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STONEMAN II TEST OF RECLAMATION PERFORMANCE

VOLUME V

SOME CONTAMINABILITY CHARACTERISTICS OF PERSONNEL EXPOSED TO CONTACT BETA RADIATION

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ABSTRACT

The possibility of combat troops being caught in low level fallout fields and suffering from beta produced skin lesions lead to the investigation of possible parameters involved in exposure to beta radiation. Using realistic conditions, volunteers crawled several hundred feet through test areas contaminated with a dry synthetic fallout material. The contamination of the subjects was measured in terms of soil loading and beta dose from La^{140}. The sources contributing to the total beta radiation were: (1) the contaminated field, (2) contamination on the clothing, and (3) contamination on the skin. It was found that soil loading on the clothing was approximately 10 times that on the skin. However the clothing provided an attenuation factor of approximately 2 to beta radiation so that the contribution from the clothing was about five times that from the contamination on the skin itself. Crawling over dry, hard dirt resulted in a soil loading on the clothing approximately 20 percent greater than that obtained on a mowed, grassy field.

Two analytical procedures were employed to determine the beta dose. Although both procedures were found to have certain advantages in the analysis, a refinement of the analytical procedures is recommended for future tests.

SUMMARY

The Problem

In 1954, personnel living for two days in a fallout area produced by a test device in the Eniwetok Proving Grounds developed skin lesions attributed to beta irradiation, while receiving a sub-lethal gamma dose. Combat troops might be exposed to similar conditions of fallout in which the development of beta produced skin lesions could lead to an adverse affect on troops in the performance of their missions. Therefore, an investigation of the problem of contact beta dose (dose due to sources on skin and clothes) to troops that may be required to operate in fallout areas was investigated to (1) ascertain environmental factors which are important in determining this dose and (2) to develop techniques for evaluating relations between these factors and the contact beta dose.

Findings

Two major factors of importance in determining contact beta dose are (1) soil (fallout) loading on skin and clothes and (2) the beta dose rate to skin resulting from radioisotopes present in this soil. After volunteer subjects performed a combat crawl through a test area covered with synthetic fallout traced with La^{140}, these factors were measured at 16 locations on the body. Soil loading on exposed skin was found to be approximately 1/10 that of adjacent clothes. Soil loading was found to be somewhat sensitive to terrain, but varied widely among subjects. The mean soil loading accrued during a crawl maneuver at each of the 16 body locations studied varied from 0.4 to 13 mg/cm^2. The transmittancy of the beta radiation from the La^{140} traced soil on the clothes was 0.5 compared with depositions directly on the skin.

ADMINISTRATIVE INFORMATION

This investigation was sponsored by The Department of the Army as a part of the technical program for Fiscal Year 1959.

The work is described as Program B-3, Problem 3 in this laboratory's Technical Program for Fiscal Year 1959, as revised 1 January 1959. In this Volume results of objective (d) are presented. The other Volumes in this series of reports include:

Vol. I	The Production, Dispersal and Measurement of Synthetic Fallout Material
Vol. II	Performance Characteristics of Wet Decontamination Procedures
Vol. III	Performance Characteristics of Dry Decontamination Procedures
Vol. IV	Performance Characteristics of Land Reclamation Methods

ACKNOWLEDGMENTS

This test could not have been conducted without the men from the 50th Chemical Platoon of the 6th Army who volunteered to be test subjects. In addition, most of the analyses and film dosimetry was performed by men from the 50th Chemical Platoon and the Mobile Construction Battalion Five, USN.

CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

This report is Volume V in a series of reports describing the Stoneman II Land Target Tests. In this volume results of objective (d), "To determine the contaminability characteristics of combat troops exposed to contact beta-radiating contamination", are submitted.

1.2 BACKGROUND AND HISTORY

On March 1, 1954, several groups of Marshallese and one group of Americans were accidentally exposed to the fallout resulting from the detonation of a nuclear device. The Marshallese were exposed to the fallout and residual contamination from approximately H+4 until H+54 hrs. Approximately 20 percent of the Rongelap group developed lesions which might be considered as comparable to second degree thermal burns. The skin lesions observed were undoubtedly the result primarily of beta radiation from fallout material deposited on the skin.[1] This event showed that direct contamination of the skin with fallout from land surface detonations can result in beta lesions to a substantial portion of a population where the gamma radiation levels are not high enough to produce extreme illness or death for a limited exposure period.

The body tissue which is most sensitive to the beta radiation from fallout external to the body is the basal layer of the epidermis.[2] This layer is protected by approximately 10 mg/cm^2 of epithelial cells. This tissue can be expected to undergo the immediate changes of vesication and tissue breakdown when subjected to an acute beta dose of 30 - 100 kilorad.* Vesication and desquamation can be expected 1-5 weeks following an acute exposure of 2.5 kilorad.[2] The Marshallese from Rongelap, who received a calculated gamma dose of 175 r, but an unknown skin beta dose, showed various degrees of skin lesions beginning at 12 days after exposure.[1]

It would be convenient if beta dose rate to a subject could be estimated from known gamma fields. Some attempts have been made to estimate the dose to a subject on an infinite uniform radioactive surface.[3,4] The considerable

*1 kilorad = 1000 rad. 1 rad = 100 erg/gm absorbed dose

discrepancy between the data from a Nevada test[5] and theory was attributed to minor irregularities of the terrain. The problem of estimating beta dose rates on the basis of gamma measurements becomes very complex with the introduction of additional factors such as shrubs, grass, rocks, structures, etc., as well as radioactivity on the subject. An alternate method of treating the beta radiations that has been suggested is to consider it as a separate radiation problem which should be controlled with its own specialized instruments and techniques.[2]

1.3 BASIC PRINCIPLES

Beta particles of many common radioisotopes have a maximum range of approximately 1-cm in tissue and 1-m in air. This property makes the computation of dose to a surface from a source not in contact with the surface dependent on geometrical configuration and source energy. Furthermore, the theoretical approach to dosage computations is complicated by the scattering of betas as they interact with matter.

The beta-ray dose rate to tissue resulting from a thin uniform source in contact with the skin has been measured and related to the surface activity of the source by $I/G = K$, where K is a constant for a given backscattering material, and a given beta emitting radioisotope. Where beta-ray dose rate, I, is given in rad/hr, and surface activity density, G, is given uc/cm^2, K has been found to be 5.05 (rad/hr)/(uc/cm^2) for P^{32}.[6] If 1 uc is taken to be 3.7×10^4 beta-rays/sec, then for P^{32}, K is equal to 0.135 $\frac{\text{mrad/hr}}{\beta/\text{sec}/\text{cm}^2}$.

The beta-ray dose rate to a given area of the skin of personnel maneuvering in an area of loosely deposited beta-emitting material is due to deposits on three essentially independent surfaces: (a) the fixed surroundings, (described as environmental beta), (b) the clothing, and (c) the skin. It follows that the total beta-ray dose rate received by a given skin area is the accumulation of the dose rates due to each of these individual sources, and can be expressed as

$$I = I_e + I_c + I_s \qquad (1)$$

where I = total beta dose rate
I_e = environmental beta dose rate
I_c = beta dose rate from radioactive material on clothing
I_s = beta dose rate from radioactive material on skin

The total beta dose is then due to the dose rates integrated over the exposure times

$$D = \quad I_e\,dt + \quad I_c\,dt + \quad I_s\,dt \qquad (2)$$

The simplest beta dosage computation problem is that of calculating beta-ray dose rate to skin from beta emitters uniformly distributed in contact with the skin. As stated previously the relationship which has been found useful is

$$I_s = KG_s \qquad (3)$$

where G_s = surface activity density on skin (β/sec/cm^2)

K = Experimentally determined proportionality constant for a given radioisotope and ~~[illegible]~~ BACKSCATTERING material $\frac{\text{mrad/hr}}{\beta/\text{sec/cm}^2}$

Specific activity and soil mass loading can be introduced into equation (4) from

$$G = LMS_f \qquad (4)$$

where L = Surface mass loading of soil comprising the source (mg/cm^2)
S_f = Specific radioactivity of the synthetic fallout (β/sec/mg)
M = Dilution factor for synthetic fallout mixed with inert soil

$$M = \frac{\text{synthetic fallout mass}}{\text{inert soil mass + synthetic fallout mass}}$$

Equation (3) can be generalized by introducing transmittancy, J, so that the equation may be applied practically to problems where the beta emitters are on the environment and clothing:

$$I = K\,J\,L\,M\,S_f \qquad (5)$$

where J = Transmittancy, determined experimentally for each source-receiver combination, which includes the factors of geometry, absorption, scattering, etc. In this equation J is equal to 1.00 for uniformly distributed beta emitters in contact with skin if the source has negligible self absorption.

In using equation (5) with environmental dose rate, I_e, the mass loading, L, of the fallout on the terrain ~~would be determined~~, and no mixing was measured. was ~~would be~~ assumed. In using equation (5) with clothing dose rate, I_c, the mass loading, L, was assumed independent of mixing and specific activity, but dependent only on clothing fibre properties and soil properties.

1.4 SCOPE OF THE TEST

The scope of the test was limited to two general variables, which were chosen after preliminary experiments. These were (1) terrain (bare stabilized soil, and dry grass) and (2) length of maneuver (combat crawl 200 ft and 500 ft). In addition, two slightly differing analytical techniques were tested and used in obtaining the data.

CHAPTER 2

PROCEDURE

2.1 DESCRIPTION OF SYNTHETIC FALLOUT

The synthetic fallout used in these tests was Ambrose clay loam which was traced with lanthanum 140. La^{140}, which has a half life of 40.2 hrs., emits both beta and gamma rays, so that a variety of radiation detectors can be used for making measurements. Volume I of this series of reports describes in detail the design and preparation of the synthetic fallout material.

2.2 DISPERSAL OF SYNTHETIC FALLOUT

The synthetic fallout was dispersed over the test area with a mechanized spreader consisting of a Modified Burch-Hydron spreader geared to the drive wheels of a dump truck. Sample pans were set out prior to synthetic fallout dispersal to measure mass loading on the ground and specific activity of the deposited material. The test area was monitored for gamma radiation level with an AN/PDR-T1B or AN/PDR-27 after synthetic fallout spreading was complete.

2.3 TEST CONDITIONS

Personnel from the 50th Chemical Platoon of the 6th Army volunteered as subjects for this field test. They wore their own combat fatigues, cartridge belts and cartridge cases and carried mock weapons. They wore elastic guards on their elbows and knees. Gas masks (Mark 9) were also worn to prevent inhalation of synthetic fallout (See Appendix A).

The two terrains selected were bare stabilized soil and dry grass. To keep the mixing of the synthetic fallout with the soil to a minimum so that M in equation (5) would have a value near 1.0, the bare soil was watered then left to bake in the sun for two days before a test. The dry grass area was prepared by mowing and raking. The grass was left 6 to 9-in. tall.

The two combat crawling distances selected were 250-ft and 500-ft and the subjects followed typical combat crawling techniques.

Three preliminary runs (designated as Runs A, B, and C) served to ascertain that the maximum permissible radiation exposure to personnel would not be exceeded. The conditions of Run A were set, on the basis of the laboratory tests, to give radiation dosages at the lower limit of dosimeter film detectability. The synthetic fallout specific activity was increased for Runs B and C to bring the radiation level up to a point compatible to both radiological safety and film dosimetry. Run C was reserved as a contingency run and for training.

There were four subjects for each of the preliminary runs. They performed a 250-ft combat crawl (Fig. 2.1) over bare stabilized soil, and then the four subjects were processed as described below in Section 2.4.

The principle test consisted of six runs; three on each of the two types of terrain. Each run included two crawling distances and two analytical procedures. Each test area was 50 x 125-ft. Six subjects maneuvered on a test areas along lanes which prevented their crawling over the same area more than once.

2.4 MEASUREMENT TECHNIQUES

2.4.1 Specific Activity Measurements

Soil samples of the test area surface were collected before and after each run to measure specific activity. These samples were collected by placing the entrance of an air sampler close to the ground until approximately 5 gm was collected on the filter. The material was then scraped from the filter into a weighing bottle for gamma radioassaying and weighing.

2.4.2 Beta Dose Rate Measurements

Measurements of beta-ray dose rates were made by exposing, for known times, suitable photographic films and calculating dose rate from film density. Dupont dosimeter films 555 and 510 were procured in conventional dental-sized light-tight packets. The lower portion of each packet was shielded by a 0.025-in. thick lead shield so that gamma ray dose could be measured and subtracted from the open-window film reading. The film packet was protected from moisture and contamination by a polyethylene envelope. Film exposure density was read from six pre-selected locations on each film, three from the open-window portion and three from the lead-shielded portion, using either of two Macbeth-Ansco densitometers. A density vs. dose plot was obtained by exposing these films to a La^{140} source calibrated with an

Fig. 2.1 Subjects Performing Combat Crawl on Bare Stabilized Soil Contaminated With Synthetic Fallout

extrapolation ionization chamber similar in design to that of Loeringer.[7] Six to ten dosimeter films with graded known exposures to the La^{140} source were developed with each lot of test run films as a process control measure.

The radiation doses considered were environmental beta dose, clothing beta dose, and skin beta dose. Two beta dosage measurement procedures were employed to measure these doses. Procedure I measured total beta-ray dose during the maneuver and beta-ray dose from both skin and clothes absorbed during an interval following the maneuver. Prior to maneuvers two sets of dosimeter films, Set A and Set B, were applied face out to the skin of the subjects at preselected locations on the body, shown in Fig. 2.2 and Table 2.1. Set A was removed upon the subjects emerging from the test area after less than a quarter hour's exposure. Set B remained in place for 5 to 6 hours. Since the time spent in the test area was insignificant compared to the total dosimetry period, essentially all of the measured dose was due to contamination on the clothes and skin. The overall procedure is diagrammed in Fig. 2.3.

TABLE 2.1

Dosimetry Film Schedule for Determining Beta Contribution of the Various Sources

Set No.	Purpose	Subject and Position	Location	Exposure Time
A	Total Dosage During Maneuver	Skin face out	Test area during maneuvers	1.2 hr
B	Total Dosage	Skin face out	Test area during maneuvers and dosimetry area	5 hrs
C	Dose from skin contamination	Skin cast face down	Dosimetry area	2 days
D	Dose from clothing contamination	Phantom face out	Dosimetry area dress in contaminated clothing	2 days
E	Dose from distributed source on the ground	Phantom face out	Test area after maneuvers	1 day

Procedure II, diagrammed in Fig. 2.4 measured the three component beta doses separately. Subjects were only radiological safety dosimetry, Set A, during the maneuver. The dosimetry film schedules, Table 2.1, followed when they returned to the analysis building. Their clothes were removed and placed on phantoms (Fig. 2.6) outfitted with dosimeter film Set D to measure the dose from contamination on the clothing. These phantoms were mannequins covered with 5/8-in. polyethylene jackets to give beta scattering and absorption similar to that of a human body. Skin casts (Fig. 2.7) to remove soil from skin without disturbing the soil distribution (Appendix B) were made at the locations on the body shown in Fig. 2.5. The casts were mounted face up on a laminated phenolic board. Dosimeter film Set C was placed face down in contact with the casts to measure skin dose and to radioautograph the distribution pattern of the radioactive particles. These film sets were exposed for two days. Phantoms 60-in. tall x 16-in. wide were outfitted with dosimeter film Set E covered with herringbone twill cloth and set up in the test area to measure environmental beta dose. These phantoms were 1-in. sheet masonite. Film Set E was exposed for about 1 day.

Fig. 2.2 Clothes Sampling Locations

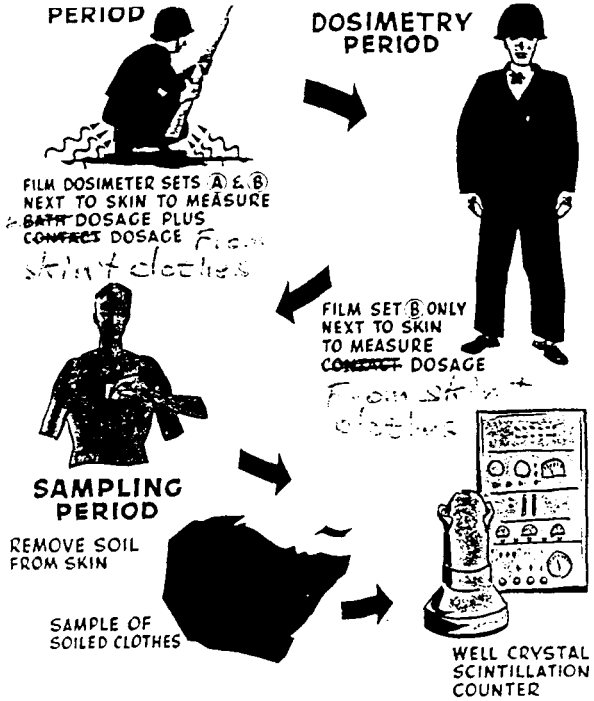


Fig. 2.3 Beta Dosage Measurement Procedure I and Local Radioactity Measurement Procedure

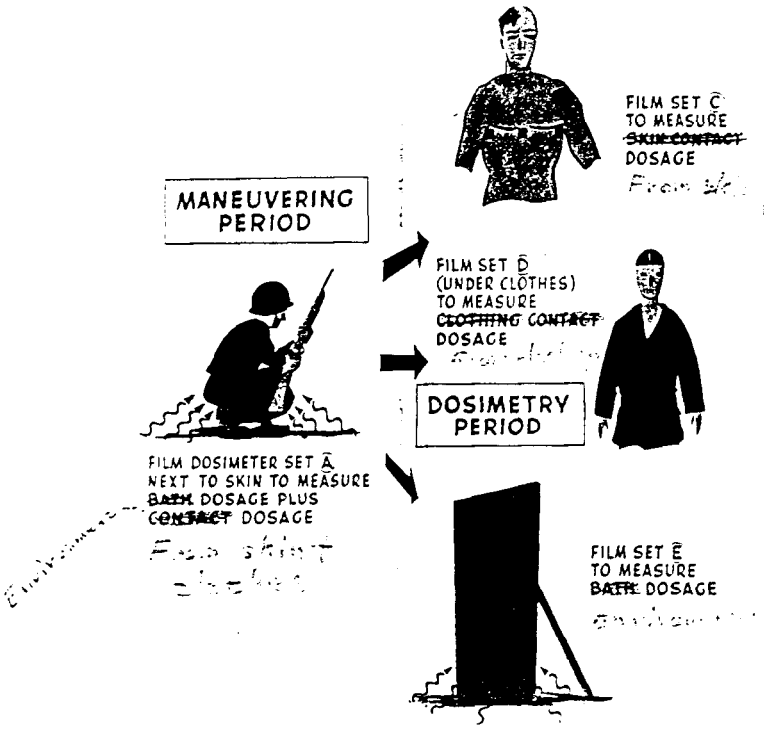


Fig. 2.4 Beta Dosage Measurement Procedure II

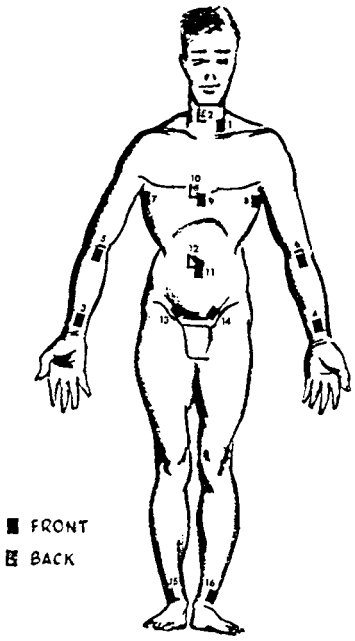


Fig. 2.5 Skin Cast And Dosimeter Film Locations

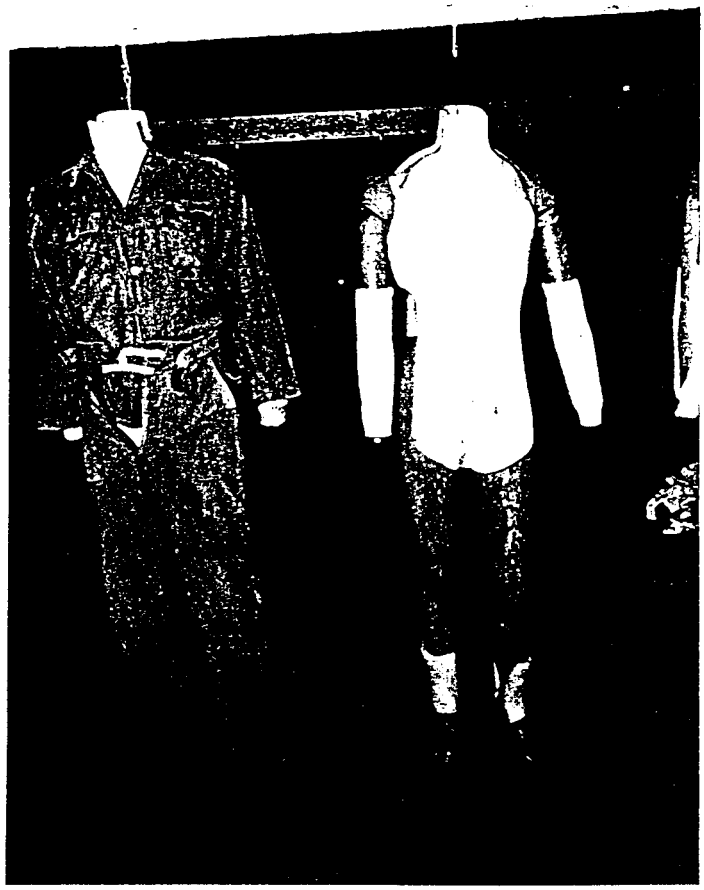


Fig. 2.6 Phantoms, Prior to dressing and after dressing with contaminated clothing

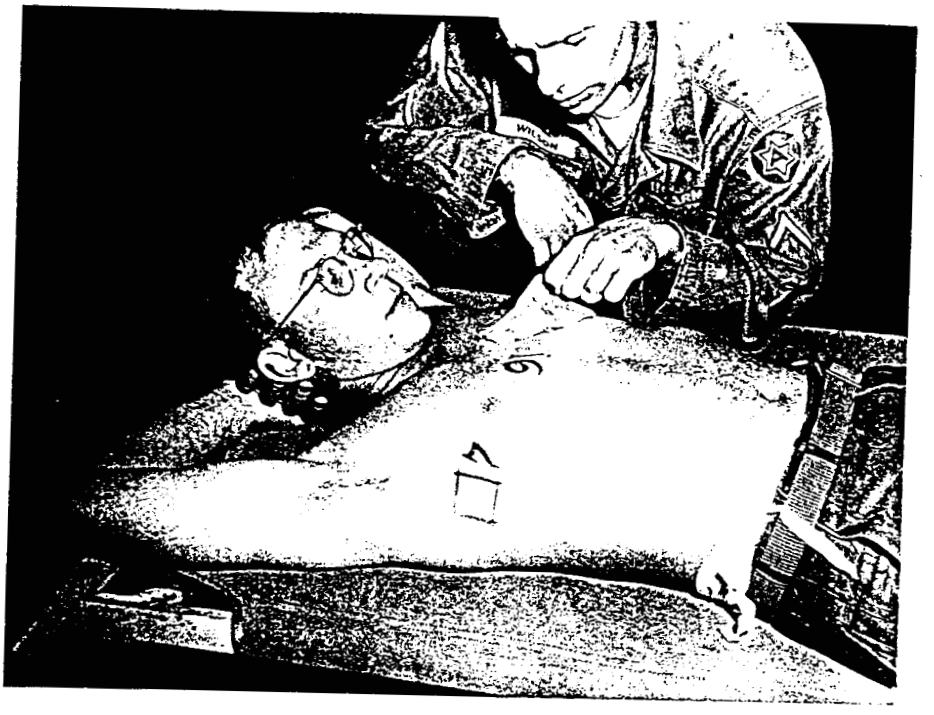


Fig. 2.7 Skin Cast Being Removed From Test Subject

2.4.3 Surface Activity Density Measurements

Surface activity density was measured at the conclusion of the dosimetry period by cutting away 2 x 1-1/2-in. clothing samples and making 1 x 1-1/2-in. skin casts (Appendix B) directly over dosimeter films and then gamma radioassaying these samples. Samples were taken from subjects analyzed by both beta dosage measurement procedures. Locations are shown in Fig. 2.2. The expressions for calculating surface activity density (at base time), G_o, is

$$G_o = \frac{C_1 A_t e^{\lambda t}}{lw} \qquad (6)$$

where C_1 = geometry factor of gamma radioassay instrument (betas/count)
A_t = sample activity at the time of counting (count/sec)
t = time of counting (hrs after base time)
lw = area of sample (cm^2)
λ = decay constant (0.017/hr for La^{140})

Sample mean soil loading, L, was calculated from

$$L = \frac{G_o}{S_o} \qquad (7)$$

where S_o = specific activity at base time (betas/sec/mg)

2.4.4 Respiratory Measurements

Nostril swabs of each subject were taken before and after each test run to indicate the possible presence of radioactivity in the nostril.

Gas mask cannisters were radioassayed following each test run. The soil mass collected in the cannister during the test run was calculated on the basis of an empirical calibration of the gamma radiation counter.

2.4.5 Radiological Safety Procedures

Radiological safety procedures which were employed are described in Appendix A.

CHAPTER 3

RESULTS

3.1 BETA DOSE RATES

Clothing beta dose rates were related to surface activity density of the clothes through equations (4) and (5), in the form $J = I/KG$. (The K value for La^{140} is 0.182 $\frac{mrad/hr}{\beta/s/cm^2}$, based on laboratory experiments). Table 3.1 gives the transmittancy of La^{140} through clothes.

The transmittancy data of the beta radiation from the level terrain were plotted vs mass loading for each height above the terrain. Smoothed curves were fitted to the data points and transmittancy values for 30 mg/cm^2 and 40 mg/cm^2 were obtained by interpolating along these curves. The transmittancy values for these two mass loadings were then replotted vs height above the terrain, (Fig. 3.1).

3.2 SOIL LOADING

Soil loading on skin and clothes was calculated from soil specific activity and unit area activity of skin and clothes using equation (7). The data for the 250-ft and 500-ft crawl distances were combined, as no difference in soil loading due to distance (see Figs. 3.2 and 3.3) was evident. The results are presented in Table 3.2 and Figs. 3.2 and 3.3.

A print (magnification 4X) of a dosimeter film in direct contact with a skin cast is shown in Fig. 3.4.

3.3 GENERAL RESULTS

The test runs were made in the morning at approximately 0830; ambient temperature was approximately 65°F. The mean times required by the subjects to crawl 250 ft was 4.4 min; 500 ft, 9.5 min. The mean specific activity and mean mass loading of the synthetic fallout as dispersed on the test areas are given in Table 3.3. The mean beta radiation dosages received by the subjects in the course of Runs A, B, and C, used for establishing test conditions of the principle test runs, are given in Table 3.3.

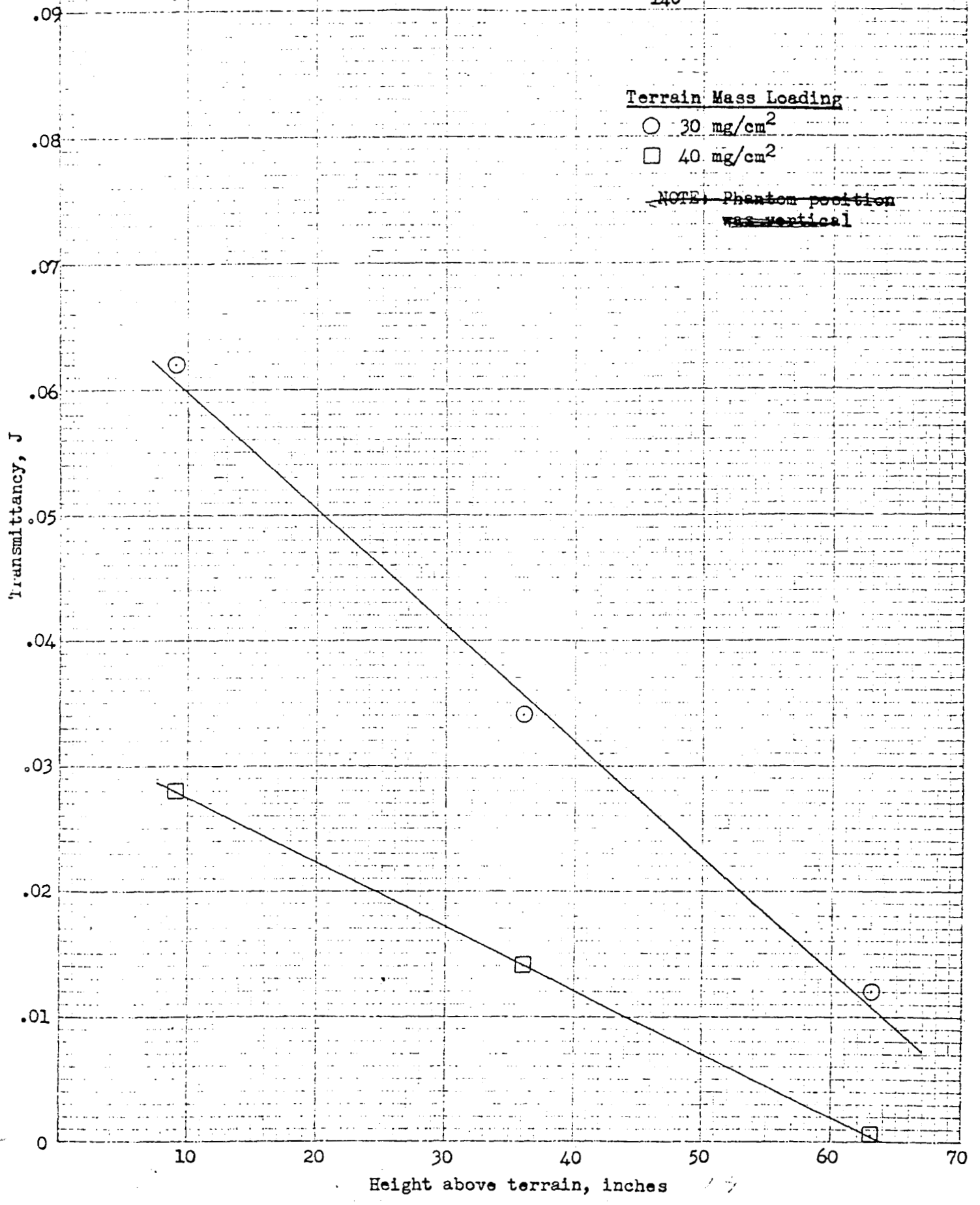
TABLE 3.1

Transmittancy of La^{140} Traced Synthetic Fallout on Clothes

	Location	Transmittancy ~~Efficiency~~, γ(a)
1	lapel	0.5
2	collar, back	0.4
3,4	jacket cuffs	0.8
5,6	inside elbows	2. (b)
7,8	below armpits	1. (b)
9	mid chest	0.5
10	mid back	0.6
11	belt, front	0.4
12	belt, back	0.6
13,14	groin	0.6
15,16	ankles	0.3

a. Standard deviation is approximately ± 200%
b. These areas were adjacent to heavily soiled areas (see Discussion).

FIG. 3.1. Beta radiation transmittancy values vs. height above dry, hard terrain contaminated with La_{140}.



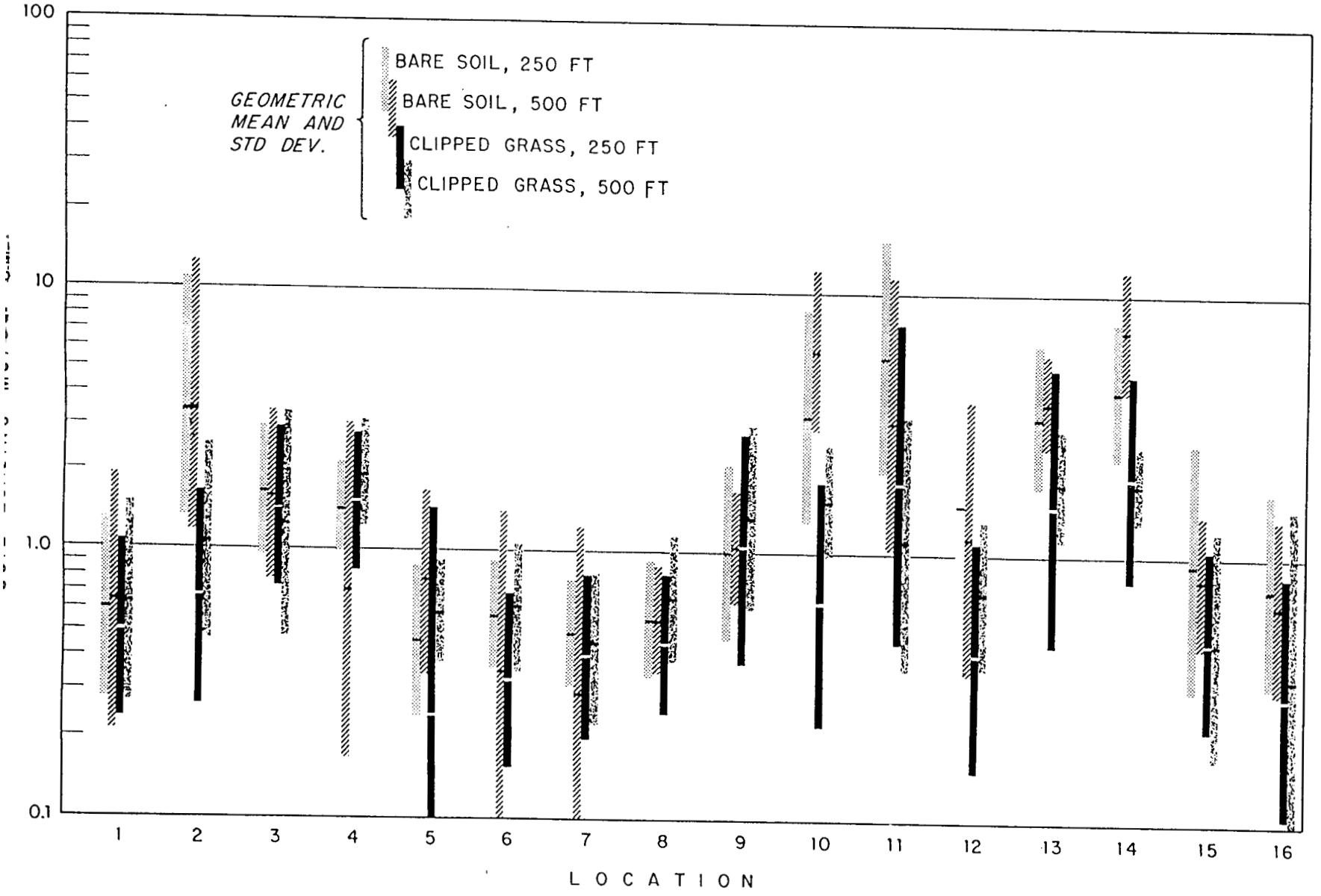


Fig. 3.2 Soil Loading On Clothing After Combat Cond

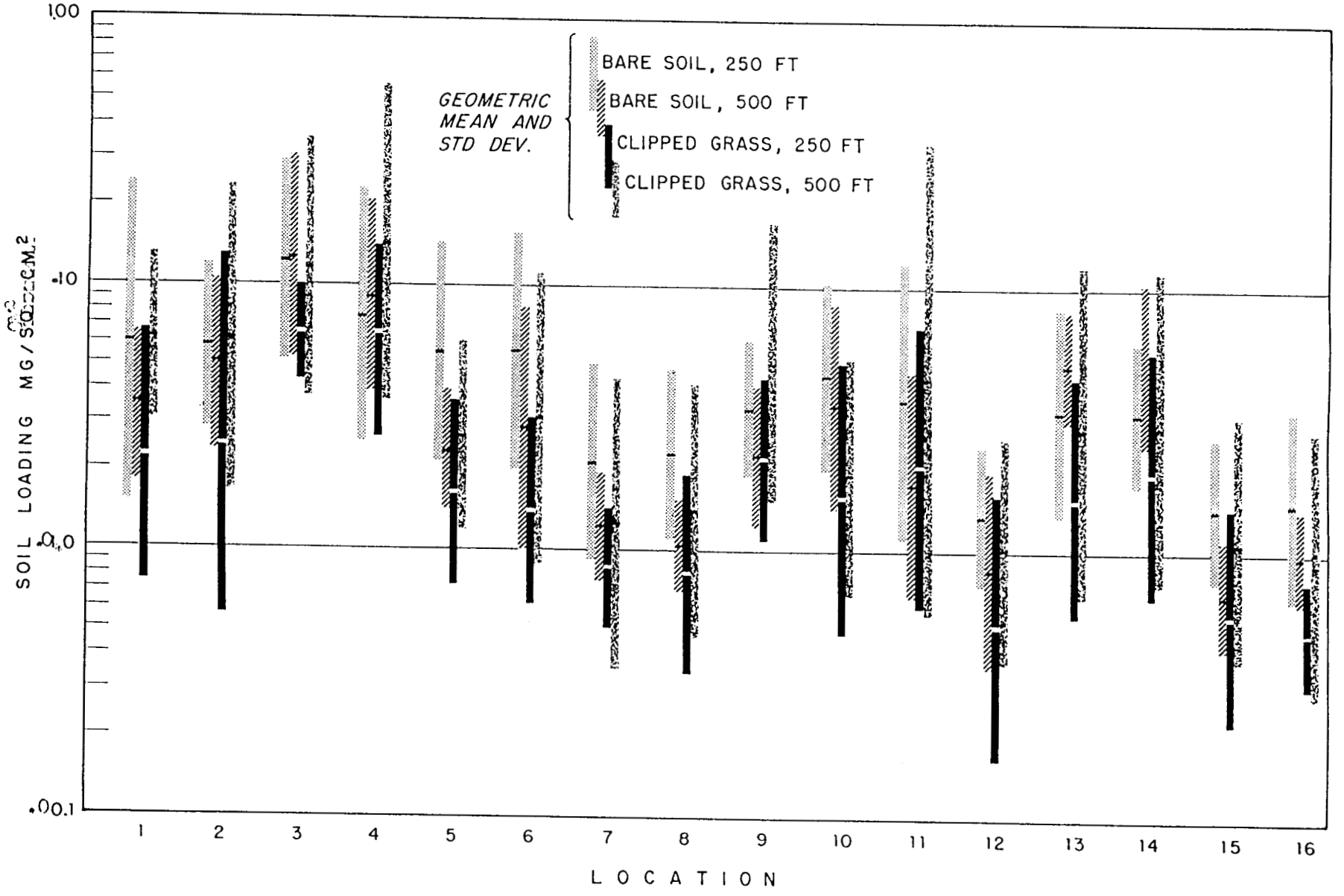


Fig. 3.3 Soil Loading On Skin After Combat Crawl

TABLE 3.2

Soil Loading on Skin and Clothes Following Combat Crawl Maneuver. Figures in table give geometric mean of mass loading in mg/cm^2.[a]

Location		Bare Soil		Stubble Grass	
		Skin	Clothes	Skin	Clothes
1	neck, side	0.05	0.6	0.04	0.6
2	neck, back	0.05	4.	0.04	0.9
3,4	wrists	0.1	1.	0.1	2.
5,6	inside elbows	0.04	0.5	0.02	0.4
7,8	below armpits	0.02	0.5	0.01	0.5
9	chest	0.03	1.	0.04	1.
10	back	0.04	5.	0.02	1.
11	belt, front	0.03	5.	0.03	2.
12	belt, back	0.01	1.	0.01	0.6
13,14	groin	0.04	5.	0.02	2.
15,16	ankles	0.01	0.8	0.01	0.4
	knee[b]	-	13.	-	5.
	elbow[b]	-	8.	-	1.

a. Standard deviation is approximately ± 150%.
b. Data from Run 3 only.

TABLE 3.3

Synthetic Fallout Mass Loading and Specific Activity on Test Area

Run	Terrain	SFO Mass Loading (mg/cm²)	SFO Specific Activity (β/s/mg)	Test Area Surface Soil Specific Activity (β/s/mg)	Radiation Level, 3 ft. Gamma (mr/hr)	Observed β Dose to Test Subjects ~~Min.~~/Mean (rad)	Max. (rad)
A	Bare Soil	34.1	114	* 185	28	.113	.383
B	Bare Soil	45.[illegible]	498	245	126	.613	2.400
C	Bare Soil	51.2	517	453	152	.260	1.020
1a	Bare Soil	44.1	408	396 ± 150	-		
1b	Grass	40.6	388	415 ± 153	-		
2a	Bare Soil	39.6	420	349 ± 116	140		
2b	Grass	45.0	427	* 744 ± 125	114		
3a	Bare Soil	25.3	365	205 ± 077	87		
3b	Grass	28.3	367	339 ± 025	122		

*High values believed due to preferential pickup of finer particles.

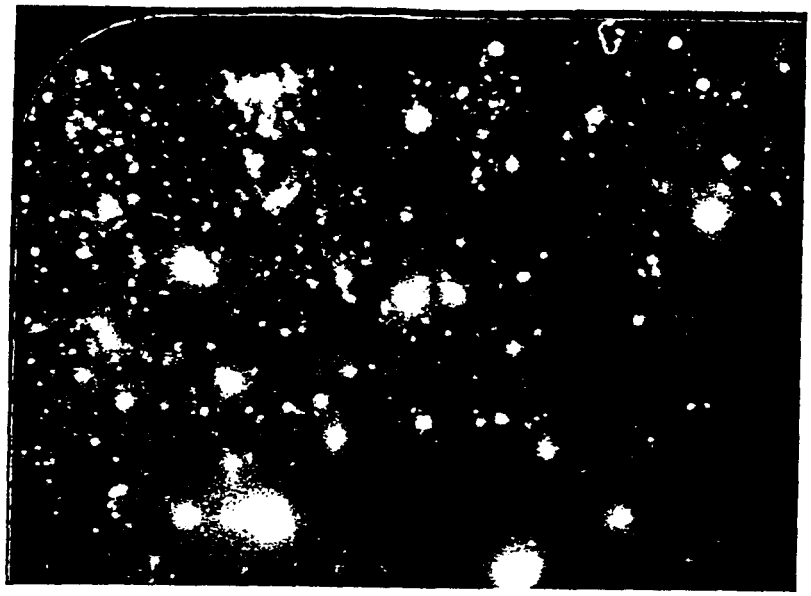


Fig. 3.4 Radioautograph Print of Skin Cast From Groin Sampling Location, ~~[illegible]~~ X4

The results from Run A showed that specific activity could be increased by a factor of four while keeping within the established 15 β rad maximum permissible level.

The results of Run B approached the optimum conditions for the test runs: with a synthetic fallout specific activity of 500 β/sec/mg the mean exposure was 0.6 β rad, well into the "quantitative region" of the dosimeter film; and the maximum exposure (one film only) was 2.4 β rad, well below the established maximum permissible level.

Nostril swabs taken before and after the maneuver of Test Runs 2 and 3 showed approximately 30 ugm soil in nostrils. The gas mask canisters showed a mean retention of 270 mg of soil with a minimum value of 42 mg and a maximum of 1300 mg.

Only one urine specimen showed significant radioactivity above background: after Run 3, one subject showed a count of 3462 ± 64c/min in one 24 hr. urine sample.*

*H.V. Weiss, USNRDL Memo to W.L. Taylor, 22 Sept. 1958.

CHAPTER 4

DISCUSSION OF RESULTS

4.1 SOIL LOADING

Table 3.2 and Figs. 3.2 and 3.3 indicate that the soil loading resulting from crawling through cropped grass was approximately 60 percent that from bare soil. The grass apparently acted as both a brush and a cushion between the body and loose soil and thereby lessened soil buildup somewhat. These tables also show that exposed skin was loaded only approximately 10 percent as heavily as the adjacent clothing and, as expected, covered skin was even less soiled.

The elbow and knee areas showed the highest soil loading. These data were collected for Run 3 only. As elbow and knee pads were worn under the clothing there may be a bias to the results; therefore, they were not used to draw conclusions.

The broad spread of the individual soil load values about the mean for a given sample location at one set of test conditions is much greater than that attributable to sampling techniques and instrumentation. This spread in the data is interpreted to be a result of physiological and personal differences among the test subjects. In addition, the movements of any one test subject did not appear to follow a uniform pattern of motion during the maneuver so as to yield data for the study of this factor. Perspiration was noted visually to have a marked effect on soil loading of the skin. Those subjects whose skins were dampened by perspiration showed higher soiling temporarily; however as soon as the skin dried, much of this soil dropped from it. No dampening of clothes due to perspiration was noted. Had the test runs required sustained exertion over a longer period, perspiration probably would have affected the soil loading on clothes.

The minimum soil loading of clothes which was visible was approximately 0.5 mg/cm^2. The maximum soil loading which did not appear to be "caked" was approximately 5 mg/cm^2. With the aid of prepared standard of soiled cloth and trained personnel, it should be possible to obtain rapid estimates of soil loading on clothes accurate to $\pm$ 50% within this range.

4.2 DOSIMETRY

Dosimetry checks were made by re-reading and re-calculating randomly chosen small groups of dosimeter films using different instruments and different technicians. Agreement for the Dupont 555 films was ± 0.045 rad or ± 3.5%, whichever was greater. Agreement for the Dupont 510 film was ± 3 rad. This uncertainty became very important in the environmental beta measurements, where gamma radiation dose was greater than the beta dose, as the beta radiation dose was determined by difference.

The accuracy of the transmittancy, J, is dependent upon the ratio of the beta dose rate and surface activity density as well as the location of the film with respect to the soiled clothing sample. The problem of location was minimized by cutting away the clothing sample directly over the dosimeter film before removing the film.

Factors which contributed to the distribution of the individual transmittancy factors about the mean for a given sampling location are weight of the cloth, number of cloth layers, distribution of soil throughout the cloth, and spacing between the cloth and skin. Differences in soil loading on areas bounding the sample location also contributed to the variability of the individual transmittancy factors. No quantitative data were collected which would be useful in evaluating the relative importance of these factors; however, ~~Fig. 3.5 shows that in some cases soil loading was very [illegible]~~ It is a well known fact that soil loading on clothes often appears very [illegible]

The transmittancy factors reported for the sample location inside elbow and below armpit (Table 3.1) were influenced by high soil loading of the immediate surroundings which added to the dosage due to soil on the cloth covering the films, thereby giving an apparent transmittancy greater than 1.00.

The films of Set 3 indicated low mean dosage and spotty distribution. A few exposures made in a dark room with the film in contact with the skin cast clearly show the skin pattern (Fig. 3.4). Because of this dosage distribution, the skin mean soil loading results of Table 3.2 should consider this distribution. Although the mean soil loading is relatively low, the spotty distribution shows that small areas of skin were subjected to high dosage. The dosimetry technique used cannot yield quantitative data on germinal layer dose from near-point sources on the skin surface because of geometrical problems. The germinal layer is shielded from soil by approximately 10 mg/cm^2 of epithelial cells while one emulsion of the film has no shielding, and the other has 30 mg/cm^2.

The transmittancy results of this test for environmental beta dose are much lower than those given in a theoretical study.[3] Three factors in this test which may account for the difference are (1) the lower maximum

beta energy (2.51 mev compared to 4.0 mev of Reference 4), (2) the roughness of the terrain (compared to the ideal plane of Reference 4) and (3) the mass loading of synthetic fallout on the terrain (compared to the negligible mass loading of Reference 4). The lower maximum energy of the beta radiation would result in much more attenuation with distance. The terrain roughness and mass loading both would result in self-absorption that would also attenuate the intensity of the beta rays.

4.3 DOSAGE ANALYSIS PROCEDURES

4.3.1 Analytical Procedure I

The beta dosage measurement Procedure I had the advantage over Procedure II because it involved the least disturbance of the soil loadings on the skin and clothing of the subject after the maneuver through the synthetic fallout. (The films of Set A were attached to cords. A sharp tug on the main cord was all that was necessary to remove this film set). However, the tincture of benzoin liquid adhesive, which was necessary to fasten films to the skin of the subjects, became noticeably soiled, and thereby interfered with making skin casts. Also, the contact dosage to film Set B was lower than that of the Set D film of Procedure II due to the shorter exposure time, and in addition, Set B films had a higher radiation background due to their being worn during the maneuver through the synthetic fallout. The latter two factors combined to make the Procedure I dosimetry data less reliable and more difficult to interpret than Procedure II dosimetry.

4.3.2 Analytical Procedure II

Beta dosage measurement Procedure II had the distinct advantage of a 2 day (controlled) dosimeter film exposure period which permitted adequate film exposure without greatly complicating the test procedures. There was no obvious disturbance and redistribution of the soil on clothes and skin as a result of removing the clothes from the subjects and placing them on the phantoms. The fit of the clothing on the phantoms was not as natural as on the subjects, but the effect of this on the values of the transmittancy factors when compared to those calculated from Procedure I data was not apparent.

4.3.3 Refinement of Analytical Procedures

The measurement techniques could be extended in future tests to include greater detail in the data. For example, the effect of irregular clothing contamination upon skin dose could be better documented by photographing portions of the clothing and then cutting away relatively large (10 x 10 in.)

samples and placing these as naturally as possible, under safelight, against a sheet of radioautograph film on a phantom. Promptly following radioautograph exposure, a full size print of the photo and the radioautograph would be compared with the sample for the selection of suitable small samples for radioassay. The results of the radioassay then could be related to the dose rate, as has been done in this report. A similar technique could be applied to studying the soil on exposed skin. This more detailed approach coupled with a very careful appraisal of the actions and physiological peculiarities of the test subjects would afford a better opportunity for determining the factors responsible for the broad spread in the data of the present test.

A direct measure of the mean mass loading of the soil on clothing areas appears possible by refining the ignition techniques used in this test to reduce sample volume (Appendix D) and by controlling more accurately the size of the sample area. The basis for this suggestion is that there is approximately 5 percent weight loss of soil and greater than 95 percent weight loss of cloth upon ignition: almost all that remains from the ignition is soil. This technique would also enable one to obtain accurate clothing-soil specific activity data.

4.4 SYNTHETIC FALLOUT

Laboratory testing of the synthetic fallout has demonstrated that the La^{140} tracer becomes absorbed onto the soil particles and provides an accurate tracer of the soil under physical and chemical conditions of greater severity than those encountered in this test.*

The data of Table 3.3 comparing synthetic fallout and test area specific activity is interpreted as indicating little overall mixing of synthetic fallout with the non-traced test area soil. Therefore the test area soil stabilization was sufficient from the standpoint of experimental control. If much non-traced soil had mixed with the synthetic fallout, interpretation of the data would have been more difficult. The spread in the data on test area specific activity is attributed to irregular local mixing of small quantities of non-traced soil with synthetic fallout.

The use of the stabilized soil and dry grass areas in the tests, however, leaves unanswered the question of the degree to which fallout might mix with the natural soil during a maneuver such as was used. Factors such as available loose soil, fallout mass loading, mechanical action, wind, rain, time after deposition and fallout particle size distribution as compared to that

*Wiltshire, L.L., et al, "The Adsorption of La^{140} on Ambrose Clay Loam", USNRDL TM-67, 3 Jan. 1957.

of the soil are undoubtedly involved. The study of the affinity of particles for cloth vs. particle size, coupled with the particle size distributions of fallout and soil, could also lend additional information to the importance of this kind of mixing or dilution as well as to the retention of the soil particles on skin and clothing.

CHAPTER 5

APPLICATION OF DATA

Application of the data to a stated exposure to fallout is given here in the form of an example computation to illustrate one possible procedure for estimating beta dose to personnel. The conditions of exposure are taken to be as follows: two groups of troops enter a fallout area 24 hrs. after burst and, to accomplish a mission, are required to maneuver over a bare stable soil; the specific activity of the fallout in the area is 10^{11} fissions*/mg, and the fallout mass loading on the terrain is 30 mg/cm^2, equivalent to approximately 2300 r/hr at 1 hr after burst. Group A remains in the fallout areas; Group B leaves the fallout area after 2 hrs, but does not dust its clothes nor clean up.

Two major assumptions were made in the computations: (1) there is no mixing of the fallout with soil; and (2) the fallout has approximately the same beta energy spectrum as La^{140}.

The doses were calculated for locations 13 and 14 (groin). This location was chosen since it was found to be one of the locations most likely to be heavily loaded with soil (fallout dust), and beta lesions in this region would be very effective in reducing personnel efficiency.[8]

The doses due to beta and gamma were calculated by integration using data based on unfractionated mixed fission products of U^{235}.[9] Dose rates were calculated from the experimental results using the formulae presented in Section 1.3.

The environmental beta dose rate is given by:

$$I_e = K\, J_s\, L_e\, S \qquad \text{(eq. 6)}$$

$$K = 0.182\ \frac{\beta\ \text{mrad/hr}}{\beta/\text{sec/cm}^2} \quad \text{from Section 3.1}$$

*1 fission = 2 radioactive atoms of fission products produced at zero time; therefore 10^{11} fissions/mg = 2×10^{11} atoms of fission products per mg of fallout.

$J_e = 0.034$ from Fig. 3.1, 36-in. high, 30 mg/cm^2 soil loading

$S = \frac{.0279\ \beta/\text{sec}}{10^4\ \text{fissions}} \times 10^{11}$ fissions/mg at H+24 hrs (Ref. 9)

$I_e = 0.182\ \frac{\beta\ \text{mrad/hr}}{\beta/\text{sec/cm}^2} \times (0.034) \times (30\ \frac{\text{mg}}{\text{cm}^2}) \times (\frac{.0279\ \beta/\text{sec}}{10^4\ \text{fissions}} \times 1 \times 10^{11}\ \text{fissions/mg})$

$I_e = 51.8\ \beta$ rad/hr at H+24 hrs.

The beta dose from radioactive material on clothing is given by:

$$I_c = K\ J_c\ L_c\ S \qquad \text{(eq. 5)}$$

and the beta dose from radioactive material on skin is given by:

$$I_s = K\ L_s\ S \qquad \text{(eq. 3 and 4)}$$

K and S have been given previously.

$J_c = 0.6$ from Table 3.1 location 13, 14.

$L_c = 5.$ mg/cm^2 from Table 3.2, location, groin (clothes)

$L_s = 0.04$ mg/cm^2 from Table 3.2, location, groin (skin)

$I_c = 0.182 \times 0.6 \times 5. \times \frac{.0279 \times 10^{11}}{10^4} = 152.0$ rad/hr

$I_s = 0.182 \times 0.04 \times \frac{.0279 \times 10^{11}}{10^4} = 2.2$ rad/hr

The gamma doses were calculated in a similar manner from data of Ref. 9. In calculating gamma dose due to soil on clothes, the value for K was obtained by multiplying K given in Ref. 9 by 0.5.

The calculation results are plotted on Fig. 5.1.

Figure 5.1 shows that the rate of increase of gamma dose is sharply arrested when the subjects of Group B leave the fallout area, but the rate of increase of the beta dose remains substantially the same due to the fallout on clothing.

The accumulated beta doses for Group B, which left the fallout area after a 2-hr stay time have been replotted in Fig. 5.2. However, in this figure only the interval including the standard deviation is indicated. This interval includes the estimated dosage absorbed by 2/3 of the group. Or, to view the problem from another standpoint, 1/6 of the group would be expected to absorb dosages in excess of the upper boundary.

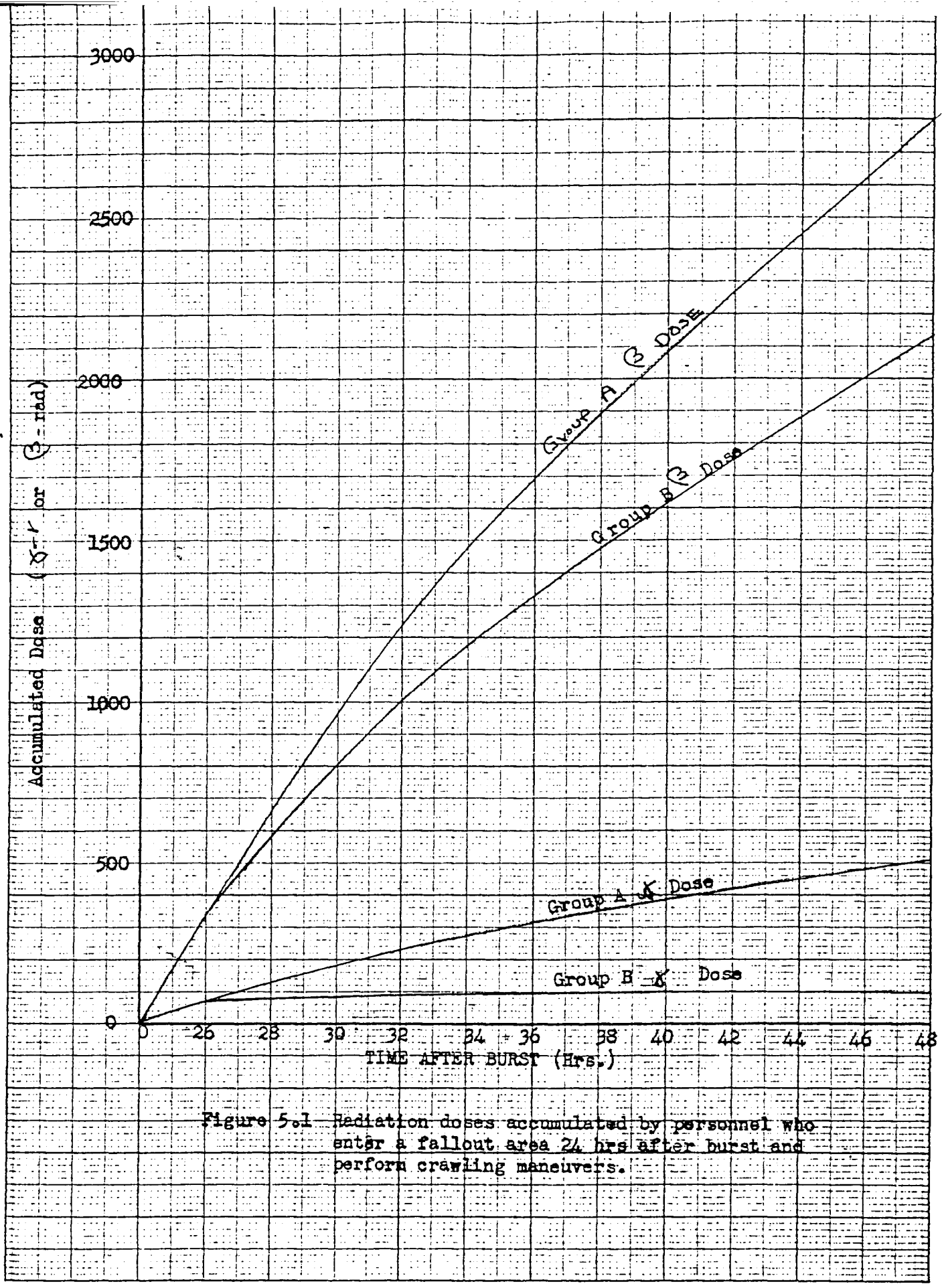


Figure 5.1 Radiation doses accumulated by personnel who enter a fallout area 24 hrs after burst and perform crawling maneuvers.

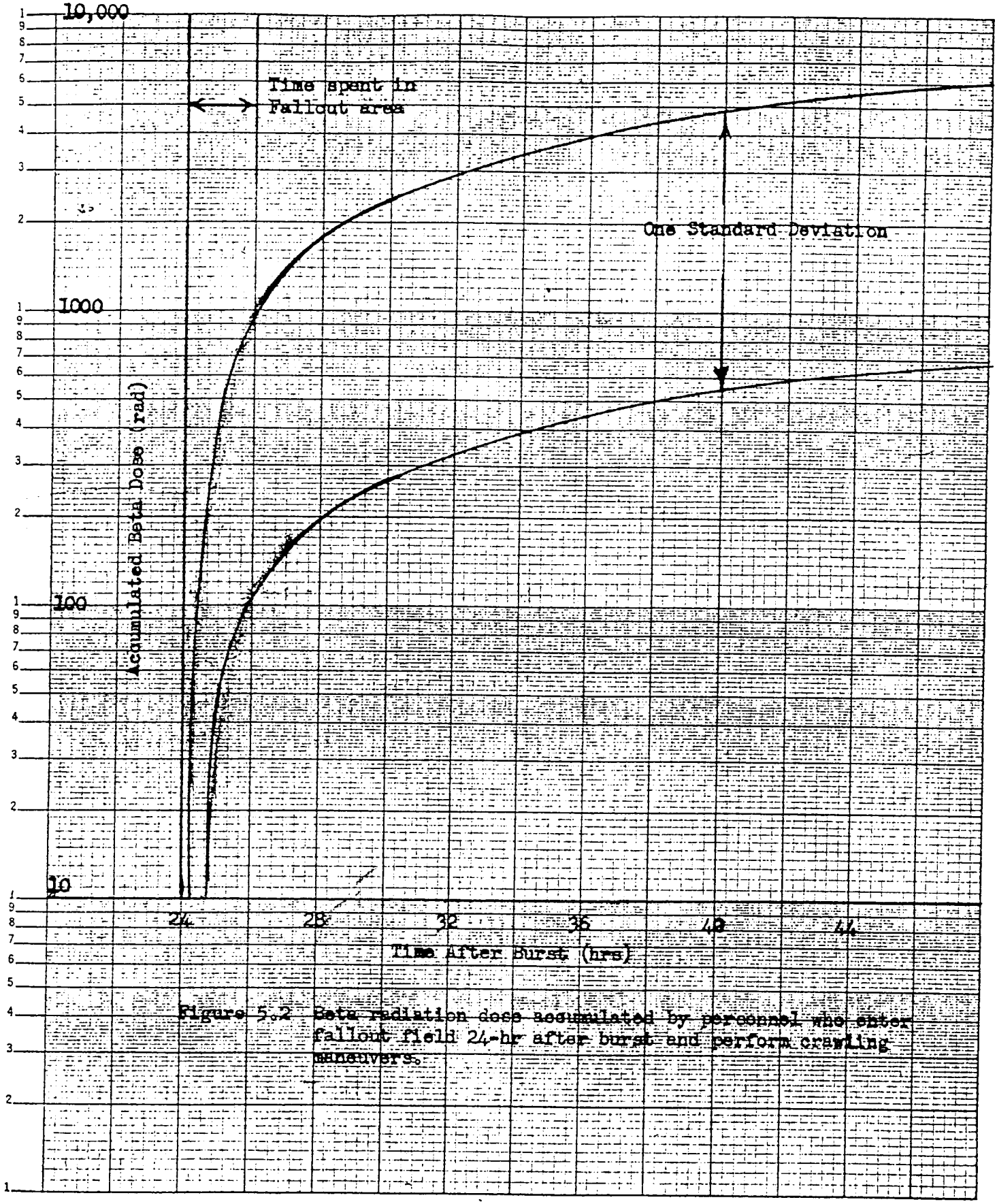


Figure 5.2 Beta radiation dose accumulated by personnel who enter fallout field 24-hr after burst and perform crawling maneuvers.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Three factors important in determining the rate of beta dose delivery to the skin of troops that have operated in a contaminated area are: (1) the mass loading of soil on skin and clothes, (2) the specific beta activity of this soil, and (3) the transmission of the beta radiation through the clothes to the skin.

The mean soil loading resulting from crawling over a contaminated grassy area was 60% of the mean resulting from crawling over a contaminated stabilized bare soil area. Crawl distance, within 250-500 ft limits, had no significant effect on soil loadings with the types of terrain and climatic conditions used in the tests.

The contaminated soil on combat fatigues was approximately 50% as effective in producing beta dose at the skin from La^{140} relative to its being in contact with skin.

Contaminated soil on the exposed skin produced small areas of relatively high concentrations of radioactivity (and dose-rate); however, the mean dose from soil on skin was approximately 1/5 the mean dose from soil on the clothes.

If further study of contact beta radiation is contemplated, consideration should be given to measurements that will give more detailed information with regard to the distribution of the fallout particles on skin and clothing as well as some of the "human" factors in order to isolate some of the causes of the large deviations found.

Under contaminating conditions similar to those carried out in the reported tests, beta dose contribution from environmental, clothing, and skin sources to personnel operating in an area of heavy fallout would be relatively minor in relation to the co-existing gamma radiations. Whereas, if personnel were removed from the fallout field after a stay of short duration, limiting the gamma dosage to non-casualty levels, the beta radiation from radioactive particles clinging to clothes and skin could cause casualty producing skin lesions.

Personnel withdrawn from a fallout field in which intimate contact with the ground surface was involved should be allowed to shower and given a complete change of clothes as soon as possible. If conditions do not permit this degree of personal sanitation, field expedient methods of removing visible dust from clothing and skin should be initiated. In this study, decontamination actions after exposure were not investigated since all the subjects were utilized to study the contamination problem itself and to derive the dose rate - soil loading calibration factors; in future studies, if carried out, a larger number of subjects could be processed wherein some of them could be used to evaluate personnel decontamination measures such as suggested above.

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APPENDIX A

RADIOLOGICAL SAFETY

The contamination of and dosage to personnel volunteering as subjects in the test runs was controlled by the following means:

a. Synthetic fallout: The La^{140} was chemically separated from Ba^{140} parent and was checked for radiochemical purity prior to each test run.

b. The test area was monitored to determine gamma radiation intensity before the maneuvering period, and the total time interval for maneuvering was set short enough to assure a gamma dosage considerably below the MPD.

c. Pocket ionization chambers and dosimeter film badges were worn throughout the test runs to give a continuous indication and a permanent record of gamma dosage.

d. In order to prevent inhalation of the synthetic fallout, gas masks (Mark 9) were worn during the runs.

e. A Radiological Safety representative was present during the test runs to assess and advise the project officer on the radiological situation.

f. The monitoring period, with its thorough radiation survey of the subject was used to determine if prompt showering were advisable and to determine the time required for optimum film exposure during the dosimetry period.

g. Subjects were released from the test only after showering and Radiological Safety monitoring.

h. Twenty-four hour urine specimens from the subjects were collected and radioassayed.

i. All volunteer subjects for these tests were thoroughly informed as to radiological health aspects of their participation. Written statements of voluntary participation were obtained from each man.

APPENDIX B

ANALYTICAL TECHNIQUES

Two useful analytical techniques were developed: Sample volume reduction and quantitative removal of soil from skin.

Clothing samples soiled with La^{140} traced synthetic fallout were reduced in volume by ashing them at 500-700°C for 2-3 hr in a muffle furnace. Each sample was in a crucible with twice the capacity of the bulk sample volume. After the firing and cooling, the contents of the crucible was brushed, onto a square of saran film which was then rolled into a small bulk and radioassayed. The brush was cleaned by tapping it against the lip of the crucible between samples. The mean loss was 5 percent, with no contamination of controls, despite visible dust drifting off the saran film.

Three methods were tried in an attempt to collect quantitatively the soil from a known area of skin for mean soil loading measurements: The first was to mask the area with plastic adhesive tape and scrub the area with dampened cotton sponges; the second was to remove the soil with adhesive cellophane tape; the third was to remove the soil as a skin as a skin impression with a plastic cast.

Two methods were tried in an attempt to make radioautographs of the synthetic fallout on the skin using beta dosimeter films: the first was to fasten the film packet to the skin with various adhesive tapes; the second was to expose the packet to the skin impression of a cast taken from the subject.

Both of the above problems were solved by the plastic cast. For soil collecting, the sponge washing procedure was unsatisfactory due to inability to mask the area reliably, and the adhesive cellophane tape required about 6 applications to remove visible soil and left the skin raw. For radioautographs, the skin perspired under the dosimeter film and caused a redistribution of the soil on the skin. Several casting compounds were tried: collodian, liquid lucite, and unpigmented liquid envelope. Collodian adhered tightly and wasn't removable in one piece, liquid lucite pulled out hairs and left the skin irritated due to its chlorinated solvent. But liquid envelope appeared satisfactory in that it made intimate contact

with the skin, it dried in 20 min., was flexible enough so that it "squeegeed" the hairs as it was removed, and it even removed the visible soil from the pores and crevices. A though the methyl ethyl ketone solvent left the skin dried, no inflammation nor tenderness was noted 20 min or more after removing the cast. Radiation measurements indicated approximately 10% residual radiation which, in part, must have been due to radiation from adjacent areas.

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The possibility of combat troops being caught in low level fallout fields and suffering from beta-produced skin lesions leads to the investigation of possible parameters involved in exposure to beta

(over)

1. Beta ray- Dosage determination.
2. Clothing- Contamination.
3. Radiation contamination- Sources.
4. Skin- Contamination.
I. Black, R.H.
II. Title.
III. NY 320-001-9, U.S. Army.

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