UNCLASSIFIED

6245

Defense Documentation Center

Defense Logistics Agency

Cameron Station • Alexandria, Virginia

UNCLASSIFIED

AD A073470

019506

WT-1172

AEC Category: HEALTH AND SAFETY
Military Categories: 5-45 and 5-50

TECHNICAL LIBRARY
of the
DEFENSE NUCLEAR
AGENCY
AUG 7 1974

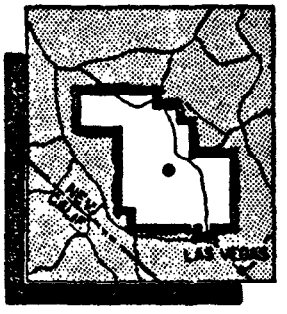
Operation TEAPOT

NEVADA TEST SITE

February – May 1955

Project 37.3

EVALUATION OF THE ACUTE INHALATION HAZARD FROM RADIOACTIVE FALL-OUT MATERIALS BY ANALYSIS OF RESULTS FROM FIELD OPERATIONS AND CONTROLLED INHALATION STUDIES IN THE LABORATORY



Issuance Date: February 28, 1958

CIVIL EFFECTS TEST GROUP

Statement A 6/29/79 NY
Approved for public release;
Distribution unlimited.

79 08 21 042

AD A073470

DDC ACCESSION NUMBER

II

LEVEL

DATA SHEET

PHOTOGRAPH

THIS SHEET

1

INVENTORY

WT-1172

DOCUMENT IDENTIFICATION

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

DISTRIBUTION STATEMENT

Accession For
NTIS GRA&I [X]
DDC TAB [ ]
Unannounced [ ]
Justification
per Doc.
By
Distribution/
Availability Codes
Dist | Avail and/or special
A

DISTRIBUTION STAMP

DDC
RECEIVED
SEP 5 1979
E

DATE ACCESSIONED

79 08 21 042

DATE RECEIVED IN DDC

PHOTOGRAPH THIS COPY

Report to the Test Director

EVALUATION OF THE ACUTE INHALATION HAZARD FROM RADIOACTIVE FALL-OUT MATERIALS BY ANALYSIS OF RESULTS FROM FIELD OPERATIONS AND CONTROLLED INHALATION STUDIES IN THE LABORATORY

By

G. V. Taplin
O. M. Meredith, Jr.
H. Kade

Approved by: K. H. LARSON
Director
Program 37

Approved by: ROBERT L. CORSBIE
Director
Civil Effects Test Group

University of California at Los Angeles
School of Medicine
Atomic Energy Project
Los Angeles, California
June 1957

ABSTRACT

An evaluation of the acute inhalation hazard from radioactive fall-out materials has been made by analysis of results from animal exposures during field operations and from controlled inhalation studies in the laboratory.

Rabbits and rats have been subjected to controlled inhalation exposures to dusts prepared by micropulverizing fused insoluble radioactive siliceous material obtained from Area 3 at the Nevada Test Site, Operation Upshot-Knothole. In these laboratory studies, field conditions were simulated in respect to duration of exposure, particle-size distribution, and levels of air-borne radioactivity involved. The relation between particle size, dust concentration, and duration of exposures to initial deposition in the lungs and gastrointestinal tract has been determined. In addition, the rates of removal have been measured. The laboratory studies demonstrate two important physiological-safety factors against the retention of dangerous quantities of inhaled particulate materials. These are, first, the filtration mechanism of the upper respiratory passages which limits pulmonary retention to particles of small size (below 5.0 μ), and, second, the normal clearance mechanisms of the upper and lower lung passages which remove initially deposited large and small particles at rapid rates.

The results from exposing several groups of rabbits to fall-out material (by inhalation only) at stations located along two arcs, 7 and 106 miles from a tower detonation, are almost entirely negative. Urine specimens obtained during the first day following detonation contained minute but measurable amounts of soluble radioactive material which had a relatively short half life (1 to 2 days). Lung specimens had no detectable radioactivity when measured 6 to 21 days later; however, samples of intestine from the same animals still had measurable levels of beta activity.

The total integrated internal radiation exposure could be expressed in millirep, even at the close stations, where the integrated external gamma-ray exposure was found to be 14 to 32 r. At the 106-mile stations, no measurable radioactivity was present in specimens of lung or urine; however, the levels of radioactivity in intestine samples were either negative or several times lower than those found in animals at the near stations. The external gamma-ray dose was less than 4.0 r.

From careful consideration of numerous pertinent physical and physiological factors and from analysis of field and laboratory investigations, it is evident that there is no apparent situation in nuclear warfare where, during the first few days after the detonation, one could inhale sufficient radioactive material to induce a serious radiation injury to lungs or intestines without simultaneously being subjected to supralethal doses of external beta-gamma radiation.

ACKNOWLEDGMENTS

The authors express their appreciation for the cooperation of, and assistance rendered by, the following groups and individuals:

Kermit H. Larson, Director, Program 37, and Chief, Radio-Ecology Division, Atomic Energy Project, University of California at Los Angeles (UCLA)
Leonard Baurmash, Project Officer, Project 37.2, and Chief, Dust and Fume Section, Industrial Hygiene Division, Atomic Energy Project, UCLA
Robert Lindberg, Project Officer, Project 37.1, and Chief, Biological Field Survey Section, Radio-Ecology Division, Atomic Energy Project, UCLA
Jon Olafson, Chief, Plant Biochemistry Unit, Radio-Ecology Division, Atomic Energy Project, UCLA
Patricia Peel, Lung Transport Section, Pharmacology-Toxicology Division, Atomic Energy Project, UCLA
Rhoda Devick, Lung Transport Section, Pharmacology-Toxicology Division, Atomic Energy Project, UCLA
G. Sprague, Lung Transport Section, Pharmacology-Toxicology Division, Atomic Energy Project, UCLA
Camille Finnegan, Lung Transport Section, Pharmacology-Toxicology Division, Atomic Energy Project, UCLA
Philip Noyes, Lung Transport Section, Pharmacology-Toxicology Division, Atomic Energy Project, UCLA
S. Wayne McFarland, Colorimetric Dosimetry Section, Diversified Problems Division, Atomic Energy Project, UCLA
Arthur Dunn, Lung Transport Section, Pharmacology-Toxicology Division, Atomic Energy Project, UCLA
Louis B. Silverman, Chief, Health Physics Section, Biophysics Division, Atomic Energy Project, UCLA
Richard K. Dickey, Health Physics Section, Biophysics Division, Atomic Energy Project, UCLA
James S. Grevior, M.D., Lung Transport Section, Pharmacology-Toxicology Division, Atomic Energy Project, UCLA
Mary Louise LaNier, Lung Transport Section, Pharmacology-Toxicology Division, Atomic Energy Project, UCLA
Fred A. Bryan, M.D., Professor of Medicine (Industrial), Department of Medicine, Medical Center, UCLA
Harriette Buettner, General Toxicology Section, Pharmacology-Toxicology Division, Atomic Energy Project, UCLA
Thomas J. Haley, Chief, Pharmacology-Toxicology Division, Atomic Energy Project, UCLA

We are indebted to Miss Frances A. Miller, Biophysics Division, and Mrs. Harriet Newton, Pharmacology-Toxicology Division, Atomic Energy Project, UCLA, for the appearance of this report in its final form. For their tireless efforts in typing the manuscript and for their patience and understanding when changes and corrections in assembling this report have been necessary, we are deeply grateful.

CONTENTS

ILLUSTRATIONS

CHAPTER 2 PROCEDURES

ILLUSTRATIONS (Continued)

TABLES

CHAPTER 1

INTRODUCTION

1.1 OBJECTIVES

The purposes of this project were, first, to determine the pulmonary uptake of soluble and insoluble particulate radioactive fall-out material in rabbits from acute inhalation exposures at two test sites along the estimated midline of the fall-out path following a tower detonation and, second, to measure the pulmonary uptake and clearance in rabbits following controlled inhalation exposures (UCLA dust chamber) to 0- to 5.0-μ size particulate material of high-level radioactivity obtained from the Nevada Test Site.

1.2 BACKGROUND

Various dusts have been studied in this laboratory to determine their pulmonary absorption, distribution, and clearance, following single and/or repeated controlled inhalation exposures of rats and rabbits. The materials tested have included soluble agents, such as penicillin,[1] and insoluble particulate materials, such as P^{32}-labeled *B. subtilis* spores,[2] barium sulfate,[3] colloidal prodigiosin dusts,[4,5] and micropulverized radioactive siliceous material[6,7] from the Nevada Test Site having beta-gamma radioactivity of 1×10^6 d/min/g. The latter material was collected from Area 3 near Ground Zero 5 days after a tower detonation in the Upshot-Knothole series, spring 1953.

Results have demonstrated the importance of particle size[8] in initial penetration and retention in the lungs vs the gastrointestinal tract (see Table 1.1), the relation of concentration of dust particles[6] to the rate of pulmonary clearance (see Tables 1.1 and 1.2), and the relation between duration of exposure[7] in hours to the amount of insoluble material initially deposited in the lungs (see Table 1.3). Most important, pulmonary clearance studies[1] have shown that insoluble dusts are removed rapidly upward from the lungs (exponential decline of pulmonary content) and finally leave the body through the gastrointestinal tract (see Table 1.4). Furthermore, insoluble materials are cleared from the lungs more rapidly and efficiently in radiated animals[5] than in control animals owing to increased mucous secretions and phagocytic factors (see Table 1.2). Soluble dusts, such as penicillin, are absorbed within a few hours from mucous membranes of the entire respiratory tract and enter the blood stream.[1] Inhaled sodium penicillin is absorbed and removed from the body at rates similar to those following intramuscular injection[1] of this same material.

The levels of radioactivity over the thyroid gland and in blood and urine samples in human subjects following oral administration of I^{131}-labeled NaI have been reported.[9] Preliminary studies in rabbits have shown agreement with the human data.

The operations of this field project were designed to gain information concerning the biological fate of short-half-lived soluble and insoluble isotopes, especially I^{131}, following acute inhalation exposures to fresh radioactive fall-out materials.

Table 1.1 — RELATION OF PARTICLE SIZE TO ORGAN DEPOSITION OF INHALED RADIOACTIVE SILICEOUS DUST IN FEMALE DUTCH RABBITS*†

Mean particle size of dust,‡ μ	Beta-gamma activity§ above background, d/sec				
	Lungs	Stomach	Small intestine	Caecum	Large intestine
0.47	13.9	47.4	51.6	21.1	7.1
5.00	370.0	2330			
9.00	49.9	7050			

*All values represent the mean from four separate animals exposed simultaneously.

†All animals were given a single 4-hr head exposure to the dust and were sacrificed 0 to 1 hr later.

‡Dust concentration used was 2×10^6 d/min/m^3.

§Values shown for beta-gamma activity were determined from ashed specimens of whole organs.

Table 1.2 — RATE OF REMOVAL OF PRODIGIOSIN DUST* FROM LUNGS OF NORMAL AND X-IRRADIATED RABBITS

Time of determination (after dust exposure), hr	Micrograms of prodigiosin per gram of lung tissue†	
	Normal rabbits	Irradiated rabbits (7 days after 800-r whole-body radiation‡)
0	4.0	5.0
24	1.0	0.15
48	0.6	0.0
72	0.0	0.0

*Density of prodigiosin dust = 1.0.

†Each value represents the mean from six separate animals.

‡250-kvp X-rays having a beam with a half-value layer of 1.93 mm of copper.

Table 1.3 — EFFECTS OF 10-FOLD DIFFERENCES IN DUST CONCENTRATION ON INITIAL PULMONARY RETENTION IN RABBITS FOLLOWING SINGLE INHALATION EXPOSURES OF INCREASED DURATION TO TWO DUST CONCENTRATIONS

Duration of exposures, hr	Total activity in lungs,* d/sec	
	Dust concentration of 2×10^5 d/min/m^3	Dust concentration of 2×10^6 d/min/m^3
1	6.84	118
2	21.6	224
4	39.2	370
8	85.6	402

*Each value for lung radioactivity represents an average from four separate animals exposed simultaneously.

Table 1.4 — PARALLEL RELATION BETWEEN RATES OF PULMONARY AND GASTROINTESTINAL-TRACT CLEARANCE OF RADIOACTIVE SILICEOUS PARTICLES* FOLLOWING A SINGLE 4-HR INHALATION EXPOSURE OF RABBITS

Time of sacrifice, days	Total beta-gamma activity in ashed specimens, d/sec	
	Lungs†	Gastrointestinal tract‡
0	372	2330
2	282	1750
4	106	534
7	55.7	202
28	9.01	40.6
56	4.96	22.7
84	4.35	10.9
112	0.80	21.0

*Density of siliceous material = 2.5.
†Average of four rabbits.
‡Stomach only.

CHAPTER 2

PROCEDURES

2.1 FIELD OPERATIONS

In cooperation with other projects of Program 37, several groups of rabbits were transported to and from predetermined locations on the predicted path of fall-out by members of Project 37.3. Two additional groups of animals were employed for control purposes: One was kept at the laboratory in Mercury; the other was transported to and from the fall-out areas to evaluate the amount of exposure during transport only. The preshot placement of experimental and control groups of rabbits is given in Table 2.1.

At each fall-out station, facilities and equipment for measuring air-borne radioactivity, soil contamination, plant contamination, particle-size distribution, and accumulated external gamma-radiation exposures were provided and operated by Projects 37.1 and 37.2. Chemical dosimeters were supplied by Project 39.6.

Table 2.1 — PRESHOT PLACEMENT OF RABBITS FOR INHALATION EXPOSURES TO FALL-OUT MATERIALS, APPLE II, MAY 5, 1955

Animal group	No. of animals	Approximate distance from Ground Zero	Location*†
MC	1	7-mile arc	At animal quarters
A	4	7-mile arc	0.8 mile west
B	4	7-mile arc	2.6 miles west
C	8	7-mile arc	4.1 miles west
TC	2	7-mile arc	Aboard truck
D	2	106-mile arc	8 miles west
E	2	106-mile arc	0.5 mile east
F	2	106-mile arc	4 miles east
G	2	106-mile arc	8 miles east
H	2	106-mile arc	16 miles east
TC	2	106-mile arc	Aboard truck

*For the 7-mile arc the locations were made with reference to the Mercury highway, Nevada Test Site, along road through Area 2.

†For the 106-mile arc the locations were made with reference to Warm Springs, Nev., along U. S. Highway 6.

2.2 LABORATORY OPERATIONS

A field laboratory and animal quarters were established at Mercury to make observations and measurements on all animals during the initial 72-hr period after inhalation exposures to fall-out materials. Upon return of the animals from the field, the following procedures were performed:

1. Each animal was decontaminated until external levels of gamma radioactivity were reduced to 0.05 mr/hr or less.
2. Bladder urine was expressed manually and collected.
3. Each animal was placed in a separate metabolism cage.
4. External measurements of thyroid gamma-ray activity were made one or more times daily.
5. Urinary excretion was measured, and samples were collected systematically.
6. At 72 hr postexposure, all animals were sacrificed, refrigerated (dry ice), and shipped to the laboratory at the Atomic Energy Project, UCLA, for radioassay of various organs to determine the fate of the inhaled fall-out material.

2.3 INSTRUMENTATION

2.3.1 Inhalation Exposure Equipment

During inhalation exposure to fall-out, all animals were placed in separate restraining boxes designed to permit head exposure only and also to prevent simultaneous ingestion of materials on the ground (see Fig. 2.1). Upon recovery following fall-out exposure, each animal was cleaned superficially and a plastic collar was secured around the neck. The collars were employed to prevent neck injuries during transport and the ingestion of fall-out material contaminating the fur.

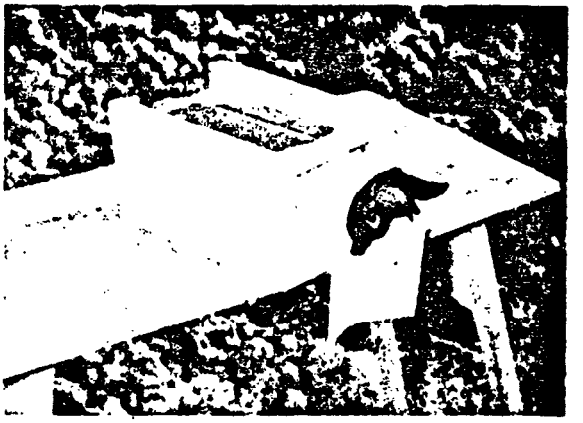


Fig. 2.1—Restraining box for inhalation exposure with shield to prevent ingestion.

2.3.2 Radiation Detection Equipment

A collimated gamma-ray scintillation counter (NaI crystal) connected to a scaler was used to measure gamma radiation externally over the thyroid area (see Fig. 2.2). The sensitivity of this equipment was sufficient to register the presence of as little as 0.003 μc of I^{131} in the thyroid with the procedures employed.

Radioassay of urine samples was made with standard counting equipment, using a 1.4 mg/cm^2 mica window for dried samples. This equipment was provided by Project 37.1, and counting procedures established by this group were employed.[10]

2.3.3 Apparatus for Collection of Urine Specimens

Specially designed individual metabolism cages were employed (see Fig. 2.3).

2.3.4 Counting Equipment for Radioassay of Tissue Specimens

Tissue specimens were weighed, ashed, and assayed in the laboratory at the Atomic Energy Project, UCLA. The probable error of radioassay on samples which contained radioactivity in amounts exceeding twice the background was 5.0 per cent or less. Negative values given in this report are from samples which read definitely less than 1.5 times background, where the probable errors would have been in excess of 20 per cent.

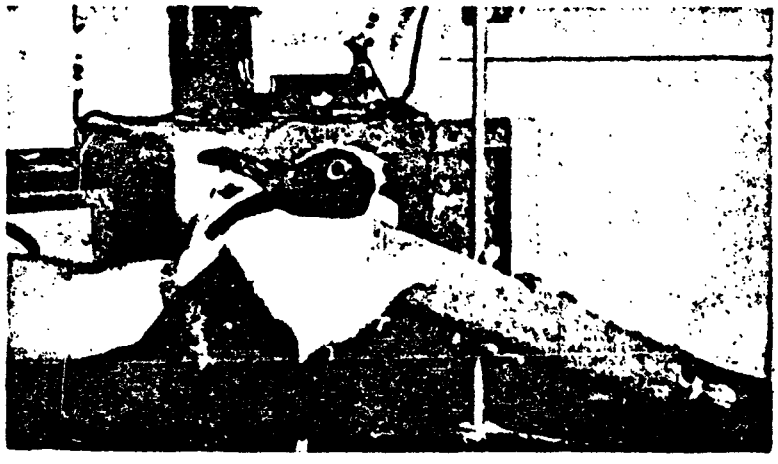


Fig. 2.2— Arrangement of apparatus for measurement of thyroid I^{131} uptake in rabbits.

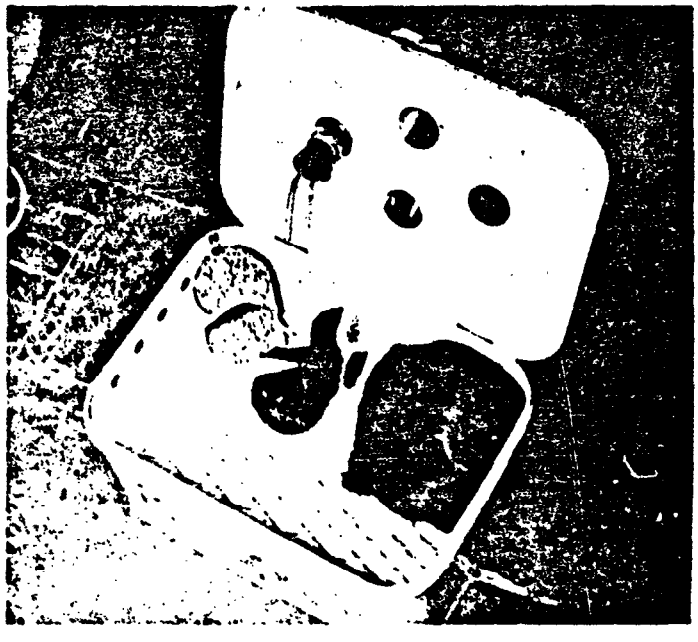


Fig. 2.3— Metabolism cage for postexposure urine and feces collection.

CHAPTER 3

RESULTS

3.1 AIR-BORNE RADIOACTIVITY LEVELS AND GROUND SURFACE CONTAMINATION

Data presented in Table 3.1 show the levels of beta-gamma radioactivity measured at the three stations on the 7-mile arc and at the four stations on the 106-mile arc. These measurements were made by Project 37.2. It is apparent that the major exposure of animals located on the 7-mile arc occurred during a period of about 90 min after the cloud reached the sites. Likewise, at the 106-mile arc, the major exposure occurred during a period of about 90 min immediately after the cloud reached these sites. Although the animals remained under fall-out for about 8 hr, more than 90 per cent of the total inhalation exposure occurred during the first 90 min.

From the values shown for air-borne vs soil contamination, it is evident that most of the radioactivity must have been on large particles which were not drawn into the air samplers. This is the best explanation for the gross differences between levels of activity in the air and on the ground surface.

It is important to note that the percentage of radioactivity present in the 0- to 5.0-μ particle-size range in soil samples is much greater at the distant stations compared with values found at the 7-mile-arc stations. This relation is in accord with theoretical predictions and provides information which clarifies the biological findings.

The values given for mean size of particles found on cascade-impactor samples are based on measurements of radioactivity and standardization of the impactors with material of similar density (2.5) and of known particle-size distribution. Actual measurements of particle size by microscopic methods were not made, nor were the relative numbers of radioactive and nonradioactive particles determined. From the work done by others,[10] it is likely that the majority of particles in the 0- to 5-μ size range found on impactor slides and filters are nonradioactive.

It is important to emphasize that the low levels of radioactive fall-out materials found are probably related to two main factors: (1) The bomb was detonated from a 500-ft tower, and (2) the ground surrounding the tower was paved with asphalt. The combination of these factors could reduce the amount of fall-out considerably.

3.2 THYROID MEASUREMENTS

Animals exposed at the 7- and 106-mile stations were examined three times in the field (H + 33, 53, and 73 hr), using external gamma-ray scintillation-counting techniques similar to those employed clinically for thyroid uptake of I^{131} (see Fig. 3.1). Prior to making such measurements, each animal was decontaminated externally, using a vacuum cleaner. The majority of exposed animals and the restraining boxes were contaminated slightly, to the extent that gamma-ray activity before decontamination registered by a survey meter was 2 to 3 mr/hr (background of 0.05 mr/hr) at H+18 to 30 hr. In general, levels of gamma-ray activity over

Table 3.1—DISTRIBUTION OF ENVIRONMENTAL RADIOACTIVITY AT FALL-OUT EXPOSURE STATIONS, APPLE II, MAY 5, 1955*

Station	Air sampling times, hr after H-hour	Median diameter,† μ	Radioactivity in soil§ mμc/m³,‡ H+12 hr	Radioactivity in soil§ μc/ft², H+12 hr	Radioactivity in soil§ % total activity in 0- to 5-μ particle-size fraction	Integrated external gamma-ray exposures, r Film readings	Integrated external gamma-ray exposures, r Chemical dosimeter readings
			7-mile arc				
A	0.25–1.83		274.0	74.5	0.65	14	<25
	1.83–3.83		6.7				
	3.83–5.83		2.0				
	5.83–7.83		0.07				
	7.83–9.83		0.06				
B	0.20–1.83		637.0	2070.1	0.08	27	25
	1.83–3.83		9.2				
	3.83–5.83		1.8				
	5.83–7.83		0.1				
	7.83–9.83		0.01				
C	0.13–1.83	0.46	175.0	2475.5	0.60	32	25
	1.83–3.83		3.5				
	3.83–5.83		0.9				
	5.83–7.83		0.5				
	7.83–9.83		3.1				
			106-mile arc				
D	2.67–4.33		4.5	5.7		Lost	<10
	4.33–6.33		0.5				
	6.33–8.33		0.02				
	8.33–10.33		0.00				
E	3.25–4.33	3.75	9.0	7.33		1.5	<10
	4.33–6.33		1.1				
	6.33–8.33		0.5				
F	3.08–3.83		0.006	39.6		1.5	<10
	3.83–5.83		16.5				
	5.83–7.83		0.8				
	7.83–9.83		1.2				
G	3.08–4.33	1.5	0.02	19.9	25.8	4.2	<10
	4.33–6.33		109.0				
	6.33–8.33		0.35				
	8.33–10.33		0.48				
H	3.08–4.33		40.2	39.8	6.70	2.4	<10
	4.33–6.33		0.3				
	6.33–8.33		1.8				

*Data supplied by Project 37.2.
†Data calculated from radioactivity measurements.
‡UCLA automatic high-volume air-sampler data.
§Values from fall-out tray data and soil surface samples.

Fig. 3.1—Arrangement of apparatus for measurement of thyroid I^{131} uptake in humans.

the thyroid gland did not exceed background. Three instances of higher levels were subsequently demonstrated to indicate external contamination of the hide, rather than actual thyroid radioactivity, when the glands were removed and assayed in a deep-well scintillation counter.

3.3 DETERMINATIONS OF RADIOACTIVITY IN SAMPLES OF URINE

Animals recovered from both the 7- and 106-mile-arc stations were studied during the first 3 days following head exposure to fall-out. The first urinary collection period was from H+14 to 18 hr, the second was from H+18 to 33 hr, and the third was from H+33 to 53 hr. Samples from the first collection period, from animals at the 7-mile arc, were counted twice: first at H+55 hr and again at H+117 hr.

The values for beta-gamma activity found are presented in Table 3.2. The initial radioactivity levels were so low that, when samples were recounted 3 days later, the values obtained were too low to permit accurate measurements. However, when the values obtained on samples collected immediately after return of the animals to Mercury are corrected for decay and extrapolation is made to H+12 hr, it is seen that small amounts of soluble radioactive materials were present. From the rapid decay rate estimated from recounting these early samples (at 55 and 117 hr), it is possible that I^{133} was involved; however, because of low initial levels, this possibility could not be established with certainty.

All samples from animals exposed at the 106-mile stations were found to have no measurable radioactivity when counted at H+55 hr and later. Thus it is impossible to determine what the actual levels would have been immediately after exposure. However, they were undoubtedly lower than those found in animals exposed at the 7-mile stations.

Table 3.2 — RADIOACTIVITY IN URINE SAMPLES FROM RABBITS EXPOSED TO RADIOACTIVE FALL-OUT, APPLE II, MAY 5, 1955

Animals	Beta-gamma radioactivity levels in urine samples, d/sec (H+14 to 18 hr collection period)		
	5-ml aliquots counted at H+55 hr*	5-ml aliquots counted at H+117 hr*	Total activity in sample at H+12 hr†
A_1-A_4	4.85 (3.12–6.80)	1.84 (1.26–2.51)	1430 (567–3030)
B_1-B_4	5.34 (3.89–6.95)	2.04 (1.37–3.08)	2000 (1112–3120)
C_1-C_9	6.45 (1.56–28.1)	1.55 (0.58–1.96)	1930 (175–9240)
Unexposed animals, 4	0.475 (0.128–0.970)		

*Background counting rate was 1.57 d/sec at H+55 hr and 1.27 d/sec at H+117 hr.
†These values are corrected for decay, using the $t^{-1.2}$ factor.

Table 3.3 — RADIOACTIVITY (BETA-GAMMA) OF TISSUE SPECIMENS FROM ANIMALS EXPOSED TO FALL-OUT MATERIAL BY INHALATION ONLY, APPLE II, MAY 5, 1955

Animal No.	Radioactivity,* mμc/organ		Time of radioassay, days postshot
	Gastrointestinal tract	Caecum	
	7-mile Arc		
A_1	11.10	9.70	6
A_2			7
A_3	7.92	7.08	21
A_4	5.90	7.37	21
B_1	4.37	3.33	8
B_2	8.63	4.64	8
B_3	6.64	12.60	21
B_4			21
C_1	7.59	7.41	18
C_2	4.22	4.57	6
C_3	7.66	5.93	20
C_4			18
C_5			6
C_6	8.59	11.00	11
C_7	2.57	5.87	15
C_8	3.02	2.22	11
T_1			6
T_2			8
	106-mile Arc		
D_1			17
D_2			13
E_1			13
E_2			18
F_1	2.55	3.68	11
F_2	2.60	2.91	8
G_1			13
G_2			8
H_1	4.51	2.98	8
H_2	4.15	4.75	8
TC_1			13
TC_2			20

*These values are expressed with reference to H+72 hr. The $t^{-1.2}$ rule was used for calculation of decay.

3.4 RADIOASSAY OF TISSUE SPECIMENS

Data presented in Table 3.3 show the levels of beta-gamma activity found in ashed samples of gastrointestinal tract and caecum from animals exposed at the 7- and 106-mile stations. Counts were made at different time intervals; but values given have been corrected for decay and self-absorption and have been extrapolated to H + 72 hr, when the animals were sacrificed. Where no values are recorded, the levels were too low to read. It is apparent that a high percentage of animals from the 7-mile stations showed definite, although low, levels of radioactivity in their gastrointestinal tracts, whereas the animals from the 106-mile stations had lower levels with negative results in more than half of the samples.

CHAPTER 4

DISCUSSION AND CONCLUSIONS

4.1 DISCUSSION

The evaluation of the acute hazard from inhaling radioactive fall-out materials following atomic explosions requires careful consideration of numerous physical and physiological phenomena. Among the physical factors the more important are (1) the quantity of radioactive material produced, governed by (a) type of detonation (high altitude, tower, surface, or subsurface) and (b) yield of the weapon, usually expressed as equivalent kilotons of TNT; (2) the inhalability of the radioactive material, dependent upon (a) the mean physical density of the particulate material, (b) the electrical charge on the particles in respect to their tendency to form aggregates or to remain dispersed, and (c) the amount of radioactivity in fall-out particles of the respirable particle-size range (0.1 to 5.0 μ); (3) the duration of exposure as determined by (a) wind speed and direction, (b) distance from Ground Zero, and (c) meteorological "shear" effects; and (4) the effective radiation life span of these inhaled particles as governed by their chemical nature and derivation from (a) mixed fission products and (b) activation of soil, water, or man-made structures at and adjacent to Ground Zero.

The more important physiological factors which are pertinent in evaluating the acute inhalation hazard from fall-out include (1) the filtering effect of the upper respiratory passages in preventing large particles from entering the lungs and (2) the physiological defense mechanisms which are involved in clearance of foreign particles from the respiratory passages. These include the reflex mechanisms of coughing and sneezing, ciliary activity of cells lining the respiratory tree, and the phagocytic action of bronchiolar and alveolar histiocytes. In addition, the dilation of blood vessels in response to irritants results in transudation of fluid to dissolve and remove by absorption any soluble particles and increased mucous secretion to mobilize and float away insolubles.

Before one can state that a certain level of air-borne radioactivity may present a hazard, it is necessary to define what is meant by the term "hazard" and to make a distinction between short- and long-term hazards. Prior to Operation Buster-Jangle (1951), radiological-safety criteria were established by the Jangle Feasibility Committee.[11] The criteria, applying to the inhalation hazard as well as other aspects of radiological safety, were designed to apply to peacetime nuclear weapons testing and not to the more serious situation which could be expected in the event of nuclear warfare. The following limiting values applicable to the inhalation of fall-out material were used: (1) The average air concentration of fall-out particles during the first 24 hr should not exceed 100 $\mu c/m^3$, (2) any portion of that value which is of respirable particle size should not exceed 1 $\mu c/m^3$, and (3) no single particle should exceed 10^{-2} μc measured at H+4 hr. These limiting values were designed to prevent the public from exposure to fall-out which could conceivably result in long-term radiation injury to the lungs and other internal organs. Studies by the Los Alamos off-site air-sampling group[12] made during the Nevada tests in 1951 through 1953 have demonstrated that the amounts of radioactivity in particles found in air samples (cascade-impactor data) are only a few per cent of the ac-

tivity in larger particles collected on fall-out trays at the same sites. The mean size of particles (mean diameter on a weight basis) from such air samples has averaged approximately 30 μ, and few particles have exceeded 50 μ, by optical measurement. Values for radioactivity per cubic meter of air obtained from low- and high-volume air samplers include particles of respirable size (0.1 to 5.0 μ). However, it is apparent that the amount of radioactivity in this small size range is undoubtedly a minute fraction of the activity in the total air sample. Furthermore, studies by the Army Chemical Corps[11] have shown that only one out of approximately each 10,000 particles found in air samples is radioactive. The report by G. M. Dunning,[13] summarizing the results of all continental atomic tests to date, states that in no instance did air-borne contamination exceed 1.3 $\mu c/m^3$ for any 24-hr period and that under such conditions the calculated dose to the lungs would be only 130 mrep. In view of these data, there is an obvious need for establishment of more practical criteria regarding health hazards associated with air-borne contamination.

Thus, from physical considerations alone, it is apparent that the danger from inhaling radioactive fall-out particles in significant amounts during the first few days postdetonation is impossible without simultaneously being subjected to at least 100 times as much external beta-gamma radiation exposure. Actually, the potential acute inhalation hazard is further reduced by the physiological-safety factors previously listed. For example, if one were inhaling air-borne particles in the 0.1- to 50.0-μ size range, the 5- to 50-μ size particles would initially be trapped in the nose and upper respiratory tract. If these particles were insoluble, they would be carried rapidly to the throat, swallowed, and eliminated in the feces within a few days. Furthermore, the great majority (85 to 90 per cent) of 0.1- to 5.0-μ particles would be distributed initially in the trachea, bronchi, and bronchioles. This material retained in the ciliated air passages is removed upward rapidly by ciliary action and likewise swallowed and eliminated in the feces. The 10 to 15 per cent of material deposited in the lung alveoli is also eventually removed by phagocytic action but at much slower rates (weeks to months). These fine particles (0.1 to 2.0 μ), however, account for only a minute fraction of the total inhaled radioactivity. Thus it is apparent, from both physical and physiological considerations, that any possible internal hazard from inhalation in nuclear warfare during the first few days following an atomic explosion would constitute a negligible quantity, percentagewise, when compared with the corresponding external gamma-ray and/or beta-ray exposure during this period.

These conclusions are further substantiated by the results of controlled laboratory inhalation studies, plus the field data presented from head exposures of rabbits to radioactive fall-out material at near (7-mile) and distant (106-mile) stations, as follows:

1. Radioassay of lung specimens from animals exposed (head only) to fall-out at both the 7- and 106-mile stations gave entirely negative results when measurements were made 6 to 21 days later. However, the specimens of intestines in the same animals still showed definite, although small, amounts of radioactivity. From these field data it is not possible to quantitate the relative local hazard to pulmonary vs gastrointestinal tissues; however, the field results showed that the intestinal organs accumulated the bulk of the retained radioactivity, even after inhalation exposures performed in a manner designed to minimize actual ingestion of radioactive materials.

2. The negative findings in thyroid tissue indicate that I^{131} in absorbable form from either the lungs or gastrointestinal tract was not present in significant amounts. However, it is possible that I^{133}, or some other soluble and absorbable isotope, may have been present in the inhaled materials because urine samples collected during the first 24 hr contained measurable amounts of isotopes having a shorter half life than that of mixed fission products.

3. In contrast to these essentially negative findings for internal radiation exposure, the integrated doses of external gamma radiation, to which the animals were exposed simultaneously, were 14 to 32 r at the 7-mile-arc stations and 1.5 to 4.2 r at the 106-mile-arc stations, as measured by both film and chemical methods of dosimetry.

As in the laboratory studies,[14] animals retain far greater amounts (factors of 10 to 150 times) of radioactive particles in the intestinal tracts than are retained in the respiratory organs following an acute inhalation exposure. Under field conditions, where the greatest amount of radioactivity is found in the larger particles, the acute radiation damage from inhalation, if any, is far more likely to involve the intestinal organs than those of the respiration

because the bulk of all initially inhaled insoluble material is sooner or later deposited in the intestines, where it remains for longer periods before being eliminated.[11]

It should be emphasized that these deductions and experimental results in the laboratory were obtained with insoluble radioactive particulate materials. If the radioactive fall-out materials had contained a high percentage of soluble and therefore absorbable substances, the dangers from inhalation could be greater from the physiological standpoint. However, the same physical factors would apply as in the case of insoluble air-borne particles, with the exception that a considerable fraction of the larger particles, trapped in the upper respiratory passages, would be absorbed into the general circulation rather than removed and subsequently excreted in the feces. With soluble particulate materials the local radiation danger to alveolar areas of the lungs would be negligible because of the extreme rapidity of absorption from such surfaces. Likewise, the duration of exposure to the mucous-membrane surfaces of the respiratory passages and mucosal lining of the intestines would be relatively short. The main physiological-safety factor with inhaled soluble particulate materials would be rapid and effective urinary excretion. The danger from inhalation would not be from radiation to the lungs or intestines but rather to the bone marrow and possibly to the kidneys. But again, from physical reasons alone, the danger from external radiation exposure to fall-out of soluble materials also would far exceed that from all the inhaled and the subsequently swallowed particles combined if no protective measures were employed.

This discussion has been limited to an evaluation of the acute inhalation hazard from radioactive fall-out materials under actual field conditions in Nevada and from data obtained in the laboratory, where field conditions were simulated. The authors realize that there may well be considerable danger from repeated long-term (months to years) inhalation and concurrent ingestion exposures to radioactive air-borne particles. Under such conditions one is dealing with long-lived isotopes and must consider the absorption and deposition of microcurie amounts of isotopes such as Sr^{90}, Pu^{239}, Ca^{45}, etc., in the bones or accumulation of particulate materials in the lungs over long periods of time. The present investigations have been limited to short-term experiments designed to study only the acute or short-term aspects of the overall inhalation problem.

Although the primary objective of this project was to evaluate the acute inhalation hazard, it seems apropos, in view of the repeatedly expressed concern[13,15,16] over the potential hazard from retaining a single particle of high activity in the lung and its possible relation to subsequent lung cancer, to reiterate the results of some data, previously published only in UCLA quarterly reports (Reports UCLA-175, 195, 216, and 238), which are pertinent to this problem and also to the long-term inhalation hazard.

First, a controlled experiment was made in 100 rats to investigate possible carcinogenic effects of large-particle retention. Five particles of pure silica, each measuring approximately 1000 μ, were implanted in the left lung through a 15-gauge needle. The next week radioactive particles of similar size and chemical composition (obtained from the site of Trinity shot) were implanted by the same techniques in the right lung of the same animals. The radioactive particles had reached a plateau regarding radioactive decay and were water insoluble. The radioactivity per five particles averaged 25 d/min of alpha rays and 75 d/sec of beta-gamma rays. At monthly intervals beginning 3 months after implantation, groups of 10 rats were sacrificed, and attempts were made to identify the particles on each side. Localization was not possible in nearly 60 per cent; however, in these cases the entire thorax was ashed and counted, and the original amount of beta-gamma radio .ctivity was still present. In a few instances of this type, particles were identified in the pleural space at the base of the lung. The important findings were that (1) there was no evidence, in microscopic sections immediately surrounding the position of the embedded particles, of malignant cellular change and (2) the same foreign body reaction surrounded both radioactive and nonradioactive particles.

It is estimated that the amount of radiation received in the first 15 μ around each particle during the 12-month period was approximately 80 rem, due primarily to alpha radiation. In the next few millimeters the beta dose was estimated at 340 rep. The conclusions from this 1-year study were that the amount of radioactivity used was too little and the time of exposure was too short to induce neoplastic changes in surrounding lung tissue.

A carcinogenic effect to bronchopulmonary tissue probably requires a total dose of at least 2000 rep.[17] Such a dose could hardly be attained locally for the following reasons: (1) Neither particles larger than 20 μ in the pulmonary tree nor particles larger than 5.0 μ in the alveoli[18] have been demonstrated by us; (2) particles between 5.0 and 20 μ have a maximum initial radioactivity at H + 4 hr of about 0.5 mμc, and the $t^{-1.2}$ decay factor reduces this activity by a factor of 100 during the first week and to negligible levels thereafter; (3) particles of 5.0- to 20-μ size in the bronchi are rapidly transported upward by a constantly moving layer of mucus propelled by ciliary action, thereby limiting the duration of exposure at any local area to a maximum period of a few minutes; and (4) the largest particles which may be lodged in the alveoli (up to 5.0 μ) are rapidly engulfed by lung histiocytes.

Some additional work pertinent to the long-term inhalation hazard has been performed and described in UCLA quarterly reports, Reports UCLA-238, 260, and 267. These controlled studies were performed in a large inhalation chamber using both rats and rabbits. The radioactive dust was obtained from an area near a crater following the Buster-Jangle series in 1952. The dust concentration employed was 2.0×10^4 d/min/m^3, and the particles were in the 0.1- to 5.0-μ size range. Animals were given head exposures 6 hr daily, 5 days per week, for a total of 60 exposures. Following each exposure all animals were vacuumed and placed in clean individual cages until reexposed in the chamber. Three series of experiments of this type were made to obtain data on an adequate number (90) of animals. In each series, animals of both types were sacrificed after 10, 20, 30, and 60 days to determine accumulated pulmonary deposition and fate of inhaled material in all major organs, including bone. In addition, lung clearance studies were made on alternate animals by assaying ashed organ specimens after increasing times following completion of a given number of inhalation exposures.

Briefly, the major results of these studies showed that (1) the amount of pulmonary retention of radioactive particles increased with the numbers of daily exposures up to 20 days and then remained nearly stationary; (2) the amounts of beta-gamma radioactivity per lung never exceeded 17 d/sec; (3) clearance from the lungs following repeated exposure was rapid during the first few weeks and became slower thereafter; however, about 70 per cent clearance was attained in 60 days; and (4) because of the low water solubility (1 per cent) of the material and the minute amount retained in the lungs and intestines, values for radioactivity in other organs, including bone, seldom exceeded twice the background. The type of material, air concentration, and particle-size range should have given maximum lung retention, and these conditions simulated in many ways the worst conditions one might expect during a 3-month period after a near surface detonation of a nominal weapon in a semiarid area such as the Nevada Test Site.

Even under these conditions the amounts of radiation exposure to lungs and other organs did not approach levels which could cause detectable physiological changes and were less than 0.0001 of the minimum doses which have been shown to induce acute radiation pneumonitis (2000 to 3000 rep).[19]

Furthermore, these studies demonstrated the efficiency of the respiratory organs in respect to their capacity to remove inhaled foreign particulate materials at a rate almost equal to the rate of deposition from continuing inhalation exposures. Extrapolation from the very gradual accumulation of particulate material in the lungs indicates that retention of physiologically significant quantities of such particles might be attained if similar daily exposures were made for several years. These findings and estimates are in accord with the long periods (5 to 20 years) of exposure required to induce silicosis and other pneumoconioses in man.

In a comprehensive summary and evaluation of the acute and chronic effects of radioactive particles on the pulmonary tract, the conclusions[20] are:

1. The acute external beta-gamma radiation hazard is many times greater than that from inhalation, and an additional safety factor for the lung (of perhaps 10) is represented by the respiratory tract clearance mechanisms.

2. In industrial or research work with nuclear reactors and radioisotopes, situations may occur wherein relatively small numbers of people may receive significant radiation exposure to parts of the respiratory system from inhaling radioactive particles containing long-lived isotopes of high specific activity, without simultaneously exceeding tolerance levels for whole-body exposure.

3. Little information is available on the potential hazard to the respiratory system and other organs following chronic exposure to small amounts of long-lived radioisotopes such as Sr^{90} and Pu^{239}. The occurrence of epidermoid carcinoma in the lungs of mice after exposure to plutonium particles suggests that accumulations of such materials may present a similar hazard to man.

Finally, the results of thorough studies of animals and humans accidentally exposed to radiation from fall-out during the Pacific field tests in the spring of 1954 demonstrate[21] that:

1. External gamma radiation is by far the most serious hazard in the fall-out area.

2. Beta radiation of the skin can be a problem even in the absence of lethal doses of associated gamma-radiation exposure.

3. Some degree of internal contamination will occur in persons exposed to fall-out, but the amounts deposited in the body will be relatively small. It appears certain that no contribution to the acute medical picture will result from this cause and furthermore that, although data are incomplete, little or no long-term hazard is likely, particularly if reasonable precautions are taken to avoid excessive inhalation and ingestion of contaminated materials during and after the fall-out period.

4.2 CONCLUSIONS

From careful analysis of field studies made following the Apple II tower detonation and from extensive inhalation studies performed during the past 6 years in the laboratories of the Atomic Energy Project, UCLA, six important conclusions have been reached regarding the possible acute hazard from inhaling radioactive fall-out materials:

1. There is no apparent situation in nuclear warfare in which it would be possible, during the first few days following a detonation, to inhale amounts of fall-out materials sufficient to cause acute radiation injury to the lungs or intestinal tract without simultaneously receiving supralethal external doses of beta-gamma radiation.

2. From consideration of physical factors alone (such as strength and type of detonation, particle-size distribution, decay rates, meteorological conditions, air-borne radioactivity levels, and percentage of radioactivity in the 0.1- to 5.0-μ size range), the acute external beta-gamma radiation hazard is at least 1000 times greater than that from inhalation.

3. When physiological phenomena are also considered, the defense mechanisms of the respiratory organs effectively reduce the pulmonary hazard by at least another factor of 10.

4. The possibility of inducing bronchial or pulmonary carcinoma by the inhalation and long-term retention of a single radioactive particle (20 μ in size) appears remote on the basis of both physical and physiological considerations.

5. From the results of repeated (60) 6-hr inhalation exposures of rats and rabbits to radioactive insoluble particles (0.1 to 5.0 μ) under controlled conditions in the laboratory, it is estimated that, because of lung clearance mechanisms, similar daily exposures would have to be continued for 5 to 20 years in order to accumulate sufficient quantities of such materials to induce pathological lesions in the lungs.

6. Under field conditions and in laboratory studies designed to permit acute exposure by inhalation, and to prevent simultaneous ingestion of radioactive fall-out particulate materials, the radiation exposure to the intestinal organs exceeded that to the organs of respiration by factors of 10 to 150. Direct ingestion of such materials would further increase the intestinal and internal hazard.

4.3 RECOMMENDATIONS

In future investigations emphasis should be shifted to the long-term (years) pulmonary neoplastic effects from acute and chronic inhalation exposure to long-lived alpha-emitting radioisotopes, especially Pu^{239}, and to the chronic effects in the intestines and bones from acute and chronic ingestion of Sr^{90} and Pu^{239}.

REFERENCES

1. G. V. Taplin, F. A. Bryan, L. Baurmash, W. W. Greene, E. Hayes, W. Ralston, and W. Adolph, Relation of Particle Size to Inhalation Therapy with Micropulverized Penicillin Preparations, Ann. West. Med. Surg., 4: 383 (1950).
2. G. V. Taplin, J. S. Grevior, M. L. Gautschi, and C. Finnegan, Pulmonary Distribution of Radioactive Particles in Rabbits After Inhalation and Intravenous Injection, Ann. Allergy, 9: 703 (1951).
3. G. V. Taplin, J. S. Grevior, and H. Drusch, Pulmonary Penetration of Fine Particles Administered by Intratracheal Insufflation and Inhalation, Ann. West. Med. Surg., 4: 391 (1950).
4. G. V. Taplin, J. S. Grevior, C. Finnegan, and A. Dunn, Clearance of Prodigiosin Dust from the Respiratory Tract of Normal and X-irradiated Rabbits, Ann. Allergy, 10: 397 (1952).
5. G. V. Taplin, J. S. Grevior, C. Finnegan, A. Dunn, and P. Noyes, Further Studies of the Mechanism of Pulmonary Clearance of Prodigiosin in Normal and Irradiated Rabbits, Ann. Allergy, 11: 1 (1953).
6. G. V. Taplin, O. M. Meredith, H. Kade, C. Finnegan, and R. Devick, The Effect of Particle Size on Pulmonary Absorption and Distribution, Report UCLA-297, p. 36, 1954.
7. G. V. Taplin, O. M. Meredith, H. Kade, C. Finnegan, and R. Devick, The Effect of Ciliary Action on Pulmonary Absorption and Distribution, Report UCLA-297, p. 38, 1954.
8. G. V. Taplin, O. M. Meredith, H. Kade, C Finnegan, and M. C. Langford, The Effect of Particle Size on Pulmonary Absorption a Distribution, Report UCLA-286, p. 33, 1954.
9. E. T. Feldstad, The Diagnostic Use of Radioiodine . .cer-vial Solution, Radiocaps, RISA, Nachromate, Abbott Laboratories, Chicago, 1954.
10. R. G. Lindberg, E. M. Romney, Jon H. Olafson, and K. H. Larson, The Factors Influencing the Biological Fate and Persistence of Radioactive Fall-out, Project 37.1 Report, ITR-1177, 1955 (to be superseded by WT-1177).
11. Charles Robbins, Hugh R. Lehman, David R. Powers, and James D. Wilcox, Airborne Particle Studies, Project 2.5a-1 Report, WT-392, July 1952.
12. C. P. Skillern, W. S. Johnson, and H. F. Schulte, Some Observations on Air Sampling Techniques Used at the Nevada Proving Ground, Report LA-1685, June 1954.
13. Gordon M. Dunning, Discussion of Radiological Safety Criteria and Procedure for Public Protection at the Nevada Test Site, AEC Report WASH-290, February 1955.
14. George V. Taplin, Orsell M. Meredith, Jr., Harold Kade, Camille Finnegan, and Margaret C. Langford, The Effect of Particle Size on Pulmonary Absorption and Distribution, Report UCLA-276, p. 41, Jan. 10, 1954.
15. Robert G. Lindberg, James T. Scanlan, James C. Watson, William A. Rhoads, and Kermit H. Larson, Environmental and Biological Fate of Fall-out from Nuclear Detonations in Areas Adjacent to the Nevada Proving Grounds, Project 27.2 Report, WT-812, February 1954.
16. Falconer Smith, D. W. Boddy, and Marvin Goldman, Biological Injury from Particle Inhalation, Project 2.7 Report, WT-396, June 18, 1955.
17. E. Lorenz et al., J. Natl. Cancer Inst., 6: 349 (1945).
18. George V. Taplin, Orsell M. Meredith, Jr., Camille Finnegan, Philip Noyes, Gerald Sprague, and Margaret C. Langford, The Effect of Particle Size on Pulmonary Absorption and Distribution, Report UCLA-267, p. 22, Oct. 10, 1953.

19. National Academy of Sciences – National Research Council, Pathological Effects of Atomic Radiation, Publication 452, III-13, 1956.
20. National Academy of Sciences – National Research Council, Pathological Effects of Atomic Radiation, Publication 452, III-15, 1956.
21. E. P. Cronkite, V. P. Bond, and C. L. Dunham, Some Effects of Ionizing Radiation on Human Beings, Report TID-5358, p. 105, July 1956. (For sale by Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.