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CLEANING EFFECTIVENESS

Carl J. Miller
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A.P.

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REMOVAL EFFECTIVENESS OF SIMULATED DRY FALLOUT FROM
PAVED AREAS BY MOTORIZED AND VACUMIZED STREET SWEEPERS

by
D. E. Clark, Jr.
W. C. Cobbin

U.S. NAVAL RADIOLOGICAL
DEFENSE LABORATORY

SAN FRANCISCO • CALIFORNIA • 94135

ABSTRACT

Four motorized sweepers were evaluated as waterless decontamination procedures to be used in the operational recovery of extensive paved areas contaminated with fallout from a land-surface nuclear detonation. Numerical values of fallout particle size and deposited initial mass levels obtained from a recently developed mathematical fallout model were used in the experimental design.

Sweeping effectiveness was dependent upon both environmental and machine parameters. Least effective sweeping results were obtained on rough surfaces with small particle sizes deposited at high initial mass levels. The best sweeping effectiveness for a given effort expenditure was done at the fastest forward speed. The effectiveness of sweeping was dependent upon its degree of utilization of air-broom and vacuum dust-control systems; the Tennant Model 100DS, a machine incorporating both systems, showed the greatest sweeping effectiveness and the fastest removal rate.

Three passes in 3rd gear, (11 mph, T100 Sweeper) showed a residual mass less by a factor of 5 than that for an equivalent amount of effort of one pass in 1st gear, (2.3 mph, T100 Sweeper), where effort is defined as being proportional to the time spent sweeping a given area.

Previously developed theoretical equations describing decontamination in terms of residual mass as a function of expended effort were not valid for the majority of the tests. This was because the equations were sensitive to speed in the normal operating range of the machines (where it is most important that speed apply), and because no allowance was made in the equations for a change in effectiveness with rate of effort expenditure.

SUMMARY

The Problem

Reclamation of extensive paved areas contaminated with fallout from a land-surface nuclear detonation may be required. In regions of limited water supply, decontamination procedures that can be effectively applied will be restricted. Motorized street sweepers, potentially applicable to the waterless decontamination methods, should be evaluated. Specifically, these machines should be tested on typical paved surfaces under expected fallout environments, to determine separately the effect of fallout particle size, deposited initial mass, surface roughness, machine speed, and operating features on sweeping effectiveness. Limitations and advantages of the machines should be determined so that improvements could be recommended.

Findings

Using radionuclide-traced sand to simulate dry fallout from nuclear weapons detonated on a land surface, effectiveness and effort data were obtained for four different sweeping machines on asphalt and concrete surfaces for six particle-size ranges and eight initial-mass levels.

The sweeping effectiveness (defined as the residual mass in g/ft^2) achieved depended upon the degree to which certain machine design features were used. The Tennant Model 100DS, a machine especially designed for decontamination, had the highest degree of effectiveness as well as the fastest rate of removal. This performance substantiated an inference from previous tests that a combination of two methods could retain the good features of each separate method.

Previously developed theoretical mathematical equations describing decontamination in terms of residual mass as a function of expended effort were not valid for the majority of tests.

The general decontamination equation cannot include speed because where one method may improve with speed another may not. For sweepers, effectiveness increased with speed. The rate of removal as well as final residual mass obtainable was a function of speed.

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CHAPTER I

INTRODUCTION

Survival and recovery during the various periods after a land-surface nuclear-weapon detonation requires proper countermeasures. Decontamination is the major countermeasure to be used during the operational recovery period, which occurs after the emergency period of shelter protection and before the long-term recovery period of contamination control.

The decontamination procedure to be used after each contaminating event depends upon the fallout characteristics, the decontamination materials and equipment available, and the nature of the surfaces requiring decontamination. For a land-surface detonation, the radioactivity is associated with the fallout particles in such a way that the prime criteria for decontamination are mass removal and disposal. In regions where enough water is not available, waterless methods must be used to remove and dispose of the fallout mass. Street sweepers of various designs and operating characteristics are commonly available for waterless cleaning of extensive paved areas.

Because most sweepers are designed and used for sweeping leaves and street debris, they may not be capable of effectively removing fallout particles. To determine their decontamination capability, a group of four sweepers (namely - W450, T100, T100AB and T100DS described in 2.1) was tested under controlled, simulated-fallout conditions.

1.1 HISTORY

The usefulness of street sweepers in decontamination procedures was recognized as early as 1948. Operation Streetsweep¹ initiated a series of evaluations based on the continually increasing awareness of the problem and a need for its solution. Operation Streetsweep, using ferromagnetic particles of two size ranges to simulate fallout, established that large particles are more easily removed by sweeping than are small particles under the same conditions. In 1948, Operation Supersweep,²

using three sizes of radiotantalum particles, showed that small particles are the most difficult to remove from macadam and concrete test-sample surfaces. These surfaces were manually swept with brooms. Firehosing proved more effective than manual sweeping where effectiveness is measured by the residual in mass on the surface after application of the cleaning procedure (usually as percent of the initial mass). In Operation Stoneman I³ (1956 at Camp Stoneman, California), a motorized sweeper was evaluated on asphalt and concrete surfaces that were contaminated with a dry synthetic fallout material dispersed at an initial mass level of 250 g/ft². A removal of 87-90 % of the initial mass from the surface was achieved. In Operation Stoneman II⁴ (1958) more extensive sweeper tests were conducted on asphalt and concrete surfaces using three initial mass levels and a fallout simulant covering a broad particle-size range. Motorized and vacuum-equipped motorized sweepers removed more than 95 % of the initial mass. An improvised air broom, consisting of a manifold with air nozzles mounted close to the pavement at the rear of an air compressor truck was also tested. It produced a high removal effectiveness (greater than 99 %), but it created a dust cloud and redispersed the contaminant onto downwind areas.

1.2 BACKGROUND

Recently developed concepts of fallout characteristics show a relationship between deposited initial mass and particle-size range.^{5,6} The application of these concepts has permitted the systematic selection of simulated fallout environment during the present evaluation of street sweepers for use in waterless decontamination.

When combined with decontamination data⁴ from previous sweeper tests, the concepts suggest that: (a) Optimum and limiting sweeper speeds in relation to mass level, particle size, and surface type should be established to aid in radiological recovery planning. (b) Previously derived theoretical equations as shown below describing decontamination by sweepers should either be verified or new equations should be established.

$$M = M^* + (M_0 - M^*) e^{-KE} \quad (1.2)$$

where M is the residual mass after effort expenditure E (g/ft²)
M* is the residual mass at an infinite effort level (g/ft²)
M₀ is the initial mass level g/ft²
e^{-KE} is the fraction of removable mass remaining after expending the effort, E equip-min/10⁴ ft² and K is proportionality constant.

(c) The promising air-broom and vacuum-equipped, motorized sweeper combination should be tested to see if the good features of each method can be retained in the combined method.

1.3 OBJECTIVES

The present series of sweeper tests was designed to answer most of the questions raised by previous test results. The general objectives of this sweeper evaluation series were:

(a) To determine the sweeping effectiveness of motorized and "vacuumized" street sweepers for waterless decontamination procedures, in the light of recently developed concepts of fallout particle size and initial mass level.

(b) To establish the limitations of existing street sweepers for decontamination with respect to the most recent concepts of fallout characteristics.

(c) To reveal sweeper design or operational improvements which would increase their effectiveness in decontamination procedures.

1.4 APPROACH

The following approach was taken to determine the effect of fallout characteristics on the effectiveness of several machines in decontamination procedures.

Four different machines (as described in 2.6) were tested: (1) Wayne Model 450 motorized sweeper (W450); (2) Tennant Model 100 "vacuumized" sweeper (T100); (3) Tennant Model 100 "vacuumized" sweeper with improvised air broom attachment (T100AB); and (4) Tennant Model 100DS "vacuumized" sweeper with air broom (T100DS).

Each of the four machines was tested at three forward speeds to determine the optimum rate of effort expenditure in relation to effectiveness achieved for the several fallout conditions simulated. The forward speeds were determined by the transmission gear used when the engine was

run at the governed speed required for efficient broom and/or vacuum system operation.

Sweeping effectiveness was measured in terms of the absolute residual mass (g/ft²). The machine that left the least residual mass for the same effort expenditure and initial conditions was rated the most effective. The use of residual number or fraction remaining can be readily obtained from the data for planning reclamation operations. They can be misleading if the initial conditions are not specified.

Asphalt and concrete surfaces were used to determine how surface roughness affects sweeping effectiveness. Surface roughness of pavements can be indicated only in a qualitative manner because no absolute measurement for gross roughness is available. For these sweeping evaluation tests all surfaces of each type used were considered typical but not identical.

Six particle-size ranges were used in combination with 5 initial mass levels in conformance with recently developed concepts of fallout characteristics.⁵ The size ranges were nominally selected according to particulate material readily classified by sieving from commercially available sand. Table 1.1 shows the estimate of fallout characteristics simulated; corresponding to each of the nominal size material are the estimated ranges of weapon yield, standard intensity, initial mass level, and downwind distance. The several specific mass levels chosen were held constant so that particle size effect could be measured. Only one size range (750-1000 μ) used was not estimated by the strictest interpretation of the model. However, it can be included by broader interpretation of the model and shows how particle size affects sweeping effectiveness.

TABLE 1.1

Estimated Fallout Characteristics

Available Material Particle Size (μ)	Weapon Yield (KT)	Std. Intensity (r/hr at 1 hr)	Initial Mass (g/ft ²)	Downwind Distance (mi)
44 - 74	1 - 10 ⁵	1 - 4,400	0.03 - 130	24 - 280
74 - 177	1 - 10 ⁵	42 - 27,500	1.3 - 825	9.2- 125
177 - 300	1 - 10 ⁵	100 - 24,500	3.0 - 735	4.3- 90
200 - 400	1 - 10 ⁵	120 - 23,000	3.6 - 690	3.5- 83
300 - 500	1 - 10 ⁵	140 - 22,500	4.2 - 675	2.7- 79
750 -1000	1 - 10 ⁵	117 - 22,000	3.5 - 660	1.8- 75

Verification of empirical and theoretical equations fitted to data of previous tests was attempted by obtaining residual mass values at high values of effort. This was necessary because certain constants in the empirical curves of residual mass vs effort expended were dependent upon an extrapolation to the ultimate residual mass achieved with infinite effort.

Although the present series of tests were designed primarily for sweeper evaluation studies the data obtained was also used to verify Eq. 1.2. Therefore environmental factors were controlled as closely as possible to eliminate any ambiguity in the results.

1.5 SCOPE

Although over 100 individual tests were performed, it was not possible to cover all combinations of machine and environmental parameters. To get as much data as possible with a limited number of tests, required a judicious selection of test parameters where the results of one test were analyzed to determine which test should be done next. This procedure applied particularly to the determination of optimum operating speeds and the effective removal of high initial mass levels. Certain tests were repeated at different times to determine the consistency of repetition.

CHAPTER 2

DESCRIPTION OF TEST PROCEDURES AND MEASUREMENTS

Two factors affect motorized sweeping effectiveness. The first is environmental and includes weapon detonation conditions, surface type and roughness, and contaminant particle size and initial mass level. The second is operational and includes machine design features such as broom material, rotational speed, equipment maneuverability, operator convenience, forward speed, width, as well as the methods of handling and storing the swept material.

2.1 DESCRIPTION OF MACHINES

A general description of the four sweepers tested is presented in this section. Detailed specifications of each machine are presented in Appendix D.

The Standard Wayne Model 450 Street Sweeper (Fig. 2.1) was used for motorized sweeping. This machine utilizes a 58-in.-wide, 36-in.-diameter, floating-type main broom made of palmyra stalk. It has a conveyor system that deposits the swept material into a 3-yd³ hopper. It has four speeds forward and one in reverse. This machine has neither a vacuum system for dust control nor an air broom for blowing dust out of cracks and crevices.

The Tennant Model 100 Street Sweeper (Fig. 2.2) was used for vacuumized sweeping. This machine utilizes a 48-in.-wide, 29-in.-diameter, fixed-mounting-type main broom, that is expandable to compensate for bristle wear. The broom is located forward of a 1-3/4-yd³ hopper. The hopper may be dumped by a hydraulic system. The machine is equipped with a sealed vacuum system with filter bags to collect the dust. The filter bags are cleaned by a hydraulically operated shaker. The machine has four speeds forward, one in reverse.

The Vacuumized Sweeper T100AB (Improved Air Broom) (Fig. 2.3) is the Tennant 100 machine, except for an improvised air broom. The air



Fig. 2.1 Wayne Model 450 Motorized Sweeper



Fig. 2.2 Tennant Model 100 Vacuumized Sweeper



Fig. 2.3 Tennant Model 100AB Vacuumized Sweeper With Auxiliary Air Supply for Improved Air Broom

broom is a 46-in.-long, 2-1/2-in.-diameter manifold, centrally fitted with a high-pressure air-hose connector. The manifold has 42 air nozzles on 1-in. centers. These 1/16-in.-diameter nozzles are directed forward toward the surface at a 45° angle. The manifold is in a fixed position at the rear and parallel to the main broom within the vacuum system (Fig. 2.4).

The air broom is activated via 50-ft length of high-pressure air hose from a 105-CFM compressor. During a sweeping pass the compressor is towed by an auxiliary vehicle beside the sweeper. The compressor is run at a static gauge pressure of 100 psi, which drops to a dynamic pressure of 40 psi and remains constant when the air broom is in operation.

The Vacuumized Sweeper TLOODS was designed for the USAF by G. H. Tennant Co. specifically for decontamination⁸ (Fig. 2.5). It is equipped with a vacuum system and dust collector filters and built-in air broom. It has four speeds forward and one in reverse. It utilizes a 87-in.-long, 36-in.-diameter, fixed mounting-type main broom with adjustable expanding brushes to maintain a constant diameter. It has a 4-yd³ hydraulically-operated hopper.

This machine may be operated manually or by remote control, which allows the operator to stay completely out of the radiation field.

2.2 SELECTION OF TEST SITE

A physical inspection of the available paved surfaces at Camp Parks, Calif., was made to determine their suitability for the tests. Those selected were an exposed concrete floor of an old building, and an adjacent asphalt surface. Their proximity to one another made it convenient to conduct tests with minimum equipment, simulant, and manpower.

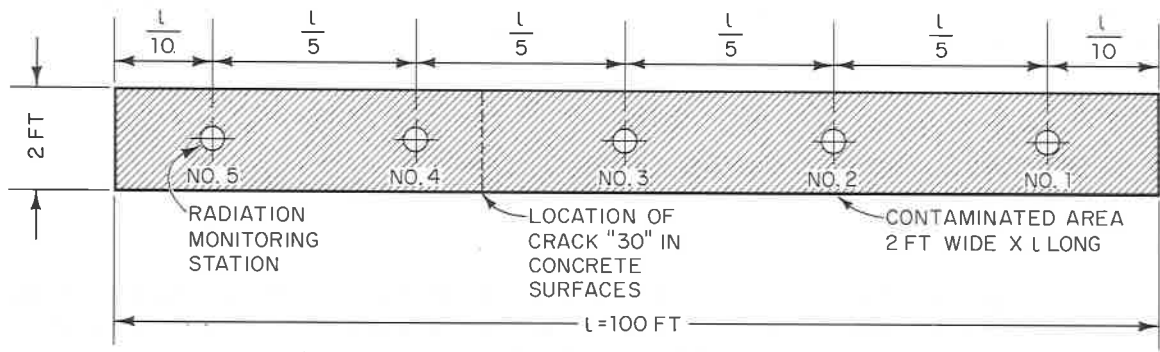
The use of several narrow test strips 2 ft wide x 100 ft long (Fig. 2.6) on these two areas further reduced requirements for simulant, logistic, and manpower. The multiple test strips, three on the concrete and three on the asphalt surfaces, were used sequentially to allow time for decay of the radionuclide tracer. The low background thus achieved permitted meaningful radiation measurements while using a simulant of low specific activity. The radiation dose to the investigators under these conditions was minimized.



Fig. 2.4 Detail of Improvised Air Broom (not installed)
Used on Tennant Model 100



Fig. 2.5 Tennant Model 100DS Vacuumized-Air Broom Sweeper. Remote control center in background.



(EXCEPT FOR SEVERAL TESTS WHERE HIGH MASS LEVEL OR SHORTAGE OF SIMULANT DICTATED USE OF 50 FT STRIP)

Fig. 2.6 Layout of Test Strip for Sweeper Evaluation Tests

The concrete surface had an expansion joint (called crack #30) across the three test strips. The asphalt filler material had decomposed to the point where repair was necessary. The decomposed material was removed and a patching grout of latex, sand, and cement was used to fill the crack.

After a few tests had been conducted over the area it was noted that the patch material was cracking and pulling loose, due to the shifting and settling of the sections caused by the motion of the heavy sweepers. No further repairs to the cracks were made, and it was decided to determine their effect on the sweeping effectiveness. Cracks #30, #1, and #3 were 24 in. long, 1 in. wide, 3/4 in. deep. Crack #2 was a hairline surface crack and no measurements of it were made.

2.3 EQUIPMENT ADAPTATION TO TEST REQUIREMENTS

The W450 and the T100 sweepers were not designed for decontamination purposes. Minor modifications and adjustments were made for consistent test comparisons.

The gutter brooms were removed from both sweepers because the test conditions simulating large areas do not include gutters or curbs. Also, it was found during Operation Stoneman II, that the gutter brooms created air currents which could cause re-contamination. This made the gutter brooms undesirable for decontamination of large areas.

The water spray system on the W450 is normally used as a means of dust control. This system, as at Operation Stoneman II, was deactivated to satisfy the condition that decontamination be waterless. Since this feature for dust control was not used, tests with fine particles requiring dust control were not conducted with the W450.

Several operators were trained to drive the sweepers, operate the brooms, dump the hoppers, operate the shakers, and become consistently proficient in machine operation.

To insure the best possible performance, each machine was operated at speeds that were reproducible and in accordance to manufacturer's suggestions. This required (1) selecting the proper gear for a sweeping event, and (2) operating in that gear at full throttle. This procedure insured the best performance of the main broom and the maximum vacuum for the dust control system.

Speed calibration runs were made on all machines in their different gears to establish consistent speeds for the length of the test strip. Such consistency was important because speed was directly related to the "relative-effort" used in comparing the effectiveness of the four sweepers.

Preventive maintenance was provided in accordance with the manufacturer's specifications. Prior to testing, the machines were adjusted to prepare them for operational conditions deemed necessary for decontamination purposes. The overhaul included replacing worn tires, worn brushes, rubber skirts, and other parts. Periodic routine maintenance was performed during the test series to retain the initial performance conditions.

2.4 PRODUCTION OF SYNTHETIC FALLOUT

Non-radioactive bulk carrier materials used for sweeper evaluation studies prior to the development of an adequate fallout model,⁵ were Camp Stoneman soil (Ambrose Clay Loam) and sandblast sand in two grades. The effectiveness of the sweepers tested with these materials was determined by the material weight balance technique described in Section 2.5.

Radioactively tagged bulk-carrier materials (see Appendix A) were used after the development of an adequate fallout model. Two grades of (river bottom) #60 mesh and #1 ground Del Monte sand were selected because these raw materials contained a large percentage of the size fractions predicted by the fallout model.

The radionuclide La^{140} was selected as the particle contaminant for several reasons. Its energetic gamma rays minimized the self-shielding effects of the simulant at high initial-mass levels, making the radiation measurements more nearly proportional to the mass present if the specific activity ($\mu\text{c/g}$) was uniform. Radioactive decay by a 40.2-hr half-life reduced the residual radiation levels to background in a few days and permitted reuse of the test area.

2.5 DISPERSAL OF SYNTHETIC FALLOUT

One of the criteria imposed upon the test conditions was a uniformly dispersed initial mass of material on the test area. The amount of

material dispersed depended upon the fallout conditions being simulated in a given test.

Uniform dispersal was accomplished by using a calibrated, hand-pulled garden spreader (O.M. Scott and Sons, Marysville, Ohio; Fig. 2.7). The average initial-mass level per unit area was determined by weighing the loaded spreaders (Fig. 2.8) both before and after dispersal and dividing the difference by the area covered.

Different nominal particle-size fraction ranges required a different rate of speed and setting to achieve the same unit mass loading.

2.6 MEASUREMENT TECHNIQUE

To insure uniformity of test results, the following routine was initiated: (1) a 15- to- 30-min warm-up period was allowed for electronic equipment stabilization prior to test time. (2) An initial background reading was taken prior to bringing the radioactive contaminant near the test areas, to establish the residual background in the test area. This allowed determining the quantity of contaminant that could be brought into the area for a day's run, as well as how long testing could continue in the general test area without background building up.

Radiation measurements were made by a mobile, shielded, gamma-scintillation detector (Fig. 2.9). The principle detection element of this instrument was a 1-in.-diameter, 1 in.-thick, NaI (Tl) scintillation crystal coupled to a photomultiplier tube. These were contained within a 4-in.-thick lead shield so that the center of the detector was 1 meter above the ground. A collimated 1-in.-diameter aperture subtending a 14° cone of view permitted entrance of radiation into the sensitive volume. The power supply, associated electronics, and printout system as well as the shielded detector were trailer-mounted for mobility.

The effectiveness of the decontamination procedures was determined by the comparison of radiation measurements converted to mass remaining. Reliability in the measurement was provided for by recording two 1-min. counts for each in the following sequence:

- a. A radiation standard, to determine the over-all response of the instrument.
- b. The crystal looking straight up, to determine cosmic background radiation in the atmosphere while minimizing residual counts from the test area.



Fig. 2.7 Dispersing Fallout Simulant with Calibrated Lawn Spreader



Fig. 2.8 Weighing Fallout Simulant Dispenser. Shielded mobile storage hopper in background.

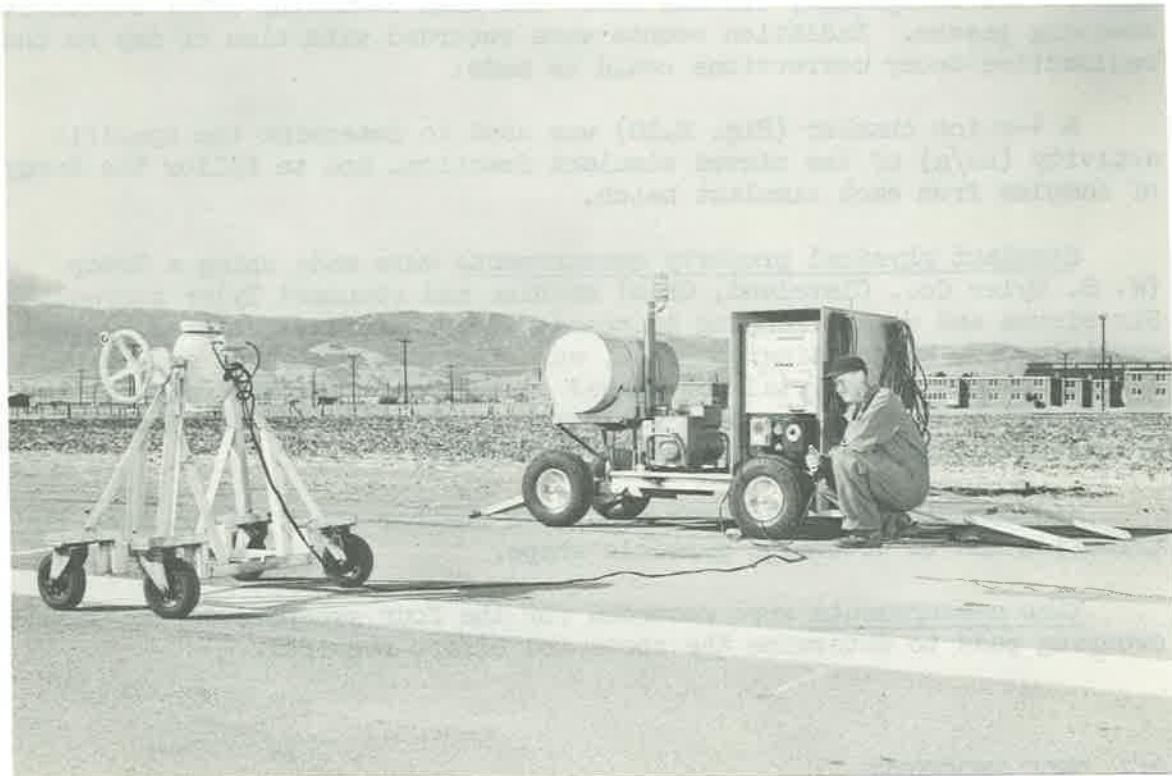


Fig. 2.9 Mobile Shielded Radiation Detector Measuring Initial Radiation Level on Test Strip

c. At each of the five monitoring points on the test strip, to collect data.

d. Another radiation standard, to further check and correct for the drift in response of the instrument during the monitoring cycle.

The above four-step sequence was carried out for each test to measure the background, initial mass, and mass remaining after successive sweeping passes. Radiation counts were recorded with time of day so that radioactive decay corrections could be made.

A 4- π ion chamber (Fig. 2.10) was used to determine the specific activity ($\mu\text{c/g}$) of the sieved simulant fractions and to follow the decay of samples from each simulant batch.

Simulant physical property measurements were made using a Rotap (W. S. Tyler Co., Cleveland, Ohio) machine and standard Tyler sieves. Six sieves and a pan, ranging in standard mesh sizes determined by the particle-size range being analysed, were thoroughly cleaned and nested. A 100-g sample of material was placed on the top sieve and rotapped for 10-min, and each sieve fraction was weighed, to determine the size distribution within a nominal particle-size range.

Microscopic inspection was used as a further check of the size distribution and to determine particle shape.

Time measurements were recorded for the four sweepers during each sweeping pass to determine the speed and effort required.

2.7 TEST PROCEDURE

The sweeping effectiveness in early tests was determined with non-radioactive simulant using a material weight-balance technique. This consisted of (a) weighing the initial mass dispersed, and (b) dumping the sweeper hopper and weighing the swept material after each successive pass. Tests conducted with non-radioactive simulant showed a 90 to 98 % material accountability when used to determine sweeping effectiveness for high initial-mass levels ($> 100 \text{ g/ft}^2$) and small amounts of effort (1 to 2 passes). However, motorized sweeping, using large amounts of effort, removes more than 98 % of the initial mass and requires a more sensitive measuring technique. When radioactive simulant was used in later tests, a direct measurement of residual mass levels of less than one percent of the initial mass could be made.



Fig. 2.10 $4\text{-}\pi$ Ionization Chamber

The following sequence was followed for each test conducted with radioactive simulant:

- a. Radiation background measurements were made as described in Section 2.6.
- b. Synthetic fallout material of the proper particle size range was dispersed as described in Section 2.5.
- c. Initial mass level radiation measurements were made as described in Section 2.6.
- d. The first sweeping pass was made over the test area at a constant selected speed achieved by starting some distance before the beginning of the test strip.
- e. Radiation measurements were made as in step c.
- f. A second pass was made over test area as in step d.
- g. Radiation measurements were made as in step c.
- h. Third and fourth sweeping passes were made over the test area as in step d.
- i. Radiation measurements were made after the fourth pass as in step c.
- j. Fifth through eighth sweeping passes were made over the test area as in step d.
- k. Final radiation measurements were made after the eighth pass as in step c.

Each pass was clocked to determine the time taken to sweep the length of the test strip. Radiation measurements were taken after only the 1st, 2nd, 4th and 8th passes. This provided data for large increments of effort and reduced the number of half-hour monitoring periods. The machines were driven from the immediate area while radiation measurements were made. Table 2.1 summarizes the test conditions. Detailed results of all tests are given in Appendix B.

A series of special measurements was also made to determine the effectiveness of sweeping material accumulating in cracks in concrete. Radiation measurements were made over crack #30 during tests of all machines except the TLOODS. Special tests were made with the TLOODS. The results of all crack tests are presented in Appendix B.

TABLE 2.1

Scope of Test Conditions

Mass (g/ft ²)	Particle Size (μ)	Surface Type	Procedure											
			W450 Gear			T100 Gear			T100AB Gear			T100DS Gear		
			1	2	3	1	2	3	1	2	3	1	2	3
20	44 -	A				1	1		1	1		1	1	
20	44 -	C										1		
20	177 -	A	1	1		2	2		1	1	1		1	1
20	177 -	C	1			1	1		1				1	1
30	177 -	A				1	1		1					
30	300 -	A				2	2		1					
60	300 -	A				1	1							
60	200 -	A				1	1		1					
100	44 -	A				1	1		1	1				
100	44 -	C												
100	74 -	A	1	2	1	1	1	1	1	1	1	2	1	1
100	74 -	C	1	1	1	1	1	1	1	2	1	1	1	1
100	177 -	A	1	2	1	2	2	2	3	2	1	1	1	1
100	177 -	C	1	1	1	1	2	2	1	1	1	1	1	1
150	200 -	A				1	1		1					
250	750 -	A				1	1		1					
400	44 -	A				1	1		1					
400	750 -	A				1	1		1					
400	750 -	C				1	1		1					
400	300 -	A				2	2		2					
400	300 -	C				1	1		1					
600	74 -	A	1	1		1	1		1	1		1	3	
600	74 -	C				1	1		1			1	1	

A = Asphalt

C = Concrete

W450 = Wayne Model 450 Motorized Sweeper

T100 = Tennant Model 100 Vacuumized Sweeper

Gear = Available forward speeds determined by drive transmission gears and governed engine speed as shown in Table 3.

Numbers indicate repetitions of each test condition.

T100AB = Tennant Model 100 Vacuumized Sweeper with Improvised Air Broom Attachment

T100DS = Tennant Model 100 Vacuumized Sweeper with Air Broom

Numbers indicate repetitions of each test condition.

CHAPTER III

RESULTS AND DISCUSSION

Effort as applied by a street sweeper is not a continuous function which can be truly represented by curves or mathematical equations. This is because sweepers are designed to operate at the governed engine speed which produces the most effective broom operation. The series of discrete forward speeds obtained with a set of transmission gears combine with integral numbers of passes over the surface swept to produce distinct levels of effort that can be applied.

Effort as defined here is inversely proportional to the forward speed and directly proportional to the time spent covering a given area. To compare the sweeping effectiveness of different sweepers independent of broom width, a concept of relative effort is defined as

$$RE = \frac{1200 \text{ (FFM)}}{\text{Fwd Speed (FFM)}} \quad (3.1)$$

The 1200-FFM value was chosen arbitrarily so that none of the sweepers had a RE < 1.0 at the fastest speed (3rd gear) tested. Relative effort values for each gear of each machine tested are given in Table 3.3. Unit relative effort corresponds to a forward speed of 1200 FPM and when the broom width of each of the machines is considered, the following theoretical area coverage rates are achieved:

<u>Machine</u>	<u>Broom Width (in.)</u>	<u>Area Coverage Rate (ft²/min)</u>
W450	58	5,800
T100 and T100AB	48	4,800
T100DS	87	8,700

The area coverage rates for unit relative effort are directly calculated for the 1200 FPM forward speed and do not account for the overlap of sweeper passes or the turn around or dump cycle time. As defined RE values are additive.

3.1 COMPARISONS OF MACHINE PERFORMANCES

Using relative effort, as defined in Eq. 3.1, and corresponding residual mass levels, determined by material weight balance techniques or from radiation measurements, Figs. 3.1-3.25 were plotted showing performance comparisons of the four machines tested. Each figure compares the machines for similar test conditions of effort expenditure rate (forward speed), surface type, and fallout characteristics of particle size and initial mass level. The curves drawn are derived from a least-squares straight-line fit of the data. The solid line portion of the curve is the region where the test data was taken. Starting from a minimum amount of effort expended in making a single sweeping pass, it continues to higher effort values determined by the additional passes made over the area. In some figures the curves have been extrapolated beyond the measured effort to permit comparisons between machines.

Each of the four machines tested can be ranked in order of decreasing effectiveness by inspecting Figs. 3.1-3.25. Although there are some variations in ranking among the 25 sets of test conditions, a majority of the sets show the following order of decreasing effectiveness within the operating range of effort values: (1) T100DS; (2) T100AB; (3) T100; and (4) W450.

3.2 EFFECTS OF MACHINE, SURFACE TYPE, AND FALLOUT SIMULANT PARAMETERS

The influence of forward speed, air broom, vacuum system, surface type, initial mass level, and particle size on sweeping effectiveness, determined from the masses remaining at three effort values for each machine, were compared. Realistic effort values were chosen which corresponded to integral numbers of passes at the normal operating speeds of each machine. Three levels of approximately equal effort expenditure were compared: (1) one pass in 3rd gear or highest speed of each machine; (2) one pass in 2nd gear or intermediate speed, or two passes in 3rd gear; and (3) one pass in 1st gear or lowest speed, 2 passes in 2nd gear, or 3 passes in 3rd gear. Tables 3.1, 3.2 and 3.3, derived from Figures 3.1-3.25, summarize the mass remaining for the six procedures contributing three levels of effort expenditure. These tables show the influence of machine, surface type, and fallout simulant parameters on sweeping effectiveness.

Inspection of Figs. 3.1-3.25 shows for a majority of tests that effort beyond that shown in Table 3.3 would not significantly increase the effectiveness. Exceptions appear in a few of the T100AB and TLOODS tests on asphalt surfaces which show an extrapolated trend. No further tests were conducted to validate this trend. The low radiation count of the residual mass (0.1 g/ft^2) in most of these cases approached the threshold of detection of the radiation monitoring instrument. In a real fallout situation, 0.1 g/ft^2 produces a standard intensity of 3 r/hr at 1 hr if the mass contour ratio of $0.030 \text{ g/ft}^2/\text{r/hr}$ at 1 hr from the model⁵ is correct.

Forward speed of all machines tested, being inversely proportional to effort as defined in Eq. 3.1, had an important effect on sweeping effectiveness. Higher sweeping effectiveness was achieved at faster forward speeds for equivalent effort except at the highest initial-mass levels. This indicates that the majority of fallout conditions simulated did not overload the sweepers and that the optimum rate of effort expenditure for effective sweeping was achieved when the fastest forward speed was used. Figure 3.26 shows a typical relationship between forward speed and sweeping effectiveness.

The consistency in forward speed of all machines tested is indicated in Table 3.4. The forward speeds of each machine measured for each pass were uniform because of governed engine speeds. However, comparable gears in different machines provided different forward speeds which were compensated for by comparing the sweeping effectiveness on a relative effort basis.

Certain combinations of machine and environmental conditions limit the use of maximum forward speed for optimum performance. The Tennant machines have their main brooms mounted in fixed bearings and the tendency of the machines to bounce at high speeds over undulations in the pavement surfaces leaves unswept areas. The bouncing also breaks the vacuum seal enclosing the broom. This reduces the desirable dust control capability built into the machines.

Other factors that limited the use of maximum forward speed were the size, weight, and maneuverability of the machine in relation to the configuration of the area swept.

The vacuum dust control systems on the Tennant machines were effective in minimizing the re-deposition of airborne particles on swept surfaces. The airflow created by the vacuum system purged and entrained many particles from the main broom bristles that would otherwise have been thrown from the brush and re-deposited in the area already swept. This re-depositing process was observed in the operation of the exposed

Figs. 3.1-3.25. Comparisons of Machine Effectiveness Resulting From Various Combinations of Particle Size, Mass Level, Surface Roughness, and Forward Speed

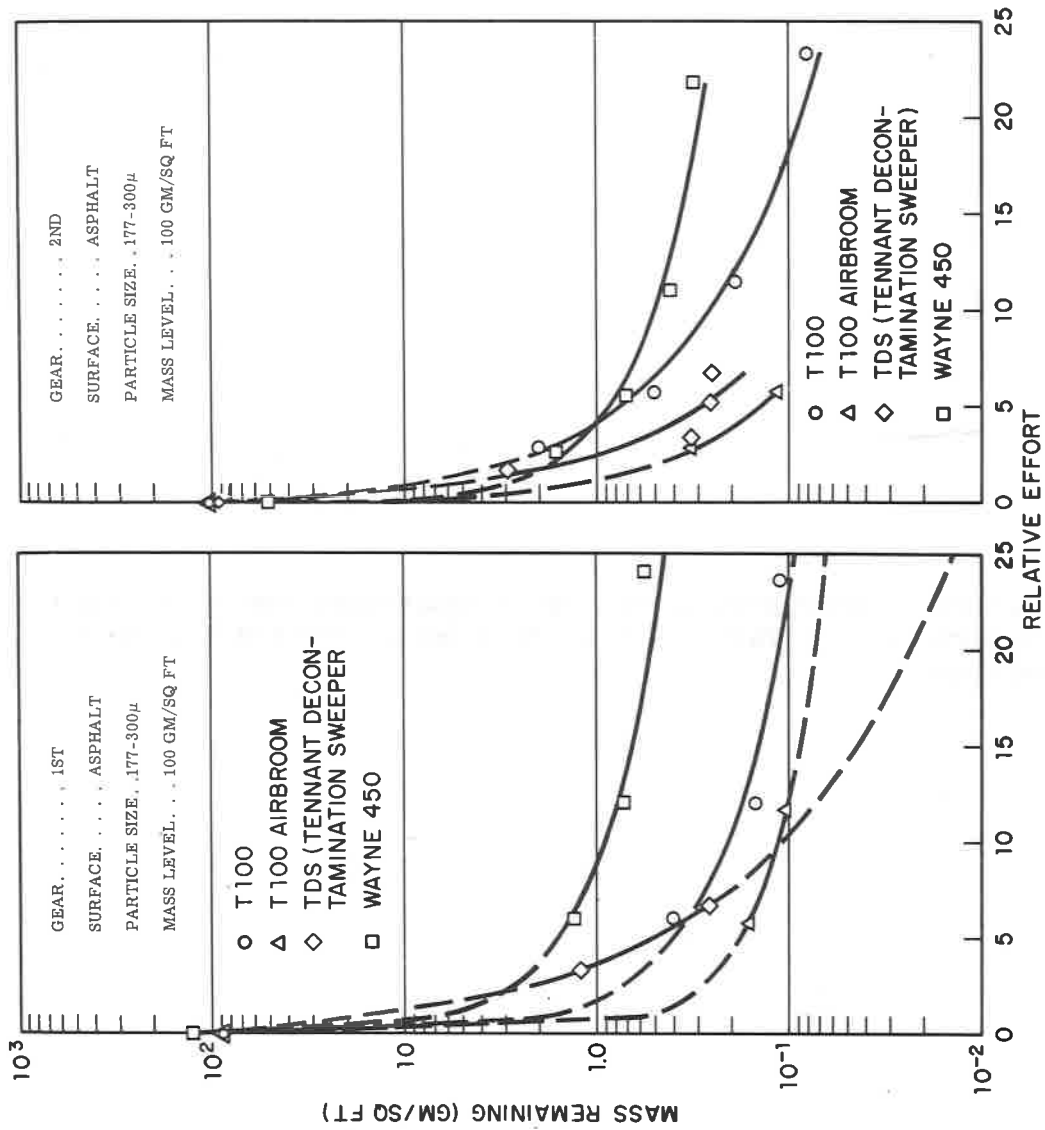


Fig. 3.2

Fig. 3.1

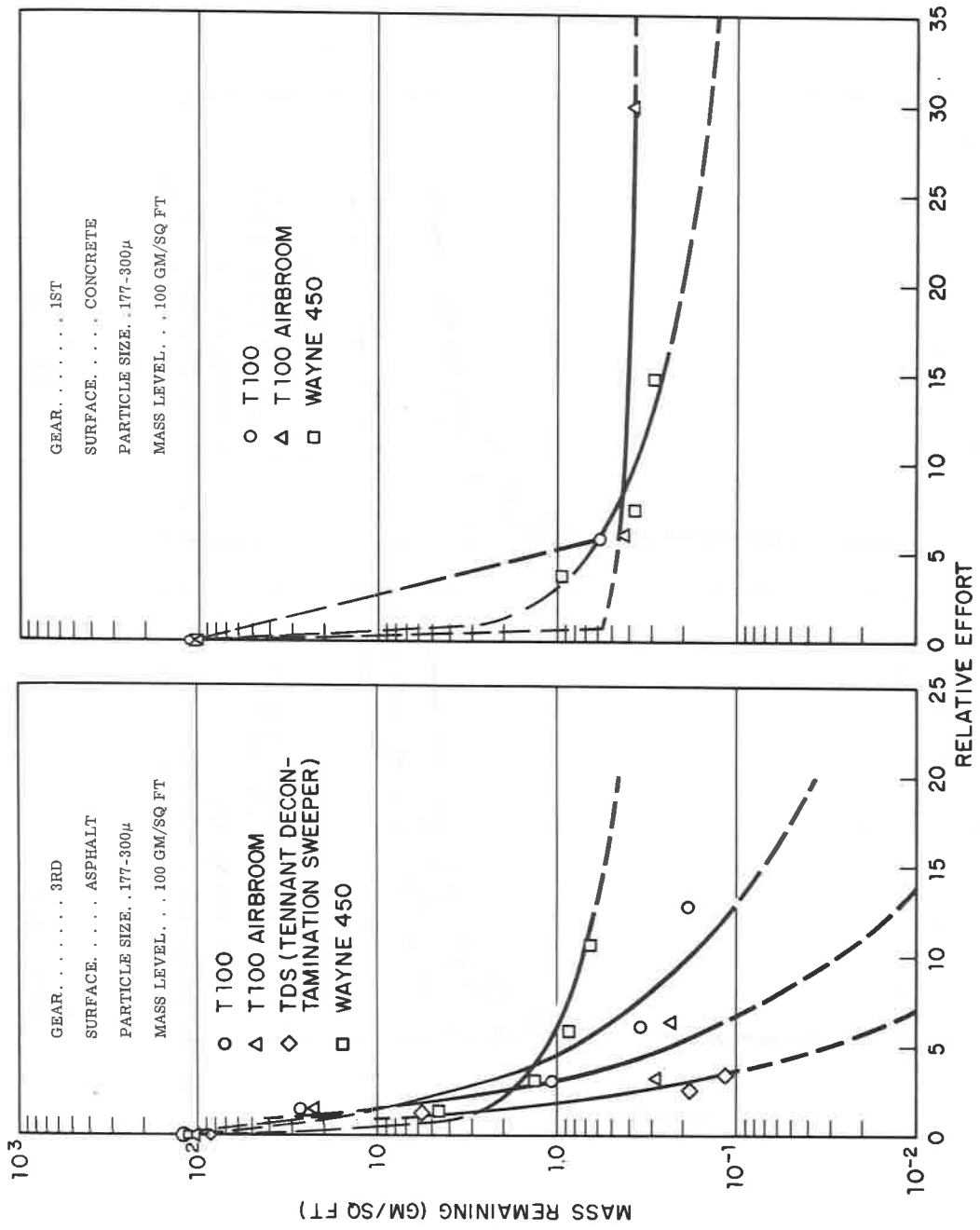


Fig. 3.4

Fig. 3.3

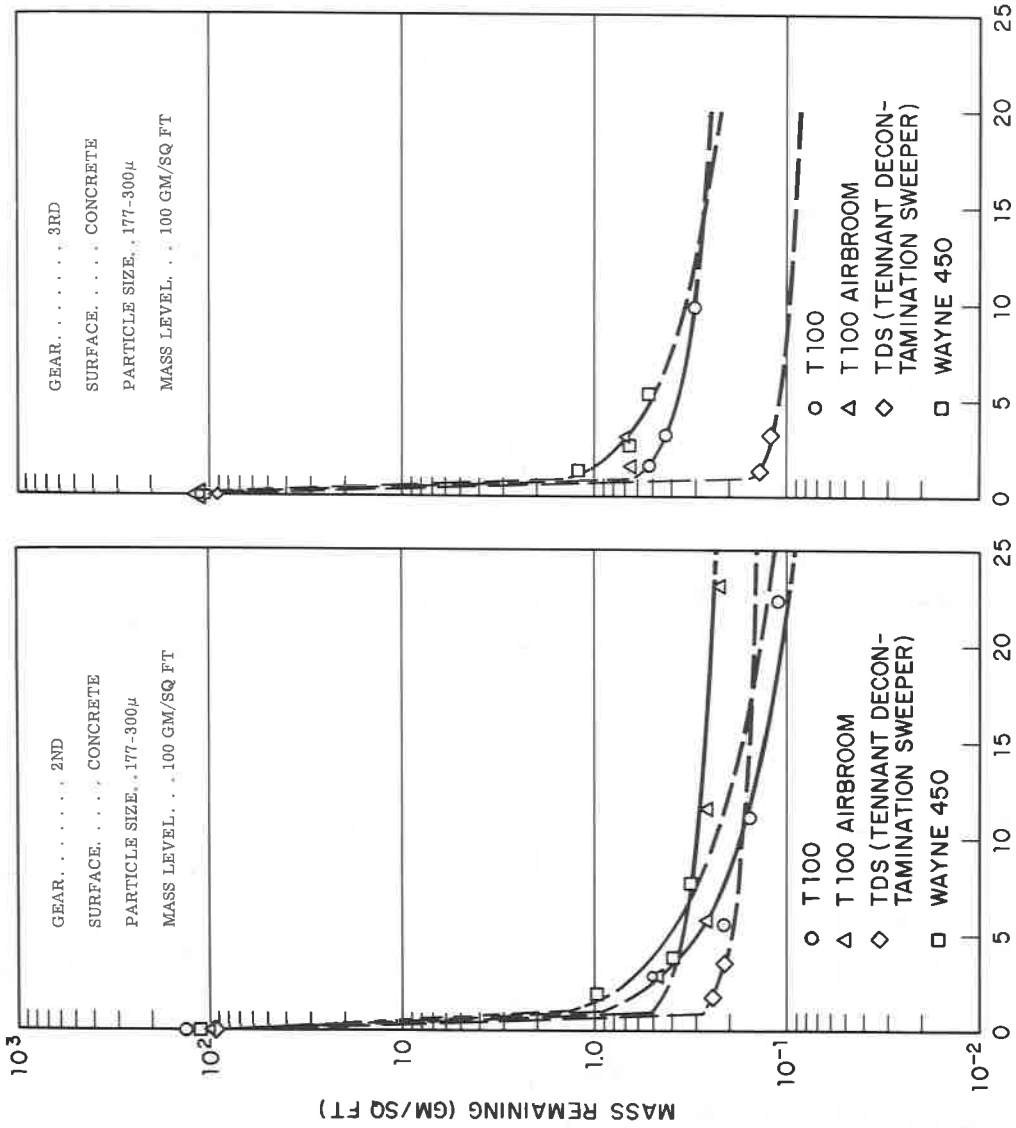


Fig. 3.5

Fig. 3.6

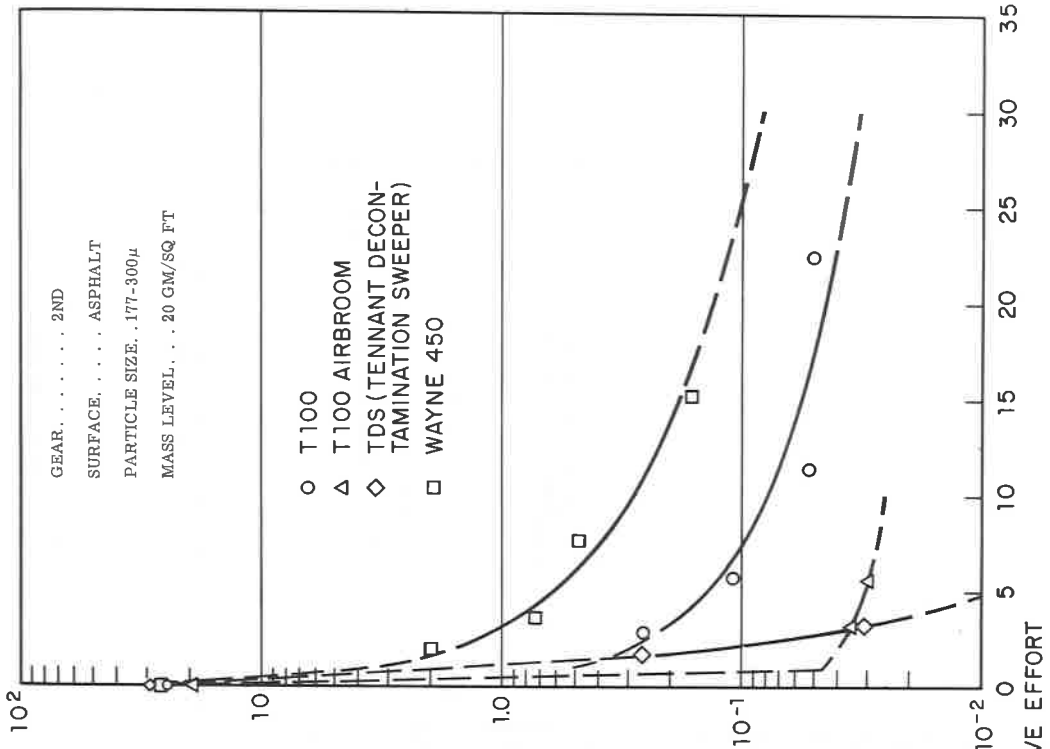


Fig. 3.7

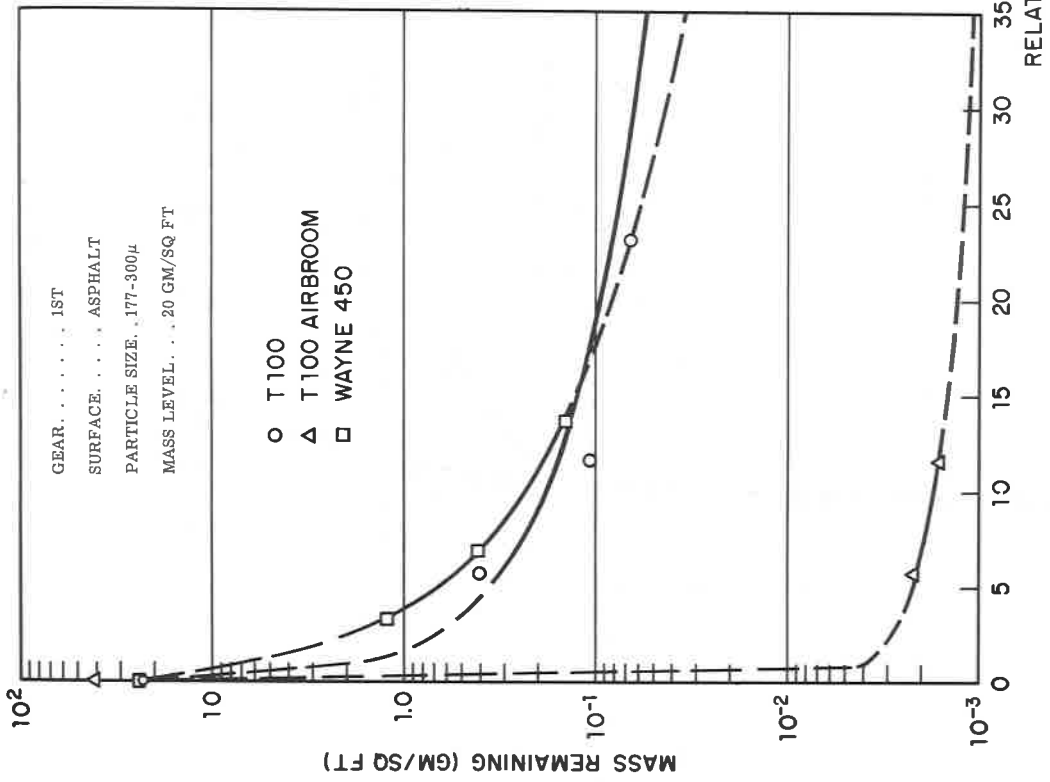


Fig. 3.8

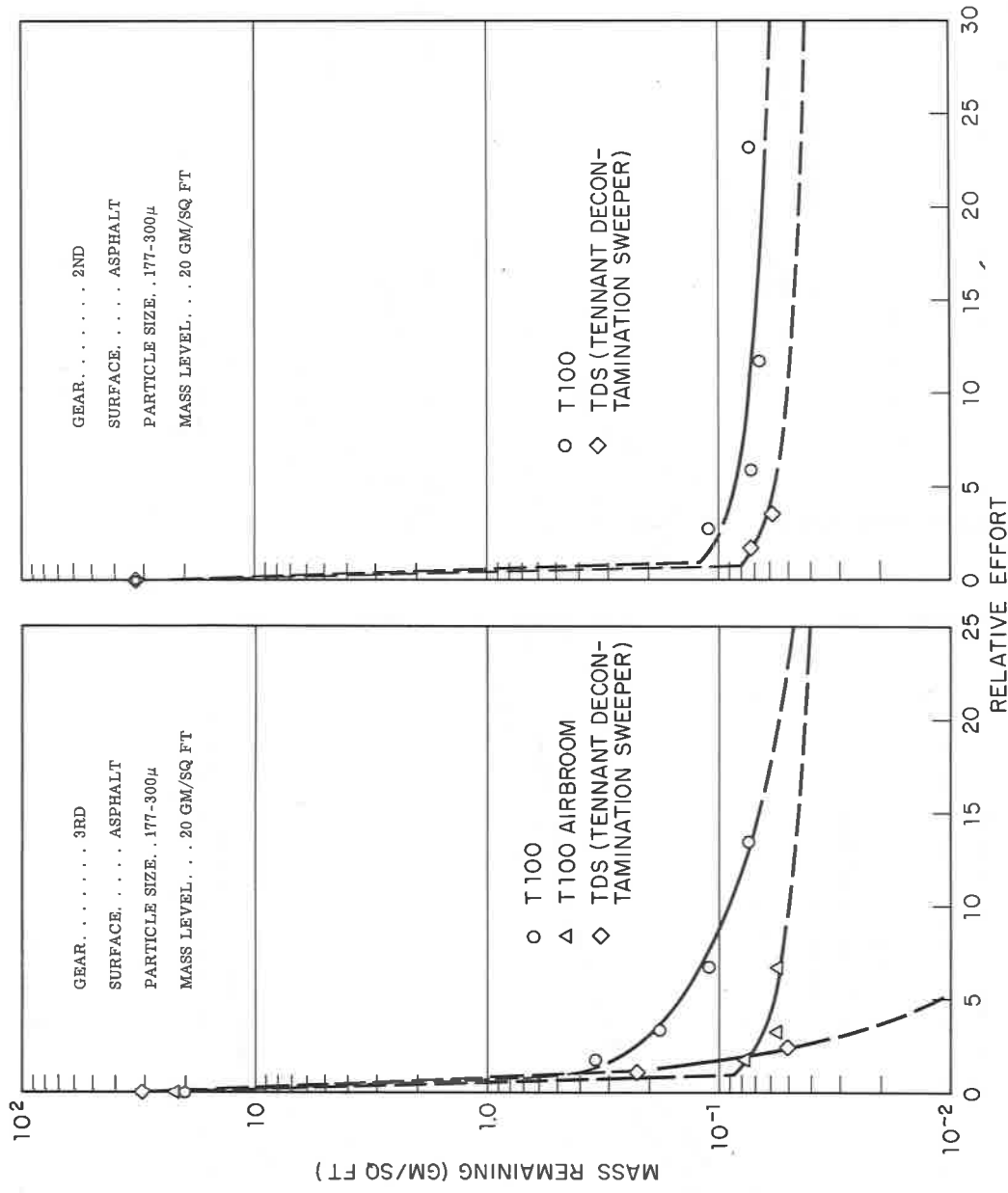


Fig. 3.10

Fig. 3.9

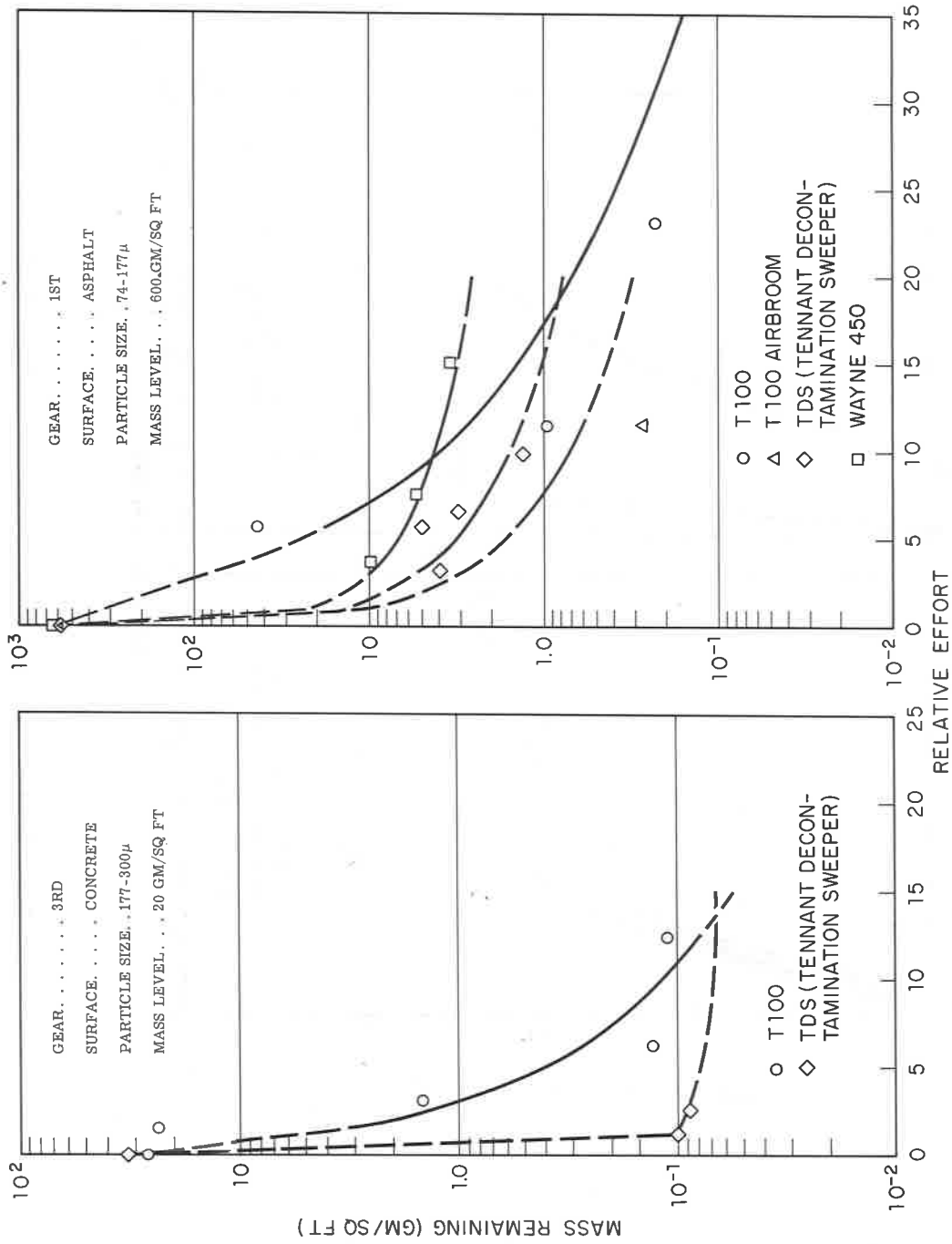


Fig. 3.12

Fig. 3.11

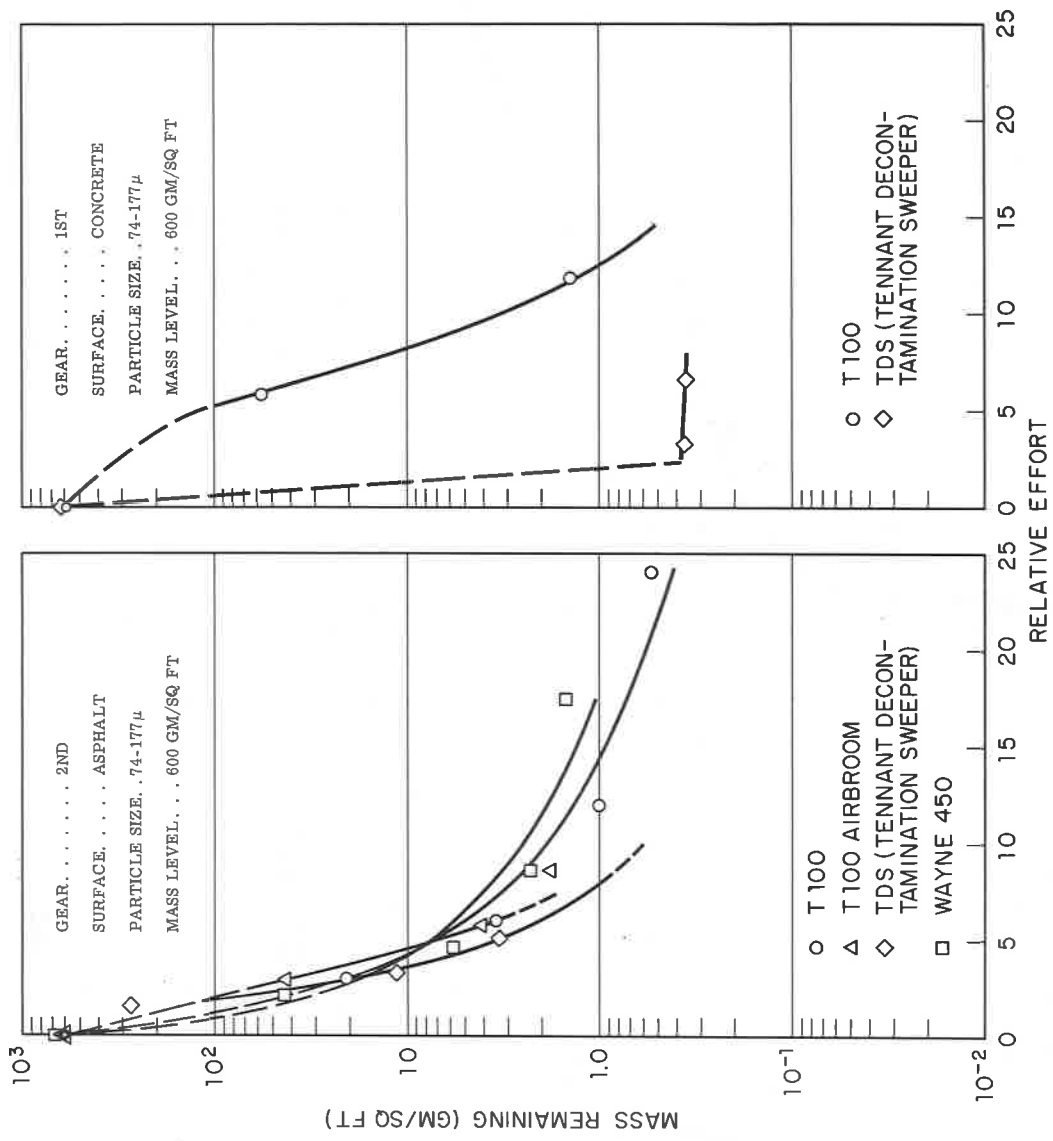


Fig. 3.14

Fig. 3.13

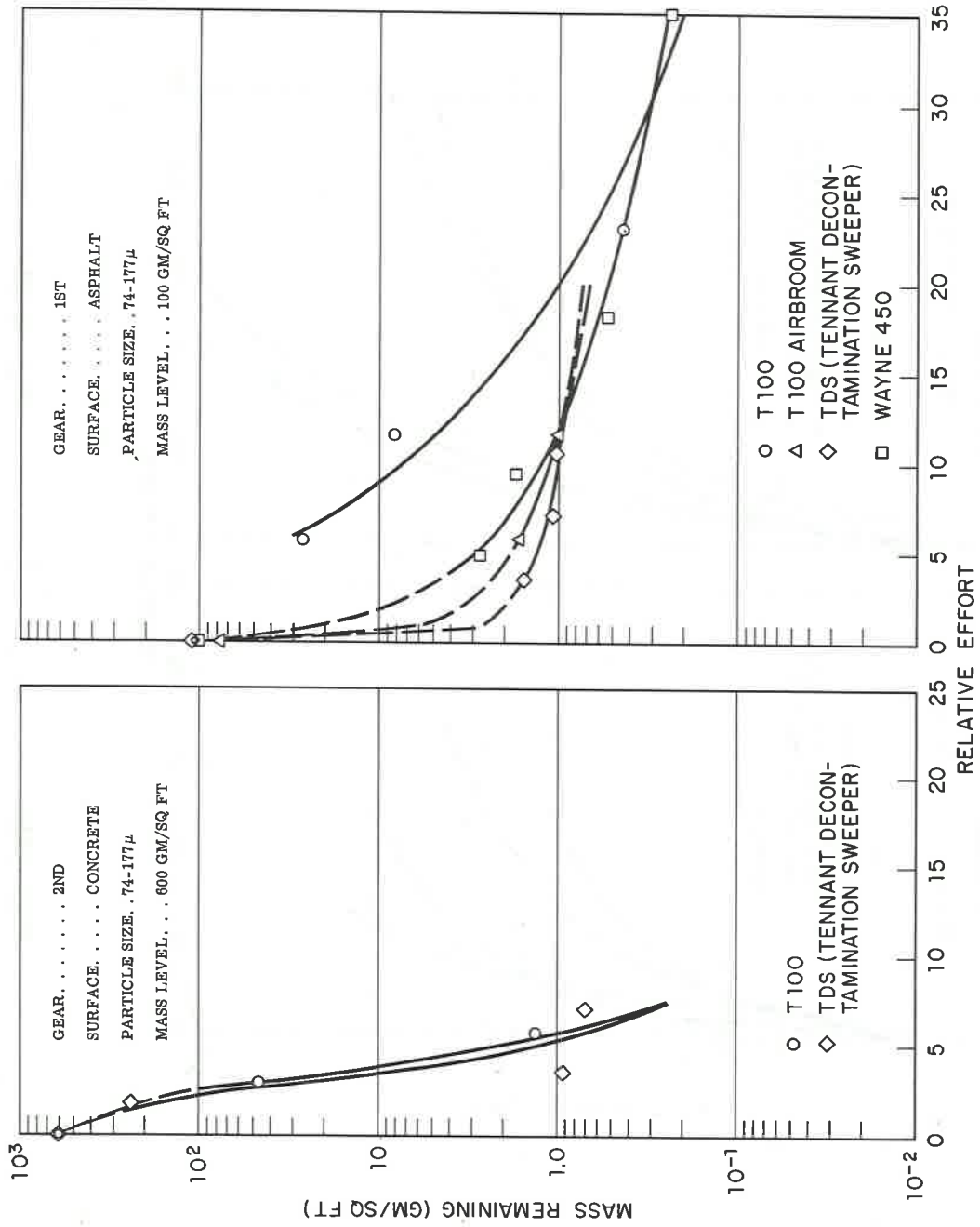


Fig. 3.16

Fig. 3.15

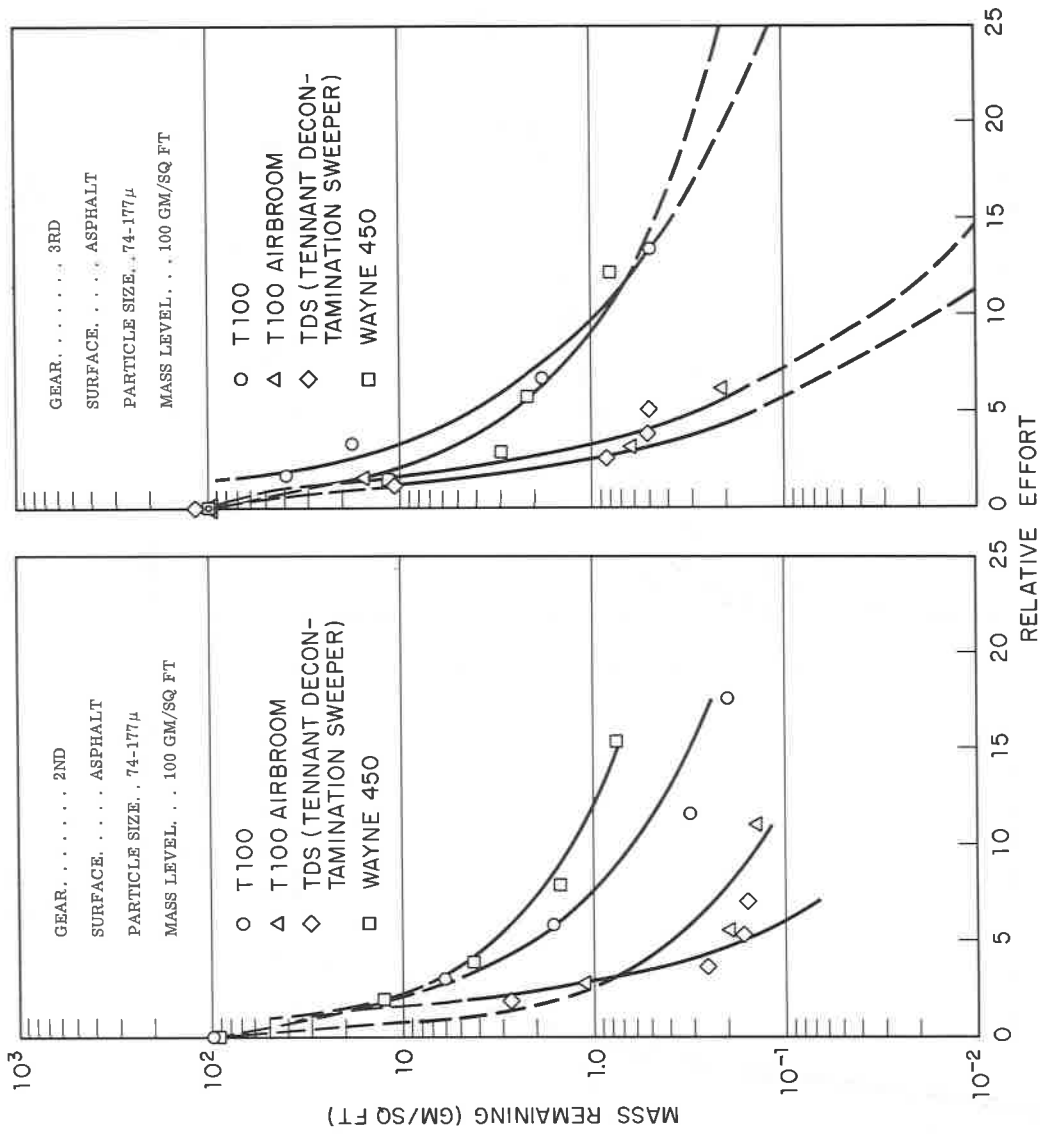


Fig. 3.17

Fig. 3.18

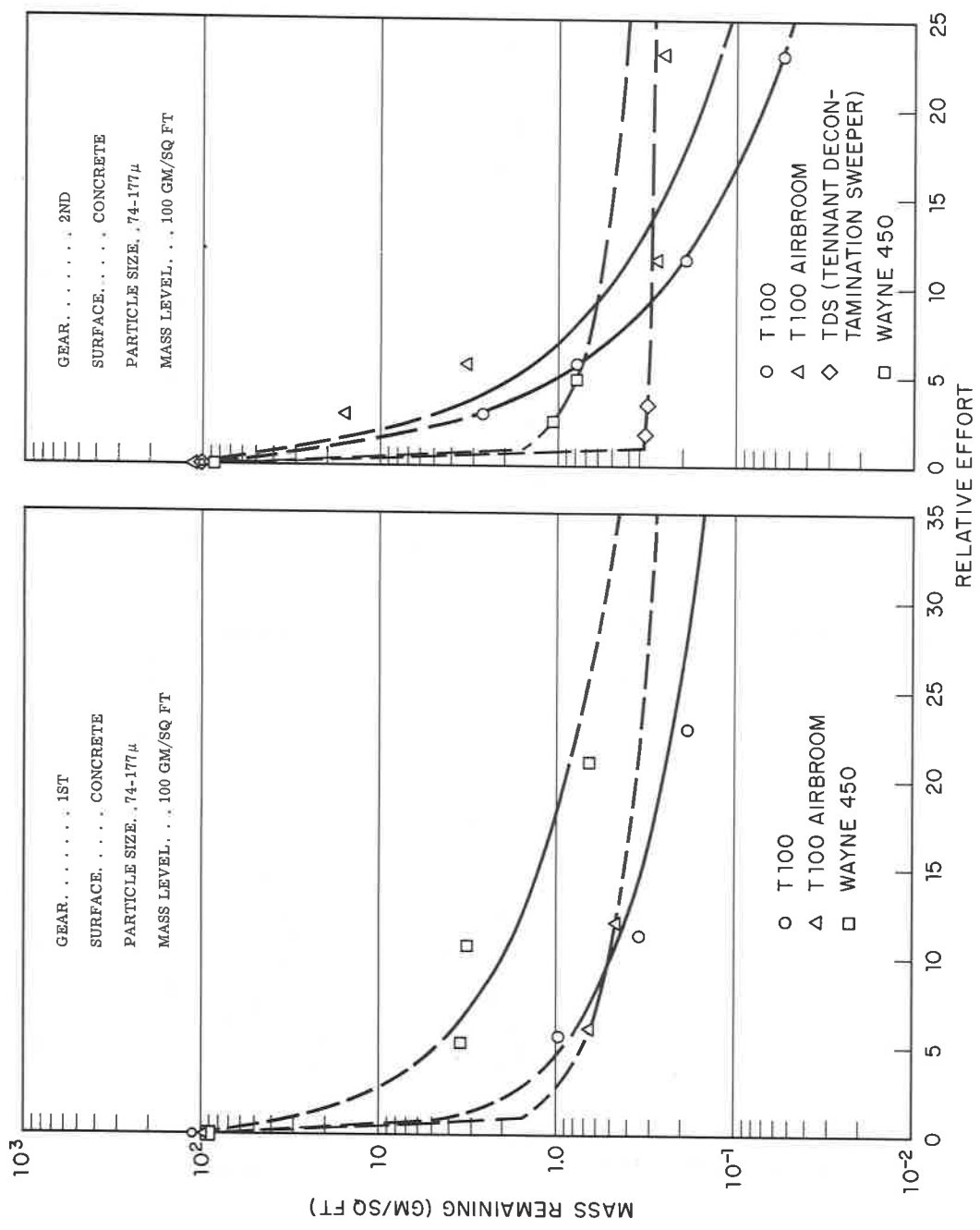


Fig. 3.20

Fig. 3.19

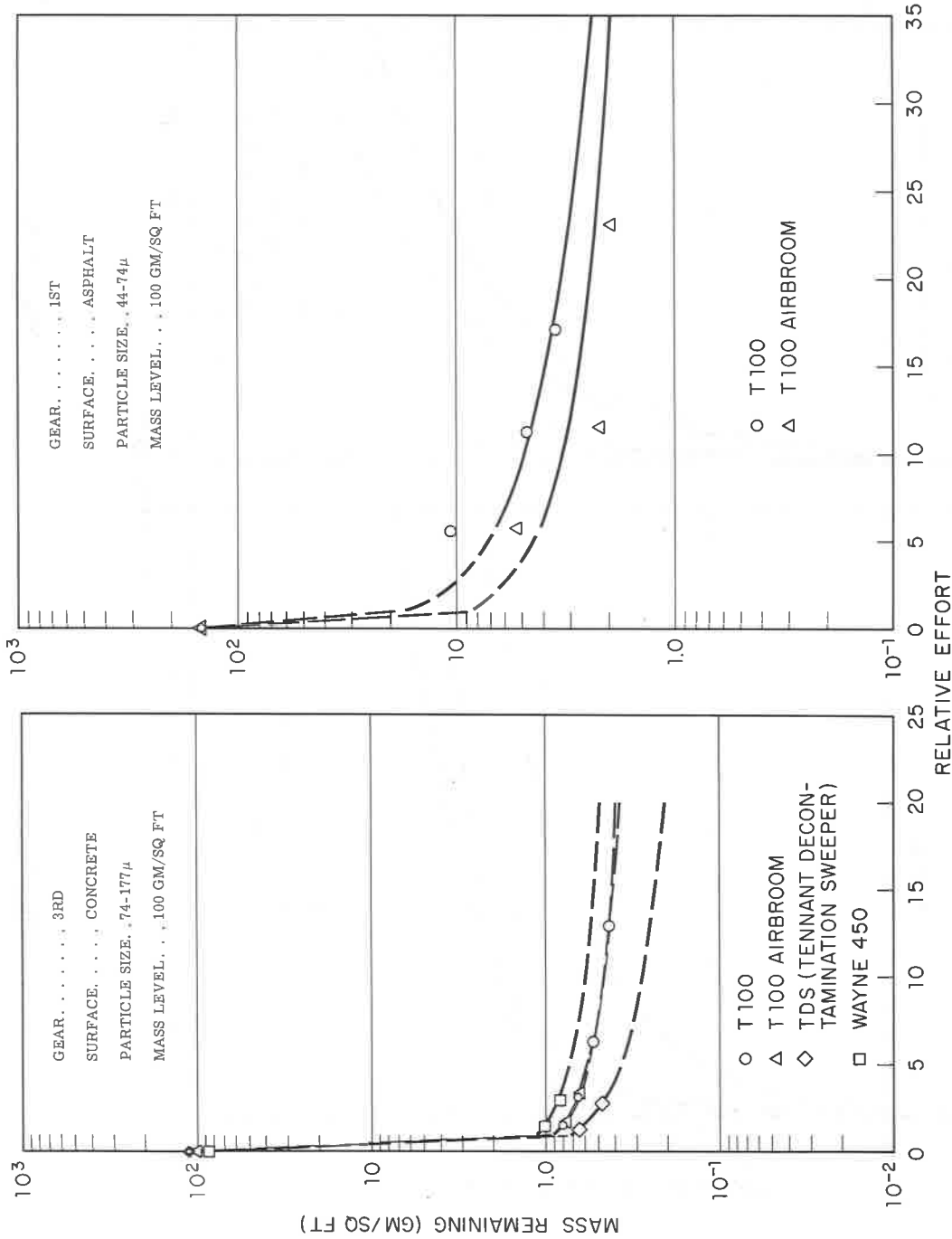


Fig. 3.22

Fig. 3.21

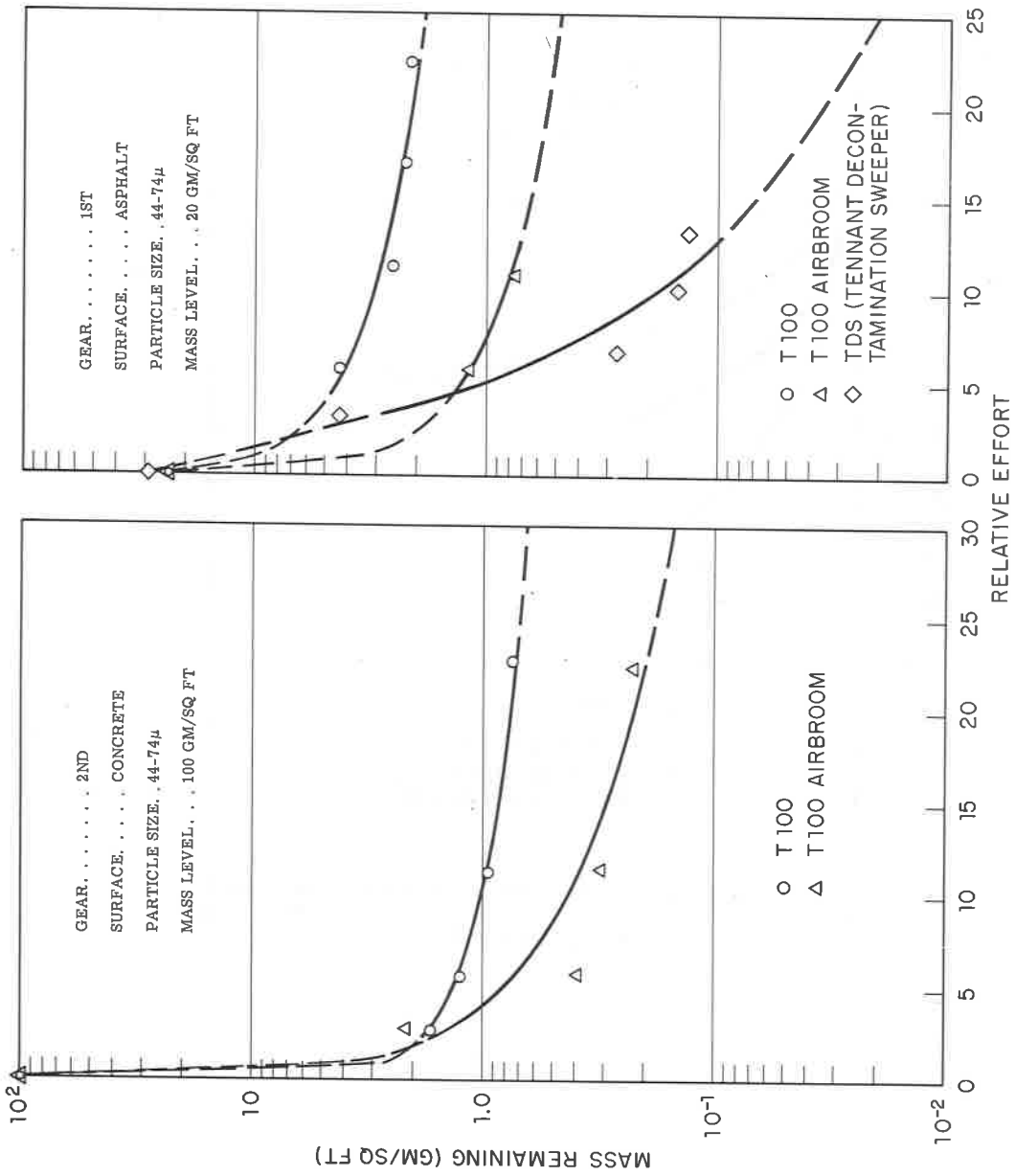


Fig. 3.24

Fig. 3.23

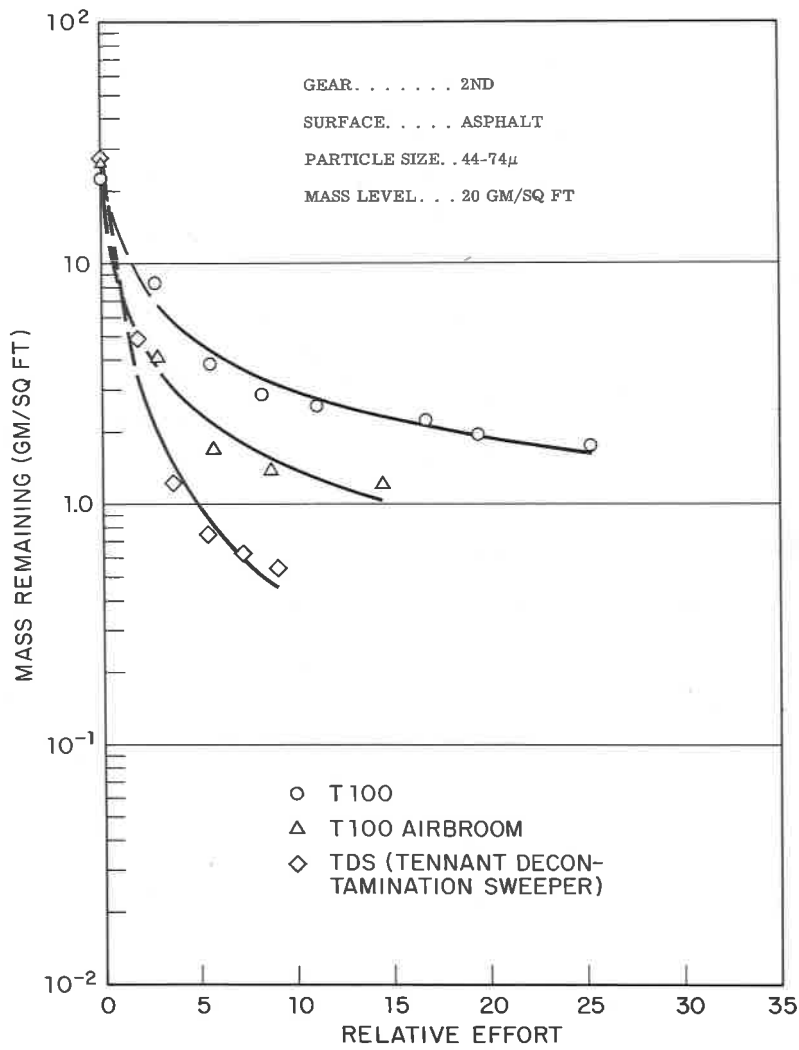


Fig. 3.25

TABLE 3.3
 Mass Remaining (g/ft^2) for High Equivalent Effort With Each Machine, for 1 Pass
 3 Passes in 3rd Gear

Machine	Gear	Relative Effort	20 g/ft^2		30 g/ft^2		60 g/ft^2		11-74 μ Asp. Conc.
			11-74 μ Asp. Conc.	177-300 μ Asp. Conc.	177-300 μ Asp.	300-500 μ Asp.	300-500 μ Asp.	200-400 μ Asp.	
W 450	1	4.32	-	0.85	0.88	-	-	-	-
	2	4.34	-	0.72	-	-	-	-	-
	3	4.17	-	-	-	-	-	-	-
T 100	1	5.83	4.0	0.30	-	-	-	-	6.5
	2	5.76	4.3	0.37	0.08	0.20	2.4	1.9	0.15
	3	4.89	-	0.30	0.43	0.02	1.5	-	0.22
T 100AB	1	5.83	2.1	.002	-	-	-	-	4.1
	2	5.76	1.2	0.03	0.04	-	-	-	6.0
	3	4.89	-	0.06	-	-	-	-	-
T 100DS	1	3.33	2.6	0.16	-	-	-	-	-
	2	3.46	1.6	0.03	0.06	-	-	-	-
	3	4.29	-	0.02	0.08	-	-	-	-

In 1st Gear, 2 Passes in 2nd Gear, or

	74-177 μ		177-300 μ		250 g/ft ² 750-1000 μ		400 g/ft ² 750-1000 μ		600 g/ft ² 74-177 μ	
	Asph. Conc.	Asph. Conc.	Asph. Conc.	Asph. Conc.	Asph. Conc.	Asph. Conc.	Asph. Conc.	Asph. Conc.	Asph. Conc.	Asph. Conc.
3.5 ✓	5.7	1.8 ✓	0.74	-	-	-	-	-	7.7	-1.2%
9.1	0.84	0.98	0.45	-	-	-	-	-	9.3	-1.5%
4.0		1.7								
3.4	0.75	1.3	0.55	-	-	-	-	-	-	-
3.6 ✓	0.78	1.3 ✓	0.34	9.1	-	0.36	-	17	60	
1.7	0.73	0.93	0.26	-	2.3	2.8	-	5.0	1.2	
		0.59	0.25			56.0				
4.5.	0.57	1.5	0.68	10.5	2.2	11.0	0.12	-	-	
		0.90	0.35							
1.8	0.66	0.17	0.45	-	-	-	-	1.4	-	
		0.04								
0.32	1.4	1.1	0.36	-	-	-	-	4.6	-	
	0.38	0.11								
0.31	0.57	0.29	0.74	-	-	-	-	-	-	
1.6	-	1.3	-	-	-	-	-	4.2	0.38	
7.5										
0.62	0.32	0.58	0.21	-	-	-	-	18	84	
								18.49		
0.23	0.39	0.06	0.11	-	-	-	-	-	-	

TABLE 3.1

Mass Remaining (g/ft^2) for Minimum Equivalent Effort with Each Machine

Machine	Gear	Relative Effort	20 g/ft^2		30 g/ft^2		60 g/ft^2		100 g/ft^2	
			177-300 μ Asp.	300-500 μ Conc.	177-300 μ Asp.	300-500 μ Asp.	200-400 μ Asp.	74-177 μ Asp.	100 g/ft^2 Conc.	177 Asp
W450	3	1.39	-	-	-	-	-	-	-	-
T100	3	1.63	1.4	3.2	0.27	2.8	17	19	1.0	2.8
			0.31	-	-	-	-	54	0.78	18
T100AB	3	1.63	0.08	-	-	-	-	-	9.5	0.77
T100DS	3	1.28	0.19	0.10	-	-	-	-	8.0	0.65
									12	9.5
									4.2	4.2

TABLE 3.2

Mass Remaining (g/ft^2) for Intermediate Equivalent with Each Machine, for 1

Machine	Gear	Relative Effort	20 g/ft^2		30 g/ft^2		60 g/ft^2		100 g/ft^2	
			44-77 μ Asp.	177-300 μ Asp. Conc.	177-300 μ Asp.	300-500 μ Asp.	300-500 μ Asp.	200-400 μ Asp.	44-74 μ Asp.	100 Conc.
W450	2	2.17	-	1.5	-	-	-	-	-	-
	3	2.78	-	-	-	-	-	-	-	-
T100	2	2.88	6.7	1.0	0.10	0.06	3.2	3.4	0.67	1.6
	3	3.26	-	0.53	0.92	-	1.8	3.5	0.56	-
T100AB	2	2.88	1.8	0.19	-	-	-	-	-	9.5
	3	-	0.06	-	-	-	-	-	-	-
T100DS	2	1.73	3.9	0.23	0.07	-	-	-	-	-
	3	2.56	-	0.04	0.09	-	-	-	-	-

Rate, for One Pass in 3rd Gear

g/ft ²	250 g/ft ² 750-1000μ	400 g/ft ² 750-1000μ	600 g/ft ² 74-177μ
Conc.	Asph.	Asph.	Asph.
1.1	110	22	73
1.8			330
0.52			0.52
0.14			0.66

Rate, for Two Passes in 2nd Gear or 2 Passes in 3rd Gear

g/ft ²	250 g/ft ² 750-1000 μ	400 g/ft ² 750-1000μ	600 g/ft ² 74-177μ
Conc.	Asph.	Asph.	Asph.
1.1	1.7	0.75	1.7
1.8	2.4	0.71	2.4
0.84	1.7	0.71	1.7
2.7	62	0.43	17
1.8	1.8	0.25	150
3.7	3.7	0.99	48
2.4	2.4	0.43	0.20
4.8	11	0.39	47
0.35	0.32	0.70	150
0.64	1.0	0.24	72
0.33	2.3	0.12	400
0.48	0.38	0.12	400

TABLE 3.4

Average Sweeping Speeds During Evaluation Studies

	T100 and T100AB			W450			T100DS		
	Gear:	1st	2nd	3rd	1st	2nd	3rd	1st	2nd
Number of Passes	118	163	110	41	54	22	25	32	15
Avg Speed (ft/min)	206 2.3	417 4.7	738 8.3	278 3.1	553 6.2	882 9.8	360 4.1	694 7.4	937 10.6
Std. Deviation	8	17	27	53	90	98	24	27	14
% Std. Deviation	3.9	4.1	3.7	19.1	16.3	11.4	6.7	3.9	1.5

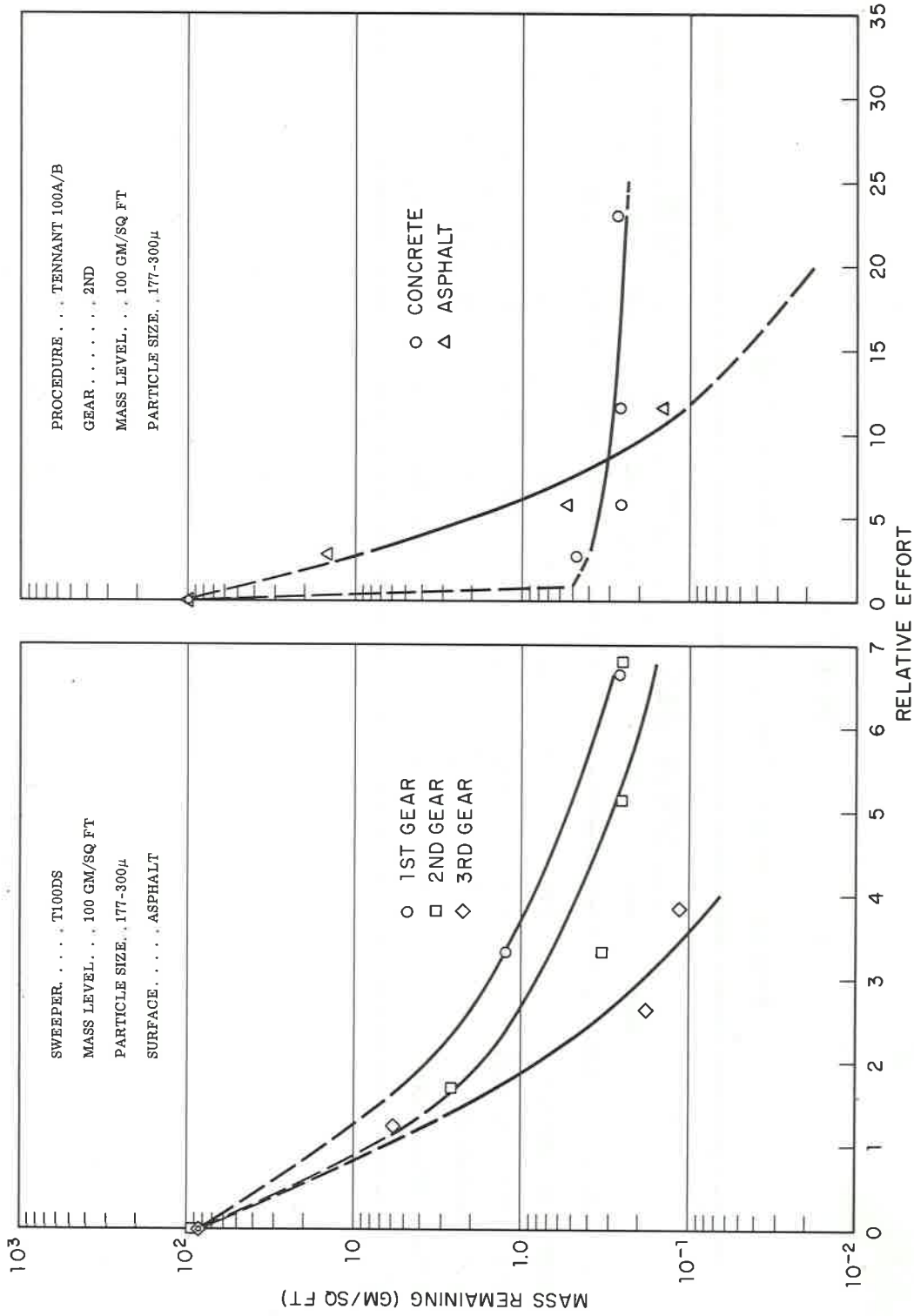


Fig. 3.27 Example of the Effect of Concrete Cracks on Sweeping Effectiveness

Fig. 3.26 Example of the Effect of Speed on Vacuumized Sweeping

brush of the W450 machine, wherein the lack of vacuum dust control accounted for its generally lower sweeping effectiveness of small particles.

Sixteen figures among Figs. 3.1-3.25 permit direct comparison of sweeping effectiveness with and without dust control, as produced with the T100 and W450 machines, respectively. Of these, nine figures indicate greater effectiveness for the T100 at effort expenditures up to the point of diminishing return, presented in Table 3.3. The W450 swept more effectively in the remaining seven tests but was ultimately surpassed by the T100 in six of the tests after extensive effort expenditure. A vacuum dust control system therefore improves sweeping effectiveness and reduces the dust problem associated with sweeping small particles.

The air broom improved the sweeping effectiveness for nearly all the tests by factors ranging between 2 and 20. The influence of the air broom on sweeping effectiveness was determined by comparisons of the T100 machine with and without the improvised air broom. Of the 21 figures in the 3.1-3.25 group which permit direct comparison of sweeping effectiveness between the T100 and T100AB, 17 figures indicate greater effectiveness for the T100AB. The other four figures show better performance for the T100 in tests done on concrete surfaces, indicating that the air broom improved the sweeping effectiveness most on the rougher asphalt surfaces. The air broom was also effective on localized roughness such as form lines and surface cracks in concrete.

Surface roughness was the environmental characteristic that had the most effect on sweeping effectiveness. Concrete surfaces were smoother and more easily cleaned than asphalt surfaces, although irregularities such as form lines and cracks presented severe localized cleaning problems. These cracks and form lines retained enough fallout simulant to significantly affect the minimum average residual-mass level that could be achieved at reasonable effort. The performance curve for a concrete surface in Fig. 3.27 shows a rapid initial-removal rate and a small, relatively irreducible average residual mass level. The problem of cleaning the cracks was investigated in a special series of tests discussed in Section 3.5.

Because of the cracks, the asphalt surfaces tested had a greater but more regular roughness than concrete. This surface characteristic made the rate of mass removal slower than for concrete, but lower average residual-mass levels could be achieved at extended effort values, as observed in Fig. 3.27. A considerable variation in surface roughness existed among the several asphalt surfaces tested. This varied from a newly paved area, quite smooth, but having small, sharp depressions which trapped the small fallout simulant used, to a less smooth weathered

street pavements that were more easily swept. These differences in roughness of the same type of surface influenced the sweeping effectiveness of all machines tested. The difficulty of defining surface roughness limits the extrapolation of the test results quantitatively to surfaces other than those tested.

Higher initial-mass levels in nearly all cases required more effort to reach a given residual mass level. The highest mass levels tested were beyond the normal sweeping capability of any of the machines and so overloaded the broom that much of the material was either not picked up or not retained in the broom bristles and was redeposited in the swept area. In the T100AB and T100DS machines, the air broom-vacuum system combination purged most of the material from the broom so that it was not redeposited. This accounts for the higher effectiveness of the T100AB and T100DS for the same expenditure of effort at high initial-mass levels. Figures 3.28 and 3.28a show the influence of initial mass on sweeping effectiveness.

The effect of particle size on all simulated fallout environments tested was that small particles were more difficult to remove than large particles. Figure 3.29 shows influence of particle size on sweeping effectiveness. The removal rate was slower and the residual mass for equal effort expenditure was higher. Small particle sizes reduced sweeping effectiveness more on asphalt than on concrete. The smallest particle sizes tested (44-74 μ) were an order of magnitude more difficult to remove than any of the larger particle sizes tested. This difficulty may not be as serious as it appears from these data because in a real fallout situation smaller particle sizes are associated with lower radiation intensities.

3.3 EVALUATION OF MACHINE OPERATING FEATURES

Basically, each of the machines had the capability to travel at several speeds, sweep the area traversed, store the swept material, and dump the stored material at some point remote from the area swept. All machines had certain design features in common, intended to achieve these basic capabilities. Although all the machines had the same basic capabilities, their effectiveness as a decontamination procedure was markedly influenced by certain detailed design differences.

The principal advantage of the W450 machine is its floating broom which permits it to easily negotiate uneven pavements while maintaining its sweeping effectiveness. Its rugged design and good road clearance enables it to travel at high speed (15-20 mph), when it is not sweeping,

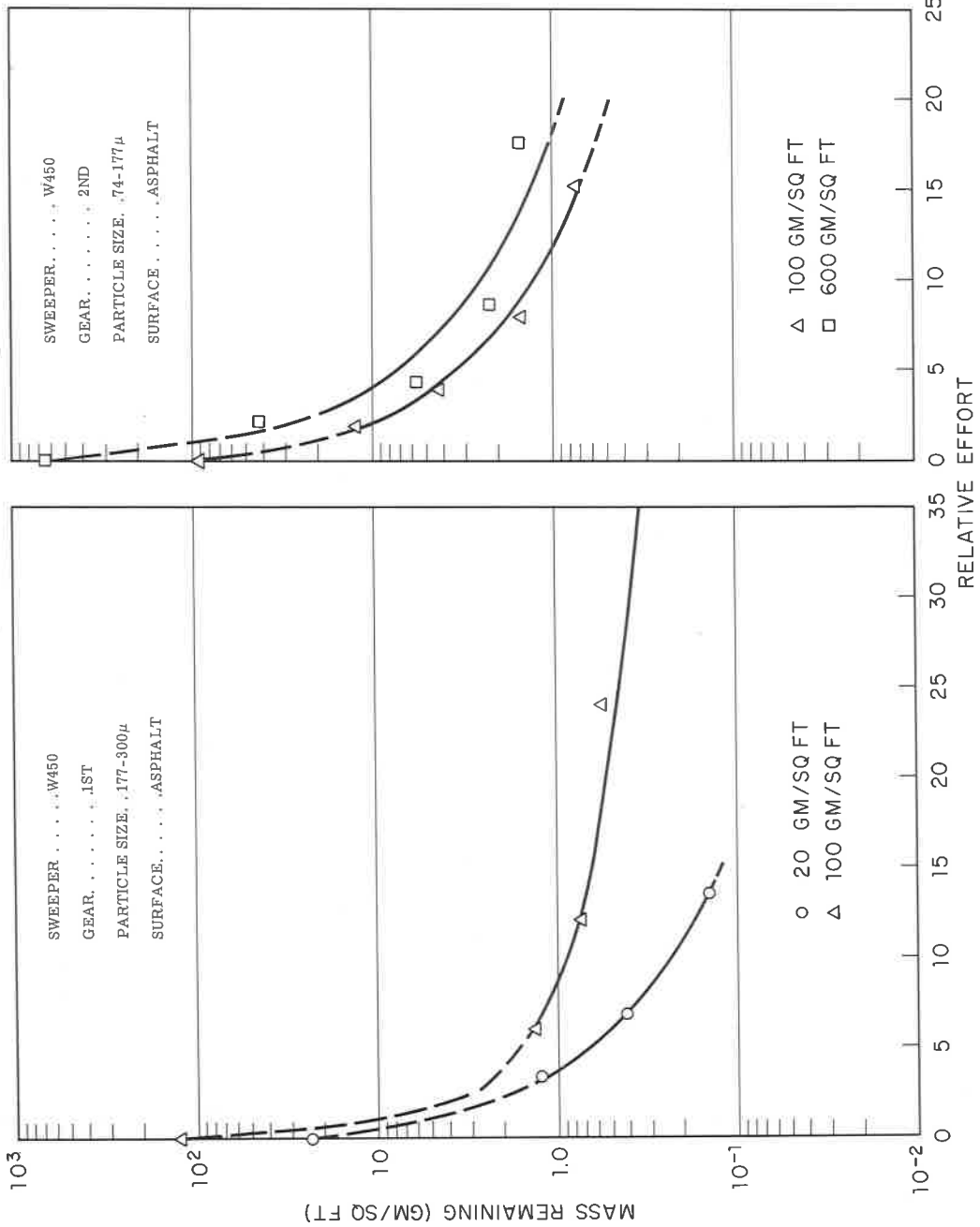


Fig. 3.28a Example of the Effect of Mass Loading on Motorized Sweeping

Fig. 3.28 Example of the Effect of Mass Loading on Motorized Sweeping

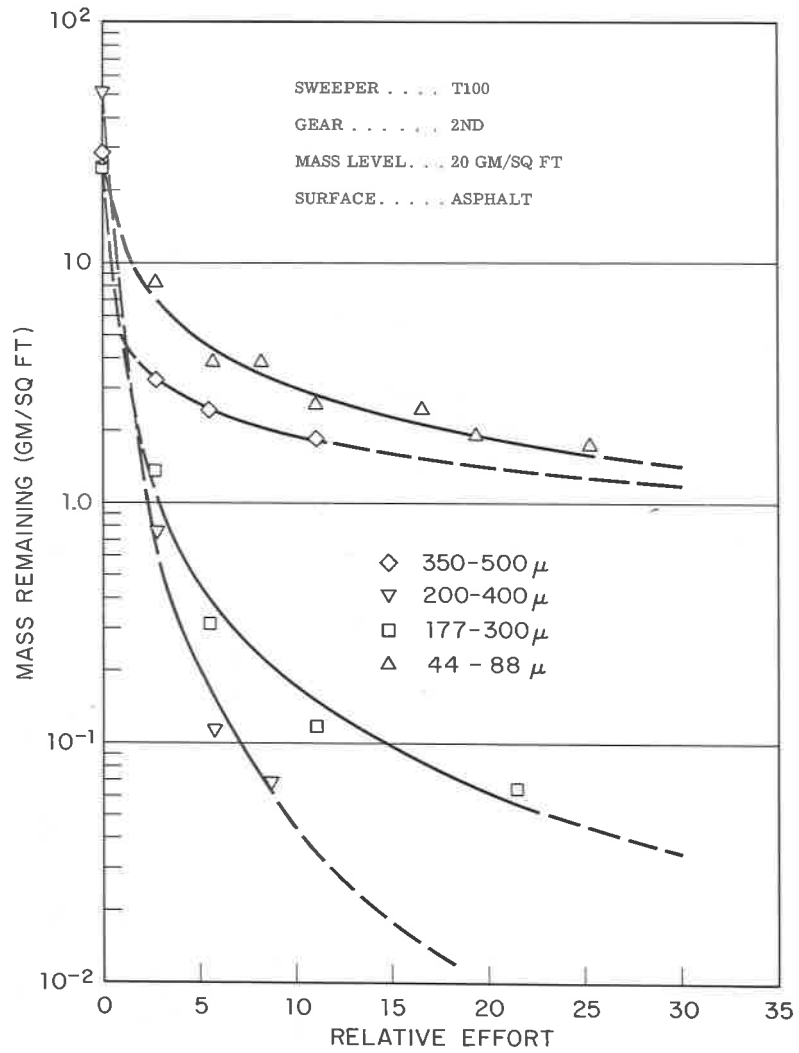


Fig. 3.29 Example of the Effect of Particle Size on Vacuumized Sweeping

over bumps, dips and railroad tracks found in the average city street. This high travel speed could be an advantage, operationally, if the dump area is far removed from the swept area.

The disadvantages of using the W450 in a decontamination procedure are due chiefly to design based on different performance criteria. The sand fallout simulant leaks through the gaps in the storage hopper, which is designed to retain trash and leaves. The loss by leakage is minimized by the material being reswept because the hopper is in front of the main broom. The water spray dust control system, adequate in its usual application, is not suitable for fallout removal.

An important feature of the T100 is the vacuum dust control system which works well for the smallest-sized simulant used. The moderate size and weight of this machine suits it well for maneuvering in areas the size of city streets.

The most undesirable operating characteristic of this machine is its tendency to bounce in 3rd gear (10.6 mph) over undulations in the pavement. The bouncing, due in part to the short wheel base, allows the rigidly mounted main broom and rubber skirt vacuum seals to leave the pavement. This break in broom contact with the surface leaves patches of unswept surface. The small road clearance discourages 3rd or 4th gear travel except on extremely smooth surfaces.

The improvised air broom tends to improve the T100 performance so that it compares favorably with the T100DS, a machine specifically designed for decontamination. Most of the undesirable operating features of the T100AB are the same as the T100. However, the improvised air broom severely limits the travel speed because of its limited road clearance when combined with the tendency of the machine to bounce. This limitation would not exist if a design similar to the T100DS were used with the air supply included as an integral unit of the machine.

The advantages of the T100DS are the specific features incorporated in its design as a decontamination procedure. These features were high forward speed, a wide broom for rapid coverage of large areas, a vacuum system for dust control, and the air broom to scour the pavement and suspend fine particle for capture in the vacuum system air stream.

Aside from a few mechanical troubles inherent in any experimental machine, the T100DS is well suited for the purpose for which it was designed: cleaning extensive areas where its large size and weight do not limit its usefulness.

3.4 EFFECT OF CONCRETE CRACKS ON SWEEPING EFFECTIVENESS

A series of special tests were conducted to specifically measure the retention of fallout material trapped in form cracks. Data for these special tests are shown in Tables B-6 and B-7, Appendix B. These contamination build-up histories show that significant amounts of material do accumulate in the cracks, while the smooth areas are being swept clean. This accumulation limits the minimum achievable radiation dose-rate at reasonable effort values. Figure 3.27 shows a comparison of sweeping effectiveness of an asphalt surface and a concrete surface using typical values of fallout environment parameters. The large cracks found in the concrete strip account for the inability to reach M^* values as low as those found for asphalt.

The concrete surface residual mass is more easily reduced to a certain level, after which further reduction is extremely difficult to achieve. The asphalt surface residual mass is reduced more slowly, initially, but reaches no plateau like that exhibited by the concrete for effort levels used here.

The difficulties presented by cracks and similar discontinuities in surfaces indicate that decontamination of cracked surfaces by sweeping should be carefully planned. Traversing of cracks should be avoided if possible by sweeping parallel to them until most of the area has been swept. This will avoid filling them with material pushed from the surrounding areas.

3.5 EXPERIMENTAL ERROR

The results of repeated tests in Tables 3.1, 3.2 and 3.3 reveal variations as high as a factor of 10 orders of magnitude between supposedly identical tests. These variations could be due to changes in either machine or environmental conditions during the time interval of several months between tests. Inconsistency of machine operation could be due to unsuspected changes in mechanical adjustments since the operating techniques were quite uniform for each set of repeated tests. Wind and moisture content of the synthetic fallout are possible environmental contributions to the inconsistencies.

Errors in test measurements to determine forward speed, initial-mass levels, and residual mass by radiation intensity measurements were much less than those mentioned above. The accuracy of the measurements was $\pm 3\%$ for forward speed, $\pm 5\%$ for initial mass level, and $\pm 15\%$ for the radiation measurements used to determine residual-mass levels.

Some error was introduced into the residual mass level measurements by the non-uniformity of the specific activity of the simulant material. Figure A.1, Appendix A, shows how specific activity increases for the smaller particles within each size group. Thus, a higher residual mass is indicated for small particles, causing them to be more difficult to remove than large particles. Specific activity varies by a factor of 3 within each size range of fallout simulant used, but the factor-of-2-variation in particle size for each range limits the effect of particle size on sweeping effectiveness. The particle size effect is most noticeable when the 44-74 μ size range is compared with the 74-177 μ and 177-350 μ material.

3.6 VERIFICATION OF SWEEPING THEORY

Previous evaluation studies⁴ derived the following equation:

$$M = M^* + (M_0 - M^*) e^{-KE} \quad (3.2)$$

where M is the residual mass after effort expenditure E (g/ft^2)
 M^* is the residual mass at an infinite effort level (g/ft^2)
 M_0 is the initial mass level (g/ft^2)
 e^{-KE} is the fraction of removable mass remaining after expending the effort, E equip-min/ $10^4 ft^2$, and K is proportionality constant

Equation 3.2 was solved for each test, by using data values of M , M_0 , and E and by making successive approximations for M^* and K for a fit through the data points on a M vs E plot.

Of the 133 test runs, only the 43 listed in Table 3.5 provided data which could be fitted to Eq. 3.2 within a factor of 2 of the measured values of the mass remaining. The fit of the equation to the data for each test can be judged by considering the number of data points and the percent variation of computed residual mass from measured residual

TABLE 3.5

Fit of Equation 3.2 to Test Data

Test No.	Test Conditions				Equation 3.2 Parameters			
	Initial Mass M_0 (g/ft ²)	Surface Type	Particle Size (μ)	Gear	No. Data Points	Maximum Variation From Data (%)	$10^4 \frac{K}{ft^2}$ min.	M* (g/ft ²)
<u>Wayne Model 450</u>								
20.4	100	C	74- 177	2	3	< 1	1.30	0.789
20.5	100	C	74- 177	3	3	< 1	2.51	0.820
21.1	20	A	177- 300	1	5	+73	0.446	0.140
23.1	100	A	74- 177	2	4	+55	0.453	0.750
<u>Tennant Model 100</u>								
2.2	250	A	750-1000	2	3	< 1	1.41	< 0.001
2.4	400	A	750-1000	3	4	-64	0.846	2.04
2.5	400	A	750-1000	2	3	< 1	0.612	3.11
2.6	400	A	750-1000	1	2	+ 2	0.615	9.10
3.1	400	A	300- 500	1	2	0	0.890	3.94
4.1	400	A	300- 500	2	3	+ 5	0.645	2.30
5.1	60	A	200- 400	2	4	+37	0.664	0.070
6.3	150	A	200- 400	1	3	< 1	0.418	0.165
7.2	60	A	300- 500	2	3	< 1	0.587	1.84
8.1	30	A	300- 500	2	4	+40	0.399	1.80
8.3	30	A	300- 500	3	4	+58	0.637	0.905
9.2	30	A	177- 300	3	3	+99	1.39	0.048
13.6	20	A	44- 74	2	8	+41	0.154	1.80
13.7	20	A	44- 74	1	5	- 6	0.205	2.20
14.7	100	C	177- 300	3	5	-20	0.420	0.279
14.8	100	A	177- 300	2	5	+36	0.163	0.120
15.1	100	A	74- 177	1	5	+25	0.113	0.088
16.12	100	A	177- 300	3	5	+45	0.477	0.270
22.1	100	A	74- 177	3	5	-37	0.285	0.450
<u>Tennant Model 100AB</u>								
13.4	20	A	44- 74	1	3	< 1	0.325	0.736
13.5	20	A	44- 74	2	5	+20	0.312	1.20
14.9	100	A	177- 300	1	3	+12	0.585	0.110
16.10	100	A	177- 300	2	3	- 8	1.05	0.110
18.1	100	A	74- 177	1	3	+30	0.535	0.100
18.4	100	A	74- 177	3	4	+75	0.719	0.199
18.6	600	A	74- 177	1	3	< 1	0.398	0.244
21.9	100	C	177- 300	3	3	+37	1.96	0.690
22.4	600	A	74- 177	2	3	< 1	0.428	0.925
23.4	100	C	74- 177	3	3	- 7	2.10	0.640
<u>Tennant Model 100DS</u>								
10.1	20	A	177- 300	2	3	+ 2	2.57	0.028
10.2	20	A	177- 300	3	3	< 1	3.71	0.049
10.4	100	A	177- 300	2	5	-19	2.66	0.058
10.8	100	C	177- 300	2	3	- 1	3.91	0.209
10.9	100	A	177- 300	1	3	< 1	1.19	0.250
11.1	100	A	74- 177	2	5	+23	1.65	0.160
11.2	100	A	74- 177	3	5	-23	1.95	0.498
11.4	100	C	74- 177	3	3	- 2	4.35	0.480
11.5	100	A	74- 177	1	4	+64	1.01	1.00
13.1	20	A	44- 74	2	6	+19	0.820	0.537
13.2	20	A	44- 74	1	5	-37	0.631	0.127

NOTES: Surface Types: A = Asphalt
C = Concrete

Gear number indicated is transmission gear used with governed engine speed.
Equation 3.2: $M = M^* + (M_0 - M^*) e^{-KE}$

mass. The best fit is the equation that matches the most data points with the least percent variation from the data. In approximating values for M^* and K it was found that the best fits of the data occurred at $E = 0$ (where $M = M_0$ by definition) and at extended values of effort where M approached M^* asymptotically. The value of K is sensitive to small changes in M at intermediate and low effort values (where the procedures would normally be used). Variations in observed M values in these regions make a computer solution of Eq. 3.2 non-convergent.

The M^* and K values of 43 tests, in which a solution of Eq. 3.2 fits the data within a factor of 2, are shown in Table 3.5. The data is also used for correlation with trends in machine and environmental parameters. A summary of the variations of ultimate residual mass attainable (M^*), and the rate of mass removal (K), with several machine and environmental parameters is in Table 3.6.

From Table 3.5 the variations show that the T100DS, a machine especially designed for decontamination, was best because it had the fastest rate of removal as well as the lowest ultimate residual mass. An accurate ranking of the remaining procedures should not be attempted with the limited number of comparisons possible in Table 3.6.

TABLE 3.6

Variation and Trends of M^* and K with Test Parameters

Parameters	M^*	K
Forward Speed	Directly	Directly
Relative Magnitude for Surface Type	Lower for Asphalt	Higher for Asphalt
Initial Mass Level	Directly	Inversely
Particle Size	Inversely	Directly
Decreasing Magnitude for Machines	1, W450 2, T100AB 3, T100 4, T100DS	1, T100DS 2, T100AB 3, W450 4, T100

Equation 3.3 developed earlier⁴ accounts for variations in initial mass level but assumes an infinite amount of effort expended:

$$M^* = M_0^* (1 + e^{-CM_0}) \quad (3.3)$$

where M^* = residual mass at an infinite effort level, g/ft²
 M_0 = initial mass level (g/ft²)
 M_0^* = the limiting upper value for M^* , a constant for a given
 surface method combination (g/ft²)
 α = spreading coefficient dependent upon the surface-method
 combination and the particle size, and density of the fallout
 material (ft²/g)

Equation 3.3 assumes that rate of effort expenditure has no influence on effectiveness. Ideally, this may be true. The limited number of test results in Tables 3.2 and 3.5 show that M^* increases with forward speed. Because of this variation of M^* with forward speed, no solution for M_0^* and α in Eq. 3.3 could be found. The present data covers a range of forward speeds higher than previously tested. These higher speeds are operationally feasible and will be shown later to be best for attaining the highest effectiveness for a given expenditure of effort. The principal adverse effect of high forward speed on most of the procedures is the loss of effectiveness for certain fallout environments. This is particularly true on the first pass over the test strip that has a high initial mass level, has uneven surfaces, or is contaminated with small particle sizes. Relatively poor performance on the first pass at high speed is usually compensated by successive high speed passes which give a net increase in effectiveness for the same time expenditure. This non-uniform sweeping performance in which the machines are overloaded during the first pass may help to explain the unsatisfactory fit of Eqs. 3.2 and 3.3 to the data. A better fit of the data to the equations might have been achieved if a larger test area had been used or if more radiation measurements had been made along the test strip to get a more representative average of residual mass after sweeping high initial mass levels.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Previously developed theoretical decontamination equations did not fit the data in a majority of the tests conducted. However, instances where the equations matched, these data were consistent with the data from the curve-fitting used for all the tests. The conclusions and recommendations suggested by the test results are presented below.

The effectiveness of the four machines evaluated for dry decontamination of large paved areas was found to be dependent upon the extent of utilization of certain machine design and operating features including: (1) a vacuumized dust control system; (2) an air broom for loosening and removing particles from surface cracks combined with the vacuum dust control system; and (3) high forward speed. These features gave better results for a given effort expenditure.

Limitations were imposed upon sweeping effectiveness by other machine design and operating features. The W450 had a dust control problem because the usual method for dust control was not used. The T100 and T100AB had a tendency to bounce at high speed, causing a loss in sweeping effectiveness by the fixed main broom leaving the surface and by leakage under the vacuum sealing skirts. The physical size and weight of the T100DS was unsuitable for maneuvering in confined areas and required strong paved surfaces to support its weight.

The performance of all four machines was influenced by environmental parameters as follows: (1) rough surfaces were more difficult to clean than smooth surfaces, with localized roughness such as expansion joint cracks especially difficult; (2) high initial mass levels required more effort to achieve the same residual mass levels; (3) small particles were more difficult to remove than large particles.

An ideal machine for dry decontamination of paved areas should have the following features: (1) a vacuum dust control system; (2) an air broom for cleaning cracks and crevices; (3) a floating type main broom, or stability at high speed to maintain broom contact with the surface; (4) good maneuverability and capability to operate on any paved surfaces; and (5) ability to travel over uneven roads at good speed, when not sweeping, to minimize dose and time expended in travel to and from the area to be swept; and (6) shielded hopper to reduced dose to operator.

4.2 RECOMMENDATIONS

Existing street sweepers should be used as dry decontamination procedures on paved areas in a region of critical water supply. Because of their ability to remove high initial-mass levels, sweepers may be used as the first in a sequence of different methods.

The feasibility of providing vacuum dust control systems and air brooms on existing sweepers should be investigated. Future sweeper design changes and new concepts of fallout environment should be analyzed and evaluated to determine their influence on dry decontamination.

Further work is required to verify existing equations or derive more applicable equations to determine effectiveness.

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APPENDIX A

CHARACTERISTICS OF SYNTHETIC FALLOUT MATERIAL

A.1 NON-RADIOACTIVE BULK-CARRIER RAW MATERIAL

Sand processing was done with a Novo sieving machine. This machine, a vibratory type, fed the sand from a storage hopper onto a screen where two fractions were obtained, one greater and one smaller than the screen mesh opening. Selected screens were used to produce the various simulant sizes used. The sieving rate of the Novo machine is about 100 lb/hr for 88-to-177- μ material and will vary with particle-size range, smaller sizes requiring more time.

The bulk carrier material described in Section 2.4 was sieved on the Novo sieving machine in the following sequence:

1. Ambrose clay loam Stoneman soil; 170-mesh screen (88 μ), producing two fractions: < 88 μ and > 88 μ .
2. Rough sharp sandblast sand of two grades:
 - a. Fine, 48 mesh (300 μ) screen producing < 300 μ > 300 μ
 - b. Coarse, 16 mesh screen (1000 μ), producing < 1000 μ > 1000 μ

The fractions were sieved with the screens, as indicated, several times to get the purest size distribution possible within the nominal particle size range. Size distribution control was maintained by frequent sampling and sieve analysis of the product.

A.2 RADIOACTIVE TRACED BULK-CARRIER MATERIAL

New concepts of bulk-carrier characteristics for contaminant used in decontamination studies were evolved with the development of the

fallout model. Two types of Del Monte river bottom sand were obtained:
(1) Smooth, rounded, naturally weathered 60-mesh sand with a particle size range from 105 to 600 μ with a sieve analyses as shown in Table A.1.
(2) No. 1 ground sand with a particle size range from sub-sieve to 350 μ , with a sieve analyses as shown in Table A.2. Particles < 74 μ were sharp and irregular from the grinding process. No. 1 ground material had the desired fractions listed in Table 1.1. Figure A.1 shows how the size fractions were obtained and Table A.2 shows their sieve analysis.

A.3 FALLOUT SIMULANT PHYSICAL AND RADIOLOGICAL PROPERTIES

Each of the 23 batches of fallout simulant used in the post fallout model sweeper evaluation tests was analyzed to determine its physical and radiological properties.

The simulant size ranges were determined as described in Section 2.5. A slight shift in particle size was observed after the sodium silicate was added to seal the radioactivity to the sand but it did not affect the test conditions appreciably.

The specific activity ($\mu\text{c/g}$) of each of the radioactively traced batch sieve fractions was measured with the 4π gamma ionization chamber (Fig. 2.10) to determine the uniformity of tagging of the simulant. The physical and radiological properties of each of the simulant batches are presented in Table A.3.

A.3.1 Relation of Specific Activity to Particle Size

The intent of the radionuclide-tagging process in the production of fallout simulant was to obtain a constant specific activity ($\mu\text{c/g}$) for all particle sizes. This would establish a direct relationship between radiation intensity and residual mass after decontamination.

The tagging process consisted of spraying a solution of the radionuclide onto the surface of the bulk carrier material. If uniform surface coverage is achieved, the amount (μc) of radioactivity on a particle will be proportional to its surface area. The radioactivity can be related to volume or mass (for uniform material density) for spherical particles of diameter d as follows:

TABLE A.1

Sieve Analysis for 60 Mesh Del Monte River Bottom Sand

Tyler Standard Sieve No.	Mesh Opening (micron)	% Retained	Cumulative % Less Than Stated Size
35	420	8.2	91.8
48	297	48.4	43.4
60	250	21.3	22.1
80	177	19.9	2.2
100	149	1.3	0.9
150	105	0.9	
Pan	105	0	

TABLE A.2

Sieve Analysis of No. 1, Ground Del Monte Sand

Tyler Sieve		Raw Material				Test Material Sieved From Raw Material					
Mesh	Microns	#1 Ground Sand		-300, + 177 μ		-177, + 74 μ		-74, + 44 μ			
		% Retained	% Cum < Stated Size	% Retained	% Cum < Stated Size	% Retained	% Cum < Stated Size	% Retained	% Cum < Stated Size		
45	350			0.44	99.42						
48	297	3.8	96.3	3.57	95.85						
60	250			17.71	78.14						
65	210			29.46	48.68	1.30	98.71				
80	177	20.8	75.5	35.00	13.68	8.35	90.36				
100	149	13.4	62.1	12.89	0.79	23.60	66.76				
150	105					35.57	31.19	3.90	96.1		
200	74	32.2	29.9			19.80	11.39	0.70	95.4		
230	62					6.39	5.00	8.70	86.7		
270	53	12.2	17.7					19.30	67.40		
325	44	7.2	10.5					43.40	24.00		
Pan	44	10.5		0.79		5.00		24.00			
Total		100.1		99.86		100.00		100.0			

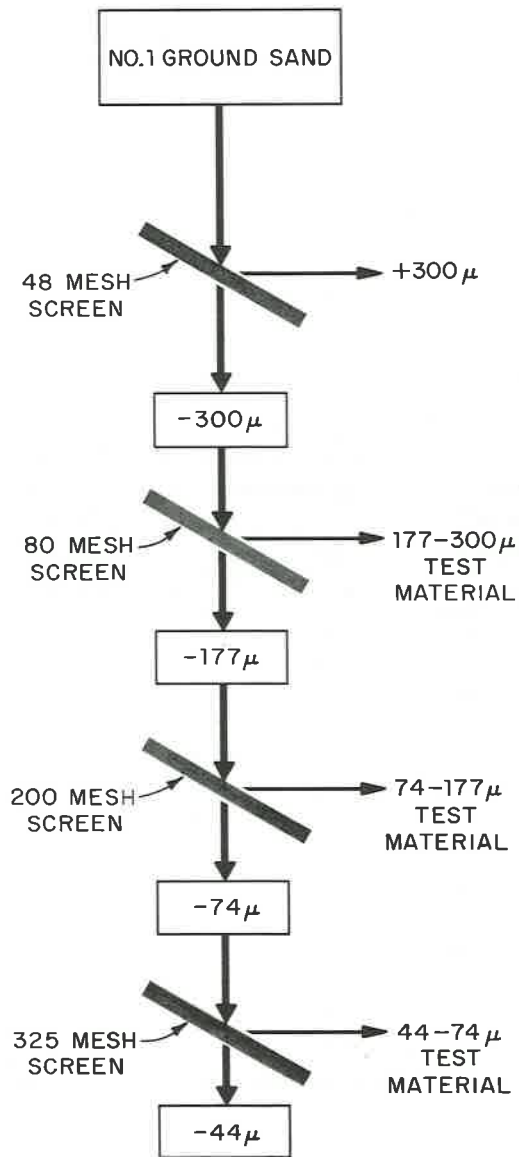


Fig. A.1 Procedure for Sieving No. 1 Ground Bulk-Carrier Raw Material With the Novo Sieving Machine

$$\frac{\text{Activity}}{\text{Mass}} \propto \frac{\text{Surface}}{\text{Volume}} = \frac{\pi d^2}{\pi d^3 / 6} = K (1/d) \quad (\text{A.1})$$

where K is a proportionality constant between specific activity ($\mu\text{c/g}$) and the reciprocal of the particle diameter ($1/d$). If this idealized relationship prevailed in practice Eq. A.1 would be a straight line with slope K in linear coordinates. However, the above idealized activity-mass proportionality to particle diameter is altered in the actual tagging operation because particles are non-spherical or agglomerated.

Figure A.2 shows the observed variation of specific activity with particle size for simulant batches of two of the particle size ranges used in the sweeper evaluation tests. Relative specific activity ($\% \text{ activity} / \% \text{ mass}$ for the averaged sieve fractions of each batch) has been plotted against the reciprocal ($1/d$) of the sieve fraction mid size, (μ). The straightness of the lines formed by segments connecting the data points of the averaged batches indicates how well Eq. A.1 applies. The consistency of the batches' size distribution in each size range can be gauged by their standard deviation as well as their proximity to the least-squares-fit of a straight line through all the data points.

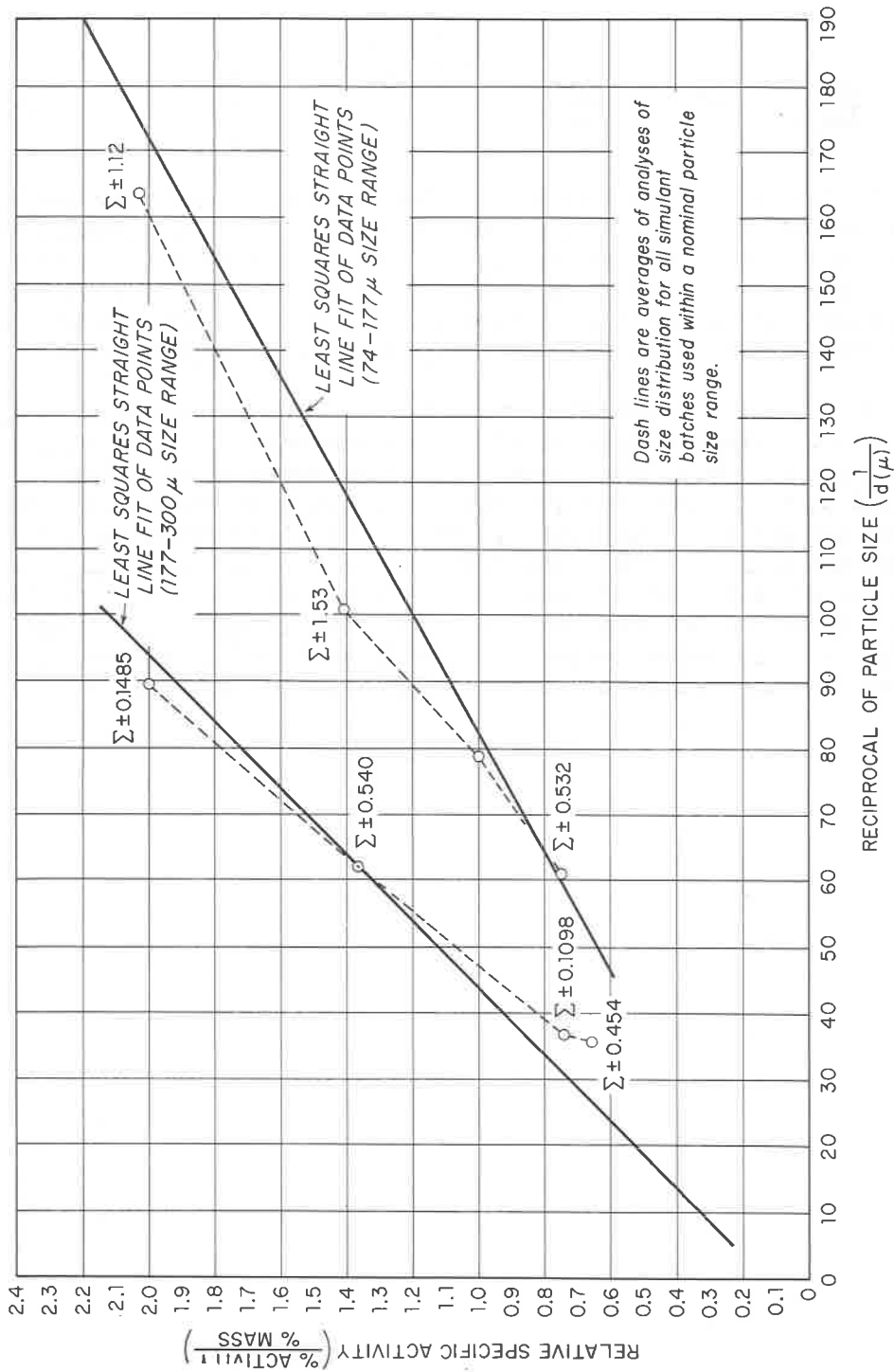


Fig. A.2 Variation of Specific Activity With Particle Size

TABLE A-3

Physical and Radiological Analyses of Synthetic Polio

U.S. Mesh	Sieve Size Microns	Batch No. 1		Batch No. 2		Batch No. 3		Batch No. 4		Batch No. 5		Batch Wt. %
		Wt. %	Act. %	Wt. %	Act. %	Wt. %	Act. %	Wt. %	Act. %	Wt. %	Act. %	
14	1190			1.9								0.1
16	1000			20.0								2.1
20	840			57.4								6.0
25	710			18.4								23.0
30	590			2.3								25.4
						0.1		0.1				21.3
35	500					2.1		2.1				6.0
40	420					6.0		6.0				23.0
45	350					23.0		23.0				25.4
50	297					25.4		25.4				21.3
60	250					21.3		21.3				15.6
70	210					15.6		15.6				4.3
80	177					4.3		4.3				1.3
100	149					1.3		1.3				0.3
120	125					0.3		0.3				0.6
140	105					0.6		0.6				15.6
												4.3
												1.3
												0.3
												0.6
170	88		0.8									15.6
200	74		0.8									4.3
230	62		57.1									1.3
270	53		33.8									0.3
325	44		8.3									0.6
Pan			8.3									0.6
Totals		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Date Mixed		8/4/59		8/4/59		9/1/59		9/23/59		10/21/59		11/5/59
µc/gm		No Activity		No Activity		No Activity		20.4		8.2		5.9
Continued												

No Activity Measurements Made

No Activity Measurements Made

TABLE A-3 (Cont'd)

Physical and Radiological Analyses of Synthetic Fallout Batches

U.S. Mesh	Sieve Size Microns	Batch No. 12		Batch No. 13		Batch No. 14		Batch No. 15		Batch No. 16		Batch No. 17	
		Wt. %	Act. %	Wt. %	Act. %	Wt. %	Act. %	Wt. %	Act. %	Wt. %	Act. %	Wt. %	Act. %
14	1190												
16	1000												
20	840												
25	710												
30	590												
35	500												
40	420					4.8	5.5						
45	350					1.6	1.8						
50	297					15.2	12.6						
60	250					27.5	24.3						
70	250												
80	177	21.1	9.4			22.6	23.4						
100	149	25.7	21.6			21.8	23.8			30.1	25.7	29.5	28.3
120	125	19.0	19.6							27.4	23.5	35.1	40.0
140	105	15.4	19.4	3.9	3.1					19.8	19.8	12.9	17.4
170	88					6.5	8.6			11.0	13.0		
200	74	12.2	19.1	0.2	0.3					4.9	6.5		
230	62			0.5	0.7					3.3	5.1		
270	53			8.7	8.7								
325	44	5.4	10.6	19.2	18.6								
Fan		1.2	0.3	43.2	38.8								
Total		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Date Mixed		7/5/60		7/26/60		8/5/60		8/12/60		12/9/60		1/3/61	
µc/gm		28.1		67.1		76.7		92.3		53.3		57.7	

APPENDIX B

RESULTS OF DRY DECONTAMINATION SWEEPER TESTS

Table B.1 is a survey of tests and their simulant batches. It also serves as an index for the data presented in Tables B.2-B.5.

Tables B.2-B.5 lists the results of the evaluation studies using non-radioactive and radioactive simulant. All radiation measurements were taken with the mobile, shielded gamma detector unit described in Chapter II.

Tables B.6 and B.7 present the results of special tests conducted to determine the influence of surface cracks on sweeping effectiveness.

B.1 CONVERSION OF RADIATION MEASUREMENTS TO MASS UNITS

The use of a radionuclide-traced synthetic fallout simulant offered advantages in the evaluation of sweepers as decontaminating methods. The high sensitivity of detection equipment affords a means of accurately measuring small amounts of residual mass through the use of high specific activity.

The natural background was established by taking a series of one minute counts during two and four hour periods. These counts were averaged to get the natural background of the general area. After obtaining radiation measurements as described in Chapter II, the following computational steps were taken to determine the residual mass:

- (1) Average the two raw counts at each of five stations.
- (2) Compute arithmetic means of stations 1-5 inclusive (\bar{x}).
- (3) Compute decay time from arbitrary zero time at noon on day batch was mixed to mid-time for measurements at stations 1-5 inclusive.
- (4) Compute decay factor (Residual) for Ia^{140} (40.2 hr. half life) at decay time in step 3.

TABLE B.1

Index of Test Numbers for Post Fallout Model Test Conditions for Simulant Batches 1-9

Initial Mass:		30 g/ft ²		60 g/ft ²		150 g/ft ²		250 g/ft ²		400 g/ft ²					
Particle Size Range:		177-300μ		300-500μ		200-400μ		750-1000μ		44-74μ		750-1000μ		300-500μ	
Surface Type:		A		A		A		A		A		A		C	
Sweeper		Gear													
Tennant 100	1			7.1	4.2	6.3	2.1	1.1	2.6	2.7	3.1	6.1			
	2	9.1	8.1 8.2	7.2 7.3	5.1		2.2		2.5	2.8	4.3 4.1	6.2			
	3	9.2	8.3		5.2		2.3		2.4	2.9	4.4	5.3			

A - Asphalt; C - Concrete

Index of Test Numbers for Post Fallout Test Conditions for Simulant Batches 10-23

Initial Mass:		20 g/ft ²				100 g/ft ²				600 g/ft ²			
Particle Size Range:		44-74μ		177-300μ		44-74μ		74-177μ		177-300μ		74-177μ	
Surface Type:		A		C		A		C		A		C	
Sweeper		Gear											
Wayne 450	1		21.1	21.3			19.1	20.2	17.7	21.5	22.3		
	2		21.2				19.2	20.4	17.8	21.4	20.6		
	3						23.1	20.5	21.10				
Tennant 100	1	13.7	14.2 16.1		13.8	15.1	15.4	14.11	21.7	18.5	23.6		
	2	13.6	14.1 16.2	14.3	13.12	18.2	15.3	14.8	14.6	22.2	23.5		
	3		14.5 16.3	14.4		22.1	23.2	16.5 16.12	16.6 14.7				
Tennant 100 w/air Broom	1	13.4	17.1		13.9	18.1	23.3	14.9 16.9	21.8	18.6			
	2	13.5	17.2	17.4	13.10	13.11	18.3	15.2 20.3	14.10	16.8	22.4		
	3		17.3				18.4	23.4	16.10 16.11	21.9			
Tennant 100 DS	1	13.2	13.3				11.5		10.9	12.2	12.3		
	2	13.1	10.1	10.5			11.6 11.1	11.3	10.4	10.8	12.4 12.5 12.6	12.1	
	3		11.2	10.6			11.2	11.4	10.3	10.7			

A - Asphalt; C - Concrete

TABLE B.2

Test Results for Motorized Sweeping, Wayne 450

Test No.	Test Date Test Area Particle Size	Pass	Forward Speed (ft/min)	E Relative Effort	M Mass Remaining (g/ft ²)	Standard Deviation of M (%)
17.7	1/10/61 A-3 177-300 μ	0	0	0	123.0	4.0
		1	200	6.00	1.3	78.1
		2	194	12.12	0.72	37.7
		3-4	202	24.00	0.57	23.0
		5-8	202	47.76	0.22	8.3
17.8	1/10/61 A-3 177-300 μ	0	0	0	51.0	10.0
		1	454	2.64	1.6	54.7
		2	416	5.52	0.70	33.0
		3-4	435	11.04	0.41	25.8
		5-8	444	21.84	0.31	11.9
17.9	1/11/61 A-3 177-300 μ	0	0	0	117.0	6.9
		1	833	1.44	4.5	33.4
		2	714	3.12	1.3	35.4
		3-4	870	5.88	0.85	20.7
		5-8	1025	10.56	0.64	31.3
19.1	1/24/61 A-3 74-177 μ	0	0	0	106.0	6.1
		1	250	4.80	2.7	21.3
		2	256	9.48	1.7	35.8
		3-4	278	18.12	0.53	20.0
		5-8	280	35.28	0.37	27.0
		9	250	40.08	0.25	18.7
19.2	1/27/61 A-3 74-177 μ	0	0	0	99.9	16.1
		1	435	2.76	7.5	50.7
		2	455	5.40	3.1	39.5
		3-4	435	10.80	1.5	38.0
		5-8	470	21.0	0.95	29.6
20.1	2/7/61 A-3 74-177 μ	0	0	0	99.9	5.1
		1	834	1.44	3.0	42.9
		2	834	2.88	2.1	59.0
		3-4	834	5.76	0.80	64.9
		5-8	740	12.24	0.37	54.8
20.2	2/14/61 C-2 74-177 μ	0	0	0	91.9	6.3
		1	227	5.28	3.4	28.1
		2	222	10.68	3.2	27.4
		3-4	232	21.0	0.65	17.3
20.4	2/16/61 C-2 74-177 μ	0	0	0	87.4	8.4
		1	476	2.52	1.1	41.3
		2	500	4.92	0.79	6.9
20.5	2/16/61 C-2 74-177 μ	0	0	0	85.1	10.5
		1	823	1.44	1.0	25.1
		2	823	2.88	0.82	17.3
20.6	2/17/61 A-2 74-177 μ	0	0	0	663.0	7.4
		1	556	2.16	5.7	48.4
		2	556	4.32	2.3	36.6
		3-4	556	8.64	1.5	35.2
		5-8	540	17.52	1.2	21.2
21.1	2/28/61 A-1 177-300 μ	0	0	0	23.8	10.5
		1	357	3.36	1.2	27.8
		2	345	6.84	0.41	33.9
		3-4	357	13.56	0.14	34.3

Continued

TABLE B.2 (Cont'd)

Test Results for Motorized Sweeping, Wayne 450

Test No.	Test Date Test Area Particle Size	Pass	Forward Speed (ft/min)	E Relative Effort	M Mass Remaining (g/ft ²)	Standard Deviation of M (%)
21.2	3/1/61 A-2 177-300 μ	0	0	0	26.1	7.4
		1	666	1.80	2.0	37.6
		2	666	3.60	0.72	21.1
		3-4	606	7.56	0.48	11.9
		5-8	635	15.12	0.16	24.9
21.3	3/3/61 C-2 177-300 μ	0	0	0	20.4	5.3
		1	250	4.80	0.88	34.0
		2	303	8.76	0.21	41.8
		3-4	309	16.32	0.09	30.0
		5-8	328	30.96	0.06	10.6
21.4	3/7/61 C-2 177-300 μ	0	0	0	112.0	5.2
		1	625	1.92	0.98	53.3
		2	588	3.96	0.39	40.7
		3-4	645	7.68	0.31	30.9
21.5	3/7/61 C-2 177-300 μ	0	0	0	107.0	6.9
		1	322	3.72	0.94	20.2
		2	322	7.44	0.37	12.8
		3-4	328	14.76	0.29	15.7
21.6	3/7/61 C-2 177-300 μ	0	0	0	106.0	1.7
		1	910	1.32	1.2	77.4
		2	910	2.64	0.66	17.4
		3-4	910	5.28	0.52	14.1
21.10	3/9/61 A-1 177-300 μ	0	0	0	96.50	3.1
		1	594	2.04	4.7	46.4
		2	594	4.08	1.4	40.3
		3-4	625	7.56	0.96	13.9
		5-8	615	15.36	0.69	15.8
22.3	3/29/61 A-2 74-177 μ	0	0	0	627.0	5.4
		1	322	3.72	9.7	40.9
		2	312	7.56	5.3	27.1
		3-4	317	15.12	3.3	34.2
23.1	4/5/61 A-2 74-177 μ	0	0	0	91.9	9.3
		1	625	1.92	12.5	55.6
		2	588	3.96	4.3	53.2
		3-4	605	7.92	1.5	43.8
		5-8	645	15.84	0.75	23.4

TABLE B.3

Test Results for Vacuumized Sweeping, T100

Test No.	Test Date Test Area Particle Size	Pass	Forward Speed (ft/min)	E Relative Effort	M Mass Remaining (g/ft ²)	Standard Deviation of M (%)
1.1	8/31/59 A-1 44-74 μ	0 1	0 200 - 2.2 wph	0 6.00	384 11.0	- 97 ✓
2.1	9/10/59 A-1 750-1000 μ	0 1 2	0 204 204	0 5.88 11.76	276 9.1 6.8	- 97 ✓
2.2	9/10/59 A-1 750-1000 μ	0 1 2	0 400 416	0 3.00 5.88	254 4.5 0	
2.3	9/10/59 A-1 750-1000 μ	0 1 2	0 768 768	0 1.56 3.12	254 119.0 27.0	- 53%
2.4	9/11/59 A-1 750-1000 μ	0 1 2 3	0 768 714 768	0 1.56 3.24 4.80	473 22.0 5.7 2.1	- 95%
2.5	9/11/59 A-1 750-1000 μ	0 1 2	0 333 217	0 3.60 9.13	469 50.0 4.5	
2.6	9/11/59 A-1 750-1000 μ	0 1	0 200	0 6.00	462 9.1	- 98 ✓
2.7	9/11/59 C-1 750-1000 μ	0 1	0 204	0 5.88	431 16.0	- 96 ✓
2.8	9/11/59 C-1 750-1000 μ	0 1	0 666	0 1.80	420 11.4	
2.9	9/11/59 C-1 750-1000 μ	0 1	0 666	0 1.80	418 22.7	
3.1	9/23/59 A-1 200-400 μ	0 1	0 339	0 3.54	400 4.5	
3.2	9/23/59 A-1 200-400 μ	0 1 2	0 400 400	0 3.00 6.00	400 146.0 53.3	
4.1	9/24/59 A-1 200-400 μ	0 1 2	0 204 208	0 5.88 11.64	400 0.36 0.23	50.6 0.11 0.11 - 99 ✓
4.2	9/25/59 A-1 200-400 μ	0 1	0 200	0 6.00	51.1 0.22	32.1 64.7 - 99 ✓

Continued

TABLE B.3 (Cont'd)

Test Results for Vacuumized Sweeping, T100

Test	Test Date Test Area Particle Size	Pass	Forward Speed (ft/min)	E Relative Effort	M Mass Remaining (g/ft ²)	Standard Deviation of M (%)
4.3	9/28/59	0	0	0	400	8.7
	A-1	1	416	2.88	123.0	65.0
	200-400μ	2	416	5.76	3.38	103.5
		3	416	8.64	0.22	84.8
4.4	9/30/59	0	0	0	400	16.5
	A-1	1	714	1.68	325	25.3
	200-400μ	2	714	3.36	103	63.8
		3	714	5.04	10.8	63.7
		4	666	6.84	2.4	55.3
		5	714	8.52	1.6	70.6
5.1	10/21/59	0	0	0	52.2	10.7
	A-2	1	416	2.88	0.76	63.1
	200-400μ	2	416	5.76	0.11	28.4
		3	400	8.76	0.07	23.4
5.2	10/23/59	0	0	0	47.7	12.0
	A-3	1	714	1.68	2.3	80.2
	200-400μ	2	770	3.24	0.32	35.9
		3	204	9.12	0.13	31.3
5.3	10/27/59	0	0	0	380	14.1
	C-3	1	714	1.68	0.70	115.6
	200-400μ	2	666	3.48	0.11	108.1
		3	204	9.36	0.06	148.8
6.1	11/6/59	0	0	0	377	11.7
	C-1 200-400μ	1	200	6.00	0.05	57.5
6.2	11/9/59	0	0	0	376	11.0
	C-2 200-400μ	1	400	3.00	0.04	105.9
6.3	11/12/59	0	0	0	149	5.9
	A-1	1	200	6.00	0.96	49.8
	200-400μ	2	204	11.88	0.17	66.1
7.1	1/28/60	0	0	0	61.3	12.2
	A-Plaza 300-500μ	1	208	5.76	6.2	75.3
7.2	2/16/60	0	0	0	53.3	9.2
	A-Plaza 300-500μ	1	435	2.76	3.6	108.3
		2	435	5.52	1.9	223.0
7.3	2/17/60	0	0	0	59.0	6.0
	A-10 300-500μ	1	435	2.76	0	-
8.1	2/12/60	0	0	0	28.4	5.2
	A-Plaza 300-500μ	1	435	2.76	3.2	26.6
		2	435	5.52	2.5	30.5
		3	213	11.16	1.8	29.8

Continued

TABLE B.3 (Cont'd)

Test Results for Vacuumized Sweeping, T100

Test	Test Date Test Area Particle Size	Pass	Forward Speed (ft/min)	E Relative Effort	M Mass Remaining (g/ft ²)	Standard Deviation of M (%)
8.2	2/15/60 A-10 300-500μ	0	0	0	29.5	6.8
		1	435	2.76	0.25	88.9
8.3	2/15/60 A-Plaza 300-500μ	0	0	0	25.0	8.4
		1	770	1.56	2.5	55.6
		2	770	3.12	2.3	66.7
		3	213	4.68	0.93	133
9.1	5/26/60 A-1 177-300μ	0	0	0	31.8	3.4
		1	416	2.88	0.14	30.3
		2	416	5.76	0.21	47.8
9.2	5/26/60 A-1 177-300μ	0	0	0	27.2	5.61
		1	714	1.68	0.26	76.1
		2	714	3.36	0.05	39.0
13.6	8/2/60 A-533 44-74μ	0	0	0	22.7	19.8
		1	434	2.76	8.3	48.1
		2	434	5.52	3.8	53.1
		3	434	8.28	2.9	47.7
		4	434	11.04	2.5	37.8
		5	212	16.68	2.2	45.2
		6	434	19.44	2.0	43.8
7	204	25.32	1.8	12.7		
13.7	8/3/60 A-533 44-74μ	0	0	0	23.8	31.4
		1	208	5.76	4.3	37.2
		2	217	11.28	2.5	42.5
		3	212	16.92	2.2	38.8
4	217	22.44	2.2	38.8		
13.8	8/3/60 A-533 44-74μ	0	0	0	150.0	8.7
		1	213	5.64	10.6	41.9
		2	213	11.28	4.7	45.9
		3	208	17.08	3.5	47.9
		4	213	23.28	3.1	45.8
5-7	213	40.36	2.6	55.3		
13.12	8/8/60 C-2 44-74μ	0	0	0	154.0	11.0
		1	416	2.88	1.7	44.3
		2	435	5.64	1.3	54.3
		3-4	426	11.28	0.94	15.8
5-8	421	22.68	0.72	23.0		
14.1	8/9/60 A-3 177-300μ	0	0	0	25.0	6.6
		1	435	2.76	1.4	83.7
		2	435	5.52	0.31	36.7
		3-4	426	11.16	0.11	29.8
5-8	421	22.56	0.06	25.6		
14.2	8/9/60 A-3 177-300μ	0	0	0	26.1	10.2
		1	213	5.64	0.73	58.6
		2	213	11.28	0.17	21.9
		3-4	211	22.68	0.11	32.4
5-8	166	51.48	0.09	27.3		

Continued

TABLE B.3 (Cont'd)

Test Results for Vacuumized Sweeping, T100

Test No.	Test Date Test Area Particle Size	Pass	Forward Speed (ft/min)	E Relative Effort	M Mass Remaining (g/ft ²)	Standard Deviation of M (%)
14.3	8/10/60 C-3 177-300μ	0	0	0	32.9	5.5
		1	416	2.88	0.11	27.1
		2	400	5.88	0.07	29.6
		3-4	407	11.76	0.07	23.7
		5-8	421	23.16	0.07	44.3
14.4	8/10/60 C-3 177-300μ	0	0	0	26.1	2.6
		1	770	1.56	23.8	46.6
		2	770	3.12	1.5	85.5
		3-4	770	6.24	0.13	25.9
		5-8	770	12.48	0.11	18.5
14.5	8/10/60 A-2 177-300μ	0	0	0	25.0	9.75
		1	714	1.68	1.5	53.85
		2	714	3.36	0.48	33.39
		3-4	714	6.72	0.14	13.21
		5-8	727	13.32	0.10	11.05
14.6	8/11/60 C-2 177-300μ	0	0	0	131	25.0
		1	416	2.88	0.51	53.9
		2	454	5.52	0.21	45.1
		3-4	435	11.04	0.15	35.2
		5-8	425	22.32	0.11	30.5
14.7	8/11/60 C-2 177-300μ	0	0	0	88.5	5.7
		1	770	1.56	22.4	108
		2	770	3.12	7.6	121
		3-4	770	6.24	0.54	72.5
		5-8	740	12.72	0.28	29.4
14.8	8/12/60 A-1 177-300μ	0	0	0	97.6	7.2
		1	416	2.88	39.9	101
		2	416	5.76	15.7	161
		3-4	416	11.52	1.5	145
		5-8	408	23.28	0.16	25.4
14.11	8/15/60 A-1 177-300μ	0	0	0	93.1	6.7
		1	204	5.88	9.0	143
		2	213	11.52	0.61	73.8
		3-4	213	22.80	0.23	37.0
		5-8	213	45.36	0.22	43.3
15.1	8/15/60 A-2 74-177μ	0	0	0	106	3.0
		1	208	5.76	26.1	135
		2	208	11.52	8.9	151
		3-4	208	23.0	0.44	85
		5-8	208	46.08	0.09	37.2
15.3	8/16/60 C-3 74-177μ	0	0	0	104	4.4
		1	416	2.88	2.7	109.0
		2	416	5.76	0.79	89.0
		3-4	416	11.52	0.19	61.0
		5-8	416	23.04	0.05	48.0

Continued

TABLE B.3 (Cont'd)

Test Results for Vacuumized Sweeping, T100

Test No.	Test Date Test Area Particle Size	Pass	Forward Speed (ft/min)	E Relative Effort	M Mass Remaining (g/ft ²)	Standard Deviation of M (%)	
15.4	8/16/60 C-3 74-177μ	0	0	0	111.0	3.1	-99% ✓
		1	213	5.64	0.97	65.0	
		2	213	11.28	0.34	57.9	
		3-4	206	22.92	0.19	74.0	
		5-8	208	45.96	0.14	75.4	
16.1	12/12/60 A-1 177-300μ	0	0	0	22.7	11.6	-98% ✓
		1	208	5.76	0.41	37.5	
		2	204	11.64	0.11	16.2	
		3-4	208	23.16	0.07	19.3	
		5-8	210	46.08	0.05	24.8	
16.2	12/13/60 A-3 177-300μ	0	0	0	26.1	4.8	
		1	416	2.88	0.26	11.0	
		2	416	5.76	0.11	29.4	
		3-4	426	11.40	0.05	34.8	
		5-8	421	22.80	0.05	44.9	
16.3	12/13/60 A-3 177-300μ	0	0	0	20.4	7.8	-93% ✓
		1	714	1.68	0.35	29.2	
		2	714	3.36	0.19	32.3	
		3-4	714	6.72	0.11	36.0	
		5-8	714	13.44	0.07	40.6	
16.4	12/19/60 A-1 177-300μ	0	0	0	88.5	10.8	-99% ✓
		1	200	6.00	0.41	29.9	
		2	200	12.00	0.15	41.1	
		3-4	208	23.52	0.11	30.2	
16.5	12/19/60 A-1 177-300μ	0	0	0	102	3.4	
		1	416	2.88	2.1	61.3	
		2	416	5.76	0.50	30.8	
		3-4	416	11.52	0.19	42.6	
		5-8	404	23.40	0.08	61.4	
16.6	12/20/60 C-1 177-300μ	0	0	0	86.3	7.4	
		1	416	2.88	0.24	35.4	
		2	416	5.76	0.25	41.3	
16.7	12/20/60 C-1 177-300μ	0	0	0	111	4.7	-99% ✓
		1	715	1.68	0.52	34.8	
		2	770	3.24	0.42	17.9	
		3-8	742	9.72	0.30	36.4	
16.12	12/21/60 A-1 177-300μ	0	0	0	101.0	5.4	-77% ✓
		1	768	1.56	29.1	71.6	
		2	768	3.12	3.3	111.4	
		3-4	768	6.24	0.53	32.6	
		5-8	740	12.72	0.27	30.7	
17.5	1/9/61 A-3 177-300μ	0	0	0	120	6.0	-77% ✓
		1	770	1.56	26.7	45.9	
		2	770	3.12	1.08	23.1	
		3-4	770	6.24	0.34	16.5	
		5-8	740	12.72	0.19	24.4	

Continued

TABLE B.3 (Cont'd)

Test Results for Vacuumized Sweeping, T100

Test No.	Test Date Test Area Particle Size	Pass	Forward Speed (ft/min)	E Relative Effort	M Mass Remaining (g/ft ²)	Standard Deviation of M (%)
18.2	1/18/61	0	0	0	99.9	8.9
	A-3	1	400	3.00	6.1	66.2
	74-177μ	2	416	5.88	1.6	100.0
		3-4	425	11.52	0.31	26.7
		5-8	435	22.56	0.20	25.2
18.5	1/19/61	0	0	0	608.0	2.1
	A-1	1	208	5.76	43.0	83.6
	74-177μ	2	208	11.52	0.96	54.3
		3-4	208	23.04	0.23	15.7
		5-8	214	46.08	0.18	18.2
21.7	3/8/61	0	0	0	115.0	4.7
	C-2 177-300μ	1	204	5.88	0.58	13.6
22.1	3/22/61	0	0	0	102.0	15.5
	A-2	1	714	1.68	39.1	61.1
	74-177μ	2	714	3.36	17.9	100.0
		3-4	714	6.72	1.7	79.2
		5-8	714	13.44	0.49	26.9
22.2	3/22/61	0	0	0	599	3.2
	A-2	1	400	3.00	20.6	37.7
	74-177μ	2	400	6.00	3.5	38.7
		3-4	400	12.00	1.1	29.3
		5-8	395	24.12	0.53	24.6
23.2	4/16/61	0	0	0	112.0	9.6
	C-2	1	770	1.56	0.79	59.5
	74-177μ	2	770	3.12	0.66	47.1
		3-4	740	6.36	0.53	36.5
		5-8	740	12.84	0.43	7.8
23.5	4/10/61	0	0	0	608.0	18.4
	C-2	1	416	2.88	46.4	72.1
	74-177μ	2	416	5.76	1.3	44.9
23.6	4/10/61	0	0	0	597	5.6
	C-2	1	204	5.88	57.3	56.8
	74-177μ	2	204	11.76	1.4	29.7

-93% ✓

-94% ✓

-62%

-94%

-90% ✓

TABLE B.4

Test Results for Vacuumized Sweeping, T100-AB

Test No.	Test Date Test Area Particle Size	Pass	Forward Speed (ft/min)	E Relative Effort	M Mass Remaining (g/ft ²)	Standard Deviation of M (%)
13.4	8/1/60 A-533 44-74μ	0	0	0	23.8	19.8
		1	208	5.76	1.2	40.2
		2	232	10.92	0.75	39.1
13.5	8/1/60 A-533 44-74μ	0	0	0	26.1	26.0
		1	347	2.88	4.2	50.2
		2	347	5.76	1.7	49.0
		3	347	8.64	1.4	58.7
4	208	14.40	1.2	49.3		
13.9	8/4/60 A-533 44-74μ	0	0	0	150.0	4.6
		1	208	5.76	5.3	57.7
		2	208	11.52	2.2	46.7
		3-4	208	23.04	2.0	43.8
		5-8	200	47.04	2.1	43.2
13.10	8/4/60 A-533 44-74μ	0	0	0	150.0	8.0
		1	435	2.76	13.5	43.8
		2	435	5.52	4.3	54.4
		3-4	435	11.04	3.2	50.0
		5-8	435	22.08	3.1	50.7
13.11	8/5/60 C-2 44-74μ	0	0	0	154.0	6.5
		1	416	2.88	2.1	119.0
		2	435	5.64	0.39	19.9
		3-4	416	11.40	0.31	26.3
		5-8	435	22.80	0.27	20.7
14.9	8/12/60 A-1 177-300μ	0	0	0	89.7	7.4
		1	208	5.76	0.17	34.5
		2	208	11.52	0.11	26.4
14.10	8/12/60 A-1 177-300μ	0	0	0	90.8	7.6
		1	416	2.88	14.7	128.0
		2	416	5.76	0.54	101.0
		3-4	407	11.64	0.15	25.2
15.2	8/16/60 C-3 74-177μ	0	0	0	114.0	8.0
		1	416	2.88	14.5	164.0
		2	416	5.76	0.32	60.0
		3-4	416	11.52	0.28	63.0
		5-8	412	23.16	0.25	53.2
16.8	12/20/60 C-1 177-300μ	0	0	0	100.0	4.4
		1	416	2.88	0.47	29.3
		2	416	5.76	0.26	30.8
		3-4	416	11.52	0.26	53.4
		5-8	412	23.16	0.27	38.6
16.9	12/21/60 A-1 177-300μ	0	0	0	104.0	11.1
		1	200	6.00	0.13	34.7
16.10	12/21/60 A-1 177-300μ	0	0	0	104.0	1.5
		1	416	2.88	0.32	25.1
		2	416	5.76	0.11	53.4

Continued

TABLE B.4 (Cont'd)

Test Results for Vacuumized Sweeping, T100-AB

Test No.	Test Date Test Area Particle Size	Pass	Forward Speed (ft/min)	E Relative Effort	M Mass Remaining (g/ft ²)	Standard Deviation of M (%)
16.11	12/21/60	0	0	0	104.0	6.4
	A-1	1	714	1.68	22.2	80.6
	177-300 μ	2	770	3.24	0.28	44.8
		3-4	740	6.48	0.23	37.5
17.1	1/5/61	0	0	0	40.9	0.4
	A-3	1	208	5.76	0.002	27.2
	177-300 μ	2	208	11.52	0.002	18.4
17.2	1/5/61	0	0	0	19.3	6.9
	A-3	1	434	2.76	0.04	9.9
	177-300 μ	2	416	5.64	0.03	10.2
17.3	1/6/61	0	0	0	22.7	4.1
	A-3	1	714	1.68	0.08	37.2
	177-300 μ	2	714	3.36	0.06	44.4
		3-4	740	6.60	0.06	17.5
17.4	1/6/61	0	0	0	25.0	11.8
	C-2	1	208	5.76	0.04	22.8
	177-300 μ	2	208	11.52	0.04	7.3
17.6	1/9/61	0	0	0	99.9	7.6
	A-3	1	714	1.68	6.2	86.2
	177-300 μ	2	714	3.36	0.23	28.0
18.1	1/18/61	0	0	0	77.2	4.5
	A-3	1	204	5.88	0.16	22.5
	74-177 μ	2	208	11.64	0.10	7.7
18.3	1/18/61	0	0	0	99.9	7.0
	A-3	1	435	2.76	1.1	107.0
	74-177 μ	2	435	5.52	0.20	11.8
		3-4	435	11.04	0.14	5.6
18.4	1/19/61	0	0	0	95.3	4.6
	A-3	1	770	1.56	15.3	47.1
	74-177 μ	2	770	3.12	0.62	26.9
		3-4	770	6.24	0.21	10.0
18.6	1/19/61	0	0	0	568.0	5.7
	A-1	1	208	5.76	5.0	134.1
	74-177 μ	2	204	11.64	0.28	25.8
20.3	2/16/61	0	0	0	81.7	12.9
	C-2	1	416	2.88	0.35	13.8
	74-177 μ	2	416	5.76	0.37	10.2
21.8	3/8/61	0	0	0	99.9	4.5
	C-2	1	200	6.00	0.44	17.2
	177-300 μ	2-8	200	29.64	0.37	30.5
21.9	3/19/61	0	0	0	111.0	20.1
	C-2	1	770	1.56	0.64	18.2
	177-300 μ	2	770	3.12	0.69	22.0

Continued

TABLE B.6

Contamination Build-up (Summary) of Crack "30"
Using W450, T100, and T100AB Machines

Machine and Test No.	Pass	Relative Effort	Residual Mass		
			Crack #30 Total Grams	Comparative	
				Crack gm/ft ²	Surface gm/ft ²
T100AB 13.11	0		30.5	183.0	154.4
	1	2.88	179.0	1074.0	2.15
	2	5.64	160.0	960.0	0.39
	3-4	11.40	119.0	714.0	0.31
	4-8	22.80	105.0	630.0	0.27
T100 13.12	0		136.0	816.0	154.4
	1	2.88	243.0	1458.0	1.7
	2	5.64	224.0	1344.0	1.3
	3-4	11.28	213.0	1278.0	0.94
	5-8	22.68	202.0	1212.0	0.72
	9	25.44	195.0	1170.0	
T100 14.3	0		5.3	32.0	32.9
	1	2.88	27.6	166.0	0.11
	2	5.88	29.7	178.0	0.07
	3-4	11.76	29.9	179.0	0.07
	5-8	23.16	29.4	176.0	0.07
T100 14.4	0		34.0	204.0	131.0
	1	1.56	77.6	466.0	0.51
	2	3.12	41.6	250.0	0.21
	3-4	6.24	51.0	306.0	0.15
	5-8	12.48	50.0	300.0	0.11
T100 14.6	0		24.0	144.0	131.0
	1	2.88	145.3	1016.0	0.51
	2	5.52	127.1	763.0	0.21
	3-4	11.04	111.1	667.0	0.15
	5-8	22.32	80.4	482.0	0.11
T100 14.7	0		317.6	1906.0	88.5
	1	1.56	144.5	867.0	22.4
	2	3.12	132.0	792.0	7.6
	3-4	6.24	121.0	726.0	0.54
	5-8	12.72	96.9	581.0	0.28
T100AB* 14.7	0		96.9	581.0	
	1	1.56	33.1	199.0	
	2	3.12	16.0	96.0	
	3-4	6.24	7.4	44.0	
	5-8	12.72	5.5	33.0	
T100 15.2	0		279.0	1674.0	113.5
	1	2.88	313.3	1880.0	14.5
	2	5.76	280.0	1680.0	0.32
	3-4	11.52	226.0	1356.0	0.28
	4-8	23.16	188.0	1128.0	0.25
T100 15.3	0		20.0	120.0	104.4
	1	2.88	109.5	657.0	2.69
	2	5.76	105.1	631.0	0.79
	3-4	11.52	96.6	580.0	0.19
	5-8	23.04	89.9	539.0	0.05

Continued

TABLE B.6 (Cont'd)
 Contamination Build-up (Summary) of Crack "30"
 Using W450, T100, and T100AB Machines

Machine and Test No.	Pass	Relative Effort	Residual Mass		
			Crack #30 Total Grams	Crack gm/ft ²	Comparative Surface gm/ft ²
T100	0		108.4	650.0	111.2
15.4	1	5.64	300.6	1804.0	0.97
	2	11.28	291.0	1746.0	0.34
	3-4	22.92	266.0	1596.0	0.19
	5-8	45.96	261.0	1556.0	0.14
	T100*	0		15.5	93.0
16.6	1	2.88	461.0	2766.0	0.24
	2	5.76	467.0	2802.0	0.25
	3-4		439.0	2634.0	
	5-8		426.0	2556.0	
	T100*	0		439.0	2634.0
16.7	1	1.68	1102.0	6612.0	0.52
	2	3.24	833.0	4998.0	0.42
	3-4	6.48	813.0	4878.0	
	5-8	12.96	798.0	4788.0	0.30
	T100	0		830.0	4980.0
16.8	1	2.88	1016.0	6096.0	0.47
	2	5.76	790.0	4740.0	0.26
	3-4	11.52	650.0	3900.0	0.26
	5-8	23.16	477.0	2862.0	0.27
	T100AB	0		4.0	24.0
17.4	1	5.76	14.2	85.0	0.04
	2	11.52	12.9	77.0	0.04
	W450	0		128.0	768.0
20.2	1	5.28	234.0	1404.0	3.43
	2	10.68	209.0	1254.0	3.16
	3-4	21.00	191.0	1146.0	0.65
	T100AB*	0		499.0	2994.0
20.3	1	2.88	593.0	3558.0	0.34
	2	5.76	528.0	3168.0	0.37
	3-4	11.52	479.0	2874.0	
	4-8	23.04	418.0	2508.0	
	W450	0		271.0	1626.0
20.4	1	2.52	343.0	2058.0	1.05
	2	4.92	333.0	1998.0	0.79
	W450	0		349.0	2094.0
20.5	1	1.44	347.0	2082.0	0.92
	2	2.88	354.0	2124.0	0.82
	W450	0		4.0	24.0
21.3	1	4.80	41.0	246.0	0.88
	2	8.76	39.0	234.0	0.21
	3-4	16.32	35.0	210.0	0.09
	5-8	30.96	38.0	228.0	0.06
	W450	0		70.0	420.0
21.4	1	1.92	319.0	1914.0	0.98
	2	3.96	307.0	1842.0	0.39
	3-4	7.68	269.0	1614.0	0.31
	Continued				

TABLE B.6 (Cont'd)

Contamination Build-up (Summary) of Crack "30"
Using W450, T100, and T100AB Machines

Machine and Test No.	Pass	Relative Effort	Crack #30 Total Grams	Residual Mass	
				Crack gm/ft ²	Comparative Surface gm/ft ²
W450	0		288.0	1728.0	106.7
21.5	1	3.72	381.0	2286.0	0.94
	2	7.44	320.0	1920.0	0.37
	3-4	14.76	312.0	1872.0	0.29
W450	0		332.0	1992.0	105.6
21.6	1	1.32	367.0	2202.0	1.16
	2	2.64	389.0	2334.0	0.66
	3-4	5.28	371.0	2226.0	0.52
T100*	0		51.0	306.0	114.6
21.7	1	5.88	427.0	2562.0	0.58
	2	11.76	493.0	2958.0	
	3-4	23.52	510.0	3060.0	
	5-8	47.04	502.0	3012.0	
T100AB	0		74.0	444.0	99.9
21.8	1	6.00	277.0	1662.0	0.44
	2	12.00	222.0	1332.0	
	3-4	24.00	211.0	1266.0	
	4-8	48.00	162.0	972.0	0.37
T100AB	0		60.0	360.0	112.2
21.9	1	1.56	279.0	1674.0	0.63
	2	3.12	200.0	1200.0	0.69
T100	0		20.0	120.0	112.4
23.2	1	1.56	125.0	750.0	0.79
	2	3.12	127.0	762.0	0.66
	3-4	6.36	134.0	804.0	0.53
	5-8	12.84	104.0	624.0	0.43
T100AB	0		161.0	972.0	97.6
23.3	1	6.00	467.0	2802.0	0.65
	2	12.00	308.0	1848.0	0.46
T100AB	0		325.0	1950.0	104.4
23.4	1	1.68	389.0	2334.0	0.76
	2	3.36	368.0	2208.0	0.64
T100	0		505.0	3030.0	608.4
23.5	1	2.88	762.0	4572.0	46.4
	2	5.76	486.0	2916.0	1.3
T100	0		585.0	3510.0	597.0
23.6	1	5.88	713.0	4278.0	57.3
	2	11.76	534.0	3204.0	1.4

TABLE B.7

Contamination Build-up in Cracks Using the T100DS Machine

Test No.	Crack	Pass	Relative Effort	Residual Mass		
				Crack Total Grams	Crack gm/1 ft ²	Surface gm/1 ft ²
10.5	1	0	0	142.3	854.0	32.9
	2	0	0	4.3	25.8	32.9
	3	0	0	87.5	525.0	32.9
	1	1	1.80	13.8	82.8	0.7
	2	1	1.80	4.3	25.8	0.7
	3	1	1.80	14.5	87.0	0.7
12.1	1	0	0	244.0	1464.0	603.8
	2	0	0	10.4	62.4	603.8
	3	0	0	255.0	1530.0	603.8
	1	1	1.80	147.0	882.0	243.4
	2	1	1.80	7.2	43.2	243.4
	3	1	1.80	169.0	1014.0	243.4
12.3	1	0	0	803.0	4818.0	628.8
	2	0	0	825.0	4950.0	628.8
	3	0	0	812.0	4872.0	628.8
	1	1	3.30	19.9	119.0	0.36
	2	1	3.30	8.1	48.6	0.36
	3	1	3.30	2.2	13.2	0.36
	1	2	6.60	14.0	84.0	0.35
	2	2	6.60	5.1	30.6	0.35
	3	2	6.60	1.9	11.4	0.35

- (5) Compute std. factor = $36000/\text{Avg Co}^{60}$ 1 min counts or
 $12000/\text{Avg Ra}$ std. 1 min counts

Giving correction factor for overall instrument response.

(6) Compute corrected zero time count = $[(\bar{x})(\text{Std. Factor}) - (\text{Nat. bkg.})] /$
Decay Factor minus artificial bkg at zero time from residual radiation
from previous tests.

- (7) Residual (g/ft^2) = $(\text{initial g}/\text{ft}^2)(\text{residual count})/(\text{initial count})$.

B.2 SWEEPER TEST RESULTS

The test results for four machines: Motorized Sweeping W450, Vacuumized Sweeping T100, Vacuumized Sweeping with improvised airbroom T100 AB and Vacuumized Sweeping T100DS listed in Chapter II are summarized in Tables B.1, B.2, B.3, B.4 and B.5 respectively.

Each test is identified by a number. The whole number designates the simulant batch, and the decimal part designates the specific number of the test conducted, with that batch. Size and specific activity of each batch are tabulated in Appendix A.

The two test surfaces, asphalt (A) and concrete (C) are followed by numbers designating the test strip used. All surfaces were assumed to be typical of their type. However, surface irregularities such as undulations, decayed form line cracks, and surface cracks had a marked influence on sweeping of some machines as described in Section B.3.

The nominal particle size range shown for each test is described in Chapter I, and is listed in the data from analyses of the batches in Appendix A.

The pass number and relative effort described in Chapter II are designated for each sweeping pass. To obtain procedure effectiveness at extended amounts of relative effort, multiple passes were made between radiation measurements as described in Chapter II.

The forward speed (ft/min) as shown was determined as described in Chapter II.

Relative effort was determined as described in Chapter III.

The average initial mass level (M_0) was computed from weighed amounts of fallout simulant as described in Chapter II. The final mass levels (M) were computed as described in Section B.1.

The percent standard deviation (+ or -) indicates the consistency of the individual residual mass measurements for each successive sweeping pass.

B.3 CONTAMINATION BUILD-UP HISTORY IN SURFACE IRREGULARITIES

Crack "30" is located on the concrete test strips approximately 30 ft from the end of the test strips between monitoring stations #3 and #4.

This crack developed from the decaying and decomposition of the expansion joints. After a few tests had been conducted on the test strips the decomposed material was dislodged and swept up leaving a crack about one inch wide, 3/4 in. deep and 24 in. long. Table B.6 shows a history of the build-up of the (contaminant) mass in the crack in relation to that on the surface during a series of tests conducted with the T100, T100 A/B and W450 procedures.

Table B.7 shows a special study of cracks #1 and #3, similar to crack #30, and a surface line, crack #2 with the T100 DS Sweeper. Test 12.3 shows an extended amount of effort being used to compare the difficulty of removing the (contaminant) mass from the cracks in relationship to the surface.

APPENDIX C

DESIGN SPECIFICATION OF SWEEPERS

C.1 The design specifications of the sweepers evaluated are given in the following tables. The information listed was obtained from manufacturer's information brochures describing the equipment, except for the improvised air broom. The improvised air broom used on the Tennant Model 100 was designed by D. E. Clark, Jr. and built at USNRDL.

TABLE C.1

OPERATING CHARACTERISTICS OF WAYNE MODEL 450

Type

Manufacture - Wayne Manufacturing Co., Newark 5, New Jersey

Model No. Wayne 450

Sweeping Speeds

Maximum 10 - 12 mph
(Travel 20-25 mph)

Minimum 2 - 4 mph

Sweeping Path

Pickup Broom 4' 10"
With one gutter broom 7' 6"
With two gutter brooms 10'

Broom Characteristics

Main (pickup) Broom
Diameter 36"
Length 58"
Broom Material Palmyra Stalk
Drive Chain Drive
Mounting Full Floating Spring Suspended
Control (Lift) Hydraulic
Reversible Yes
Speeds 2 fwd, 1 reverse

Side Brooms (Gutter)

Diameter 45"
Broom Material Standard 26" Steel Wire
Drive Direct Drive
Mounting Free Floating
Control (Lift) Hydraulic
Speeds 2 Fwd, 1 Reverse

Conveyor System

Type Ladder Type - Rubber
Drive Rubber Chain
Speeds 2 Fwd, 1 Reverse

Dirt Hopper

Capacity 3 cubic yards (Located Forward)
Dump Control Hydraulic
Dump Doors Clam Type

Water Spraying System

Tank Capacity 170 gallons
Nozzles Brass atomizing nozzles
Pump Centrifugal
Operating Controls At Driver's Position

Physical Dimensions

Wheel Base 9' - 1"
Length Overall 15' - 8"
Height 6' - 11"
Width Overall 8' - 8"
Weight 10,000 lbs
Turning Radius 14'

TABLE C.2

OPERATING CHARACTERISTICS OF TENNANT MODEL 100 AND MODEL 100 AB

<u>Type</u>	
Manufacturer	G. H. Tennant Co., Minneapolis, Minn.
Model No.	Model 100
<u>Sweeping Speeds</u>	
Maximum	15.0 mph
Minimum	2.3 mph
<u>Sweeping Path</u>	
Pickup Broom	4' 0"
With two gutter brooms	7' 4"
<u>Broom Characteristics</u>	
Main (Pickup) Broom	
Diameter	29"
Fixed Mounting Length	48"
Type	Plastic Filled (available) Wire Filled (used for tests) Constant diameter with expansion adjustment for bristle wear
Broom Material	African Bass Filled (available) Palmyra Stalk Filled (available)
Drive	Chain Drive, non reversible, constant speed
Side Brooms (Gutter)	
Diameter	32"
Broom Material	Flat Wire, or Plastic
Engine	Engine Driven Gears
Mounting	Free Floating
Control (lift)	Hydraulic
Speed	1
<u>Vacuum System</u>	
Type	Suction Type Dust Collection Through Bags
Material	Cloth Bags - 540 ft sq
Air Flow	2200 cfm
<u>Dirt Hopper</u>	
Capacity	1-3/4 cubic yards
Dump Controls	Hydraulic
Dump Doors	Rear Lift
Continued	

TABLE C.2 (Cont'd)

Physical Dimensions

Wheel Base	4' 4"
Length Overall	9' - 9-1/4"
Height	7' 2"
Width Overall	7' 4"
Weight	7600 lbs
Turning Radius	9' 2"

Airbroom (Improved for T100AB)

Type	Manifold
<u>Physical Dimensions</u>	
Length	46"
Diameter	2-1/2"
Number of Airjets	42
Jet Spring	1" center
Diameter Airjets	converging-diverging 1/16 dia throat
Mounting	Fixed
Position on Sweeper	Rear - beneath sweeper parallel to main (pickup) broom at a 45 degree angle pointing forward toward the surface
<u>Source of Airpressure</u>	
Compressor	105 cfm
Connection	50' length of high pressure hose
Adapters	2 quick fitting connectors
<u>Airpressure</u>	
Gauge before activating airbroom	100 psi
Gauge after activating airbroom	40 psi (constant)
<u>Speed</u>	
Towed with vehicle at Sweeper's speed	

TABLE C.3

OPERATING CHARACTERISTICS OF TENNANT MODEL 100 DS

Type

Manufacturer G. H. Tennant Co., Minneapolis, Minnesota
 Model No. Model 100 DS

Sweeping Speeds

<u>Transmission Gear</u>	<u>Speed Range</u>
1st	0- 5 mph
2nd	0- 10 mph
3rd	0- 15 mph
4th	0- 35 mph
Reverse	0- 5 mph

Sweeping Path

Pick up Broom 7' 3"

Broom Characteristics

Main (Pickup) Broom
 Diameter 36"
 Length 87"

Type - Adjustable expanding brush, resulting in constant diameter
 Replacement - Brush is in ten sections and may be replaced individually or in sets of ten

Broom Material Plastic
 African Bass
 Palmyra Stalk
 Wire (used for tests)

Drive Engine
 Mounting Fixed
 Control (lift) Hydraulic
 Speed (variable) 0-35 mph the same as the transmission gear speed range

Vacuum System

Type Suction-type dust collection through fabric envelopes 1180 ft² filter surface area
 Shaker Mechanism - shakes dirt into hopper - dumps with hopper

Dirt Hopper

Capacity Maximum of 4 yards
 Control Hydraulically operated dump door
 Operation Dirt load dumps at rear and is clear of machine

Dumping angle is steep enough to clean hopper of all types of dirt collected.

Physical Dimensions

Wheel Base 94"
 Length Overall 15' 3-1/8"
 Height 9' 9"
 Width Overall 96"
 Weight 20,000#
 Turning Radius 20'
 Clearance Turning Radius 21'

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3. Pavements.
4. Radioactive fallout.
5. Street cleaning apparatus.
6. Surface burst.
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- II. Cobbin, W. C.
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