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ANALYSIS OF RADIOLOGICAL DECONTAMINATION DATA OBTAINED FROM FIELD TESTS

Research and Development Technical Report USNRDL-TR-321

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Effects of Atomic Weapons

Technical Objective
AW-5c

Technical Developments Branch
C.F. Miller, Head

Chemical Technical Division
E.R. Tompkins, Head

Scientific Director
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Commanding Officer and Director
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U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY
San Francisco 24, California

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ABSTRACT

Reclamation data from Operation [redacted] are used to illustrate a method of treating and analyzing such data obtained in field-test experiments. The method utilizes available radiation-scattering computations to estimate the contribution of radiation sources outside reclaimed areas to the radiation field inside the areas. These contributions are than subtracted to determine a more accurate value of the true effectiveness of the reclamation procedure or procedures.

NONTECHNICAL SUMMARY

The Problem

In reclaiming contaminated ground areas and buildings within an extended area contaminated with radioactive fallout, the radiation measurements include contributions from radioactive sources that are deposited outside the area of interest as well as within it. In order to estimate the true effectiveness of a reclamation procedure for reclaiming a large portion of the area by reclaiming only a small part of it, the contributions of sources outside the reclaimed area to the radiation field in the smaller must be eliminated. The true effectiveness values are needed to correlate data from different tests to provide reliable performance information for planning radiological countermeasures.

Findings

The method of analyzing the data presented in the report showed that, in carrying out reclamation experiments, a certain amount of supporting data is required for estimating the effectiveness of the procedures. These include: (1) decay of the fallout field, (2) the variation of the radiation intensity with height (prior to decontamination), (3) selection of monitoring stations at preferred locations - i.e. those at which the scattered radiation contribution is the smallest, (4) selection of preferred geometric arrangement among structures, areas to be reclaimed, and monitoring stations to facilitate the data reduction and interpretation, (5) collection of fallout samples to determine the mass of fallout in the area, and (6) measurement of the fallout pattern. The method was applied to reclamation data from Operation PLUMBOB where two land areas around and the roofs on two structures in an area of light fallout were decontaminated.

The low initial radiation intensities associated with the small amount of fallout on the test area and resultant low readings on the radiacs lead to a rather large percentage error in reclamation effectiveness values. The low amount of fallout also lead to smaller decontamination performance values than would have been the case for a heavier deposit. Reclamation information at higher initial levels of fallout would be much more applicable to the design and specification of radiological countermeasure systems.

ADMINISTRATIVE INFORMATION

This report was prepared in final form for a project sponsored by the Office of Civil and Defense Mobilization. This project is described as Program B-3, Problem 1, in this laboratory's USNRDL Technical Program For Fiscal Year 1959, revised 1 January 1959. Progress in this project is most recently described in Quarterly Progress Report, 1 October to 31 December 1959, Progress Report USNRDL-P-15, January 1959.

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SECTION 1

INTRODUCTION

1.1 OBJECTIVE

The objective of this report is to present some of the available methods for analyzing and interpreting radiological countermeasure data obtained from field tests. Field radiation measurement data include contributions from sources of radiation that may be fairly far from the detector. When a small area within a large contaminated area is reclaimed, a considerable fraction of the radiation field in the reclaimed area may be contributed by surrounding sources. In order to determine the effectiveness of the reclamation procedure for reclaiming a large area from measurements on the small area, the contribution of the outside radiation sources to the radiation intensity inside the reclaimed area must be determined and subtracted. If this is not done, the resulting effectiveness values will be in error and the data cannot be correlated with results from other tests.

Pertinent data, obtained at Operation PLUMBBOB after Shot Coulomb C,[1] were analyzed and interpreted to illustrate the use of some computational methods in estimating effectiveness of reclamation of land areas and building roofs.

1.2 SCOPE

The experimental data used in demonstrating these methods are the results of reclamation procedures applied in a fallout area where rather low contamination levels from Shot Coulomb C existed. Also presented are background information and analytical techniques necessary for the reduction and interpretation of the reclamation data. The computation details are included to indicate as clearly as possible the difficulties involved and the effort required in planning, executing, and interpreting decontamination experiments carried out at field tests. Such information is often helpful in the design of future experiments of the same kind.

1.3 BASIC CONCEPTS OF DECONTAMINATION OF FALLOUT FROM NUCLEAR DETONATIONS ON LAND

1.3.1 Fallout-surface Relationship

Any concept of the interactions between fallout and material surfaces must include a precise definition of what fallout is so that the basic concepts of decontamination can be established and the appropriate interactions considered. Surface reactions, in general, are extremely sensitive to the composition of the surface and to the nature of the interacting substance. The type and degree of surface reactions of ions, colloids, and larger particles can be entirely different; in fact, surface reactions of ions of the same charge but of different size are different.

In the area of local fallout from land surface detonations, the particles carrying the radioactive elements are mainly in the form of melted silica spheres. These particles are insoluble in water and most acidic solutions and the radioactivity in them is not released in such media. However, smaller particles deposited farther downwind can have some of the more volatile radioactive elements condensed on their surface; the latter are released into water and acidic solutions. Long-range fallout and fallout particles formed from a water-soluble matrix are entirely different substances. Aqueous media will leach or dissolve fission products from the water-soluble particles and particles where the activity is only adsorbed on the surface.

The interactions of interest for fallout from a land detonation are those that take place between silica particles and surfaces, and, for regions of significant levels of local fallout, the particle sizes of interest are 75 μ and larger since these carry with them the major fraction of the radioactivity. A decontamination process that removes these particles from a surface also removes the radionuclides fused inside the particles.

1.3.2 Measurement of Decontamination Effectiveness

In a practical sense, a precise description of the nature and strength of the forces holding particles to surfaces are not required to describe, in a general way, an observed decontamination result. For this purpose approximate relationships between the mass of fallout deposited per unit area of surface and the amount remaining after application of a decontamination method such as firehosing have been developed.[2] Many of the common decontamination methods tend to reduce the initial deposit to a given amount providing the initial deposit is heavy enough to give at least a unit layer of particles on the surface; thus, if the amount remaining is a constant, R_M, for a given surface-decontamination method combination, the fraction remaining is inversely proportional to the initial amount, or

$$F = \frac{R_M}{y} \tag{1}$$

in which F is the fraction remaining and y is the amount deposited in mass per unit area. Besides the method and surface, the value of R_M presumably depends on the particle size distribution of the mass deposited; but where the general size distributions are roughly the same this effect would be small. For deposits of less than a unit layer of particles, R_M is multiplied by the fraction of the unit area covered with particles; when this is done,[2] Eq. 1 becomes

$$F = \frac{R_M (1 - e^{-ky})}{y} \tag{2}$$

in which e^{-ky} is the probability of a falling particle landing on the surface rather than on previously deposited particles at the deposit level, y, and k is a constant that depends on the roughness of the surface and on the size distribution of the particles. The limiting value of F at low values of y is R_M.

For decontamination data obtained from radiation intensity data rather than mass data, evaluation of Eq. 2 requires a relationship between mass of fallout and the radiation intensity - i. e., the average specific activity and the ionization from the emitted photons that apply to the geometry of the measurement. One general relationship[3] is

$$M_T^{\lambda}(t) = \frac{KW^n}{(A_o/A_\lambda) q\ b \left[I_{fp}(t) + I_i(t)\right]} \tag{3}$$

in which

- $M_T^{\lambda}(t)$ is the mass contour ratio given as the ratio of mass per unit area to r/hr,
- W is the total yield,
- (A_o/A_λ) is the correction factor from the scaled depth, ($\lambda = h/W^{1/3}$), to a surface detonation,
- q is the terrain factor,
- b is the ratio of fission to total yield,
- $I_{fp}(t)$ is the theoretical air ionization for a given number of fission products per unit area,
- $I_i(t)$ is the theoretical air ionization from the corresponding relative number of induced activities per unit area, and
- K is a constant which relates yield to number of fissions, fissions to number of fission products and, via their photon emission, to air ionization intensity, and lastly, yield to the mass of soil that becomes associated with the radioactive products formed in the detonation.

For an initial intensity or ionization rate, I(t), at time t after detonation, Eq. 2 is then

$$F = \frac{R_M \left[1 - e^{-kM_r(t)I(t)}\right]}{M_r(t)\ I(t)} \tag{4}$$

Equations 3 and 4 suggest several things in relation to the experimental data described in this report. Firstly, the amount of information required to interpret the data relative to data obtained from previous experiments is extensive (yield, height of burst, radioactive composition, terrain factors, etc.). Most important, of course, is the variation of F with initial intensity, I(t). Equation 4 predicts that F increases as I decreases so that an apparent low effectiveness in decontamination at low values of I(t) for a given method could be erroneously interpreted if the effect of level is not accounted for. Secondly, an error in the determination of the equation constants from empirical data at low levels would be more serious than those determined from data obtained at high levels; obviously it would be better to use Eq. 4 to extrapolate data from high levels to low ones rather than the reverse. If Eq. 4 were exact and the data also accurate, the selection of the initial level would be immaterial to the use of the data in determining the equation constants.

SECTION 2

PROCEDURES FOR AND MEASUREMENTS FROM COULOMB C EXPERIMENT

2.1 EXPERIMENTAL PROCEDURE

Two buildings were used in the experiment, two end buildings in a group of three. Their location with respect to the Coulomb C fallout area is shown in Fig. 1 by points A and B. Building A had a concrete slab roof, and B a composition-shingle gabled roof. Their respective Nevada Test Site (NTS) station numbers were 31.1E2 and 31.1C2.

The reclamation experiment was carried out in the following steps:

1. An area was staked out around each building and monitoring stations selected on the roof of each building and inside Building A.
2. The areas and buildings were monitored.
3. The area about Building A was decontaminated by scraping.
4. The roof of Building B was decontaminated by firehosing.
5. The area about Building A and Building B were monitored.
6. The roof of Building A was decontaminated by firehosing.
7. The roof of Building A was monitored.
8. The area about Building B was decontaminated by scraping.
9. The roof of Building A was further decontaminated by scrubbing with detergent and then with water.
10. The roof of Building A, and the roof of and area around Building B were monitored.

The monitoring station locations about the two buildings are shown in Fig. 2. Although a more detailed monitoring array might be desired in some technical experiments of this kind, the extra time involved to make the survey must be taken into account in the plan. A single set of measurements in each of four directions from a structure generally will give a reasonably accurate picture of the magnitude and gradient of the radiation field.

The station locations and numbers for the building roofs are given in Fig. 3. The station locations inside Building A are shown in Fig. 4. In each of the figures the direction of north is given for orientation.

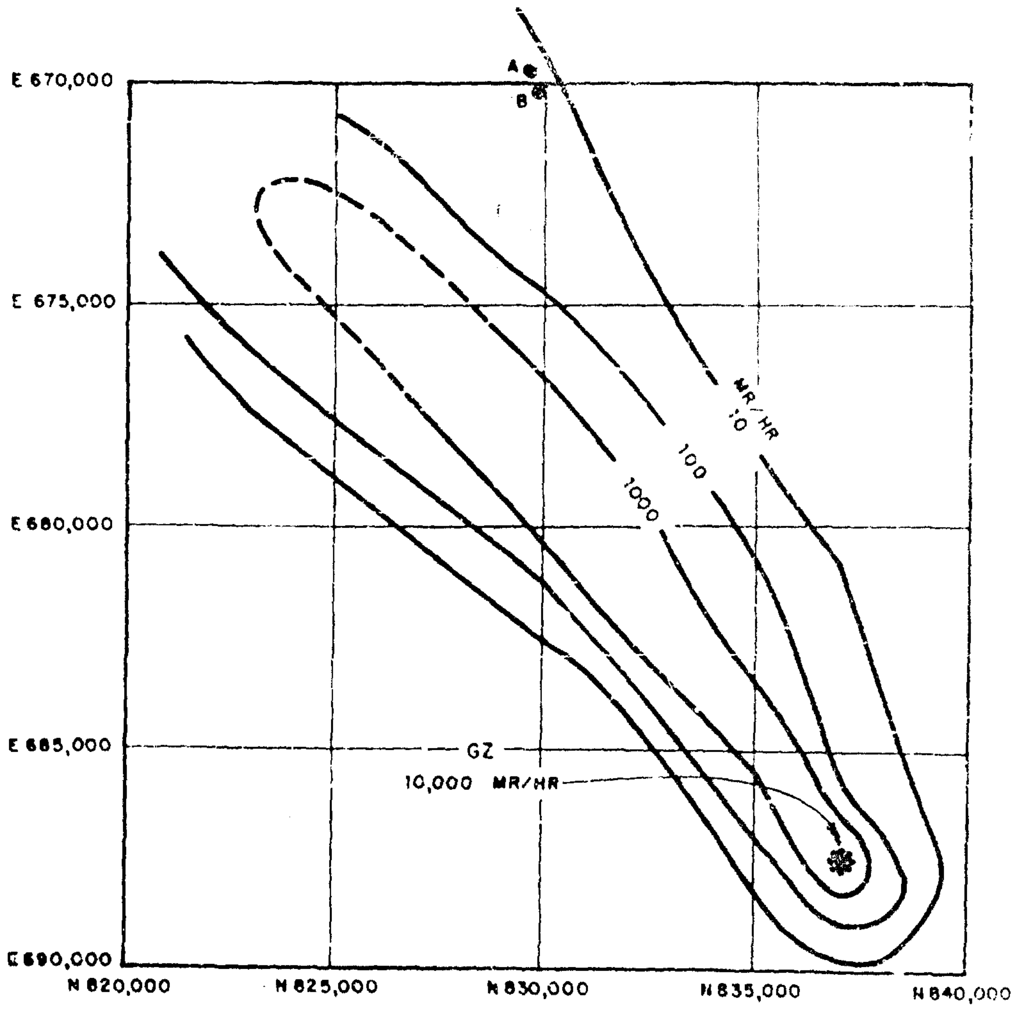

Fig. 1 Location of Buildings in Fallout Area From Shot Coulomb "C" (H+22)

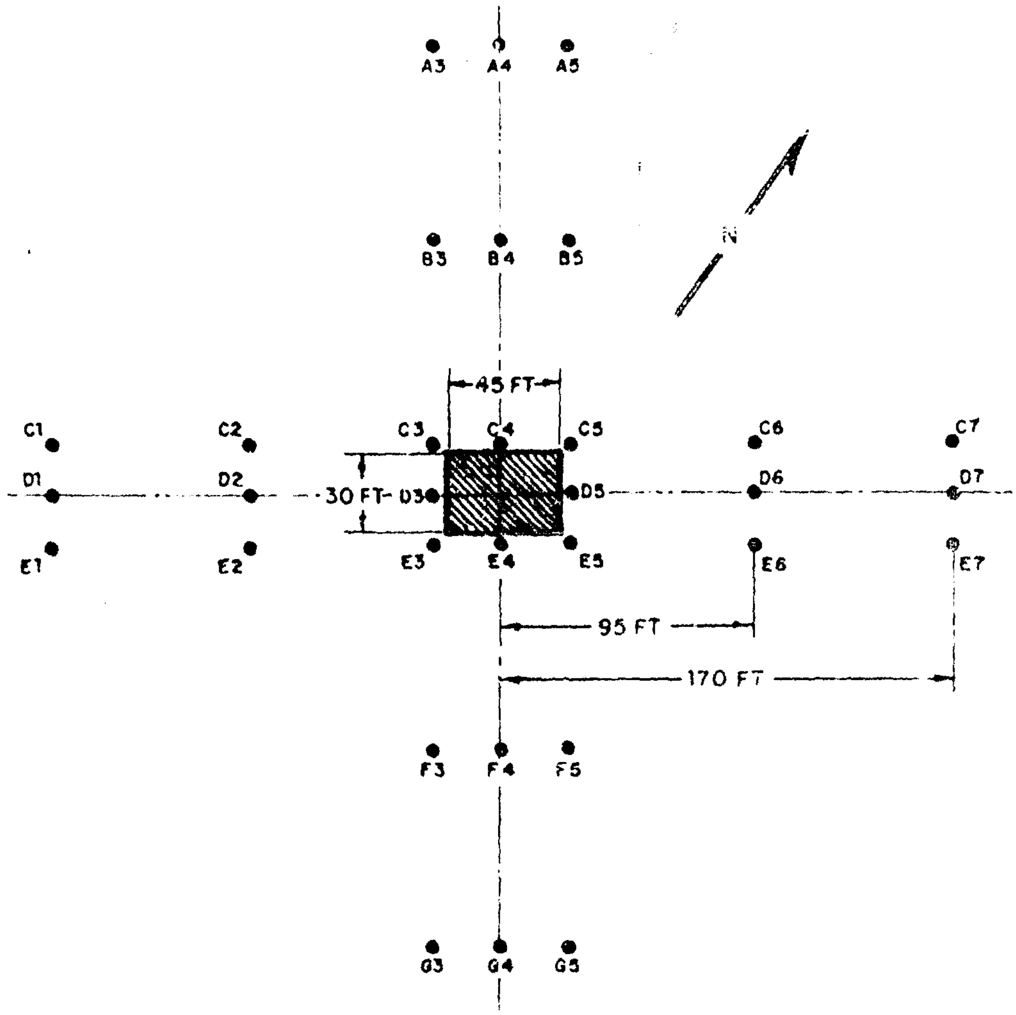

Fig. 2 Monitoring Station Locations Around Buildings A and B. Stations are coded down alphabetically and left to right numerically.

Two readings were taken at each station; one at surface level and one at 3 ft (waist level) above the surface. All measurements were made with AN/PDR-39(T1B) radiac instruments. The radiac were calibrated at the NTS Rad Safe building.

2.2 RECLAMATION PROCEDURES

2.2.1 Ground Scraping

The scraping procedure was carried out with a single motorgrader. The surface of the soil around Building A was fairly smooth and contained few, if any, large rocks. Since only a single motorgrader was to be used, the depth of cut was set to about 1-1/2 in. This permitted the motorgrader to push the windrows out to about 150 ft on each side (170 ft from center of the building). This was done by dividing the area into six sections. In each section the first cut was made on a line passing one side of the building with the topsoil being pushed outwards. The motorgrader backed across the cleared area between each cut. After several passes, when the windrow became large, the remainder of the section was halved at right angles and the soil again pushed to either side of the center cut. Only a small section remained when these windrows became large. The short windrows were pushed out by the motorgrader acting as a bulldoser or by taking a diagonal cut starting at the outer end of the windrow. A few hot spots remained where the blade "missed" due to depressions in the soil surface; time did not permit making a second pass over the area. The final area cleared around Building A was about 340 x 340 ft. The clearing began the afternoon of D+1 and ended the morning of D+2.

Around Building B, where the surface of the soil was rougher than around Building A, the motorgrader circled the building and pushed the soil outward. At the end of D+2 operations, a swath 60 ft wide (75 ft from building center) had been scraped; this was about as far as the motorgrader could be used even with the shallow cut without having to resort to removing the windrows with another piece of equipment (motorized scraper).

2.2.2 Roof Washing

The roof of Building B was washed down using a water tank truck, pump, and a firehose. The pressure was adjusted by varying the speed of the pump to produce approximately a 50-psi nozzle pressure. At the levels of radiation encountered (20 to 30 mr/hr at D+1) there were no fallout particles visible. This made it somewhat difficult to assure a good coverage with the firehose. The washing was accomplished by passing horizontally along the roof, starting at the peak, and trying to put the full

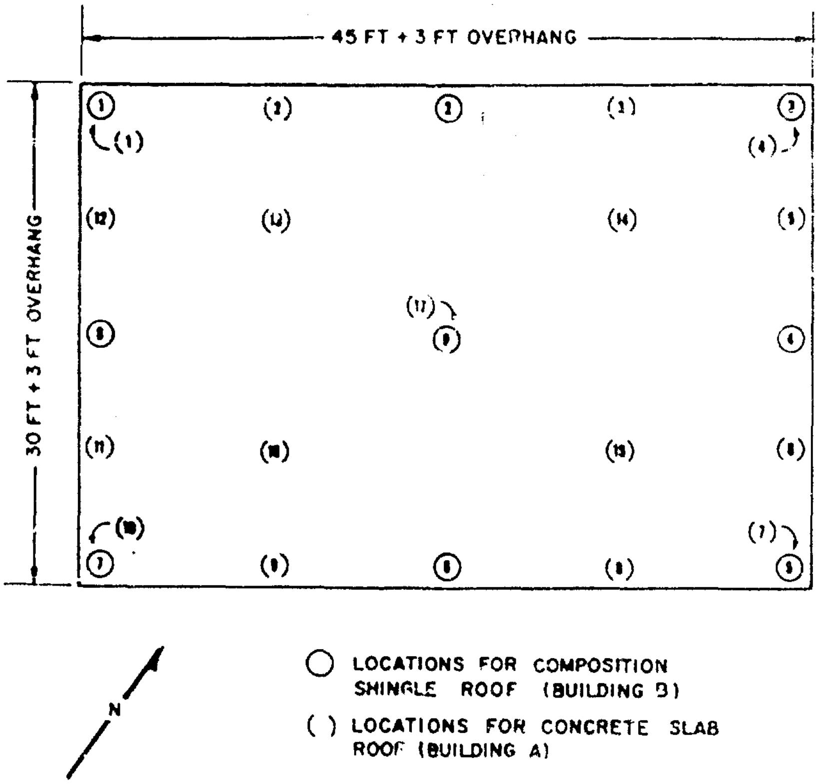

Fig. 3 Monitoring Station Locations on Roofs of Buildings A and B

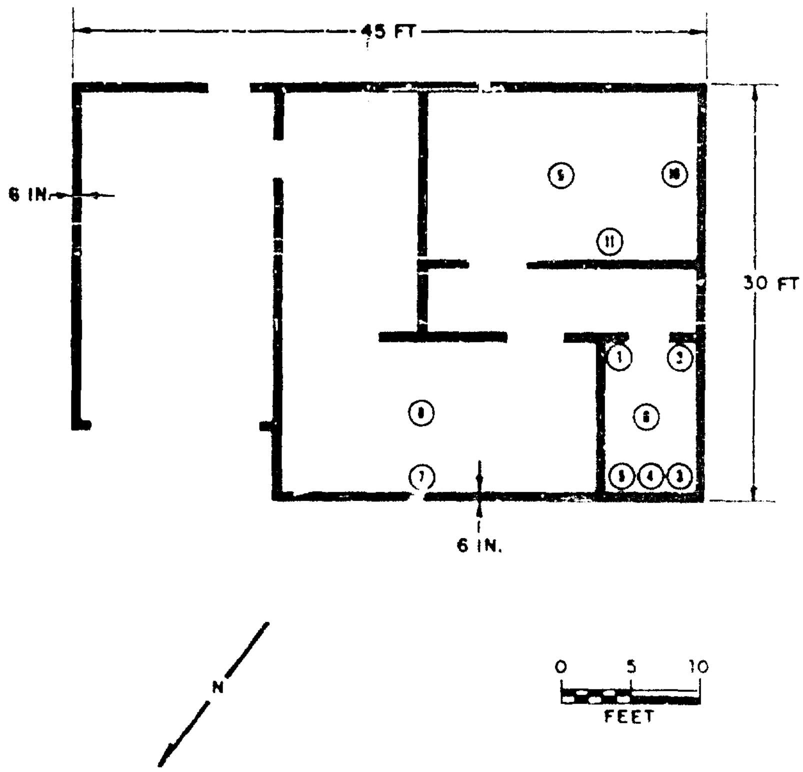

Fig. 4 Monitoring Station Locations in Building A

force of the spray on a swath 2 or 3 shingles wide.

On the concrete slab roof (Building A) some clean earth from the cleared area was sprinkled on the roof as a visual aid for the operator. In the latter case, the width of the roof was divided into strips about 5 or 6 ft wide, and each strip was cleaned by the operators swinging the hose from one edge of the strip to the other as they moved slowly along the strip. After each strip was cleaned, the nozzle operator took station on its edge so that, in swinging the nozzle, the spray would not scatter fallout particles back onto the cleaned areas.

The concrete slab roof was scrubbed with detergent after a single pass with the firehose (allowing time in between for monitoring). The detergent was mixed with water before application; the solution was poured over sections of the roof and, in the process of scrubbing, was spread about further. After one section was scrubbed, solution was poured in on an adjacent section until the whole roof had been treated. The roof was then flushed off with the firehose; the surface did not dry before it was flushed.

2.3 MEASUREMENTS

The measurements obtained on the AN/PDR-39(T1B) radiacs are given in tabular form in Appendix A.

SECTION 3

METHOD OF ANALYSIS AND TREATMENT OF THE DATA

3.1 GENERAL

Data such as that taken in the described experiment require only a correction to a common time due to radioactive decay for presentation in terms of a residual number (ratio of radiation intensity after decontamination to that prior to decontamination) for the specified reclamation operation. Since the residual number is defined as the decimal fraction of the potential dose that would be received after application of a countermeasure, its approximation by ratio of decay-corrected radiation intensities is valid only for the fallout from land detonations where the radioactive composition is not altered during reclamation or where the decay of the radioactive substances remaining on the surface after reclamation is the same as that of the original fallout.

If no errors exist in the original intensity measurements, the experimental residual numbers from them should vary from 0 to 1 depending on the location of the measurements. These residual numbers will apply only to the specified experiment and cannot be extrapolated to other levels of fallout, to other geometrical arrangements of the radioactive source, or to other-sized houses of the same construction. Further, these residual numbers are not a measure of the amount of fallout removed from the areas and surfaces by the decontamination procedures. The reason for these restrictions on the utility of the residual numbers is that each observed reading is a measure of the radiations originating from a large number of radiation sources and that the majority of the sources may be located beyond the areas and surfaces that were decontaminated.

In order to determine the true effectiveness of the reclamation procedures, the total radiation at all locations must be divided into two parts: (1) the contribution from the radioactive sources in the areas and surfaces treated and (2) that contributed from radioactive sources outside these areas and surfaces. The mathematical notation is then

$$I(o) = I_A + I \qquad (5)$$

in which $I(o)$ is the observed intensity (corrected to a given time after detonation), I_A is the intensity from the areas and surfaces of interest, and I is that contributed from other sources. In most cases it is convenient to convert the data to either a measure of the source intensity per unit area, I_o, or to that for an equivalent infinite plane source, I_∞. The ratio of the latter two quantities is designated as

$$\alpha = I_\infty / I_o \tag{6}$$

Further relations between the above quantities are defined as follows:

$$p = I / I_\infty \tag{7}$$

and

$$q = 1 - p \tag{8}$$

and, in general,

$$I_\infty = I_A + I \tag{9}$$

so that $I(o)$ is always associated with I_∞; hence

$$q = I_A / I_\infty \tag{10}$$

and

$$I_A = \alpha q \, I_o \tag{11}$$

By definition, the decontamination ratio is

$$F = I_o' / I_o \tag{12}$$

in which I_o' is the source intensity per unit area after decontamination and I_o is that prior to decontamination. At a given location within or near the treated area, q is the same before and after decontamination if the area is uniformly decontaminated so that

$$F = I_A' / I_A = \frac{I'(o) - I}{I(o) - I} \tag{13}$$

It can be seen from Eqs. 5 and 13 that if I is small compared with I_A, then F is simply $I'(o)/I(o)$; this value will be obtained if the reclaimed areas are sufficiently large or if sufficient shielding exists between the detector and the sources that contribute to I. For the large areas, the value of F is equal to the residual number.

The values of I for the experimental geometries are estimated in the remainder of the section from the computations of C. F. Ksanda, et al.[4]

The computations are intended to bias the observed readings in the proper direction to give more realisteic values of F than could otherwise be obtained from the observed data alone.

The analysis of the data from the described experiment is given as follows in the order required to reduce the data to F values. The main steps are:

1. Determination of the Decay Curve and Computation of Intensities at D+1.
2. Determination of the "Terrain Factor" From the Data for Use in Computation of p, q, and I.
3. Determination of Variation of Intensities With Altitude.
4. Determination of Scattered Components p and q, for the Various Monitoring Stations Used in the Experiment.
5. Estimation of Decontamination Ratios for the Motorgrading of the Two Areas.
6. Estimation of Decontamination Ratios for the Decontamination of the Concrete Roof of Building A.
7. Estimation of Decontamination Ratios for the Decontamination of the Composition Roof of Building B.
8. Estimation of Shielding Factors for Building A.

3.2 DETERMINATION OF THE DECAY CURVE

The measurements given in Table A.10 of Appendix A should have provided the necessary information for making the decay corrections. However, with the data plotted, the slope of the logarithmic curve appeared to be too steep in comparison with previous data from land surface detonations[7] for use. A number of repetitive measurements on and around Building B were available and these were used to determine an acceptable decay curve. The decay from 26 to 46.2 hr is computed in Table 1 and from 26 to 49.2 hr in Table 2. Because of an apparent gradient in the radiation field about Building B, the readings were averaged by groups as indicated by the station designations. In Table 3, for 27.2 to 46.2 hr, the roof readings on Building B are used; the two sets of readings were taken after firehosing and before scraping the area. If the value 0.542 is divided into 0.483, the value 0.891 is obtained for the decay from 26.0 to 27.2 hr. (a 15 min. error in measurement time would result in a significant error in the ratio at this time after burst). This manner of computing the decay includes any drift or change in calibration of the instruments when they are not used to measure the decay of the field independently. The intensity at 26 hr was arbitrarily adjusted to 30 mr/hr in plotting the curve in Fig. 5; the readings at the Field Decay Station and a -1.2 log-slope line are given for comparison. The readings at the Field Decay

TABLE 1

Computation of Decay Around Building B,
From 26 to 46.2 Hr

Station	Surface Readings (mr/hr) I_1 (H+26)	I_2 (H+46.2)	I_2/I_1	3-ft Height (mr/hr) I_1 (H+26)	I_2 (H+46.2)	I_2/I_1
A,B4	25.5	12.0	0.470	23.0	10.5	0.457
D1,2	30.5	14.5	0.475	27.0	11.5	0.426
D6,7	35.0	18.5	0.528	32.0	16.5	0.516
F,G4	40.5	21.0	0.518	35.0	16.5	0.471
Av.	32.9	16.5	0.498	29.2	13.8	0.468

$(0.498 + 0.468)/2 = 0.483$

TABLE 2

Computation of Decay Around Building B,
From 26 to 49.2 Hr

Station	Surface Readings (mr/hr) I_1 (H+26)	I_2 (H+49.2)	I_2/I_1	3-ft Height (mr/hr) I_1 (H+26)	I_2 (H+49.2)	I_2/I_1
A3,4,5	26.7	12.0	0.449	24.3	10.3	0.424
C,D,E1	28.7	13.3	0.463	25.7	11.0	0.428
G3,4,5	42.7	19.3	0.452	37.3	17.3	0.464
C,D,I7	39.7	17.7	0.440	36.0	16.3	0.453
Av.	34.4	15.6	0.452	30.8	13.7	0.442

$(0.452 + 0.442)/2 = 0.447$

TABLE 3

Computation of Decay on Roof of Building B,
From 27.2 to 46.2 hr

Station	Surface Readings (mr/hr) I_1 (H+27.2)	I_2 (H+46.2)	I_2/I_1	3-ft Height (mr/hr) I_1 (H+27.2)	I_2 (H+46.2)	I_2/I_1
1	13	9	0.69	15	9	0.60
2	17	8	0.47	17	8	0.47
3	15	9	0.60	18	9	0.50
4	14	9	0.64	20	10	0.50
5	20	9	0.45	17	10	0.59
6	20	10	0.50	20	10	0.50
7	20	11	0.55	19	11	0.53
8	18	9	0.50	15	10	0.67
9	14	8	0.57	16	7	0.44
Av.	16.8	9.1	0.552	17.4	9.3	0.533

$$(0.552 + 0.533)/2 = 0.542$$

Station at the later times may have been influenced by the scraped area at Building A - i. e., it may not have been far enough away - or the field about it may have been disturbed by the passage of vehicles between the two buildings.

The smoothed values of the decay correction factors are summarized in Table 4; the given values were used to correct all the readings listed in Appendix A (except Table A.1 and A.5) to D+1. The results are tabulated in Appendix B.

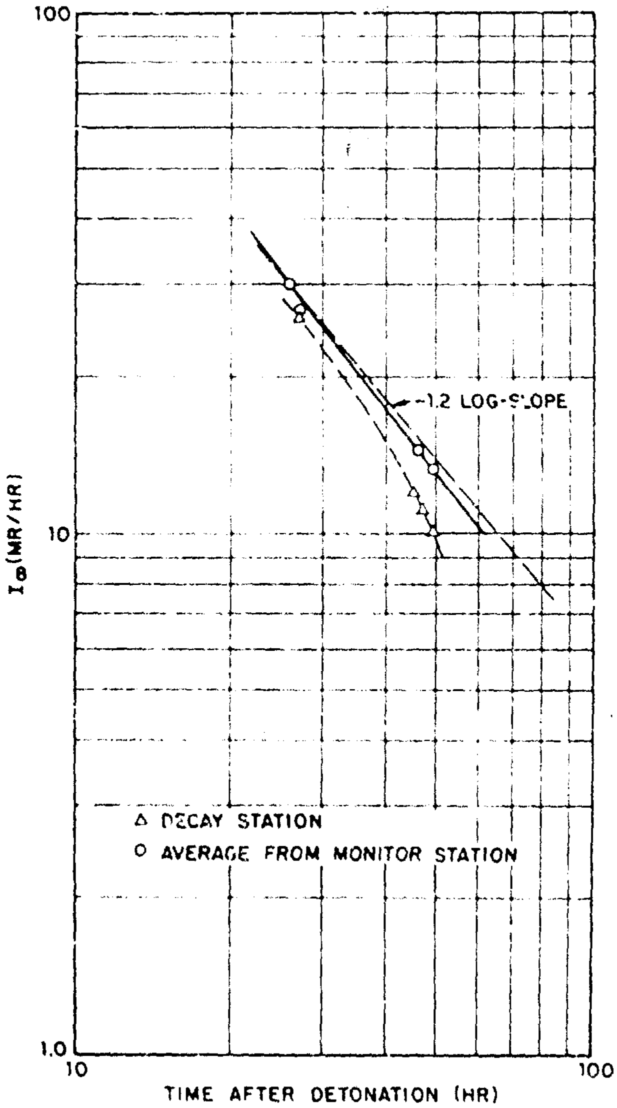

Fig. 5 Variation of Radiation Intensity with Time After Detonation

TABLE 4

Smoothed Values of Decay
Correction Factors

t (H+hr)	I(arb) (mr/hr)	Correction Factor to H+24
24	33.9	1.000
25	31.8	1.06
26	30.0	1.13
27.2	28.2	1.20
46.25	14.5	2.34
47.0	14.2	2.39
47.5	14.1	2.41
49.0	13.52	2.51
49.2	13.47	2.52
49.58	13.32	2.54
49.67	13.27	2.55

3.3 DETERMINATION OF THE "TERRAIN FACTOR" FROM THE DATA

The methods of accounting for the effect of terrain on the radiation intensity presented in Ref. 4 are: (1) mixing of the sources with soil to a depth, Z; and (2) burial of the sources to a depth, Z. In the computations to follow, the functions given for uniform mixing will be used. The depth of the mixture, Z, can be determined from radiation measurements taken at several heights above an extended source. The computations in Ref. 4 are for a photon energy of 1.25 Mev; this energy is higher than the mean photon energy of fission product photons which is between 0.5 and 0.6 Mev at the times of interest.[5] If all the real linear dimensions are multiplied by 1.5, the effect on the computations is to increase the source energy from about 0.5 to 1.25; conversely, if the linear dimensions associated with a given parameter in Ref. 4 are reduced by 2/3, the effect on the computation is to decrease the photon energy for the desired effect from 1.25 Mev to about 0.5 Mev. Although this type of scaling is not exact, it will not be in large error, especially for photon energies where the attenuation by air and sand is due mainly to Compton scattering and where the scattering build-up factor does not vary significantly with photon energy. In such a case, the difference in the linear absorption coefficients vary almost linearly with differences in the photon energy so that the ratio of the absorption coefficients at the two energies can be used as a linear scale factor on the depth of mixing, Z, the height of the measurement, h, and the dimensions of a contaminated slab (radius, R_0, or sides of a rectangle, 2a x 2b). The values of r, p, and q for this change in linear dimensions with photon energy will then remain constant. Thus, for the 3-ft readings, the height to enter in the tables in Ref. 4 is 4.5 ft or 1.37 meters.

As a first step in determining Z for the measurements, $\alpha(h')/\alpha(o)$ was computed from the α values given in Ref. 4 at Z' values of 0.5, 1.0, and 3.0 in. (using primed notation for tabular dimensions and unprimed for real dimensions). The values are plotted as a function of height in Fig. 6 and are tabulated in Table 5. The values at 1.37 m were read from the curves.

At h' of 1.37, the three values of log $\alpha(h')/\alpha(o)$ vary exactly with 1/Z'; the relationship is given by

$$\log \alpha(1.37')/\alpha(o) = -0.01868 - 0.01354/Z' . \tag{14}$$

Hence by determining $\alpha(h')/\alpha(o)$ from the ratio of the 3-ft

TABLE 5

$\alpha(h')/\alpha(o)$ at Several Values of Z' and h'

h'(m)	Z' 0.5 in.	Z' 1.0 in.	Z' 3.0 in.
0	1.00	1.00	1.00
0.5	0.950	0.968	0.979
1.0	0.919	0.944	0.961
1.37	0.900	0.928	0.948
5.0	0.769	0.817	0.867
10.0	0.656	0.716	0.784

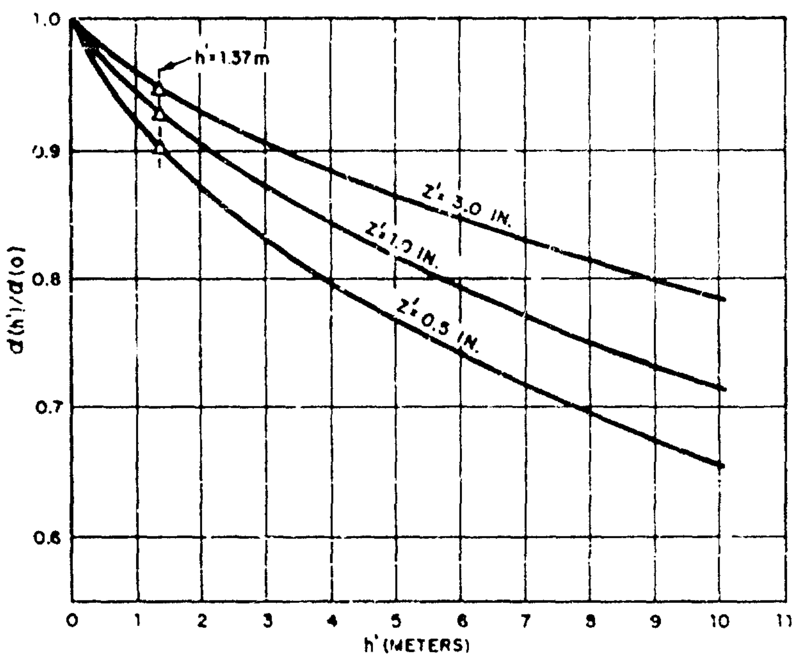

Fig. 6 Variation of $\alpha(h')/\alpha(o)$ With Height

readings to the surface readings, the appropriate value of Z can be determined from Eq. 14. The computations are summarized in Table 6; the readings which were taken near the buildings were not used. When the average value, 0.882, of $\alpha(1.37')/\alpha(0)$ is substituted into Eq. 14, the computed value of Z' is 0.38 in.; the real value of Z is therefore 0.25 in. These values of Z and Z' will be used in all the computations. For concrete or other smooth surfaces, the value of Z should be less than for a land surface; unfortunately, it is impossible to determine the value of Z for the concrete slab roof from the data (as will be seen later); so, the above value was used.

TABLE 6

Computation of $\alpha(1.37')/\alpha(0)$ From Data in Appendix A

Station	1	2	3	4	5	6	7
			From Table A.1				
A	0.857	0.882	0.857	0.075	0.871	0.923	0.781
B	0.853	0.824	0.867	-	0.828	0.821	0.926
C	0.833	0.917	-	-	-	0.828	0.893
D				X			
E	0.882	0.818	-	-		0.862	0.897
F	0.882	0.844	0.900	0.867	0.896	0.993	0.853
G	0.789	0.853	0.771	0.967	0.931	0.967	0.806
	For 35 pairs: Total, 30.324; Average, 0.866						
			From Table A.2				
A			0.933	0.931	0.931		
B			0.879	0.844	0.871		
C	0.714	-	-	-	-	0.960	-
D	-	0.788	-	X	-	0.960	1.000
E	0.800	0.857	-	-	-	-	0.889
F			0.852	0.963	0.928		
G			0.925	0.962	0.893		
	For 20 pairs: Total, 17.881; Average, 0.894						
			From Table A.4				
A			0.893	0.920	0.926		
B			0.962	0.885	0.857		
C	0.862	0.964	-	-	-	0.967	0.857
D	0.897	0.875	-	X	-	0.909	0.918
E	0.928	0.935	-	-	-	0.865	0.950
F			0.917	0.846	0.772		
G			0.886	0.738	0.857		
	For 24 pairs: Total, 21.386; Average, 0.891						
	Grand Average: 0.882						

3.4 VARIATION OF RADIATION INTENSITY WITH ALTITUDE

Using the value of Z determined in the previous paragraph and the values of α at other values of Z' and h' in Ref. 4, the values of α at Z' equal to 0.38 were determined at several values of h'. These are plotted in Fig. 7 using the real dimensions of h and Z. The value at h equal to zero was determined by dividing the value of α at 3 ft by 0.882 and therefore corresponds to the observed surface readings. The values of α for some of the monitor stations are given in Table 7; these are used in later computations.

TABLE 7

Values of α For Monitor Stations at Several Values of h

h (ft)	α	Station
0	1.73	Surface readings, ground and concrete slab
3	1.53	3-ft readings, ground and concrete slab
9	1.34	Surface readings on concrete slab
11.3	1.28	Surface readings at edge of roof of Building B
12	1.27	3-ft readings above concrete slab
14.3	1.22	3-ft readings at edge of roof of Building B
16.5	1.18	Surface readings on peak of roof of Building B
19.5	1.13	3-ft readings on peak of roof of Building B

It may be noted that $\alpha (I_\infty/I_0)$ decreases with altitude so that for a constant value of I_0 (source intensity per unit area), I_∞ decreases with height above the surface.

3.5 ESTIMATION OF p AND q VALUES FOR VARIOUS MONITORING STATIONS

The first major alteration of the radiation field in the exercise occurred when the area around Building A was scraped out to a square of dimensions 340 x 340 ft. In computing the contributions of the sources

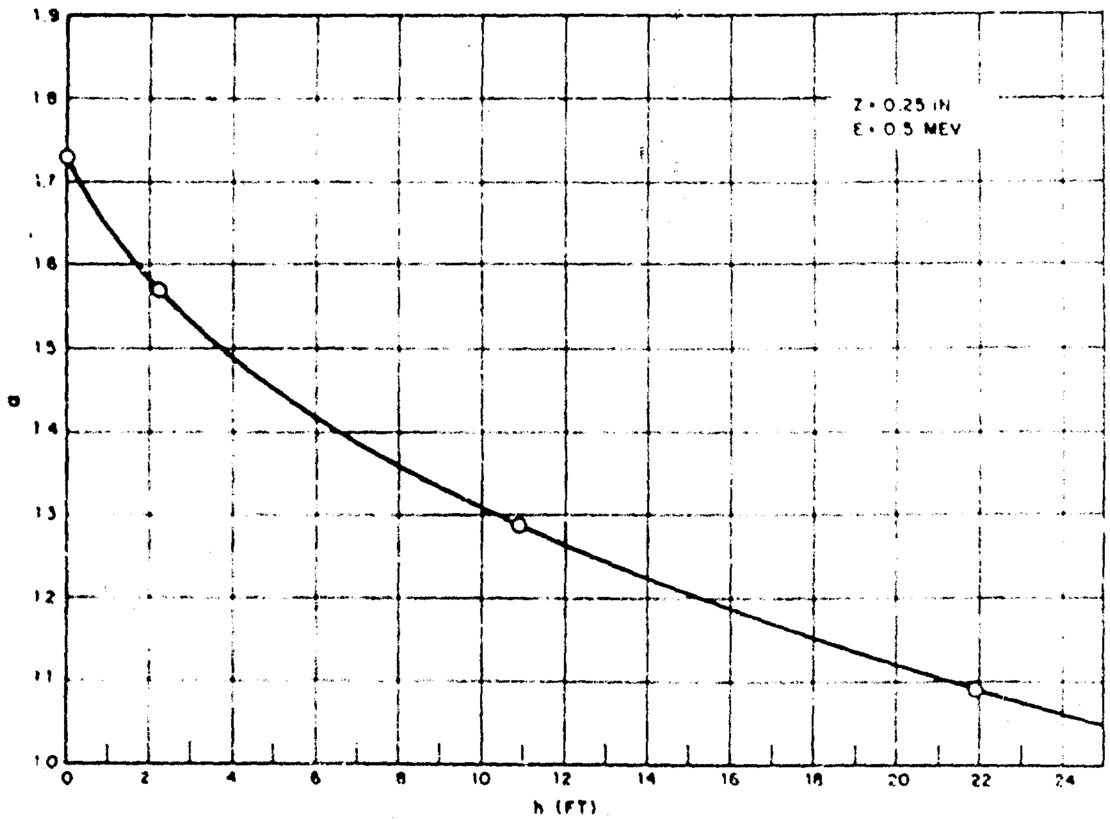

Fig. 7 Variation of σ With h for Experimental Data

outside this area (disregarding the shielded sources on top of the slab) to the monitor stations, the methods of Ref. 4 were used to estimate p and q at station A4, C4, D1, and D7 (all the same relative locations), B4, F4, D2, and D6 (all the same relative locations), the center of the building roof, the corners of the slab, and the mid-points of each side of the slab. The station lay-out and distances for the area are shown in Fig. 8. The different stations or station groups are numbered from 1 to 6.

In order to estimate q (or p) for each station or station group, the semi-width of a rectangular portion of the cleared area is designated as b and its semi-length as a, and the value of the ratio q is accordingly designated as $q(a', b')$ - in the tabular dimensions. Then, by multiplying all the real dimensions of the selected rectangles by 1.5 and converting to meters, the values of q for each point can be determined as a function of height by use of the graphs and tables of Ref. 4. In notational form, q_i for each station as determined from Fig. 8 is:

$$q_1 = q(77.7,\ 77.7);\ a/b = 1.00 \qquad (15)$$

$$q_2 = 1/2\ \left[q(77.7,\ 34.3) + q(121,\ 77.7)\right];\ a/b = 2.27,\ 1.56 \qquad (16)$$

$$q_3 = 1/2\ \left[q(85.3,\ 77.7) + q(77.7,\ 70.2)\right];\ a/b = 1.10,\ 1.11 \qquad (17)$$

$$q_4 = 1/2\ \left[q(88.7,\ 77.7) + q(77.7,\ 66.8)\right];\ a/b = 1.14,\ 1.16 \qquad (18)$$

$$q_5 = 1/4\ \left[q(70.2,\ 66.8) + q(85.3,\ 66.8) + q(88.7,\ 85.3) + q(88.7,\ 702)\right];$$
$$a/b = 1.05,\ 1.28,\ 1.04,\ 1.26 \qquad (19)$$

$$q_6 = 1/2\ q(156,\ 77.7);\ a/b = 2.00 \qquad (20)$$

TABLE 8

Summary of Computations for Contribution to Radiation at Designated Stations From Sources Distributed on Plane Area Outside the 340 x 340-ft Scraped Area[(a)]

h'	Fraction Contributed					
	p_1	p_2	p_3	p_4	p_5	p_6
1 m	0.024	0.040	0.024	0.025	0.025	0.508
6 ft	0.045	0.079	0.045	0.046	0.046	0.513
5 m	0.119	-	0.120	0.120	0.122	-
10 m	0.184	-	0.198	0.198	0.201	-

a. $p_1 = 1 - q_1$, Z = 0.25, E = 0.5 Mev

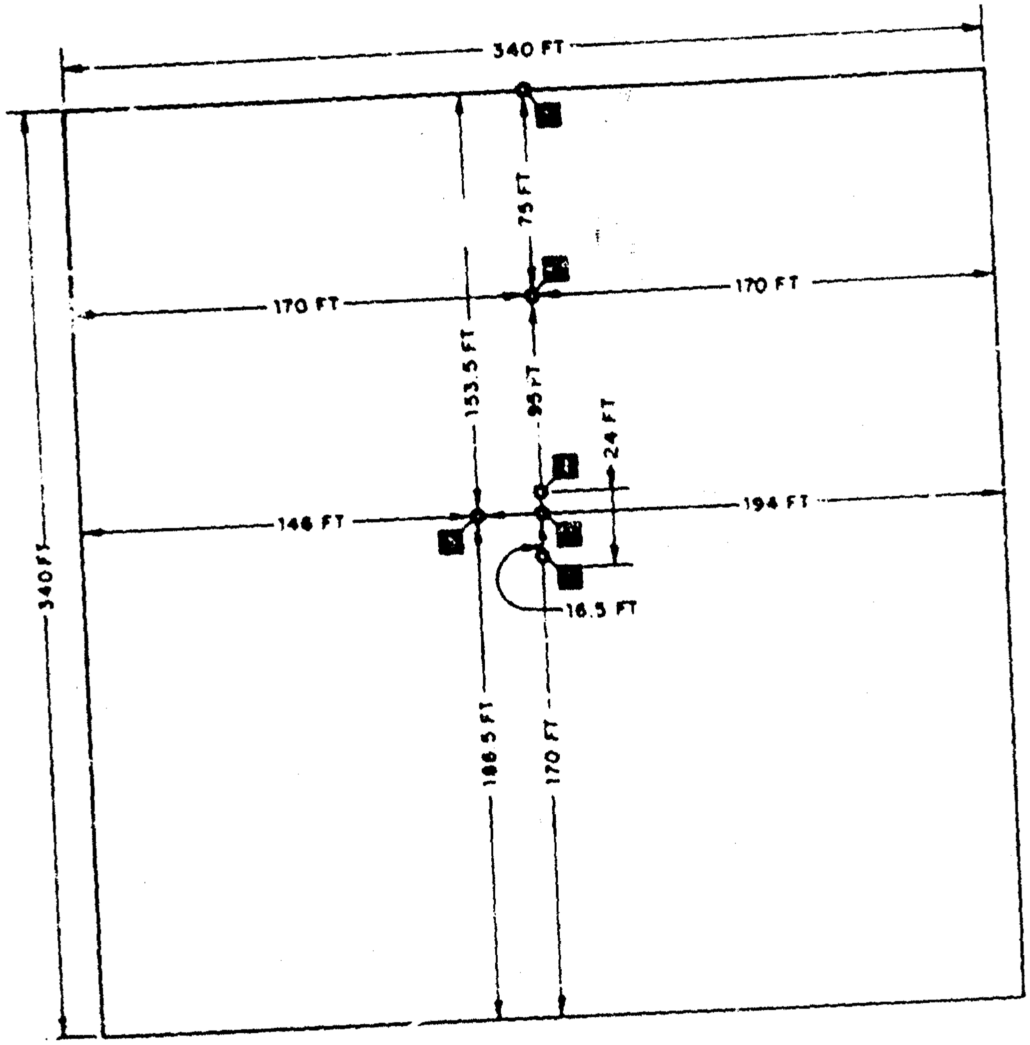

Fig. 8 Station Lay-out in Area Scraped Around Building A

The results of the computation are presented in Table 8 and are plotted as a function of 1/h in Fig. 9. It may be noted that, as h increases (1/h decreases), p increases and approaches the value of 1.0. For a given source strength I_o, the value of I(= p α I_o) over a perfectly reclaimed area (F=0) first increases with height and after a certain height begins to decrease again; this follows from the fact that α decreases with height, (see Fig. 7) and p increases with height up to a value of 1.0. The variation of p from the center of the cleared area to the midpoint of the sides is given in Fig. 10.

The variation of p with 1/h at the center of the circular scraped area, with a radius of 75 ft, around Building B is given in Fig. 11; the variation of p at 3 ft with distance from the center is shown in Fig. 12.

The radioactive sources on the ground contributing to the measurements taken on top of the concrete slab roof of Building A are shielded due to a shadow cast by the building and roof; this shielding shadow has the effect of a "cleared area" for the stations on the roof. Taking the surface of the roof as 9 ft above surface, and assuming zero transmission of photons from sources within the shadow, it is found that the shielding shadow for the 3-ft readings at all locations covers an area on the ground 192 ft long by 132 ft wide. The contributions to the radiation from sources outside the "shadowed area" to the center of the roof, the corners of the roof, and the midpoint of each side are given in Fig. 13.

The shielding shadows for the roof stations on Building B are shown in Figs. 14 and 15. These shadows indicate that certain locations on structures are less "exposed" to outside radiations from distant sources than others. The surface measurements along the roof peak, for example, are shielded to an infinite distance in the horizontal plane along the direction of the roof peak. The contributions from sources on the ground outside the shielding shadow of Building B are given in Table 9 for the monitor stations. For each station, the contribution to the surface reading is the smaller of the two.

The contribution of the sources on the concrete slab itself to the readings at the center of the slab, at each corner, and at the centers of each side are given according to station number in Table 10. The computations for the surface readings were made for a height of 2 in. It was unnecessary to make similar computations for the roof of Building B.

The values of q for the surface readings in Table 10 for the concrete roof were used, along with the data in Table B.5 (Appendix B), to estimate values of p for the roof shielding shadow. Since the data in the first column of Table B.5 were not all taken at the same stations as the remainder of the data, the q values of Table 10 were linearly interpolated to the locations of the measured values. The contributions from sources on the ground to locations near the center of the slab were taken to be zero.

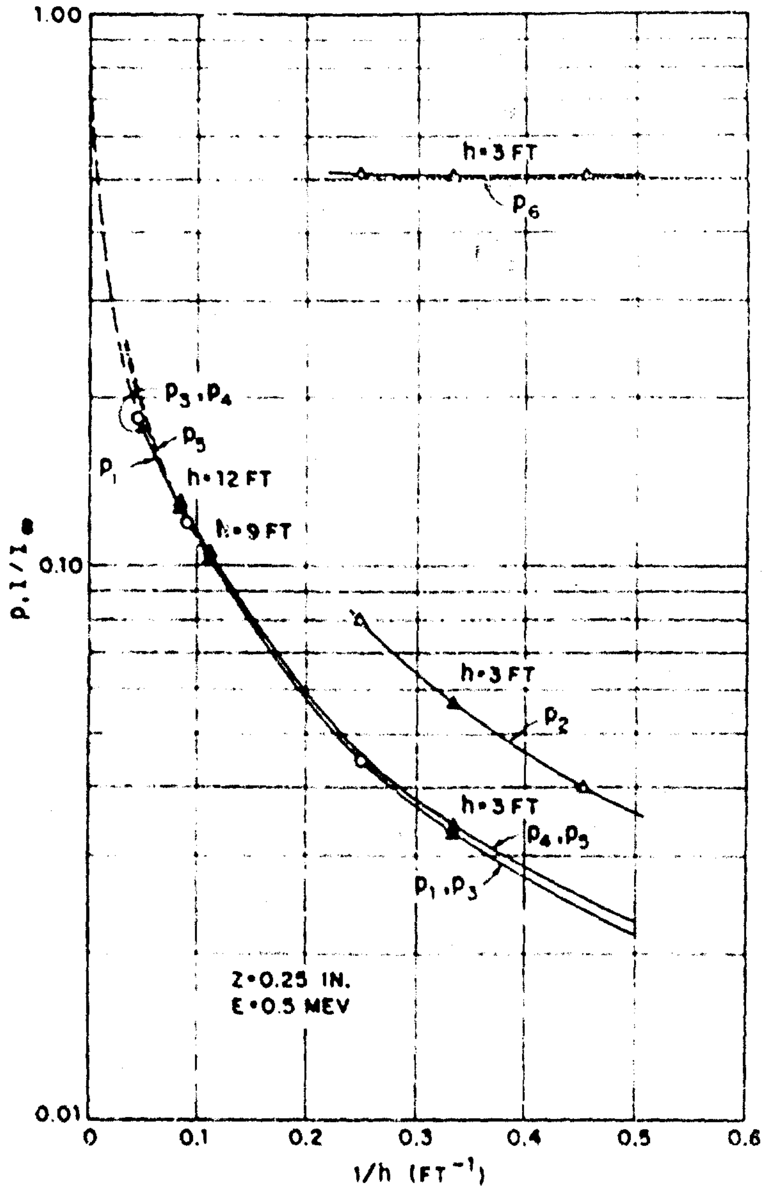

Fig. 9 Contribution of Sources Outside a 340 x 340 ft Area at Designated Stations

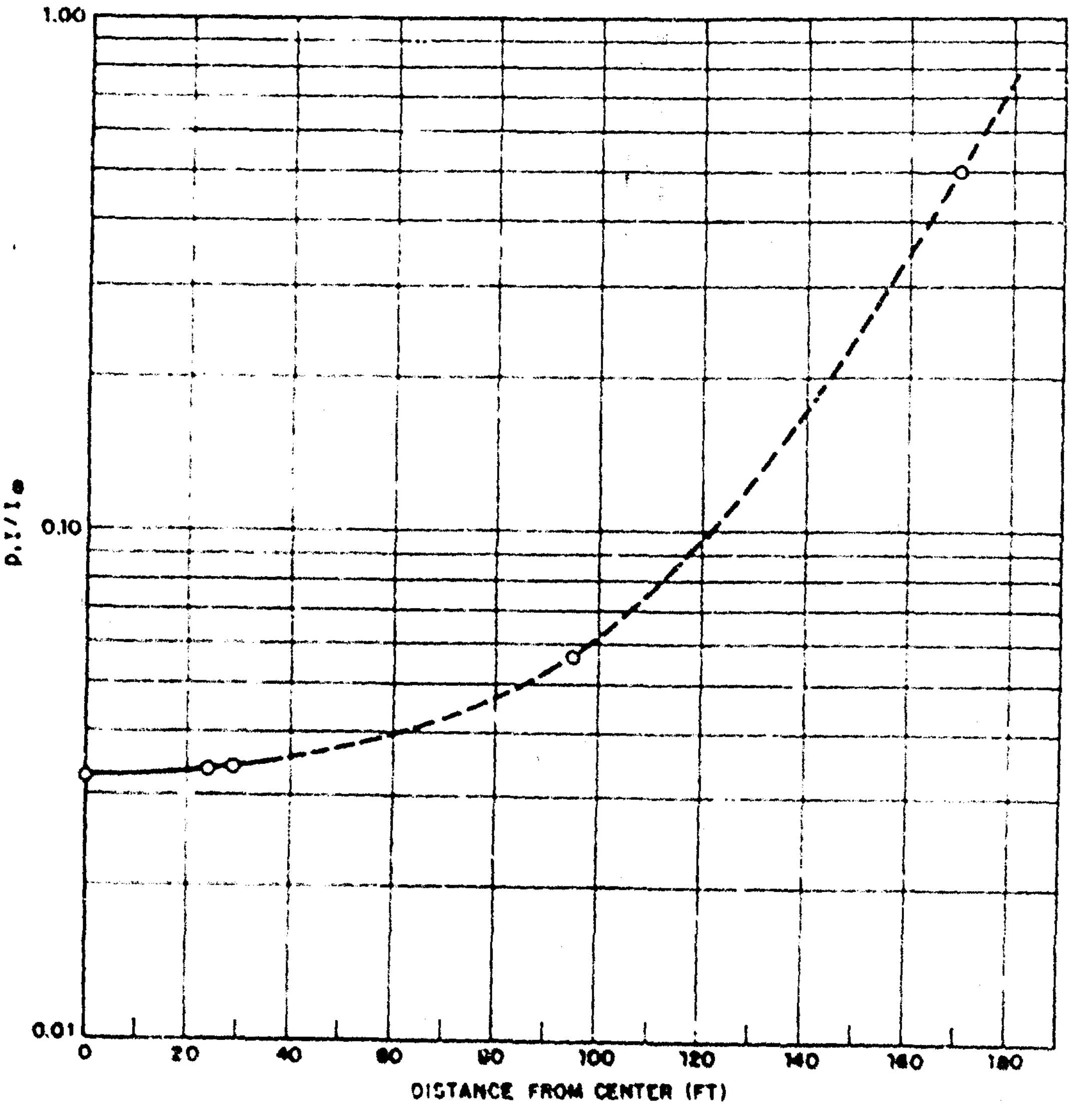

Fig. 10 Plot of I/I_{∞} for 3-ft Height From Center to Mid-point of the Sides of a 340 x 340-ft Square

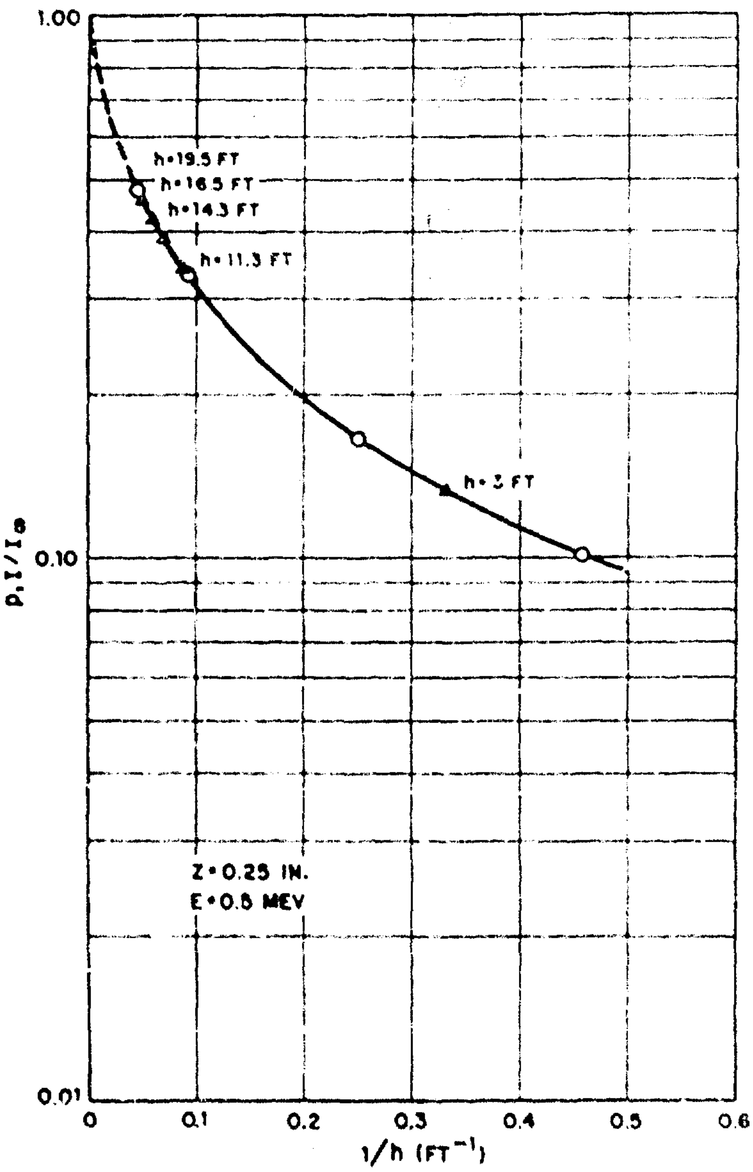

Fig. 11 Variation of I/I_∞ With Height at Center of a Circular Cleared Area of 75-ft Radius

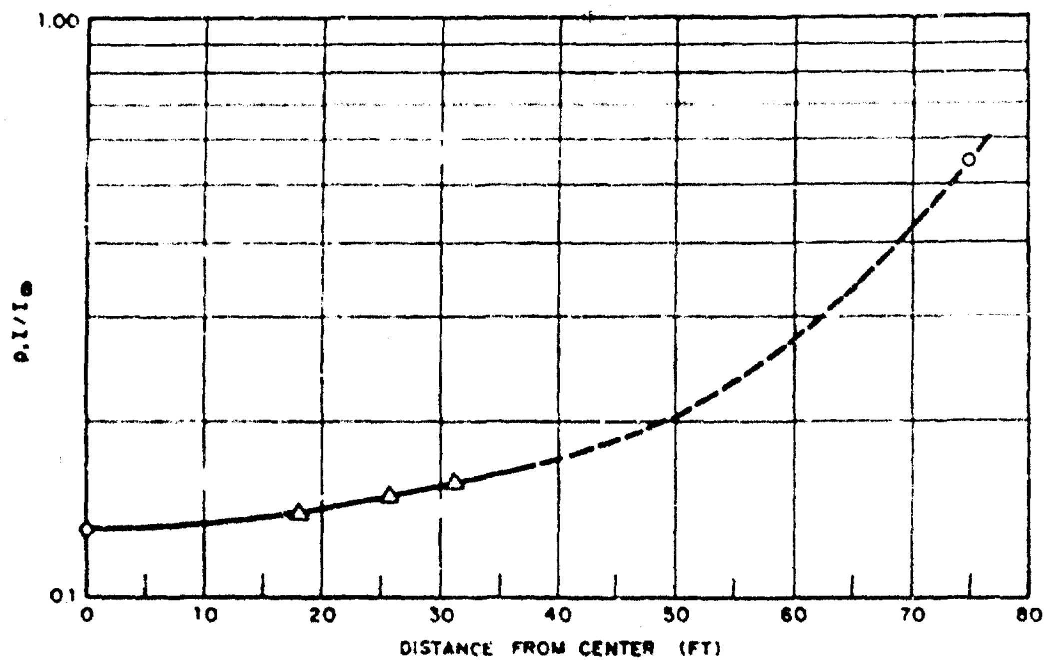

Fig. 12 Plot of I/I_{∞} at 3-ft Height From Center to Edge of Circle With 75-ft Radius

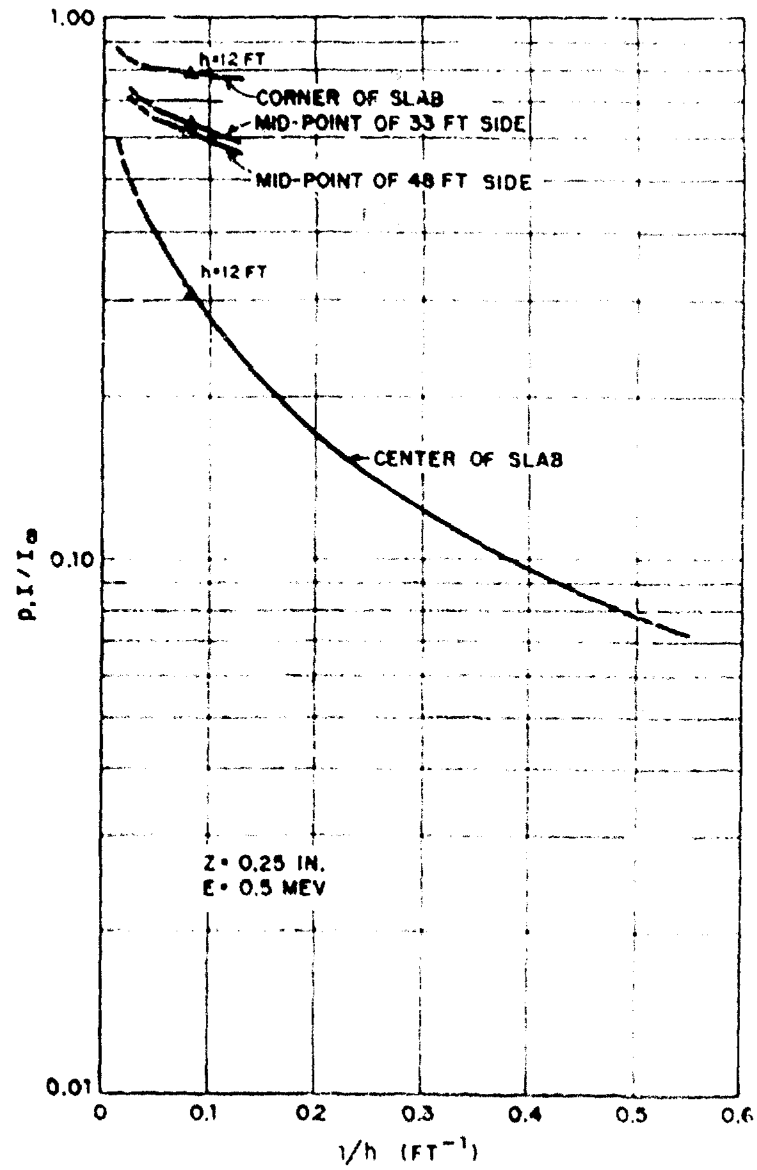

Fig. 13 Contributions to Radiation From Sources Outside the Shadow Cast by Concrete Slab Roof of Building A

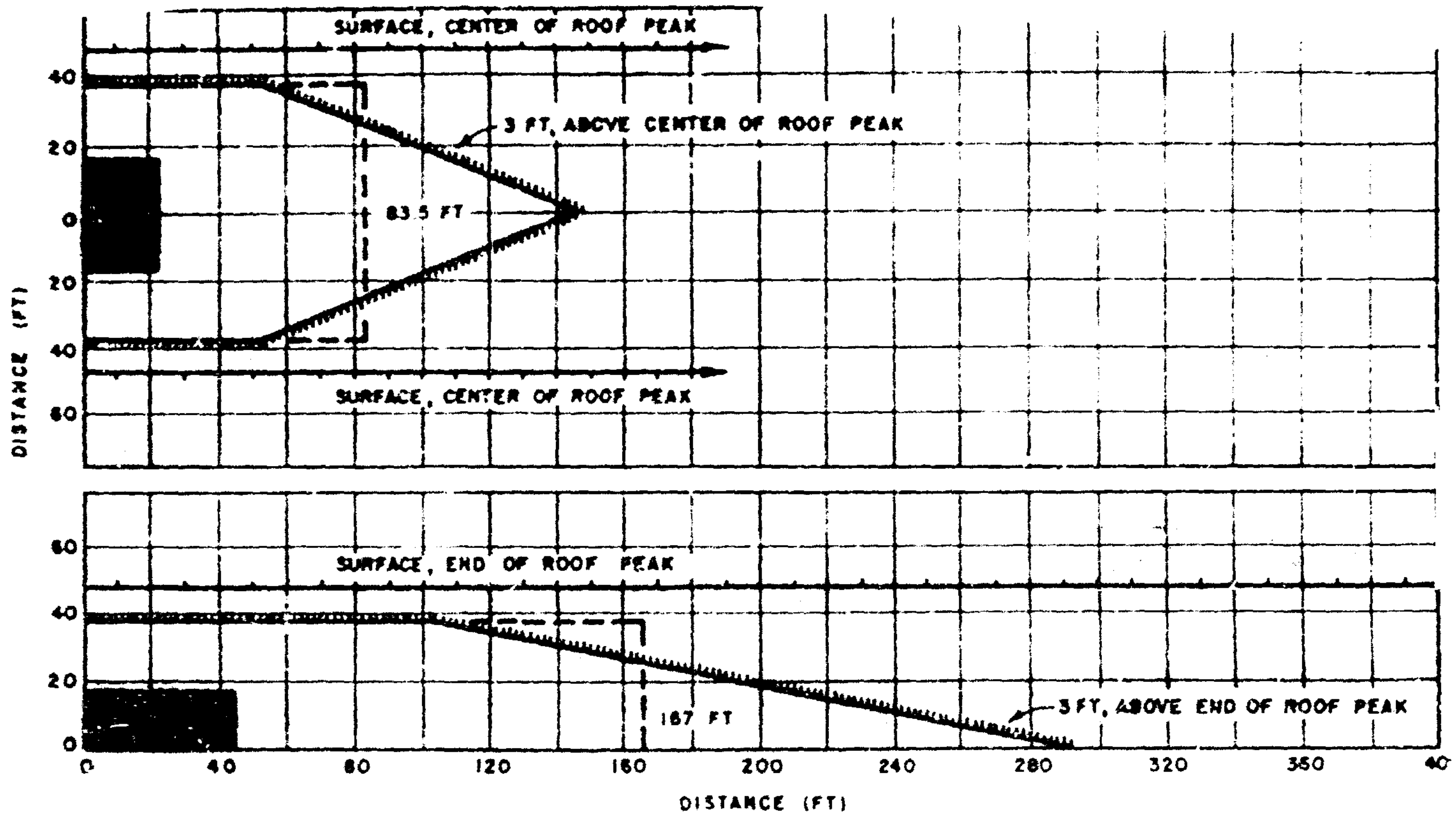

Fig. 14 Shielding Shadows of Building B at Roof Peak

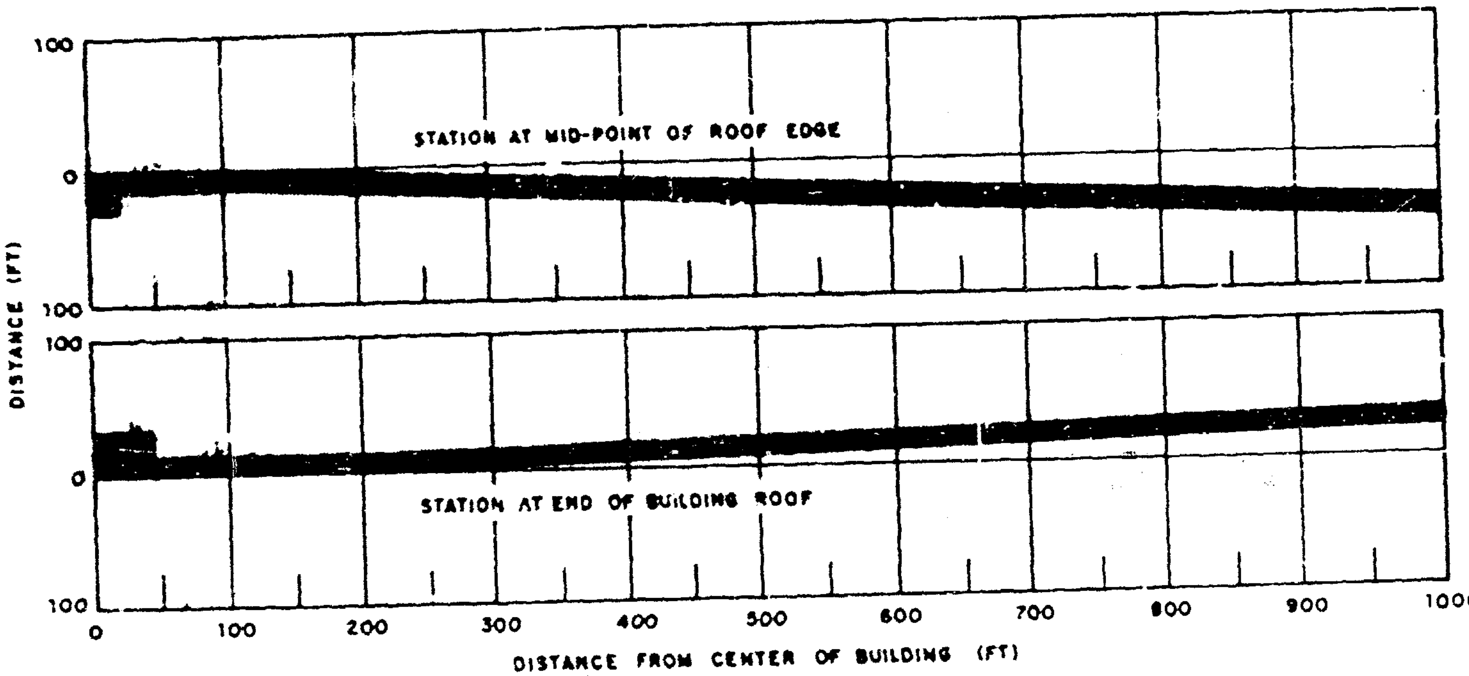

Fig. 15 Shielding Shadows of Building B for 3-ft Readings at Edge of Roof

TABLE 9

Values of I/I_∞ at Monitor Stations on Building B Roof From Sources on Ground Surface Outside the Shielding Shadow of Building B

Station	Location	$p = I/I_\infty$	
		Surface	3-foot
1	corner of roof	0.75	0.80
2	center, roof edge	0.50	0.60
3	corner of roof	0.75	0.80
4	end, roof peak	0.70	0.75
5	corner of roof	0.75	0.80
6	center, roof edge	0.50	0.60
7	corner of roof	0.75	0.80
8	end, roof peak	0.70	0.75
9	center, roof peak	0.40	0.55

TABLE 10

Contribution of Sources Deposited on Concrete Slab Roof to Radiation at Monitor Stations

Station	Location	$q = I_A/I_\infty$	
		Surface[a]	3-foot
1	corner	0.257	0.192
2	center, long side	0.547	0.330
3	corner	0.257	0.192
4	center, short side	0.544	0.307
5	corner	0.257	0.192
6	center, long side	0.547	0.330
7	corner	0.257	0.192
8	center, short side	0.544	0.307
9	center of slab	0.920	0.600

a. Height taken as 2 in.

TABLE 11

Estimation of Contribution of Sources Outside Shielding Shadow to Surface Readings on Concrete Slab Roof of Building A

Station	$I(o)$	q	I'_{∞}	I_A	I	p
1	19.4	0.257	-	5.6	13.8	0.58
2	13.6	0.402	-	8.7	4.9	0.21
3	15.5	0.402	-	8.7	6.8	0.29
4	19.4	0.257	-	5.6	13.8	0.58
5	18.4	0.400	-	8.6	9.8	0.42
6	24.2	0.400	-	8.6	15.6	0.66
7	18.4	0.257	-	5.6	12.8	0.54
8	19.4	0.402	-	8.7	10.7	0.45
9	19.4	0.402	-	8.7	10.7	0.45
10	21.3	0.257	-	5.6	15.7	0.67
11	17.4	0.400	-	8.6	8.8	0.37
12	16.5	0.400	-	8.6	7.9	0.33
13	10.6	0.50	21.2	10.8	0	0
14	9.7	0.50	19.4	10.8	0	0
15	10.6	0.50	21.2	10.8	0	0
16	12.6	0.50	25.2	10.8	0	0
17	19.4	0.92	21.1	19.9	0	0

I_{∞} (9 ft) = 23.6 (see Table 17)
$\bar{I}'_{\infty}$ = 21.6 (average for stations 13 through 17)
I_o = 12.5 (for roof contamination)

TABLE 12

Summary of p Values For Surface Readings On the Concrete Slab Roof

Stations	q	$\bar{I}(o)$	p
(1), (4), (7), (10)	0.257	14.0	0.593
(5), (6), (11), (12)	0.400	10.7	0.453
(2), (3), (8), (9)	0.402	10.5	0.445
4, 8	0.544	-	0.313
2, 6	0.547	-	0.297

The computations are given in Table 11; the value of I_∞ at 9 ft given in the table was taken from the following section. The average values of p are summarized and back-extrapolated to the original locations for q (Table 10) in Table 12.

The values of p, q, and α determined in this section are used in the following sections to aid in biasing the data in the appropriate direction so as to improve the estimates of the decontamination ratios from the experimental data.

3.6 ESTIMATION OF DECONTAMINATION RATIOS FOR MOT ADING

The average surface reading (I_∞) about Building A before grading, not taking into account those taken close to the building, was 30.2 mr/hr at 1 day; the value of α (Table 7) at this height is 1.73; hence I_o is 17.4 mr/hr. For the 3-foot readings the average value of I_∞ was 27.2 and for an α value of 1.53, the computed value of I_o is 17.8 mr/hr. Using the average, 17.6 mr/hr, for I_o, the adjusted average values I_∞ are 30.5 mr/hr at 1 day for the surface readings and 26.9 mr/hr day for 3-ft readings.

If the magnitude of the radiation field around Building B is assumed to vary linearly with distance from the building, the average value of the readings before grading would be representative of the point at the center of the area. For the average of 37.8 mr/hr at 1 day for the surface readings, I_o is 21.8 mr/hr. The 3-ft average, 33.7 mr/hr at 1 day, gives 22.0 mr/hr for I_o. With use of the average value, 21.9 mr/hr, the adjusted average values of I_∞ are 37.9 mr/hr at 1 day for the surface readings and 33.5 mr/hr at 1 day for the 3-ft readings. The ratio of the average I_o value at Building B to that at Building A is 1.24; thus the area at Building B received 24% more fallout than that at Building A.

The residual numbers for motorgrading around Building A are summarized in Table 13; those for motorgrading around Building B are given in Table 14. The residual numbers are the ratio of the decay-corrected readings taken after scraping to the decay-corrected readings taken before scraping. The lower effectiveness (higher residual number) for scraping around Building B was due to a combination of the rougher surface of the soil, more construction items (small concrete blocks, etc.) dispersed around the area, and the fact that the area scraped was small. However, for the 3-ft readings, this means that the shielding provided by the building influenced the readings at Building B to a greater extent than at Building A. This is shown by the ratio of the 3-ft residual numbers to the surface residual numbers; for the Building A area the ratio is 1.45 and for the Building B area it

TABLE 13

Residual Numbers for Motorgrading the Area About Building A

Station	1	2	3	4	5	6	7
			Surface				
A			0.750	0.461	0.155		
B			0.069	0.141	0.073		
C	0.476	0.150	0.417	0.185	0.150	0.178	0.441
D	0.300	0.409	0.277	X	0.320	0.178	0.369
E	0.906	0.160	0.196	0.172	0.253	0.178	0.410
F			0.166	0.248	-		
G			-	-	-		
	Average (to 95' from center of area): 0.206						
			3-foot Height				
A			0.636	0.582	0.331		
B			0.155	0.248	0.166		
C	0.518	-	0.229	0.424	0.738	0.185	-
D	-	0.343	0.225	X	0.343	0.185	0.458
E	0.827	0.277	0.282	0.343	0.360	-	0.550
F			0.300	0.257	-		
G			-	-	-		
	Average (to 95' from center of area): 0.298						

is 1.35. In the previous paragraphs, no computations were made to determine the effect of the building shielding shadows on the ground surface and 3-ft readings. The effect on the surface readings should be relatively small.

The average of the surface readings out to about 95 ft from the center of Building A after scraping is 6.06 mr/hr at 1 day. The average residual number defined as $\overline{I}'_{\infty}/\overline{I}_{\infty}$ is 6.06/30.5, or 0.199: this value will be taken as equal to the decontamination ratio, F, for the scraping by motorgrader. The corresponding value of I_0 is 3.50 mr/hr.

Due to the gradient in the fallout around Building B, the average value of the surface readings before and after scraping was not used to compute F; the value 0.341 will be retained as the measure of F from the surface readings for that area. The corresponding value of I'_0 is 0.341 x 21.9, or 7.47, mr/hr.

The computations of I, I'_A, and I'_{∞} for the 3-ft readings taken after scraping the area around Building A are given in Table 15. The

TABLE 14

Residual Numbers for Motorgrading the Area About Building B

Station	1	2	3	4	5	6	7
			Surface				
A			1.0	1.0	1.0		
B			0.238	-	0.625		
C	1.0	0.719	0.270	-	0.441	0.382	1.0
D	1.0	0.139	0.227	X	0.143	-	1.0
E	1.0	0.429	0.371	0.200	0.448	0.310	1.0
F			0.171	0.409	0.260		
G			1.0	1.0	1.0		
Average (to 65 ft from center of area): 0.341							
			3-ft Height				
A			1.0	1.0	1.0		
B			0.357	0.577	0.556		
C	1.0	0.433	0.400	0.565	0.520	0.455	1.0
D	1.0	0.312	0.400	X	0.357	0.588	1.0
E	1.0	0.454	0.448	0.400	0.625	0.556	1.0
F			0.351	0.270	0.605		
G			1.0	1.0	1.0		
Average (to 65 ft from center of area): 0.461							

values of p were taken from Fig. 13; the same value of p was used for all the locations near 95 ft away from the center and another single value for those near the edge of the area. The shielding of the building was neglected in the computations; however, the effect of shielding would be larger in converting I_1' to I_∞' than in the computation of I_1'. The average value, 6.04 mr/hr at 1 day, of I_∞' gives an I_0' value of 3.95 mr/hr and an F value of 0.222. These are in satisfactory agreement with those obtained directly from the surface measurements. The average value of I_0' for the two sets of data is 3.72 mr/hr; this combination of data gives a decontamination ratio value of 3.72/17.6, or 0.211.

The computation of F for the 3-ft readings taken after scraping the [illegible] Building B is given in Table 16. Due to the gradient in the field, the computations in Table 16 were made differently than in Table 15. The individual initial measurement values (Table B.3) were [illegible] to compute I and the ratio F. The average value of the latter, 0.265, is lower than

TABLE 15

Computation of I, I_A and I'_{∞} for the 3-foot Readings Taken After Scraping the Area About Building A

Station	1	2	3	4	5	6	7
			I(mr/hr at 1 day)[a]				
A	1		15.0	15.0	15.0		
B			1.7	1.7	1.7		
C	13.1	1.5	1.0	1.0	1.0	1.5	13.3
D	13.1	1.5	0.9	X	0.9	1.5	13.3
E	13.1	1.5	0.9	0.9	0.9	1.5	13.3
F			1.5	1.5	1.5	1.5	
G			13.7	13.7	13.7		
			I'_A (mr/hr at 1 day)[b]				
A			4.1	1.7	0		
B			3.1	5.5	3.1		
C	0	8.1	3.8	6.2	8.6	3.3	0
D	0	8.1	6.3	X	3.9	3.3	0
E	8.4	5.7	8.7	8.7	6.3	5.7	1.0
F			5.7	5.7	-		
G			-	-	-		
			I'_{∞}(mr/hr at 1 day)[c]				
A			-	-	-		
B			3.3	5.8	3.3		
C	-	6.6	3.9	6.4	8.9	3.5	-
D	-	8.6	6.5	X	4.0	3.5	-
E	-	6.0	9.0	9.0	6.5	6.0	-
F			6.0	6.0	-		
G			-	-	-		

Average I'_{∞} = 6.04

a. For stations A3, A4, A5, B3, B4, and B5, I_{∞} = 29.5; for stations C1, C2, D1, D2, E1, and E2, I_{∞} = 25.8; for stations C6, C7, D6, D7, E6, and E7, I_{∞} = 26.0; for stations F3, F4, F5, G3, G4, and G5, I_{∞} = 26.8. At 170 ft from center area, p = 0.510; at 95 ft, p = 0.057; and at locations near the structure p = 0.034 where $I = pI_{\infty}$.

b. $I'_A = I'(o) - I$

c. $I_{\infty} = I'_A/q$; $q = 1 - p$

TABLE 16

Computation of Decontamination Ratio for the 3-ft Readings Taken After Scraping the Area About Building B

Station	1	2	3	4	5	6	7
			$p = I/I_{\infty}$				
A			1.00	1.00	1.00		
B			.33	.33	.33		
C	1.00	.33	.156	.141	.156	.33	1.00
D	1.00	.33	.150	X	.150	.33	1.00
E	1.00	.33	.156	.141	.156	.33	1.00
F			.33	.33	.33		
G			1.00	1.00	1.00		
			$I = pI_{\infty}$ (mr/hr at 1 day)				
A			-	-	-		
B			9.3	8.6	9.0		
C	-	10.0	3.9	3.2	3.9	11.0	-
D	-	10.6	3.8	X	3.2	11.3	-
E	-	11.0	4.5	3.5	(4.7)[a]	12.0	-
F			12.3	12.3	12.6		
G			-	-	-		
			$I_A' = I'(o) - I$ (mr/hr at 1 day)				
A			-	-	-		
B			0.7	6.4	6.0		
C	-	3.0	6.1	9.8	9.1	4.0	-
D	-	0	6.2	X	4.3	8.7	-
E	-	4.0	8.5	6.5	10.3	8.0	
F		0	0.7	0	10.4		
G			-	-	-		

Continued

a. Estimated value.

TABLE 16 (Cont'd)

Computation of Decontamination Ratio for the 3-ft Readings Taken After Scraping the Area About Building B

Station	1	2	3	4	5	6	7
			$q = 1 - p$				
A			-	-	-		
B			0.67	0.67	0.67		
C	-	0.67	0.844	0.859	0.844	0.67	-
D	-	0.67	0.850	X	0.850	0.67	-
E	-	0.67	0.844	0.859	0.844	0.67	-
F			0.67	0.67	0.67		
G			-	-	-		
			$I'_{\infty} = I'_{\lambda}/q$ (mr/hr at 1 day)				
A			-	-	-		
B			1.0	9.5	8.9		
C	-	4.5	7.1	11.4	10.8	6.0	-
D	-	0.0	7.3	X	5.1	13.0	-
E	-	6.0	10.1	7.6	12.2	11.9	-
F			1.0	0.0	15.5		
G			-	-	-		
			$F = I'_{\infty}/I_{\infty}$				
A			-	-	-		
B			0.036	0.365	0.330		
C	-	0.150	0.284	0.496	0.432	0.182	-
D	-	0.0	0.292	X	0.243	0.382	-
E	-	0.182	0.348	0.304	0.508	0.331	-
F			0.027	0.0	0.408		
G			-	-	-		

Average F = 0.265

that obtained from the surface readings. The weighted mean value for the two sets of data is 0.300 (per measurement); this value of F leads to the value, 6.57 mr/hr, for I_0'.

3.7 ESTIMATION OF DECONTAMINATION RATIOS FOR CONCRETE ROOF OF BUILDING A

The variation of I_∞ and I_∞' with height above the ground is given in Table 17 using the values of I_0 and I_0' determined in the previous paragraphs.

TABLE 17

Variation of I_∞ and I_∞' with Height for I_0 Values of 17.6 mr/hr and 3.72 mr/hr, Respectively

h(ft)	I_∞ (mr/hr at 1 day)	I_∞'(mr/hr at 1 day)
0	30.5	6.44
3	26.9	5.70
9	23.6	4.99
12	22.4	4.73

From the data in Appendix B, the average of the initial surface reading on the concrete roof was 16.8 mr/hr at 1 day; after scraping the area it was 9.07 mr/hr at 1 day; after firehosing it was 5.11 mr/hr at 1 day; and after scrubbing it was 4.87; the respective residual numbers for the processes are therefore 0.54, 0.30, and 0.29. The residual numbers for the 3-ft readings for the same processes are 0.74, 0.52, and 0.52. The difference in the values at the two heights reflect the fact that the 3-ft readings were exposed to more radiation sources on the ground.

The initial source intensity on the concrete roof is estimated in Table 18 using the values of p and q determined in section 3.3. In computing the appropriate values of I_∞, the ground surface source intensity I_0 was taken as 3.72 mr/hr over the whole area (scraped plus unscraped) and from areas outside the scraped area, the ground surface source intensity, I_0, was an additional 17.6 - 3.7, or 16.9 mr/hr. The source intensity on the roof remaining after firehosing is estimated in Table 19; and the intensity after scrubbing is estimated in Table 20. It may be noted that an error of a few tenths of an mr/hr in the estimate of I, especially for the 3-ft readings, is magnified by a factor as large as 5 in the estimate of I_∞. The values of I_∞ at 3-ft for the corners of the roof are consistently high in Tables 19 and 20.

TABLE 18

Estimation of Initial Source Intensity on Concrete Slab Roof of Building A
(Values of $I(o)$, I, I_A, I'_∞, and I'_o in mr/hr at 1 day)

Surface

Station	$I(o)$	p	I	I'_A	q_1	I'_∞
1	9.6	0.59	4.1	5.5	0.257	21.4
2	7.2	0.31	2.1	5.1	0.547	9.3
3	7.2	0.59	4.1	3.1	0.257	12.1
4	4.8	0.30	2.1	2.7	0.544	5.0
5	9.6	0.59	4.1	5.5	0.257	21.4
6	9.6	0.31	2.1	7.5	0.547	13.7
7	9.6	0.59	4.1	5.5	0.257	21.4
8	9.6	0.30	2.1	7.6	0.544	14.0
9	14.4	0	0	14.4	0.92	15.7

$I_\infty = 0.103 \times (23.6 - 5.0) + 4.99 = 6.91$

Average $I'_\infty = 17.9$; $I'_o = 10.4$

3-ft Height

Station	$I(o)$	p_1	I_1 (a)	I_2 (b)	I	I'_A	q_1	I'_∞
1	9.6	0.777	3.68	2.34	6.0	3.6	0.192	18.8
2	9.6	0.625	2.96	2.30	5.3	4.3	0.330	13.0
3	7.2	0.777	3.68	2.34	6.0	1.2	0.192	6.2
4	9.6	0.677	3.20	2.30	5.5	4.1	0.307	13.4
5	9.6	0.777	3.68	2.34	6.0	3.6	0.192	18.8
6	12.0	0.625	2.96	2.30	5.3	6.7	0.330	20.3
7	9.6	0.777	3.68	2.34	6.0	3.6	0.192	18.8
8	9.6	0.677	3.20	2.30	5.5	4.1	0.307	13.4
9	12.0	0.317	1.50	2.27	3.8	8.2	0.60	13.7

Average $I'_\infty = 16.3$; $I'_o = 10.6$

a. $I_1 = 4.73 \times p_1$

b. $I_2 = 0.128(22.4 - 4.7) = 2.27$
$0.130(22.4 - 4.7) = 2.30$
$0.130(22.4 - 4.7) = 2.30$
$0.132(22.4 - 4.7) = 2.34$

TABLE 19

Estimation of Source Intensity on Concrete Slab After Firehosing
(Values of I(o), I, I_λ and I'_∞ are in mr/hr at 1 day)

Station	I(o)	I	I_λ	q_1	I'_∞
			Surface		
1	5.5	4.1	1.4	0.257	5.4
2	4.5	2.1	2.4	0.547	4.4
3	5.0	4.1	0.9	0.257	3.5
4	5.0	2.1	2.9	0.544	5.3
5	5.0	4.1	0.9	0.257	3.5
6	5.5	2.1	3.4	0.547	6.2
7	5.5	4.1	1.4	0.257	5.4
8	4.5	2.1	2.4	0.544	4.4
9	5.5	0	5.5	0.92	6.0
	Average I'_∞ = 4.90; I_o = 2.83; F = 0.274				
			3-ft Height		
1	7.5	6.0	1.5	0.192	7.8
2	6.3	5.3	1.0	0.330	3.8
3	7.5	6.0	1.5	0.192	7.8
4	7.0	5.5	1.5	0.307	4.9
5	7.5	6.0	1.5	0.192	7.8
6	6.5	5.3	1.2	0.330	3.6
7	7.5	6.0	1.5	0.192	7.8
8	7.5	5.5	2.0	0.307	6.5
9	6.0	3.8	2.2	0.60	3.7
	Average I'_∞ = 5.88; I_o = 3.84; F = 0.361				
	Average I'_∞ (a) = 4.44; I_o = 2.89; F = 0.271				

a. Omits corner readings.

TABLE 20

Estimation of Source Intensity on Concrete Slab After Firehosing and Scrubbing
(values of I(o), I, I_λ', and I_∞' are in mr/hr at 1 day)

Station	I(o)	I	I_λ'	q_1	I_∞'
			Surface		
1	5.1	4.1	1.0	.257	3.9
2	4.6	2.1	2.5	.547	4.6
3	4.6	4.1	0.5	.257	1.9
4	4.8	2.1	2.7	.544	5.0
5	4.6	4.1	0.5	.257	1.9
6	4.6	2.1	2.5	.547	4.6
7	5.6	4.1	1.5	.257	5.8
8	5.1	2.1	3.0	.544	5.5
9	4.8	0	4.8	.92	5.2
			Average I_∞' = 4.27; I_o = 2.47; F = 0.238		
			3-ft Height		
1	7.6	6.0	1.6	.192	8.3
2	6.4	5.3	1.1	.330	3.3
3	7.6	6.0	1.6	.192	8.3
4	7.4	5.5	1.9	.307	6.2
5	7.4	6.0	1.4	.192	7.3
6	6.9	5.3	1.6	.330	4.8
7	7.1	6.0	1.1	.192	5.7
8	7.1	5.5	1.6	.307	5.2
9	5.8	3.8	2.0	.60	3.3
			Average I_∞' = 5.82; I_o = 3.80; F = 0.357		
			Average I_∞'(a) = 4.56; I_o = 2.98; F = 0.280		

a. Omits corner readings.

3.8 ESTIMATION OF DECONTAMINATION RATIOS FOR COMPOSITION ROOF OF BUILDING B

Because of the gradient in the field around Building B, three average ground source intensities were used in the computations; the values of $\bar{I}_o$ for each side of house and the average for both sides is given in Table 21. The values of I_∞ at the appropriate heights above the surface of the ground for each value of $\bar{I}_o$ are given in Table 22.

TABLE 21

Computation of Average Value of I_o for Area About Building B

Area	$\bar{I}_\infty$(surface) (mr/hr at 1 day)	I_∞ (3 ft) (mr/hr at 1 day)	$\bar{I}_o$ (mr/hr)
Northwest Side	32.6	29.3	19.0
Southeast Side	43.3	38.0	24.9
Average for Area	37.9	33.5	21.9

TABLE 22

Values of I_∞ at Monitor Station Heights Above Ground Level on Roof Building B

h (ft)	I_∞ (NW)	I_∞ (SE)	$\bar{I}_\infty$
	(in mr/hr at 1 day)		
11.3	24.3	31.9	-
14.3	23.2	30.4	-
16.5	-	-	25.8
19.5	-	-	24.8

The initial contributions of the sources on the roof of Building B at each station is estimated in Table 23; that after firehosing is estimated in Table 24 along with values of F for the procedure. In these

TABLE 23

Estimation of Initial I_A Values for Roof of Building B
(Values of I(o), I, and I_A in mr/hr at 1 day)

	Surface				3-ft height			
Station	I(o)	p	I[a]	I_A'	I(o)	p	I[b]	I_A'
1	24.8	0.75	18.2	6.6	23.7	0.80	18.6	5.1
2	21.4	0.50	12.2	9.2	22.6	0.60	13.9	8.7
3	21.4	0.75	18.2	3.2	24.8	0.80	18.6	6.2
4	18.1	0.70	18.0	-	24.8	0.75	18.6	6.2
5	38.4	0.75	23.9	14.5	28.2	0.80	24.3	3.9
6	37.3	0.50	16.0	21.3	30.5	0.60	18.2	12.3
7	39.5	0.75	23.9	15.6	29.4	0.80	24.3	5.1
8	20.3	0.70	18.0	2.3	16.9	0.75	18.6	-
9	28.2	0.40	10.3	17.9	27.1	0.55	13.6	13.5
Sum				90.6				61.0

a. $I = p\, I_\infty$; $I_\infty = 24.3$ for 1, 2, and 3.
$I_\infty = 31.9$ for stations 5, 6, and 7.
$I_\infty = 25.8$ for stations 4, 8, and 9.

b. $I = p\, I_\infty$; $I_\infty = 23.2$ for 1, 2, and 3.
$I_\infty = 30.4$ for stations 5, 6, and 7.
$I_\infty = 24.8$ for stations 4, 8, and 9.

TABLE 24

Estimation of Values of I_A' and of F for Roof of Building B After Firehosing
(values of I(o), I, I_A' in mr/hr at 1 day)

	Surface				3-ft Height			
Station	I(o)	I	I_A'	F	I(o)	I	I_A'	F
1	15.6	18.2	0	0.00	18.0	18.6	0	0.00
2	20.4	12.2	8.2	0.89	20.4	13.9	6.5	0.75
3	18.0	18.2	0	0.00	21.7	18.6	3.1	0.50
4	16.8	18.0	-	-	24.1	18.6	5.5	0.89
5	24.1	23.9	0.2	0.01	20.4	24.3	0	0.00
6	24.1	16.0	8.1	0.38	24.1	18.2	5.9	0.48
7	24.1	23.9	0.2	0.01	22.9	24.3	0	0.00
8	21.6	18.0	3.6	(1.00)[a]	18.0	18.6	-	-
9	16.8	10.3	6.5	0.36	19.2	13.6	5.6	0.41
Sum			26.8	2.65			26.6	3.03
$\bar{F}$			0.296,	0.331			0.436,	0.378

a. Estimated value.

TABLE 25

Estimation of F Values of I_A' and of F for Roof of Building B After Firehosing From Second Set of Readings
(Values of I(o), I, and I_A' in mr/hr at 1 day)

Station	Surface I(o)	Surface I	Surface I_A'	Surface F	3-ft Height I(o)	3-ft Height I	3-ft Height I_A'	3-ft Height F
1	21.0	18.2	2.8	0.42	21.0	18.6	2.4	0.47
2	18.7	12.2	6.5	0.71	18.7	13.9	4.8	0.55
3	21.0	18.2	2.8	0.87	21.0	18.6	2.4	0.39
4	21.0	18.0	-	-	23.4	18.6	4.8	0.77
5	21.0	23.9	0	0.00	23.4	24.3	0	0.00
6	23.4	16.0	7.4	0.35	23.4	18.2	5.2	0.42
7	25.7	23.9	1.8	0.12	25.7	24.3	1.4	0.27
8	21.0	18.0	3.0	(1.00)[a]	23.4	18.6	-	-
9	18.7	10.3	8.4	0.47	16.4	13.6	2.8	0.21
Sum			32.3	3.94			23.8	3.08
$\bar{F}$			0.363,	0.492			0.390,	0.385

a. Estimated value.

TABLE 26

Computation of I_∞ at Monitor Station Heights on Roof of Building B After Scraping Area
(Values of I'_∞ and I_∞ in mr/hr at 1 day)

Radiation from Infinite Field for Intensity of Decontaminated Circle (I'_o = 6.57)

Surface: h(ft)	α	I_∞(NW)	I_∞(SE)	$\bar{I}_\infty$	3-ft Height: h(ft)	α	I_∞(NW)	I_∞(SE)	$\bar{I}_\infty$
11.3	1.28	8.41	8.41	-	14.3	1.22	8.02	8.02	-
16.5	1.18	-	-	7.75	19.5	1.13	-	-	7.42

Radiation From Outside Decontaminated Circle

Surface: h(ft)	α	I_∞(NW)	I_∞(SE)	$\bar{I}_\infty$	3-ft Height: h(ft)	α	I_∞(NW)	I_∞(SE)	$\bar{I}_\infty$
11.3	1.28	15.9	23.5	-	14.3	1.22	15.2	22.4	-
16.5	1.18	-	-	18.0	19.5	1.13	-	-	17.4

Surface: h(ft)	p	I_∞(NW)	I_∞(SE)	$\bar{I}_\infty$	3-ft Height: h(ft)	p	I_∞(NW)	I_∞(SE)	$\bar{I}_\infty$
11.3	0.342	5.44	8.04	-	14.3	0.390	5.93	8.74	-
16.5	0.420	-	-	7.56	19.5	0.456	-	-	7.93

Total Value of I_∞ at Monitor Stations

Surface: h(ft)	I_∞(NW)	I_∞(SE)	$\bar{I}_\infty$	3-ft Height: h(ft)	I_∞(NW)	I_∞(SE)	$\bar{I}_\infty$
11.3	13.8	16.4	-	14.3	14.0	16.8	-
16.5	-	-	15.3	19.5	-	-	15.4

TABLE 27

Estimation of Values of I_A' and of F for Roof of Building B After Firehosing and Scraping Areas Around the Building
(Values of I(o), I, and I_A' in mr/hr at 1 day)

Station	Surface					3-ft Height				
	I(o)	p	I[(a)]	I_A'	F	I(o)	p	I[(b)]	I_A'	F
1	10.2	.75	10.4	0	0.00	10.2	0.80	11.2	0	0.00
2	10.2	0.50	6.9	3.3	0.36	10.2	0.60	8.4	1.8	0.21
3	10.2	0.75	10.4	0	0.00	10.2	0.80	11.2	0	0.00
4	12.8	0.70	10.7	-	-	12.8	0.75	11.6	1.2	0.19
5	12.8	0.75	12.3	0.5	0.05	12.8	0.80	13.4	0	0.00
6	15.3	0.50	8.2	7.1	0.33	15.3	0.60	10.1	5.2	0.42
7	15.3	0.75	12.3	3.0	0.19	15.3	0.80	13.4	1.9	0.37
8	15.3	0.70	10.7	4.6	(1.00)[c]	15.3	0.75	11.6	-	-
9	12.8	0.40	6.1	6.7	0.37	15.3	0.55	8.5	6.8	0.50
Sum				25.2	2.28				16.9	1.69
Average F				0.278	0.285				0.277	0.211

a. I_{∞} = 13.8 for stations 1, 2, and 3.
I_{∞} = 16.4 for stations 5, 6, and 7.
I_{∞} = 15.3 for stations 4, 8, and 9.

b. I_{∞} = 14.0 for stations 1,2, and 3.
I_{∞} = 16.8 for stations 5,6, and 7.
I_{∞} = 15.4 for stations 4,8, and 9.

c. Estimated value.

computations, the estimate of F was made in two ways. One was by the ratio of the individual I_A'/I_A ratios and the other by the ratio of the two sums. The latter method gives greater weight to the larger values in each sum. The estimation of F from the second set of measurements before scraping the area is given in Table 25. The values of I_{∞} at the heights of the monitor stations of the roof of Building B after the scraping of the area around the house are computed in Table 26; the values are used in Table 27 to estimate the source levels on the roof of Building B from the readings taken after the area was scraped. From the six sets of F values, the grand average value from the individual ratios is 0.347 while that from the ratio of the sums is 0.340.

3.9 ESTIMATION OF SHIELDING RESIDUAL NUMBERS FOR BUILDING A

The meaning of a "shielding factor" in terms of the shielding residual number for a building will not be discussed; the residual number is defined as the ratio of the reading at a given monitor station in the building to the outside infinite field reading at 3 ft above the surface. Computed on this basis, the shielding residual numbers are given in Table 28. The high

TABLE 28

Shielding Residual Numbers for Monitor Stations Inside Building A Relative to the 3-ft Intensity (I_{∞}) From Ground Surface Source Level Outside

Station	Before Scraping[a]			After Scraping[b]			After Firehosing Roof[b]		
	Surface	3 ft	8 ft	Surface	3 ft	8 ft	Surface	3 ft	8 ft
1	-	0.04	-	0.02	0.08	0.18	0.0	0.0	0.0
2	-	0.14	-	0.11	0.11	0.18	0.08	0.08	0.15
3	-	0.19	-	0.15	0.21	0.21	0.12	0.15	0.35
4	-	0.35	-	0.15	0.15	0.26	0.08	0.08	0.15
5	-	0.12	-	0.15	0.08	0.15	0.03	0.04	0.08
6	0.07	0.10	0.22	0.09	0.15	0.21	0.03	0.15	0.15
7	-	0.39	-						
8	-	0.12	0.17						
9	-	0.18	-						
10	-	0.20	-						
11	-	0.08	-						

a. I_{∞} = 26.9 mr/hr at 1 day.
b. I_{∞} = 5.70 + 0.92 = 6.62 mr/hr at 1 day.

number for stations No. 4 and 7 are due to the fact that they were taken in back of wood panels. A more complete set of measurements was not taken in other rooms because the panels were broken out so that the interiors could have been contaminated to an unknown amount. The same situation pertained to all rooms in Building B.

According to The Effects of Nuclear Weapons[6], the comparable half-thicknesses of concrete and wood for fission product gamma rays are 2.2 and 8.8 in. With these half-thickness values for fission products deposited directly on these surfaces, the fraction of the gamma radiation passing through 6 in. of concrete would be 0.15 while the fraction passing through 1.5 in. of wood would be 0.85. However, the same reference gives 0.22 cm^{-1} for the absorption coefficient for 0.5-Mev photons incident on concrete; this value would lead to a transmission fraction of 0.035 through 6 in. of concrete (and less for a lower photon energy). Since the source energy of the photons was about 0.5 Mev on the average, the average energy of the photons incident on the surface of the building walls should be somewhat less. However, the situation is complicated by the presence of fallout on the roof (also small amounts on the outside of the walls). After firehosing, the shielding residual numbers vary between 0.03 and 0.15 for monitor stations near the outer walls.

The residual numbers for the outside reclamation procedures are given in Table 29; they were computed for the 3-ft readings by taking the ratio

TABLE 29

Residual Numbers from Measurements Inside Building A

Station	Motorgrader Scraping, at 3 ft	Motorgrader Scraping Plus Firehosing Roof, at 3 ft
1	0.42	0.00
2	0.19	0.14
3	0.27	0.19
4	0.11	0.05
5	0.15	0.09
6	0.37	0.37
Average	0.25	0.14

of the reading after the state process to the initial reading at the station. The average residual number for the complete reclamation procedure for all stations was 0.14. For the center of the room where the average shielding residual number itself was 0.13, the combined residual number for shielding plus reclamation is 0.14 x 0.13 or 0.018. Thus, even though the individual residual numbers for each countermeasure were not particularly low, the combination of the measures reduced the gamma radiation by a fairly large factor.

SECTION 4

SUMMARY AND CONCLUSIONS

4.1 SUMMARY OF METHOD PRESENTED FOR TREATING RECLAMATION DATA

The method for analyzing reclamation data taken at a field test consisted of (1) correcting all measurements to a common time after detonation by use of a suitable decay curve, (2) determining a "terrain factor" from the data for converting calculated radiation intensities to observed intensities, (3) estimating the variation of intensities with altitude over an extended contaminated open area, and (4) estimating the contributions of radiation sources from the treated and untreated areas to the observed measurements according to the geometric arrangement of the areas and monitoring location. The purpose of the computations in estimating the contribution of the radiation sources from only the reclaimed or decontaminated areas is to determine the true effectiveness of the applied method(s) so that the results can be correlated with other data and extrapolated to other than the specific test conditions. The ratios of the decay-corrected radiation intensity measurements are measures of the residual numbers for the test conditions and, even if the experiment were to be carried out on a real target complex, apply only to the conditions of that test. The numbers themselves will not apply or be readily extrapolated to other conditions.

4.2 SUMMARY OF DATA ANALYSIS

The decontamination ratios, as estimated from the experimental data with the aid of photon scattering computations, for the different surfaces and methods are summarized in Table 30. No statistical analysis of the results were made; however, a brief survey of the tables giving the computations shows that the errors were not small. It is possible that better, or more reliable, estimates would have resulted if more readings would have been taken in "preferred" locations. These should be determined from estimates of q (or p) according to the specific geometry of the structures and radiation fields prior to conducting the experiment.

TABLE 30

Summary of Estimated Effectiveness of Reclamation Procedures

Effectiveness of Motorgrading Scraping

I_{∞} at 3 ft (mr/hr at 1 day)	F Surface	F 3-ft	F Average	Residual Number Surface	Residual Number 3-ft
26.9	0.20	0.22	0.21	0.20	0.30
33.5	0.34	0.26	0.30	0.34	0.46

Effectiveness of Firehosing Concrete Roof

I_{∞} at 3 ft (mr/hr at 1 day)	F Surface	F 3-ft	Residual Number[b] Surface	Residual Number[b] 3-ft
16.1	0.27	0.37	0.56	0.70

Effectiveness of Firehosing Plus Scrubbing Concrete Roof

I_{∞} at 3 ft (mr/hr at 1 day)	F Surface	F 3-ft	Residual Number[b] Surface	Residual Number[b] 3-ft
16.1	0.24	0.36	0.54	0.70

Effectiveness of Firehosing Composition Shingle Roof

I_{∞} at 3 ft[a] (mr/hr at 1 day)	F Surface	F 3-ft	Residual Number Surface	Residual Number 3-ft
31.6	0.34	0.35	0.6 to 1.0	0.7 to 1.0

a. $33.5 \times 15/(15^2 + 5.2^2)^{1/2}$

b. Not including scraping of the area around the building.

In comparison with other results for motorgrading[7], the values of F given in Table 30 are somewhat high; for a 3-in cut, Reference 7 gives 0.15 for F. The higher values for F from the present data may be due to the difference in depth of cut as well as the differences in surface roughness of the soil.

The effectiveness values for firehosing and scrubbing cannot be directly compared to other data for those methods. For the low initial levels used in these experiments, Eq. 4 reduces to

$$F = k\, R_M \qquad (21)$$

The presently available values of k and R_M from previous data[2,7] are approximately 2 x 10^{-4} and 8 x 10^{2} (in an arbitrary system of units) for firehosing concrete; thus the maximum expected value of F for firehosing concrete would be 0.16. At the extremely low initial levels of this experiment, the larger values of could be due to (1) a distribution containing smaller particles than the distributions in the soils from which k and R_M were determined, (2) nonconformance of Eq. 4 to the true process at low levels, (3) errors in the radiation scattering estimates, (4) less complete coverage of the surface in application of the procedures during this experiment than previously accomplished (fallout level was so low the operators had no visible guide (dust cover) in carrying out the procedure), and/or (5) other differences in application of the method itself (such as nozzle pressure, rate of application, etc.). However, there are not enough experimental data of this kind available from field tests to determine which of the probable causes of the differences between similar experiments in the field are likely to be important.

For firehosing plus scrubbing on concrete, the presently available values of k and R_M[2,7] are approximately 2 x 10^{-4} and 6 x 10^{2}; these give a value of 0.12 for F. This again is lower than that derived from the present data. For firehosing composition roofing, the available values of k and R_M[2,7] values are 1 x 10^{-4} and 1.4 x 10^{4} respectively. These give 0.14 for the maximum value of F.

Of all the methods used, the motorgrader scraping effectiveness was nearest that obtained in previous experiments. The reason for this is that the results achieved by the method do not depend on any interaction between the fallout particles and a surface and hence are not sensitive to the number and size of particles deposited. Excepting for spillage, operator error, and surface roughness, scraping methods that remove an inch or two of the top soil should give a decontamination ratio equal to zero.

4.3 CONCLUSIONS

The method of treating field-test reclamation data presented in the report shows that, in carrying out reclamation experiments, a certain amount of supporting data is required for estimating the effectiveness of the procedures. These include: (1) decay of the fallout field, (2) the variation of the radiation intensity with height (prior to decontamination), (3) selection of monitoring stations at preferred locations -- i.e. those at which the scattered radiation contribution is the smallest, (4) selection of preferred geometric arrangement among structures, areas to be reclaimed, and monitoring stations to facilitate the data reduction and interpretation, (5) collection of fallout samples to determine the mass of fallout in the area, and (6) measurement of the fallout pattern.

The large variations in the data analyzed in this report were, in large part, due to the low intensities associated with the small amount of fallout on the test area. The low intensities, or low readings on the radiacs, leads to large percentage errors in the measurements and the low amount of fallout to smaller decontamination effectiveness than for large amounts. Reclamation information at higher initial levels of fallout would be much more applicable to the design and specification of radiological countermeasure systems.

Approved by:

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For the Scientific Director

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APPENDIX A

SUMMARY OF RADIATION MEASUREMENTS FROM DECONTAMINATION EXPERIMENT

All measurements were made with AN/PDR-39 (T1B) radiacs.

TABLE A.1

Measurements of Area About Building A Before Scraping (Time: 1230-1330, 12/10/57)(a)
Radiation Levels (mr/hr)

Station	1	2	3	4	5	6	7
			Surface				
A	30	34	35	32	31	26	32
B	34	34	30	28	29	28	27
C	36	36	33		26	29	28
D				X			
E	34	33	28	28	29	29	29
F	34	34	30	30	29	28	34
G	38	34	35	30	29	30	36
			3-ft Height				
A	26	30	30	28	27	24	25
B	29	28	26	15	24	23	25
C	30	33	29		22	24	25
D				X			
E	30	27	26	26	24	25	26
F	30	27	27	26	26	25	29
G	30	29	27	29	27	29	29

a. Additional sampling stations, not shown in Fig. 2, are extensions of the grid system.

TABLE A.2

Measurements of Area About Building A Before Scraping (Time: 1300, 12/10/57); Radiation Levels (mr/hr)

Station	1	2	3	4	5	6	7
			Surface				
A			30	29	29		
B			33	32	31		
C	28	30	22	24	15	25	25
D	30	33	24	X	28	25	24
E	30	28	46	39	18	25	27
F			27	27	28		
G			27	26	28		
			3-ft Height				
A			28	27	27		
B			29	27	27		
C	22	12	20	16	12	24	14
D	16	26	30	X	13	24	24
E	24	24	32	26	19	13	24
F			23	26	26		
G			25	25	25		

TABLE A.3

Measurements of Area About Building A After Scraping (Time: 1110, 12/11/57); Radiation Levels (mr/hr)

Station	1	2	3	4	5	6	7
			Surface				
A			10	6	2		
B			1	2	1		
C	6	2	4	2	1	2	5
D	4	6	3	X	4	2	4
E	12	2	4	3	2	2	5
F			2	3	15		
G			-	-	-		
			3-ft Height				
A			8	7	4		
B			2	3	2		
C	5	4	2	3	4	2	5
D	5	4	3	X	2	2	5
E	9	3	4	4	3	3	6
F			3	3	7		
G			-	-	-		

TABLE A.4

Measurements of Area About Building B Before Scraping (Time: 1400, 12/10/57); Radiation Levels (mr/hr)

Station	1	2	3	4	5	6	7
			Surface				
A			28	25	27		
B			26	26	28		
C	29	28	33	34	30	30	42
D	29	32	29	X	31	33	37
E	28	31	31	22	26	37	40
F			36	39	44		
G			44	42	42		
			3-ft Height				
A			25	23	25		
B			25	23	24		
C	25	25	22	20	22	29	36
D	26	28	22	X	19	30	34
E	26	29	26	22	21	32	38
F			33	33	34		
G			39	37	36		

TABLE A.5

Measurements of Area About Building B Before Scraping (Time: 1015, 12/11/57)

Station	1	2	3	4	5	6	7
				Radiation Levels (mr/hr)			
				Surface			
A				12			
B				12			
C							
D	14	15		X		18	19
E							
F				20			
G				22			
				3-ft Height			
A				10			
B				11			
C							
D	11	12		X		16	17
E							
F				16			
G				17			

TABLE A.6

Measurements of Area About Building B After Scraping (Time: 1310, 12/11/57)

Station	Radiation Levels (mr/hr) 1	2	3	4	5	6	7
			Surface				
A			12	12	12		
B			3	16	8		
C	12	9	4	15	6	5	18
D	14	2	5	X	2	12	18
E	14	6	5	2	5	5	17
F			3	7	5		
G			20	20	18		
			3-ft Height				
A			11	10	10		
B			4	6	6		
C	11	5	4	5	5	6	16
D	11	4	4	X	3	8	16
E	11	6	5	4	6	8	17
F			5	4	9		
G			18	17	17		

TABLE A.7

Measurements on Concrete Slab Roof of Building A

Station	Radiation Levels (mr/hr)			
	Before Ground Area Scraped (1230-1330, 12/10/57)	After Ground Area Scraped (1130, 12/11/57)	After Firehosing (1300, 12/11/57)	After Scrubbing (1335, 12/11/57)
		Surface		
1	20	4	2.2	2
2	14	3	1.8	1.8
3	15	3	2	1.8
4	20	2	2	1.9
5	19	4	2	1.8
6	25	4	2.2	1.8
7	19	4	2.2	2.2
8	20	4	1.8	2.0
9	20	6	2.2	1.9
10	22			
11	18			
12	17			
13	11			
14	10			
15	11			
16	13			
17	20			
		3-ft Height		
1	15	4	3	3
2	8	4	2.5	2.5
3	9	3	3	3
4	14	4	2.8	2.9
5	10	4	3	2.9
6	20	5	2.6	2.7
7	14	4	3	2.8
8	12	4	3	2.8
9	13	5	2.4	2.3
10	21			
11	15			
12	14			
13	11			
14	10			
15	7			
16	10			
17	14			

TABLE A.8

Measurements on Composition Shingle Roof of Building B

Station	Radiation Levels (mr/hr)			
	Before Firehosing (1400,12/10/57)	After Firehosing (1510,12/10/57)	After Firehosing (1015,12/11/57)	After Scraping Area (1340,12/11/57)
		Surface		
1	22	13	9	4
2	19	17	8	4
3	19	15	9	4
4	16	14	9	5
5	14	20	9	5
6	13	20	10	6
7	[illegible]	20	11	6
8	18	18	9	6
9	25	14	8	5
		3-ft Height		
1	21	15	9	4
2	20	17	8	4
3	22	18	9	4
4	22	20	10	5
5	25	17	10	5
6	27	20	10	6
7	26	19	11	6
8	15	15	10	6
9	24	16	7	6

TABLE A.9

Measurements Taken Inside Building A

Station	Radiation Levels (mr/hr)											
	Before Scraping (1450,12/10/57)			After Scraping NE Section (1515,12/10/57)			After Scraping (1125,12/11/57)			After Firehosing Roof (1300,12/11/57)		
	Surface	3 ft	8 ft	Surface	3 ft	8 ft	Surface	3 ft	8 ft	Surface	3 ft	8 ft
1	-	1.0	-	0.9	1.0	2.0	0.05	0.2	0.5	0	0	0
2	-	3.2	-	2.3	2.8	2.9	0.3	0.3	0.5	0.2	0.2	0.4
3	-	4.5	-	2.0	2.5	2.4	0.4	0.6	0.6	0.3	0.4	0.9
4	-	8.0	-	1.2	2.0	3.0	0.4	0.4	0.7	0.2	0.2	0.4
5	-	2.8	-	1.0	1.5	2.1	0.4	0.2	0.4	0.1	0.1	0.2
6	1.6	3.2	5.0	1.2	2.3	3.7	0.25	0.4	0.6	0.1	0.4	0.4
7	-	9.0	-									
8	-	2.8	3.9									
9	-	4.2	-									
10	-	4.6	-									
11	-	2.0	-									

TABLE A.10

Measurement of Field Decay

		Radiation Levels (mr/hr)		
Date	Time	Surface	3-ft Height	Ratio
12/10/57	1515	30	26	0.866
12/11/57	0930	15	12	0.800
12/11/57	1130	13	11	0.846
12/11/57	1330	11	10	0.909

TABLE A.11

Rate of Application of Described Reclamation Procedures

Procedure	Equipment	Personnel	Area (sq ft)	Time Required	Rate[a] (sq ft/hr)
Scraping (bldg. A area)	1 Motorgrader (8 ft blade)	1 Operator	110,000	2.5 hr	45,000
Scraping (bldg. B area)	1 Motorgrader (8 ft blade)	1 Operator	17,000	1.2 hr	14,000
Firehosing (Comp. Shingle roof)	1 Water truck w/pump, hose and nozzle	1 Tank truck operator 2 Hosemen	1,700	35 min	2,900
Firehosing (Concrete slab roof)	1 Water truck w/pump, hose and nozzle	1 Tank truck operator 2 Hosemen	1,600	25 min	3,800
Scrubbing (Concrete slab roof)	10-in. brushes detergent	3 men	1,600	12 min	2,700[b]

a. Rates do not include delay times to fill tank truck, start equipment, etc.; they are for actual time spent in doing the work.

b. Rate per man.

APPENDIX B

RADIATION MEASUREMENTS (TABULATED IN APPENDIX A) CORRECTED TO D + 1

TABLE B.1

Measurements of Area About Building A Before Scraping - Corrected to D+1 (Time, H+25.0; Correction Factor, 1.06)

Station	Radiation Levels (mr/hr)						
	1	2	3	4	5	6	7
				Surface[a]			
A			32	31	31		
B			35	34	33		
C	30	32	23	26	16	27	27
D	32	35	26	X	30	27	26
E	32	30	49	42	19	27	29
F			29	29	30		
G			29	28	30		
				3-ft Height[b]			
A			30	29	29		
B			31	29	29		
C	23	13	21	17	13	26	15[c]
D	17	28	32	X	14	26	26
E	25	26	34	28	20	14	26
F			24	28	28		
G			27	27	27		

a. **Averages:** A-B,3-5: 32.7; C-E,1-2: 31.8; C-E,8-7: 27.2; F-G,3-5: 29.2; average of the 24: 30.2.
b. **Averages:** A-B,3-5: 29.5; C-E,1-2: 25.8; C-E,6-7: 26.0; F-G,3-5: 26.8; average of the 20: 27.2.
c. Not used in computing averages.

TABLE B.2

Measurements of Area About Building A After Scraping - Corrected to D+1 (Time, H+47.0; Correction Factor, 2.39)

Station	Radiation Levels (mr/hr) 1	2	3	4	5	6	7
			Surface				
A			24	14.3	4.8		
B			2.4	4.8	2.4		
C	14.3	4.8	9.6	4.8	2.4	4.8	11.9
D	9.6	14.3	7.2	X	9.6	4.8	9.6
E	29	4.8	9.6	7.2	4.8	4.8	11.9
F			4.8	7.2	35.8		
G			-	-	-		
			3-ft Height				
A			19.1	16.7	9.6		
B			4.8	7.2	4.8		
C	11.9	9.6	4.8	7.2	9.6	4.8	11.9
D	11.9	9.6	7.2	X	4.8	4.8	11.9
E	21.5	7.2	9.6	9.6	7.2	7.2	14.3
F			7.2	7.2	16.7		
G			-	-	-		

TABLE B.3

Measurements of Area About Building B Before Scraping - Corrected to D+1 (Time, H+26.0; Correction Factor, 1.13)

	Radiation Levels (mr/hr)						
Station	1	2	3	4	5	6	7
			Surface				
A			32	28	30		
B			29	29	32		
C	33	32	37	38	34	34	47
D	33	36	33	X	35	37	42
E	32	35	35	25	29	42	45
F			41	44	50		
G			50	47	47		
			3-ft Height				
A			28	26	28		
B			28	26	27		
C	28	30	25	23	25	33	41
D	29	32	25	X	21	34	38
E	.29	33	29	25	24	36	43
F			37	37	38		
G			44	42	41		

TABLE B.4

Measurements of Area About Building B After Scraping - Corrected to D+1 (Time, H+49.2; Correction Factor, 2.52)

	Radiation Level (mr/hr)						
Station	1	2	3	4	5	6	7
			Surface				
A			30	30	30		
B			7.5	40	20		
C	30	23	10	38	15	13	45
D	35	5.0	7.5	X	5.0	30	45
E	35	15	13	5.0	13	13	43
F			7.5	18	13		
G			50	50	45		
			3-ft Height				
A			28	25	25		
B			10	15	15		
C	28	13	10	13	13	15	40
D	28	10	10	X	7.5	20	40
E	28	15	13	10	15	20	43
F			13	10	25		
G			45	43	43		

TABLE B.5

Measurements on Concrete Slab Roof of Building A - Corrected to D+1

Station	Radiation Levels (mr/hr)			
	Before Ground Area Scraped (H+?,0.968)[a]	After Ground Area Scraped (H+47.5;2.41)	After Firehosing (H+49.0;2.51)	After Scrubbing (H+49.6;2.54)
	Surface			
1	19.4	9.6	5.5	5.1
2	13.6	7.2	4.5	4.6
3	15.5	7.2	5.0	4.6
4	19.4	4.8	5.0	4.8
5	18.4	9.6	5.0	4.6
6	24.2	9.6	5.5	4.6
7	18.4	9.6	5.5	5.6
8	19.4	9.6	4.5	5.1
9	19.4	14.4	5.5	4.8
10	21.3			
11	17.4			
12	16.5			
13	10.6			
14	9.7			
15	10.6			
16	12.6			
17	19.4			
	3-ft Height			
1	14.5	9.6	7.5	7.6
2	7.7	9.6	6.3	6.4
3	8.7	7.2	7.5	7.6
4	13.6	9.6	7.0	7.4
5	9.7	9.6	7.5	7.4
6	19.4	12.0	6.5	6.9
7	13.6	9.6	7.5	7.1
8	11.6	9.6	7.5	7.1
9	12.6	12.0	6.0	5.8
10	20.3			
11	14.5			
12	13.6			
13	10.6			
14	9.7			
15	6.8			
16	9.7			
17	13.6			

a. Correction factor for H+25.0 is 1.06; average ratio of comparable locations for data in Table A.1 to that in Table A.2 is 1.10; thus multiply by 1.06/1.10 or 0.968 to obtain appropriate correction for the instrument used.

TABLE B.6

Measurements on Composition Shingle Roof of Building B - Corrected to D+1

Station	Radiation Levels (mr/hr)			
	Before Firehosing (H+26.0;1.13)	Before Firehosing (H+27.2;1.20)	Before Firehosing (H+46.2;2.34)	Before Scraping Area (H+49.7;2.55)
		Surface		
1	24.8	15.6	21.0	10.2
2	21.4	20.4	18.7	10.2
3	21.4	18.0	21.0	10.2
4	18.1	16.8	21.0	12.8
5	38.4	24.1	21.0	12.8
6	37.3	24.1	23.4	15.3
7	39.5	24.1	25.7	15.3
8	20.3	21.6	21.0	15.3
9	28.2	16.8	18.7	12.8
		3-ft Height		
1	23.7	18.0	21.0	10.2
2	22.6	20.4	18.7	10.2
3	24.8	21.7	21.0	10.2
4	24.8	24.1	23.4	12.8
5	28.2	20.4	23.4	12.8
6	30.5	24.1	23.4	15.3
7	29.4	22.9	25.7	15.3
8	16.9	18.0	23.4	15.3
9	27.1	19.2	16.4	15.3

TABLE B.7

Measurements Taken Inside Building A - Corrected to D+1

Station	Radiation Levels (mr/hr)											
	Before Scraping (H+26.8;1.17)			After Scraping NW Section (H+27.2;1.20)			After Scraping (H+47.4;2.41)			After Firehosing Roof (H+49.0;2.51)		
	Surface	3 ft	8 ft	Surface	3 ft	8 ft	Surface	3 ft	8 ft	Surface	3 ft	8 ft
1	-	1.2	-	1.1	1.2	2.4	0.12	0.5	1.2	0	0	0
2	-	3.7	-	2.8	3.4	3.5	0.7	0.7	1.2	0.5	0.5	1.0
3	-	5.2	-	2.4	3.0	2.9	1.0	1.4	1.4	0.8	1.0	2.3
4	-	9.4	-	1.4	2.4	3.6	1.0	1.0	1.7	0.5	0.5	1.0
5	-	3.3	-	1.2	1.8	2.5	1.0	0.5	1.0	0.2	0.3	0.5
6	1.9	2.7	5.8	1.4	2.6	4.4	0.6	1.0	1.4	0.2	1.0	1.0
7	-	10.5	-									
8	-	3.3	4.6									
9	-	4.9	-									
10	-	5.4	-									
11	-	2.3	-									