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The Retention of Fallout Particles on Roofs Having Different Slopes

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THE RETENTION OF FALLOUT PARTICLES ON ROOFS HAVING DIFFERENT SLOPES

BY

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THE RETENTION OF FALLOUT PARTICLES ON ROOFS

HAVING DIFFERENT SLOPES

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser | Date

Head, Civil Engineering Department | Date

DEDICATION

I wish to dedicate this thesis to my wife, Lavonne, for her continual encouragement and support throughout this study.

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INTRODUCTION

General

Since World War II the continual buildup and spread of nuclear arms has produced a pressure situation between nations. As more and more nations become nuclear powers and continue to expand their arsenals, the chance of a nuclear attack, either by accident or by specific intent, increases. If a full-scale nuclear attack should develop, the only chance of survival would rest with a fully prepared population. Even with a fully prepared population many would not survive.

The National Fallout Shelter Program is helpful in preventing casualties in the event of a nuclear attack. Studies show, however, that such casualties would be very high. The reason for this conclusion is that it is economically unfeasible to protect all of the people from the immediate effects of a nuclear explosion consisting of initial radiation, thermal radiation, and blast. A significant number of people could survive if they were provided protection from radioactive fallout. A complete fallout shelter program would accomplish this.(1)

Background

There are three types of nuclear radiation.(2-All) These three types of radiation are Alpha, Beta, and Gamma. The Alpha radiation consists of particles that are similar to the nucleus of a helium atom. Beta radiation consists of high speed electrons. Gamma radiation is a form of electromagnetic energy similar to X-rays.(2-All)

Of these three types of radiation, Alpha and Beta particles are readily attenuated and are of little concern to the shelter analyst.(2-A23) This statement cannot be made of Gamma radiation, which is capable of penetrating several feet of concrete. Thus Gamma radiation is of primary concern to the shelter analyst.

From the above discussion a fallout shelter can be defined as any structure that has a certain standard of protection against Gamma radiation. The definition of fallout protection is established by the Office of Civil Defense. The current standard states that a structure must provide a protection factor of at least 40 before it can be marked as a fallout shelter. A protection factor of 40 means that 1/40 or 2.5 percent of the radiation on the outside penetrates to a person within the fallout shelter.(1-13,14)

It is important to note that a fallout shelter is not a specifically constructed building. Any building, whether it be a church, school, or bank, provides some fallout protection. This protection can reach an adequate level if certain considerations are taken into account in the design. This is known as slanting. (2-7.1) Such slanting techniques can usually be accomplished with little or no increase in cost.

For simplicity, consider the following example. Assume a rectangular block house as shown in Figure 1. A radiation detector is located within the block house at a standard distance of three feet above the ground.(2-3.5) Surrounding the block house is an infinite field uniformly contaminated with fallout particles. The

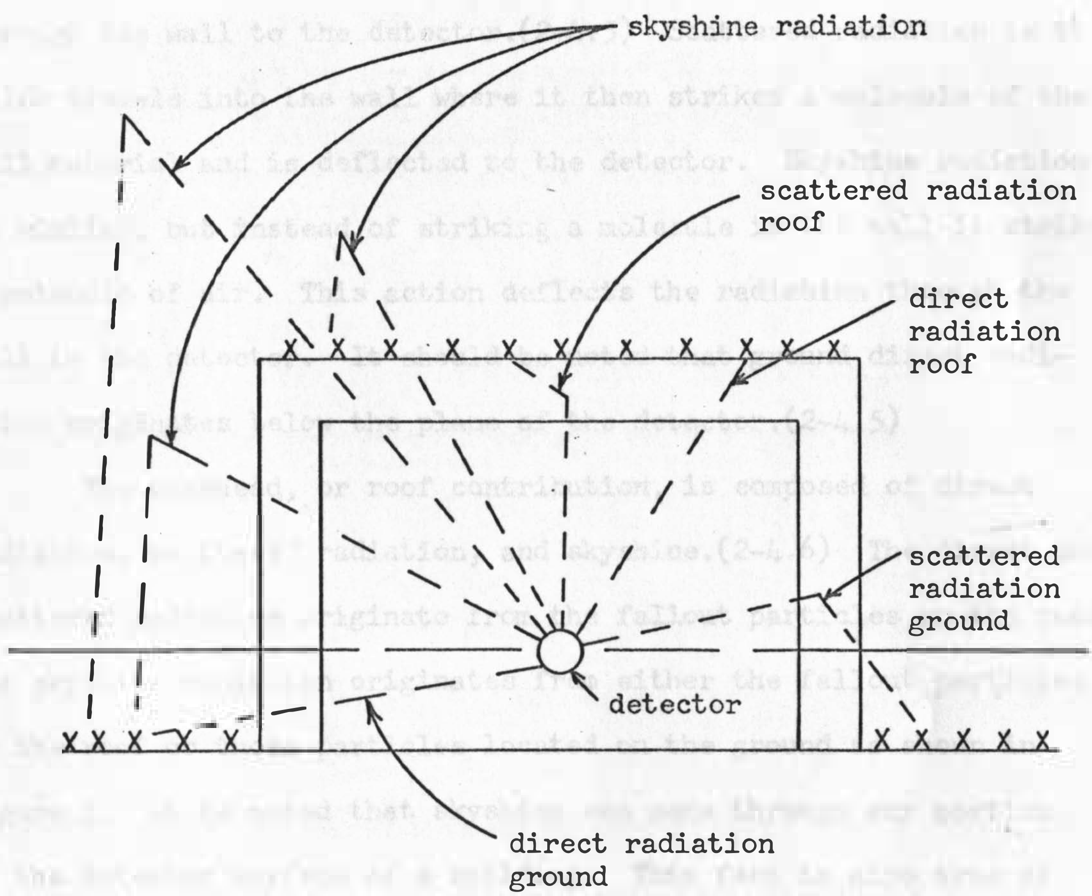

Figure 1
Radiation Contributions

protection factor of this block house is dependent upon two basic types of radiation contribution--roof contribution and ground contribution.(3-8) The ground contribution is further broken down into direct radiation, scattered radiation, and skyshine.(3-9) Direct radiation is that which travels directly from some point on the ground through the wall to the detector.(2-4.5) Scattered radiation is that which travels into the wall where it then strikes a molecule of the wall material and is deflected to the detector. Skyshine radiation is similar, but instead of striking a molecule in the wall it strikes a molecule of air. This action deflects the radiation through the wall to the detector. It should be noted that ground direct radiation originates below the plane of the detector.(2-4.5)

The overhead, or roof contribution, is composed of direct radiation, scattered radiation, and skyshine.(2-4.6) The direct and scattered radiation originate from the fallout particles on the roof. The skyshine radiation originates from either the fallout particles on the roof or those particles located on the ground as shown in Figure 1. It is noted that skyshine can come through any portion of the interior surface of a building. This fact is also true of wall scattered radiation.(2-4.5)

In this study the roof contribution is of particular interest. Most analysis of fallout shelters assumes a uniformly contaminated flat roof without regard to pitch or roofing materials. The Office of Civil Defense has several methods of handling the effect of a linearly sloping roof. These methods were compared in a Master's

Thesis submitted by Yager at South Dakota State University in 1968. (4) This study did not consider the effect that different roof materials would have on the retention of fallout particles.

The limited information regarding the retention characteristics of roofing materials is reflected by the following quotation:

> Since little data are as yet available on the retentive characteristics of roof coverings on fallout particles, it is recommended that all roofs be considered fully contaminated regardless of their smoothness and pitch. In cases of extreme pitch and smoothness the analyst might exercise other judgement, but he should do so only with extreme caution. (2-6.19)

Yager in his Master's Thesis recommended that a project be carried out which would study the retention of fallout particles on various roofing materials.(4) It was with this objective in mind that this study was undertaken.

Fallout particles are formed by a nuclear detonation. The explosion generates tremendous heat which vaporizes the weapon and nearby structures as well as earth materials. If the detonation is close enough to the earth's surface, tons of soil will be carried into the atmosphere. As the cloud rises, cooling takes place thus resulting in the condensation of vaporized debris. This action forms radioactive fallout particles which are carried by the wind.(2-2.5) These particles range in size from less than one micron to several millimeters.(5-436)

It has been found convenient to divide fallout into two parts. (2-2.6) These two parts are early fallout and delayed fallout. Early fallout has been arbitrarily defined as that fallout that reaches the ground within 24 hours after the explosion. Delayed fallout is that fallout that arrives later. Early fallout is composed mainly of visible particles and constitutes the greatest hazard to the population.(5-415) Delayed fallout consists of very fine invisible particles which travel extremely long distances. These particles have no appreciable rate of fall. The delayed fallout will usually reach the ground along with precipitation such as rain or snow.(5-438) The hazard from delayed fallout arises from the fact that it may enter the body by means of food or drink.(5-474) Though the actual percentage of early and delayed fallout varies, it can be assumed that in a surface burst 60 percent of the radioactivity is early fallout and the remaining 40 percent is delayed fallout.(5-437)

As mentioned previously, the fallout particles have a wide range of sizes, the early fallout being composed primarily of visible particles. For example, in the Bravo test, conducted by the United States, it was observed that the fallout consisted of particles ranging from fine sand (about 100 microns or less) to 0.4 inches in diameter at the point of the burst.(5-41) In the Marshall Islands tests the fallout was visible as white powder or dust. It was felt that this light color was the result of calcium oxide or carbonate of which the particles were mainly composed. It was pointed out that it is quite probable that whenever there is enough fallout to pose a hazard it will be visible as dust.(5-653)

Fallout particles tend to be quite smooth and spherical because they are formed by the solidification of droplets of vaporized material. However, many particles are quite irregular in size and angular in shape.(5-495)

Objectives

The objectives of this investigation were to study the following effects, using a wind velocity of zero:

1. The retention of fallout particles on wood shingles, asphalt roofing, and metal roofing.
2. The effect of roof slope on the retention of fallout particles.
3. The effect that particle size has on the retention of fallout particles.

PARAMETERS, EQUIPMENT, AND PROCEDURE

Establishment of Parameters

In order to accomplish the objectives of this study it was thought impractical to construct full scale roofs because of the large size involved. Also, there are an infinite number of possible sizes and shapes for various roof systems. Scale models were considered unfeasible because it is very difficult to scale down roof texture and particle size to the scale utilized in constructing the model roof. It was finally decided that regular roofing materials would be used in sections one square foot in horizontal projected area. This would be similar to isolating one square foot of a particular roof area.

The three roof coverings used were asphalt roofing, wood shingles, and sheet metal roofing. In choosing these particular materials, three different textures were included. The asphalt was covered with sand particles and was very rough when compared to the sheet metal. The wood shingles had a roughness somewhere between asphalt roofing and sheet metal.

The slopes used ranged from 0 to 40 degrees in increments of 10 degrees. This decision was arbitrary, but it was felt that this range of slopes would include the majority of roof pitches presently being used.

At the outset of this study it was decided that particles would be divided into categories and distributed from a given height onto the roof sections. This division was necessary in order to include the effect of particle size as a variable in the study of the retention. The range of particle size to be used was decided after studying the referenced literature. This literature includes the chart that appears in The Effects of Nuclear Weapons.(5-496) This particular chart gives the time of fall of different-sized particles and the approximate percentage of total radioactivity that these particles carry.(5-499) From this chart it was decided to use three categories of particle sizes.

The first category included those particles retained on the U. S. standard sieve number 100 and which passed the U. S. standard sieve number 60. These particles ranged in size from 250 microns to 149 microns. From the chart it was determined that these particles would carry approximately 15 percent of the total radioactivity.

The second category included those particles retained on the number 140 sieve which passed the number 100 sieve. These particles ranged in size from 149 microns to 105 microns and normally account for about 18 percent of the radioactivity.

The third category consisted of those particles retained on the number 200 sieve which passed the number 140 sieve. These particles varied in size from 105 microns to 74 microns and normally carry approximately 20 percent of the radioactivity. Overall, the particles studied ranged in size from 250 microns to 74 microns and represented 53 percent of the radioactivity present in early fallout.

Mortar sand was sieved over the previously mentioned sieves to obtain the necessary particle sizes. From preliminary tests it was decided that six grams of each particle size was needed for each test.

One of the most difficult aspects of the test procedure was in determining the distance through which the particles were to be dropped. This determination was necessary in order to insure that the particles reached terminal velocity before contact with the roof. A particle falling through air accelerates for a certain distance because of the action of gravity. At some distance from the initial position of the particle acceleration ceases as a result of friction. When the particle reaches this point of zero acceleration, it attains a constant velocity which is known as the terminal velocity.

Terminal Velocity

At terminal velocity the weight of the falling particle is balanced by the buoyant effect and the frictional resistance of the fluid media.(6-188) It was important that the particles used in this research be dropped so that they reached their terminal velocities before they contacted the roof sections under test. These particles had to be falling at terminal velocity if they were to duplicate the action of fallout particles that had fallen thousands of feet. In this study it was necessary to know the distance a particle had to travel in air to reach terminal velocity.

Stokes investigated the theoretical settling velocity of spheres and derived an equation that gives their terminal velocity. (6-189) It was thought that this equation would prove helpful in approaching the problem at hand. However, Stokes' equation is valid only for low Reynolds numbers (up to about 0.5). At higher Reynolds numbers the fall velocity of spheres is less than that calculated by the equation. Also, if particles of equal volume and specific gravity are compared, the fall velocity will be greatest for spherical objects. (6-189) This is important in that velocity calculated on the assumption of spherical particles will be conservative when applied to angular particles such as those used in this study.

The Reynolds number is a means of measuring the similarity of two different fluid flows.(6-91) It is defined as the ratio between the inertial forces and the viscous forces.(7-77) Newton's first law pertains to inertia and states: "In the absence of external influences a given mass tends to remain at rest or move in a straight line with a uniform velocity."(7-8) The inertial force is that force associated with the mass of the moving fluid. Viscosity is defined as the property of a fluid to resist the shear between fluid layers.(7-21) The viscous force is that force associated with this shearing action. An additional term used to compute the Reynolds number is kinematic viscosity. This term is equal to the viscosity divided by fluid density.(7-24)

If it is assumed that Stokes' equation applies to fallout particles, the terminal velocity of particles such as those retained on the number 100 sieve can be estimated by the following formula: (6-189)

$$V = \frac{2gr^2(\rho_2 - \rho_1)}{9\mu}$$

Where

V = terminal velocity
g = acceleration of gravity
r = radius of particle
μ = viscosity of air
ρ_2 = density of the particle
ρ_1 = density of medium

For the calculation of terminal velocity these terms have the following values.

V = the velocity to be calculated
$g = 32.2\ ft/sec^2$
$r = 2.42 \times 10^{-4}\ ft$
μ = viscosity of air at approximately room temperature. $1.238 \times 10^{-5}\ lbs\ sec/ft^2$ (7-25)
$\rho_2 = 2.65$ specific gravity $\times\ 62.4\ lbs/ft^3 = 165.3\ lbs/ft^3$ (8-28)
ρ_1 = density of air at approximately room temperature. $0.0747\ lbs/ft^3$ (7-25)

The final result is:

$$V = \frac{(2)(32.2)(5.85 \times 10^{-8})(165.2)}{(9)(1.238 \times 10^{-5})} = 5.6\ ft/sec.$$

The Reynolds number may then be calculated as follows: (7-360)

$$Re = \frac{DV}{\nu}$$

Where:

D = diameter of the particle
V = velocity of the particle
ν = kinematic viscosity of the fluid

These terms have the following values:

$D = 4.84 \times 10^{-5}$ ft
$V = 5.6$ ft/sec
ν = kinematic viscosity of air at approximately room temperature $= \mu/\rho_1 = 1.655 \times 10^{-4}$ ft^2/sec.

The calculation is given below.

$$Re = \frac{(4.84 \times 10^{-5})(5.6)}{(1.655 \times 10^{-4})} = 16.4$$

The Reynolds number so obtained is greater than 0.5 and is therefore out of the range of Stokes' equation. This result implies a different approach to the problem.

O'Brien and Hickox point out that at terminal velocity the fluid resistance must equal the weight of the particle minus the force of buoyancy.(6-188) Proceeding from this premise the following equation is given:

$$gv(\rho_2 - \rho_1) = C_r \frac{1}{2} \rho_1 A V^2$$

Where:

v = volume of particle
g = acceleration of gravity
ρ_2 = density of the particle
ρ_1 = density of the fluid
A = projected area of the particle
V = velocity of the particle relative to the fluid
C_r = drag coefficient

If the assumption is made that the particles are spherical, their volume is given by $v = 4/3\ \pi r^3$ and their area is πr^2. Substituting these values into the equation and solving for the square of the velocity gives the result as follows:

$$V^2 = \frac{g8r(\rho_2 - \rho_1)}{3C_r\rho_1}$$

A graph of drag coefficient versus the Reynolds' number is given in Rouse.(9-215) This graph is a composite of the work of many researchers. Included is the drag coefficient of spheres and disks falling in a wind tunnel. It appears reasonable to utilize this graph to obtain the drag coefficient for a particle falling through air.

The use of this chart is exemplified as follows. Going into the chart with the Reynolds number previously calculated, a drag coefficient, $C_r = 3.5$, is chosen. If this value is placed in the equation given by O'Brien and Hickox, which has been solved for the square of the velocity, a terminal velocity can be calculated. All other values are the same as those used in Stokes' equation. The result is as follows:

$$V^2 = \frac{(32.2)(8)(2.42 \times 10^{-4})(165.3 - 0.0747)}{(3)(3.5)(0.0747)} = 3.6 \text{ ft/sec}$$

$$Re = \frac{(4.84 \times 10^{-4})(3.6)}{(1.655 \times 10^{-4})} = 10.5$$

Returning to the chart in Rouse, the drag coefficient corresponding to this Reynolds number is about 4.0. Recalculating the velocity, using this drag coefficient, results in a velocity of 3.4 ft/sec which corresponds to a Reynolds number of about 9.9. Again, returning to the chart in Rouse, it is seen that acceptable convergence has been obtained since the drag coefficient is about 4.0.

Reasoning further, if this particle were falling in a vacuum, the equations of motion could be applied to calculate the distance of fall required for the particle to reach the terminal velocity calculated above. This distance is the minimum distance required for this particle to reach terminal velocity.

For example, using the equations of motion, the distance a particle must fall (in a vacuum) to attain a velocity of 3.4 ft/sec can be calculated.(10-394)

$$V^2 = Vo^2 + 2a(S - S_o)$$

Where:

Vo = initial velocity
S_o = initial position of the particle
S = final position of the particle
V = final velocity of the particle
a = acceleration

The terms have the following values for this particular calculation:

$Vo = 0$
$S_o = 0$
S = the distance to be calculated
V = 3.4 ft/sec
a = 32.2 ft/sec^2

The result is:

$$(3.4) = (2)(32.2)(S)$$

$$S = 0.1798 \text{ ft} = 2.2 \text{ inches}$$

As mentioned previously this distance is the minimum distance required for the particle to reach terminal velocity.

To further establish the distance that it takes for a particle to attain terminal velocity, an experiment was carried out on the settling rate of a particle in water. For this experiment a 1000 milliliter graduated cylinder filled with water was used. Those particles passing the number 60 sieve and retained on the number 100 sieve were dropped from a given position in the graduated cylinder. The time needed for these particles to fall from 0 to 10 inches in increments of 2 inches was measured by means of a stop watch.

The results of this experiment appear in Table 1. Inspection of Table 1 reveals that the differential velocity increases up to 4 inches after which the differential velocity is less. Since the differential velocity is greater at 4 inches than at any other distance, it can be assumed that terminal velocity occurs somewhere between 4 to 6 inches of fall.

Terminal velocity in air will be reached more quickly than in water because of lower frictional values encountered in air. The decrease in velocity after 4 inches of fall results from the spiraling of the particles after terminal velocity is reached. From this experiment it can be assumed that these particles reach terminal velocity in air in a distance less than 6 inches.

In summary, the largest particles that were used in this study reached terminal velocity within a fall distance of 2 to 6 inches.

TABLE 1

Settling Rate In Water Of Particles Passing Number 60 Sieve and Retained On Number 100 Sieve

Distance of drop (inches)	Time of fall (seconds)	Differential time (seconds)	Differential velocity (inches/second)
2	1.5	1.5	1.3
4	2.8	1.3	1.5
6	4.6	1.8	1.1
8	6.2	1.6	1.2
10	8.1	1.9	1.0

The smaller particles used reached terminal velocity in a shorter distance than did the larger particles because of their lighter weight. When the equipment was being constructed, it was decided to be ultra conservative in choosing a distance of free fall for the particles. In keeping with this decision, a free-fall distance of approximately 29 inches was selected for the tests on the roof sections.

Equipment

The equipment used in this laboratory study was locally constructed in the Civil Engineering Department. Included were roof sections and uprights required for holding the roof sections at the proper slope; a plywood enclosure which served as a shield to isolate the roof sections from air currents; a frame for mounting the sieves over the roof sections; and three aggregate sieves.

Roof sections for three types of roofing material which corresponded to one square foot of projected area were cut for slopes of 0, 10, 20, 30, and 40 degrees. This amounted to a total of 15 roof sections. The roof coverings of either wood, asphalt, or sheet metal were fastened to sections cut from 1/2-inch plywood. These are shown in Figure 2. Five small uprights were constructed for supporting the roof sections at the required slopes.

The enclosure constructed of 1/2-inch plywood appears in Figure 3. This enclosure served to isolate the roof sections from the air currents in the laboratory, thus minimizing the influence

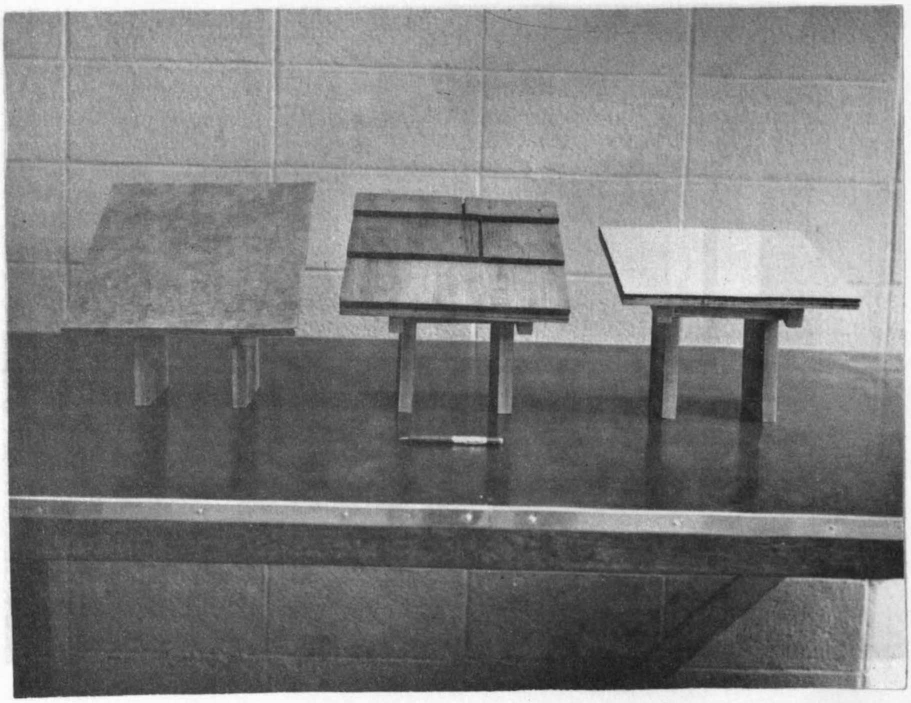

Figure 2
Roof Sections and Stands

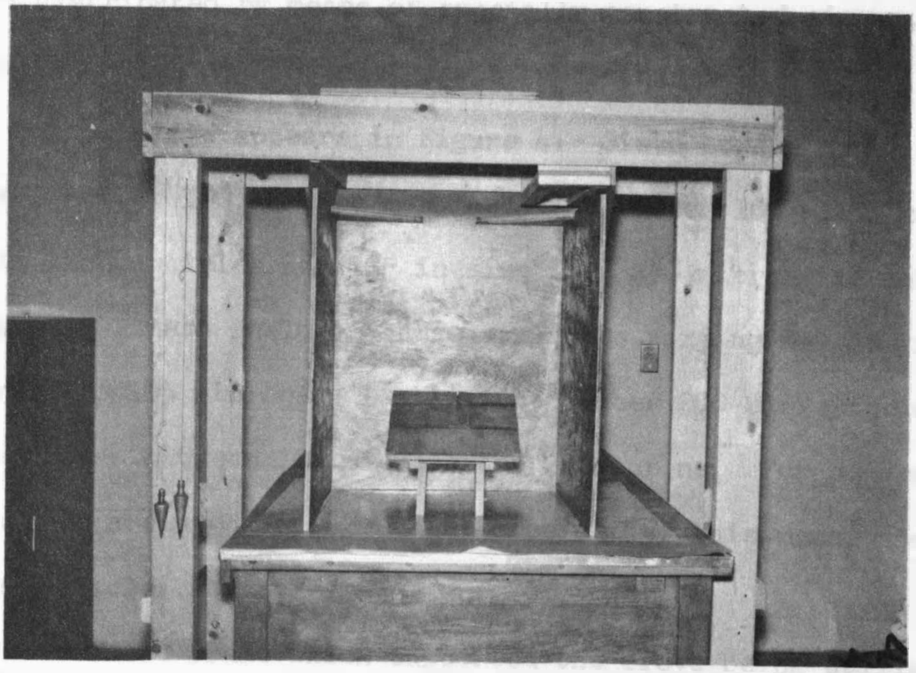

Figure 3
Plywood Enclosure and Overhead Frame

that air currents would have upon the fall of the particles. A piece of galvanized sheet metal was used as a bottom for the enclosure. The particles that were not retained on the roof were recovered from the smooth sheet metal surface.

The retention characteristics of each category of roofing material was studied. Particles were obtained by sieve analysis and were distributed by means of specially constructed sieves. These sieves were one foot square and fabricated from 26-gage sheet metal. Such a sieve appears in Figure 4. Sieve screen sizes were number 60, number 100, and number 140. The number 100 sieve corresponds to the particles ranging in size from 250 microns to 149 microns. The number 140 sieve includes those particles ranging in size from 149 microns to 105 microns. Lastly, the number 200 sieve includes those particles between 105 microns and 74 microns. For convenience, sieve numbers are used in subsequent sections of this report to indicate particle categories.

An overhead frame which supported the sieve being utilized was constructed and mounted over the roof section enclosure. The general characteristics of the overhead frame is shown in Figure 3.

Procedure

All laboratory tests were conducted in the Civil Engineering Department laboratories at South Dakota State University. A selected roof section was placed on a support designed for the correct slope. The roof section and support were then centered under the sieve mounting frame. Plumb bobs were used to center the roof sections.

Figure 4
A Typical Sieve for Distributing the Particles

After the roof section was properly aligned, the plumb bobs were removed. Next, the door was placed on the front of the enclosure and the selected sieve was placed on the overhead frame.

The chosen sieve depended upon the particles that were to be distributed. For instance, six grams of the particles passing the number 60 sieve and retained on the number 100 sieve were scattered over the number 60 sieve. The sieve was then struck very lightly causing the sieve to vibrate and allowing the particles to fall from the sieve to the roof section below.

After the particles had been distributed, the roof section and support were carefully removed. A small brush was used to recover the particles that remained on the sheet metal floor. These particles were placed in a container and weighed. The initial weight minus the weight of the recovered sample yielded the weight retained on the roof section.

A total of 251 tests were made, using the three roofing materials. Of these 251 tests, 92 utilized wood shingles, 83 were conducted on asphalt roofing, and 76 were carried out on the metal roofing.

Each sample was tested and designated by a number such as, W-100-10-1. The first letter was either W, for wood; A, for asphalt; or M, for metal. The second group of numbers represents the sieve number on which the particles were retained. The third group represents the roof slope in degrees. The last number represents the number of the test in the series. For example, if there were five tests in the W-100-10 series, the fifth test would be designated as W-100-10-5.

DISCUSSION OF RESULTS AND CONCLUSIONS

Discussion of Results

Table 2 gives the total weight in grams retained on each roof section. It also gives the normalized value for the various roofing materials tested. The normalized value was obtained by dividing all weights by the weight retained on the flat roof. The values in Table 2 were obtained by averaging selected tests in a given series. For each series of tests an average and a standard deviation were computed after having discarded data showing extreme deviations. Subsequent to computing the standard deviation and the average for each group, three standard deviations were computed. The previously rejected data were then inspected to see if any results fell within plus or minus three standard deviations of the average. If the excluded results fell within this range, they were included; and a new average was computed. If the results were outside this range, they were excluded from the computations. A complete set of the data also appears in the Appendix. The tests which were used in computing the averages appearing in Table 2 are indicated in the Appendix by the letter "x".

During the tests on wood shingles it was noticed that the number 100 particles started to move down the roof when the roof section was inclined 20 degrees. For this same material the number 140 particles and the number 200 particles did not start down the roof until the slope had been increased to 40 degrees. This observation can be seen by inspecting the graph that appears in Figure 5.

TABLE 2

Results

		Particle size					
		Number 100 Sieve		Number 140 Sieve		Number 200 Sieve	
Material	Slope	Average	Normalized value	Average	Normalized value	Average	Normalized value
Wood Shingles	0	5.46	1.00	5.53	1.00	5.52	1.00
	10	5.34	0.98	5.73	1.04	5.41	0.98
	20	4.58	0.84	5.59	1.01	5.63	1.02
	30	3.22	0.59	5.54	1.00	5.51	1.00
	40	0.58	0.11	4.21	0.76	5.17	0.94
Asphalt Roofing	0	5.69	1.00	5.86	1.00	5.58	1.00
	10	5.59	0.98	5.92	1.01	5.74	1.03
	20	5.32	0.94	5.80	0.99	5.62	1.01
	30	4.85	0.85	5.74	0.98	5.59	1.00
	40	3.81	0.67	5.48	0.94	5.43	0.97
Metal Roofing	0	5.71	1.00	5.84	1.00	5.67	1.00
	10	5.28	0.92	5.79	0.99	5.61	0.99
	20	2.86	0.50	4.98	0.85	5.53	0.97
	30	0.01	0.00	0.28	0.05	4.85	0.85
	40	0.03	0.01	0.03	0.01	0.18	0.03

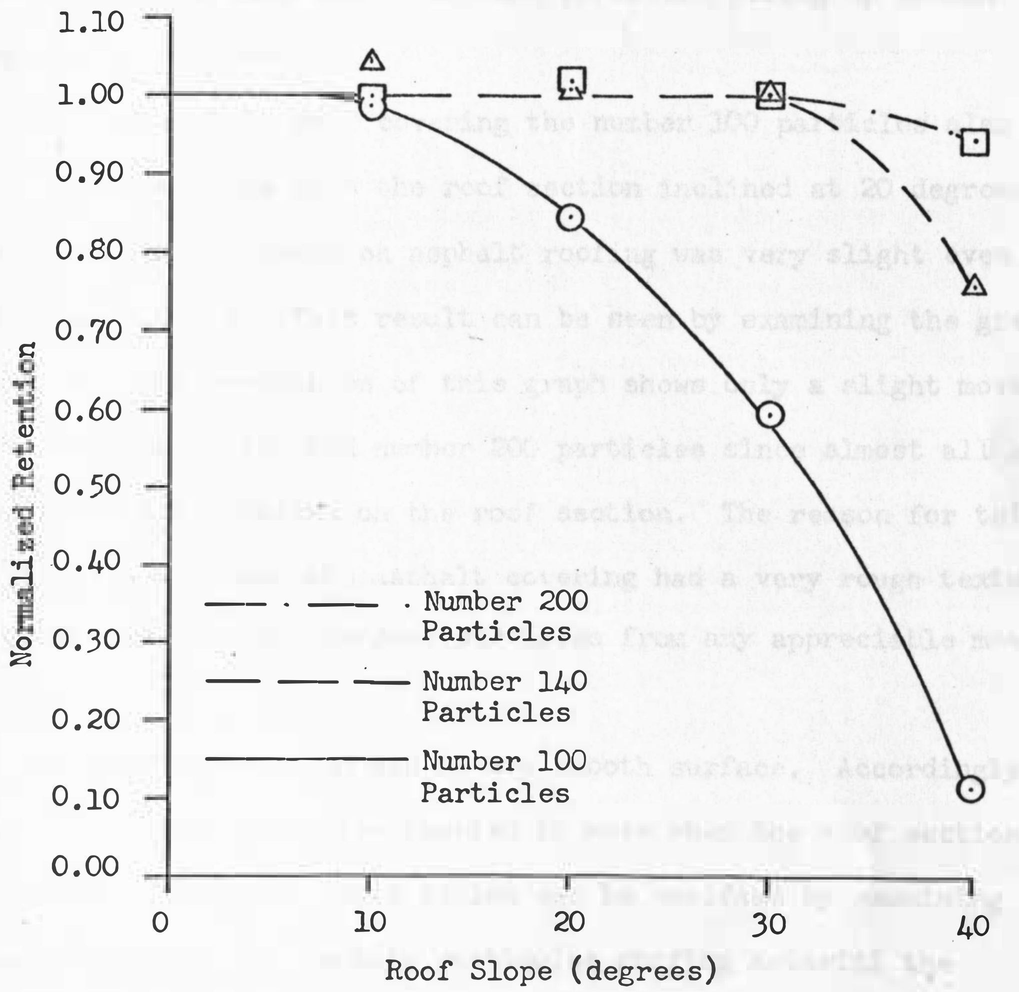

Figure 5
Normalized Retention vs Roof Slope for Wood Shingles

For wood shingles, the particles, once they started to travel, tended to be caught in small drifts. One particle would become lodged in the texture of the wood with following particles piling up behind causing drifts to form.

For the asphalt roof covering the number 100 particles also started down the slope with the roof section inclined at 20 degrees. However, particle movement on asphalt roofing was very slight even at a 40-degree slope. This result can be seen by examining the graph in Figure 6. Interpretation of this graph shows only a slight movement for the number 140 and number 200 particles since almost all of the particles are retained on the roof section. The reason for this high retention was that the asphalt covering had a very rough texture which prevented even the largest particles from any appreciable movement.

The sheet metal used had a very smooth surface. Accordingly, the number 100 size particles started to move when the roof section was inclined 10 degrees. This action can be verified by examining the graph of Figure 7. On this particular roofing material the particles tended to form drifts across the roof. The graph shows that all of the number 100 and number 140 particles slid off the roof. This result was not entirely true since a few scattered particles were retained. The graph also shows that even the number 200 particles traveled to a great extent on the 40-degree slope.

It may be important to point out that the metal roofing had a nail through the center of the roof section. This nail caused the

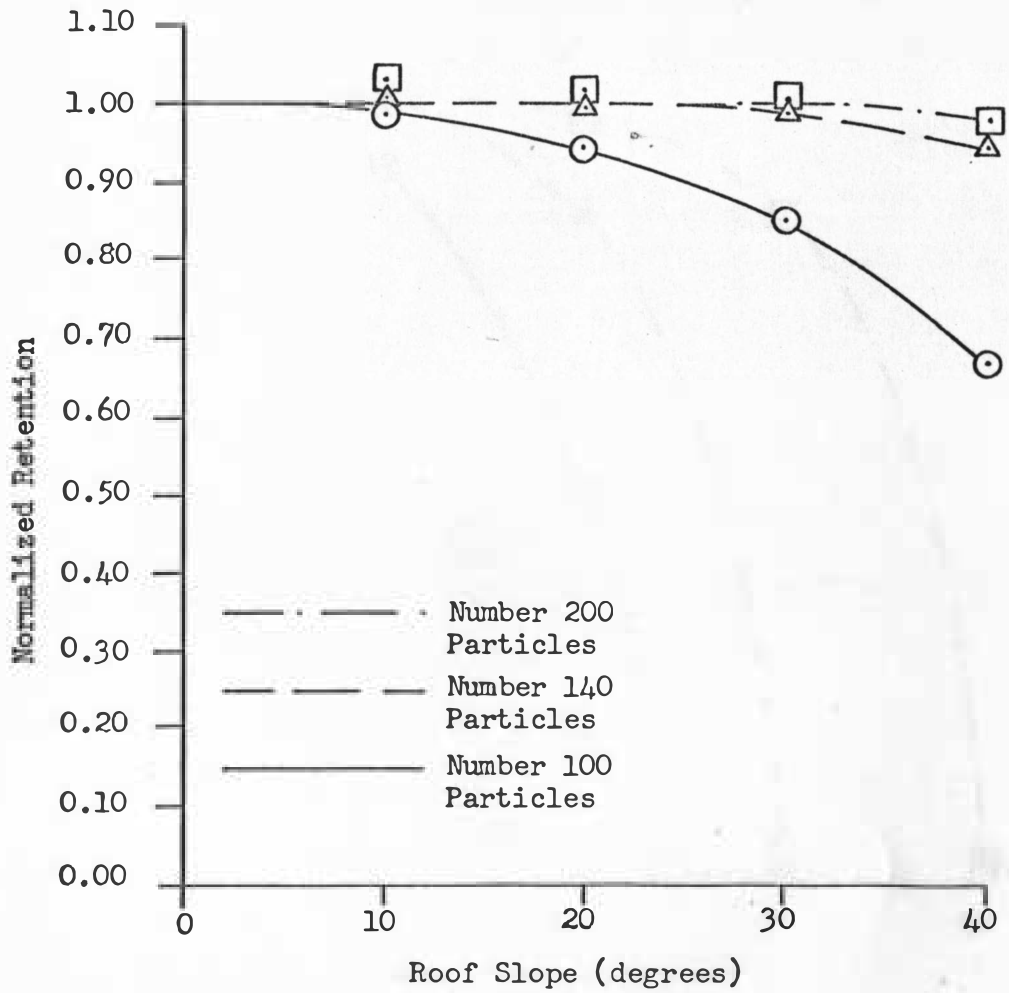

Figure 6
Normalized Retention vs Roof Slope for Asphalt Roofing

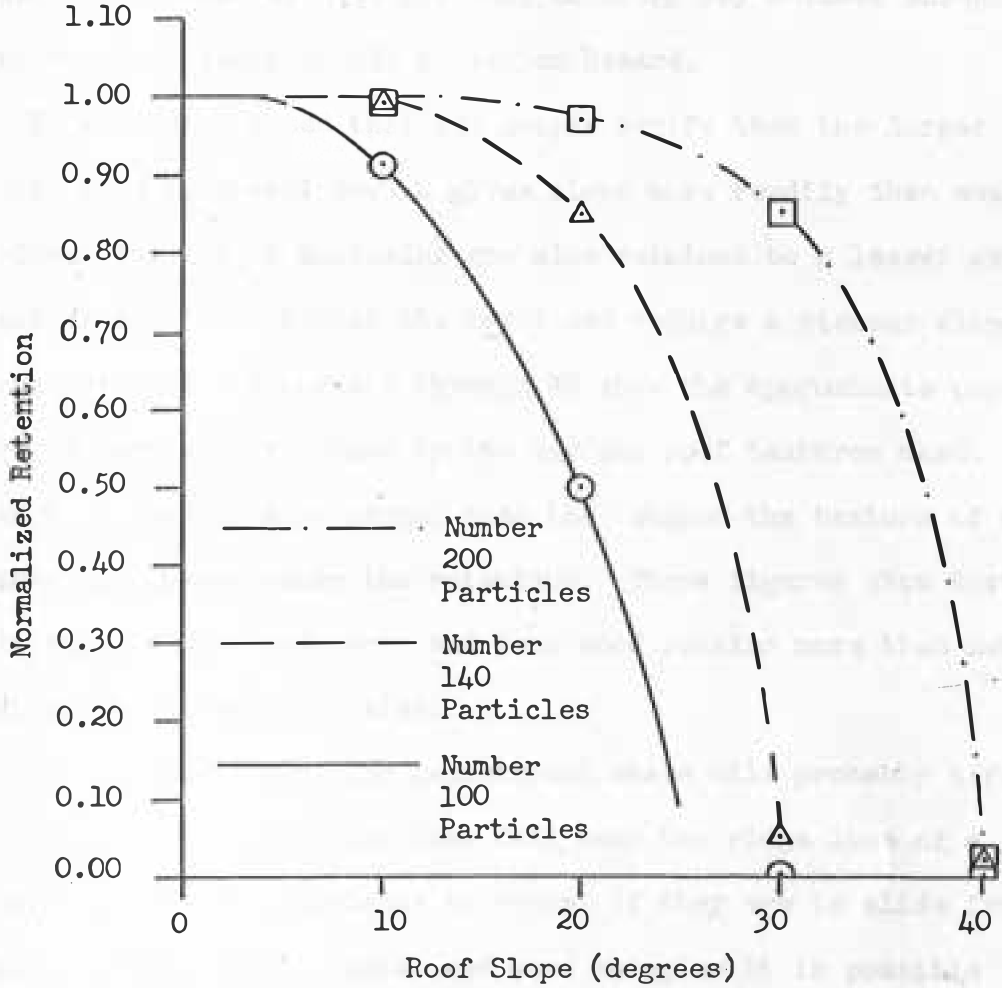

Figure 7
Normalized Retention vs Roof Slope for
Metal Roofing

number 140 particles and number 200 particles to collect around its upper side. This situation points out that even for steep roofs the fasteners needed to hold the roof covering may collect enough fallout to cause considerable radiation hazard.

It should be noted that all graphs verify that the larger particles tend to travel down a given slope more readily than smaller particles. The larger particles are also retained to a lesser extent. The smaller particles travel the least and require a steeper slope to initiate movement. Figures 5 through 10 show the approximate percentage of particles retained by the various roof textures used. Figures 8, 9, and 10 also reveal that the rougher the texture of the roof covering, the greater the retention. These figures show that asphalt retains more than wood and that wood retains more than metal, regardless of the particle size.

For an actual roof the geometrical shape will probably affect the retention. The particles that fall near the ridge line of a roof have considerable distance to travel if they are to slide from the roof. In the case of metal and wood shingles it is possible that the wind could play a very important role in the decontamination of a roof. These textures retain the particles in a more exposed manner, thus allowing the wind to sweep them from the roof.

All tests in this study were conducted on dry roofing material. The presence of any moisture would have a tendency to cause the particles to adhere to the roof in the position where they first contacted the roof surface.

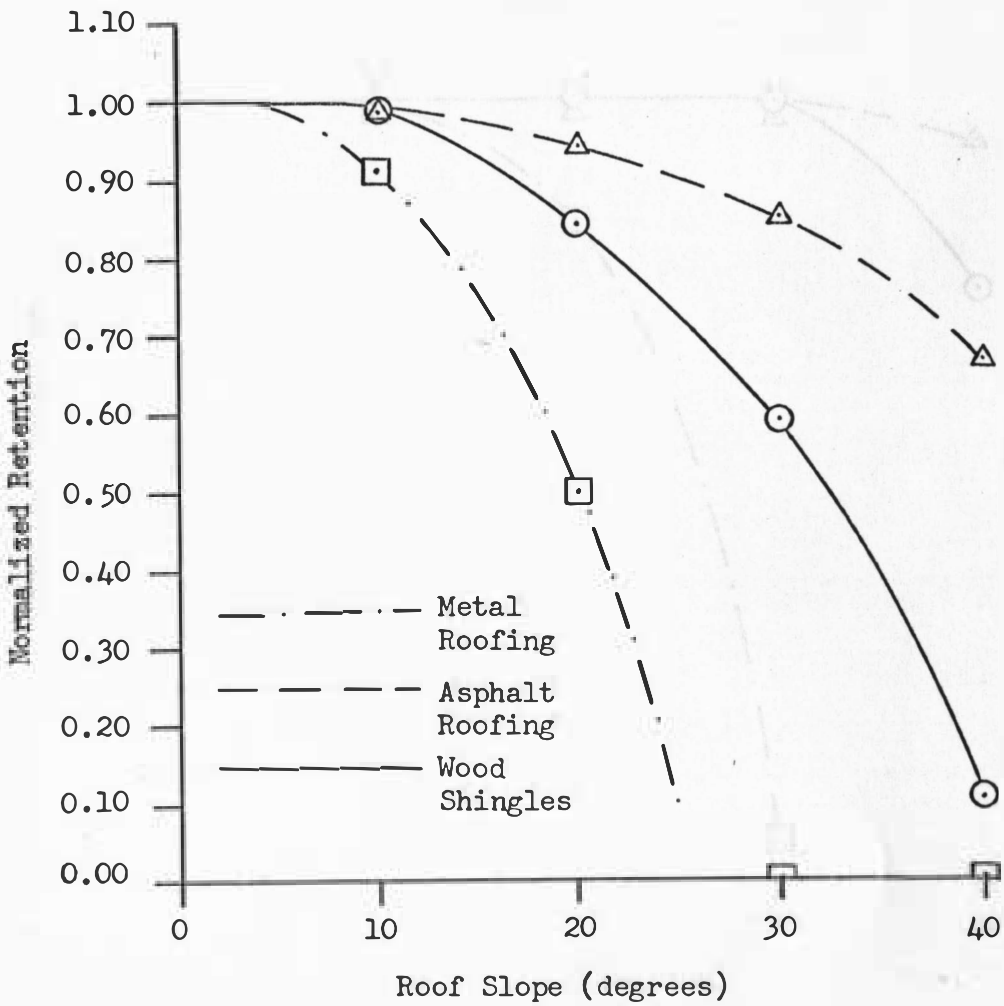

Figure 8
Normalized Retention vs Roof Slope for Number 100 Particles

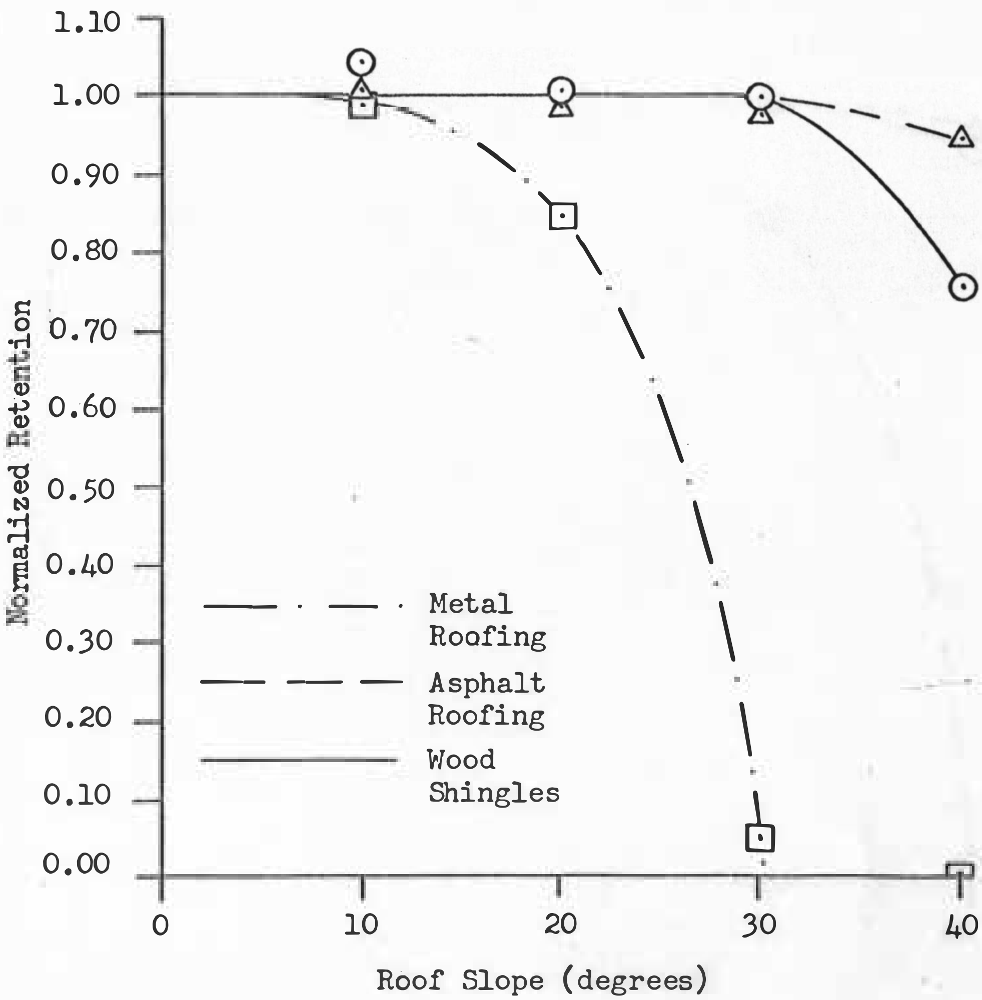

Figure 9
Normalized Retention vs Roof Slope for Number 140 Particles

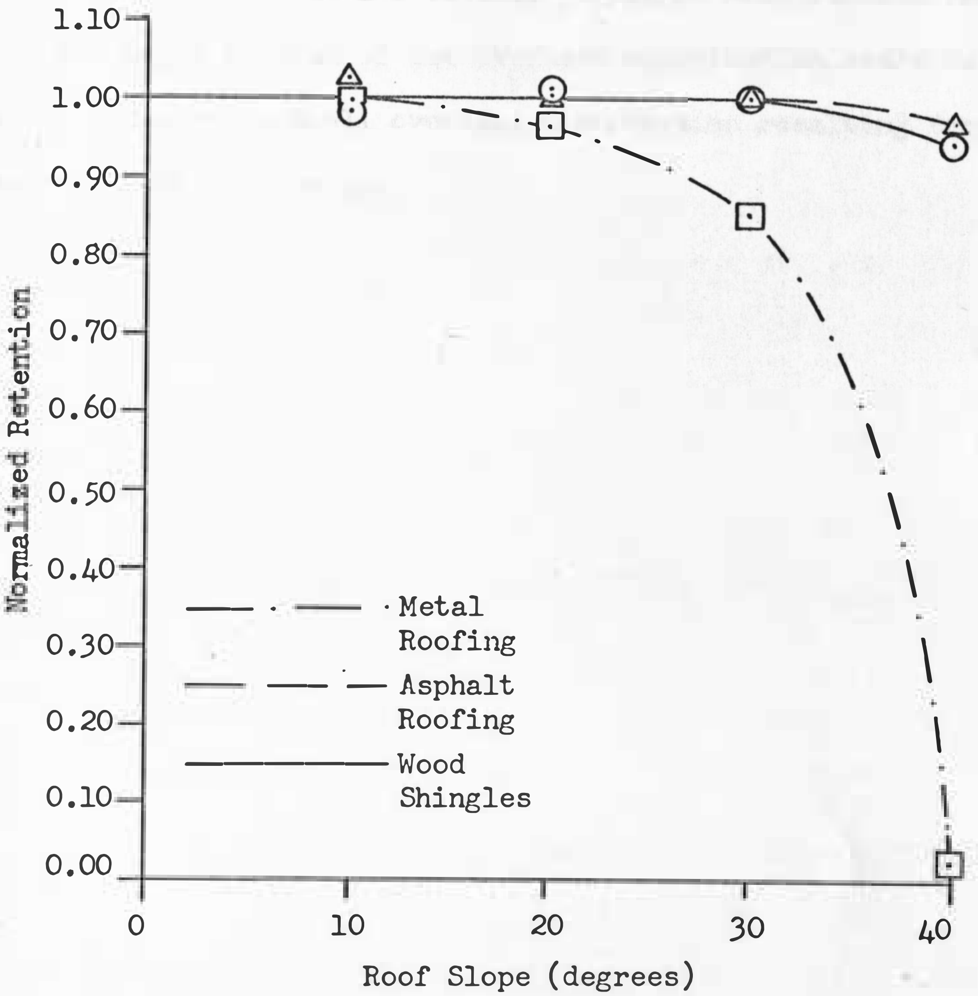

Figure 10
Normalized Retention vs Roof Slope for Number 200 Particles

The overhead contribution that reaches a detector located in a structure is composed of direct radiation, scattered radiation, and skyshine radiation. If all fallout particles were removed from the roof, the major portion of the overhead contribution would be eliminated. However, a small overhead contribution resulting from skyshine would still be present.

Conclusions

Through this study the following conclusions were reached:

1. The degree of roof slope does have a definite effect upon particle movement which directly affects their retention.
2. The size of the fallout particles has a definite bearing on the quantity retained. Fine particles show very little movement on the roof surface. Conversely, the coarser particles exhibit a greater tendency toward movement on the steeper slopes.
3. The texture of the material greatly affects the retention of fallout particles. Textures such as asphalt will retain more than either wood or metal. For smooth surfaces such as metal the movement of the smaller particles on steep slopes is appreciable.
4. Due to the limited scope of this study a change in the present method of analysis for overhead fallout contribution is not recommended at this time.

Areas for Future Study

It is recommended that the following areas of future study be investigated:

1. The decontamination potential of wind.
2. The drift pattern that fallout creates as the wind deposits particles on and around a structure.
3. The relationship between roof area and perimeter on the retention of fallout.

LITERATURE CITED

1. Romm, Joseph, Background of Civil Defense and Current Damage Limiting Studies, TR-35, Office of Civil Defense, Washington, D. C., (June 1966).

2. Shelter Design and Analysis, TR-20, Vol. 1, Office of Civil Defense, Washington, D. C., (July 1967).

3. Knott, Albert, Shelter Design In New Buildings, TR-43, Office of Civil Defense, Washington, D. C., (March 1967).

4. Yager, Dwayne, Overhead Contribution From A Sloping Roof, CE-57, M. S. Thesis, South Dakota State University, (1968).

5. The Effects of Nuclear Weapons, United States Atomic Energy Commission, Washington 25, D. C., (February 1964).

6. O'Brien, Morrough P., and Hickox, George H., Applied Fluid Mechanics, McGraw-Hill Book Company, Incorporated, New York, (1937).

7. Eskinazi, Salamon, Principles of Fluid Mechanics, Allyn and Bacon, Incorporated, Boston, (1963).

8. Hough, B. K., Basic Soils Engineering, The Ronald Press Company, New York, (1957).

9. Rouse, Hunter, Fluid Mechanics For Hydraulic Engineers, McGraw-Hill Book Company, New York, (1938).

10. Beer, Ferdinand P., and Johnston, E. Russel, Jr., Mechanics for Engineers Statics and Dynamics, 2nd Ed., McGraw-Hill Book Company, Incorporated, New York, (1962).

APPENDIX

ORIGINAL DATA

Designation	Weight retained on the roof section (grams)	Checked if used to compute the average
W-100-0-1	5.31	
W-100-0-2	5.43	x
W-100-0-3	5.54	x
W-100-0-4	5.53	x
W-100-0-5	5.56	x
W-100-0-6	5.44	x
W-100-0-7	5.40	x
W-100-0-8	5.42	x
W-100-0-9	5.40	x
W-100-0-10	5.40	x
W-140-0-1	5.55	x
W-140-0-2	5.56	x
W-140-0-3	5.58	x
W-140-0-4	5.44	x
W-200-0-1	5.37	x
W-200-0-2	5.19	
W-200-0-3	5.27	
W-200-0-4	4.86	
W-200-0-5	5.38	x
W-200-0-6	5.16	
W-200-0-7	5.38	x
W-200-0-8	5.12	
W-200-0-9	5.65	x
W-200-0-10	5.73	x
W-200-0-11	5.59	x
W-200-0-12	5.67	x
W-200-0-13	5.34	x
W-100-10-1	5.40	x
W-100-10-2	5.39	x
W-100-10-3	5.22	x
W-100-10-4	5.37	x
W-140-10-1	5.76	x
W-140-10-2	5.67	x
W-140-10-3	5.76	x
W-140-10-4	5.74	x

ORIGINAL DATA (continued)

Designation	Weight retained on the roof section (grams)	Checked if used to compute the average
W-200-10-1	5.34	x
W-200-10-2	5.53	
W-200-10-3	5.04	
W-200-10-4	5.47	x
W-200-10-5	5.50	x
W-200-10-6	5.46	x
W-200-10-7	5.28	x
W-100-20-1	4.65	x
W-100-20-2	4.60	x
W-100-20-3	4.54	x
W-100-20-4	4.50	x
W-100-20-5	4.59	x
W-140-20-1	5.56	x
W-140-20-2	5.56	x
W-140-20-3	5.54	x
W-140-20-4	5.73	x
W-140-20-5	5.56	x
W-200-20-1	5.71	x
W-200-20-2	5.53	x
W-200-20-3	5.65	x
W-200-20-4	4.85	
W-200-20-5	5.62	x
W-100-30-1	2.80	
W-100-30-2	3.14	x
W-100-30-3	3.27	x
W-100-30-4	3.21	x
W-100-30-5	3.27	x
W-140-30-1	5.14	
W-140-30-2	5.48	x
W-140-30-3	5.50	x
W-140-30-4	5.67	x
W-140-30-5	5.54	x
W-140-30-6	5.51	x

ORIGINAL DATA (continued)

Designation	Weight retained on the roof section (grams)	Checked if used to compute the average
W-200-30-1	5.32	x
W-200-30-2	5.59	x
W-200-30-3	5.35	x
W-200-30-4	5.54	x
W-200-30-5	5.63	x
W-200-30-6	5.61	x
W-100-40-1	0.71	x
W-100-40-2	0.60	x
W-100-40-3	0.43	x
W-100-40-4	0.51	x
W-100-40-5	0.47	x
W-100-40-6	0.73	x
W-140-40-1	4.46	
W-140-40-2	4.27	x
W-140-40-3	4.56	
W-140-40-4	4.26	x
W-140-40-5	4.19	x
W-140-40-6	4.13	x
W-200-40-1	5.02	x
W-200-40-2	5.05	x
W-200-40-3	5.23	x
W-200-40-4	5.28	x
W-200-40-5	5.25	x
W-200-40-6	5.18	x
A-100-0-1	5.69	x
A-100-0-2	5.66	x
A-100-0-3	5.75	x
A-100-0-4	5.68	x
A-100-0-5	5.69	x
A-140-0-1	5.88	x
A-140-0-2	5.77	x
A-140-0-3	5.91	x
A-140-0-4	5.89	x
A-140-0-5	5.83	x

ORIGINAL DATA (continued)

Designation	Weight retained on the roof section (grams)	Checked if used to compute the average
A-200-0-1	5.54	x
A-200-0-2	5.54	x
A-200-0-3	5.68	x
A-200-0-4	5.52	x
A-200-0-5	5.61	x
A-100-10-1	5.64	x
A-100-10-2	5.58	x
A-100-10-3	5.58	x
A-100-10-4	5.62	x
A-100-10-5	5.52	x
A-140-10-1	5.92	x
A-140-10-2	5.64	
A-140-10-3	5.95	x
A-140-10-4	5.89	x
A-140-10-5	5.93	x
A-140-10-6	5.91	x
A-200-10-1	5.80	x
A-200-10-2	5.69	x
A-200-10-3	5.72	x
A-200-10-4	5.71	x
A-200-10-5	5.76	x
A-100-20-1	5.23	x
A-100-20-2	5.26	x
A-100-20-3	5.44	x
A-100-20-4	5.36	x
A-100-20-5	5.33	x
A-140-20-1	5.68	
A-140-20-2	5.77	x
A-140-20-3	5.80	x
A-140-20-4	5.82	x
A-140-20-5	5.83	x
A-140-20-6	5.78	x

ORIGINAL DATA (continued)

Designation	Weight retained on the roof section (grams)	Checked if used to compute the average
A-200-20-1	5.53	x
A-200-20-2	5.64	x
A-200-20-3	5.58	x
A-200-20-4	5.64	x
A-200-20-5	5.76	x
A-200-20-6	5.59	x
A-100-30-1	4.67	
A-100-30-2	4.87	x
A-100-30-3	4.97	x
A-100-30-4	4.86	x
A-100-30-5	4.71	x
A-100-30-6	4.83	x
A-140-30-1	5.80	x
A-140-30-2	5.70	x
A-140-30-3	5.73	x
A-140-30-4	5.81	x
A-140-30-5	5.67	x
A-200-30-1	5.58	x
A-200-30-2	5.55	x
A-200-30-3	5.72	x
A-200-30-4	5.49	x
A-200-30-5	5.63	x
A-200-30-6	5.45	
A-100-40-1	3.74	x
A-100-40-2	3.86	x
A-100-40-3	3.96	x
A-100-40-4	3.69	x
A-100-40-5	3.93	x
A-100-40-6	3.68	x
A-140-40-1	5.60	x
A-140-40-2	5.37	x
A-140-40-3	5.59	x
A-140-40-4	5.37	x
A-140-40-5	5.52	x
A-140-40-6	5.45	x

ORIGINAL DATA (continued)

Designation	Weight retained on the roof section (grams)	Checked if used to compute the average
A-200-40-1	5.41	x
A-200-40-2	5.54	
A-200-40-3	5.41	x
A-200-40-4	5.41	x
A-200-40-5	5.44	x
A-200-40-6	5.46	x
M-100-0-1	5.72	x
M-100-0-2	5.68	x
M-100-0-3	5.68	x
M-100-0-4	5.73	x
M-100-0-5	5.72	x
M-140-0-1	5.90	x
M-140-0-2	5.88	x
M-140-0-3	5.93	x
M-140-0-4	5.90	x
M-140-0-5	5.87	x
M-200-0-1	5.75	x
M-200-0-2	5.55	x
M-200-0-3	5.63	x
M-200-0-4	5.64	x
M-200-0-5	5.80	x
M-100-10-1	5.27	x
M-100-10-2	5.41	x
M-100-10-3	5.30	x
M-100-10-4	5.13	x
M-100-10-5	5.26	x
M-140-10-1	5.82	x
M-140-10-2	5.66	x
M-140-10-3	5.89	x
M-140-10-4	5.77	x
M-140-10-5	5.83	x

ORIGINAL DATA (continued)

Designation	Weight retained on the roof section (grams)	Checked if used to compute the average
M-200-10-1	5.55	x
M-200-10-2	5.65	x
M-200-10-3	5.50	x
M-200-10-4	5.63	x
M-200-10-5	5.27	
M-200-10-6	5.71	x
M-100-20-1	2.90	x
M-100-20-2	2.93	x
M-100-20-3	2.85	x
M-100-20-4	2.76	x
M-100-20-5	3.02	x
M-140-20-1	4.78	x
M-140-20-2	5.12	x
M-140-20-3	5.07	x
M-140-20-4	4.94	x
M-140-20-5	4.78	x
M-140-20-6	5.21	x
M-200-20-1	5.67	x
M-200-20-2	5.57	x
M-200-20-3	5.50	x
M-200-20-4	5.45	x
M-200-20-5	5.47	x
M-200-20-6	5.04	
M-200-20-7	5.50	x
M-100-30-1	0.22	
M-100-30-2	0.00	x
M-100-30-3	0.06	x
M-100-30-4	0.00	x
M-100-30-5	0.00	x
M-100-30-6	0.00	x

ORIGINAL DATA (continued)

Designation	Weight retained on the roof section (grams)	Checked if used to compute the average
M-140-30-1	0.32	x
M-140-30-2	0.26	x
M-140-30-3	0.29	x
M-140-30-4	0.29	x
M-140-30-5	0.25	x
M-200-30-1	4.58	x
M-200-30-2	4.89	x
M-200-30-3	5.08	x
M-200-30-4	4.96	x
M-200-30-5	4.72	x
M-200-30-6	5.28	
M-100-40-1	0.03	x
M-100-40-2	0.03	x
M-140-40-1	0.05	x
M-140-40-2	0.00	x
M-140-40-3	0.03	x
M-200-40-1	0.24	
M-200-40-2	0.13	x
M-200-40-3	0.10	x
M-200-40-4	0.14	x
M-200-40-5	0.13	x