AD A 995 184

WT-743 (EX)
EXTRACTED VERSION

OPERATION UPSHOT-KNOTHOLE

Project 4.1
The Radiation Hazards to Personnel Within an Atomic Cloud

AD A995184

Nevada Proving Grounds
March–June 1953

Headquarters Field Command
Armed Forces Special Weapons Project
Sandia Base
Albuquerque, New Mexico

NOTICE

This is an extract of WT-743, which remains classified SECRET/RESTRICTED DATA as of this date.

Extract Version Prepared for:

Director
DEFENSE NUCLEAR AGENCY
Washington, DC 20305

1 AUGUST 1983

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: WT-743 (EX)	2. GOVT ACCESSION NO.: AD-A995 184
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): OPERATION UPSHOT-KNOTHOLE Project 4.1, The Radiation Hazards to Personnel Within an Atomic Cloud	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER: WT-743 (EX)
7. AUTHOR(s): Wright H. Langham; LASL, E. C. Anderson, LASL; Paul M. Crumley, Capt., USAF; Payne S. Harris, Maj.; Ernest A. Pinson, Lt. Col., USAF	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Air Force Cambridge Research Center Cambridge, Massachusetts	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: HQ Field Command Armed Forces Special Weapons Project Sandia Base, Albuquerque, New Mexico	12. REPORT DATE: December 1953
	13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; unlimited distribution.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This report has had the classified information removed and has been republished in unclassified form for public release. This work was performed by Kaman Tempo under contract DNA001-79-C-0455 with the close cooperation of the Classification Management Division of the Defense Nuclear Agency.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Operation UPSHOT-KNOTHOLE
Radiation Hazards

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Experiments on Shots 4 and 9 were conducted to determine the magnitude of the hazards associated with flight through the head of an atomic cloud a few minutes after detonation. The total gamma radiation dose and the dose rate were measured by various integrating dosimeters and ionization chambers carried through the cloud by parachute-borne canisters and in QF-80 drone aircraft. The internal radiation dose from inhalation of fission products was evaluated from Zr^{97} and Mo^{99} analyses of tissues of mice and monkeys flown through the cloud. Measuring devices were utilized on and in the drones to measure temperature and pressure conditions.

FOREWORD

This report has had classified material removed in order to make the information available on an unclassified, open publication basis, to any interested parties. This effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is all currently classified as Restricted Data or Formerly Restricted Data under the provision of the Atomic Energy Act of 1954, (as amended) or is National Security Information.

This report has been reproduced directly from available copies of the original material. The locations from which material has been deleted is generally obvious by the spacings and "holes" in the text. Thus the context of the material deleted is identified to assist the reader in the determination of whether the deleted information is germane to his study.

It is the belief of the individuals who have participated in preparing this report by deleting the classified material and of the Defense Nuclear Agency that the report accurately portrays the contents of the original and that the deleted material is of little or no significance to studies into the amounts or types of radiation received by any individuals during the atmospheric nuclear test program.

ABSTRACT

Experiments on Shots 4 and 9 were conducted to determine the magnitude of the hazards associated with flight through the head of an atomic cloud a few minutes after detonation. The total gamma radiation dose and the dose rate were measured by various integrating dosimeters and ionization chambers carried through the cloud by parachute-borne canisters and in QF-80 drone aircraft. The internal radiation dose from inhalation of fission products was evaluated from Zr^{97} and Mo^{99} analyses of tissues of mice and monkeys flown through the cloud inside a sealed compartment pressurized to 5 psi above ambient pressure by the ventilating system of the drone aircraft. Temperature tapes and a pressure measuring device were utilized on and in the drones to measure temperature and pressure conditions encountered during cloud passage.

Results showed that dose rates of from 38,000 to 7500 /hr were encountered in the clouds 2.7 to 5.2 min after detonation. The average dose rates observed (including previous data from Operation GREENHOUSE) may be represented by the equation

$$\bar{D} = 1.31 \times 10^5 t^{-2.06}$$

where $\bar{D}$ is in r/hr and t is the time of cloud penetration expressed in minutes. This equation is applicable from 2.7 to 25 min after detonation.

The integrated external gamma radiation dose varied from 5.7 to 200 r depending on the time of penetration, the rate of travel through the radiation field and the section of the radiation field traversed. The experimental results support the conclusion that less than 50 r of external gamma radiation may be received by a flight crew flying through the head of an atomic cloud from detonations of 30 KT or less provided time of entry is not earlier than 4 min and the aircraft is traveling at a speed of 400 knots or greater.

The internal radiation hazard resulting from the inhalation of fission products and unfissioned Pu^{239} and U^{235} during cloud passage appeared to be entirely insignificant compared to the integrated external dose received. The ratio of the internal to external radiation hazard was about 1/100 and was predicted, on the basis of theory, to be independent of bomb yield.

Indications were that no significantly high temperatures or pressure changes were encountered in the cloud at the times of drone passage.

Page 4 - Blank

FOREWORD

This report is one of the reports presenting the results of the 78 projects participating in the Military Effects Tests Program of Operation UPSHOT-KNOTHOLE, which included 11 test detonations. For readers interested in other pertinent test information, reference is made to WT-782, Summary Report of the Technical Director, Military Effects Program. This summary report includes the following information of possible general interest.

a. An over-all description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the 11 shots.

b. Compilation and correlation of all project results on the basic measurements of blast and shock, thermal radiation, and nuclear radiation.

c. Compilation and correlation of the various project results on weapons effects.

d. A summary of each project, including objectives and results.

e. A complete listing of all reports covering the Military Effects Tests Program.

Page 6 - Blank

ACKNOWLEDGMENTS

The authors wish to acknowledge the technical assistance of a large number of persons who contributed to the success of Project 4.1.

The following members of the Air Force Cambridge Research Center contributed materially to implementation of the program, chemical analyses of samples or execution of general or specific parts of the project: K. C. Kaericher, Capt., USAF; D. B. Williams, Maj., USAF; Dr. J. F. Spalding; Miss Ann Meagher; M/Sgt J. W. Mauget; T/Sgt E. J. Young; T/Sgt J. D. Dodman, and M/Sgt R. C. Ernst.

The following members of the Naval Air Development Center aided the program greatly by modifying the telemetering canisters and allied electronic equipment and by providing technical advice and services: Mr. E. J. Caris and Mr. C. W. Fay.

The following members of the USAF School of Aviation Medicine rendered valuable assistance in the execution of the project by handling the monkeys used in the experiment, and by giving advice and help during the operational phases of the project: H. M. Sweeney, Col., USAF; John Pickering, Lt Col, USAF; Dr. Sylvan J. Kaplan, and Walter Rambach, Lt., USAF.

Dr. R. W. Spence and Mr. James Gilmore of J-11, LASL, provided important help with the methods of analysis and the interpretation of results. Dr. Harold Plank and Mr. Philip Moore also of J-11, LASL, were responsible for the pressure measurements in the cloud.

The following Staff Members of Group H-4, LASL, either participated in the operational phases of the program or contributed materially by carrying out the radiochemical analyses: Dr. John Storer; Mr. Ogden Johnson; Mr. John Furchner; Samuel Rothermel, Maj., MC, USA; Dr. Gordon Gould; Dr. Irene Boone; Dr. Harry Foreman; Dr. Marion Vier; Dr. C. C. Lushbaugh; Mr. James Perrings, and others.

Considerable credit is due the following organizations for providing equipment, personnel and operational support.

Group H-4, Health Division, Los Alamos Scientific Laboratory, Los Alamos, N. M.

The 3205th Drone Group, Eglin AFB, Fla., which provided, maintained, and operated the QF-80 drone aircraft that penetrated the cloud.

The Naval Air Development Center, Johnsville, Pa., which provided the canisters and extensive supporting equipment.

The 4925th Test Group, Kirtland AFB, N. M., which provided the aircraft and operating crews that dropped the canisters.

The USAF School of Aviation Medicine, Randolph AFB, Texas, which provided the monkeys used in the experiment.

CONTENTS

ILLUSTRATIONS

Page 12 - Blank

TABLES

 Page 14 - Blank.

CHAPTER 1

OBJECTIVE

The general objective of Project 4.1 was to define and evaluate the magnitude and importance of the various potential hazards to which a flight crew would be exposed on flying through the head of the mushroom-shaped cloud formed by the detonation of an atomic weapon. This information is an essential element of operational planning to assure, as far as possible, the safety of air crews in the execution of atomic warfare. Thus, the parameters of the experimental conditions for Project 4.1 were adjusted, where possible, to simulate the worst conditions to be expected in the event of an atomic cloud penetration on a bombing mission. The parameters required were as follows: 1) penetration of the head or mushroom of the cloud, 2) penetration within a few minutes after detonation, and 3) penetration at about 25,000 ft mean sea level (MSL) or higher.

The potential hazards investigated were external gamma radiation dose and dose rate, internal radiation dose due to inhalation of fission products, maximum or peak temperature inside the cloud, and the pressure changes encountered during penetration.

In order to evaluate the above hazards the specific objectives of the operation were as follows: 1) measurement of the external gamma radiation intensity, 2) measurement of the integrated external gamma radiation dose during cloud passage, 3) determination of the fraction of the fission cloud deposited in the lungs of mice and monkeys from inhalation, 4) determination of the peak temperature of the skin of aircraft, and 5) measurement of pressure changes encountered by the drones during penetration.

CHAPTER 2

BACKGROUND AND THEORY

2.1 EXTERNAL GAMMA RADIATION INTENSITY

During Operation SANDSTONE Scoville, Cody, and King (14) first attempted to estimate the dose rate in an atomic cloud from film badge results and cloud transit time of B-17 drone aircraft. They concluded that at 7 min after detonation the average dose rate within the aircraft passing through the mushroom head was of the order of 50,000 r/hr. A more specific attempt to measure the radiation intensity as a function of time after detonation was made at Operation GREENHOUSE by Koch (10) using the logarithmic recording ion chambers used in the present study. At times of about 4 min after detonation he found average gamma intensities inside droned B-17 aircraft of about 10^4 r/hr. At times of about 10 min he found the average rates to be about 10^3 r/hr. Measurements were made at penetration altitudes ranging from 16,000 to 30,000 ft. No particular correlation with altitude of penetration or bomb yield was found. The variation with time of entry, however, was very pronounced as expected from the decay of fission products and the expansion of the cloud. As the detonations during GREENHOUSE were relatively high in yield it was not possible to intercept the head of the cloud, therefore, all measurements were made in the stem. The wide discrepancy between the results of Koch and of Scoville, Cody, and King given above is not clear other than to say that the results of Scoville et al were admittedly subject to considerable uncertainty.

The gamma radiation intensity within an atomic cloud has received theoretical consideration by Gallentine, (6) Cohen and Plessett, (4) Teresi, (17) Landahl, (11) Alaoglu (2) and others. The outstanding feature of many of these calculations is the very high gamma intensities encountered at very early times and comparatively low altitudes, due to the small cloud size and the high fission product activity.

2.2 INTEGRATED EXTERNAL GAMMA RADIATION DOSE

The first attempt to measure the integrated gamma radiation hazard of flying through an atomic cloud was that of Scoville, Cody, and King (14) mentioned earlier. They concluded that the radiation dose to (B-17) aircraft personnel would be less than the LD-50 but might, under some conditions, be several hundred roentgens (r). In shots X-Ray and Yoke the integrated doses inside the B-17 drones were in general found to be less than 400 r, while in shot Zebra where several of the planes passed through the head of the cloud, exposures of greater than 400 r were obtained. Interpretation of these results in terms of the hazard to flight personnel was complicated by the fact that the planes made multiple passes through the cloud and it was not possible to draw any conclusions as to the relative importance of each pass.

Koch (10) obtained rather reliable estimates of total radiation dose by integrating the rate meter results obtained during GREENHOUSE. The highest total dose obtained on a single pass through the cloud was 117 r while the average for all measurements on the first pass at about 4 min after detonation was 41 r. All measurements were made through the stem of the cloud. The ionization chamber results were about twice the readings obtained on NBS film badges. While the average energy of the radiation may not be as low as the 200 kev concluded by Koch, the difference in energy dependence of these two methods of measurement would lead one to expect the ionization chamber to give higher doses than those obtained with NBS film badges.

A biological measurement of the total gamma radiation dose was made at GREENHOUSE by the Biomedical Group, Los Alamos Scientific Laboratory (LASL).(1) The quantitative relationship between thymus weight loss of the mouse and radiation dose gave integrated dose values that ranged from 75 to 190 r. Although the radiation doses were very near the limit of sensitivity of the method the measurements agreed in general with those reported by Koch. The biological results were somewhat higher (up to a factor of 2) than NBS film badge readings indicating that the average energy of the gamma radiation is quite low, a conclusion also reached by Koch. The mice could be flown only at altitudes of 20,000 ft or lower; therefore, because of the kilotonnages and times of passage, penetration was made through the stem of the mushroom only.

The results derived theoretically (4,11,17) agree generally with the experimental values for the few cases where comparison is possible. No concerted effort has been made either to obtain data under the conditions of the predictions or to make predictions for the conditions that have been studied.

2.3 INTERNAL HAZARD FROM INHALATION OF FISSION PRODUCTS

The theoretical reports mentioned in paragraph 2.2 have given some attention to the possible importance of the hazard resulting from the inhalation of fission products during flight through the cloud. Some authors (11,17) have concluded the hazard to be negligible while others (4) have greatly over-emphasized its possible importance. The first experimental data on this point were obtained at GREENHOUSE using mice.(1)

The evaluation of the results was complicated by a large amount of ingested activity as a result of the mice licking their contaminated fur. In spite of the uncertainty in the magnitude of the uptake by ingestion, the total amount of fission products found inside the mice was so small as to indicate that the internal hazard was negligible compared with the external gamma dose. This observation is in agreement with the theoretical conclusion reached by Teresi (17) and Landahl.(11)

Because of the complication created by ingestion and because of the difficulty in the extrapolation of results from mouse to man, it was decided to repeat the studies using both mice and monkeys. It was also hoped that exposures could be made in the head of the cloud rather than in the stem.

CHAPTER 3

INSTRUMENTATION

3.1 EXTERNAL GAMMA RADIATION INTENSITY

Two different methods were used to determine the gamma radiation dose rate in the cloud. The first method was to drop canisters, containing ionization chambers with amplifiers and telemetering equipment, vertically through the cloud. The second method, previously used during GREENHOUSE, was to place recording dose rate meters in droned F-80 aircraft which were flown horizontally through the radiation field.

3.1.1 Instrumentation of Parachute-borne Canisters

The basic equipment used to make gamma intensity measurements vertically through the cloud consisted of a droppable detector-transmitter unit AN/USQ-1 and a VHF radio receiver AN/ARR-29. The droppable package was composed essentially of an ionization chamber connected to a VHF transmitter by a linear amplifier covering the range 0-100,000 r/hr and modulating circuits, a mechanical timer, power source, external heater, parachute assembly, and an externally mounted film pack. The receiver was a wide-band VHF type designed for the 160 megacycle range. A detailed description of this equipment in its original form, including allied equipment and operating characteristics, is given in JANGLE Report WT-370.(3) The following modifications were made to adapt the JANGLE radiac equipment to the requirements of Project 4.1, UPSHOT-KNOTHOLE:

1) The maximum gamma intensity range of the AN/USQ-1 was increased to 100,000 r/hr and the units calibrated in this range.

2) The AN/ARR-29 VHF receivers were peaked and directional antennas were adapted to the receivers to increase the telemetering range to give a readable signal at 15 miles.

3) The mechanical timer inside the AN/USQ-1 was modified to turn the unit off after 4 min of operation to prevent interference with the group of canisters released at a later time.

4) Operation of the beacon channel circuitry was eliminated.

5) The AN/USQ-1 was equipped with an external heater and suitable insulation to provide proper operating temperatures at high altitude.

6) The air brake device used in low speed launchings was replaced with a specially designed parachute and suspension cradle arrangement to permit releases at high speed.

7) An arrangement for remotely turning on the unit as it was released from the aircraft was provided.

8) A timing system was incorporated in the recorder.

The modified AN/USQ-1 units were calibrated against a 208 curie Co^{60} source over a range of intensities from zero up to about 47,000 r/hr. For each intensity the shift in frequency of the transmitted signal caused by the introduction of the radiation flux was measured. This gave a curve of radiation intensity versus frequency shift for each unit. Application of these laboratory-prepared curves to the frequency shift produced during penetration of the cloud gave the intensity of radiation in the cloud.

In order to subtract the transmitter shift due to internal heating of the unit immediately after being turned on, several records were made in the laboratory under no-radiation conditions. An average of these results for each unit was then applied to the records taken in the field.

Operational procedures required the droppable units to remain in unheated bomb bays at high altitudes for extended periods. This would have caused the batteries and electronic components to cool below minimum operation temperatures. External heaters surrounded by insulation provided an acceptable solution to the problem. The essential features of heaters and insulation are shown in Figs. 3.1 and 3.2. This assembly consisted of a thermostat and small wire heating element which was wound in a spiral around the outside of the canister shell. The heating element was covered with an adhesive tape which in turn was covered with insulating material. Power to the heater was supplied from the airplane's electrical system through a quick disconnect which released when the weight of the canister was exerted on the connecting wires. This arrangement essentially reduced the temperature gradient of the canister surface to zero and retained ground level temperatures inside the canisters during flight. The insulation prevented the interior of the canister from cooling below the minimum operating temperature during descent.

Tests during JANGLE showed that the air brake device on the AN/USQ-1 was not suitable for launching at speeds much greater than 150 knots nor from a standard bomb release. Either of these objections would cause the brake to be unacceptable for use, therefore, a completely new device was developed to give the desired rate of fall and stability, with the added requirement that it permit the AN/USQ-1 to be released in flight from the standard bomb system of an aircraft traveling at 450 knots.

The Parachute Branch of the Wright Air Development Center provided the assembly shown in Fig. 3.2 which met all of the above requirements. A 26 lb lead nose was attached to the bottom end of the AN/USQ-1 to assist its separation from the airplane immediately on release. The harness arrangement provided a convenient means of attaching the parachute to the canister and for holding the D-rings used to suspend the unit from a standard bomb shackle. The parachute riser pulled the arming pin for remotely starting the unit.

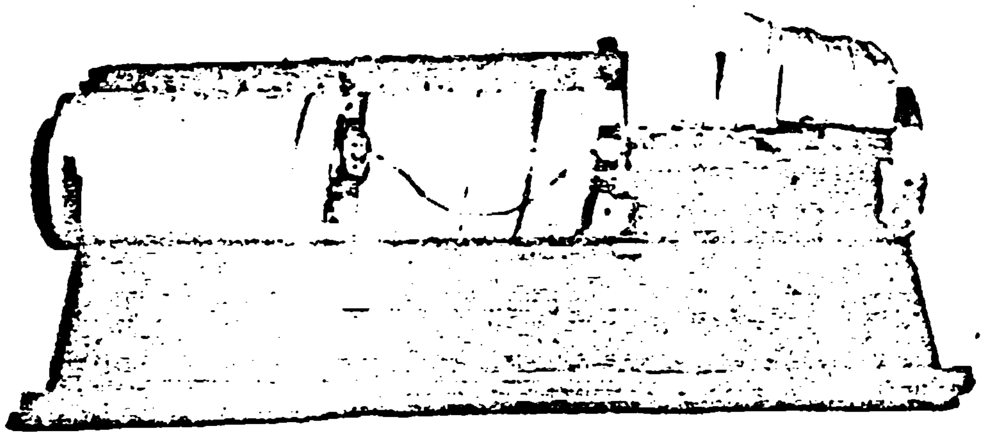

Fig. 3.1 AN/USQ-1 Detector-Transmitter with Insulation and Tape Cut Away to Show Heater Filament and Thermostat.

An accurate means of relating the measured radiation intensities with the time after detonation was provided by an accurate timer equipped to mark the recording tapes with a pip at 10 sec intervals. This pip could be initiated manually, a feature which was used to mark the tapes with a series of three pips at the instant of bomb flash.

3.1.2 Instrumentation in Drone Aircraft

The recording rate meters used to measure gamma radiation intensity in the drone aircraft were those used previously in GREENHOUSE by the Naval Radiological Defense Laboratory. The design and operating characteristics of these units are fully described in GREENHOUSE Report WT-11.(10) The rate meters consisted essentially of four parts: 1) A power supply to operate from the 28 volt DC

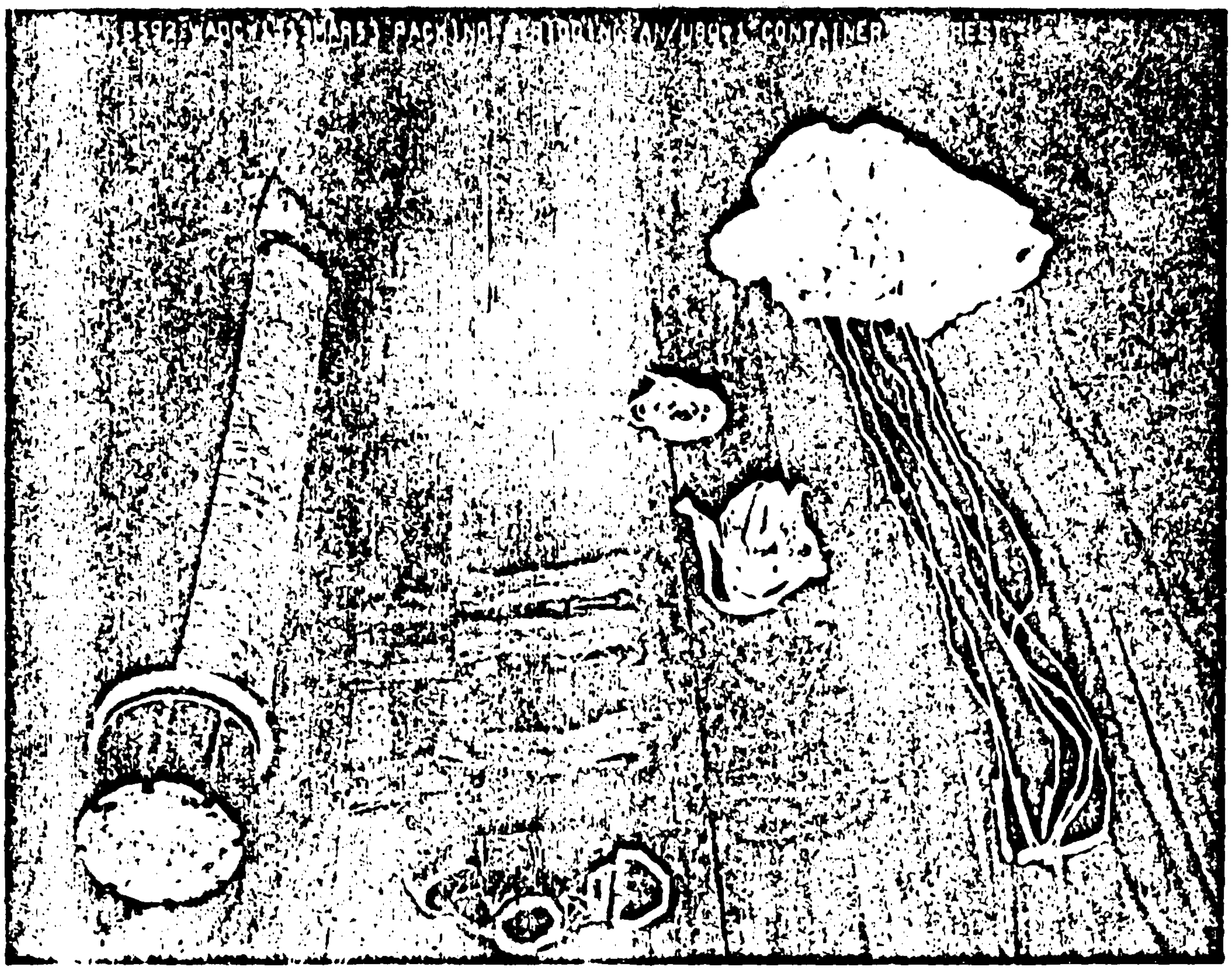

Fig. 3.2 AN/USQ-1 Parachute-borne Assembly Showing Insulation and Nose Weight, Parachute, Riser and Suspension Harness

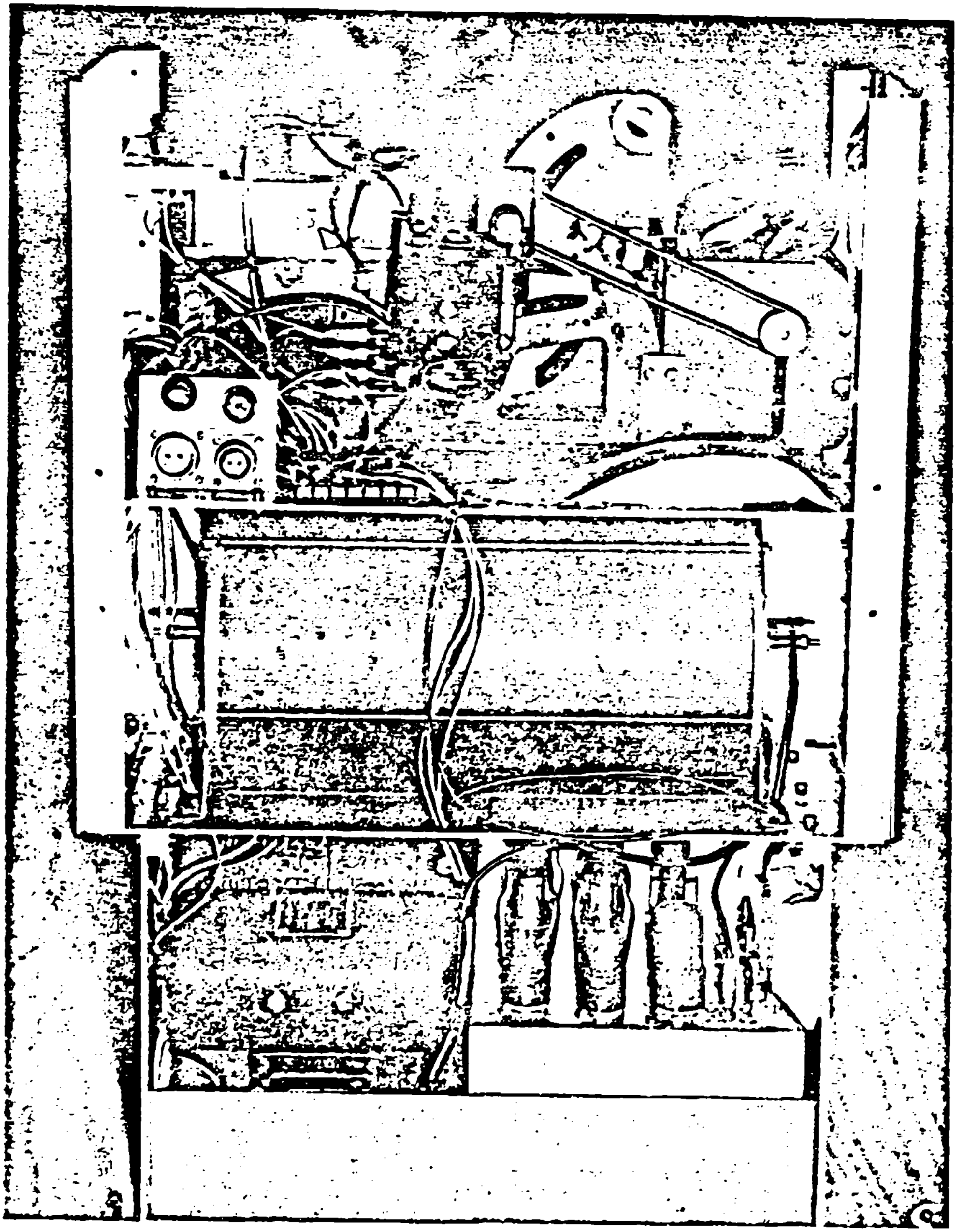

Fig. 3.3 Modified Recording Rate Meter with Side Panels Removed Showing Positions of NBS Film Packs

generator in the aircraft, 2) a special nitrogen filled ionization chamber, 3) a logarithmic amplifier designed to measure dose rates of from 1 to 10^6 r/hr, and 4) a hot wire recorder.

Because of the space limitations in the cockpit of the QF-80 aircraft, it was necessary to rearrange the components of the rate meter. The modified unit is shown in Fig. 3.3 The rate meter was also modified so that a radiation intensity of 15 r/hr closed a relay which energized a solenoid used to initiate air flow through the cascade impactor used for particle size studies by Project 2.1. The air flow through the impactor was directed in parallel with the flow through the animal exposure container. When the radiation intensity dropped to 5 r/hr the relay reopened de-energizing the solenoid and cutting off the air flow.

After modification of the rate meters they were calibrated over the dosage range of 26-65,000 r/hr using 200 KV X rays, Co^{60} gamma rays and a 20,000 curie Ba-La source having an average gamma energy of 1.3 Mev. The composite calibration curve is given in Fig. 3.4.

3.2 INTEGRATED EXTERNAL GAMMA RADIATION DOSE

The integrated external gamma radiation dose during cloud passage was measured using a number of standard integrating dosimeters. The principal dosimeter used, and the one perhaps giving the most reliable results, was the NBS film pack covering the dosage range from 0-1500 r. Three film packs were placed inside the chassis of each recording rate meter in the drones. Taplin chloroform dosimeters, Sievert ionization chambers, and $FeSO_4$ chemical dosimeters were placed in each animal exposure container. NBS film packs were also attached to the outside of each of the parachute-borne canisters to measure the integrated gamma radiation dose during vertical descent through the cloud.

3.3 INSTRUMENTATION FOR THE STUDY OF INTERNAL HAZARD

Determination of the internal radiation hazard associated with early passage through an atomic cloud required the most involved and difficult measurements. Sixty CF1 mice (30 gm) and two male macacus monkeys (weighing approximately 3 kg each) were placed aboard each of the two QF-80 aircraft. Since droning of the aircraft resulted in the loss of the cockpit pressure seal, it was necessary to enclose the animals in a pressurized container. Outside air was pressurized and warmed by the aircraft pressure and heating system and led directly into the animal container without being filtered. After passage through the animal container the air was exhausted directly into the cockpit. Extensive testing prior to the operation was necessary in order to determine the proper temperature and pressure settings compatible with animal survival during the exposure. On the basis of the pre-test studies it was decided that the allowable conditions

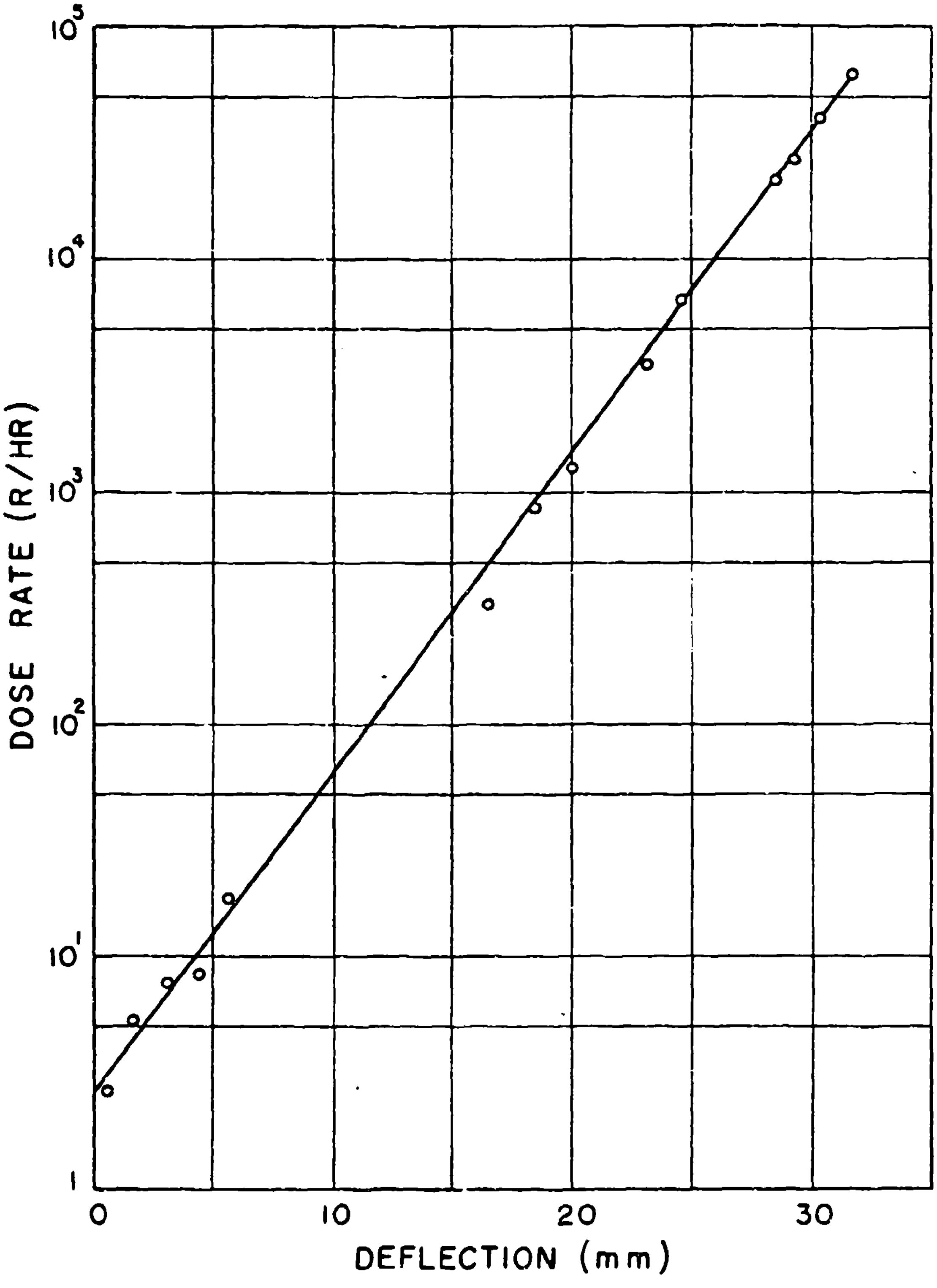

Fig. 3.4 Composite Calibration Curve for Recording Rate Meter

within the animal containers were a temperature range of 40 to 100°F and an air pressure setting of at least 5 psi above ambient air pressure conditions. Because of pressure variation with aircraft power setting, a pressure relief valve was incorporated into the animal container. The pressure valve was set to operate at a differential of 5 psi. At the chosen operating altitudes of 28,000 to 32,000 ft MSL the air pressure maintained inside the animal exposure container corresponded to an altitude of 11,000 to 14,000 ft. The outlet orifice of the animal exposure container was adjusted to give a flow rate of at least 8 cu ft/min at an overpressure of 5 to 6 psi. Since the volume of the container was 1 cu ft, this flow rate provided at least eight air changes per minute.

A cascade impactor was incorporated into the air flow system of the animal exposure container as a part of the particle size study under Project 2.1 (WT-717). This did not alter the flow of air through the animal container.

Figure 3.5 shows the airtight animal exposure container complete with air intake opening, exhaust orifice, solenoid valve, cascade impactor, and pressure regulator. The radiation rate meter is also shown.

The arrangement of the animals in the exposure container is shown in Figs. 3.6 and 3.7. The monkeys were placed in restraining boxes and lowered into the container first. The mice, confined in a wire mesh cage which was fastened to the lid of the exposure container, were suspended above the monkeys. The lid of the exposure container was sealed with a neoprene gasket and tightened with wing nuts.

Each drone aircraft carried wing-tip tanks in which were placed filters to collect fission product samples exterior to the aircraft. Analyses of the filter samples were used to calculate the total number of fissions occurring in the bomb and to compare the fission product concentrations in the cloud with that in the tissues.

3.4 CLOUD TEMPERATURE

Temp-tapes were attached on the inside of the thin skin of the drone aircraft to estimate the maximum temperature encountered in the cloud. One tape was attached on the inside of the nose wheel door. Another was attached to the upper part of the nose section on the inside of the equipment access panel. These temp-tapes changed color at temperatures in excess of 65°C and were capable of registering the maximum temperature attained by the skin of the aircraft to ± 15°C in the range of 65° to 175°C.

3.5 CLOUD PRESSURE[a]

On Shot 9 a pressure measuring device was attached to the

(a) This phase of Project 4.1 was proposed and carried out by Mr. Philip Moore and Dr. Harold Plank, J-11, LASL

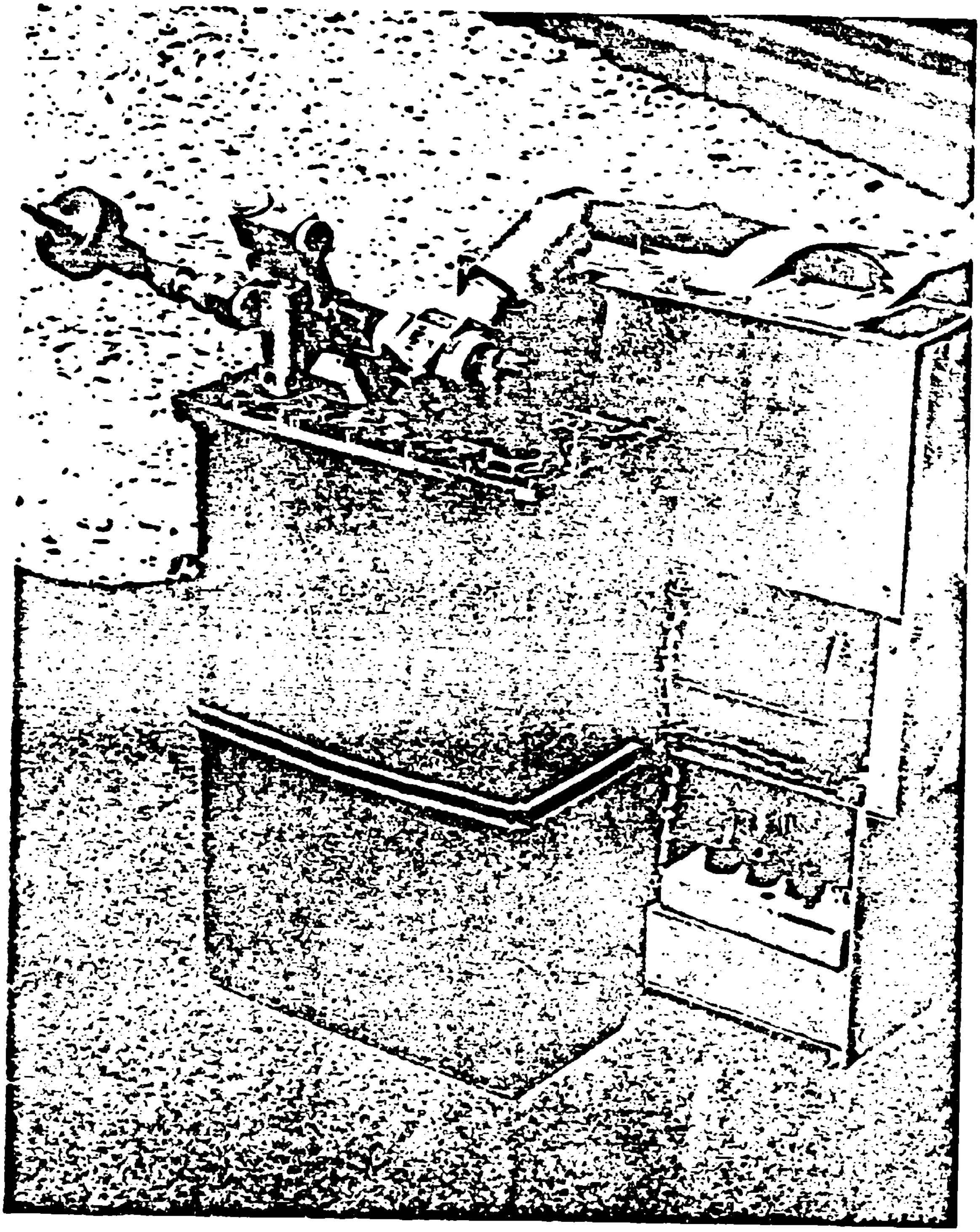

Fig. 3.5 Animal Exposure Container Complete with Air Intake Opening, Exhaust Orifice, Solenoid Valve, Cascade Impactor and Pressure Regulator

Fig. 3.6 Monkeys in Restraining Boxes Inside Exposure Container

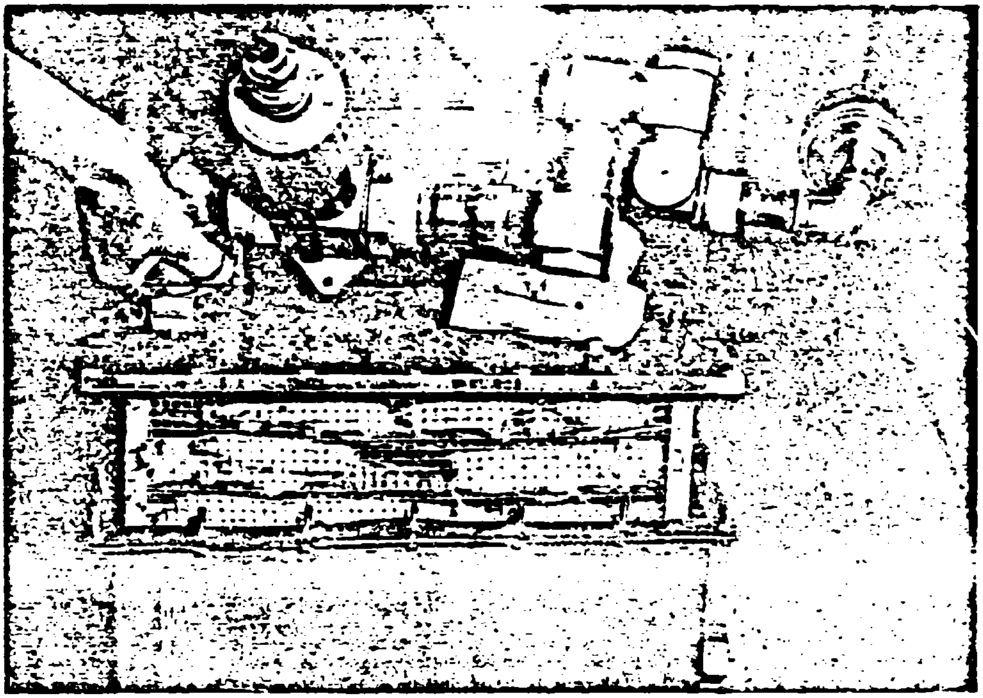

Fig. 3.7 Mice in Wire Cage Being Placed in Exposure Container

radiation rate meter in one of the aircraft. This unit consisted of an altimeter modified through an electrical circuit to measure pressure change as a function of change in electrical resistance. Using the power supply of the rate meter and a second hot wire recorder variations in pressure during flight were recorded. The sensitivity of the instrument was such that a pressure change equivalent to a change in altitude of ±100 ft could be recorded.

CHAPTER 4

OPERATIONS

4.1 CANISTER DROP OPERATIONS

Airplanes were to drop 10 parachute-borne canisters, containing telemetering facilities, through each air burst shot of the test series. These units were released in trail displaced horizontally at intervals of about 700 ft, five canisters being dropped from each of two aircraft. One group of canisters was released at 35,000 ft MSL at H + 1.7 min. These canisters intercepted the cloud as it reached 26,000 ft and passed through the radiation field at a relative rate of approximately 150 ft/sec. The other group of five canisters was released at an altitude of 49,000 ft MSL at H + 7 min, and was expected to intercept the cloud at 40,000 ft MSL and pass through it at approximately 200 ft/sec. Plans were that the third canister released in each group would traverse the approximate horizontal center of the visible cloud, and of the remaining four, two would be dropped on each side. This plan would provide for radiation dose readings from two canisters through each side of the cloud and one through the center.

Prior to takeoff NBS film packs were secured to the outside of each canister. On D + 1 day the canisters were recovered and the film packs removed for determination of the integrated radiation dose received by each unit.

4.2 DRONED AIRCRAFT OPERATIONS

The monkeys were placed in the restraining boxes and the mice in the wire cages 2.4 hrs before shot time to provide for a rest period after handling. The rest period was to minimize the possibility of the animals hyper-ventilating during passage through the cloud. At H-1 hour, with the drones ready for takeoff, the animals and integrating dosimeters were placed in the exposure container and he container placed in the cockpit and immediately attached to the ventilating system. Before loading the radiation rate meter aboard the aircraft, three NBS film packs were aped to the inside of the chassis. The positions of the film packs are shown in Fig. 3.3.

The rate meter was placed in the cockpit followed by the animal exposure container. Both units were secured to the seat of the aircraft with the shoulder straps.

The planes climbed to their penetration altitudes of 28,000 and 30,000 ft MSL on Shot 4 and 30,000 and 32,000 ft on Shot 9 where they orbited for approximately one-half hour before shot time. The orbiting period was utilized to position the drones accurately by ground radar control so that the predetermined position of the cloud could be intercepted at a specified time within plus or minus 1 sec. After bomb detonation the drones were directed once through the cloud, immediately returned to base and the animals sacrificed using chloroform. All animals were sacrificed in approximately 30 min after passing through the cloud to minimize biological fractionation and translocation.

Immediately after sacrifice the mice were dipped in molten paraffin to fix any fission product activity deposited on the fur. The purpose of this procedure was to control contamination of tissues and organs during their removal from the carcass. The dead animals were placed in a refrigerated compartment, put aboard an aircraft and flown to Los Alamos for analysis.

Upon reaching Los Alamos all animals were autopsied immediately. The lungs, livers, and gastrointestinal tracts of five mice were pooled or grouped for analysis making a total of 12 samples of each organ from the 60 animals in each drone plane. The skins of the monkeys were resected to avoid fission product contamination of the underlying tissues. The lungs, bronchial trees above the hilus, the livers, and gastrointestinal tracts were taken and analyzed individually.

The tissue samples were digested to remove organic matter using perchloric and nitric acids. The inorganic residue was dissolved in 2N HNO_3, diluted to volume and aliquots analyzed for Zr^{97} (17 hr half-life) and Mo^{99} (67 hr half-life). The methods used for the analyses were those used by Group J-11, LASL, for the chemical determination of bomb yield.(15)

During cloud passage each aircraft carried specifically designed tip tanks equipped with cloud sampling filters. These filters provided for the collection of a representative cloud sample simultaneously with the exposure of the animals. Analysis of the tip tank filters and the animal tissues by the same analytical procedures facilicated interpretation of the biological results in terms of the fraction of the bomb cloud retained by the animals from inhalation during the cloud pass. The tip-tank filter samples were also analyzed by Group J-11, LASL, to determine bomb yield and to provide a calibration of the methods used for analysis of the tissue samples.

CHAPTER 5

RESULTS

5.1 EXTERNAL GAMMA RADIATION INTENSITY

5.1.1 Results from Canisters

Although the experimental plan called for parachute-canister drops on each air burst detonation of the UPSHOT-KNOTHOLE series, the only participation was in Shots 4 and 9.

On Shot 4 it appeared that the canisters missed the radiation cloud entirely since a strong telemetered signal was received from all 10 canisters, but the records showed no indication of radiation.

On Shot 9 the canisters were not released from the higher airplane because of malfunction of the bomb bay doors. Of the five units released from 35,000 ft, telemetered data were obtained from two units and film badge readings from four. The first, second, and fifth canisters in order of release were slightly off frequency. This caused the recorders to zero off scale and resulted in no data being obtained from the ionization chambers. Canisters 3 and 4 gave good records with No. 3 going off scale on passage through the most intense part of the radiation field. The respective dose rate curves are shown in Figs. 5.1 and 5.2. Maximum intensities of 27,000 and 38,000 r/hr were recorded in the cloud at 2.7 min. Indications were that the canisters fell somewhat short of the cloud center.

5.1.2 Results in Drone Aircraft

Operation of the recording rate meters in the drone aircraft was about 50 per cent effective. On Shot 4 the lower drone (28,000 ft MSL) missed the visible cloud but penetrated the radiation field. The tape on the recording rate meter jammed, however, about 10 sec after entry. At that time the rate meter registered a maximum radiation intensity of about 7500 r/hr 3.7 min after detonation. This, of course, was near the boundary of the radiation field. The rate meter on the higher aircraft (30,000 ft) gave a complete and continuous record of the radiation intensity which showed a maximum dose rate of 7600 r/hr 4.5 min after T_0 (Fig. 5.3). There was no indication on the

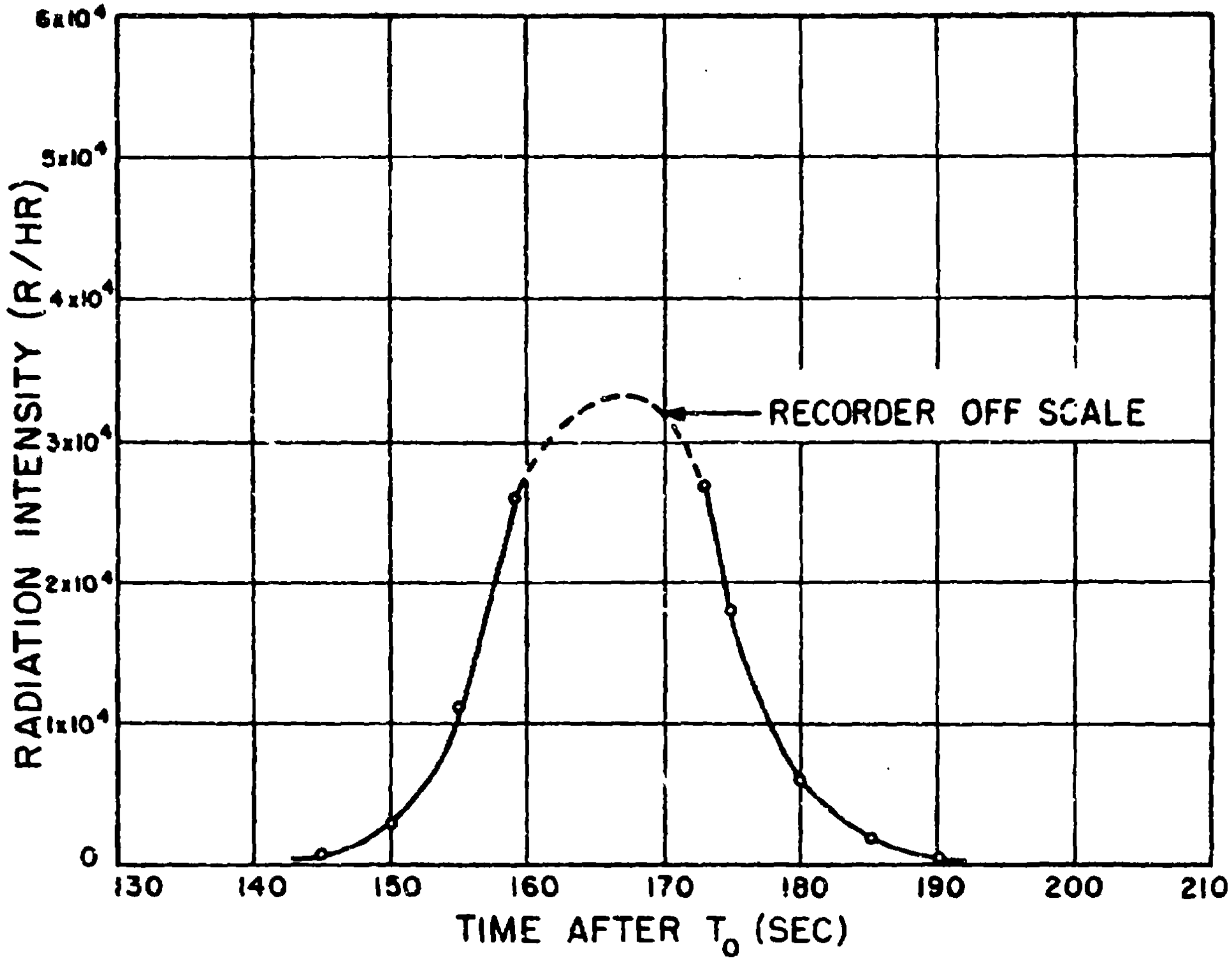

Fig. 5.1 Gamma Radiation Intensity Curve from Parachute-borne Canister No. 3 (Shot 9)

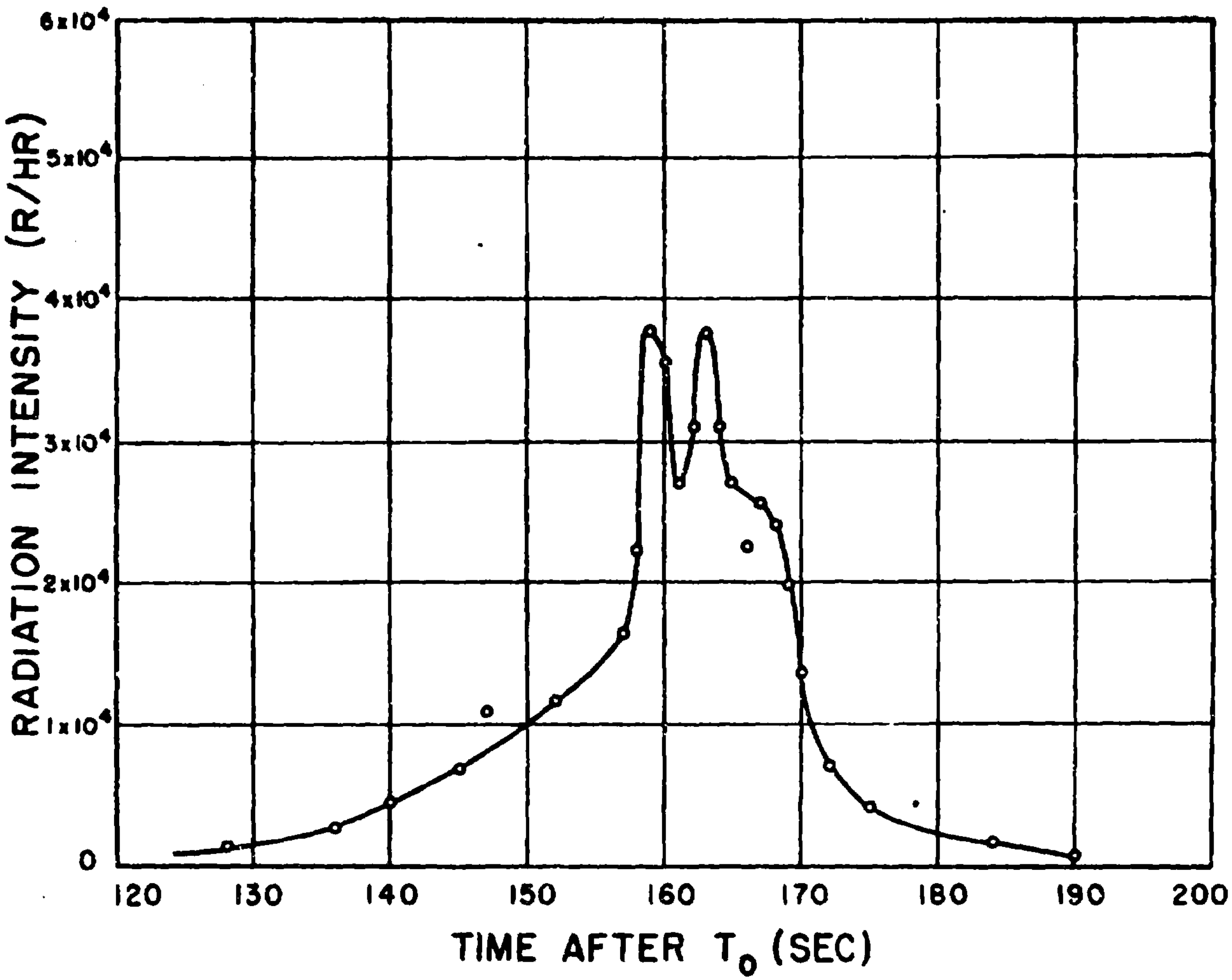

Fig. 5.2 Gamma Radiation Intensity Curve from Parachute-borne Canister No. 4 (Shot 9)

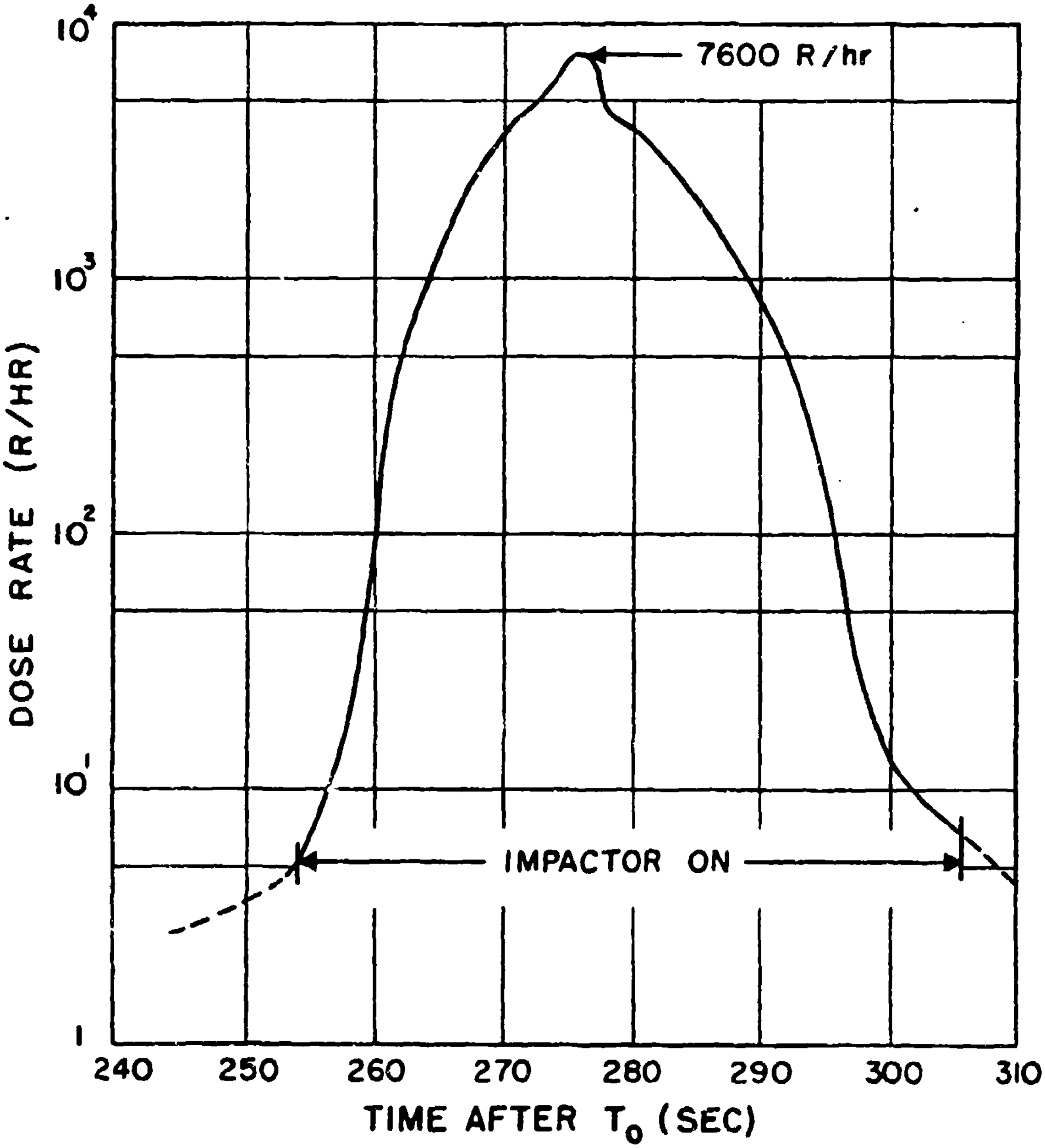

Fig. 3.3 Gamma Radiation Intensity Curve from Recording Rate Meter in Drone Aircraft (Shot 4)

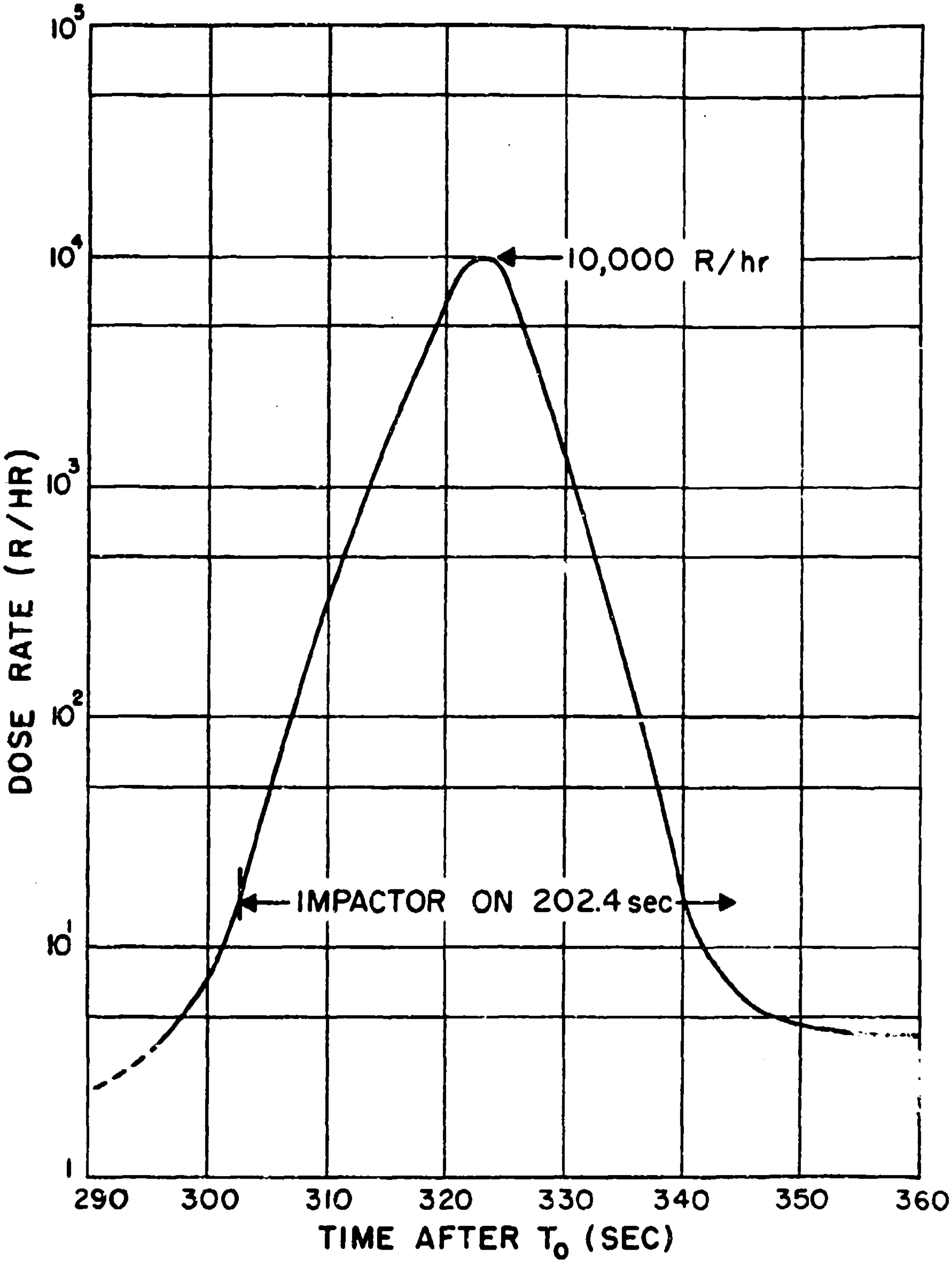

Fig. 5.4 Gamma Radiation Intensity Curve from Recording Rate Meter in Drone Aircraft (Shot 9)

tape of a turbulent non-homogeneous radiation field.

On Shot 9 the drone aircraft missed the visible cloud on the first pass but both made successful penetrations on a second trial. The tape on the rate meter in the lower plane (30,000 ft MSL) jammed and no record of dose rate was obtained. The rate meter on the higher plane (32,000) ft gave a complete and continuous record of the radiation intensity which showed a maximum value of 10,000 r/hr 5.4 min after detonation (Fig. 5.4). Again there was no indication of a non-homogeneous radiation field. The results of the radiation intensity measurements and the conditions for both the canister and drone aircraft rate meter readings are summarized in Table 5.1. The values for maximum radiation intensity differ from those given in the preliminary report due to recalibration of the equipment and more accurate analysis of the records.

5.2 INTEGRATED EXTERNAL GAMMA RADIATION DOSE

As mentioned in paragraph 3.2, NBS film packs were attached to the parachute-borne canisters used in the radiation dose rate studies. These film packs provided a measurement of the total integrated gamma radiation dose received by the canisters during passage through the radiation field.

All canisters dropped during Shot 4 missed the cloud and the film badges showed readings of only 0.4 r which was considered to be background. During Shot 9, all of the five film packs from the 35,000 ft drop plane hit the cloud and four were recovered. These showed dosages of from 77 to 200 r. The integrated radiation doses received by canisters 3 and 4 were also determined by integrating under the radiation intensity curves shown in Figs. 5.1 and 5.2. The integrations showed accumulated doses of 174 and 185 r, respectively.

The drone aircraft carried NBS film packs, Taplin chloroform dosimeters, $FeSO_4$ dosimeters, Sievert ionization chambers, and the recording dose rate meters which could give total integrated dose. Satisfactory readings were obtained from the film packs, the Taplin dosimeters, and the integrated dose rate curves. The NBS film packs in the drones that traversed the visible cloud showed doses of 11, 21, and 29 r. Integration of the rate meter curves given in Figs. 5.3 and 5.4 showed total radiation doses of 18 and 37 r.

The data collected on the two shots by the various dosimeters and the conditions of measurement are summarized in Table 5.2.

5.3 INTERNAL HAZARD FROM INHALATION OF FISSION PRODUCTS

The animal exposure containers functioned exceptionally well. All animals were returned from flights in good condition with the exception of one mouse that was killed when his head was caught in the exit tube of the pressure regulating valve. The condition was eliminated on subsequent experiments. Neither mice nor monkeys showed any physical or physiological symptoms of overheating, chilling, anoxia,

TABLE 5.1 - Maximum Gamma Radiation Intensity in an Atomic Cloud

Shot	Method of Cloud Penetration	Altitude of Penetration (ft)	Maximum Dose Rate (r/hr)	Time of Penetration,[c] (Min after Detonation)
4	Aircraft[a]	28,000	7,500	3.7
	"	30,000	7,600	4.5
9	Canister 3	26,500 ± 1000	27,000[b]	2.7
	"	26,500 ± 1000	38,000	2.7
	Aircraft	30,000	Tape jammed	6.8
	"	32,000	10,000	5.2

(a) Plane penetrated radiation field but missed visible cloud, tape on recorder jammed about 10 sec after entering radiation field.
(b) Recorder went off scale.
(c) Refers to visible cloud.

or radiation damage.

The animals were killed within 30 min after detonation time (T_0) and the carcasses were delivered to the LASL in approximately 6 hr after shot time.

During Shot 4 the 28,000 ft drone was too low to penetrate the visible cloud and the activities in the samples, if any, were below the limits of detection. The 30,000 ft drone made a successful interception and traversed the lower half of the cloud. During Shot 9 both drone aircraft missed the visible cloud on the first pass. The cloud stabilized, however, and a second pass resulted in successful interceptions by both planes, although the penetration times were somewhat later than planned. The 30,000 ft drone passed very nearly through the center of the cloud in both the horizontal and vertical axis. The 32,000 ft drone passed through the upper one-third of the cloud and considerably to one side. With few exceptions animal tissues from the successful flights contained very low but measurable activities.

The lungs, livers, and gastrointestinal tracts of the mice and monkeys were analyzed for Zr^{97} and Mo^{99}. The lungs of the monkeys were divided at the hilus into bronchial and alveolar portions. All analyses were completed within a period of time not exceeding one half-life of the isotope.

The observed Zr^{97} and Mo^{99} activities were corrected for

TABLE 5.2 - Integrated External Gamma Radiation Dose Received During Passage Through an Atomic Cloud

Shot	Method of Cloud Penetration	Method of Measurement: NBS Film (r)	Method of Measurement: Integration of Dose Rate (r)	Method of Measurement: Taplin Dosimeter (r)	Visible Cloud: Altitude of Penetration (ft)	Visible Cloud: Time in Cloud (sec)	Visible Cloud: Time of Penetration (min)
4	Canisters 1-5	0.4 [a]	---	---	---	0	---
	Aircraft [b]	5.7	---	< 15	28,000	0	3.6
	"	11.3	18	< 15	30,000	10 [c]	4.4
9	Canister 1	77	---	---	26,500 ± 1000	20 [d]	2.5 ± 0.1
	" 2	---	---	---	---	---	---
	" 3	120	185	---	26,500 ± 1000	40 [d]	2.5 ± 0.1
	" 4	180	174	---	26,500 ± 1000	42 [d]	2.5 ± 0.1
	" 5	200	---	---	26,500 ± 1000	43 [d]	2.5 ± 0.1
	Aircraft	29.0	---	15-25	30,000	34 [c]	6.8
	"	21.3	37	15-25	32,000	20 [c]	5.2

(a) Considered to be background, canisters missed cloud.
(b) Plane flew beneath visible cloud but penetrated radiation field.
(c) That time between entry into the cloud and being sighted by pilot after exit.
(d) Calculated from rate of fall and the assumption that 1) canister No. 5 hit center of cloud, 2) canister spacing of 700 ft, and 3) cloud was a sphere of 6500 ft diameter.

TABLE 5.3 - Fraction of the Total Fission Products Found in Tissues of Mice Based on Analyses of the Tissues for Zr^{97} and Mo^{99} (a)

Shot	Penetration Altitude (1000 ft)	Fraction in Lungs		Fraction in Liver		Fraction in GI (c) - Tract	
		Zr	Mo	Zr	Mo	Zr	Mo
4	28 (b)	$< 2 \times 10^{-20}$	$< 1 \times 10^{-19}$	$< 2 \times 10^{-20}$	$< 1 \times 10^{-19}$	$< 2 \times 10^{-20}$	$< 1 \times 10^{-19}$
	30	1.54×10^{-18}	1.15×10^{-18}	10×10^{-20}	1.46×10^{-18}	0.84×10^{-18}	2.60×10^{-18}
9	30	1.23×10^{-18}	1.84×10^{-18}	4.0×10^{-20}	3.86×10^{-18}	3.07×10^{-18}	10.2×10^{-18}
	32	0.84×10^{-18}	0.92×10^{-18}	6.6×10^{-20}	1.14×10^{-18}	0.91×10^{-18}	2.19×10^{-18}
Average		1.2×10^{-18}	1.3×10^{-18}	6.9×10^{-20}	2.2×10^{-18}	1.6×10^{-18}	5.0×10^{-18}

(a) Each result is the average of the analyses of tissues from 60 mice.

(b) Drone aircraft entered radiation field but passed below visible cloud.

(c) Gastrointestinal.

TABLE 5.4 - Fraction of the Total Fission Products Found in Tissues of Monkeys Based on Analyses of the Tissues for Zr^{97} and Mo^{99} (a)

Shot	Altitude (1000 ft)	Fraction (c) in Bronchi (d)		Fraction (c) in Alveoli (d)		Fraction (c) in Liver		Fraction (c) in GI Tract	
		Zr	Mo	Zr	Mo	Zr	Mo	Zr	Mo
4	28 (b)	< 1	< 5	< 1	< 5	< 1	< 5	< 1	< 5
	30	5.4	56	355	350	2.28	252	—	—
9	30	1	5	226	122	3.72	170	15.3	77.6
	32	2.3	62	163	230	3.20	343	4.95	115
Average		2.9	41	250	230	3.1	250	32	96

(a) Each result is the average of the analyses of tissues from two monkeys.

(b) Drone aircraft entered the radiation field but passed below the visible cloud.

(c) Multiply each value by 10^{-19} to obtain actual fraction observed.

(d) The lungs were divided at the hilus into bronchial and alveolar portions.

chemical recovery, counting efficiency, and radioactive decay to obtain the activities in the various tissues of T_0. From the known fission yields of the isotopes, the total number of fissions necessary to produce the observed activities were calculated.

The tip-tank filters from each drone aircraft and other filter samples collected for bomb efficiency measurements were analyzed by J-11, LASL. From these data the total number of fissions occurring in the detonation and the bomb yields were calculated. The calculated[a] for Shots 4 and 9 were 10.6 and 26.4 KT, respectively, and the respective numbers of fissions produced were 1.50×10^{24} and 3.64×10^{24}.(16) Assuming that the Zr and Mo activities found in the tissues were representative of the total fission product mixture, the fractions of the bomb fission cloud found in the tissues of the animals were calculated by dividing the observed activities expressed in terms of number of fissions, by the total number of fissions occurring in the detonation.

These results are summarized in Tables 5.3 and 5.4 for mice and monkeys, respectively.

Analyses of the tip-tank filters for Zr^{97} and Mo^{99} showed that the ratio of Zr and Mo activities in the cloud, corrected to T_0, was 6.5/1. Summation of the total activities at T_0 found in the animals gave a Zr to Mo ratio of 2.3/1 in mice and 3.2/1 in monkeys.

5.4 PEAK TEMPERATURE

On both shots the temp tapes attached to the skin of the aircraft failed to register. This observation indicates that at the times and altitudes of penetration the temperatures reached by the skin of the aircraft in the cloud were less than 65°C.

5.5 PRESSURE CHANGES IN THE CLOUD

The pressure measuring device mentioned in paragraph 3.5 was installed in the drone aircraft that penetrated the Shot 9 cloud at 32,000 ft. The device appeared to function satisfactorily and examination of the record showed a pressure increase in the cloud at the time of penetration (5.2 min after detonation) equivalent to less than that which would result from a change of 100 ft in altitude.

(a) Radiochemical yields for Shots 4 and 9 are 11.0 and 26.0, respectively, for report purposes.

CHAPTER 6

DISCUSSION

6.1 EXTERNAL GAMMA RADIATION INTENSITY

The data on maximum gamma radiation dose rates in the head of the clouds from two detonations of the UPSHOT-KNOTHOLE series are summarized in Table 5.1. The maximum dose rate measured in the cloud from Shot 4 (10.6 KT) 4.5 min after detonation was 7600 r/hr. The maximum dose rates measured in the cloud from Shot 9 (26.4 KT) 2.7 and 5.4 min after detonation were 38,000 and 10,000 r/hr, respectively. The two measurements on Shot 9 are in agreement when corrected for the difference in time of penetration and the expansion of the cloud. The corresponding dose rate curves are given in Figs. 5.1, 5.2, 5.3, and 5.4. These results are in general agreement with those obtained by Koch (10) during GREENHOUSE and with the lower values predicted from theoretical considerations (4,11,17).

The agreement between the present measurements made in the head of the cloud with those made by Koch (in which penetration was through the stem) suggests that dose rate measurements in the stem of the mushroom cloud may apply to the head itself. Consideration of the present data on dose rate along with the more complete studies by Koch provides a basis for a general analysis of the dose rate problem within an atomic cloud.

All available data of the average dose rate within an atomic cloud at early times are compiled in Fig. 6.1. Of the 35 points, 32 are from Koch's report and 3 are from the present study. His results are from three GREENHOUSE shots and covering times from 3.3 to 25 min after detonation. The 3 points from UPSHOT-KNOTHOLE cover sizes of 10.6 to 26.4 KT and times from 2.7 to 5.2 min. Altitudes of penetration range from 10,000 to 32,000 ft, and penetrations include both the stem and the cap of the mushroom.

Considering the range of conditions, the results are surprisingly consistent, the scatter about the line being about a factor of 2 each way. Particularly interesting is the lack of correlation with kilotonnage. A least-squares analysis of the data led to the best fit curve labeled $\bar{D}$, whose equation is

$$\bar{D} = 1.31 \times 10^5 t^{-2.06} \qquad (6.1)$$

Page 44 Deleted.

where t is the time after detonation in min and $\bar{D}$ is in r/hr.

Some insight into the factors determining this relationship may be derived from the following considerations: Since even at times of a few minutes the cloud is already several gamma mean free paths in diameter, the dose rate may be regarded as determined by the migration of the active material to a distance at which air absorption shields the aircraft. The dose to the aircraft is therefore received entirely from a sphere of constant effective radius. The amount of active material within this sphere is just some constant divided by the volume of the entire cloud, assuming uniform distribution of the fission products.

If we assume for simplicity that the volume of the cloud is a linear function of time (data on the "nominal cloud" given in the Effects of Atomic Weapons (12) show roughly this dependence) and correct the dose curve $\bar{D}$ of Fig. 6.1 for cloud expansion by multiplying every point by a number proportional to the time since detonation, we obtain the curve labeled $\bar{D}t$. (This curve was arbitrarily made to pass through the average point of all the data; therefore, only the slope is of significance.) Mathematically this reduces the exponent of t by one, and the equation of the new curve is of the form

$$\bar{D}t = k \cdot t^{-1.06}. \qquad (6.2)$$

For comparison, the experimental curve for the total gamma energy emitted by the fission products as a function of time (9) (labeled $t^{-1.20}$) is given normalized to the average point. The close agreement between the last two curves would seem to indicate that the two major factors influencing the dose rate in an atomic cloud are decay of the fission products (as $t^{-1.20}$) and expansion of the cloud (roughly as $t^{1.0}$).

A similar analysis of the maximum dose rates found in the same 35 measurements yields a least-squares equation:

$$D_{max} = 2.17 \times 10^5 t^{-1.98}. \qquad (6.3)$$

That is, local concentrations of fission products and geometric factors lead to maximum rates of about twice the average rates.

From the above discussion the following generalizations regarding dose rate in an atomic cloud may be made.

1) The dose rate in the cloud is relatively independent of kilotonnage. (Independence of kilotonnage results from the fact that total quantity of fission products and cloud volume both vary linearly with kilotonnage, and therefore cancel in their effects on dose rate.)

2) To within a factor of 2, the average dose rate in a cloud is given by

$$\bar{D} = 1.31 \times 10^5 t^{-2.06} \qquad (6.1)$$

where $\bar{D}$ is the average dose rate in r/hr and t is the time since detonation in min.

3) The two prime factors contributing the above equation are the decay of the fission products as $t^{-1.20}$ and the expansion of the cloud, roughly as $t^{1.0}$.

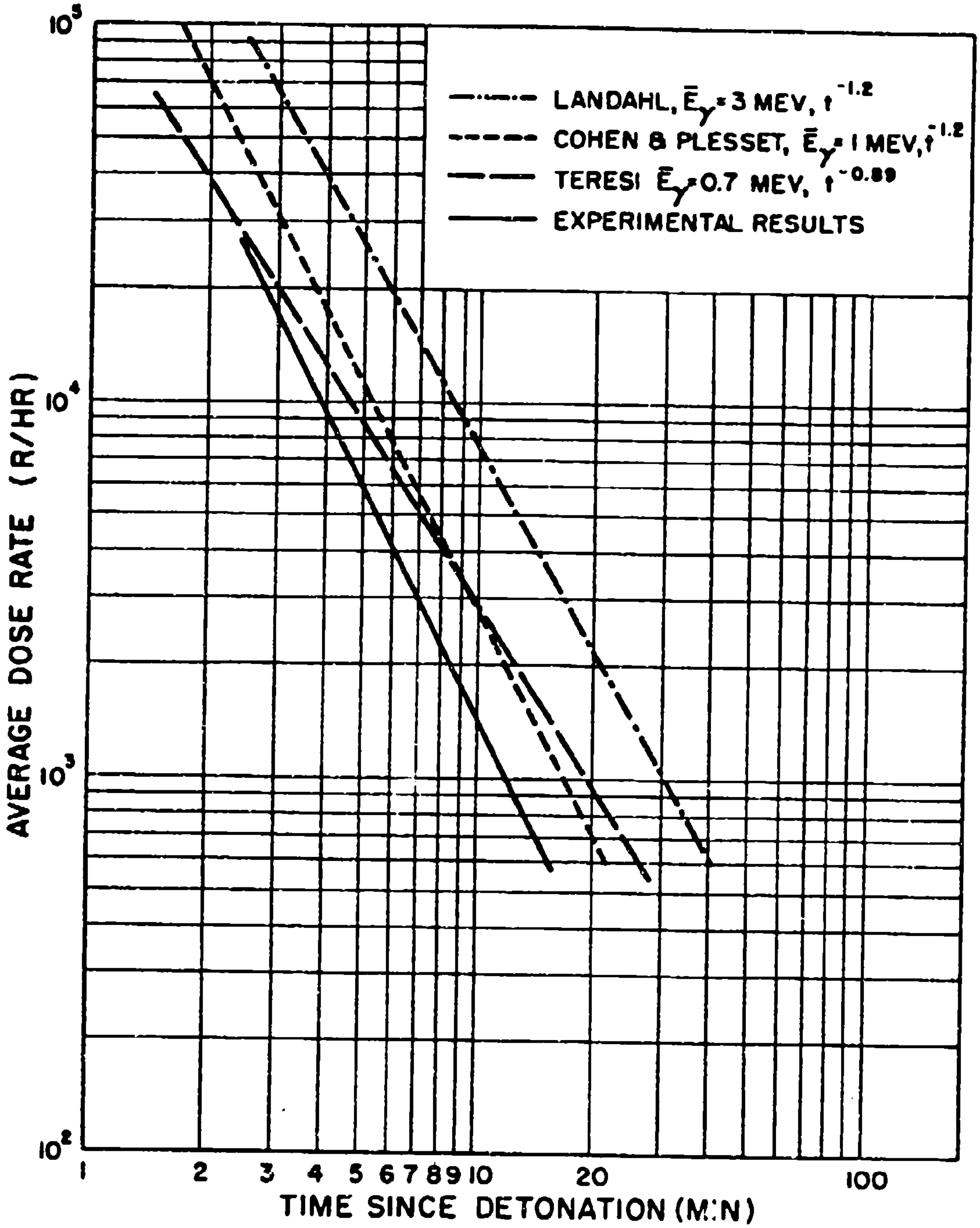

Fig. 6.2 Observed and Theoretical Curves for Gamma Radiation Intensity in an Atomic Cloud as a Function of Time after Detonation

Additional information regarding radiation dose rate in an atomic cloud may be obtained by comparison of the observed results with theoretical predictions.

At least three theoretical predictions of the gamma dose rate in an atomic cloud have been made. A comparison of these predictions with the experimental results is given in Fig. 6.2. The theoretical results were all calculated for a 20 KT weapon and are reported in terms of the dose rate expected at a given altitude, the time of passage being the time at which the center of the cloud reaches that altitude. The rate of rise given by Cohen and Plesset (4) is used in all three papers. We have therefore plotted the theoretical predictions in terms of the time of passage and have converted to dose rate for those cases in which the original data predicted total integrated dose. Since the same aircraft (300 mph) and cloud diameters (those given by Cohen and Plesset) were used throughout the three papers, the conversion is straightforward. Landahl (11) and Cohen and Plesset both use $t^{-1.2}$ as the decay function for the gamma emission and find curves whose slopes are in agreement with this experiment. As mentioned above, this decay law is verified by the experiments of Katcoff et al.(9) Teresi (17) on the other hand has used $t^{-0.89}$ for the decay, clearly an erroneous choice.

The other outstanding difference between the calculations is the different assumptions as to the effective gamma ray energy, Landahl using 3 Mev, Cohen and Plesset, 1 Mev, and Teresi several values from which we have chosen the lowest, 0.7 Mev. It is clear that the extent of disagreement is a result of the choice of gamma energy, and that by assuming an energy somewhat lower than 0.7 Mev, together with the proper exponent for the decay of γ-emission, good agreement with the experimental results could be obtained. The conclusion that the average gamma energy is quite low was reached on experimental grounds by Koch, by the Biomedical Group of LASL, and in the present experiment.

A number of generalizations may be made from the data shown in Fig. 6.2.

The theoretical analyses of Cohen and Plesset and of Landahl predict the proper time dependence of dose rate, the former results being somewhat better.

Both Cohen and Plesset and Landahl consistently arrive at too high a dose rate due to the assumption of too high an average gamma energy.

Teresi has used very nearly the proper gamma energy, but his predictions are too high at times greater than 4 min due to the use of the wrong value for the decrease in gamma ray emission with time. At shorter times his results for $E_\gamma = 0.7$ Mev agree well with the experimental observations.

6.2 INTEGRATED EXTERNAL RADIATION DOSE

The various measurements of total external radiation dose accumulated by passing through the head of the clouds from Shots 4 and 9 are summarized in Table 5.2

The $FeSO_4$ dosimeters and Sievert ionization chambers were unsatisfactory. The former was unsatisfactory because the radiation doses were below the range of the method and the latter because of unknown factors probably related to pressure and temperature effects. The Taplin dosimeters indicated total doses of <15 and 15-25 r which were consistent with NBS film badge results.

Obviously the total dose received in a single cloud pass is a function of the time after detonation and the total time required to traverse the cloud. Film packs in drone planes that traversed the cloud at 400 knots 4.5, 5.2, and 7 min after detonation showed accumulated doses of 11,21 and 29 r, the length of time inside the cloud being different for each penetration as shown in Table 5.2. Film badges dropped through the cloud vertically at speeds of 90 knots at 2.7 min after detonation showed total doses of from 77 to 200 r depending on distance of penetration from cloud center. It is difficult to compare accurately these total doses independently of the rate curves (Figs. 5.1, 5.2, 5.3, 5.4) which give the length of time exposed. Assumption of a spherical cloud permits estimation of the approximate times inside the visible cloud. Application of these times to the total doses gave results that are not seriously inconsistent.

The integrated dose rate curves from the drones gave higher total doses than the film packs by a factor of about 2, which may be explainable on the basis of the possibly large error in reading the log scale recording tapes for higher intensities and the lack of response of the NBS film packs to the very low energy radiation filtered by the 1.03 mm of tin and 0.3 mm of lead surrounding the film package. Results of integration of the rate curves from the parachute-borne canisters are consistent with the corresponding film pack readings and compare well with the total doses received by the drone planes when the earlier time of cloud penetration and the slower rate of fall of the canisters are taken into consideration.

These observations of total integrated dose are in general agreement with the lower values predicted from theoretical considerations (4,11,17).

Since the dose rate is relatively independent of bomb yield and the total integrated dose is directly dependent only on transit time, the total dose received by personnel flying through the cloud may be calculated from the cloud size, the speed of the aircraft and the average dose rate as a function of time after detonation given by curve D in Fig. 6.1.

6.3 INTERNAL HAZARD FROM INHALATION OF FISSION PRODUCTS

Both mice and monkeys were used to estimate the internal hazard from the inhalation of fission products during flight through the cloud. Monkeys were used because their respiratory anatomy and physiology closely resemble that of man. However, because of the restricted space in the QF-80 aircraft only two monkeys could be flown in each plane. Sixty mice were added to each aircraft to permit better statistical evaluation, to correlate present results with data collected at GREENHOUSE, and to attempt a correlation between mice and monkeys.

All animals were sacrificed as soon as possible after exposure to avoid metabolic fractionation and translocation of the inhaled fission products. The lungs, livers, and gastrointestinal tracts of the animals were analysed for Zr^{97} and Mo^{99}. Assuming that the Zr and Mo activities found in the tissues were representative of the total fission product mixture, the fraction of the bomb fission cloud found in each tissue was estimated. These results are summarized in Tables 5.3 and 5.4 for mice and monkeys, respectively. The fission product activities found in the majority of samples were quite low. The aliquots taken for analysis gave net counting rates of 1/5–4 times background, therefore, the results may be good to only ± 20 per cent due to statistical counting errors alone.

When these data and the data for the tissue activities at T_0 are studied, a number of pertinent points are apparent. These points are considered below.

6.3.1 Fractionation and Translocation of Zr and Mo

Analyses of the tip-tank filter samples showed a Zr^{97}/Mo^{99} activity radio in the cloud of 6.5 when calculated to T_0. Comparison of this ratio with the ratios of the total activities found in the animals (2.3 in mice, 3.2 in monkeys) shows that Zr and Mo were fractionated during the experiment. The fractionation was a factor of 2 in monkeys and a factor of 3 in mice. These results could be produced either by loss of Zr in the ventilating system of the aircraft and the exposure container or by much lower retention of Zr by the animal. It is doubtful, however, on the basis of laboratory retention studies of inhaled aerosols that even with 100 per cent retention of Mo the Zr retention could be low enough to account for the observed difference in the Zr/Mo ratios. In the latter connection attention should be directed to the probable difference in the solubility of the oxides of Zr and Mo. The ZrO_2 is quite insoluble while the most likely oxide of Mo (MoO_3) is quite soluble. Whether these differences in solubility would contribute to the fractionation of Zr and Mo is controversial. There is no doubt, however, that solubility contributed materially to the metabolic translocation of Mo to the liver. The data in Tables 5.3 and 5.4 show that the amount of Zr in the liver was only about 1/100 of that found in the lungs. The amount of Mo found in the liver, however, was equal to or greater than that in the lungs. These observations prompted a subsequent experiment in which two groups of mice were given a solution of fission products prepared from the tip-tank filter samples. One group received the solution intratracheally and the other orally. The animals were killed 30 min later and livers, lungs, and gastrointestinal tracts analysed for Zr and Mo activity. The results showed that Zr was not absorbed either from the lung or from the gastrointestinal tract. Over 99 per cent remained in the lung or the gut 30 min after administration. Molybdenum, however, was readily absorbed from the lung and to the extent of about 10 per cent from the gut. The lung absorption data are not directly applicable to the present problem, however, because the Mo was in solution when administered which would eliminate the effect of rate of solution of MoO_3 on rate of metabolic translocation.

6.3.2 Ingestion of Fission Products

During the experiments conducted at GREENHOUSE (1) the amount of activity ingested by mice was about 100 times that deposited in their lungs. Reference to the data in Table 5.3 shows that appreciable amounts of activity were ingested by the mice in the present experiments. The amounts, however, were not nearly as great. The amount of Zr ingested by mice was approximately equal to the amount found in the lungs while the amount of Mo in the gastrointestinal tract was about four times that in the lungs. Obviously the major part of the ingested material resulted from the mice licking their fur. The much smaller amounts of ingested activity observed in the present studies, as compared with those observed during the GREENHOUSE experiments, probably resulted from earlier sacrifice of the animals.

The monkeys were restrained in a manner which minimized the possibility of licking (see Fig. 3.6), therefore, the amounts of Zr and Mo found in the gut were much less than for mice. Only about one-eighth as much Zr was found in the gastrointestinal tract as in the lungs and only about one-third as much Mo.

It seems reasonable to assume that the amount of ingested activity found in the animals has very little application to the internal hazard confronting aircrews flying through an atomic cloud even though the possibility exists that some inhaled material may be passed into the oropharynx by ciliary action and then swallowed. In the applied case ingestion may be considered negligible and inhalation may be assumed to be the primary hazard.

On the basis of the above assumption the data for fraction of the fission cloud deposited in the lungs were recalculated and adjusted for metabolic translocation of Mo using the results of the preliminary experiment mentioned under section 6.3.1. The correction applied was to add in the results for monkey bronchi and, in case of both mice and monkeys, to add the Mo in the liver minus 10 per cent of that found in the gut. The corrected values were then converted from fractions of the cloud to fission products expressed as total fissions required to produce the observed activities. The conversion was made merely by multiplying the fraction of the cloud deposited in the lungs by the number of fissions occurring in each detonation. These results are summarized in Table 6.1. These data indicate average values of 6.1×10^6 and 10.3×10^7 for the fission products (expressed as number of fissions) deposited in the lungs of mice and monkeys, respectively. The value for mice, based on the average Mo results, is 9×10^6 which compares favorably with the average value of 8×10^6 for GREENHOUSE (1) Shots Dog and Easy which was also based on assay of Mo in the lungs of mice. The excellent agreement is perhaps fortuitous.

Prior to adjustment for metabolic translocation the Mo and Zr results showed essentially equal fractions of the fission cloud in the lungs of the animals, therefore, correction of the Mo value by adding a major portion of the activity found in the liver produced a

TABLE 6.1 - Fission Products (Expressed as Total Number of Fissions) Found in Lungs of Mice and Monkeys, Adjusted for Metabolic Translocation

Shot	Total Fissions in Shot	Altitude (1000 ft)	Total Fissions in Lung			
			Mice		Monkeys	
			Zr	Mo	Zr	Mo
4	1.50×10^{24}	28[a]	$< 3 \times 10^4$	$< 1 \times 10^5$	$< 1 \times 10^5$	$< 7 \times 10^5$
		30	2.31×10^6	3.52×10^6	5.40×10^7	9.87×10^7
9	3.64×10^{24}	30	4.47×10^6	16.7×10^6	8.26×10^7	10.5×10^7
		32	3.06×10^6	6.70×10^6	6.01×10^7	22.7×10^7
Average			3.3×10^6	9.0×10^6	6.6×10^7	14.1×10^7
Average Zr and Mo			6.1×10^6		10.3×10^7	

(a) Drone plane penetrated radiation field but flew below visible cloud. Not included in average.

discrepancy of a factor of 2-3 between the Zr and Mo results. There was no logical basis, however, to ignore the rapid metabolic translocation of Mo and the high concentrations found in the liver. The averages of the adjusted Zr and Mo values are believed therefore to represent the amounts of fission products deposited in the lungs of the animals to within a factor of 2. The factor of uncertainty obviously resulted from the fractionation of Zr^{97} and Mo^{99} activities during the animal exposures. The explanation for this observed fractionation is a matter of conjecture at the present time.

6.3.3 Extrapolation of Results

The average values for fission products deposited in the lungs of mice and monkeys may be compared and extrapolated to man on the basis of respective minute respiratory volumes. The minute respiratory volumes of various laboratory animals and man were shown by Guyton (7) to be correlated with the body weight according to the expression

$$\text{respiratory volume/min in cc} = 2.1 \times (\text{body wt in gm})^{3/4}.$$

Using the above expression the respiratory volumes for a 30 gm mouse, a 3 kg monkey, and a 70 kg man are 27, 850, and 9000 cc/min, respectively.

Dividing the average values given in Table 6.1 by the corresponding minute respiratory volumes gave values of 2.2×10^5 and 1.3×10^5 for the fission products deposited per cc of respiratory volume per minute by mice and monkeys respectively.

These values agree remarkably well considering the difference in size and respiratory anatomy of the two species and support the feasibility of extrapolating the data for monkeys to man. The results obtained for monkeys may be extrapolated to man merely by multiplying 1.3×10^5 by the appropriate minute respiratory volume. This calculation indicates that a man flying through the cloud from an atomic bomb under the conditions of this experiment would deposit in his lungs the fission products from 1.2×10^9 fissions. Concerning the relative importance of the internal hazard as compared to the external hazard, only an order of magnitude of agreement of the above data is essential to support the conclusion made later in the report.

The above result may be applied directly to general operational conditions for military aircraft. During the experiment the animals were in a pressurized compartment at a pressure approximately 5 psi above ambient conditions. The total pressure inside the exposure container when the drones were at 28,000 - 32,000 ft was about 10 psi which is approximately equal to the operational pressure in military aircraft. The total volume of the container was only 1 cu ft and the air flow rate was adjusted to provide approximately eight air changes per minute. Although the rate of air change in the exposure container was far greater than that for military aircraft, theoretical treatment of the effect of rate of air flow on the inhalation hazard inside the plane indicates that the hazard is relatively independent of the rate of turnover of cabin air, being slightly greater for higher rates of air flow.

Obviously the amount of fission products inhaled during passage will have an inverse linear relationship with the speed of the aircraft.

6.3.4 Internal Radiation Hazard from Inhalation

Three major factors must be considered in evaluating the internal radiation hazard from inhalation of radioactive material during flight through an atomic cloud. The first factor is that of radiation dose delivered to the lungs by deposition of the gross fission product mixture, second is the systemic radiation hazard resulting from absorption and local deposition of the relatively long lived nuclides such as Sr^{90}-Y^{90}, and third the alpha radiation hazard to the system and the lung from inhalation of unfissioned Pu^{239} and U^{235}.

Calorimetric measurements by Day and Cannon (5) indicate that the total energy release rate in the form of beta and gamma radiation from a mixture of fission products is given by the expression

$$E(t) = 5.1\ t^{-1.23} \qquad (6.4)$$

where E is the total energy release rate in Mev/sec/fission and t is the time since fission in seconds.

The maximum dose rate to tissue from the gross fission product mixture may be calculated by assuming uniform distribution of the fission products and total absorption of the radiation energy in the tissue or organ. The dose rate, d, in mrep/hr from the products of 10^6 fissions/gm of tissue as a function of time after fission (sec) is given by the following calculation:

$$d(t) = 5.1\ \text{Mev/sec/f} \times 10^6\ \text{f/gm} \times Kt^{-1.23} = 3.16 \times 10^5\ t^{-1.23} \qquad (6.5)$$

where $$K = \frac{3.6 \times 10^3\ \text{sec/hr} \times 1.6 \times 10^{-6}\ \text{erg/Mev}}{9.3 \times 10^{-2}\ \text{ergs/gm/mrep}}.$$

The above expression is plotted in Fig. 6.3 in which mrep/hr from the products of 10^6 fissions/gm is plotted against time after fission in seconds. Reference to this graph shows that the dose rate delivered to tissue from the products of 10^6 fissions/gm should be about 280 mrep/hr, 5 min after detonation. Taking 1.2×10^9 as the number of fissions producing the products deposited in the lung of a man during flight through the cloud at 5 min after detonation, the maximum dose rate delivered to 1000 gm of lung (assuming uniform distribution and total energy absorption) would be

$$\frac{1.2 \times 10^9 \times 280}{1 \times 10^3 \times 10^6} = 336\ \text{mrep/hr}.$$

By integrating the previous expression for dose rate an expression is obtained for the total dose D delivered over an infinite time to a tissue that picks up the products of 10^6 fissions/gm of organ at

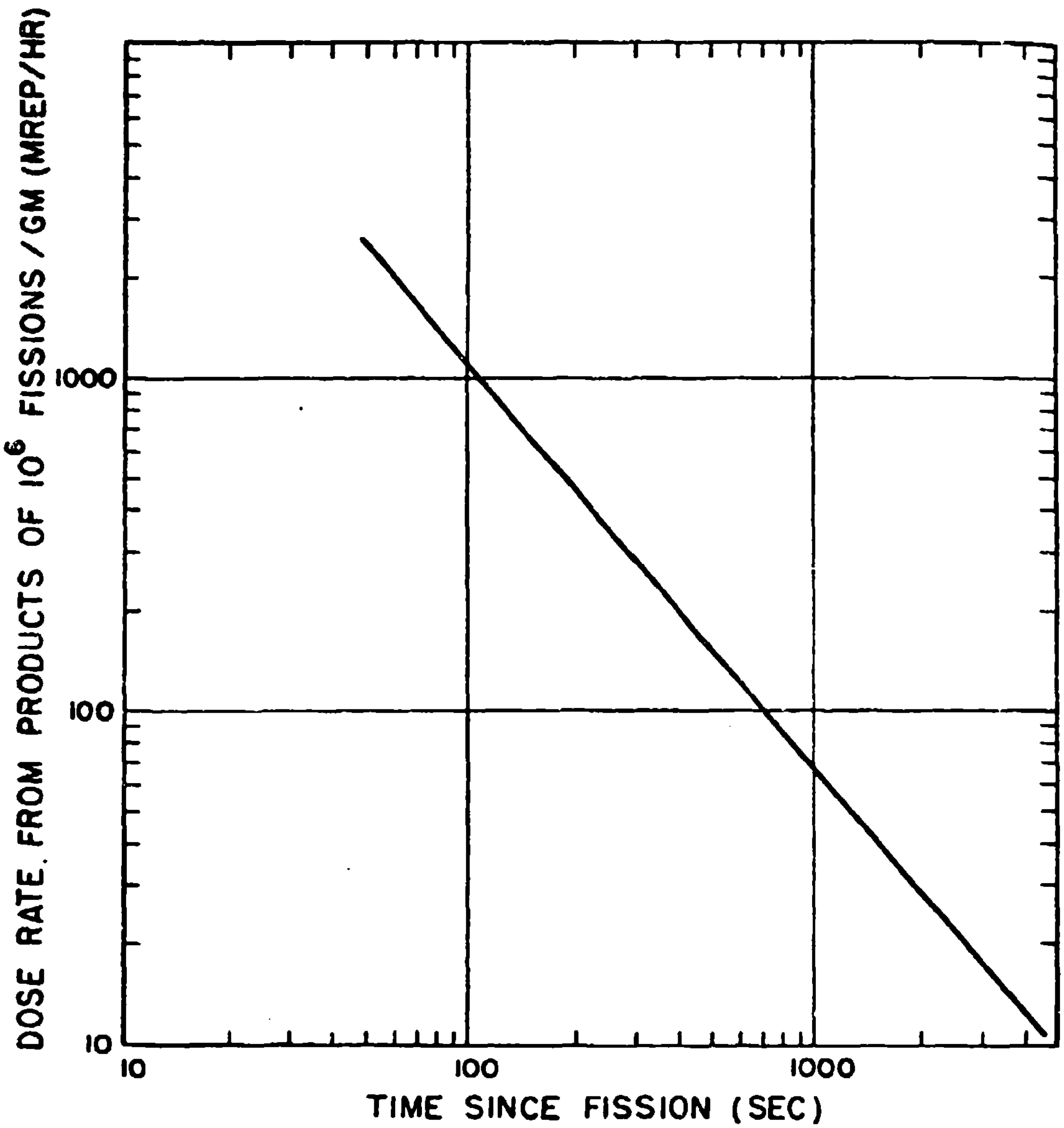

Fig. 6.3 Dose Rate to Tissue by the Gross Fission Product Mixture from 10^6 Fissions/gm as a Function of Time after Fission

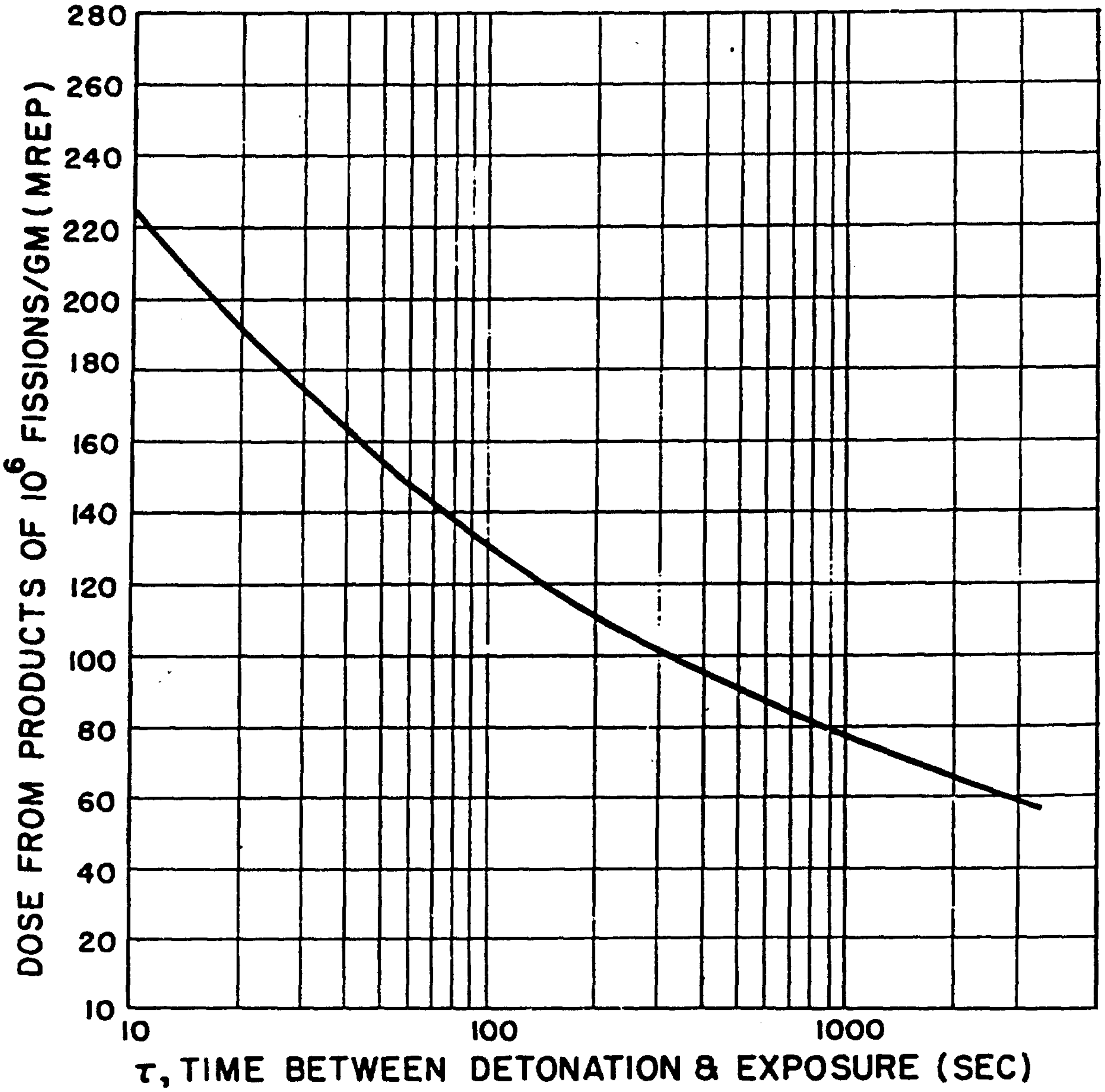

Fig. 6.4 Integrated Radiation Dose to Tissue by the Gross Fission Product Mixture from 10^6 Fissions/gm as a Function of Time after Fission

time τ (sec) after detonation. The integrated equation is as follows:

$$D = \int_{\tau}^{\infty} d(t)dt = 382\ \tau^{-0.23}\ \text{mrep}/10^6\ \text{fissions/gm}. \qquad (6.6)$$

The above expression is plotted in Fig. 6.4 and shows that the integrated dose from the products of 10^6 fissions/gm deposited at 5 min after detonation would be approximately 100 mrep.

Taking 1.2×10^9 as the number of fissions producing the fission products deposited in the lungs of a man flying through the cloud at 5 min after detonation the integrated radiation dose delivered to his lungs would be

$$\frac{1.2 \times 10^9 \times 100}{1 \times 10^3 \times 10^6} = 120\ \text{mrep}.$$

If an uncertainty factor of 2 is introduced to allow for the fractionation of Zr^{97} and Mo^{99} during the experiment then the maximum estimate of internal radiation dose to the lungs is 240 mrep. The maximum external radiation dose shown by the film packs was 29 r, therefore, the ratio of external to internal hazard from flight through the cloud at about 5 min after detonation is approximately 100/1.

The independence of external dose rate on bomb yield was explained in section 6.1 and was attributable to both total fission product yield and cloud volume varying linearly with kilotonnage, the concentration of fission products in the air being independent of bomb size. The total external dose therefore varies with bomb size only as the time of transit through the cloud varies. A similar situation holds for the internal hazard. Assuming ventilation normal for pressurized aircraft, the amount of respiratory uptake depends on the concentration of fission products in the cloud and on the transit time. Therefore, the ratio of external to internal hazard should be independent of kilotonnage. Likewise, since the radioactive decay of the fission products governs the time dependence of both the external and internal hazards their ratio is time independent. The above discussion applies only to those situations where the cloud radius is several gamma mean free paths, a condition fulfilled for all the shots considered.

The systemic hazard from absorption and deposition of the long lived fission products may be calculated from data given in Hunter and Ballou's (8) curves of relative fission product activity as a function of time after fission.

The most hazardous long lived nuclides are those formed in relatively high yield and which deposit in bone upon absorption into the systemic circulation. The Sr^{90}-Y^{90} pair is by far the most important. The present data show that a man in an aircraft flying through the cloud from Shot 9 at about 5 min after detonation would deposit in his lungs the fission products from about 1.2×10^9 fissions. Using 22 per cent absorption of the Sr^{90} from the lung (13) and the fission yield of Sr^{90} given by Hunter and Ballou (8), the calculated amount of these nuclides deposited in the skeleton would be 10^{-6} μc[a]. Comparison of the above result with the maximum permissible amount of Sr^{90}-Y^{90} of 1 μc recommended in the NBS Handbook 52 (13) shows the chronic hazard from this source to be quite negligible.

The next most important bone seeking nuclides are Ce^{144}-Pr^{144} which are less readily absorbed from the lung and only about one-sixth as hazardous as Sr^{90}-Y^{90}. These results indicate that the systemic hazard from lung absorption of the relatively long lived bone seeking fission products inhaled during flight through the cloud is insignificant.

The internal hazard from inhalation of unfissioned Pu^{239} or U^{235} may be shown to be completely negligible by taking Shot 4 as a specific example. Radiochemical determination of yield and calculation of the amount of Pu^{239} produced by neutron interaction with the tamper showed that the amount of unfissioned plutonium in the cloud was about

Estimation of the average fraction of the cloud that would be deposited in the lungs during passage gave a value of 4.2×10^{-16}. The amount of plutonium deposited would be that fraction of

The recommended maximum permissible amounts of plutonium in the lungs and in the bone are 0.8×10^{-2} μc and 4×10^{-2} μc, respectively.(13) Unfissioned U^{235} is even more insignificant.

The above considerations assume a nominal distribution of the inhaled activity within the body. Consideration has been given to the possibility that insoluble radioactive particles might be inhaled and deposited in the lung alveoli or pulmonary (hilar) lymph nodes and produce localized "hot spots." While the significance of such a possibility is as yet indeterminate, it is felt that the relative importance of this hazard is not sufficient to materially affect the conclusions drawn.

It seems reasonable, therefore, to conclude that the potential internal radiation hazard from inhalation is quite insignificant compared to that from external gamma rays. These insignificant internal radiation hazards may be minimized even further if desired by such operational practices as closing the aircraft ventilating system and wearing oxygen masks over the target.

6.4 PEAK TEMPERATURE

None of the individual elements of the temperature tapes which were selected to change color at various temperatures responded. This indicated that the temperature reached by the thin skin of the aircraft as it passed through the head of the cloud was less than 65°C.

---

[a] $$\frac{1.2 \times 10^{9} \times 2.7 \times 10^{-9}\ Sr^{90}\ \text{dis. min}^{-1}\ \text{fission}^{-1} \times 0.22 \times 2\ Y^{90}}{2.2 \times 10^{-6}\ \text{dis. min}^{-1}\ \mu c^{-1}}$$

$$= 0.6 \times 10^{-6}\ \mu c\ Sr^{90}\text{-}Y^{90}.$$

6.5 PRESSURE CHANGES IN THE CLOUD

The pressure measuring device installed in the drone aircraft that penetrated the Shot 9 cloud 5.2 min after detonation showed a pressure variation less than that corresponding to a change in altitude of 100 ft. It may be assumed, therefore, that no serious pressure differential and associated turbulence was encountered in the cloud at time of penetration.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

Data collected in the present and in past studies of conditions within an atomic cloud support a number of conclusions regarding the hazards to personnel flying through the cloud at relatively early times.

1. The average and maximum external gamma radiation dose rates within the cloud are dependent on penetration time and independent of kilotonnage for the range of conditions studied KT, 2.7 - 25 min, penetration altitudes of 16,000 - 32,000 ft and with bursts occurring near the surface of the earth). The average dose rate $\bar{D}$, in r/hr as a function of time after detonation may be estimated by the expression

$$\bar{D} = 1.31 \times 10^5 t^{-2.06}$$

where t is the time of penetration in minutes.

2. The integrated external dose received by flying through the cloud is dependent only on time of penetration (dose rate) and on the transit time through the cloud, the latter being dependent on cloud size and thus on kilotonnage. Total doses of less than 50 r may be expected upon flying through the clouds from detonations of 30 KT or less provided penetration times are not earlier than 4 min and the speed of the aircraft is 400 knots or greater.

3. The internal radiation hazard from inhalation of fission products during flight through the cloud is negligible compared to the external hazard. The ratio of the internal to external radiation dose is approximately 1/100 as an upper limit. The total internal dose is dependent only on the time of penetration (dose rate) and transit time and is independent of kilotonnage except insofar as cloud size and thus transit time is dependent on the bomb yield. The ratio of the internal to external hazard is independent of kilotonnage. The total internal radiation dose to the lungs from inhalation of fission products during flight through the cloud from a 30 KT bomb 5 min after detonation is about 240 mrep as an upper limit.

4. The internal alpha radiation hazard from unfissioned Pu^{239} and U^{235} is insignificant.

5. The internal radiation hazard from inhalation of long lived bone-seeking fission products, such as, $Sr^{90}-Y^{90}$ and $Ce^{144}-Pr^{144}$, is insignificant.

6. Penetration of the cloud resulting from bombs of 30 KT or less at times later than 4 min after detonation does not subject the plane and personnel to serious temperature or pressure changes.

7.2 RECOMMENDATIONS

On the basis of the present and past studies of the radiation hazards within an atomic cloud the following recommendations may be proposed.

1. It is recommended that no further studies of the relative internal hazard of flight through an atomic cloud be made. This is not intended to exclude laboratory studies on the possible effects of the deposition of insoluble radioactive particles in the lung alveoli and lymph nodes.

2. In the event of future studies of external gamma radiation dose rate and integrated dose in clouds from weapons up to 30 KT yield, it is recommended that consideration be given to the utilization of high-speed manned aircraft. The use of manned aircraft would provide more accurate data on area and altitude of penetration and transit time through the cloud. Such studies may also include evaluation of the shielding characteristics of the aircraft in the various crew positions. Especially attractive advantages of employing manned aircraft are the increased control, maneuverability and resulting ease of hitting the cloud, elimination of ground control radar facilities, and decreased probability of aircraft loss. It would permit utilization of a type of aircraft suited to extensive instrumentation and capable of flying well above 30,000 ft, a combination not available in present drone aircraft.