0.2
	G-056	2111	0.2	0.0
	G-058	2087	0.4	0.1
	G-060	2092	0.7	0.2
		2134	0.3	0.1
	G-062	2133	2.1	0.0
	G-064	2031	12.2	0.3
		2172	6.0	0.1

Loc.	Casella dpm	Sample Rate	BR/SR	dpm Presented
E-056	393	17.0	1.47	578
E-060	58.5	20	1.25	73.1
G-050	11.5	16	1.56	17.9
G-052	70.8	16.0	1.56	110
G-054	242	16.0	1.56	378
G-056	223	16.0	1.56	348
G-058*	255	19.6	1.28	326
G-060	288	22.5	1.11	320
G-062	2680	18.0	1.39	3725
G-064	5950	18.0	1.39	8270
I-057	490	17.0	1.47	720
I-061	2440	13.0	1.92	4860

*No samplers. Mean of four samplers at G-056 and G-060 used.

TABLE 3.4 LUNG BURDENS OF BURROS AS PERCENT OF RESPIRABLE FRACTION

Day	Loc.	Animal No.	Lung dpm	Lung Burden (%)
0	E-056	3039	128	17.4
		3176	89.8	12.2
	E-058	3147	13.5	18.1
	E-060	3138	23.0	24.0
		3146	96.9	101.0
	G-050	3127	14.3	10.0
	G-052	3007	33.8	15.4
	G-056	3113	52.8	10.1
	G-058	3019	142	21.7
	G-062	3131	1500	16.1
	G-064	3011	3553	21.1
	I-057	3008	172	9.6
		3051	247	13.7
	I-059	3032	1132	21.8
	I-061	3005	1590	17.8
		3020	1850	20.7
3	E-056	3004	42.2	5.7
	E-058	3074	10.3	13.8
		3133	13.1	17.6
	E-060	3130	21.6	22.5
	G-050	2073	7.5	5.2
	G-052	3067	53.8	24.4
	G-056	3136	36.6	7.0
	G-058	3107	31.9	4.9
	G-062	3065	328	3.5
	G-064	3055	2940	17.4
	I-055	3059	24.3	6.4
		3105	62.0	16.3
	I-057	3068	117.5	6.5
	I-059	3101	1332	25.6
		3110	626	12.0
	I-061	3018	956	10.7
7	E-056	3126	39.2	5.3
		3144	64.2	8.7
	E-058	3200	32.6	3.7
	E-060	3075	5.4	5.6
		3137	20.0	20.8
	G-050	3102	6.0	4.2
	G-052	3135	13.7	6.2
	G-056	3177	94.7	18.1
	G-058	3015	70.7	10.8
	G-062	3141	1228	10.2
	G-064	3043	2530	15.0
	I-057	3003	94.9	5.3
		3125	110	6.1
	I-059	3040	385	7.4
	I-061	3006	420	4.7
		3050	1047	11.7
14	E-056	3111	60	8.2
	E-058	3010	4.9	6.6
		3023	16.4	22.0
	E-060	3031	8.7	9.1
	G-050	3033	23.1	16.2
	G-052	3001	57.2	26.0
	G-056	3041	31.2	6.0
	G-058	3109	52.1	8.0
	G-062	3025	948	10.2
	G-064	3076	2390	14.2
	I-055	3042	60.3	15.9
		3053	85.7	22.6
	I-057	3118	599	33.3
	I-059	3035	409	7.9
		3045	1050	20.2
	I-061	3120	18.4	0.2
195	G-050	3021	5.5	3.8
	G-056	3002	12.6	2.4
	G-058	3027	42	6.4
	G-062	3143	135	1.4
	G-064	3028	120	0.7
456	G-050	2122	12.8	9.0
	G-056	3037	7.0	1.3
	G-058	3017	34.4	5.3
	G-062	3140	93	1.0
	G-064	3069	265	1.8

LOCATION	CASELLA dpm	SAMPLE RATE	BR/SR	dpm PRESENTED
E-056	331	22.5	2.22	735
E-058	33.6	22.5	2.22	74.6
E-060	33.5	17.5	2.86	95.8
G-050	50.0	17.5	2.86	143
G-052	77.0	17.5	2.86	220
G-056	235	22.5	2.22	522
G-058[a]	255	19.6	2.56	653
G-062	3250	17.5	2.86	9295
G-064	5900	17.5	2.86	16870
I-055	171	22.5	2.22	380
I-057[b]	810	22.5	2.22	1800
I-059	2340	22.5	2.22	5200
I-061	4020	22.5	2.22	8920

a. No sampler. Mean of four samples from G-056 and G-060 used.

b. Mean of two samplers.

TABLE 3.5 LOG NORMAL MEDIAN TISSUE BURDENS OF DOGS, SHEEP AND BURROS, EXPRESSED AS PER CENT OF RESPIRABLE (<10μm) AEROSOL

Days	0	3	7	14	36	99	195	456	730	913
DOGS										
Femur	0.15	0.27	0.45	0.92			2.02	1.04		
Kidney	0.10	0.09	0.80	1.00			1.20	0.44		
Liver	0.57	0.59	0.78	1.38			3.47	1.40		
Lung	21.5	17.8	23.5	18.1			7.88	3.51		
Hilar L.N.	0.60	0.01	1.00	1.70			1.70	0.80		
SHEEP										
Femur	0.04	0.39	0.23	0.05	1.10	0.06	0.29	0.10	0.07	0.03
Kidney	0.05	0.01	0.01	0.00	0.03	0.00	0.06	0.06	0.11	0.03
Liver	0.14	0.35	0.11	0.08	1.00	0.14	0.08	0.12	0.12	0.16
Lung	9.41	2.62	1.94	0.92	1.32	0.20	0.42	0.68	0.12	0.18
Hilar L.N.	0.05	0.02	0.01	0.01	0.01	0.04	0.11	0.06	0.15	0.05
BURROS										
Femur	0.15	0.80	0.35	0.14			2.9	0.04		
Kidney	0.08	0.05	0.10	0.10			0.14	0.03		
Liver	4.0	3.0	4.3	2.3			2.7	1.1		
Lung	17.9	10.4	9.3	10.1			2.28	2.51		
Hilar L.N.	0.04	0.01	0.00	0.01			0.08	0.03		

TABLE 3.6 MEAN HILAR LYMPH NODE CONCENTRATIONS AT TIME T AS PER CENT OF LUNG CONCENTRATIONS AT TIME 0

	Day									
Animal	0	3	7	14	36	99	195	456	730	913
Burros (1)	0.1	8.6	7.2	0.5	--	--	12.2	20.5	--	--
Sheep (2)	5.8	--	--	--	7.7	29.8	42.2	0	149.0	102.6

(1) Means of results for Stations G-062, G-064, I-059, and I-061.

(2) Means for Station G-062. Station G-064 had no D-0 sacrifice and lung burdens for other stations were too low for purposes of this analysis.

TABLE 3.7 PLUTONIUM LEVELS IN SHEEP TISSUES PRESUMED TO BE PLUTONIUM-FREE (dpm)

	Laboratory		
Tissue	2	3	4
Lung	4.5	0	4.4
Liver	9.5	6.1	1.3
Tibia	33.6	4.0	1.2

TABLE 3.8 MEDIAN PLUTONIUM LEVELS FOUND IN URINE AND FECES OF SHEEP SACRIFICED AT $2\frac{1}{2}$ YEARS (dpm)

	Exposed		Controls	
Day	Urine	Feces	Urine	Feces
1	17,250	1375	20.0	1500
2	4,555	374	12.4	7.5
4.5(1)	2,120	675	5036	42.6
6	1,944	1592	310	74.0
7	1,840	1019	220	234
8	563	704	34.1	184
36	361	95.6	1.9	10.4
99	12	10.0	2.2	15.4
195	4.6	11.6	4.0	11.6
456	1.2	6.6	0.4	7.8
730	1.6	6.1	2.1	1.8
913	2.6	7.7	2.5	7.3

(1) From analysis of one-half of combine Day 4 and Day 5 samples.

TABLE 3.9 MEDIAN TOTAL DEPOSITION: SUM OF LUNG, TRACHEA, GI TRACT, AND PHARYNGEAL AND NASAL MUCOSA EXPRESSED AS PER CENT OF TOTAL AEROSOL INHALED

Species	dep (%)	$\sigma g.$	Range (%)
Dog	400	4.9	3.1-4189
Sheep	9.3	5.0	0.4- 110
Burro	10.5	2.5	0.3- 51.6

TABLE 3.10 MEDIAN LUNG BURDENS EXPRESSED AS PER CENT OF RESPIRABLE AEROSOL FOR DOUBLE TRACKS AND CLEAN SLATE II DOGS AND SHEEP

	DOUBLE TRACKS*		CLEAN SLATE II		RATIO DT/CS-II	
	3 Days	7 Days	3 Days	7 Days	3 Days	7 Days
Dogs	20.0	19.7	5.4	5.9	3.7	3.3
Sheep	2.2	1.5	0.6	1.0	3.7	1.5

* Double Tracks values taken from regression lines in Figures 3.2 and 3.3.

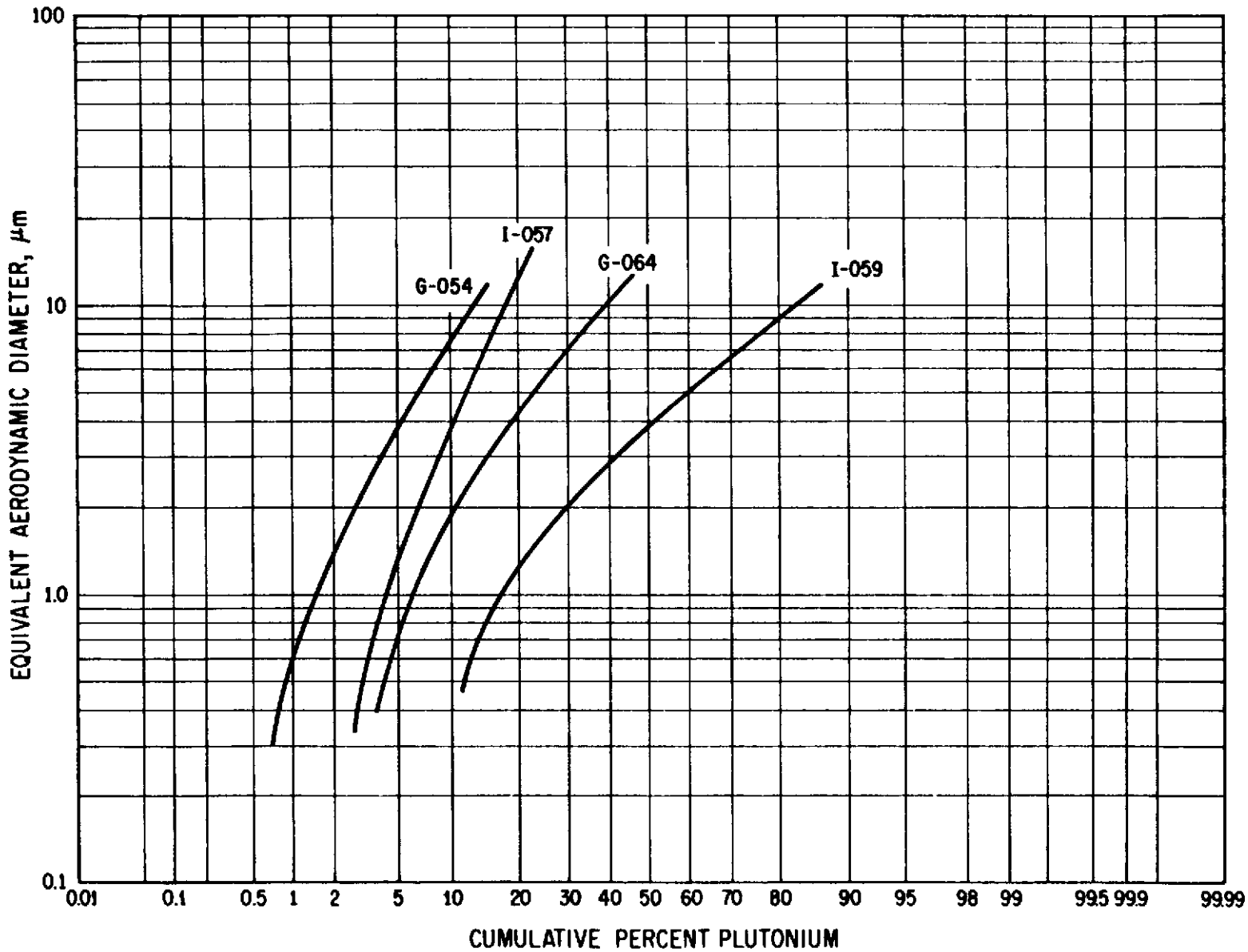

Figure 3.1 Some representative distribution curves for the Double Tracks aerosol.

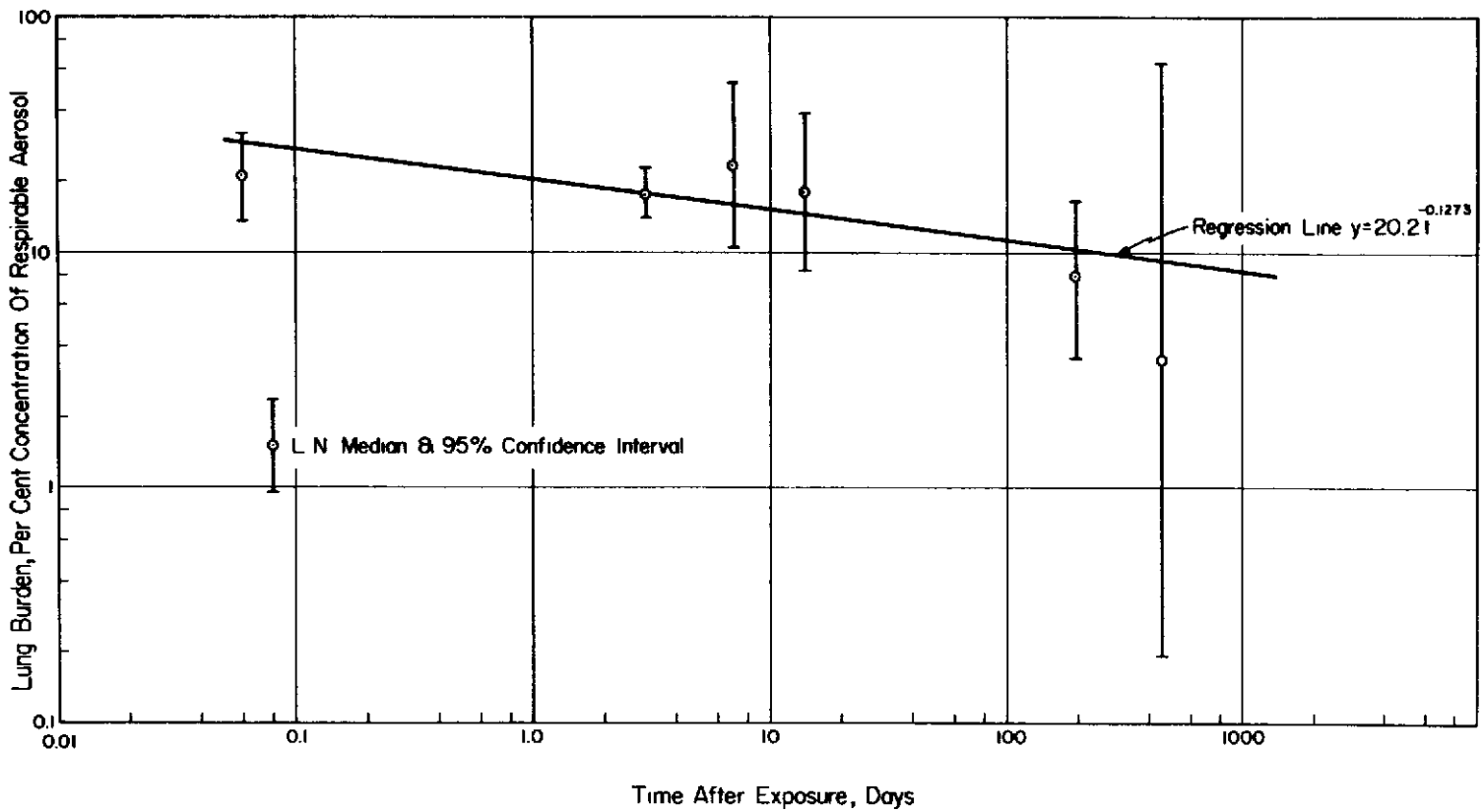

Figure 3.2 Log-normal median lung burdens in dogs as percent of respirable aerosol, expressed as power function.

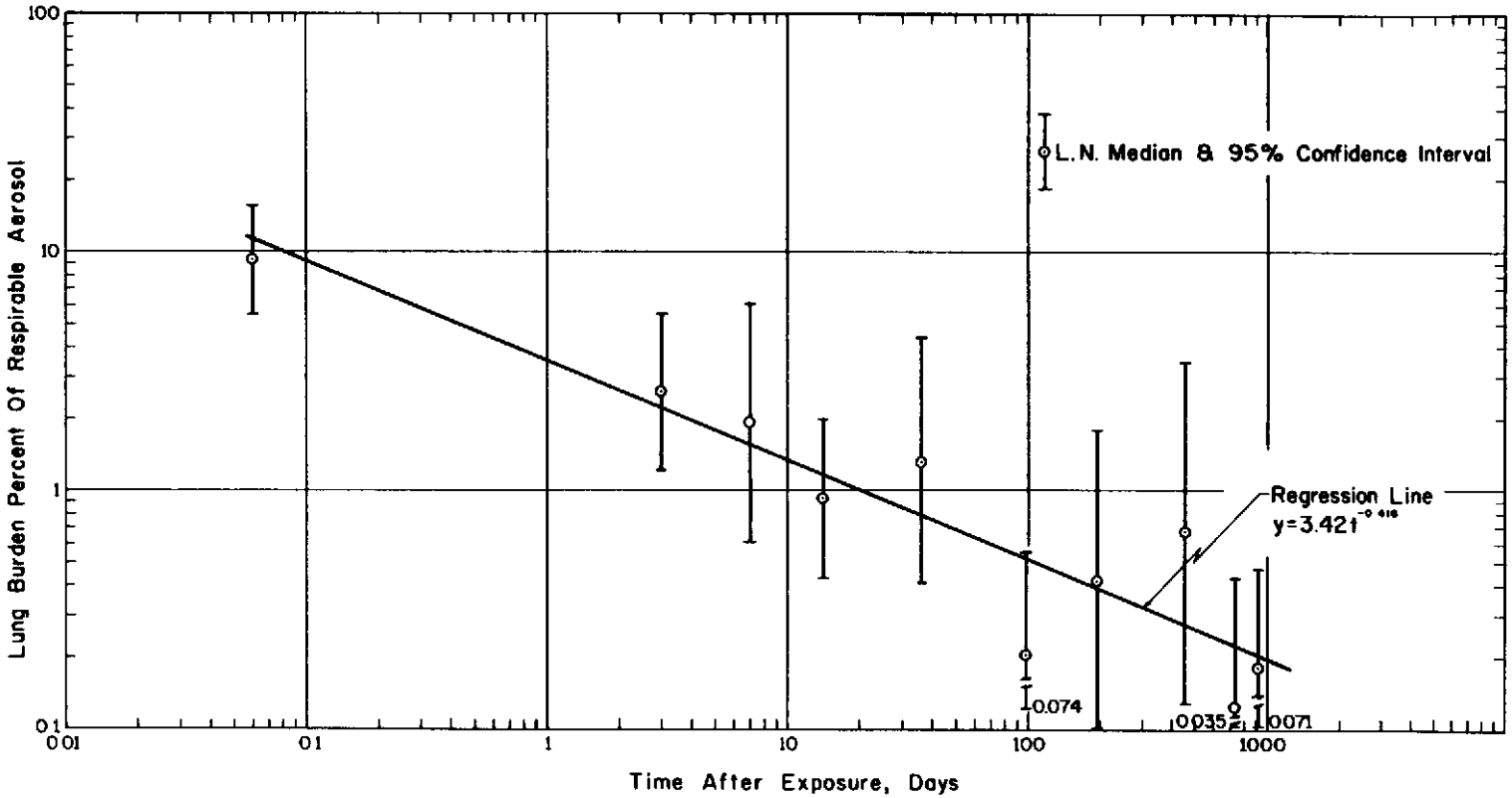

Figure 3.3 Log-normal median lung burdens in sheep as percent of respirable aerosol, expressed as power function.

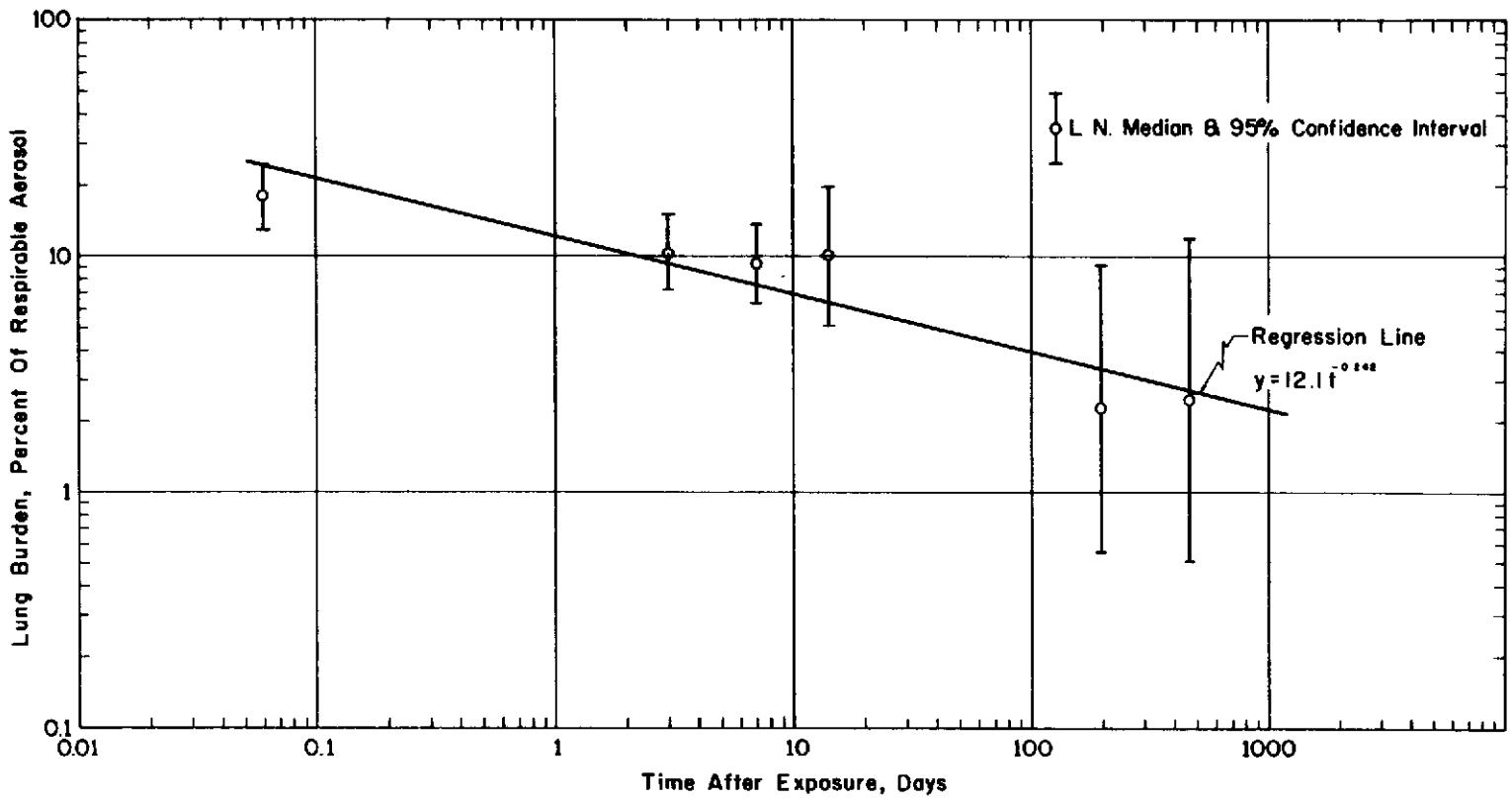

Figure 3.4 Log-normal median lung burdens in burros as percent of respirable aerosol, expressed as power function.

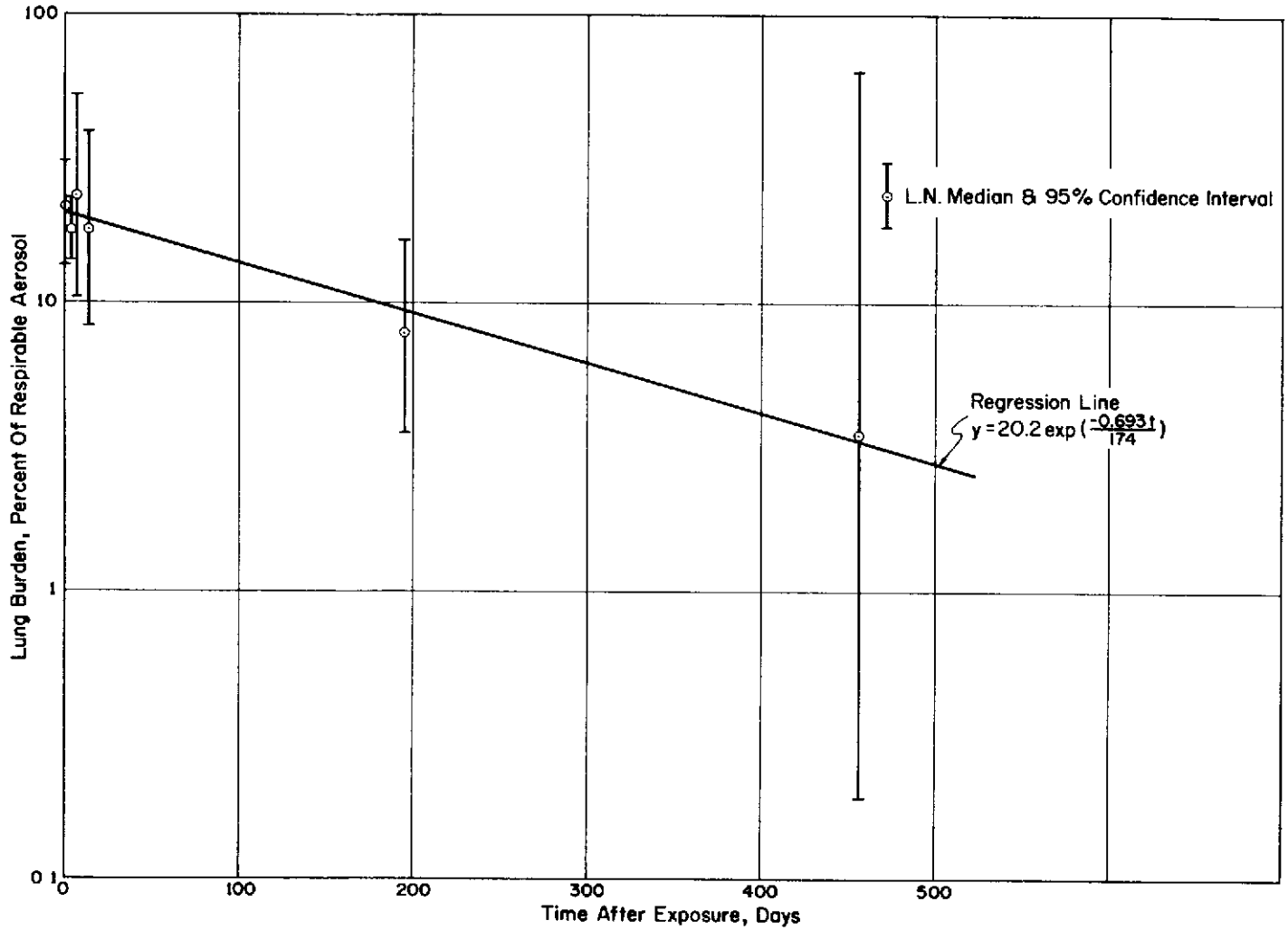

Figure 3.5 Log-normal median lung burdens in dogs as percent of respirable aerosol, expressed as single exponential function.

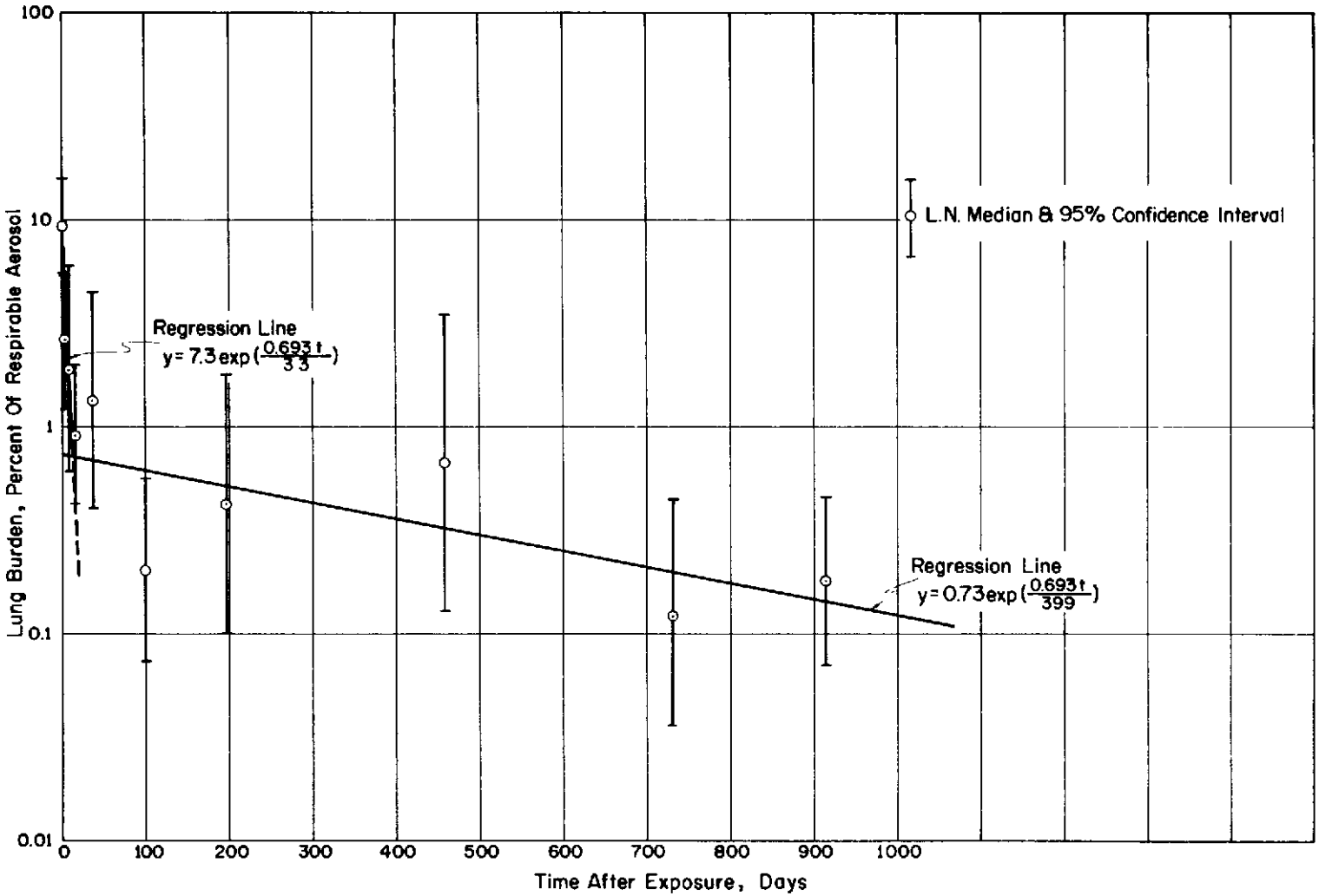

Figure 3.6 Log-normal median lung burdens in sheep as percent of respirable aerosol, expressed as double exponential function.

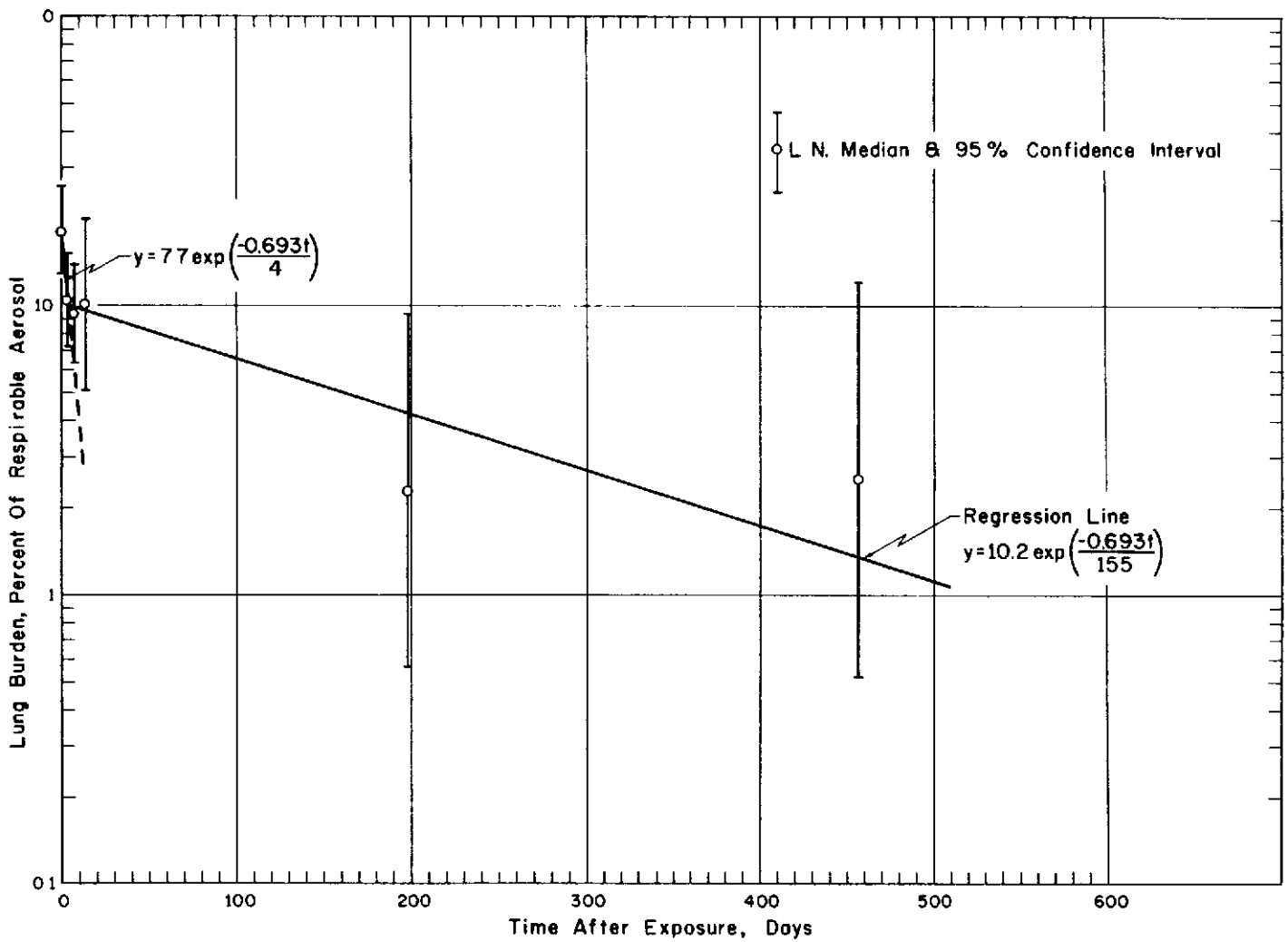

Figure 3.7 Log-normal median lung burdens in burros as percent of respirable aerosol, expressed as double exponential function.

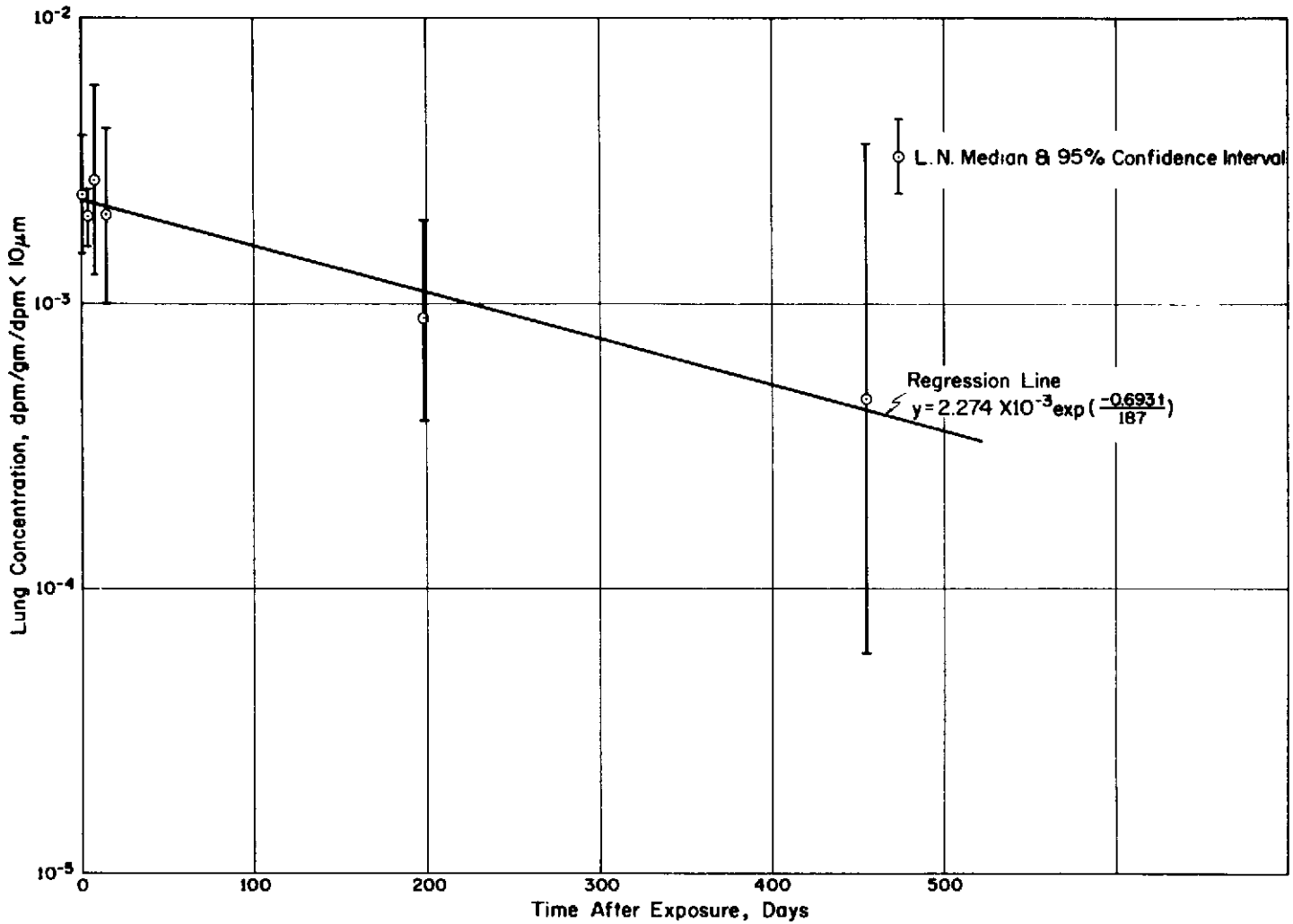

Figure 3.8 Log-normal median lung concentrations in dogs as dpm/gm/dpm of respirable aerosol, expressed as single exponential function.

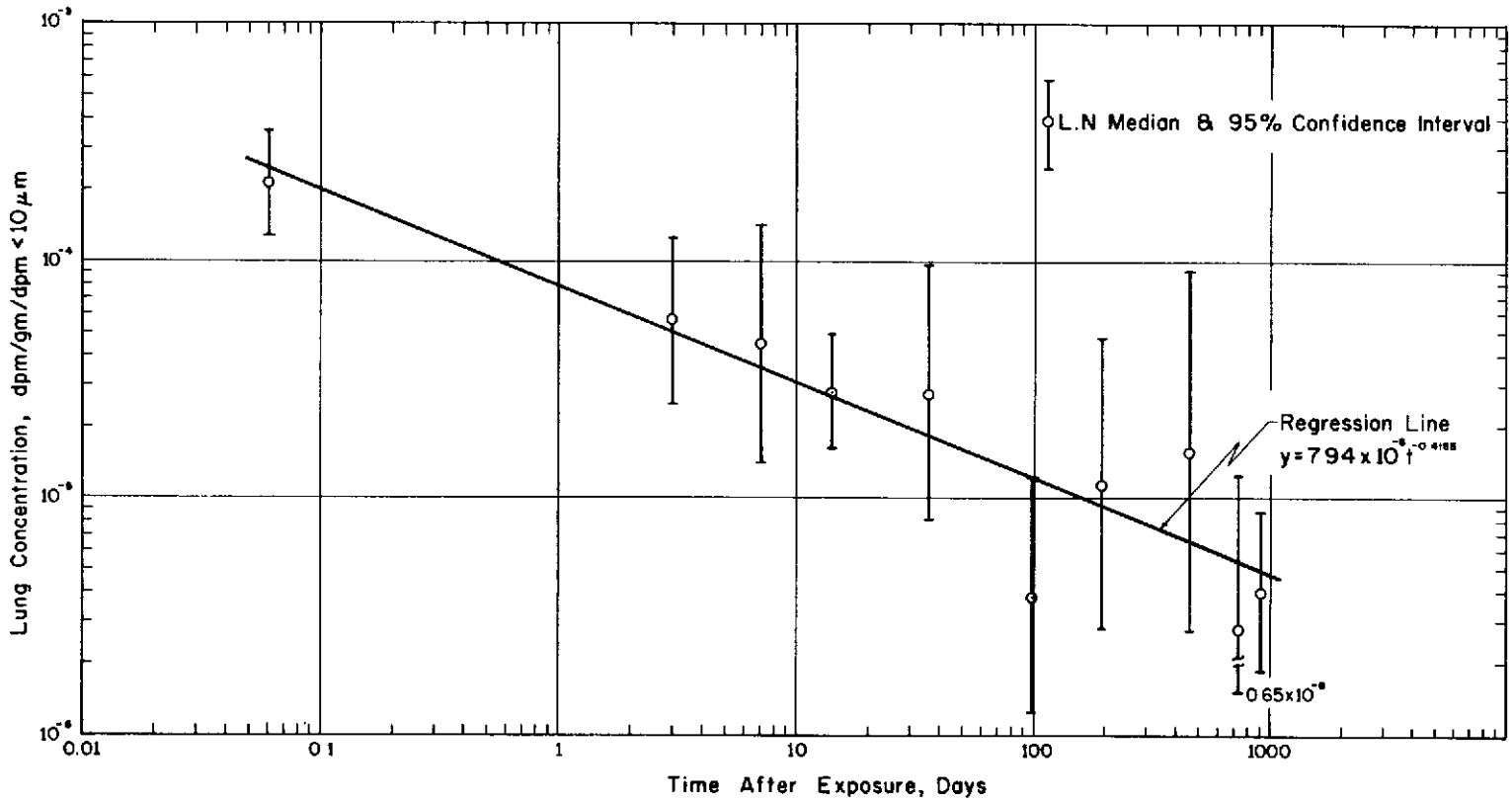

Figure 3.9 Log-normal median lung concentrations in sheep as dpm/gm/dpm of respirable aerosol, expressed as power function.

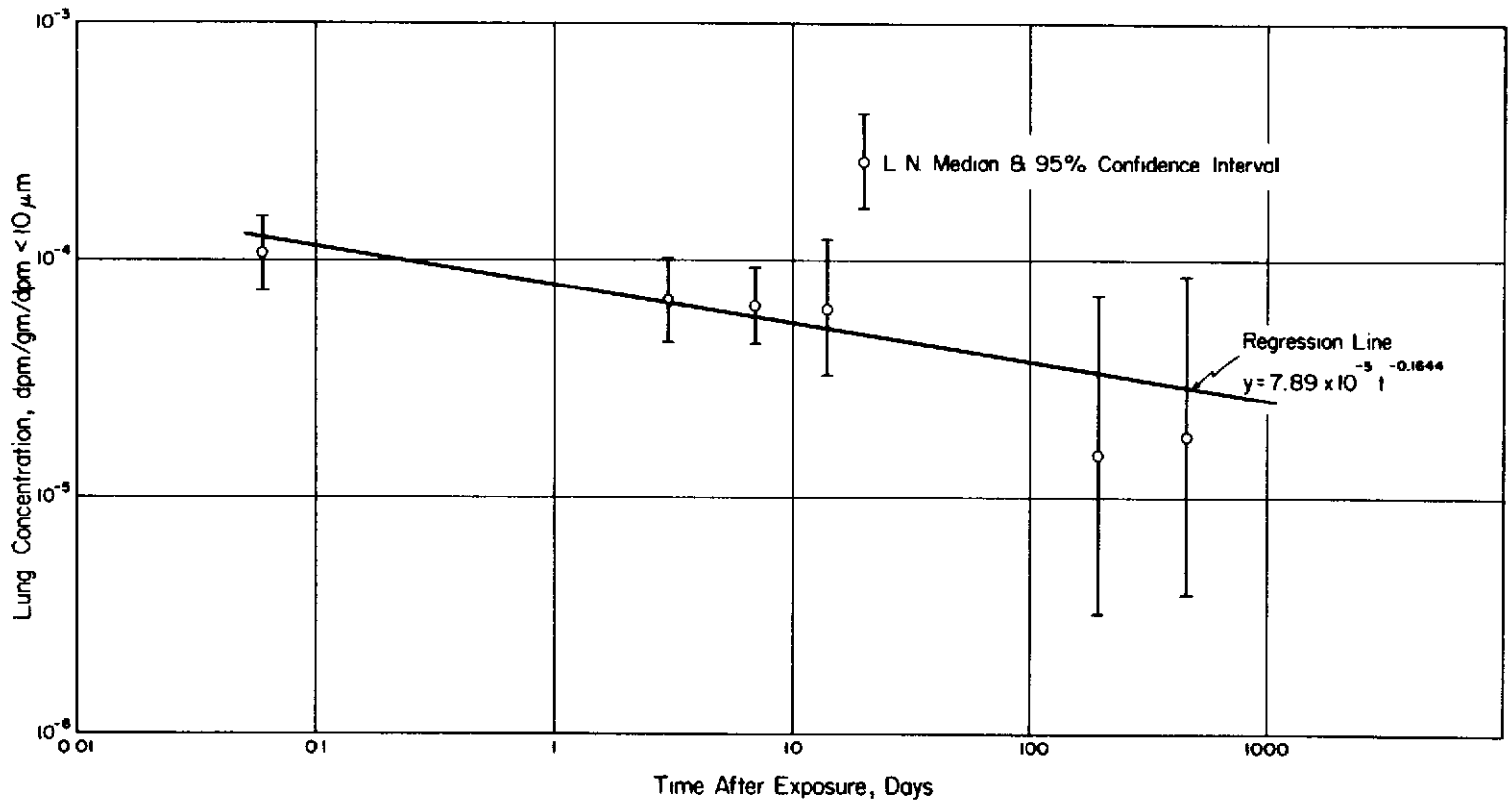

Figure 3.10 Log-normal median lung concentrations in burros as dpm/gm/dpm of respirable aerosol, expressed as power function.

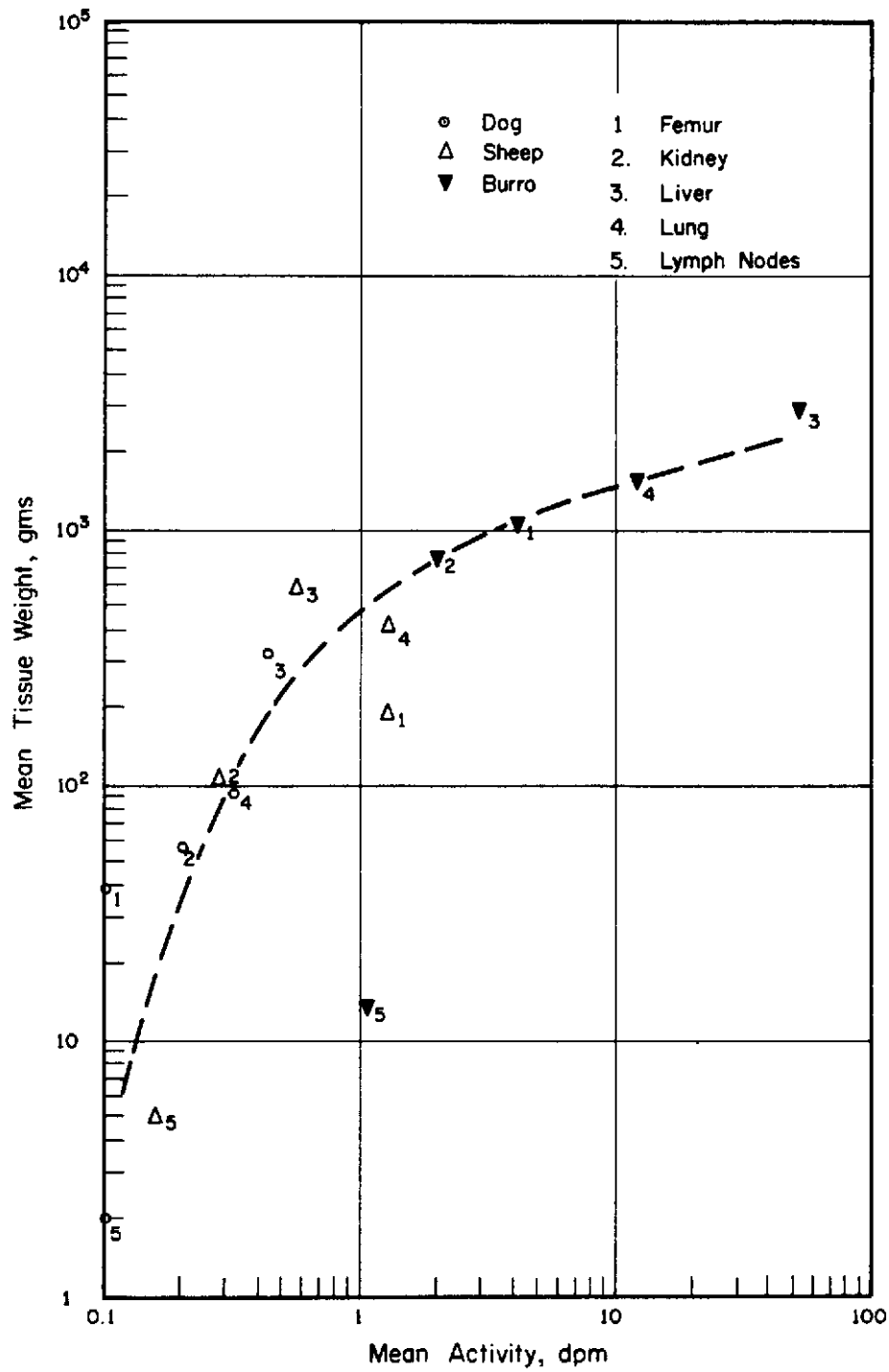

Figure 3.11 Plutonium activities in tissues from control animals.

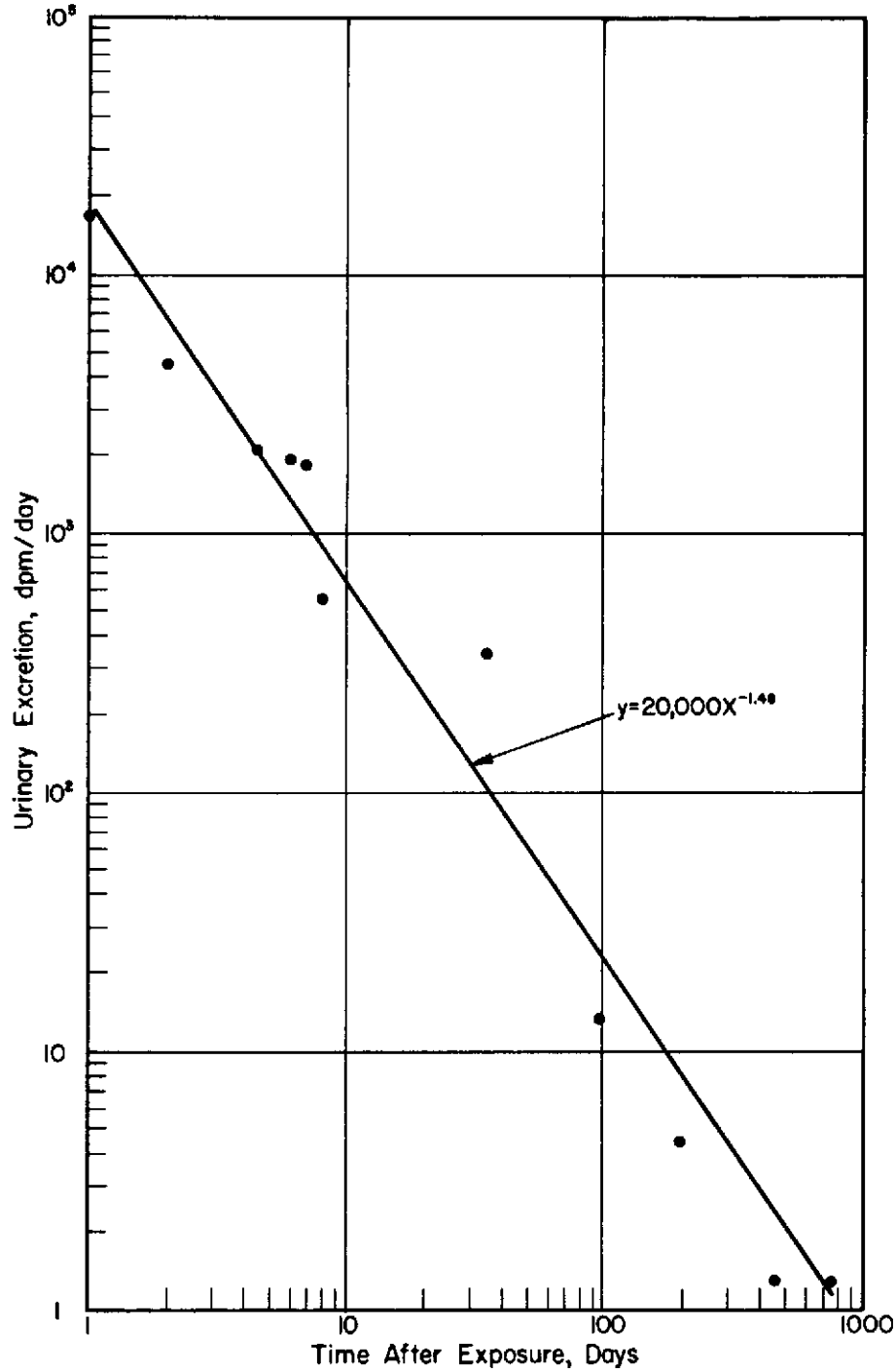

Figure 3.12 Observed urinary plutonium excretion in sheep.

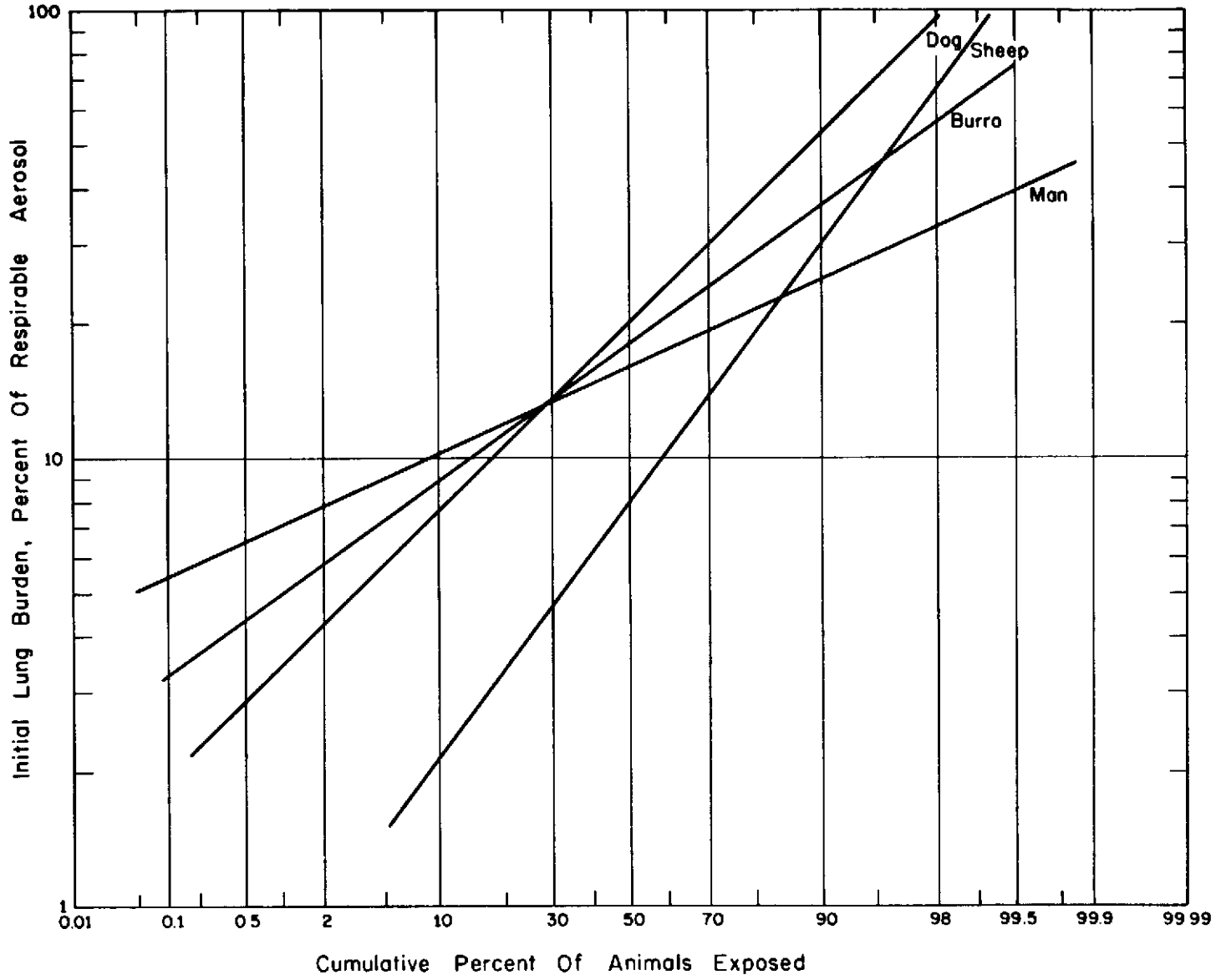

Figure 3.13 Distributions of percent of respirable aerosol initially deposited in exposed populations of dogs, sheep, burros, and man.

CHAPTER 4

DISCUSSION

4.1 INTRODUCTION

As part of a much larger series of experiments, the biological work of Operation Roller Coaster proved to be both interesting and informative. In general, it met the objectives posed for it and added insight to several ramifications outside the original scope of the studies. In an investigation of this magnitude, the possibilities for additional interpretation of the results are almost limitless, and in the course of time as new laboratory studies and new concepts bear on the Roller Coaster findings, these will be applied, and any additional knowledge which is developed will be published. At this juncture, it seems unlikely that any fundamental changes in the present interpretations would result; rather, supportive information would be expected to refine and strengthen the Roller Coaster story.

Accomplishment of the goals set for this work taxed the ingenuity and physical capability of many people, but predictably it is now evident that procedural improvements could have been made. To have increased somehow by at least an order of magnitude the initial lung burdens of the highest animals and to have reduced the spread between highest and lowest would indeed have been a significant gain. Alternatively, if a gamma-emmitting tracer such as Pu-237 could have been added or if Am-241 could be shown to serve biologically as a tracer

for Pu, far superior determinations of early lung clearance would have been possible. The limitations of the Clean Slate II study have already been mentioned. Finally, if dogs or burros, rather than sheep, had been selected for the longest term phase of the studies, much more reliable definition of clearance kinetics at later times would have been achieved. Such improvements notwithstanding, the results of the biological work are not seriously inferior to laboratory studies of Pu inhalation, and extrapolation to weapon accidents can be made with a much higher degree of confidence than was heretofore possible.

Before entering into the discussion of the results in detail, it is perhaps useful to restate briefly the objectives of these studies:

1. Expose a large number of animals to the Double Tracks detonation cloud.
2. Characterize the aerosol breathed by the animals.
3. Establish the initial depositions and the clearance kinetics of the retained aerosol.
4. Investigate the translocation of plutonium to other sites in the body.
5. Compare animal results with corresponding estimates for man.
6. Discover, if possible, if any differences exist in the clearance of plutonium inhaled from relatively clean and dusty releases.

4.2 EXPOSURE

Within the limits of prediction, the exposure was the best possible. According to the results of other measurements, the highest animals were at or near the line of peak concentration of the cloud. Moderate wind shear led to very steep cross-wind gradients on the western limits, particularly at these close distances, and at the same time generated more gradual gradients in the west-east direction. To nearly all indications, the animals with the highest lung burdens were, as hoped, close to the location of highest total respirable aerosol at ground level at the selected ranges.

There was evidence of regions of higher amounts of respirable aerosol on the array, but these regions were much closer to Ground Zero, and there was some evidence of overloading of impactors, which leads to over-estimating the respirable fraction. Even at distances as far removed from GZ as the animal array, all aerosol to which the animals were exposed of necessity came from the stem (a 10 μm particle under the influence of gravity alone would have settled less than two meters in transit from GZ to Arc G), and the limited cross-wind dispersion of the cloud meant only minor dilution by this mechanism while at the same time turbulent diffusion was enriching the ground level cloud from elevated portions of the source.

The much lower levels for both animals and samplers on Arc E as contrasted to Arcs G and I in spite of azimuthal correspondence do not signify that the respirable cloud skipped this range. Rather, the cloud first headed slightly west of south and then veered

somewhat to the east, and in consequence the peak concentration occurred some ten degrees west of the westernmost animals on this arc, while the easterly veering caused the peak to fall at the western extremes of the other two parts of the animal array. In this regard, the impactor data completely substantiates the animal findings.

The number of animals used in this study is one of its strong points. Obviously, from the viewpoint of the statistician there is scarcely such a thing as enough animals in biological investigations. Biological variation has become a by-word and an escape hatch of workers in this area, and with reason, for this is a very real phenomenon. But by having large enough populations at each datum point, meaningful statistical evaluations of the data can be made and estimates of the reliability calculated.

In the early phases of this study, datum points represent results for 15 to 22 individuals of the species, and the mean geometric standard deviation of deposition fractions for these species was 3.1 which is an indication of reasonably good consistency, at least in biological studies. Later points suffer from smaller populations but suffer even more from low lung burdens, which resulted both from low initial burdens and the kinetics of removal; thus, the statistics of analysis are of more concern than the statistics of group sizes.

4.3 AEROSOL RESULTS

The disparity between the Double Tracks aerosol and aerosols usually used in the laboratory constitutes one of the reasons

for studying the accident hazard in the field rather than in the laboratory. To attempt to generate and disperse for inhalation studies an aerosol of the characteristics found would be extremely difficult technologically. A further reason, of course, was that prior to Roller Coaster little was known of either the chemical or physical nature of this kind of explosively generated aerosol except that TG-57 results pointed to its being highly polydisperse. Physically it has now been described in considerable detail by Friend and Thomas (Reference 10), and additional insight has been provided by Perry et al. (Reference 11) and Sherwood (Reference 23). These workers verified the polydispersity, particularly in the smaller size range (< 30 μm), and they found that individual particle density is variable, also in part as a function of size. Particles less than 1 to 2μm (real size) approach the density of pure metal oxide.

The particle chemistry is less well defined in the respirable size range, although Perry and co-workers found that smaller particles showed increasing crystalline phase corresponding most closely to PuO_2 or PuO_2-UO_2 compositions. There were only minor amounts of other plutonium compounds. Above the respirable range, there was a varied assortment of glassy or mineral particles with associated plutonium either in or on the particles.

The value of considering only the respirable fraction of the aerosol from the standpoint of characterization is clear. Consistency is generally much improved, and the adverse affects of the probabilistic nature of sampling are minimized. In view

of the large geometric standard deviations of the aerosol distributions, however, the extent of improvement is somewhat surprising. Very few particles are represented by the activities reported for even the highest samples, and it seems almost fortuitous that the respirable fraction shows such agreement among samplers. As was indicated earlier, there are differences even between pairs of impactors within a few to several feet of each other. Shreve et al. (Reference 24) have examined the statistics of replicate Roller Coaster impactors and have shown that the ratios of 99 percent of a large series of randomly arranged pairs of samples will range from about 15 percent to over 600 percent of the median, whether one is considering total sample or respirable fraction only. It is unfortunate that for one station (G-058) one Casella malfunctioned, and the other was inadvertently used for individual particle studies, following which it was unusable for aerosol characterization. It happens, though, that apparently between Station G-056 and G-060 the gradient in plutonium levels was not steep, and, although interpolation between them is probably in error, it may be taken that the error is not great.

It is similarly unfortunate that from a number of other stations one of the pair of samplers was used for particle analysis, since it was thus necessary to assume that the respirable aerosol measured for one wagon was applicable to both. The results for the four Clean Slate II impactors, together with the findings of Shreve et al., emphasize the risk of this. Within the statistical

limitation of the biological results, however, the only station for which the estimated respirable aerosol seems in error is for Double Tracks dogs at E-058. The burro sampler at this location was used to estimate respirable fraction for dogs, and an analysis of results for these dogs indicates that the respirable fraction estimate is too low by perhaps a factor of two. A complication, however, is that dog lungs at this location are mostly very low so that a 1 or 2 dpm variation about the median has a marked affect on calculated lung burden ratios.

No use was made in these studies of the total air samplers associated with some of the wagons. They were originally intended for use in evaluating the particulate, and as has been indicated already, the total sample has little meaning in relation to the animals. They did serve a useful purpose in adducing whether or not an anomalous total impactor result was real or artifactual.

4.4 ANIMAL RESULTS

4.4.1 Double Tracks. The animal results make it clear that although there are similarities between them and corresponding parameters for man, there are also differences, even as there are significant differences among the three species. The reasonably good agreement amongst the three and in comparison to man imply that the breathing rates selected are not greatly in error. Initial deposition, however, is highly sensitive to the characteristics of the aerosol. The curves of Stewart et al. (Reference 16) for initial lung retention of unit density spheres in man range from 0.6 at

0.1 μm to 0.001 at 20 μm, with an intermediate minimum of 0.3 at about 0.25μm, Morrow and Casarett (Reference 25) found 0.56 deposition in dogs for a plutonium oxide aerosol whose mass median diameter was 2.5 μm, with $\sigma_g = 1.86$, and 0.88 for one whose mass median diameter was 1.6 μm, $\sigma_g = 1.72$, but this higher initial deposition is almost certainly attributable to differences between the respiratory tracts of dog and man rather than any peculiarity of a plutonium aerosol. Size distribution will affect deposition, but whether a larger standard deviation will increase or decrease initial deposition depends on the mass median diameter.

Estimates of initial deposition derived from the regression analyses of power functions for the three species likewise indicate a higher fraction for dog than for either of the other two experimental species or for man, although the fraction so estimated is a factor or two to three lower than those found by Morrow and Casarett. This estimate, however, is highly sensitive to the Time Zero assumption, since mathematically initial deposition becomes infinitely large as the time after exposure becomes infinitely small. This is one of the disadvantages of the power function treatment, although it can easily be shown that this peculiar attribute of the function has little significance when manipulations such as radiation dosage calculations are made. As was mentioned earlier, for present purposes power function Time Zero has been taken as H + 1½ hours, since all animals were sacrificed between H + 1 and H + 2 hours.

The differences in slopes for the three regression lines are a matter of some concern. Similarity between even two of the three

would simplify extrapolations to man, since it would then be not unreasonable to assume that man corresponded to the similarly responding animals. A fit can be forced between dog and burro but only because of the magnitude of the 95 percent confidence intervals. The slope of the line for sheep is so much greater than for the other two species it cannot be made to relate to results for them at all.

The importunity of the limited number of early time sacrifice periods is evident in Figure 3.2, 3.3, and 3.4. Nearly two decades are encompassed on the time scale between the first and second sacrifice periods, yet in the next two decades there are four sacrifices in dog and burro and six in sheep. Thus the first two sacrifices carry an undue weight in calculating the regression lines. Fortunately whatever adverse effect this weighting may have is counterbalanced by the greater number of animals per point in the early-time results.

Analysis of the animal results in terms of single- or double-exponential functions also shows dog to be highest of the three in initial deposition, and furthermore the data permit derivation of only a single exponential. This may be contrasted with the work of Morrow et al. (Reference 22) who found distinct evidence of bi-phasic clearance and could describe clearance kinetics closely with double exponentials. These workers found that the slowly cleared portion (which is of greatest concern from a radiation standpoint) ranged from slightly over 5 percent of the initial dose to more than 60 percent , with a mean near 35 percent . This discrepancy between the Roller Coaster results and those of Morrow et al. may reflect

differences in methods of determining the initial lung burden, which they estimate by assuming the lung burden to be the difference between measurements of the amounts of inspired and expired aerosols. Roller Coaster initial lung burdens are based on analyses of lungs from animals sacrificed soon after exposure. Thus, part of the initial lung burden estimated for the laboratory dogs is attributable to upper respiratory tract deposition, which could not be adequately determined for the Roller Coaster animals for reasons mentioned earlier.

The results for dogs in this study, when clearance is considered to proceed exponentially, compare quite favorably with the results of Morrow et al., lending support to the belief that to a considerable extent the Double Tracks aerosol was composed by PuO_2. Even though the data permit derivation of only a single exponential, its constants are not markedly different from those established by carefully controlled laboratory studies. Thus, although procedures and aerosols used in the laboratory were quite different, one may deduce that the slowly cleared fractions in the laboratory dogs amounted to something like twenty per cent of the respirable aerosol, in comparison to 20.2 percent found for Roller Coaster dogs. Clearance half-time for dogs exposed in the field was found to be 174 days, which is considerably shorter than the mean of 290 days found by Morrow et al. but well within their range of 120 to 500 days. The laboratory results have particular meaning since the values reported are for individual animals and illustrate once again the important role of biological variation.

The double exponential treatment of sheep data emphasizes to a pronounced degree the extensive early clearance. In the first five days, ninety percent of the initial lung burden is cleared. This fact together with the much lower initial deposition in the species clearly demonstrates the unsuitability of sheep for inhalation studies of long duration. As a ruminant the sheep is markedly different in a number of characteristics from the other two species and from man, and apparently these differences extend over into respiratory parameters as well. Even amongst individual sheep there seem to be extreme differences. The 95 percent confidence intervals at each sacrifice time in most cases are considerably larger for sheep than for the other two species. At least for the Roller Coaster aerosol, sheep show a much longer long-term clearance half-time than dog: 399 days versus 174 days. It should be noted, however, that the half-time determined for sheep corresponds more closely to the 365 days frequently assumed for man for plutonium clearance than does the dog value.

Results for burro also conform satisfactorily to a double exponential, and so considered, correspond well in several regards with estimates for man. The initial deposition of 17.9 percent agrees well with the estimate by Stewart and Wilson of 16 percent for man. Slightly over half of this is cleared slowly, which agrees with the NBS Handbook 47 value. Half-time for the slowly cleared portion is 155 days, which relates reasonably well with the half-time found for dogs but is less than half the value frequently used for man. The disagreement between burro and sheep in long-term clearance is evident.

It is apparent that in many regards results for burro agree rather well with estimates for man and correspond much more closely than either of the other two species. In part this may be a reflection of the anatomical similarities between horse and man noted by McLaughlin, Tyler, and Canada (Reference 27). The burro is a different species from the horse but must be very similar in many regards because of the ease with which horse and burro inter-breed. The agreement between burro and man may also reflect the over-all higher quality of burro results in consequence of the much higher absolute lung burdens. Generally the burro results for each sacrifice period are more self-consistent than either dogs or sheep, as evidenced by the smaller confidence intervals.

In weighing the relative merits of analyzing clearance kinetics by power functions or by exponential functions, it is not easy to assign preference to one or the other. The regression analysis of dog data demonstrates clearly that in this species the single exponential form is the description of choice. It is not possible to derive a more usual double exponential for this species. Analyses of sheep and burro data show that they surely correspond more closely to power functions than to single exponentials. It is possible, however, to derive double exponentials which visually seem to be apt descriptions, although it is very difficult to make a rigorous comparison between the double exponentials and their corresponding power functions. A certain amount of intuition is inherent in the double exponentials so derived because it is necessary to assign arbitrarily certain data to early times and remaining data

to later times, and the equations then become quite sensitive to the quality of the data.

For extrapolative purposes the power function relation is considerably more useful at early times because of its straight-line nature on log-log paper. The abrupt break in typical double- exponential curves as one rate constant takes over from the other makes assignment of sacrifice time extremely critical and extrapolations to Time Zero for estimation of initial deposition subject to large errors. As will be shown in a subsequent section, calculation of radiation dose is relatively simpler with exponentials and furthermore with the usual constants for clearance kinetics converges on the limit for infinite dose much more rapidly than comparable power functions, so that lifetime dose is relatively insensitive to lifetime length. Whether this fortuitous attribute has any radiological significance is another question.

The authors' equivocal position on the two forms has been mentioned; it is evident that there is no clear-cut basis for selecting one over the other, and the user of these results is advised to apply whichever approach will serve him best. Within the limits of experimental results either will prove reasonably valid.

The lack of improvement in confidence intervals where lung concentrations are considered as compared to lung burdens (in both cases in relation to respirable aerosol, of course) is surprising. Certainly there is no basis for assuming that all animals breathe at the same rate, and the breathing rates used in these calculations

were, after all, somewhat arbitrarily selected. In particular, one would expect improvement in burro results because of the considerably greater range in body weight of these animals compared to sheep and dogs, which were of quite uniform size. Apparently other factors than sheer size are controlling, however, because in the species in which it should be most evident there is virtually no discernible change (with due allowance for scale difference).

This does not diminish the usefulness of the concentration curves, however, for extrapolative purposes following an accidental detonation. It has been mentioned earlier that animal lungs collected soon after the incident could serve as monitors of human exposure, and that for practical purposes it would be of relatively minor importance which animals were sacrificed for the purpose. In the real course of events, however, it is most unlikely that organization could be so effective as to accomplish collection of lung samples a few hours after the catastrophe. Much more probably, this would not be accomplished until a few days had elapsed.

At such later times, the selection of subjects for sacrifice must be done with much more care, and ideally they should consist of animals of the same species, breed, and size as those for which the concentration curves were determined. In an accident situation some leeway is perhaps permissible. For example, in lieu of other alternatives it is probably reasonable to suppose that concentrations in any breed of dog would not be grossly different from those indicated by the regression line for the experimental beagles. Since the sheep used in these studies (Rambouillet) showed considerable variability

in spite of their homogeneity of lineage and physical characteristics, it is probable that results for sheep of any strain would be within the limits of the experimentals. Extrapolation from burro to horse or mule can only be conjectural, but the genetic similarities of the three would imply that results for the latter two should be reasonably comparable to those for burro and thus could, with some judicious interpretation, serve for this purpose.

For conservatism, one could establish a regression line for the upper limit of the 95 percent confidence intervals for each species. The merit of this is probably more dependent on the particular accident situation than on any real significance scientifically, and it is likely the purposes of extrapolation would be as well served by assuming the collected samples to correspond to medians and using the observed confidence intervals to estimate extremes of concentration.

It must be emphasized that extrapolations to Time Zero from later times cannot be done with animals other than those discussed above. Nothing is known, for example, of the clearance kinetics in bovines, and the differences found for the three experimental species make it clear that there are likely to be significant interspecific differences in all cases. One could be gravely misled if similar extrapolations were attempted with cows or goats or swine.

This position is at some variance with that of Morrow (Reference 26) who has stated that, based on the literature and his own studies, the parameters of early clearance seem to be characteristic of species while those of long-term clearance depend on the nature of the

material being cleared. The results of this experiment support his view only in the most general way; in exponential form, the half-times for long term clearance range from 155 days for burro to 399 days for sheep. Thus, there is agreement merely to the extent that all three species show relatively slow long-term clearance. There is a corresponding disparity when slopes are compared for the power function treatments. It is interesting to note in passing, however, that if for the dog Days 7 through 456 only are considered, the slope is closely similar to that for sheep, thus emphasizing the pronounced effect of early-time data on power function analysis.

For clarity, it is perhaps worthwhile to amplify on the proposed extrapolative procedure. Let us suppose that an accident occurs in a rural area and a sheep herder and some of his flock are engulfed in the cloud. Assuming that the animals in closest proximity to the herder can be identified, a limited sample of these could be collected and their lungs analyzed. If sacrifice occurred 3 days after the accident and mean concentrations were found to be 1.0×10^{-4} dpm per gram of tissue, this would be very nearly twice the regression line value for Day 3. Extrapolation to 0.06 hour would yield initial mean depositions of 5.0×10^{-4} dpm/gm. If the proposition is valid that man will show roughly the same initial lung concentration as the animals, then the sheep herder will also have 5.0×10^{-4} dpm/gm, and with suitable assumptions the amount of plutonium which he breathed from the cloud can be estimated.

There is a very important limitation in applying the lung concentration clearance curves in this way. The curves are known to be

appropriate only for the site conditions obtaining at the detonation point of the Double Tracks event. They are probably suitable for an accident in a paved area and also, though perhaps less reliably, in sparsely vegetated areas when the detonation occurs on impact with the ground. There is no basis except lack of other knowledge for applying them to accidents in which the detonation occurs in grassy or wooded areas, although it is probably safe to assume that extrapolations based on samples collected within a week or less of the accident will be useful though less reliable than for accident conditions corresponding more closely to Double Tracks. The important point, of course, is that animal data such as this is likely to be the only measure of exposure to humans in consequence of an accident.

4.4.2 Translocation. There is clear evidence in Table 3.7 of translocation of some of the plutonium deposited in the lungs of sheep and burros to the hilar lymph nodes, and it is useful to consider the implications of this.

Lymph node build-up in sheep appears to be very roughly proportional to $t^{0.5}$. The very small number of values precludes a more precise determination of the relationship, but it is perhaps noteworthy that this rough estimate is quite comparable to the more refined estimate for dogs in the laboratory studies.

Estimation of a rate constant for burro requires even more imagination, but assigning a slope comparable to that for sheep does not stretch credibility too far. Since laboratory dogs and field sheep and burros apparently agree in build-up rates, it is probably permissible to assume man fits the same pattern.

There are, however, at least two important points which must be borne in mind when considering lymph node burdens. The first is that although during the period of the experiment they rise steadily in the sheep and burros, this cannot continue without limit unless a pool of plutonium other than the lung is acting as a reservoir supplying activity to the lymph nodes. By the time of final sacrifice in the sheep absolute lung burdens were very low and generally comparable with absolute hilar lymph node burdens, so that plutonium cleared from the lung would be inadequate to maintain the rate of build-up observed in the lymph nodes. Using the 155-day half-time for long term clearance in burros would lead to similarly low absolute lung burdens at times corresponding to the $2\frac{1}{2}$ -year final sacrifice in sheep.

It is interesting to note in passing that the rate of build-up in sheep lymph nodes fairly closely approximates the rate of decrease in lung burdens. The organ masses differ roughly by two orders of magnitude, so that one implication of the inversely comparable rate constants is that lymph node collects a constant fraction (near 0.01) of the material cleared from lung.

The second point is one made by Wilson et al. (Reference 2) with reference to localization in lymph node. In their view, based on studies with UO_2, material collected in lymph nodes tends to be concentrated in the center of the nodes, and the germinal tissue of the organ is largely beyond the range of α particles from collected plutonium. In consequence of this observation, they propose reduction of calculated dose to lymph node by a factor of twenty. One could perhaps question

the magnitude of the reduction, but not that a reduction is warranted, provided α particles are the only emission present.

Even for levels of exposure which might be anticipated for an accident situation, insult to lymph node is of less concern than dose to lung, in spite of the increase of lymph node burdens with time. Truly massive inhalation doses would be required to achieve significant radiation doses in lymph nodes, and the consequences to lung would continue to be of greater concern even in this case.

4.4.3 Clean Slate II. Mention has been made in Section 3.3.7 of the surprising differences found for the animals exposed on Clean Slate II as compared to Double Tracks. They are sufficiently different and sufficiently important that they deserve consideration in some depth.

If it is assumed that the effect is in evidence only for early clearance and that long-term clearance is unchanged, then these results signify that at least a 3-fold benefit is achieved from the standpoint of weapons storage simply by housing them in typical earth-covered magazines, at least as indicated by the findings for dogs and sheep. If the long-term clearance rate is also enhanced, even greater benefit is derived. This cannot be quantitated because of the limitations of the 7-day extent of the experiment. Further, these effects are but two of many hazard determinants.

It is indeed fortunate that this after-thought experiment was tried. Many physical studies were undertaken to assess the affect of overburden, but the results are equivocal, not because of the

quality of the work but because of the difficulties of interpretation and application. That the soil and plutonium interacted is strongly evident. Extensive normalization procedures involving considerations of meteorology and cloud physics and explosive phenomena tell us that dispersal of plutonium was indeed much more limited in extent and that the levels of ground contamination were higher. One is thus left with the dilemma of whether a little real estate heavily contaminated is a lesser general hazard than a lot of countryside more lightly burdened.

A similar argument obtains with regard to respirable concentration. Again higher levels were found for Clean Slate II but over a more limited area. The soil undeniably affected the fate of the plutonium present at the time of the detonation, but it is a moot question as to whether it improved the situation.

The benefits as seen from the biological results are not subject to arguments of this kind. The presence of soil undeniably reduces the radiation insult to the lung because some attribute of it causes greatly enhanced clearance, and much of the plutonium is removed before it has a chance to irradiate lung tissue.

This is obviously an important finding and one that must be assessed with great care. As was pointed out earlier, the reliability of the results was unusually high. There is even a measure of conservatism at least as far as the dogs are concerned; a field note written immediately after withdrawal from the array states that the impactors operated 3 to 5 minutes in the cloud. Cloud passage was probably as rapid as for Double Tracks, but, if not, these

samplers perhaps shut down while plutonium was still present. The important consequence of this, if such were the case, would be to imply an increase in the amount of the respirable fraction, thereby further decreasing the 3- and 7-day dog lung fractions. Because the samples collected are probably valid ones, however, no cognizance has been taken of the field remark except to note the possible element of conservatism introduced.

Since these results may well have important bearing on transport and storage policy, it is essential to find explanations for the observations in order that there may be a firm scientific basis for making use of them. Two possibilities present themselves:

(1) LaBelle and Brieger (References 28, 29) have shown that the presence of inert particles in the lung can alter the elimination pattern of the active substance and that this is the result of a release of phagocytes into the lung. It is not clear whether this effect changes the half-time for clearance or simply the extent. The Clean Slate II cloud did indeed have large amounts of inert dust in it from the violent disruption of the magazine, and there is no doubt that at least to some extent this mechanism was functioning. However, to achieve clearance to the extent found would, according to the work of LaBelle and Brieger, have required enormous lung burdens of inert dust, and the air concentration would have had to be so high as to be virtually irrespirable. In one study they found that lung burdens of the order of 0.5 mg of carbon black per gram of lung were required to achieve a 5-fold reduction in lung burden of

deposited uranium in 24 to 48 hours, as compared to uranium lung burden with no carbon black present. Converted to sheep in the Clean Slate II field this would have required an air concentration of 16 grams of respirable aerosol per cubic meter of air.

(2) As described earlier, Morrow (Reference 26) has proposed that while early clearance is probably related to species, long-term clearance may be a function of material. LaBelle and Brieger (Reference 28) also noted that clearance is not predictable on the basis of the contaminant's chemistry. Thus, seemingly similar substances (e.g. irregular insoluble dusts) may have widely different clearance rates. The one-year half-time commonly taken for plutonium clearance has been mentioned; Friendbery & Polley (Reference 30) found that silica, which at least superficially would seem to be similar to plutonium oxide, is removed with a 30-day half-time. The chemical composition of the respirable fraction of the Clean Slate II aerosol is unknown, but silica was an important constituent of the Nevada soil at the site of the detonation (Reference 11). Many other minerals were of course present, but clearance rates for these are not known. It seems highly likely, therefore, that the clearance being measured in the Clean Slate II animals is that of a composite mineral aerosol for which the plutonium is serving as a firmly attached tracer.

One must then ask what particulate data can be presented to substantiate this hypothesis.

Perry et al. (Reference 11) and Sherwood (Reference 21) in their examination of particles from Double Tracks and Clean Slate II (as well as the other two events) found numbers of particles in both these events which fit the descrip-

tion of a mineral particle with attached plutonium. In Double Tracts, however, only larger, irrespirable particles fit this description; the smaller sizes were virtually free of mineral fractions nearly to the upper respirable limit, i.e., respirable size particles were almost wholly metal oxides. The fraction of meatl oxides in respirable particles for Clean Slate II was very much lower, and Friend (Reference 30) in his characterization of the Clean Slate II aerosol states that there are numerous respirable particles with minute amounts of plutonium. It is his proposition that the effect of the overburden is to quench the large hot metal particles before they can explode into numerous fine ones (a common event in plutonium and occurring to a lesser extent in uranium), to give a relatively few large particles (ca. 100μm) carrying most of the aerosolized plutonium. It seems likely that the plutonium on respirable particles consisted of extremely finely divided metal oxide fume which attached itself firmly by unknown mechanisms to fine mineral particles, remembering DT was very clean, CS II very dusty.

Thus, it is seen that there are consistent biological and physical reasons for the observed differences between Double Tracks and Clean Slate II, and taking advantage of the implications is probably justified. One should hesitate to extrapolate much beyond the extent of the actual data, except that it is probably valid to assume that the three-fold reduction in lung burdens found at early times in the Clean Slate II animals would obtain at later times as well. It should be borne in mind, however, that burros, which seem to bear the closest relation to man, were not used in this portion of the work, and that while the evidence points to low plutonium content of each respirable particle, such evidence is limited in extent.

This phenomenon of rapid clearance may throw light on the results of the TG-57 biological studies which seem anomalous in comparison to the Double Tracks results. At least to first appearances there are many close similarities between the two trials. The amounts of plutonium and high explosive were the same, both were fired at ground level, and at least as far as can be determined, maximum respirable concentrations at ground level occurred at roughly corresponding distances, even though meteorology was different for the two detonations.

There was one highly significant difference, however. For Double Tracks, considerable care was taken to minimize entrainment of inert dust into the cloud, while the TG-57 round was fired in contact with the desert floor. The explosion of the latter created only a small crater, in contrast to the Clean Slate II event, in which nearly twenty times as much high explosive was involved. Thus, the amount of soil ejected for interaction with the plutonium in the TG-57 simulant was very much less, but at the same time the scale of events was also less, so that it is reasonable to suppose that at least to some extent the TG-57 trial was a scaled-down version of Clean Slate II and that the aerosol formed corresponded more closely to that derived from this event than to the aerosol resulting from Double Tracks.

If this in truth happened, then lung buildup with time would be even less evident than was postulated for the Double Tracks-type plutonium aerosol presumed to be present in TG-57. The time

to maximum lung burden derived for that experiment would have been much shorter and the amount of the maximum much smaller for the acute animals for which there seemed to be no time dependence from zero to thirty days. It may be supposed then that the rate of elimination of the initial lung burden, altered from that for plutonium oxide by the latter's attachment to inert dust, was fairly closely balanced by the rate of uptake of resuspended plutonium. This cannot be quantitated because of the absence of samplers for the first three weeks of the TG-57 long-term studies; it is not known whether the 35-day half-time of air concentration reduction determined for the TG-57 site and size distribution extrapolates linearly to Time Zero or if there is a short-term rapid clearance of airborne levels.

4.5 POPULATION SEGMENTS

The use of population segments has been touched on earlier. They are an extremely important concept in hazard analysis and deserve additional emphasis.

A variable of any population has a distribution about a central tendency. In many instances, this distribution is normal, i.e., the sum of positive deviations of the variable from the mean equal the sum of those below provided enough measurements have been taken. In a log-normal distribution, the log of the variable measurements are equally distributed about the mean. There are many ways to describe the uniformity of the measurements in relation to the mean;

standard deviation, standard error, and variance are three. The important thing, though, is that measurements of any variable can never be wholly uniform. Either the variable itself or measurements of it will differ from estimates of the mean, and the amount and frequency with which this occurs is a function of the dispersion of the population of measurements.

Thus, in any finite series of measurements there is always a finite probability of one of the measurements differing markedly from most of the other measurements. This is particularly applicable to measurements of biological factors, and ample evidence of it has been seen in the preceding parts of this report.

When we say that median deposition for man is 16 percent, we are saying that a long series of determinations will center on this result, but because these are biological measurements we expect and find variations about this central tendency, and we express this variation by saying that 90 percent of the people measured will show depositions ranging from 0 to 25 percent or that 99 percent will show depositions less than 37 percent. This still leaves 1.0 percent of the population unaccounted for. Statistically, there is a small but finite probability that some member of the population will show 100 percent deposition.

The initially deposited fractions for various segments of the three animal species and for man are presented in Table 4.1, which is derived from Figure 3.13. The table and figure emphasize the much broader dispersion of the animal data in comparison to man. Even

the animal results alone show considerable differences, species to species, in the distribution of results for initial deposition fractions. It is not possible to attribute these differences to any known characteristics of the animals or the experiment. One can conjecture that the much steeper slope for dog as compared to burro results, at least in part, from the generally low values for plutonium in dog lungs, with attendant analytical inaccuracies. Sheep has already been shown to differ from the other animals and man in a number of ways, and the dispersion seen here may be characteristic for the species. In all three species the relatively small number of animals making up the population sample would be expected to result in some increase in the measure of dispersion over and above any other factors such as analytical errors or specific characteristics.

In this as in other ways, of the three species burro is seen to compare best to man. Even so, results for this animal are so disparate from estimates for man that it is probably not warranted to attempt to use measures of burro population segments in any extrapolations to man. The data for man are based on studies relating to large number of human subjects and thus are probably more valid from this standpoint than are those for burro.

The possibility than an exposed individual will show an initial deposition much higher than the median is of particular significance in the framework of hazards prediction. It is just as essential to decide what segment of an exposed population shall not exceed a

certain dose as it is to establish what dose shall not be exceeded. To say that no one will be allowed to exceed a certain dose requires either that the allowable dose be set irrationally high or that the potentially hazardous operation not be undertaken at all. Since neither approach is reasonable in an accident situation, we can expect to find an outlying individual whose dose exceeds the allowable. If the selected population segment is too small, a number of excessive doses may be found. A careful balance is needed, then, between the magnitude of the allowable dose and the size of the population segment which will be expected not to exceed that dose. In essence, this becomes the concept of calculated risk with the risk reduced to as small an amount as is consistent with needs.

4.6 DOSAGE CALCULATIONS

The insult of concern from deposited plutonium is, of course, the radiation dose it contribues at the site of deposition. In the lung, response to irradiation seems to be related both to total dose and to dose rate, at least for massive doses. Morrow et al. (Reference 22) and Bair and Willard (Reference 32) have both shown that total doses in excess of 1,000 rads lead to fibrosis, and dose rates of 1,000 or more rads per month will cause such extensive fibrosis as to lead to death in relatively short times (2 months to a year).

The consequences of high but sublethal doses seem to depend on total dose. Bair and Willard found lung tumors in dogs which received total doses of 12,000 to 23,000 rads over the course of 3 years, while

none of the dogs studied by Morrow et al. showed any tumor development from lower total doses for shorter times but at similar dose rates.

For hazard considerations it is necessary to select arbitrarily, but with all possible scientific insight, maximum dose which might be experienced by an equally arbitrarily selected segment of the population. Here the picture is far from clear. Obviously the doses administered to dogs in the above mentioned laboratory studies are greatly in excess of any permissible dose in considerable portions of the human population. The response to much lower doses for longer periods approaching the lifetime of the individual is very poorly defined at present. Tumor incidence is almost certainly the response of concern to low, long-term doses, but it is not known, for example, whether there is a threshold of tumor production from radiation in the lung. If not, then one must base acceptable dose on an allowable increase in tumor incidence.

Some latitude is permitted in accident situations as compared to occupational exposure. Philosophically, an accident is recognized as a one-time occurrence, and while it is obviously desirable to minimize accidental exposure, different rules for exposure generally apply. For example, the NCRP (Reference 33) has proposed that an accidental or emergency exposure of 25 rem to the whole body (or major portion thereof) need not be included in determining the radiation status of an individual if exposed only once. A logical extension of this philosophy is that while such a dose is evidently undesirable, it is

sufficiently low not to cause injury. Yet the accidental detonation of a weapon is an accident in every sense, and any accident carries with it the possibility of injury. Once again, the concept of calculated risk is introduced: in establishing transport and storage criteria what risk of injury to what fraction of the exposed population is permissible? Certainly many factors, most of them non-scientific, enter into answering this question.

The role played by clearance kinetics in calculating radiation dose to the lung is of very great importance. If there were no clearance of a deposited lung burden, then annual dose would amount to about one rem for each picocurie per gram of lung tissue, and total dose would be a direct function of time after exposure.

The principal effect of clearance is to decrease dose rate with increasing time because of the continuing reduction in amount of radioactive material present in the lung. It is for this reason that careful evaluation of the kinetics of removal is so important. If a single exponential is appropriate, as was found for dog, doubling the half-time of clearance doubles the total dose. If it is demonstrated that a double exponential best applies, the rate of dose accumulation is very markedly reduced during the first few days as the material under control of the early-clearance phase is removed. If clearance is best described by a power function, usually a large fraction of the lung burden is removed at early times, but unless the negative exponent on time is large, dose will continue to accumulate for very long times.

There is ample evidence of clearance from the lungs of Roller Coaster animals, but as has been discussed above there is generally little basis in the results for selecting one form of kinetics over another. There are considerable differences in estimates of dose depending on which kinetics are applied, as shown in Table 4.2.

This table was derived by assuming that a Cascade impactor sampling from a cloud at 17.5 lpm showed 0.1 μCi of the plutonium collected to be $<10\mu m$. Lung concentrations, and hence doses, were calculated for various times of interest using the parameters established experimentally for the animals. The values for man were calculated by assuming that man follows the kinetics of removal of burro but shows a different initial lung burden (16 percent of the respirable aerosol versus 17.9 percent for exponential or 24.2 percent for power function) and a different breathing rate (20 lpm versus 50 lpm). The amount of respirable aerosol was selected to be 0.1 μCi because it leads to an estimate of an initial lung burden in man which approximates reasonably closely the maximum permissible lung burden recommended by the ICRP.

By inspection of Part A of this table, it is seen that at one year the two functions, power and exponential, lead to about the same results for cumulative dose in each species. Beyond this time dose accumulates much more slowly under the exponential treatment, and by fifty years cumulative dose is four to twenty-four times as high by power function as by exponential. Furthermore,

the dose calculations show that by ten years, essentially all the dose has been delivered as determined by exponentials, whereas even by fifty years dose is still accumulating according to the power function evaluation.

Species by species, sheep shows the least disparity between the two treatments, a consequence of the relatively large negative exponent in the power function and the large $T\frac{1}{2}$ for the long term clearance phase. Because the two correspond to some extent, it is instructive to examine the results in somewhat more detail and in so doing shed some light on the contrasts between the two mathematical procedures. It can be seen that the exponential form estimates a considerably more rapid accumulation of dose in the first ten days. Between ten and one hundred days the rate of accumulation drops drastically, and the total dose at the latter time is only about twenty percent higher than at the former. This change in rate of accumulation relates to the contribution from the plutonium which is cleared rapidly. In 33 days the rapidly cleared fraction is only 0.1 percent of its initial amount and thus is essentially removed as a contributor of radiation.

The rate of build-up from power function analysis is slower and even by three years does not equal the dose estimated by exponentials. From this time on, however, exponentially calculated dose increases very much slower than would be determined by the power function, and the latter is still increasing at fifty years, albeit more slowly than at earlier times.

Part B of Table 4.2 is arranged to facilitate comparison of results by species within each function. It is immediately apparent that the calculated doses for power function are quite disparate at all times, the high-low ratio ranging from about three at one day to more than 36 at fifty years. When compared exponentially there are certainly differences among the four species at the stated times, but the ratios of differences are much reduced, ranging from two at one day to nine at 100 days. The ratio at fifty years has decreased from the 100-day high to six.

If nothing else, Parts A and B of Table 4.2 emphasize how risky is the estimation of dose following exposure even with the greatest possible care in deriving expressions for clearance kinetics. Estimation on the basis of power function may be unduly conservative, or alternatively to place reliance on the estimates by exponentials may represent dangerous unconcern. One may say, however, that the power function estimate for dog is unrealistic, since Stewart and Wilson have shown that a single exponential is a better fit to results for dog than the best estimate of a power function for these data.

As has been indicated repeatedly in foregoing parts of this report, sheep is so different from the other two experimental animals and probably from man as well that results for this species should play only a minor part in extrapolating to man. The burro, however, shows gratifyingly close similarity to man in many regards,

and it is for this reason that burro clearance kinetics, with suitable modifications of input parameters, have been used to calculate dose estimates for man. The reader should not be misled by the apparent constancy of the proportionality of dose estimates for burro and man; this is inherent in the calculation. Rather, he should recognize that if there is any merit in an animal-man extrapolation, a standard man, standing in a cloud which time-integrates to 5×10^3 μg-sec/m^3, would receive an initial lung burden the dose from which is probably quite fairly represented by the cumulative doses shown. Of the two treatments, that representing double-exponential clearance compares considerably more closely to the kinetics commonly taken for man in published lung models and is probably to be preferred.

Part C of the Table 4.2 presents the input parameters used in performing the dose calculations, and most of these are self-evident or have been discussed elsewhere. Some aspects are worth highlighting, however. Lung weights for the animals are means of 100 to 150 determinations, while that for man is drawn from the so-called Standard Man , as is the 20-lpm minute volume. The value b represents the percentage of the respirable aerosol remaining in the lung on D + 1 day. It is, of course, mathematically derived. y_1 and $T\frac{1}{2}_1$ represent the fraction of the respirable aerosol deposited in the early-clearance compartment and the half-time of its removal, respectively, while y_2 and $T\frac{1}{2}_2$ represent the same for the slow-clearance compartment. Initial deposition by

power function is determined by assuming Time 0 to be 0.06 day and solving the equation for 0.06^a. By exponential treatment, initial deposition equals $y_1 + y_2$. In dog, of course, no early clearance was found, and $y_1 = 0$. In sheep $y_1 = 91$ percent of the material initially deposited, and thus not only is the initial deposition low, very little of what is deposited remains in the lung for appreciable lengths of time. In burro, 57 percent is cleared slowly. The specific activity is that measured for samples of the metal used to fabricate the simulants. It differs from that for ${}_{94}Pu^{239}$ because of the isotopic makeup of the metal.

In the double-exponential treatment of sheep and burros, it is interesting to note how minor is the role played by the rapidly cleared material. Even though this fraction constitutes 91 percent of the initial burden in sheep, it contributes only 7.7 percent of the total dose. In burro, where 44 percent is cleared rapidly, the dose from this portion is 1.9 percent. This emphasizes how important is the half-time for long-term clearance, since it is clearly controlling in dose estimation.

TABLE 4.1 INITIALLY DEPOSITED PERCENTAGES OF RESPIRABLE AEROSOL IN ANIMALS AND MAN FOR VARIOUS POPULATION

Species	Population Fractions, Percent			
	50	90	95	99
Dog	20.2	56.0	70.0	115
Sheep	8.0	30.0	43.8	89.0
Burro	17.9	36.3	44.2	65.0
Man *	16.0	25.0	28.4	37.0

* Values for man are those suggested by Stewart and Wilson (Reference 19).

Example: Of an exposed population of dogs half will show initial depositions ranging from 0 to 20.2 percent of the respirable aerosol inhaled, and 95 percent will show initial depositions ranging from 0 to 70.0 percent.

TABLE 4.2 CUMULATIVE DOSES IN RADS AT VARIOUS TIMES AFTER EXPOSURE

A. Compared by Function

	DOG		SHEEP		BURRO		MAN	
	Power	Exp.	Power	Exp.	Power	Exp.	Power	Exp.
1d	0.010	0.010	0.004	0.007	0.007	0.009	0.003	0.005
10d	0.084	0.098	0.019	0.072	0.045	0.069	0.018	0.037
100d	0.635	0.823	0.077	0.092	0.264	0.440	0.107	0.239
1y	1.97	1.92	0.168	0.213	0.705	0.951	0.285	0.518
3y	5.14	2.47	0.312	0.354	1.62	1.17	0.654	0.636
10y	14.7	2.51	0.634	0.403	4.05	1.18	1.64	0.641
50y	59.9	2.51	1.63	0.410	13.7	1.18	5.53	0.641

B. Compared by Species

	POWER				EXPONENTIAL			
	Dog	Sheep	Burro	Man	Dog	Sheep	Burro	Man
1d	0.010	0.004	0.007	0.003	0.010	0.007	0.009	0.005
10d	0.084	0.019	0.045	0.018	0.098	0.072	0.069	0.037
100d	0.635	0.077	0.264	0.107	0.823	0.092	0.440	0.239
1y	1.97	0.168	0.705	0.285	1.92	0.213	0.951	0.518
3y	5.14	0.312	1.62	0.654	2.47	0.354	1.17	0.636
10y	14.7	0.634	4.05	1.64	2.51	0.403	1.18	0.641
50y	59.9	1.63	13.7	5.53	2.51	0.410	1.18	0.641

C. Input Parameters

	PHYSIOL.		POWER $Y = bt^a$			EXPON., $Y=Y_1\exp\left\{\frac{-.693t}{T_{\frac{1}{2}1}}\right\}+Y_2\exp\left\{\frac{-.693t}{T_{\frac{1}{2}2}}\right\}$				
	Lung Wt. gms	Min.Vol. Cpm	b %	a	Init.Dep. %	Y_1 %	$T_{\frac{1}{2}1}$ days	Y_2 %	$T_{\frac{1}{2}2}$ days	Init.Dep. %
Dog	94	3	20.2	-0.1273	29.0			20.2	174	20.2
Sheep	430	25	3.42	-0.416	11.1	7.3	3.3	0.73	399	8.0
Burro	1530	50	12.1	-0.242	24.2	7.7	4	10.2	155	17.9
Man	1000	20	8.0	-0.242	16.0	6.9	4	9.1	155	16.0

NOTES:

(1) Man assumed to follow burro kinetics.
(2) Assumed aerosol is 0.1μm collected by Casella impactor sampling at 17.5 liters per minute.
(3) Specific activity taken as 15.3g/Ci.

CHAPTER 5

CONCLUSIONS

The reliability of the results of this experiment is far superior to those for similar earlier studies. Analytical and contamination controls permit a high degree of reliance to be placed on the findings.

The respirable aerosol is best defined as being that fraction of the parent aerosol composed of particles less than 10μm equivalent aerodynamic diameter. The highly variable nature of the total aerosol prevents any rational correlation between it and the uptake by samplers or animals. It has been shown that 10μm is an appropriate cutoff for animal considerations.

The agreement between respirable fractions as determined by impactor samples and initial lung burdens measured in the animals indicates first that the impactors are competent samplers relative to the animals and second that aerosol data from other experiments either as part of Roller Coaster or of other trials may properly be related to initial lung burdens animals would have acquired had they been present.

The importance of locating air samplers close to the animals in a field trial has been amply demonstrated in this study. The point-to-point variation of plutonium levels in the detonation cloud is so extreme that extrapolation from a sample collected in one location to an animal in another is almost certain to be in

error unless concentration gradients are small. The evidence of this study is that inhalation investigations under field conditions require that samplers be as close to the breathing zone of the animals as possible and, in any event, should not be more than 10 to 12 feet distant. In addition, replicate sampling should always be done.

Considering animal groups in an experiment of this sort to be log-normally distributed is a useful way to account statistically for the usually found biological variation. The log-normal distribution is a completely defined and frequently used statistical concept, and its use permits ready enumeration of different fractions of the populations being considered.

The correlation amongst animals and between animals and samplers strengthens the confidence with which extrapolation to man is made. There are several aspects of the animal results which correspond quite well with published values of the same characteristics for man. Initial depositions in the animals encompass that predicted for man, and when the data are treated as exponential functions sheep and burro show biphasic clearance patterns as expected for man. Sheep diverge from the other three species in showing a much more extensive early clearance even though the rate is not greatly different from the others. This limits the usefulness of sheep in inhalation studies. Of the three test species, the burro seems generally to show best agreement with comparable parameters for man.

There is no firm basis for assigning the data to power functions or single- or multiple-exponential functions. Data for dog conform more closely to a single exponential than to a power function, while the reverse is true for sheep and burro. The latter species do conform well to double exponentials, but it is not feasible on any basis other than intuition to assign a preference to the double-exponential treatment or the power function. Total-dose estimates by power function are probably conservative, but if one must choose between one form of expression or the other, the weight of precedent would favor the exponential, even though this may underestimate the dose.

Lung is the critical organ as evidenced both by this work and by laboratory studies. Translocations to other tissues were undetectable except in lymph nodes of animals with highest lung burdens. Only in the event of (relatively) very high initial lung burdens might the lymph node concentration become of concern.

A very interesting and potentially useful finding is that initial lung concentrations for the three species are almost the same even though there is wide disparity in size, breathing rate, lung weight, and many other characteristics. Median dog: sheep : burro lung concentration ratio is 1.0 : 0.900 : 0.917, and man's place in this ratio would be 0.40 on the assumption of 16 percent deposition in a 1000-gram lung. Thus, plutonium quantities measured in lungs collected from animals soon after an accident can provide useful indication of the degree of exposure

suffered by humans in close proximity to them. Essentially the animal functions as a continuously monitoring air sampler. Obviously the usefulness of animal lungs is highest when the lungs collected are those of dogs, sheep, or burros, but the similarity of results for these three species may signify that other large animals (e.g., goats or cattle) could be used in the absence of the three experimental species. Unfortunately, timing is critical. The rapid early clearance means that collection should be accomplished not more than six hours after an accident and preferably within one to two hours.

One of the most promising findings of this work was the enhancement of clearance as a result of involvement of large amounts of inert soil in the detonation. This is attributed to the more rapid clearance of mineral particles for which the plutonium is merely serving as a tracer. Reduction in lung burden and in radiation dose by factors of three appears to be possible simply by storage under earth cover (at least as shown for dogs and sheep). Since the data do not extend beyond seven days, it is not prudent to attempt to make any more elaborate extrapolation than the factor-of-three reduction in lung burdens and hence in dose. Consistent biological and physical reasons for this enhancement have been presented, and consequently it is believed that it is legitimate to take account of the effect in drawing up transport and storage criteria. It is of interest to note that this useful observation was not predictable on the basis of physical evaluations of scavenging .

APPENDIX

SUMMARY OF RAW DATA

TABLE A.1 DOG TISSUE WEIGHTS, GRAMS

Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes
1001	C-1y	38.4	83.3	391.7	192.4	2.3
1002	E58-3	47.8	67.0	324.2	144.7	2.4
1003	E58-3	39.5	51.5	302.2	85.1	1.9
1004	C-7	35.9	40.1	234.9	80.8	2.8
1005	C-14	43.9	75.0	341.2	162.5	3.3
1006	I59-3	43.6	62.3	336.0	86.0	---
1007	I59-7	44.0	86.3	424.2	109.7	2.8
1008	I59-14	29.4	39.2	248.4	70.3	1.8
1009	I59-14	25.1	49.7	328.1	72.2	1.7
1010	C-3	40.2	56.3	450.6	100.5	1.2
1011	I59-3	36.0	52.9	345.0	80.7	1.8
1012	I59-3	41.1	55.5	299.9	78.7	0.8
1013	I59-3	47.1	78.0	351.6	111.6	3.4
1014	G60-7	31.5	53.5	241.7	73.1	1.0
1015	I59-7	47.9	62.6	350.0	90.6	2.1
1018	CSII-3	51.2	66.6	351.0	112.2	1.5
1019	CSII-7	47.4	59.0	342.1	94.0	1.8
1020	CSII-7	38.8	57.8	260.4	83.5	1.4
1021	E58-14	43.0	56.2	286.1	105.4	0.8
1022	I59-0	37.3	57.7	302.8	97.1	2.8
1023	CSII-7	33.9	59.4	349.3	94.5	0.7
1024	E58-0	31.9	48.1	296.6	76.6	2.1
1025	I59-3	34.3	55.9	303.7	82.7	1.8
1027	E58-14	50.0	56.1	410.4	118.5	2.9
1028	I59-7	37.9	77.4	384.6	86.4	0.9
1029	I59-0	40.3	57.5	284.2	103.4	2.4
1031	C-14	39.0	64.1	421.3	118.7	3.4
1032	I59-14	33.4	71.6	374.6	94.1	1.3
1033	C-7	39.6	64.8	357.4	92.7	2.3
1034	E58-7	39.6	66.7	462.3	93.5	1.8
1035	I59-0	42.0	69.7	261.7	85.6	1.7
1036	E58-7	40.9	67.5	507.4	104.7	1.4
1037*	I59-3	39.5	49.0	225.0	74.0	1.2
1038	G54-7	36.9	58.4	475.0	94.0	1.7
1039	G60-1y	82.5	52.5	370.0	101.0	4.5
1040	E58-0	39.2	59.8	240.0	88.0	1.5
1041	G54-0	44.4	66.4	395.2	113.2	2.0

* Inadvertantly sacrificed, necropsied on D + 3.

TABLE A.1 (Continued)

Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes
1042	I59-3	34.9	58.0	235.7	72.7	2.0
1043	E58-7	40.5	78.9	685.0	98.5	1.5
1044	C-14	28.8	61.3	296.2	74.0	3.0
1045	CSII-3	36.2	102.7	372.3	102.8	1.9
1046	CSII-3	43.1	59.2	295.1	92.3	2.3
1047*	G60-3	37.4	47.6	326.7	98.0	3.2
1048	G60-1y	27.0	51.3	281.0	75.5	1.0
1049	I59-14	46.8	45.5	314.4	97.7	2.9
1050	E58-0	40.6	50.3	291.4	93.8	2.8
1051	G54-7	26.7	39.8	208.3	62.5	2.4
1052	G54-3	37.6	67.7	295.6	139.4	3.7
1053	E58-14	40.0	65.2	318.2	90.8	2.1
1054	E58-0	25.0	38.9	238.8	60.0	2.2
1055	G60-3	29.6	56.6	246.7	75.0	2.1
1056	G54-1/2y	42.0	30.0	320.0	99.5	2.0
1057	G54-1/2y	26.0	41.0	369.0	86.0	1.2
1059	G60-3	31.8	46.0	327.0	88.1	2.3
1060	C-0	47.5	55.1	395.3	91.7	1.9
1061	I59-7	30.9	51.9	398.2	70.5	1.6
1062	CSII-7	41.2	76.4	404.5	108.2	0.8
1063	G60-7	35.3	44.0	425.6	93.7	1.9
1064	E58-7	34.0	60.6	430.5	82.6	1.7
1065	G54-14	34.0	55.6	272.4	74.0	1.4
1067	G60-0	28.1	37.1	203.0	65.5	1.9
1068	G60-1/2y	34.0	63.0	272.0	82.0	1.0
1069	E58-0	34.1	49.6	251.5	80.8	2.7
1072	G54-1y	70.0	78.0	300.0	110.0	1.5
1073	CSII-7	47.1	63.0	379.2	147.0	2.4
1074	C-0	40.7	50.6	213.2	75.8	3.2
1077	G60-14	31.2	40.6	298.5	66.2	1.0
1078	G60-1y	36.0	28.0	203.0	68.0	1.7
1080	G54-7	37.5	54.0	343.0	90.0	0.9
1081	I59-0	46.2	59.5	311.5	103	1.4
1082	G60-7	28.1	49.1	273.4	54.4	1.8
1083	G54-1y	47.0	54.5	357.0	94.5	1.5
1084	I59-3	32.0	51.6	274.7	75.7	1.2
1085	G60-3	32.3	53.5	456.4	72.3	2.5

TABLE A.1 (Continued)

Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes
1086	E58-14	27.7	48.2	278.1	71.7	1.3
1087	I59-0	41.5	64.3	284.3	99.6	1.9
1088	E58-3	44.0	50.5	250.3	83.1	1.9
1090	G54-1y	44.0	50.0	363.0	121.0	1.8
1091	E58-3	37.8	58.5	298.0	106.1	2.3
1092	I59-14	47.4	83.3	411.3	108.3	---
1094	I59-3	58.3	78.6	353.0	128.5	3.6
1096	C-0	37.5	75.1	305.1	102.9	2.2
1097	CSII-7	42.4	60.4	289.4	95.7	0.7
1098	C-3	30.4	49.4	225.4	73.8	1.1
1099	G60-0	45.9	56.8	338.6	113.4	1.5
1100	G54-14	39.0	60.5	285.1	93.4	2.2
1101	G54-3	36.7	59.3	325.1	84.2	1.7
1102	C-1/2y	38.5	54.5	295.0	79.5	1.5
1103	I59-7	38.0	96.9	363.3	103.4	3.8
1104	C-3	47.5	67.7	389	129	1.7
1105	E58-14	31.2	42.4	230.7	86.8	2.4
1107	G54-3	39.0	51.5	274.1	71.6	0.8
1109	G60-14	32.4	52.4	225.0	77.1	2.8
1110	C-7	41.3	60.2	315.2	99.4	2.1
1111	C-1y	55.0	54.0	354.0	98.0	1.0
1113	E58-14	34.9	53.2	311.2	100.0	0.6
1115	E58-3	26.5	41.5	230.3	65.4	1.3
1117	G54-0	37.5	47.5	378.0	89.7	2.0
1118	E58-7	37.8	53.8	243.1	87.6	2.4
1119	CSII-3	50.8	52.1	343.0	105.5	1.1
1120	G60-1y	48.0	63.0	392.0	98.0	3.0
1123	E58-7	36.8	58.5	635.2	106.5	2.4
1124	G60-1/2y	37.5	48.0	419.5	103.0	4.5
1125	G54-0	27.4	45.1	221.4	64.0	1.3
1126	G54-14	42.3	78.9	432.3	114.3	1.9
1129	G54-1/2y	40.0	73.0	392.0	81.0	0.8
1131	E58-3	38.2	71.0	365.0	112.4	2.8
1132	G60-0	42.2	55.5	306.2	118.1	2.2
1134	CSII-3	31.6	41.7	264.6	75.0	1.0
1150	E58-0	37.1	55.9	283.3	96.1	1.5

TABLE A.2 SHEEP TISSUE WEIGHTS, GRAMS

Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes	Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes
2001	C-90	199	98	589	454	6.0	2059	G52-3	221	103	577	444	3.5
2003	E56-0	192	89	602	502	10.0	2060	E60-14	200	114	715	510	8.5
2004	G62-1y	240	118	520	394	5.7	2061	I57-0	186	107	581	486	9.2
2005	G60-0	219	88	606	432	2.0	2062	G58-1/2y	153	113	537	380	2.5
2006	G58-30	141	98	490	388	3.0	2063	E56-14	155	96	584	420	9.0
2008	C-14	191	167	603	373	8.5	2064	E60-7	207	104	515	556	7.9
2009	G64-7	200	103	573	440	5.0	2067	G64-2y	162	98	380	334	1.3
2011	G58-2y	199	107	549	514	1.7	2068	G50-7	192	105	530	380	6.0
2012	C-7	185	110	516	504	8.5	2069	G54-0	181	90	500	238	2.5
2013	G64-14	183	103	710	446	9.6	2070	E60-14	187	100	635	388	8.9
2015	E56-7	210	97	482	357	7.6	2072	G60-1y	202	105	535	365	7.4
2017	G54-1y	340	143	640	440	24.0	2074	E56-3	190	126	579	588	8.1
2019	CSII-7	174	106	705	383	5.4	2075	G54-90	207	104	541	445	3.7
2021	G56-30	192	110	662	549	5.3	2076	G56-7	208	120	651	468	11.2
2022	E60-0	182	90	500	438	7.6	2077	G64-1/2y	166	122	592	338	3.0
2023	G62-2y	192	104	644	500	1.6	2081	G60-30	175	110	579	397	5.5
2024	I61-3	179	111	486	387	7.9	2082	G62-90	226	134	884	464	1.0
2025	G54-90	184	96	545	439	4.2	2083	G50-2y	195	121	432	380	1.9
2026	E60-30	210	117	678	650	7.3	2085	G50-90	223	124	649	526	5.5
2027	G58-7	196	109	606	454	10.0	2087	G58-2 1/2y	207	137	505	456	2.1
2029	G60-3	186	100	620	505	2.0	2088	G56-2y	192	81	403	453	1.7
2030	E56-14	207	138	773	380	8.7	2091	E56-7	222	96	535	400	4.5
2031	G64-2 1/2y	185	120	617	552	2.2	2092	G60-2 1/2y	167	102	411	497	1.4
2032	CSII-7	190	128	678	385	6.5	2093	E60-7	196	107	556	535	9.9
2033	G54-3	184	112	690	447	7.6	2094	I57-14	164	124	650	418	4.2
2034	G58-0	180	110	608	522	10.0	2095	G58-14	189	90	607	380	10.0
2035	G60-90	196	114	631	544	8.5	2096	G62-1/2y	179	87	609	485	12.0
2036	G52-2 1/2y	159	74	384	396	2.3	2097	C-2 1/2y	176	106	428	432	0.4
2037	C-90	193	104	551	395	6.6	2098	G60-2y	166	103	481	386	2.0
2038	G56-1y	254	99	528	470	12.4	2099	G52-1/2y	169	119	581	460	7.0
2039	G64-14	222	130	805	560	---	2100	CSII-7	170	116	588	362	5.6
2040	E56-7	179	96	518	403	13.5	2104	I57-3	183	88	511	464	7.1
2041	C-30	175	102	694	420	3.5	2105	I57-14	177	103	723	393	4.9
2042	G54-1/2y	199	118	762	394	5.5	2106	E56-3	207	115	554	419	3
2044	E60-14	196	145	611	398	7.8	2108	C-1/2y	152	118	552	367	3.0
2045	G56-90	193	102	634	602	5.7	2109	CSII-3	166	85	527	422	5.8
2047	I61-3	200	94	500	640	9.2	2110	CSII-7	162	356	603	105	9.8
2050	CSII-7	202	131	920	469	4.5	2111	G56-2 1/2y	195	124	580	448	2.7
2051	G52-1/2y	176	102	545	337	3.0	2112	C-0	185	90	561	380	3.0
2052	E60-0	175	103	530	488	4.5	2113	G64-1y	203	128	580	417	23.7
2053	I57-7	190	102	537	430	5.0	2114	G50-1y	225	113	470	474	7.7
2054	G52-1y	320	134	516	441	6.0	2115	C-14	181	133	776	557	7.5
2056	I57-7	190	91	---	470	2.0	2116	I61-0	210	98	650	422	4.0

TABLE A.2 (Continued)

Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes	Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes
2117	I61-7	238	114	554	411	8.4	2163	G50-30	188	120	748	417	2.5
2118	C-3	203	100	513	502	14.0	2164	C-3	206	89	527	411	8.5
2119	I57-7	182	98	612	405	8.2	2165	C-7	200	88	535	348	3.5
2121	I61-7	217	96	536	340	3.0	2166	G52-90	206	100	621	396	2.5
2123	E56-14	239	133	760	478	6.0	2167	G50-1/2y	162	114	588	322	2.5
2124	G62-30	174	107	795	513	6.8	2168	G56-0	175	104	651	680	8.2
2125	G54-2y	199	114	660	459	2.0	2169	E56-0	203	118	609	423	10.8
2126	G52-0	204	130	624	456	10.0	2171	CSII-3	177	105	566	414	6.5
2127	CSII-7	164	103	920	688	7.8	2172	G64-2 1/2y	191	108	434	436	1.6
2128	G62-30	142	90	490	490	3.7	2173	G62-0	200	91	465	422	9.9
2129	G52-30	173	138	940	520	4.0	2175	I61-14	192	95	607	410	6.0
2130	I61-7	219	105	530	410	2.5	2176	G64-3	192	100	540	380	4.0
2131	I61-14	198	117	671	391	5.5	2177	G50-30	146	102	540	412	2.0
2133	G62-2 1/2y	162	85	362	383	1.0	2178	CSII-3	207	108	596	387	6.2
2134	G60-2 1/2y	177	96	408	404	1.0	2179	E56-0	195	85	534	442	3.0
2135	G60-7	203	113	775	453	18.8	2181	C-7	167	85	498	386	20.0
2136	G62-14	180	141	808	495	12.3	2182	G60-90	206	90	622	502	8.5
2137	I61-0	205	110	573	492	2.5	2183*	E60-0	179	107	637	500	7.6
2139	C-14	237	132	996	483	9.0	2184	E56-3	220	98	565	396	7.7
2140	E60-0	182	87	442	335	3	2185	G58-1y	236	94	301	388	7.5
2141	E60-7	172	107	543	388	7.9	2186	G64-90	215	119	795	502	5.1
2142	C-3	219	114	522	430	3.5	2187	G60-1/2y	199	118	762	394	5.5
2143	I57-0	173	102	531	444	10.5	2189	G54-0	173	93	604	390	1.4
2144	I57-3	193	100	540	439	3.5	2190	G50-3	211	112	573	391	2.5
2145	G52-2y	181	113	548	392	1.5	2191	I61-14	194	115	650	391	6.2
2146	G62-3	187	88	609	598	25	2192	C-2y	182	89	454	349	1.7
2147	G56-1y	256	114	515	360	15.5	2193	I57-14	188	112	750	404	7.8
2148	G50-14	197	138	743	433	9.5	2194	G52-7	229	98	650	410	4.0
2150	I57-3	242	110	550	490	2.5	2196	I61-0	222	130	580	470	2.2
2151	G56-1/2y	179	134	735	436	1.5	2199	CSII-3	222	89	633	580	5.4
2153	E60-3	204	124	650	500	3	2200	C-1/2y	213	139	1235	627	0.5
2154	G58-30	163	100	578	412	5.8	NO #	C-0	194	92	573	312	9.5
2155	CSII-3	162	108	568	385	9.1	C	C-0	184	73	472	340	6.0
2156	G62-1/2y	163	102	545	337	3.0	3077	C-2y	184	114	526	444	0.6
2157	G50-2 1/2y	188	123	562	468	1.8	B (3078)	G54-2 1/2y	211	124	685	462	3.1
2158	G56-14	164	98	614	335	7.0	3079	C-2 1/2y	175	95	595	408	2.2
2159	C-1y	297	143	570	468	9.0	242	C-1/2y	159	114	805	361	2.2

* Found dead on truck, necropsied on D-Day although scheduled for D + 3.

TABLE A.3 BURRO TISSUE WEIGHTS, GRAMS

Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes	Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes
3000	C-1y	1092	1000	2550	1610	31.0	3066	C-7	922	845	3482	1361	7
3001	G52-14	1132	769	3158	1522	10.2	3067	G52-3	919	880	3188	1450	7.5
3002	G56-1/2y	844	604	3221	1292	6.5	3068	I57-3	1103	765	3245	1419	10
3003	I57-7	1290	785	3670	1760	12	3069	G64-1y	1058	1225	3650	1414	9.5
3004	E56-3	1066	823	2055	1545	9	3073	G50-3	1120	695	2663	1340	15
3005	I61-0	917	712	1930	1457	8.7	3074	E58-3	775	597	3099	1064	7
3006	I61-7	922	790	2004	1117	18	3075	E60-7	1025	700	2815	1400	27
3007(31)	G52-0	1010	912	3252	2115	10.6	3076	G64-14	1275	995	4595	1690	19
3007(26)	E54-14	1115	960	3700	1565	16.5	3101	I59-3	1225	774	2831	1376	11
3008	I57-0	1155	855	3496	1858	15.4	3102	G50-7	1315	765	4030	1500	24
3010	E58-14	1125	630	2100	1285	36	3103	E54-7	1040	782	2865	1530	9
3011	G64-0	871	743	2460	2460	9.0	3105	I55-3	1125	885	3961	1450	7
3012	C-14	1315	885	3335	1715	14	3107	G58-3	923	835	3225	1945	10
3013	E54-14	855	562	2476	1237	10	3108	I55-7	1142	765	3580	1500	18
3015	G58-7	1030	640	2660	1255	14	3109	G58-14	1280	815	4000	1910	18
3017	G58-1y	1015	718	3250	1200	20.5	3110	I59-3	1045	831	2900	2200	12.4
3018	I61-3	1157	1113	1725	1589	10	3111	E56-14	1121	815	3022	1784	7.9
3019	G58-0	987	724	2490	1556	16.6	3113	G56-0	960	891	2647	2569	12.4
3020	I61-0	1065	657	3490	2165	13	3118	I57-14	1184	830	4135	2475	8
3021	G50-1/2y	870	635	2695	1580	15.0	3120	I61-14	1226	915	4080	1580	19.3
3023	E58-14	1035	785	3770	1530	33	3122	G50-1y	1580	1408	4360	1610	70.0
3025	G62-14	987	828	3655	1760	9.5	3123	C-14	1279	770	3868	1910	11
3027	G58-1/2y	968	582	3039	1332	13.5	3125	I57-7	1160	830	2900	1500	10
3028	G64-1/2y	897	916	3515	1490	26.0	3126	E56-7	1120	630	2900	1645	24
3029	I55-0	988	882	2665	2278	10	3127	G50-0	1127	830	2900	1655	7.6
3031	E60-14	1127	725	3735	1450	9.4	3130	E60-3	977	805	2210	1347	8
3032	I59-0	1037	620	2800	2255	9.4	3131	G62-0	1090	670	2263	1282	6.3
3033	G50-14	1100	815	3415	1585	19	3132	C-3	955	780	1934	1486	8
3035	I59-14	1235	690	3090	1535	18	3133	E58-3	1175	670	2670	1462	14
3036	E54-3	865	640	2311	1220	9	3134	E54-3	980	855	2872	1445	11
3037	G56-1y	1264	928	3390	1651	26.0	3135	G52-7	995	605	2320	1300	15
3039	E56-0	900	445	2200	952	13.3	3136	G56-3	1195	732	2452	1435	21
3040	I59-7	1235	610	2770	1515	24	3137	E60-7	919	543	1584	1445	6
3041	G56-14	1345	650	2960	1285	14	3138	E60-0	909	559	2245	1269	7.6
3042	I55-14	1262	710	3032	1557	19	3139	C-0	920	685	2240	1165	3
3043	G64-7	1124	590	2790	1538	7.1	3140	G62-1y	873	721	2378	1194	17.0
3045	I59-14	1085	815	2935	1565	18	3141	G62-7	1085	995	3025	1725	15
3049	C-0	985	1015	4303	1647	15	3143	G62-1/2y	1010	914	4204	2035	4.0
3050(18)	C-0	900	985	2500	1970	9	3144	E56-7	1085	770	3945	1295	8
3050(19)	I61-7	1037	738	2690	1412	13	3146	E60-0	1240	939	3155	1920	9
3051	I57-0	1295	820	3200	2617	7.2	3147	E58-0	1006	720	3520	1905	8
3053	I55-14	1440	1095	4560	1825	26	3148	E54-0	971	858	3280	1487	12.2
3055	G64-3	905	960	3799	1674	15	3176	E56-0	984	525	2090	1480	11
3057	C-7	1385	1055	4190	2160	9	3177	G56-7	995	835	2500	1530	14
3059	I55-3	1030	795	3510	1278	---	3178	C-3	810	780	2600	1390	9
3060	C-1/2y	821	480	797	1060	3.5	3180	C-14	1065	878	3225	1460	14.5
3064	C-3	1014	790	4037	1849	6	3199	C-7	1170	880	4150	1630	21
3065	G62-3	1132	756	2405	1534	9	3200	E58-7	1320	725	3185	1470	9.5

TABLE A.4 LOCATIONS OF INDIVIDUAL ANIMALS

Location	Sample Number	Animal Number	Sac. Day	Location	Sample Number	Animal Number	Sac. Day
E-054	9685	3148	0	E-058		1043	7
Burro		3036	3	Dog		1064	7
		3134	3	(cont.)		1118	7
		3103	7			1123	7
		3007(26)	14			1021	14
		3013	14			1027	14
E-056	9653	2003	0			1053	14
Sheep		2169	0			1086	14
		2179	0			1105	14
		2074	3			1113	14
		2106	3	E-058	9689	3147	0
		2184	3	Burro		3074	3
		2015	7			3133	3
		2040	7			3200	7
		2091	7			3010	14
		2030	14			3023	14
		2063	14	E-060	9651	2022	0
		2123	14	Sheep		2052	0
E-056	9687	3039	0			2140	0
Burro		3176	0			2183	0
		3004	3			2153	3
		3126	7			2064	7
		3144	7			2093	7
		3111	14			2141	7
E-058	----	1024	0			2044	14
Dog		1040	0			2060	14
		1050	0			2070	14
		1054	0			2026	36
		1069	0	E-060	9690	3138	0
		1150	0	Burro		3146	0
		1002	3			3120	3
		1003	3			3075	7
		1088	3			3137	7
		1091	3			3031	14
		1115	3	G-050	9667	2190	3
		1131	3	Sheep		2068	7
		1034	7			2148	14
		1036	7			2163	36

TABLE A.4 (Continued)

Location	Sample Number	Animal Number	Sac. Day
G-050		2177	36
Sheep		2085	99
(cont.)		2167	1/2y
		2114	1y
		2083	2y
		2157	2 1/2y
G-050	9677	3127	0
Burro		3073	3
		3102	7
		3033	14
		3021	1/2y
		3122	1y
G-052	9666	2126	0
Sheep		2059	3
		2194	7
		2129	36
		2166	99
		2051	1/2y
		2099	1/2y
		2054	1y
		2122	1y
		2145	2y
		2036	2 1/2y
G-052	9678	3007(31)	0
Burro		3067	3
		3135	7
		3001	14
		3116	1/2y
G-054	9664	2069	0
Sheep		2189	0
		2033	3
		2025	99
		2075	99
		2042	1/2y
		2017	1y
		2125	2y
		3078(B)	2 1/2y
G-054	9696	1041	0
Dog		1117	0
		1125	0
		1052	3
		1101	3
		1107	3
		1038	7
		1051	7
		1080	7
		1065	14
		1100	14
		1126	14
		1056	1/2y
		1057	1/2y
		1083	1/2y
		1072	1y
		1090	1y
G-056	9662	2168	0
Sheep		2076	7
		2158	14
		2021	36
		2045	99
		2151	1/2y
		2038	1y
		2147	1y
		2088	2y
		2111	2 1/2y
G-056	9680	3113	0
Burro		3136	3
		3177	7
		3044	14
		3002	1/2y
		3037	1y
G-058	----	2034	0
Sheep		2027	7
		2095	14
		2006	36
		2154	36

TABLE A.4 (Continued)

Location	Sample Number	Animal Number	Sac. Day	Location	Sample Number	Animal Number	Sac. Day
G-058		2062	1/2y	G-062	9657	2173	0
Sheep		2185	1y	Sheep		2146	3
(cont.)		2011	2y			2136	14
		2087	2 1/2y			2124	36
G-058	----	3019	0			2128	36
Burro		3107	3			2082	99
		3015	7			2096	1/2y
		3109	14			2156	1/2y
		3027	1/2y			2004	1y
		3017	1y			2023	2y
G-060	9658	2005	0			2133	2 1/2y
Sheep		2029	3	G-062	9683	3131	0
		2135	7	Burro		3065	3
		2081	36			3141	7
		2035	99			3025	14
		2182	99			3143	1/2y
		2187	1/2y			3140	1y
		2072	1y	G-064	----	2176	3
		2098	2y	Sheep		2009	7
		2092	2 1/2y			2013	14
		2134	2 1/2y			2039	14
G-060	9694	1067	0			2186	99
Dog		1099	0			2077	1/2y
		1132	0			2113	1y
		1047	3			2067	2y
		1055	3			2031	2 1/2y
		1059	3			2172	2 1/2y
		1085	3	G-064	9684	3011	0
		1014	7	Burro		3055	3
		1063	7			3043	7
		1082	7			3076	14
		1077	14			3028	1/2y
		1109	14			3069	1y
		1068	1/2y	I-055	9647	3029	0
		1124	1/2y	Burro		3059	3
		1039	1y			3105	3
		1048	1y			3108	7
		1078	1y			3042	14
		1120	1y			3053	14

TABLE A.4 (Continued)

Location	Sample Number	Animal Number	Sac. Day	Location	Sample Number	Animal Number	Sac. Day
I-057	9655	2061	0	I-059		1032	14
Sheep		2143	0	Dog		1049	14
		2104	3	(cont.)		1092	14
		2144	3	I-059	9675	3032	0
		2150	3	Burro		3101	3
		2053	7			3110	3
		2056	7			3040	7
		2119	7			3035	14
		2094	14			3045	14
		2105	14	I-061	----	2116	0
		2193	14	Sheep		2137	0
I-057	9649	3008	0			2196	0
Burro	9629	3051	0			2024	3
		3068	3			2047	3
		3003	7			2117	7
		3125	7			2121	7
		3118	14			2130	7
I-059	9693	1022	0			2131	14
Dog		1029	0			2175	14
		1035	0			2191	14
		1081	0	I-061	9676	3005	0
		1087	0	Burro		3020	0
		1006	3			3018	3
		1011	3			3006	7
		1012	3			3050(19)	7
		1013	3			3120	14
		1025	3				
		1037	3				
		1042	3				
		1084	3				
		1094	3				
		1007	7				
		1015	7				
		1028	7				
		1061	7				
		1103	7				
		1008	14				
		1009	14				

TABLE A.5 TOTAL SAMPLE ACTIVITY, DPM (DOGS)

Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes	Trachea	Stomach	Phar Muc	Nas Muc
1001	C-1y	0.0	0.2	0.4	0.9	0.0	-------	-------	--------	-------
1002	E58-3	0.1	0.0	0.6	1.3	0.1	-------	-------	--------	-------
1003	E58-3	0.1	0.1	0.2	1.2	0.0	-------	-------	--------	-------
1004	C-7	0	0	0	0	0	-------	-------	--------	-------
1005	C-14	0	0	0.9	0.7	0	-------	-------	--------	-------
1006	I59-3	0.1	0.3	0.6	53.0	0.0	-------	-------	--------	-------
1007	I59-7	0	0	0	65.9	0	-------	-------	--------	-------
1008	I59-14	0	0	0	18.4	0	-------	-------	--------	-------
1009	I59-14	0	0	0	46.3	0	-------	-------	--------	-------
1010	C-3	0.0	0.3	0.6	0.6	0.1	-------	-------	--------	-------
1011	I59-3	0.1	0.2	0.3	35.3	0.2	-------	-------	--------	-------
1012	I59-3	0	0	1.0	15.5	0	-------	-------	--------	-------
1013	I59-3	0.2	0.1	0.7	47.0	0.0	-------	-------	--------	-------
1014	G60-7	0	0	0.7	69.1	0	-------	-------	--------	-------
1015	I59-7	0	0	0	47.6	0	-------	-------	--------	-------
1018	CSII-3	1.6	0.5	0.8	0.9	0.5	-------	-------	--------	-------
1019	CSII-7	0.2	1.4	2.0	5.7	0.1	-------	-------	--------	-------
1020	CSII-7	0.0	0.0	1.4	3.4	0.0	-------	-------	--------	-------
1021	E58-14	0	0	0	3.7	0	-------	-------	--------	-------
1022	I59-0	0.0	-------	0.2	50.3	3.8	457	386	5.3	4.8
1023	CSII-7C	1.0	0.0	0.8	3.1	-----	-------	-------	--------	-------
1024	E58-0	0.1	0.0	-----	5.4	0.0	0.2	85.6	0.1	0.2
1025	I59-3	0.0	0.1	0.5	92.3	0.0	-------	-------	--------	-------
1027	E58-14	0	0	0	46.2	0	-------	-------	--------	-------
1028	I59-7	0	0	1.2	55.4	0	-------	-------	--------	-------
1029	I59-0	0.0	0.0	0.2	45.8	4.2	21.3	255	0.2	22.1
1031	C-14	0	0	0	0	0	-------	-------	--------	-------
1032	I59-14	0	0	0	37.1	0	-------	-------	--------	-------
1033	C-7	0	0	0	0	0	-------	-------	--------	-------
1034	E58-7	0	0	0	2.5	0	-------	-------	--------	-------
1035	I59-0	0.0	0.0	0.2	51.7	-----	0.8	104	1.1	0.1
1036	E58-7	0	0	0	10.6	0	-------	-------	--------	-------
1037	I59-3	0.3	0.1	0.2	32.2	0.0	-------	-------	--------	-------
1038	G54-7	0	0	0	3.4	0	-------	-------	--------	-------
1039	G60-1y	0	0	0	4.4	1.1	-------	-------	--------	-------
1040	E58-0	0.1	0.1	0.5	0.6	0.1	0.2	2890	1.1	7.0

TABLE A.5 (Continued)

Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes	Trachea	Stomach	Phar Muc	Nas Muc
1041	G54-0	0.5	0.3	-----	13.7	0.0	10.4	535	0.0	0.4
1042	I59-3	0.1	0.2	0.6	91.8	0.1	-------	-------	--------	-------
1043	E58-7	0	0	1.0	2.9	0	-------	-------	--------	-------
1044	C-14	0	0	0	0	0	-------	-------	--------	-------
1045	CSII-3	1.0	0.4	-----	6.3	0.2	-------	-------	--------	-------
1046	CSII-3	0.1	0.1	0.5	15.3	0.0	-------	-------	--------	-------
1047	G60-3	0.1	0.1	0.3	8.0	0.1	-------	-------	--------	-------
1048	G60-1y	0	0	1.2	5.9	2.3	-------	-------	--------	-------
1049	I59-14	0	0	0	59.9	0	-------	-------	--------	-------
1050	E58-0	0.0	0.0	0.1	2.6	0.1	7.6	16,400	16.4	249
1051	G54-7	0	0	0	1.0	0	-------	-------	--------	-------
1052	G54-3	0.4	0.1	0.5	6.0	0.0	-------	-------	--------	-------
1053	E58-14	0	0	0	0	0	-------	-------	--------	-------
1054	E58-0	0.0	0.0	0.1	3.6	1.2	1.2	3260	0.6	0.4
1055	G60-3	0.1	0.1	0.2	9.4	0.0	-------	-------	--------	-------
1056	G54-1/2y	0.4	0.2	0.4	1.1	0.9	-------	-------	--------	-------
1057	G54-1/2y	0.5	0.4	2.4	2.4	3.7	-------	-------	--------	-------
1059	G60-3	0.4	0.1	0.3	10.1	0.0	-------	-------	--------	-------
1060	C-0	0.1	0.0	-----	1.0	0.0	0.0	5.8	0.0	.2
1061	I59-7	0	0	0	14.1	0	-------	-------	--------	-------
1062	CSII-7	0.0	0.4	1.0	2.9	0.1	-------	-------	--------	-------
1063	G60-7	0	0	0	0.8	0	-------	-------	--------	-------
1064	E58-7	0	0	1.2	3.6	0	-------	-------	--------	-------
1065	G54-14	0	0	0	12.5	0	-------	-------	--------	-------
1067	G60-0	0.1	0.1	0.2	10.5	0.1	0.1	9.8	0.1	0.1
1068	G60-1/2y	1.3	0.5	7.9	5.4	0.5	-------	-------	--------	-------
1069	E58-0	0.1	-------	0.7	1.2	1.1	0.1	1150	0.1	0.0
1072	G54-1y	0.8	0	0.5	8.2	0	-------	-------	--------	-------
1073	CSII-7	0.2	0.1	0.9	3.9	0.1	-------	-------	--------	-------
1074	C-0	0.1	0.0	0.6	0.2	0.0	-------	2.3	0.1	0.4
1077	G60-14	0	0	0	6.3	0	-------	-------	--------	-------
1078	G60-1/2y	0	0	0	0	0	-------	-------	--------	-------
1080	G54-7	0	0	0	12.5	0	-------	-------	--------	-------
1081	I59-0	0.3	0.2	0.5	49.1	0.1	7.7	761	0.1	2.6
1082	G60-7	0	2.6	0	2.8	0	-------	-------	--------	-------
1083	G54-1/2y	0.8	0.2	1.4	6.2	0.9	-------	-------	--------	-------
1084	I59-3	0.6	0.2	0.3	30.4	0.1	-------	-------	--------	-------

TABLE A.5 (Continued)

Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes	Trachea	Stomach	Phar Muc	Nas Muc
1085	G60-3	0.2	0.0	0.6	5.6	0.0	-------	-------	--------	-------
1086	E58-14	0	0	0	0	0	-------	-------	--------	-------
1087	I59-0	0.4	0.0	0.4	60.1	0.6	1.6	2750	0.2	0.2
1088	E58-3	0.5	0.0	0.8	0.6	0.2	-------	-------	--------	-------
1090	G54-1y	0	0	0	3.4	0	-------	-------	--------	-------
1091	E58-3	0.0	0.1	0.3	0.9	0.0	-------	-------	--------	-------
1092	I59-14	0	0	0.7	70.0	-----	-------	-------	--------	-------
1094	I59-3	0.5	0.2	0.1	106	0.0	25.0	238	1.2	15.3
1096	C-0	0.0	0.6	0.3	0.2	0.0	0.0	4.8	0.0	1.6
1097	CSII-7	0.2	0.2	0.8	3.0	0.0	-------	-------	--------	-------
1098	C-3	0.4	1.6	0.3	0.5	0.2	-------	-------	--------	-------
1099	G60-0	0.2	0.1	0.7	10.9	-----	0.3	1170	38.6	94.9
1100	G54-14	0	0	0.8	4.4	0	-------	-------	--------	-------
1101	G54-3	0.1	0.0	0.4	4.5	2.8	-------	-------	--------	-------
1102	C-180	0.3	0.2	2.4	0.8	0.6	-------	-------	--------	-------
1103	I59-7	0	0	1.9	56.4	0	-------	-------	--------	-------
1104	C-3	0.1	0.1	0.4	0.3	0.1	-------	-------	--------	-------
1105	E58-14	0	0	0.6	0	0	-------	-------	--------	-------
1107	G54-3	0.5	0.0	0.5	8.1	0.1	-------	-------	--------	-------
1109	G60-14	0.8	0	0	3.3	0	-------	-------	--------	-------
1110	C-7	0	0	0	0.6	0	-------	-------	--------	-------
1111	C-180	0	0	0	0	0	-------	-------	--------	-------
1113	E58-14	0	1.4	0	0.8	0	-------	-------	--------	-------
1115	E58-3	0.1	0.1	0.4	1.1	0.0	-------	-------	--------	-------
1117	G54-0	0.0	0.1	0.4	4.0	0.9	2.0	708	10.7	14.9
1118	E58-7	0	0	0	1.9	0	-------	-------	--------	-------
1119	CSII-3	0.2	0.1	1.4	4.7	0.2	-------	-------	--------	-------
1120	G60-1y	22.6	0	26.2	0	0	-------	-------	--------	-------
1123	E58-7	0	0	0	5.4	0	-------	-------	--------	-------
1124	G60-1/2y	1.7	0.6	2.3	3.9	0.3	-------	-------	--------	-------
1125	G54-0	0.3	0.4	0.4	3.8	0.1	0.6	8330	1.0	1.0
1126	G54-14	0	0	0.8	11.1	0	-------	-------	--------	-------
1129	G54-1/2y	0.9	0.6	0.6	2.9	0.7	-------	-------	--------	-------
1131	E58-3	0.1	0.4	0.2	1.9	0.1	-------	-------	--------	-------
1132	G60-0	0.2	0.1	-----	3.2	0.0	0.1	23.8	0.1	-------
1134	CSII-3	1.2	1.2	7.5	1.0	0.1	-------	-------	--------	-------
1150	E58-0	0.0	0.0	0.1	0.6	0.1	0.0	2580	0.0	0.0

TABLE A.6 TOTAL SAMPLE ACTIVITY, DPM (SHEEP)

Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes	Trachea	Stomach	Phar Muc	Nas Muc
2001	C-90	0.2	0.2	0.1	0.4	0.0	-------	-------	--------	-------
2003	E56-0	0	0	0	115	0	8.1	2410	0	0
2004	G62-1y	0	0	138	1.1	0	-------	-------	--------	-------
2005	G60-0	0.1	0.1	4.7	24.0	0	0.1	90.7	--------	273
2006	G58-30	0.2	0.2	0.4	1.0	0.1	-------	-------	--------	-------
2008	C-14	0.1	0.1	0.5	1.1	0.1	-------	-------	--------	-------
2009	G64-7	0	0	1.6	0.7	0	-------	-------	--------	-------
2011	G58-2y	0	0	0.7	0.3	0	-------	-------	--------	-------
2012	C-7	0.2	0.0	0.3	0.5	0.0	-------	-------	--------	-------
2013	G64-14	0.2	0.3	2.9	93.0	0.7	-------	-------	--------	-------
2015	E56-7	0.3	1.6	0.0	6.2	0.2	-------	-------	--------	-------
2017	G54-1y	0	0	0	27.1	0	-------	-------	--------	-------
2019	CSII-7	0.0	0.3	0.7	3.9	0.1	-------	-------	--------	-------
2021	G56-30	6.9	2.6	1.7	1.1	0.0	-------	-------	--------	-------
2022	E60-0	44.2	15.3	3.4	5.6	0.4	0.3	90.6	0.2	5.6
2023	G62-2y	0.3	0.9	0.8	1.3	1.6	-------	-------	--------	-------
2024	I61-3	0.2	0.2	0.7	139	0.1	-------	-------	--------	-------
2025	G54-90	0.2	0.2	0.5	0.5	0.1	-------	-------	--------	-------
2026	E60-30	4.7	0.0	3.7	1.1	1.2	-------	-------	--------	-------
2027	G58-7	0.5	0.2	0.7	10.2	0.2	-------	-------	--------	-------
2028	CSII-3	1.6	0.5	0.8	10.8	0.0	-------	-------	--------	-------
2029	G60-3	5.5	0.0	3.1	10.7	0.0	-------	-------	--------	-------
2030	E56-14	0.2	0.0	0.4	5.1	0.2	-------	-------	--------	-------
2031	G64-2 1/2y	0.3	0.4	1.6	12.2	10.0	-------	-------	--------	-------
2032	CSII-7	0.2	0.0	2.0	4.3	0.0	-------	-------	--------	-------
2033	G54-3	0.5	0.1	1.3	109.9	0.7	-------	-------	--------	-------
2034	G58-0	0	1.2	0	76.5	0	8.5	217	4.6	53.8
2035	G60-90	0.1	0.1	0.3	1.0	0.7	-------	-------	--------	-------
2036	G52-2 1/2y	0.4	0.2	0.8	1.3	0	-------	-------	--------	-------
2037	C-90	0.4	0.1	0.5	0.3	0.1	-------	-------	--------	-------
2038	G56-1y	0	0	0	0	0	-------	-------	--------	-------
2039	G64-14	0.0	0.2	3.1	2.8	-----	-------	-------	--------	-------
2040	E56-7	2.4	0.3	0.2	-----	0.0	-------	-------	--------	-------
2041	C-30	3.3	1.3	1.3	2.3	0.1	-------	-------	--------	-------
2042	G54-1/2y	0.7	0.3	-----	0.9	0.3	-------	-------	--------	-------
2044	E60-14	0.0	0.0	4.0	5.5	0.0	-------	-------	--------	-------

TABLE A.6 (Continued)

Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes	Trachea	Stomach	Phar Muc	Nas Muc
2045	G56-90	0.2	0.1	0.4	0.3	0.2	-------	-------	--------	-------
2047	I61-3	0.1	0.1	1.4	151	0.1	-------	-------	--------	-------
2050	CSII-7	0.3	0.1	0.3	90.6	0.0	-------	-------	--------	-------
2051	G52-1/2y	10.9	0.1	0.0	1.1	0.9	-------	-------	--------	-------
2052	E60-0	0.2	0.1	1.1	5.4	0.2	0.6	28.0	--------	0.5
2053	I57-7	0	0	1.6	31.0	0	-------	-------	--------	-------
2054	G52-1y	0	0	30.4	0	0	-------	-------	--------	-------
2056	I57-7	0	0	0	8.2	0	-------	-------	--------	-------
2059	G52-3	0	3.1	0	1.3	0	-------	-------	--------	-------
2060	E60-14	0.2	0.0	0.5	2.6	0.1	-------	-------	--------	-------
2061	I57-0	0	0.6	0	41.7	0	.3	2490	0.6	2.2
2062	G58-1/2y	0.0	0.6	2.7	1.4	0.1	-------	-------	--------	-------
2063	E56-14	1.2	0	0.8	1.0	0	-------	-------	--------	-------
2064	E60-7	0.1	0.0	0.3	3.6	0.2	-------	-------	--------	-------
2067	G64-2y	0	0	0.9	2.4	0	-------	-------	--------	-------
2068	G50-7	0	0	0	1.6	0	-------	-------	--------	-------
2069	G54-0	0	0	0	50.3	0	18.9	2390	--------	.3
2070	E60-14	1.8	0.0	0	5.4	0.3	-------	-------	--------	-------
2072	G60-1y	0	0	0	1.5	0	-------	-------	--------	-------
2074	E56-3	-----	2.2	0.6	16.9	0.0	-------	-------	--------	-------
2075	G54-90	0.1	0.1	0.4	0.3	0.1	-------	-------	--------	-------
2076	G56-7	9.2	0.0	2.2	3.5	0.0	-------	-------	--------	-------
2077	G64-1/2y	0.7	0.9	1.3	2.8	1.0	-------	-------	--------	-------
2081	G60-30	1.8	0.0	2.3	57.3	0.0	-------	-------	--------	-------
2082	G62-90	0.5	0.0	0.5	3.4	0.2	-------	-------	--------	-------
2083	G50-2y	1.0	0	0	0.3	0	-------	-------	--------	-------
2085	G50-90	0.1	0.2	1.4	0.4	0.0	-------	-------	--------	-------
2087	G58-2 1/2y	0.2	0.2	0.7	0.4	0.1	-------	-------	--------	-------
2088	G56-2y	0	0	0	0	3.1	-------	-------	--------	-------
2091	E56-7	0	0	0	1.0	0	-------	-------	--------	-------
2092	G60-2 1/2y	0.1	0.1	0.5	0.7	0.1	-------	-------	--------	-------
2093	E60-7	0.7	0.1	0.7	1.1	0.0	-------	-------	--------	-------
2094	I57-14	6.6	1.1	0.6	7.0	0.0	-------	-------	--------	-------
2095	G58-14	0.2	0.0	0.6	4.4	0.0	-------	-------	--------	-------
2096	G62-1/2y	1.9	0.8	0.9	3.6	6.0	-------	-------	--------	-------
2097	C-2 1/2y	0.9	0	0.4	0.3	0.1	-------	-------	--------	-------
2098	G60-2y	0.5	2.2	0.4	0.3	0	-------	-------	--------	-------

TABLE A.6 (Continued)

Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes	Trachea	Stomach	Phar Muc	Nas Muc
2099	G52-1/2y	13.4	0	0.0	2.2	1.1	-------	-------	--------	-------
2100	CSII-7	0.2	0.1	0.8	4.3	0.0	-------	-------	--------	-------
2104	I57-3	1.1	0.1	61.8	25.8	0.0	-------	-------	--------	-------
2105	I57-14	0.5	0.0	0.7	4.1	0.0	-------	-------	--------	-------
2106	E56-3	0	0	0.8	9.6	0	-------	-------	--------	-------
2108	C-180	0.0	0.7	0.0	0.0	0.1	-------	-------	--------	-------
2109	CSII-3	0.2	0.7	1.3	7.6	0.1	-------	-------	--------	-------
2110	CSII-7C	0.1	0.0	0.5	5.1	0.1	-------	-------	--------	-------
2111	G56-2 1/2y	0.1	0.1	2.6	0.2	0.6	-------	-------	--------	-------
2112	C-0	0.2	0.2	0.6	10.8	0.0	0.3	165	--------	0.8
2113	G64-1y	0	5.6	26.2	155.7	0.5	-------	-------	--------	-------
2114	G50-1y	0	0	0	0	99.6	-------	-------	--------	-------
2115	C-14	0	0	0	0	0	-------	-------	--------	-------
2116	I61-0	0	0	0	371	0	42.8	1460	--------	215
2117	I61-7	0.6	0.0	3.4	120	0.0	-------	-------	--------	-------
2118	C-3	2.6	0.4	1.2	1.6	0.0	-------	-------	--------	-------
2119	I57-7	0.0	0.0	0.4	5.8	0.1	-------	-------	--------	-------
2121	I61-7	0	0	0	112	0	-------	-------	--------	-------
2123	E56-14	0	0	0	7.4	0	-------	-------	--------	-------
2124	G62-30	0.1	0.0	1.2	14.0	0.7	-------	-------	--------	-------
2125	G54-2y	0.4	0	0.5	0.7	2.9	-------	-------	--------	-------
2126	G52-0	0	0	0	9.0	0	0.5	1550	.3	.2
2127	CSII-7	0.1	0.1	1.8	36.0	0.1	-------	-------	--------	-------
2128	G62-30	4.9	0.8	2.3	37.9	0	-------	-------	--------	-------
2129	G52-30	0.0	0.1	0.9	0.9	0.0	-------	-------	--------	-------
2130	I61-7	0	0	0	125	0	-------	-------	--------	-------
2131	I61-14	0	0	0	65.0	0	-------	-------	--------	-------
2133	G62-2 1/2y	0.4	0.4	1.8	2.1	0.7	-------	-------	--------	-------
2134	G60-2 1/2y	0.2	0.1	0.7	0.3	0.1	-------	-------	--------	-------
2135	G60-7	5.5	0.0	0.6	19.5	0.0	-------	-------	--------	-------
2136	G62-14	-----	0.2	5.2	-----	-----	-------	-------	--------	-------
2137	I61-0	0.0	0.0	0.8	424	0.1	11.8	545	--------	12.1
2139	C-14	0.5	0.0	0.8	0.8	0.5	-------	-------	--------	-------
2140	E60-0	0.0	0.2	0.3	37.2	0.1	16.7	53.0	--------	6.0
2141	E60-7	7.4	0.0	1.9	1.4	0.0	-------	-------	--------	-------
2142	C-3	3.8	0.2	1.0	2.9	-----	-------	-------	--------	-------
2143	I57-0	0.1	0.1	18.8	133.9	0.5	57.2	125	12.9	21.9

TABLE A.6 (Continued)

Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes	Trachea	Stomach	Phar Muc	Nas Muc
2144	I57-3	0.7	0.0	1.5	22.2	0.3	-------	-------	--------	-------
2145	G52-2y	0.7	0	0.3	0	0	-------	-------	--------	-------
2146	G62-3	47.3	0.2	2.3	2.9	-----	-------	-------	--------	-------
2147	G56-1y	2.9	0	0	6.5	0	-------	-------	--------	-------
2148	G50-14	1.4	0.4	0.2	0.3	0.0	-------	-------	--------	-------
2150	I57-3	27.8	0.0	-----	22.2	0.0	-------	-------	--------	-------
2151	G56-1/2y	2.5	0.3	7.0	0.8	0.3	-------	-------	--------	-------
2153	E60-3	32.9	0.5	2.6	1.6	4.9	-------	-------	--------	-------
2154	G58-30	1.9	1.6	0.5	1.6	0.6	-------	-------	--------	-------
2155	CSII-3	1.1	0.3	3.2	8.0	0.3	-------	-------	--------	-------
2156	G62-1/2y	0.5	0.3	1.8	7.7	0.2	-------	-------	--------	-------
2157	G50-2 1/2y	0.2	0.1	0.4	0.1	0	-------	-------	--------	-------
2158	G56-14	0	0	1.1	1.3	0	-------	-------	--------	-------
2159	C-1y	0	0	0	0	0	-------	-------	--------	-------
2163	G50-30	1.7	0.0	3.4	1.9	0.0	-------	-------	--------	-------
2164	C-3	0.4	0.1	0.8	0.3	0.1	-------	-------	--------	-------
2165	C-7	0	0	0	0	0.3	-------	-------	--------	-------
2166	G52-90	0.1	0.1	0.7	0.5	0.1	-------	-------	--------	-------
2167	G50-1/2y	3.3	0.9	0.7	3.5	0.2	-------	-------	--------	-------
2168	G56-0	40.7	2.7	23.8	250.6	0.8	0.2	1214	0.1	2.2
2169	E56-0	575	0.6	15.1	57.5	0.8	3.9	150	1.9	11.5
2171	CSII-3C	0.1	-------	0.6	-----	0.5	-------	-------	--------	-------
2172	G64-2 1/2y	0	0.1	7.3	6.0	5.3	-------	-------	--------	-------
2173	G62-0	0.3	2.7	1.3	283	0.4	4.6	1203	1.3	207
2175	I61-14	0	0	0	64.3	0	-------	-------	--------	-------
2176	G64-3	0.5	0.0	9	317	0.0	-------	-------	--------	-------
2177	G50-30	2.2	0.0	0.6	0.7	0.1	-------	-------	--------	-------
2178	CSII-3	0.5	0.5	7.5	-----	0.2	-------	-------	--------	-------
2179	E56-0	0.0	0.1	0.2	58.8	0.1	7.6	136	--------	2.4
2181	C-7	6.4	1.0	0.7	1.3	0.0	-------	-------	--------	-------
2182	G60-90	0.1	0.0	1.1	0.1	0.0	-------	-------	--------	-------
2183	E60-0	0	0	0	2.3	0	0	918	0	0
2184	E56-3	3.7	0.0	3.7	8.3	-----	-------	-------	--------	-------
2185	G58-1y	16.7	0	0	11.2	0	-------	-------	--------	-------
2186	G64-90	37.5	0.1	0.8	21.9	3.3	-------	-------	--------	-------
2187	G60-1/2y	7.1	0.2	0.9	1.0	0.3	-------	-------	--------	-------
2189	G54-0	0.2	0.1	0.6	5.2	0.0	0.0	54.0	--------	0.5

TABLE A.6 (Continued)

Animal Number	Location-Sacrifice	Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes	Trachea	Stomach	Phar Muc	Nas Muc
2190	G50-3	0	0	0	1.9	0	-------	-------	--------	-------
2191	I61-14	0.6	0.3	2.9	40.8	0.0	-------	-------	--------	-------
2192	C-2y	0.4	0.8	0.6	0	0.5	-------	-------	--------	-------
2193	I57-14	0	0	0	1.7	0	-------	-------	--------	-------
2194	G52-7	1.8	0	0	289	0	-------	-------	--------	-------
2196	I61-0	0.2	0.3	0.8	71.9	0.6	28.3	472	--------	47.5
2199	CSII-3	1.1	0.1	0.5	6.1	0.0	-------	-------	--------	-------
2200	C-1/2y	7.0	0.3	2.3	1.2	0.5	-------	-------	--------	-------
2302	C-0	0	0	0	0	0	0.5	23.9	--------	0
2307	C-0	0	0	0	0	0	0	23.5	0	0
3077	C-2y	1.9	0	0	0.3	0	-------	-------	--------	-------
B(3078)	G54-2 1/2y	0.3	0.1	0.4	0.8	0.2	-------	-------	--------	-------
3079	C-2 1/2y	0.6	0.1	1.1	3.3	0.7	-------	-------	--------	-------
242	C-30	0.2	0.4	0.3	0.4	0.0	-------	-------	--------	-------

TABLE A.7 TOTAL SAMPLE ACTIVITY, DPM (BURROS)

Animal Number	Location-Sacrifice	Left Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes	Right Femur	Trachea	Stomach	Phar Muc	Nas Muc
3000	C-1y	6.8	0	11.7	1270	0	-----	-------	-------	--------	-------
3001	G52-14	0	0	1.8	57.2	0	-----	-------	-------	--------	-------
3002	G56-1/2y	28.8	4.2	17.5	12.6	1.4	-----	-------	-------	--------	-------
3003	I57-7	1.4	0.3	22.0	94.9	47.1	-----	-------	-------	--------	-------
3004	E56-3	16.5	1.1	22.7	42.2	0.5	-----	-------	-------	--------	-------
3005	I61-0	6.8	0.1	17.8	1590	0	0.7	288	1030	1.2	3.8
3006	I61-7	1.2	0.4	8.3	420	0.1	-----	-------	-------	--------	-------
3007(31)	G52-0	0	0	20.8	33.8	0	0	0.8	50.7	3.8	0
3007(26)	E54-14	1.1	0	39.8	188	0	-----	-------	-------	--------	-------
3008	I57-0	1.0	0.2	33.0	172	0.4	0.7	33.7	65.6	2.0	7.6
3010	E58-14	0.6	0.5	3.5	4.9	0.0	-----	------	-------	--------	-------
3011	G64-0	2.1	10.0	42.7	3553	0.1	2.1	1029	1543	396	185
3012	C-14	1.2	0	2.1	0.6	0	-----	-------	-------	--------	-------
3013	E54-14	1.0	3.2	2.9	6.4	0.0	-----	-------	-------	--------	-------
3015	G58-7	1.6	1.8	12.2	70.7	0.2	-----	-------	-------	--------	-------
3017	G58-1y	0	0	11.1	34.4	0	-----	-------	-------	--------	-------
3018	I61-3	-----	0.7	26.0	956	0.0	-----	-------	-------	--------	-------
3019	G58-0	15.3	2.1	22.4	142	1.3	21.9	19.8	422	--------	148
3020	I61-0	1.0	0	6.6	1850	.2	.4	311	1180	61.8	52.0
3021	G50-1/2y	9.8	1.3	35	5.5	0.2	-----	-------	-------	--------	-------
3023	E58-14	1.7	0.1	16.0	16.4	0.4	-----	-------	-------	--------	-------
3025	G62-14	1.4	0	33.3	948	0	-----	-------	-------	--------	-------
3027	G58-1/2y	15	0.8	27.3	42	0.2	-----	-------	-------	--------	-------
3028	G64-1/2y	2.4	0.6	109	120	7.5	-----	-------	-------	--------	-------
3029	I55-0	-----	4.7	68.6	-----	2.5	1.6	1.6	42.9	0.0	2.8
3031	E60-14	1.4	0.2	13.1	8.7	0.0	-----	-------	-------	--------	-------
3032	I59-0	2.5	13.7	66.3	1132	-----	33.8	264	200	58.4	3380
3033	G50-14	0.9	0	14.3	23.1	0	-----	-------	-------	--------	-------
3035	I59-14	1.7	0.0	26.7	409	0.1	-----	-------	-------	--------	-------
3036	E54-3	7.3	0.8	23	3.0	0.1	-----	-------	-------	--------	-------
3037	G56-1y	0	0	3.4	7.0	0	-----	-------	-------	--------	-------
3039	E56-0	0.8	0.0	15.2	128	0.2	0.8	-------	36.2	0.1	174
3040	I59-7	1.2	0.4	11.0	385	0.1	-----	-------	-------	--------	-------
3041	G56-14	2.0	1.3	20.9	31.2	0.0	-----	-------	-------	--------	-------
3042	I55-14	1.4	0	13.6	60.3	0	-----	-------	-------	--------	-------
3043	G64-7	1.7	0.4	46.0	2530	0.6	-----	-------	-------	--------	-------

TABLE A.7 (Continued)

Animal Number	Location-Sacrifice	Left Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes	Right Femur	Trachea	Stomach	Phar Muc	Nas Muc
3045	I59-14	0	0	32.5	1050	0	-----	-------	-------	--------	-------
3049	C-0	325	11.1	87.9	7.8	1.9	-----	-------	-------	--------	-------
3050(18)	C-0	-----	0.8	-----	8.5	3.3	3.7	1.2	1.4	--------	0.4
3050(19)	I61-7	10.7	0.6	26.1	1047	-----	-----	-------	-------	--------	-------
3051	I57-0	1.7	0.1	94.4	247	0.1	1.8	78.5	95.0	--------	11.3
3053	I55-14	1.7	.4	32.4	85.7	0	-----	-------	-------	--------	-------
3055	G64-3	2.0	0.4	74.9	2940	0.5	-----	-------	-------	--------	-------
3057	C-7	9.4	0.8	160	16.3	6.9	-----	-------	-------	--------	-------
3059	I55-3	9.9	0.4	76	24.3	-----	-----	-------	-------	--------	-------
3060	C-1/2y	4.0	8.0	9.0	2.5	0.1	-----	-------	-------	--------	-------
3064	C-3	2.4	0.4	115.6	8.5	0.1	41.5	-------	-------	--------	-------
3065	G62-3	1.6	0.4	96.2	328	1.7	5.1	-------	-------	--------	-------
3066	C-7	17.4	1.6	71.9	7.1	0.2	-----	-------	-------	--------	-------
3067	G52-3	7.4	1.4	11.0	53.8	8.9	-----	-------	-------	--------	-------
3068	I57-3	4.7	0.1	52.5	117.5	0.1	-----	-------	-------	--------	-------
3069	G64-1y	2.2	3.2	72.5	265	3.8	-----	-------	-------	--------	-------
3073	G50-3	5.8	1.1	8.7	7.5	0.2	-----	-------	-------	--------	-------
3074	E58-3	0.5	0.0	15.9	10.3	0.0	-----	-------	-------	--------	-------
3075	E60-7	1.6	4.8	13.5	5.4	0.0	-----	-------	-------	--------	-------
3076	G64-14	0	0	18.3	2390	0	-----	-------	-------	--------	-------
3101	I59-3	1.4	0.6	75.8	1332	-----	-----	-------	-------	--------	-------
3102	G50-7	1.5	8.6	12.6	6.0	0.0	-----	-------	-------	--------	-------
3103	E54-7	299	1.6	59.1	9.2	0.0	-----	-------	-------	--------	-------
3105	I55-3	1.7	0.3	34.0	62.0	0.0	-----	-------	-------	--------	-------
3107	G58-3	15.8	2.3	16.7	31.9	0.0	-----	-------	-------	--------	-------
3108	I55-7	2.6	0.4	81.8	-----	0.2	-----	-------	-------	--------	-------
3109	G58-14	0	0	14.3	52.1	0	-----	-------	-------	--------	-------
3110	I59-3	6.2	0.7	66.3	626	0.0	-----	-------	-------	--------	-------
3111	E56-14	0	10.2	47.0	60.0	0	-----	-------	-------	--------	-------
3113	G56-0	1.9	0.3	59.6	52.8	0.1	1.8	17.4	27.8	0.1	0.2
3118	I57-14	-----	12.2	30.1	599	5.3	-----	-------	-------	--------	-------
3120	I61-14	0.4	1.0	35.6	18.4	0.0	-----	-------	-------	--------	-------
3122	G50-1y	0	0	123	12.8	0	-----	-------	-------	--------	-------
3123	C-14	0	0	2.1	0	0	-----	-------	-------	--------	-------
3125	I57-7	2.2	-------	56.4	110	0.0	-----	-------	-------	--------	-------
3126	E56-7	1.5	0.6	82.2	39.2	0.1	-----	-------	-------	--------	-------
3127	G50-0	14.5	1.0	127	14.3	0.2	13.6	12.7	2.1	1.3	336

TABLE A.7 (Continued)

Animal Number	Location-Sacrifice	Left Femur	Kidneys	Liver	Lungs	Hylar Lymph Nodes	Right Femur	Trachea	Stomach	Phar Muc	Nas Muc
3130	E60-3	8.0	0.1	66	21.6	0.4	-----	-------	-------	--------	-------
3131	G62-0	0	0	77.7	1500	0	2.5	172	7590	451	2.0
3132	C-3	1.6	1.4	81.4	17.8	-----	-----	-------	-------	--------	-------
3133	E58-3	6.3	0.9	0	13.1	0.2	-----	-------	-------	--------	-------
3134	E54-3	1.8	4.5	86.9	7.6	0.8	-----	-------	-------	--------	-------
3135	G52-7	1.1	228	13.1	13.7	0.1	-----	-------	-------	--------	-------
3136	G56-3	36.9	7.7	16.9	36.6	0.0	-----	-------	-------	--------	-------
3137	E60-7	0.9	2.4	15.9	20.0	0.1	-----	-------	-------	--------	-------
3138	E60-0	1.0	0	20.2	23.0	7.3	0.7	72.8	6.0	0	0
3139	C-0	1.0	1.8	24.7	25.1	0.2	0.2	1.0	0.7	0.0	0.4
3140	G62-1y	5.4	1.2	98.9	93.0	5.5	-----	-------	-------	--------	-------
3141	G62-7	4.1	0.8	100	1228	0.8	-----	-------	-------	--------	-------
3143	G62-1/2y	9.0	1.0	144	135	0.7	-----	-------	-------	--------	-------
3144	E56-7	3.9	36.8	56.0	64.2	0.0	-----	-------	-------	--------	-------
3146	E60-0	5.4	1.5	262	96.9	0	1.3	9.0	6.8	1.0	8.8
3147	E58-0	1.1	1.1	25.3	13.5	0.1	1.0	1.4	3.4	2.7	3.4
3148	E54-0	1.0	1.1	25.8	18.1	0.6	20.2	3.6	-------	--------	1.3
3176	E56-0	1.1	1.4	5.9	89.8	0	3.4	2.1	25.1	13.5	2.8
3177	G56-7	3.7	4.6	121	94.7	0.1	-----	-------	-------	--------	-------
3178	C-3	3.4	0.4	81.2	6.8	0.4	2.0	0.2	-------	0.4	0.4
3180	C-14	1.2	0.7	0.0	53.6	0	-----	-------	-------	--------	-------
3199	C-7	1.2	0.6	20.4	1.2	0.1	-----	-------	-------	--------	-------
3200 (AKA 3114)	E58-7	1.1	0.1	12.2	32.6	0.0	-----	-------	-------	--------	-------

TABLE A.8 CASCADE IMPACTOR RESULTS

Sample			Plutonium, dpm, on impactor stages					Total	Pu<10μm		Samp. Rate, 1/min.
Stat.	No.	Animal	1	2	3	4	5		%	dpm	
E-054	9685	Burro	73.0	0.26	0.24	0.13	0.43	74.06	1.5	1.1	17.5
056	9653	Sheep	2016	338	69.4	16.7	15.5	2455.6	16.	393	17.0
056	9687	Burro	1752	228	56.3	14.5	15.7	2066.5	16	331	22.5
058		Dog	Estimated from result obtained at the E058 burro position								
058	9689	Burro	3327	19.8	8.6	2.5	3.2	3361.1	1.0	33.6	22.5
060	9651	Sheep	7270	38.4	4.7	1.1	2.2	7316.4	0.80	58.5	20.
060	9690	Burro	243	26.	6.5	2.8	1.13	279.4	12.	33.5	17.5
G-050	9667	Sheep	27.2	7.3	4.4	1.0	1.07	41.0	28.	11.5	16.
050	9677	Burro	988	24.9	3.8	23.5	0.8	1041.0	4.8	50.	17.5
052	9666	Sheep	561	43.0	26.9	6.4	6.4	643.7	11.	70.8	16.
052	9678	Burro	3010	49.2	16.3	3.2	3.2	3081.9	2.5	77.0	17.5
054	9664	Sheep	1140	157	102	10.3	15.2	1424.5	17.	242	16.
054	9696	Dog	997	110	29.1	11.6	15.0	1162.7	13	151	17.5
054	9627	Dog	863	110	117	86.5	74.3	1250.8	29.	363	22.5
056	9662	Sheep	1444	189	63.2	8.5	11.5	1716.2	13.	223	16.
056	9680	Burro	2710	139	62.4	13.2	17.2	2941.8	8.0	235	22.5
058		Sheep	Estimates from results obtained at the G056 and G060 positions								
058		Burro								255	
060	9626	Sheep	989	110	45.7	69.2	96.7	1310.6	22.	288	22.5
060	9694	Dog	3510	187	87.8	22.5	19.8	3827.1	7.2	276	17.5
062	9657	Sheep	4092	1817	891	168	273	7241.	37.	2680	18.
062	9683	Burro	2600	1610	1300	359	379	6248.	52.	3250	17.5
064	9656	Sheep	7780	4490	1565	607	818	15260.	39.	5950	18.
064	9684	Burro	4230	3520	2530	612	910	11802	50.	5900	17.5
I-055	9647	Burro	603	98.8	48.1	14.0	12.7	776.6	22.	171	22.5
057	9655	Sheep	2330	259	147	33.1	113	2882.1	17.	490	17.
057	9649	Burro	904	679	214	59.5	59.5	1916.	49.	939	22.5
057	9629	Burro	2030	378	165	29.3	125.	2727.3	25.	682	
059	9693	Dog	Estimates from results obtained at the I059 burro position								
059	9675	Burro	1950	917	631	713	211	4422.	53.	2340	22.5
061	9668	Sheep	3750	1340	1211	152	331	6784.	36.	2440	13.
061	9676	Burro	5070	2580	1190	209	298	9347	43.	4020	22.5

TABLE A 9 URINARY EXCRETION DATA, DPM

Days After Exposure	ANIMAL NUMBER AND LOCATION																
	2031 G-064	2036 G-052	2087 G-018	2092 G-060	2111 G-056	2133 G-062	2134 G-060	2157 G-050	2172 G-064	3078 G-054	2057 Cntrl	2097 Cntrl	218 Cntrl	238 Cntrl	241 Cntrl	247 Cntrl	3079 Cntrl
1	18800	23500	15.4	23400	23000	15700	6090	56600	10700	12800	20.0	-					
2	2370	4830	917	4680	5160	2390	6890	1920	4900	4430	12.4	-					
445*	2510	15400	862	1140	6320	4260	12500	7680	2230	4220	10000	73.2					
6	1291	6489	2227	346	3540	1998	1348	4100	1891	625	136	490					
7	1610	7796	737	453	1493	2070	2104	9131	2135	613	300	139					
8	455	181	1460	178	253	1070	197	1670	671	853	46.7	21.5					
34	659	677	559	102	330	162	138	1090	312	0							
35	798	Lost	210	29.6	550	2980	71.2	234	458	1040							
36	523	561	14400	29.3	64.6	712	66.7	4960	199	14.4			4.7/day*	0.6/day*		2.2/day*	
37	25.4	148	207	263	124	635	105	1680	537	66.2							
38	2830	4780	40.6	46.4	2890	741	35.7	89.3	1840	36.0							
97	12.7	Lost	56.0	3.7	64.8	19.0	290	343	19.2	4.2							
98	1.9	7.2	39.6	4.0	9.7	1.4	7.1	6.7	3.3	24.0							
99	1.8	10.8	10.2	1.3	18.2	4.0	9.2	16.6	3.0	9.8					3.0/day*	1.4/day*	
100	14.3	776	9.2	0	111	51.3	0	20.7	21.7	0							
101	1390	2.6	14.1	0.1	388	245	9.8	7.3	672	1.3							
194	4.6	6.2	12.0	3.0	9.7	4.6	3.9	4.5	Lost	5.4							
195	5.2	4.0	2.5	4.2	4.7	6.6	Lost	7.3	30.7	5.2							
196	5.1	4.4	2.5	4.5	5.7	Lost	5.5	18.8	12.3	6.5		5.1/day*				2.8/day*	
197	5.7	2.9	4.0	29.3	4.0	6.7	2.8	2.8	Lost	4.8							
198	1.5	6.5	2.8	3.3	5.5	2.6	2.5	6.9	56.0	4.4							
446	-	1.6	0	-	0.5	-	-	0	-	1.2		0					-
447	-	0	0	-	2.2	-	-	0.9	-	1.7		0					-
448	-	2.6	0.9	-	0	-	-	0.6	-	1.1		1.9					-
449	-	0.9	0	-	1.1	-	-	0	-	3.4		1.2					-
450	-	0	0	-	3.2	-	-	2.1	-	10.9		0.9					-
451	0.8	-	-	0.4	-	0	0	-	0	-		-					0
452	7.2	-	-	9.5	-	11.0	0.5	-	0	-		-					0.4
453	0	-	-	0	-	0	0.7	-	0	-		-					0
454	1.2	-	-	0	-	0	1.3	-	0	-		-					0
455	0	-	-	9.5	-	Lost	0	-	0.4	-		-					0
726	2.0	0.6	3.7	1.5	0	3.0	-	2.7	3.2	1.0							1.3
727	1.6	1.7	0	2.4	1.1	1.3	0.5	1.5	1.9	1.4							-
728	4.3	1.0	6.8	4.9	2.7	1.2	0.5	0	0.9	1.0							2.9
729	3.8	2.0	0	0	2.1	17.1	0	0	2.1	0.7							2.1
730	1.0	0.8	2.7	0	1.2	0.4	0	0.4	3.0	0.5							2.2
908	1.7	2.0	2.5	14	3.0	2.5	2.4	3.7	5.0	2.1							4.4
909	1.3	1.8	2.0	1.9	1.7	1.5	1.3	2.4	1.9	7.0							2.5
910	2.3	3.9	3.0	4.3	3.6	1.6	1.9	1.9	2.1	1.2							1.9
911	2.9	4.4	2.5	2.6	3.0	2.0	1.0	2.4	1.3	1.6							-
912	2.7	1.2	4.6	2.6	2.6	1.5	1.6	2.4	1.5	1.2							

* Combined collection for the period indicated.

TABLE A 10 FECAL EXCRETION DATA, DPM

Days After Exposure	ANIMAL NUMBER AND LOCATION																
	2031 G-064	2036 G-052	2087 G-058	2092 G-060	2111 G-056	2133 G-062	2134 G-050	2157 G-050	2172 G-064	3078 G-054	2057 Cntrl	2097 Cntrl	218 Cntrl	238 Cntrl	241 Cntrl	247 Cntrl	3079 Cntrl
1	1910	963	3670	128	44.5	1110	1640	9110	1390	55.4	1500	-					
2	1420	42.6	1.5	927	118	70.7	11.4	628	1610	3190	11.7	3.2					
445*	4080	1710	3920	1130	304	284	2420	644	499	1570	72.5	12.7					
6	936	6173	481	69.0	20.4	2539	2285	3112	2248	100	144	4.3					
7	5588	4278	136	1027	963	1011	1709	2063	927	90.6	15.3	453					
8	1371	363	1062	868	176	689	59.6	218	719	780	4.6	364					
34 - 38 +	113.2	21.4	95.0	43.2	335	102	Lost	82.8	96.2	Lost			6.8	14.0			
97 - 101 +	36.2	9.5	23.4	5.9	2.8	17.7	356	7.9	10.6	4.8					7.7	23.0	
194 - 198 +	28.0	19.4	12.1	12.3	53.6	5.0	11.2	8.7	10.2	9.0		11.1				12.0	
446 - 450 +	-	8.1	6.6	-	2.7	-	-	7.5	-	6.7		10.0					-
451 - 455 +	1.1	-	-	4.3	-	5.1	8.1	-	9.1	-		-					5.7
726 - 730 +	6.8	0.5	0.1	5.6	10.6	0.6	8.2	6.6	14.0	1.5		2.0					1.6
908 - 912 +	5.6	10.0	4.0	6.0	12.6	5.8	9.4	11.4	4.4	16.0		4.2					10.4

* Combined sample. Total for both days.

\+ Combined five-day sample. Average daily excretion for the period.

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R.H. Wilson, Project Officer, J.L. Terry, Lt Col, USAF VC; University of Rochester, Atomic Energy Project, Rochester, N.Y. 14620

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13. ABSTRACT Dogs, burros, and sheep were allowed to breathe from the cloud generated by the high-explosive detonation of a plutonium-bearing nuclear weapon simulant. No nuclear yield was present in the explosion. Animals were sacrificed serially from H + 1 hour to D + 2½ years to quantitate initial tissue burdens, to establish lung clearance kinetics, and to determine extent of translocation to other organs. Ten dogs and ten sheep were exposed in a similar trial in which more explosive was used and the weapon simulants were housed in a typical earth-covered high-explosive storage magazine, to establish in a limited way if the admixed earth in any way effected the clearance kinetics. Half of those animals were sacrificed on D + 3, the remainder on D + 7.

Initial lung concentrations were shown to be quite closely comparable among the three species if exposed to the same cloud integral of respirable aerosol, and it is proposed that these species in particular and probably other large animals can serve as monitors of exposure if sacrificed soon after an accident.

The presence of large amounts of inert dust in the storage magazine trial resulted in a three-fold reduction in lung burden as compared to the dirt-free trial. This may be conservative, but the scarcity of data and the short duration of this phase of the studies preclude any more precise estimate of the benefit of earth-covered storage. It is believed that the altered clearance kinetics are those of the inert dust for which the plutonium serves as a tracer.

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Deposition and clearance kinetics						
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