ABSTRACT

A conventional motorized street flusher was evaluated as a suitable decontamination tool to be used in the operational recovery of extensive paved areas contaminated with fallout from a land-surface nuclear detonation. The selection of fallout parameters such as particle size and initial mass levels was based on a theoretical fallout model.

The flusher nozzle orientation was adjusted for maximum decontamination effectiveness. This adjustment can be applied to any flusher to be used for similar purposes. Using a fixed set of flusher adjustments and constant-size test area, the effects of 4 particle size ranges, 3 mass levels, and 2 types of surfaces on removal effectiveness were determined.

The least effective removal by flushing (2.2 g/ft^2 residual mass) for a given expenditure of effort was obtained at high initial mass loadings (100 to 600 g/ft^2) on asphalt surface using small particles (44-88 μ and 88-177 μ). The best removal effectiveness by flushing (0.06 g/ft^2 residual mass) for the same expenditure of effort was obtained using low initial mass loading (20 g/ft^2) on concrete surface with 350 to 700 μ particle sizes.

A majority of the tests conducted were in agreement with previously developed theoretical equations describing decontamination in terms of residual mass as a function of expended effort.

SUMMARY

The Problem

Reclamation of extensive paved areas contaminated with fallout from a land-surface nuclear detonation may be required. The decontamination procedure used, of the several available, depends on the particular environmental and contamination conditions in conjunction with the capabilities of the procedures. In regions where an adequate water supply is available, wet decontamination such as motorized flushing may be the primary procedure; or it may be used in combination with dry procedures as a final clean-up method. Therefore motorized flushing should be evaluated under predicted fallout conditions of mass loadings, particle sizes, and surface roughness. Variation in machine parameters such as water pressure, nozzle orientation, and speed should be tested to determine the conditions of optimum effectiveness for decontamination purposes.

Findings

Using radionuclide-traced sand to simulate dry fallout from a nuclear weapon detonation on a land surface, motorized flushing effectiveness data were obtained for one optimum combination of machine and operational parameters. This optimum combination was tested under several environmental conditions including mass levels of 20, 100, and 600 g/ft^2, and particle size ranges of 44-88 μ, 88-177 μ, 177-350 μ and 350-700 μ, on asphalt and concrete surfaces.

The effectiveness achieved depended upon the critical adjustment of flusher parameters which included nozzle orientation and nozzle pattern adjustments. The highest degree of effectiveness achieved was with low mass loadings (20 g/ft^2) on concrete surface using large particle sizes (350-700 μ and 177-350 μ). The observed rate of removal as well as final residual mass obtainable were a function of mass loading and particle size.

CONTENTS

TABLES

FIGURES

FIGURES (Cont'd)

At Operation Stoneman I[2] in 1956 conventional motorized flushing was used on dry simulated fallout at a deposited mass level of 250 g/ft^2. Water consumption rates of 0.5 gal/ft^2 were used and produced 2 % residual mass levels.

At Operation Stoneman II[3] in 1958, conventional and improvised motorized flushing were tested using dry fallout simulant at 10, 33, and 100 g/ft^2 initial deposit mass levels. Using improved nozzle adjustments and higher water pressures than before, the water consumption rates were 0.12 to 0.16 gal/ft^2 with a residual mass level from 1 to 6 % of the initial mass level.

Motorized flushing at Camp Parks in 1959 and 1960 during Target Complex Experiments I and II[4] and III[5] was an integral part of the whole recovery sequence, so that the individual effectiveness of the flusher was not determined.

Recently developed concepts of fallout environment show a relationship between deposited initial mass and particle size range.[6] These model relationships have permitted the systematic selection of simulated fallout environments for the present evaluation of a motorized street flusher for decontamination. Previous evaluations of wet decontamination procedures[3,4,5] and the recently developed concepts of fallout environment simulation[6] indicate that the present tests should attempt the following: (a) to verify previously established wet method decontamination parameter relationships or establish new relationships; and (b) to determine specifically and separately the effects of deposited mass level, particle size, and surface roughness on decontamination effectiveness.

1.2 OBJECTIVES

The present series of motorized flusher evaluation tests was intended to:

a. Measure and select the best operative conditions for available motorized street flushers, including design improvements in equipment and operational procedures.

b. Determine the decontamination effectiveness of street flushers performing at optimum operating conditions of nozzle orientation, water pressure, and forward speed in the removal of fallout simulant of various particle sizes and mass loading from paved surfaces of asphalt and concrete.

1.3 APPROACH

The broad scope of the objectives implies a large number of tests to cover all combinations of parameters for flusher and expected fallout environment. To reduce the number of tests, a fixed optimum combination of machine parameters was first established. This combination was then applied to a series of different fallout environments to determine the effect of several environmental factors in greater detail.

Optimum machine operating conditions were established as follows:

a. A single intermediate forward speed of 6 mph was selected and maintained throughout the test series. This speed provides adequate maneuvering capability and is representative of flusher operation for a majority of applications.

b. Water pressure was maintained near maximum to impart as much kinetic energy as possible to the particulate on the contaminated surface.

c. Previous experience and a series of preliminary tests were used to establish the best nozzle attitude settings, location on flusher, and use of individual or combinations of nozzles.

Several flushing techniques and sequences of techniques were tried on the test area before a uniform procedure was adopted which would permit an accurate determination of the effect of environmental factors.

Environmental factor effects were then determined as follows:

a. A special test area was constructed for environment control to permit measurement of decontamination effectiveness as reflected by residual mass, using either a material weight balance technique or a radionuclide-traced fallout simulant.

b. Equal areas of asphalt and concrete were used to determine the effects of surface roughness. Surface roughness of pavements can be indicated only in a qualitative manner on a relative basis, since there is no standardized method of comparing two surfaces in different locations. For these tests, only one concrete area and one asphalt area was used to provide an unchanging surface parameter while mass level and particle size effects were determined.

c. Four available particle size ranges were used at three initial mass levels in conformance with recently developed concepts of fallout environment.[6] Table 1.1 shows the estimated range of fallout environments

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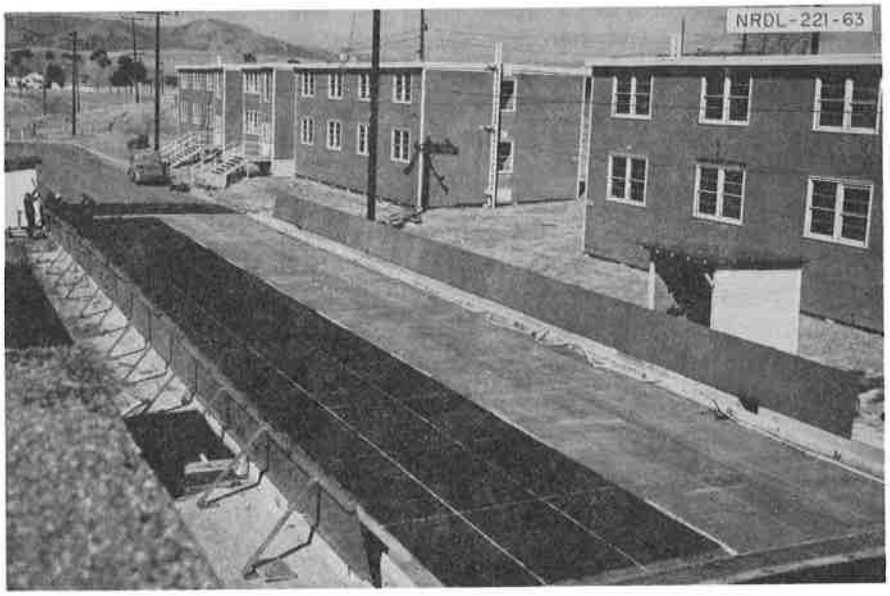

Fig. 2.1 Special Test Area for Evaluation of Wet Decontamination Procedure.

The test area was large enough to permit taking sufficient radiation readings to establish average values and to simulate a possible operational procedure for the flusher, yet it was small enough to allow carrying out the tests with a moderate amount of materials and manpower, and obtain reasonable values for water consumption per square foot.

2.2 DESCRIPTION AND ADJUSTMENT OF FLUSHER

The flusher used for the tests was a World War II vintage machine which was up-dated with a higher-capacity pump and a set of new nozzles. The features it had in common with most flushers were: (a) a large-capacity water storage tank mounted on a truck chassis and filled by hose from a fire hydrant; (b) an auxiliary engine driving a water pump to provide the required water pressure and flow for the nozzles; and (c) several nozzles with orientation adjustments and whose operation is independently controlled by the operator. Detailed specification of the machine is given in Appendix D.

Pretest speed calibration runs with the flusher resulted in the performance curves shown in Fig. 2.2. Low- and high-range rear axle settings could be used with each of the 5 forward gears. The 6-mph forward speed with the truck engine operating at 1350 rpm (transmission gear L3) was used. An engine tachometer mounted in the cab enabled the driver to maintain the exact rpm.

The design of a standard flusher nozzle was studied to determine its applicability to decontamination where high pressure and velocity with a low flow rate is desirable. Although the nozzle orifice gap could be decreased to achieve desirable results, it was decided to use newly purchased and unaltered standard nozzles at the two front nozzle positions so that the test results would be representative of commercially available and extensively used equipment. The use of a standard nozzle at the right rear position was not desirable because it provided neither sufficient pressure nor a confined stream pattern. Therefore a specially designed* nozzle was scaled up and adapted for use on the flusher. This nozzle produced a 30° included angle of spray that was a compromise between the 70° included angle of the standard flusher nozzle and the narrow stream of a standard fire nozzle. The left rear nozzle was a standard flusher nozzle used only to wash down the test area splash boards (Fig. 2.12). The flow rate vs pressure performance of each nozzle is shown in Fig. 2.3.

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*By W. L. Owen of this laboratory.

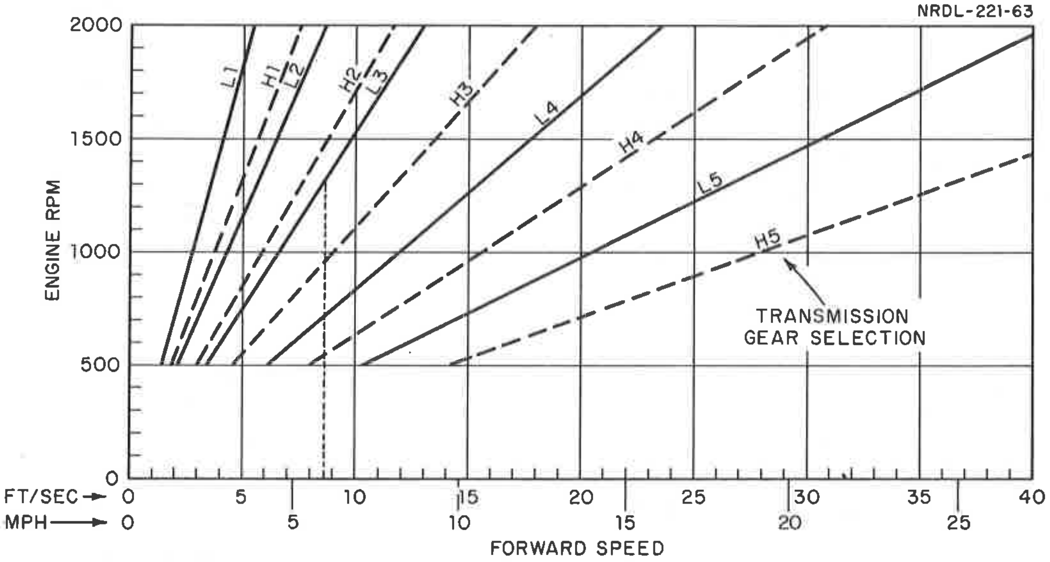


Fig. 2.2 Street Flusher Performance

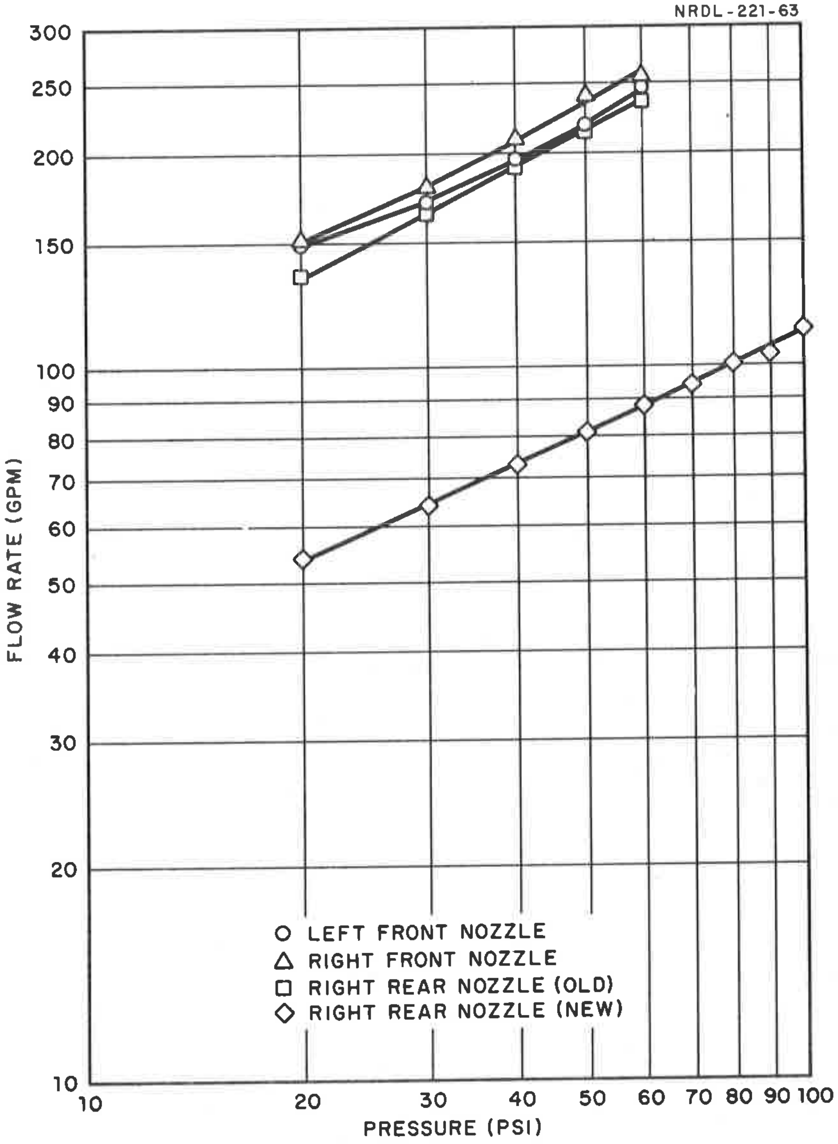


Fig. 2.3 Calibration of Nozzle Flow Rates at Pressures of Interest

Fig. 2.5 Front Nozzle Operation Showing Protractor Bar Used to Obtain Proper Nozzle Orientation. Protractor points occur every 10 degrees.

Fig. 2.6 Three-nozzle Operation at Settings Used for Evaluation Tests.

TABLE 2.1

Optimum Nozzle Settings and Pressures

Nozzle:	Left Front	Right Front	Right Rear
Dip Angle:	10°	22°	10°
Azimuth Angle:	35°	35°	15°
		Pressure (psi)	
1st Pass:	40	40	-
2nd Pass:	35	35	60
3rd Pass:	-	35	60

Note: Forward speed was constant for all passes at 6 mph.

The radionuclide La^{140} used to tag the bulk carrier material was selected for several reasons. Its energetic gamma rays minimized the shelf-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 (μc/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. Existing facilities for the preparation and handling of the La^{140} developed for other reclamation projects[4,5] were available at Camp Parks.

Coating the tagged bulk carrier with sodium silicate and baking for 1 hr at 2000°F formed a waterproof glaze which assured that the activity remained fixed to the bulk carrier so that it was not transferred to the test surface.

2.4 DISPERSAL OF FALLOUT SIMULANT

One of the criteria imposed upon the test conditions was a uniformly dispersed initial mass of fallout simulant on the test area. The mass loading depended upon the fallout environment being simulated.

Uniform dispersal was achieved by using a calibrated, hand-operated garden spreader (Fig. 2.7; O. M. Scott and Sons, Marysville, Ohio). The average initial mass level was determined by weighing the spreaders before dispersal and again afterwards. The uniformity of dispersal was visually better than that achieved previously with a dump truck.

2.5 MEASUREMENT TECHNIQUE

All measurement instrumentation was given an adequate warm-up period, and background and calibration readings were made whenever test measurements were made.

Simulant property measurements were made with Rotap machine (W. S. Tyler Co., Cleveland, Ohio) and standard Tyler sieves. Six sieves and a pan, nested with graduated mesh sizes, were thoroughly rotapped for 10 min to separate a 100-g sample into sieved fractions. Each fraction was weighed and its activity measured in the 4-pi ionization chamber (Fig. 2.8) to determine its specific activity (μc/g). The properties of each batch mixed are tabulated in Appendix B. Microscopic examination of the sieve fractions was also used to determine the size distribution as well as shape, and uniformity of the simulant batches.

Machine variables of forward speed, nozzle water pressure, and operational decontamination procedures were controlled for uniformity in all tests using activity. Forward speed was measured with a cab-mounted engine tachometer. Nozzle water pressure was measured by probes at each nozzle. The probes were manifolded to a pressure gauge in the cab where the pressure was manually controlled by the pump engine throttle. Duplication of operational decontamination procedures for each test was assured by operator pretest training and familiarization; and by external direction as the tests were being run.

Radiation measurements were made by a specially built mobile, shielded, gamma scintillation detector (Fig. 2.9). The radiation detection element was a NaI (Tl) scintillation crystal (1 in. diameter by 1 in. thick) that was coupled to a photomultiplier tube, all contained within a 6-in.-thick lead shield. A collimated aperature 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 procedure was determined by comparing radiation measurements before and after each event.

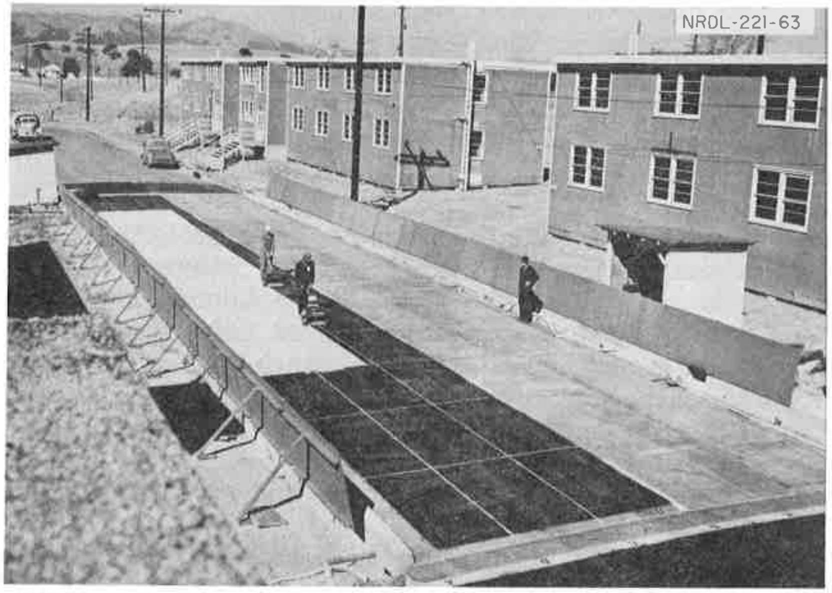


Fig. 2.7 Dispersal of Synthetic Fallout on Test Area by Hand-pulled Garden Spreader.

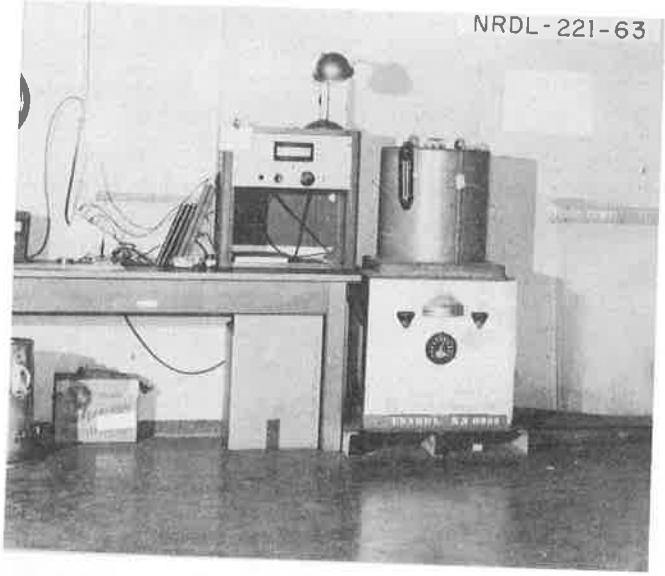


Fig. 2.8 4-pi Ionization Chamber

Fig. 2.9 Measuring Radiation Intensity of Synthetic Fallout with Scintillation Counter and Hand-held Radiac.

Reliability in the measurements made with the shielded detector was provided for by recording a series of two 1-minute counts in the following sequence:

a. Count a Co^{60} radiation standard, to determine the overall response of the instrument.

b. Count a sample from the synthetic fallout simulant batch to check simulant decay.

c. Count at each of the monitoring stations on the test area to collect data.

d. Repeat steps a and b as a further check on instrument response and decay.

The above four-step sequence was carried out for each test to measure the background, initial mass, and mass remaining after successive flushing passes. Time of day was recorded for each pair of counts to facilitate decay correction.

Hand-held portable radiacs, ANPDR-39 (T1B), were used as a check on the mobile shielded detector and for general monitoring purposes, such as controlling radiation dosage to personnel during preparation and dispersal of the simulant.

The 4-pi ionization chamber was used to assay the gross and sieved samples of the fallout simulant. It also followed the radioactive decay of each simulant batch as a check on radionuclide purity.

2.6 TEST PROCEDURE

Each of the tests with radioactive fallout simulant was conducted on a concrete or asphalt surface at initial mass level, particle size range, forward speed, and operational sequence required by the test conditions as follows:

a. Radiation background measurements were made as described in Section 2.5.

b. Synthetic fallout material of the desired particle size range and mass level was dispersed over an area 15.5 x 90 ft, as described in Section 2.4.

c. Initial mass level radiation measurement were made as described in Section 2.5.

d. One flushing cycle of the entire test area was made, consisting of 3 passes (as shown in Fig. 2.10) and described as follows:

1. First pass at crown of half-contaminated street, using both front nozzles at 40 psi to flush contaminant forward and toward the gutter.
2. Second pass alongside the gutter using 3 nozzles (Fig. 2.11), front nozzles at 35 psi and right rear nozzle at 60 psi, with a slight overlap of area cleaned on first pass.
3. Third pass in the gutter against the curb using two nozzles, right front at 35 psi and right rear at 60 psi, to flush material into catch basin or beyond test area.
4. All material flushed beyond test area was washed by firehose to catch basins and sumps, so that it would not contribute to radiation readings on test area. Contaminant was flushed from side boards into drain ditches as shown in Fig. 2.12, using left rear nozzle.

e. Radiation measurements were made as in Section 2.5.

f. Second flushing cycle was completed as in (d).

g. Final radiation was measured as in Section 2.5.

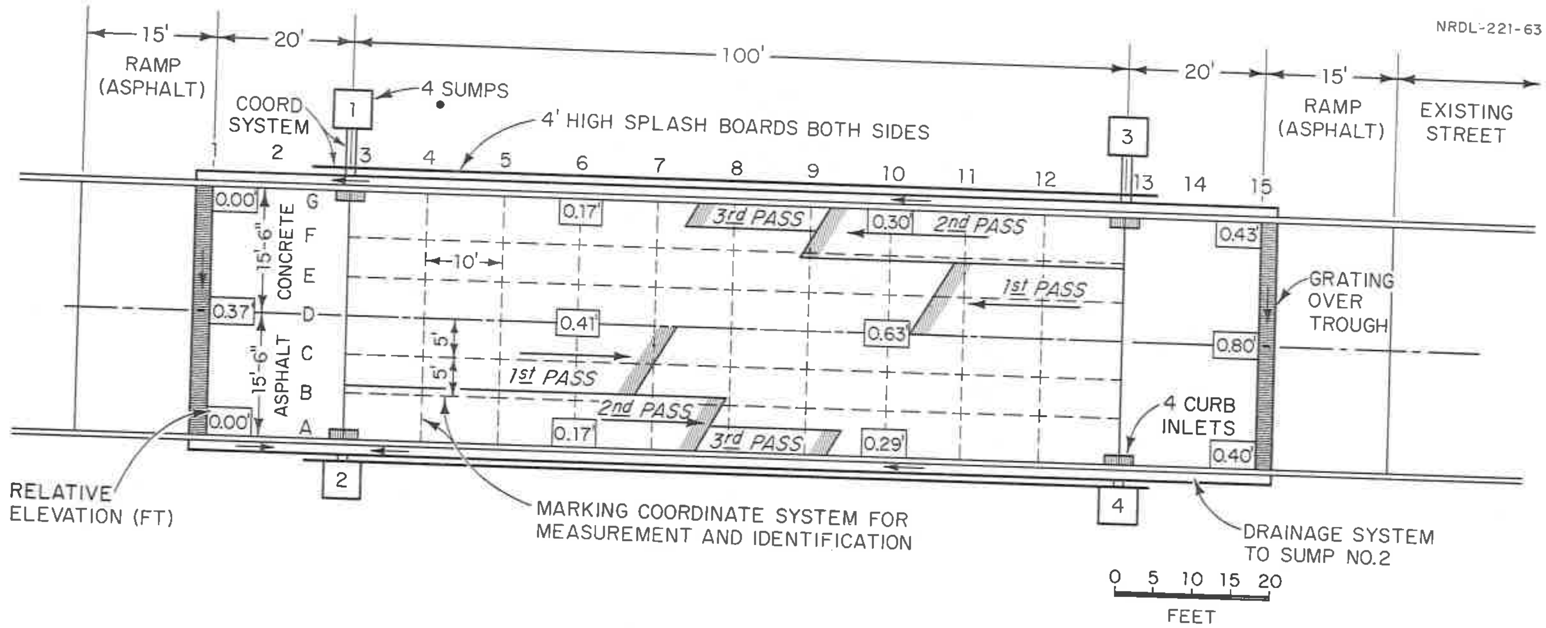


Fig. 2.10 Plan of Test Area Showing Contaminant Control Features and Flusher Pass Sequence.

Fig. 2.11 Second Flushing Pass at Curb Using Three Nozzles.

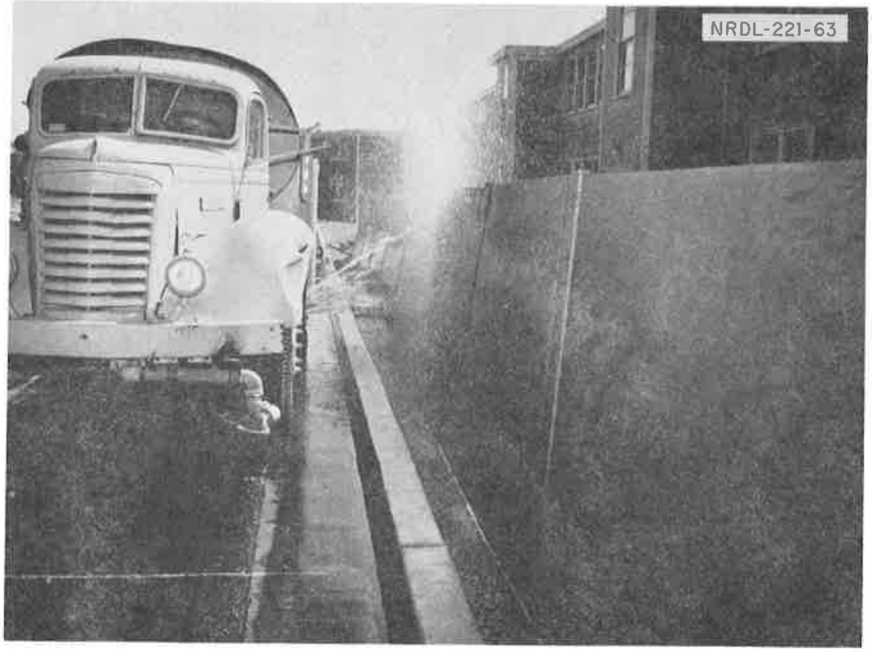


Fig. 2.12 Flushing Contaminant From Side Splash Boards into Drain Ditch Before Taking Radiation Reading on Test Surface.

CHAPTER 3

RESULTS AND DISCUSSION

The variation of effort that can be applied by a motorized flusher is infinite, within the limits of the ranges of the machine parameters of forward speed, water pressure, nozzle orientation, and of the operational procedures of nozzle usage and coverage of the area to be decontaminated. All the machine parameters and operational procedures were determined and held constant for the tests as described in Section 2.2 because of the limited scope of this test series. Under these test conditions distinct levels of effort were applied to the surface as defined by integral numbers of three-pass flushing cycles (Section 2.2) over the test area.

Effort is defined as being inversely proportional to the forward speed (or directly proportional to the time spent covering a given area). The relationship can be represented mathematically as:

$$E = \frac{K}{S}$$

where E = effort in equipment-min/10^4 ft^2
S = forward speed in ft/min
and K is the proportionality factor.

In Reference 7 (the sweeper report), relative effort, RE, is defined as the ratio of actual effort E to a standard effort, which is shown to be equivalent to the expression

$$RE = \frac{1200}{S} \qquad (3.1)$$

where 1200 is an arbitrary speed selected to give RE values greater than unity. Using this relationship the work described here can be more easily compared with that of other tests - for instance, sweeper results in Reference 7*.

---

*Such a comparison is shown in Section 3.6.

The test condition prescribed a constant flusher speed of 6 mph or 528 ft/min. Therefore,

$$\text{RE (flusher)} = \frac{1200}{528} = 2.27$$

As long as the forward speed is held constant, 2.27 will be the RE for a complete coverage of the test area. For two coverages the RE will equal 2 x 2.27 = 4.54.

It was explained earlier in Section 2.6 that one coverage required a three pass flushing cycle. With a pass width of 9 ft (total frontal width of flushing pattern for 3 nozzles), the single pass rate would be 9 x 528 = 4752 ft^2/min. However, the test strip is 15.5 ft wide and three passes are required for complete coverage. Therefore an average pass width is 15.5/3 or 5.2 ft, and the average flushing rate is only 5.2 x 528 or 2746 ft^2/min.

Relative effort RE, then, is a function of speed only. It indicates neither the actual cleaning rate nor the absolute effort required. These two quantities are dependent upon the configuration of the area cleaned and upon the build-up of material which requires successive flushing passes to clear the remaining area. In addition, any allowances made for turn-around losses, tank-filling and post-flushing of redeposited material for ultimate disposal will further reduce the above rate estimates.

Using test conditions with fixed machine parameters, identical procedures were used to conduct 22 tests. The results of these tests are summarized in Table 3.1. The fallout environments simulated are given in terms of particle size and initial mass level; two surfaces, asphalt and concrete were used; and residual mass levels were computed from radiation readings as described in Appendix C. Corrected radiation measurements for all tests are given in Table C.1.

3.1 COMPARISON OF TESTS

The test results in Table 3.1 can be used for graphical presentation of data or to verify previously developed equations for the performance of wet decontamination methods. Using relative efforts as defined in Eq. 3.1 and corresponding residual mass levels determined from radiation measurements, Figs. 3.1 through 3.21 were plotted in three groups to show the effects of particle size, mass loading, and surface roughness on decontamination effectiveness.

TABLE 3.1

Residual Mass Levels (g/ft^2) Attained by Flusher for Various Fallout Conditions

		Residual Mass (g/ft^2) Particle Size (μ)										
		44-88μ		88-177μ			177-350μ				350-700μ	
	Cycle*	Initial Mass Level g/ft^2										
		20	100	20	100	600	20**		100**		20	1.00
Asphalt	1	0.56	0.70	0.75	1.09	65.74	0.20	0.21	1.71	0.74	0.15	3.70
	2	0.42	0.32	0.48	0.66	2.20	0.03	0.11	0.00	0.20	0.055	0.26
Concrete	1	0.31	1.17	0.23	1.74	32.61	0.74	0.11	1.10	0.70	0.082	1.22
	2	0.27	1.09	0.22	0.80	1.76	0.21	0.088	0.23	0.24	0.057	0.14

* One cycle equals a three-pass flushing operation.

**For the 177-350μ particle size range duplicate tests were conducted.

Figs. 3.1-3.4

Comparisons of Effects of Particle Size on the Decontamination Performance of a Conventional Motorized Street Flusher, Using Test Procedures Described in Section 2.6.

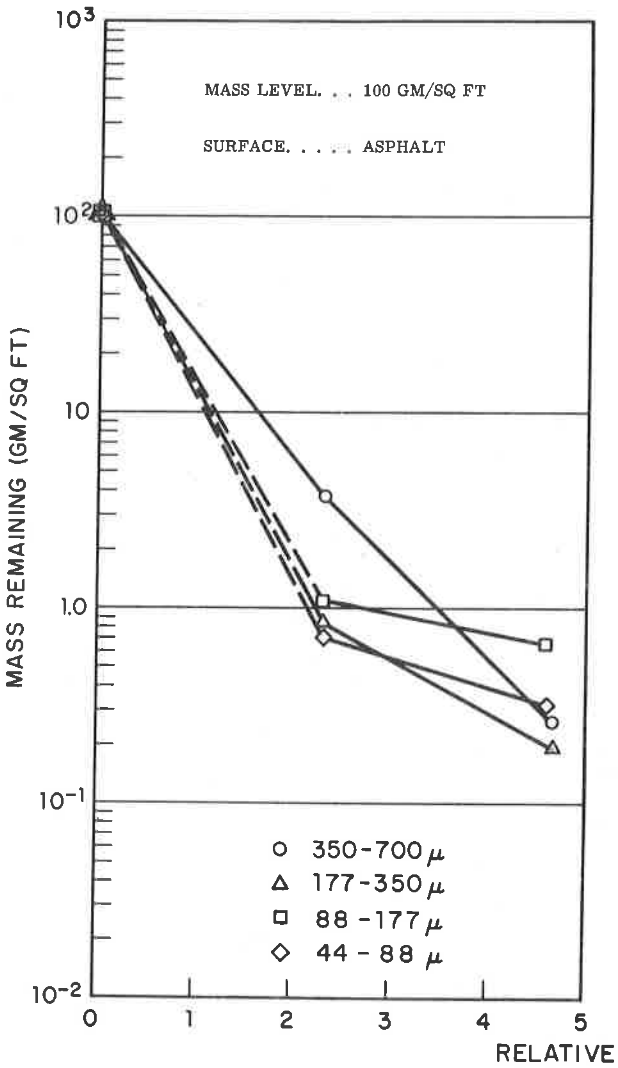

10^3
10^2
10
1.0
10^{-1}
10^{-2}
MASS REMAINING (GM/SQ FT)
MASS LEVEL. . . 100 GM/SQ FT
SURFACE. . . . . ASPHALT
○ 350-700 μ
△ 177-350 μ
□ 88 -177 μ
◇ 44 - 88 μ
0
1
2
3
4
5
RELATIVE EFFORT

Fig. 3.1

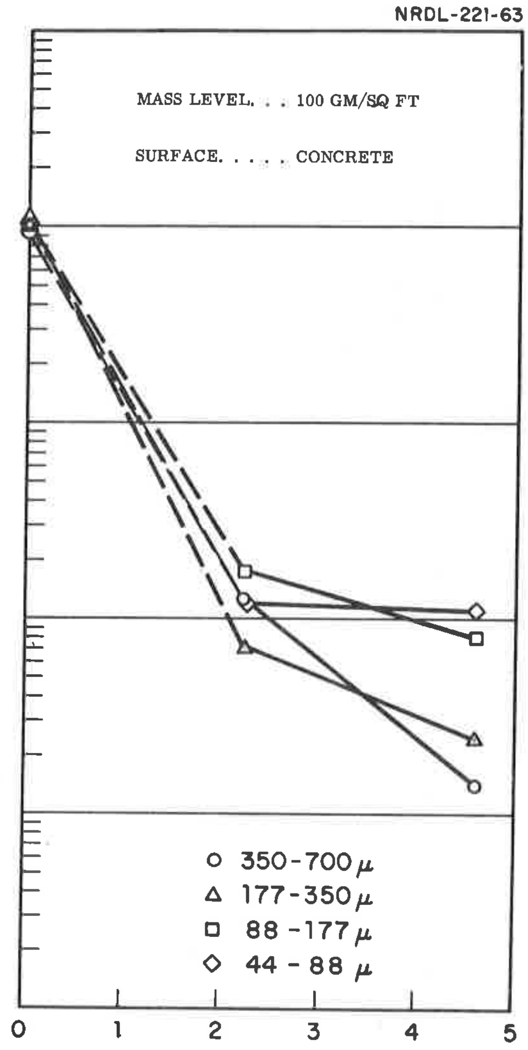
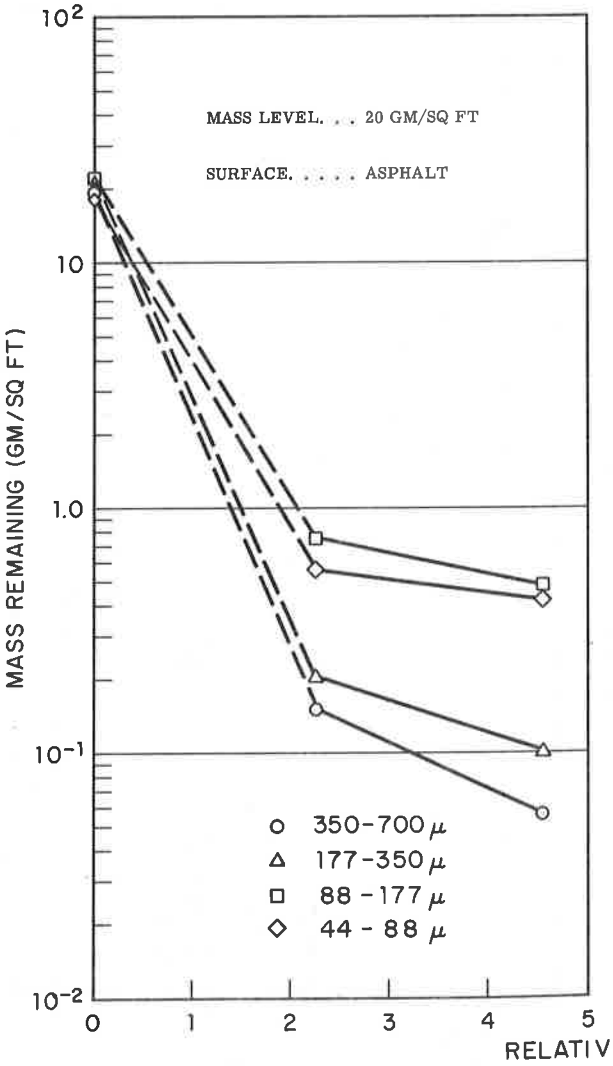
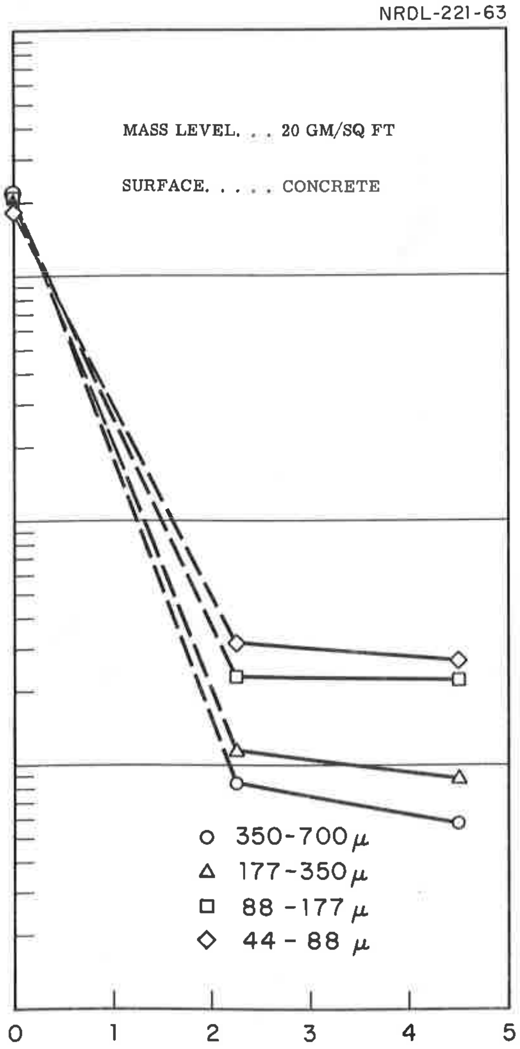

NRDL-221-63
MASS LEVEL. . . 100 GM/SQ FT
SURFACE. . . . . CONCRETE
○ 350-700 μ
△ 177-350 μ
□ 88 -177 μ
◇ 44 - 88 μ
0
1
2
3
4
5

Fig. 3.2



MASS LEVEL. . . 20 GM/SQ FT
SURFACE. . . . . ASPHALT
MASS REMAINING (GM/SQ FT)
10^2
10
1.0
10^{-1}
10^{-2}
0
1
2
3
4
5
RELATIVE EFFORT
○ 350-700 μ
△ 177-350 μ
□ 88 - 177 μ
◇ 44 - 88 μ

Fig. 3.3



NRDL-221-63
MASS LEVEL. . . 20 GM/SQ FT
SURFACE. . . . . CONCRETE
0
1
2
3
4
5
○ 350-700 μ
△ 177-350 μ
□ 88 - 177 μ
◇ 44 - 88 μ

Fig. 3.4

Figs. 3.5-3.12

Comparisons of Effects of Initial Mass Levels on the Decontamination Performance of a Conventional Motorized Street Flusher, Using Test Procedures Described in Section 2.6.

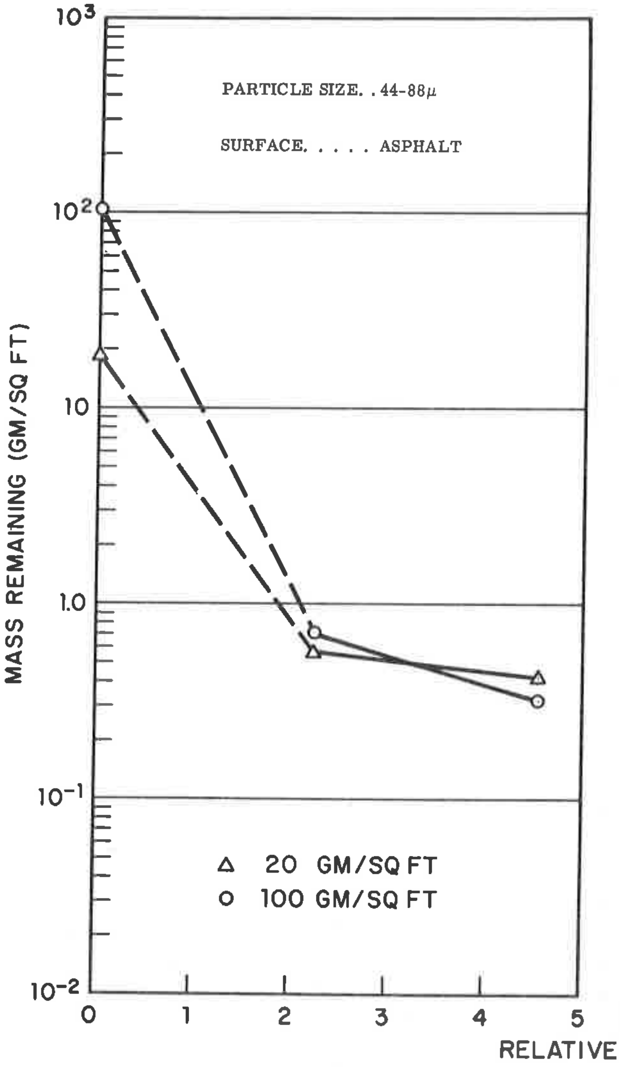

10³
10²
10
1.0
10⁻¹
10⁻²
MASS REMAINING (GM/SQ FT)
PARTICLE SIZE. . 44-88μ
SURFACE. . . . . ASPHALT
△ 20 GM/SQ FT
○ 100 GM/SQ FT
0
1
2
3
4
5
RELATIVE EFFORT

Fig. 3.5

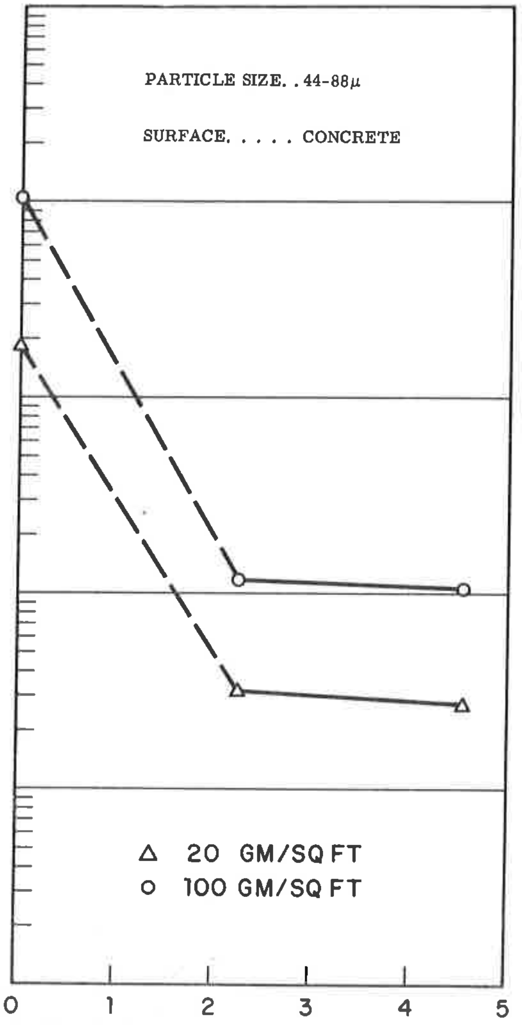

PARTICLE SIZE. . 44-88μ
SURFACE. . . . . CONCRETE
△ 20 GM/SQ FT
○ 100 GM/SQ FT
0
1
2
3
4
5

Fig. 3.6

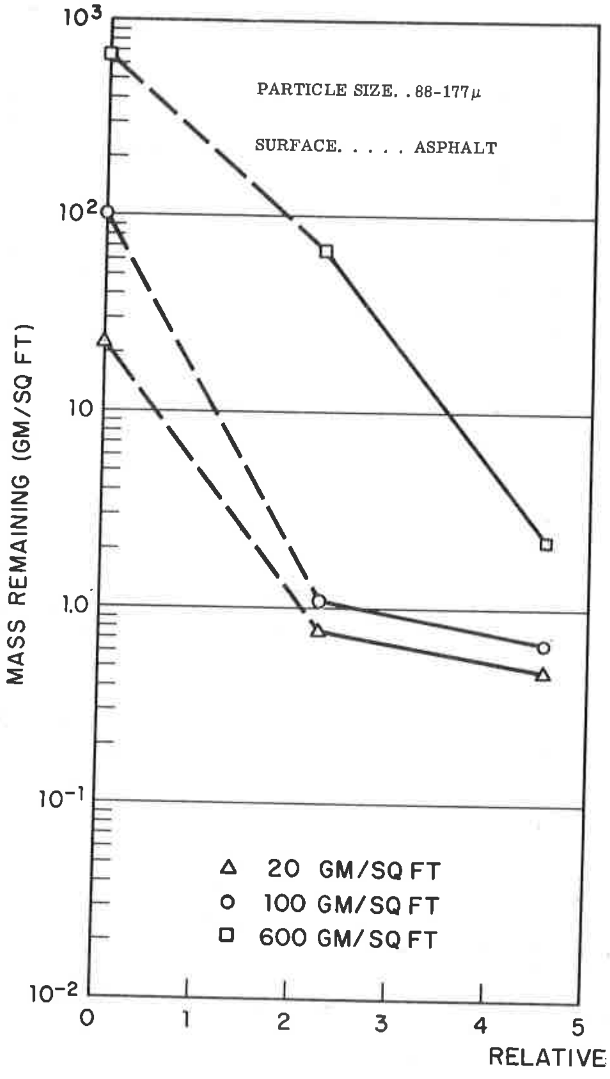

10^3
10^2
10
1.0
10^-1
10^-2
MASS REMAINING (GM/SQ FT)
PARTICLE SIZE. . 88-177μ
SURFACE. . . . . ASPHALT
△ 20 GM/SQ FT
○ 100 GM/SQ FT
□ 600 GM/SQ FT
0
1
2
3
4
5
RELATIVE EFFORT

Fig. 3.7

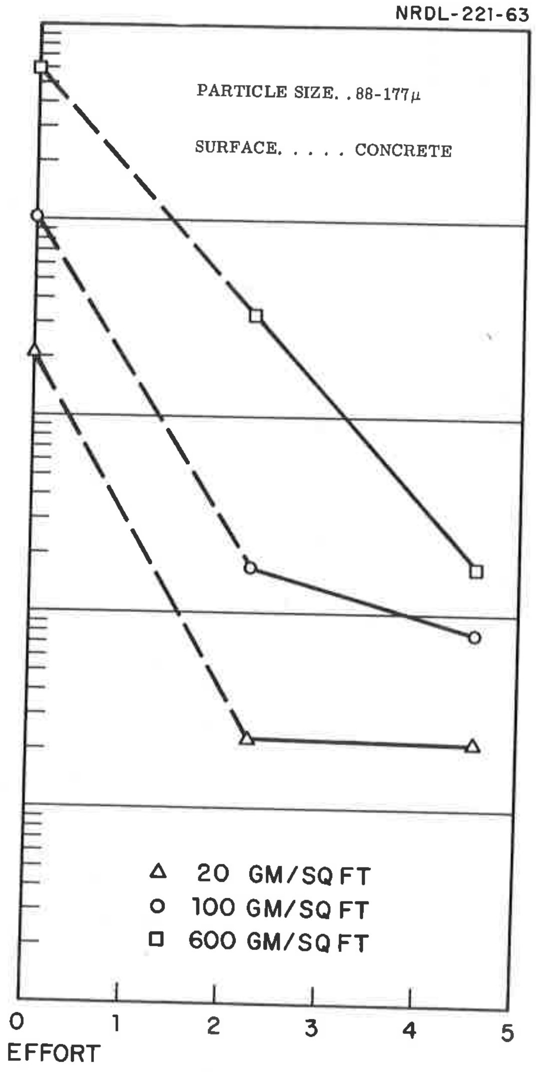

NRDL-221-63
PARTICLE SIZE. . 88-177μ
SURFACE. . . . . CONCRETE
△ 20 GM/SQ FT
○ 100 GM/SQ FT
□ 600 GM/SQ FT
0
1
2
3
4
5

Fig. 3.8

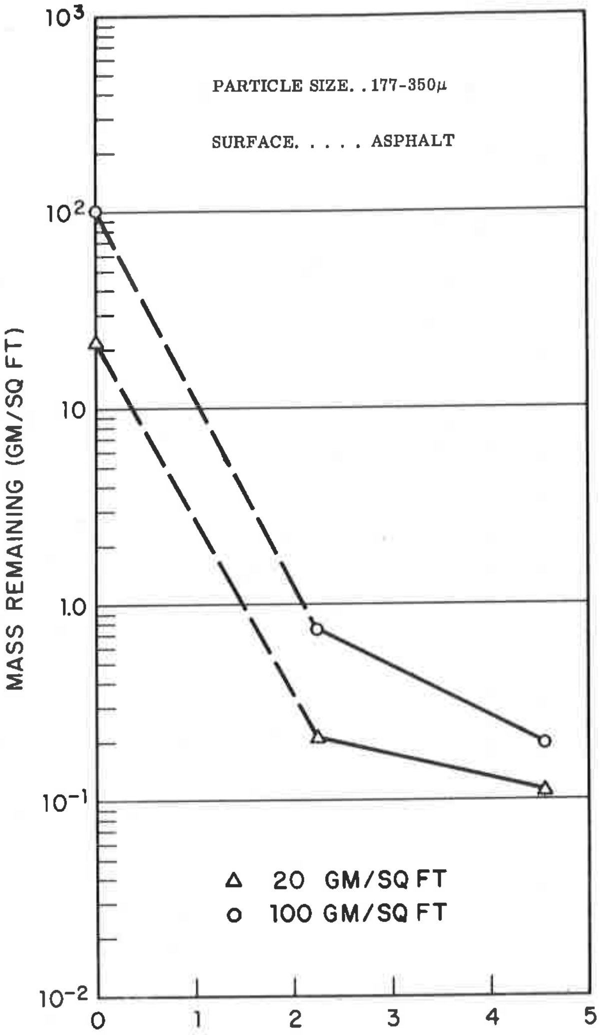


Fig. 3.9

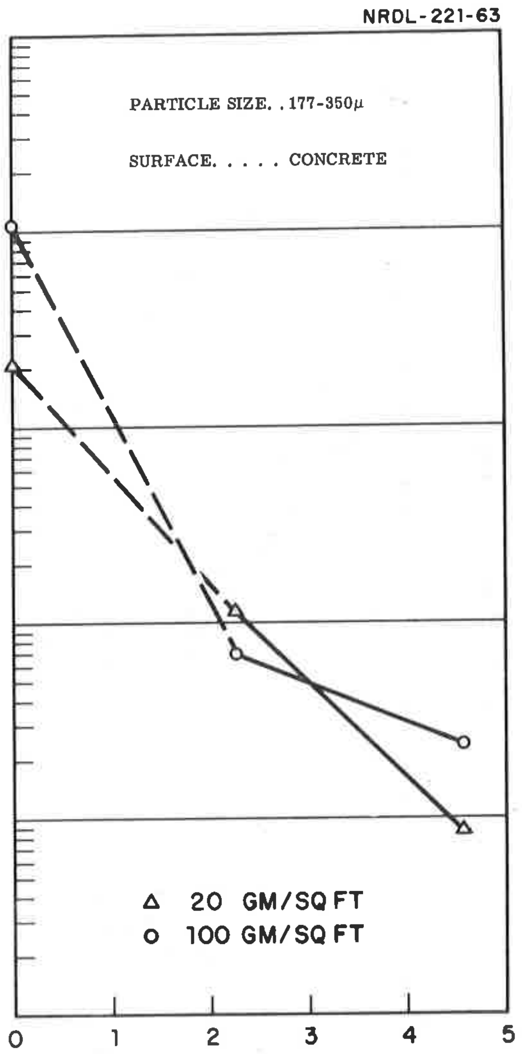


Fig. 3.10

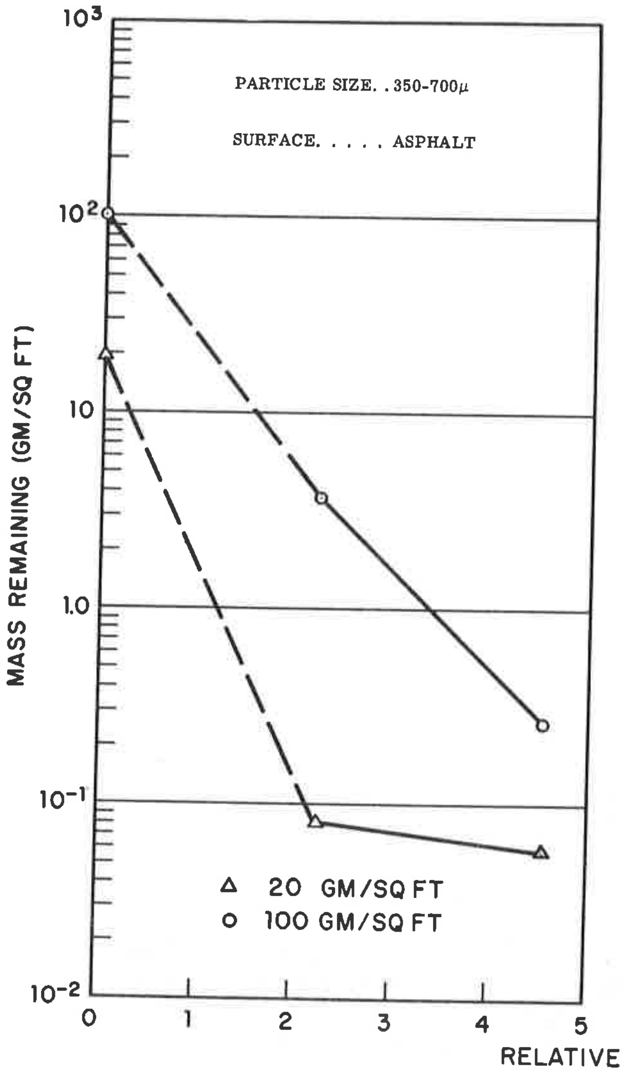


Fig. 3.11

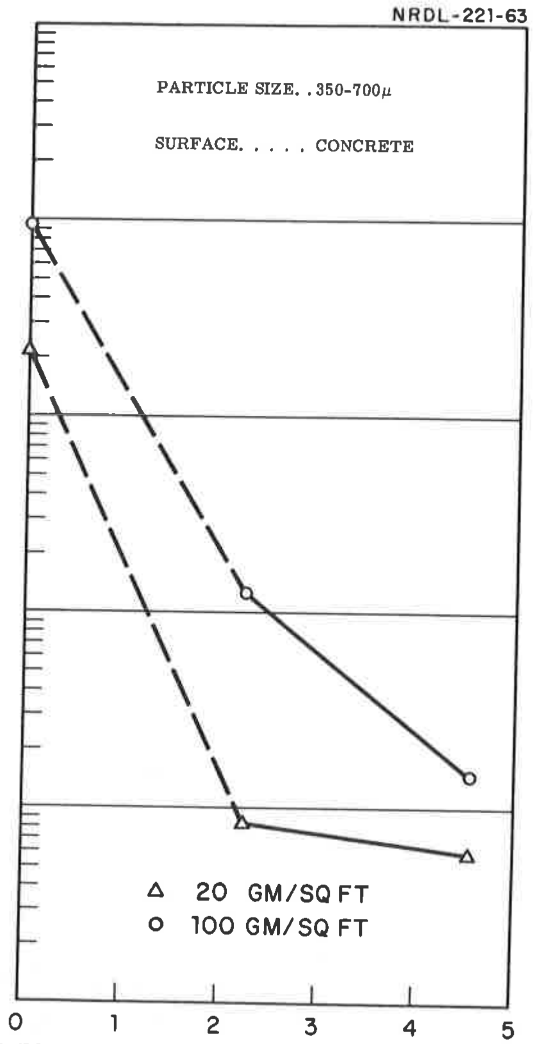


Fig. 3.12

Figs. 3.13-3.21

Comparisons of the Effects of Surface Roughness on the Decontamination Performance of a Conventional Motorized Street Flusher, Using Test Procedures Described in Section 2.6.

NRDL-221-63

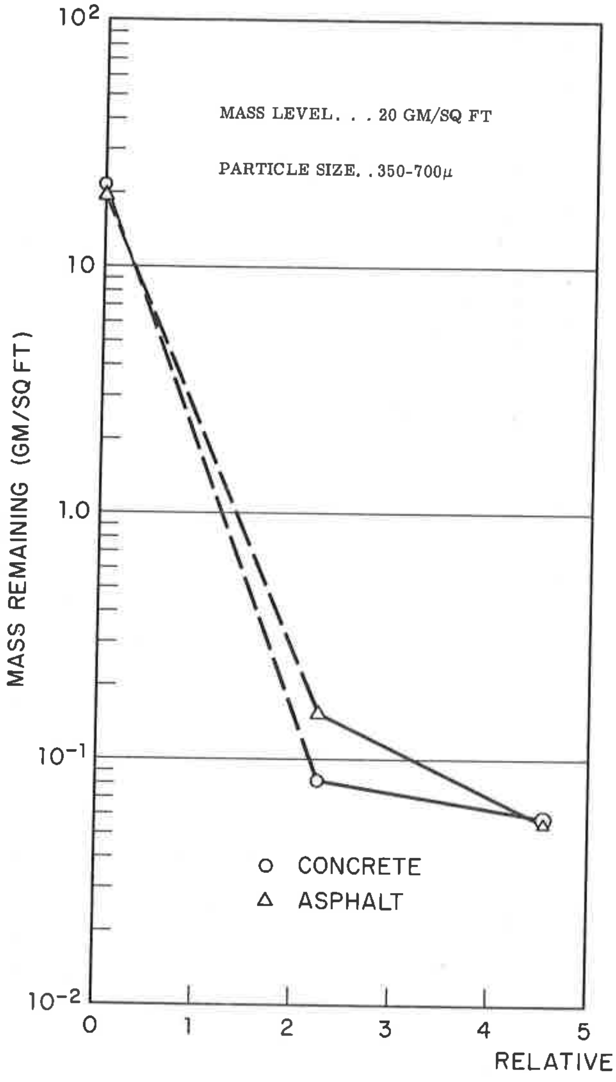


Fig. 3.13

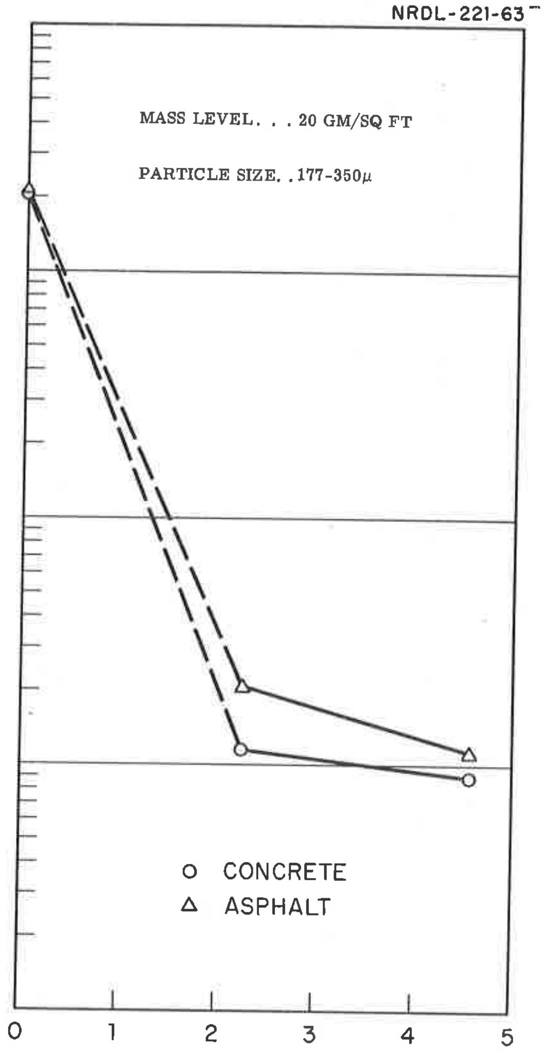


Fig. 3.14

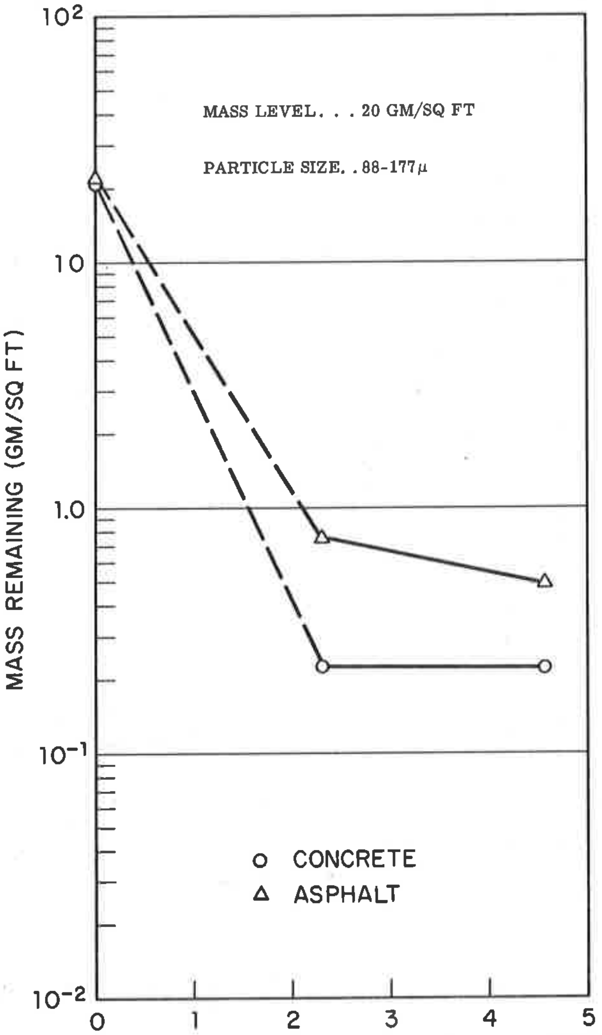


Fig. 3.15

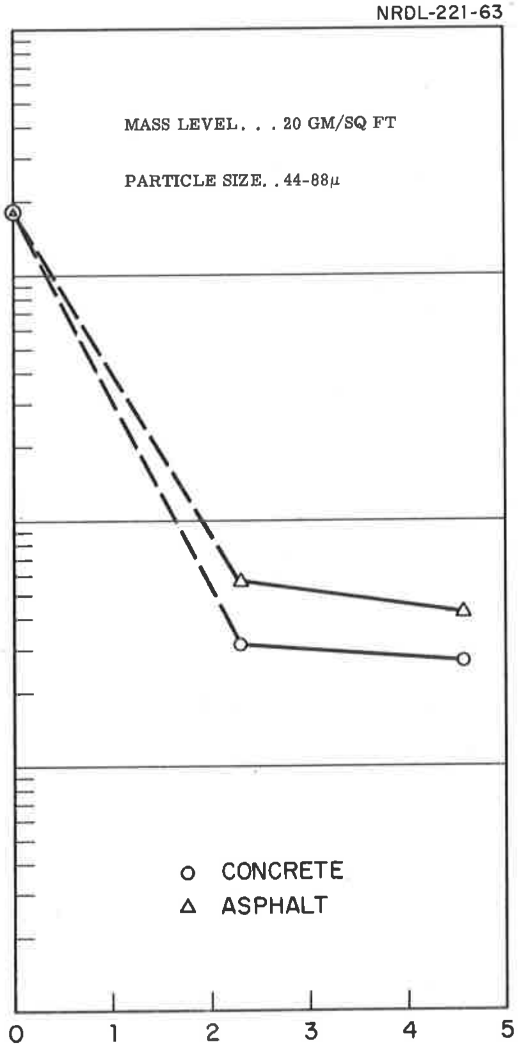


Fig. 3.16

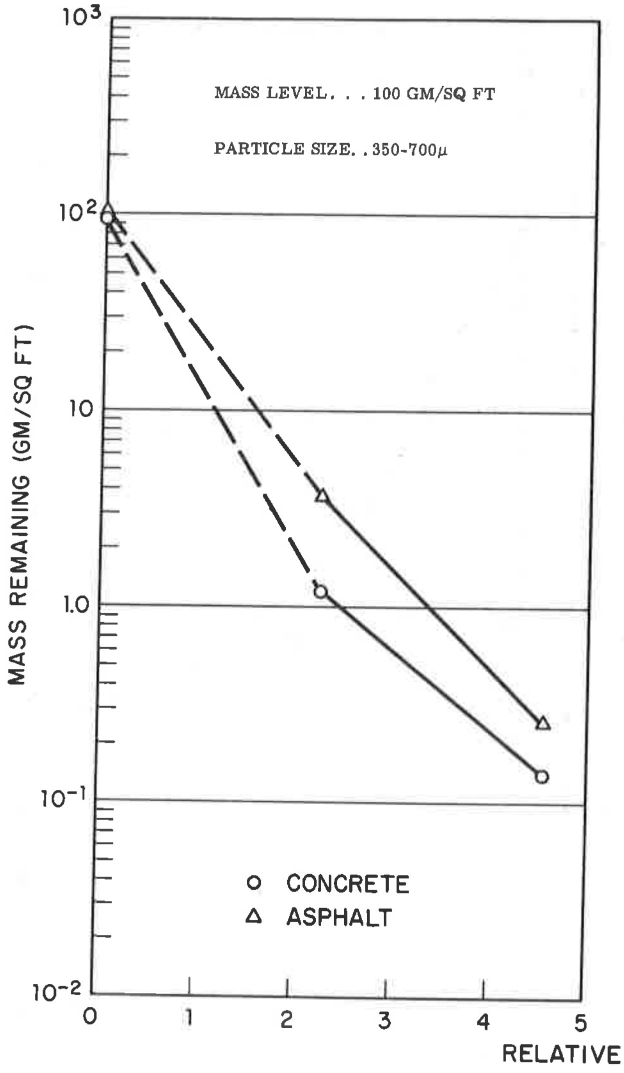


Fig. 3.17

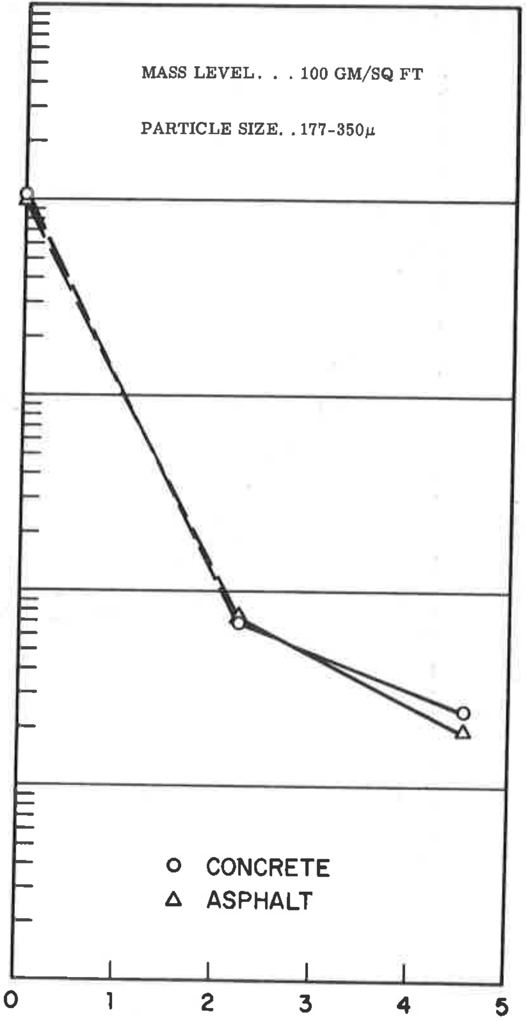


Fig. 3.18

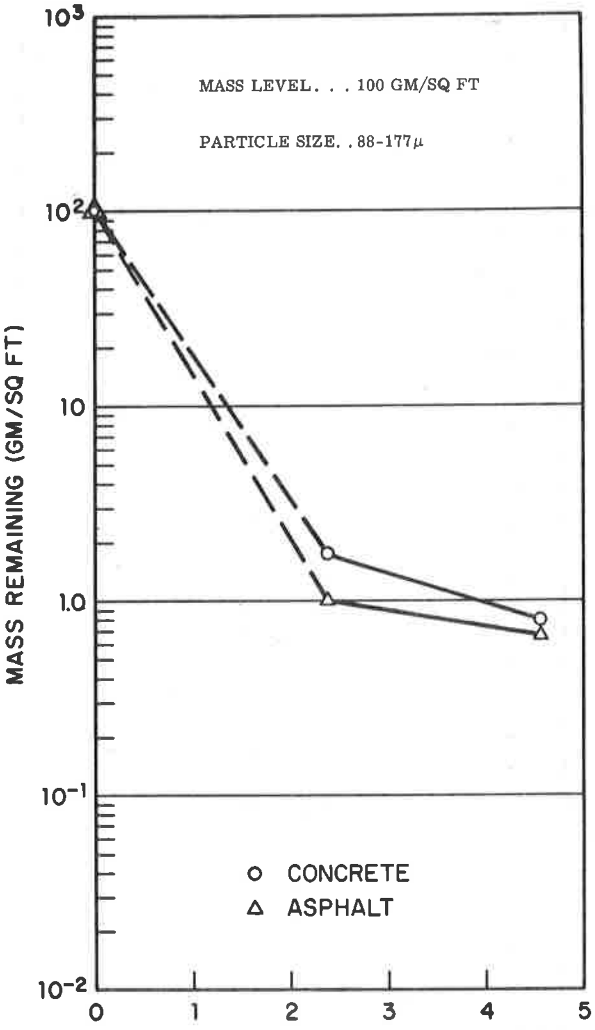


Fig. 3.19

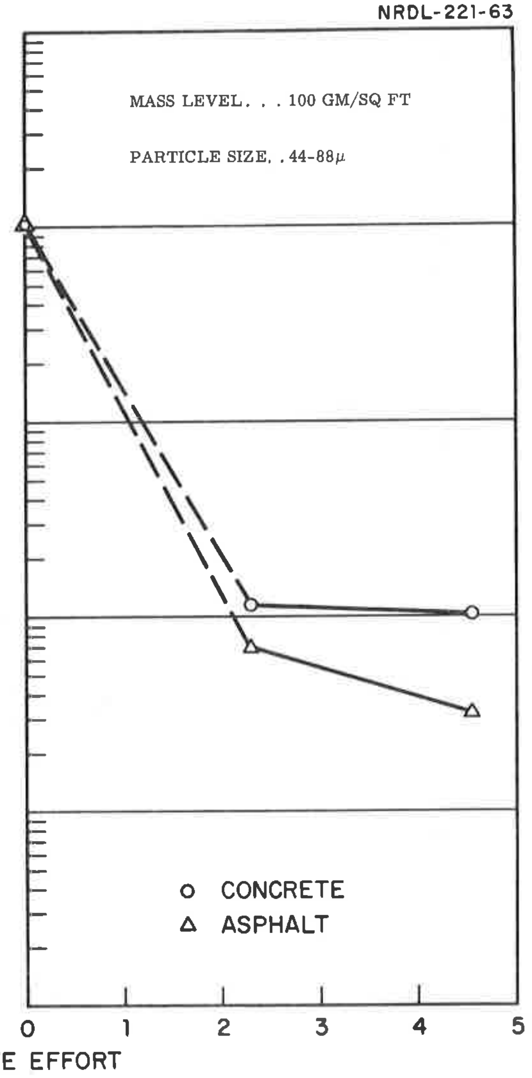


Fig. 3.20

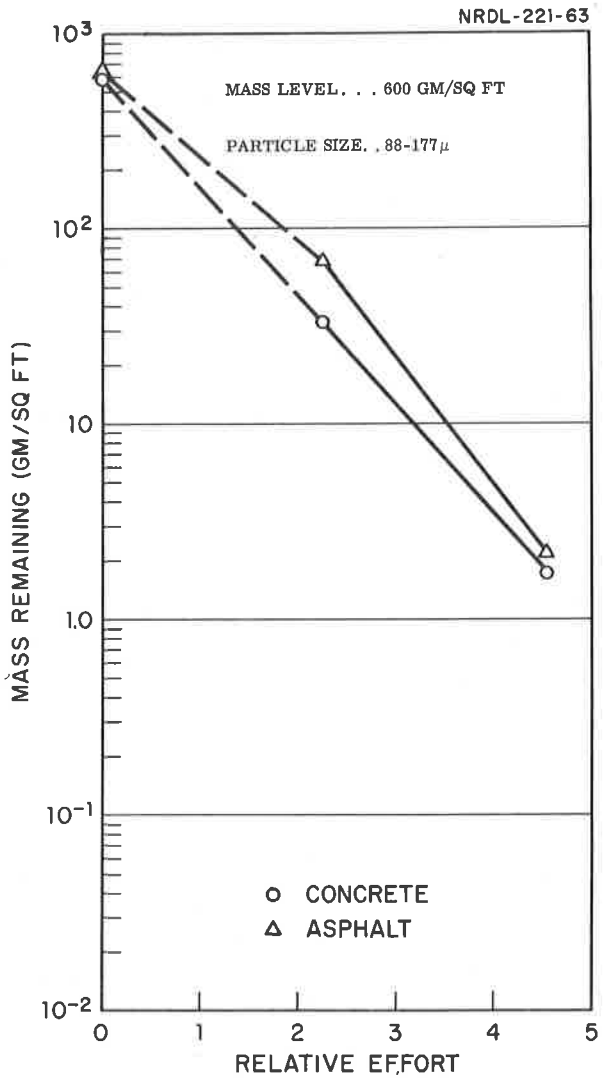

NRDL-221-63
MASS LEVEL. . . 600 GM/SQ FT
PARTICLE SIZE. . 88-177μ
MASS REMAINING (GM/SQ FT)
10^3
10^2
10
1.0
10^-1
10^-2
0
1
2
3
4
5
RELATIVE EFFORT
○ CONCRETE
△ ASPHALT

Fig. 3.21

Only two data points appear for each test representing the residual mass after the 1st and 2nd cleaning cycles (each cleaning cycle representing three passes) so the shape of a smooth curve which fits the data could not be drawn. All conclusions drawn from these curves are for limited data from specific test conditions.

3.2 EFFECTS OF PARTICLE SIZE, MASS LEVELS AND SURFACE TYPE

Particle Size effects on decontamination are shown in Figs. 3.1-3.4. In all tests conducted the smallest particles were more difficult to remove than the largest particles. In Fig. 3.1 and 3.3 for asphalt surfaces, an inversion in the order of particle size vs. residual mass is seen: the 44-88μ particle size shows a lower residual mass than the 88-177μ particle size and the 177-350μ particle sizes (Fig. 3.1) shows a lower residual mass than the 350-700μ particle size. Although the removal effectiveness indicates inconsistencies due to flusher steering errors in the experimental results, the results as a whole shows small particles to be more difficult to remove than large particles at the same effort expenditure.

High initial mass levels consistently showed a greater residual mass level than lower mass levels after the same effort expenditure. Figures 3.5-3.11 show the effects of initial mass on the decontamination effectiveness of conventional motorized flushing. In addition to the problem of moving a higher mass per unit area, the build-up of material flushed to adjacent areas further compounds the mass removal problem, as described in Section 3.5 and discussed further in Section 3.6.

Surface type effects on decontamination effectiveness were not as conclusive as expected, due to the deterioration of the concrete surface prior to and during the evaluation studies using radioactive simulant. The concrete test surface had deep cracks at the expansion joints, and several rough spots were formed due to disintegration of the concrete. However, of the 9 tests conducted to allow comparison of surface type vs. effort, 5 showed that concrete was less difficult to clean than asphalt. One test showed about the same difficulty, and three tests showed asphalt to be less difficult to clean than concrete. The last three results were no doubt due to the contaminant retained in the large expansion joint cracks. An example of this effect can be seen in Fig. 3.20. Note the residual mass 1.2 g/ft^2 remaining after the first pass and the 1.02 g/ft^2 remaining after the second pass. The flatness of the curve indicates that a large amount of effort would be required to reach the same residual mass as attained on the asphalt surface.

It should be emphasized that although general conclusions may be drawn on particle size, mass level, and surface type effects, they are the results from only one set of flusher adjustments.

3.3 WATER CONSUMPTION

The water consumption rate was 0.14 gal/ft^2 for each complete 3-pass cleaning cycle used in the flusher evaluation tests. This rate is similar to that of previous tests mentioned in Section 1.1 but applies only to the present test procedure. Other flushing procedures would require different consumption rates. An ideal flushing situation, where a single, 9-ft-wide path at higher speed (12 mph) is adequate, could have a water consumption rate of 0.032 gal/ft^2 using the two front nozzles. At the other extreme, a heavy mass loading on a large area would require a slower speed, multiple passes, and manual firehose clean-up after flushing. This extreme situation might be handled more expeditiously by a different or combination method, with flushing being the final clean-up of low residual mass achieved by another method such as sweeping.

3.4 EXPERIMENTAL ERROR

The results of duplicate tests shown in Table 3.1 vary by as much as a factor of 7. The differences are due almost entirely to variations in operating techniques (mainly directional control of the flusher truck) from test to test. The accuracy of direct measurements was ± 3 % for forward speed, ± 5 % for initial mass level, and ± 15 % for the radiation measurements used to determine residual mass level, thus these items did not contribute significantly to observed differences.

Some error was introduced into the residual mass level measurements for several reasons: (a) As shown in Fig. B.1 (Appendix B) the specific activity increased for smaller particles within a given particle size range. (b) However flushing selectively removed the larger particles more readily than the smaller and more active particles within a particle size range. Therefore, calculations of residual mass M based on radiation measurements will be conservative (too high).

For instance, residual mass is calculated from the expression

$$M = M_o \frac{R}{I_o}$$

where M_o = initial mass loading, g/ft^2
R = residual radiation reading, mr/hr
I_o = initial radiation reading, mr/hr

For the above-noted reasons, the residual radiation reading R will be high, since a disproportionate amount of small but more radioactive particles will be left after flushing. Therefore the estimates of mass will also be high.

Specific activity varied by a factor of 3 within each size range of fallout simulant used, but the relatively narrow size ranges (a factor of 2) permitted a valid determination of the effect of particle size on flushing effectiveness.

Transfer of activity from the simulant to the test surfaces by leaching or ion exchange contributed less than 0.1 % error to the measurements and was therefore ignored as a source of experimental error.

Form line cracks in the concrete surface retained some simulant and produced some localized high radiation readings. These radiation readings were deleted from calculations as indicated in Appendix C. However, the frequency of random surface cracks at monitoring stations was not sufficient to create a serious bias in the data when these readings were averaged with the rest of the stations to obtain a representative residual reading for the whole test surface.

3.5 FLUSHING THEORY

Previous wet decontamination evaluation studies derived the following equation:

$$M = M^* + (M_o - M^*)\ e^{-3K_oE^{1/3}} \tag{3.2}$$

where M is the residual mass (g/ft^2) after finite effort expenditure E.
M^* is the residual mass (g/ft^2) at an infinite effort level
M_o is the initial mass level (g/ft^2)
K_o is the proportionality constant expressing removal rate
E is the effort expended (equipment $min/10^4\ ft^2$)
$e^{-3K_oE^{1/3}}$ is the fraction of removable mass remaining after expending the effort, E.

Equation 3.2 was solved for each test using data values of M, M_o, and E, and making successive approximations for M* and K_o for a fit through the data points on an M vs E plot (see Fig. 3.22 for such a plot). The existence of only two data points and a limited number of tests for each surface-method combination made it impossible to evaluate other previously derived equations[3] relating initial mass to residual mass at infinite effort for a given decontamination method.

Of 22 test runs, 13 listed in Table 3.2 provided data which could be fitted to equation 3.2. The variation of ultimate residual mass attainable (M*) and rate of mass removal (K_o) are consistent with results presented graphically in Section 3.1. The M* values indicate small particles are more difficult to remove than large particles, concrete surfaces have lower residual mass than asphalt for the same test condition, and higher initial mass levels require more effort to achieve the same residual mass level. The K_o values show faster removal rate for concrete surfaces and lower mass levels. No clear cut trend of removal rates with respect to particle size was indicated.

3.6 COMPARISON OF MOTORIZED STREET FLUSHING AND MOTORIZED STREET SWEEPING

Figure 3.22 compares the relative performance of street flushing with street sweeping methods. Test results were taken for like conditions of mass loading, particle size and surface type. Each curve was plotted according to its respective cleaning equation.

From the distinct separation between the curves, it appears that flushing is the superior method. However, comparing these two performances in this manner assumes both methods carry out their respective cleaning task to a similar state of completeness. This occurs only in one particular situation, the reclaiming of open roadways where flushing does not create a disposal problem.

It is more likely that sweepers and flushers will be operating on streets bordered by curbs or on extensive areas such as parking lots and industrial aprons. Under these conditions flushers usually cannot do a complete job of reclamation. As the work progresses the flusher will eventually reach the point where it can no longer push aside the mass build-up of fallout material. A secondary method is then required to get rid of this accumulation of spoil.

TABLE 3.2

Fit of Equation 3.2 to Test Data

Test Conditions		Equation 3.2 Parameters	
Test No.	Initial Mass M_o (g/ft^2)	$-3K_o$ $\left(\frac{10^4\ ft^2}{\text{equip min}}\right)^{1/3}$	M^* (g/ft^2)
C-20-W	21.5	4.25	0.051
A-20-W	19.5	3.24	0.019
C-20-X	20.7	4.31	0.083
A-20-X	21.8	3.29	0.073
C-100-X	107.4	3.34	0.076
C-20-Y	21.0	4.85	0.218
A-20-Y	22.1	2.56	0.328
C-100-Y	102.2	2.79	0.353
A-100-Y	101.9	3.34	0.507
A-20-Z	18.4	2.91	0.356
C-100-Z	102.5	4.52	1.074
C-20-Z	18.6	3.81	0.259
A-100-A	103.5	3.45	0.192

Notes:

Test Code is: surface type - nominal initial mass - particle size

A = Asphalt
C = Concrete
W = 350-700μ

X = 177-350μ
Y = 88-177μ
Z = 44-88 μ

Equation 3.2: $M = M^* + (M_o - M^*)\ e^{-3K_oE^{1/3}}$

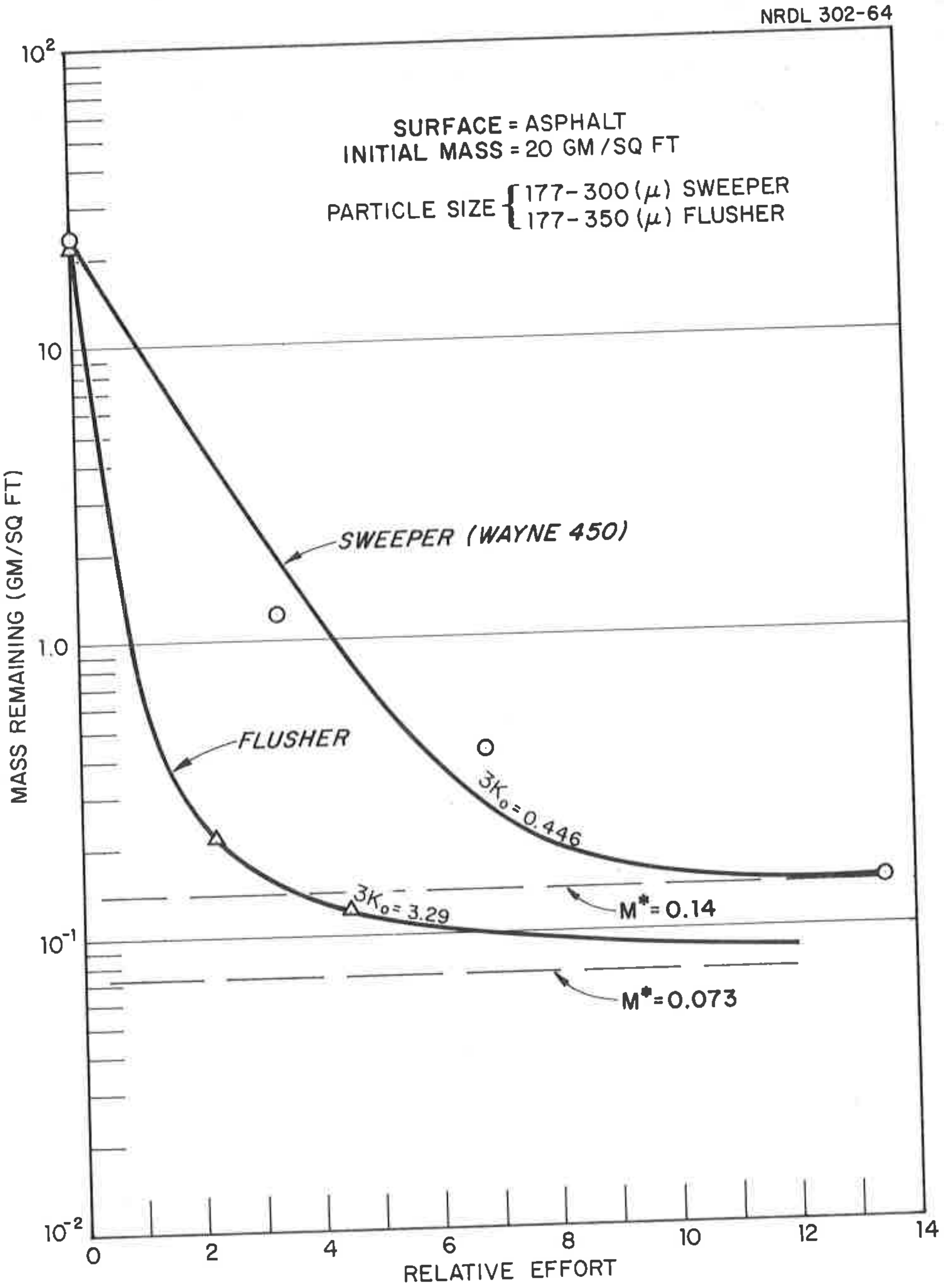


Fig. 3.22 Comparison of Cleaning Performances of Motorized Street Sweeping and Motorized Street Flushing.

For this more general situation, a comparison of the above curves is misleading, since the flusher curve does not take into account the additional effort required to complete the reclamation of a given area. Thus, comparisons of these or similar pairs of method performance curves must not be made without consideration of the inherent differences between methods.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Previously developed theoretical decontamination equations fit data for a majority of the tests. With the exception of some of the factors related to removal rate (K_O), good agreement was found between the equation and the data. The conclusions suggested by the test results are presented below.

The systematic procedure for adjustment and orientation of the nozzles described in Section 2.2 can be applied beneficially to any motorized flusher to achieve optimum decontamination performance.

Under the test conditions used, mass level had the greatest influence on flushing effectiveness. Particle size had the next greatest effect and surface type had the least effect. Some variations in uniformity of distribution were noted on the concrete surface when form lines accumulated the material. Under comparable test conditions, high initial mass levels were harder to remove than low initial mass levels, small particles were harder to remove than large particles, and rough asphalt surfaces retained a greater residual mass than smooth concrete surfaces.

Motorized flushing is an effective decontamination procedure for recovery of extensive areas if the following problems are recognized and overcome: (a) a possible shortage of water; (b) an insufficient number of flushers; (c) the accumulation of flushed material due to high initial mass level and/or the accelerated build-up of flushed material in an extensive area having a low initial mass level; and (d) the safe handling and ultimate disposal of the flushed material.

The consumption rates attained in the present evaluation tests are ideal from the standpoint of water economy in that only consumption on the test area was measured. Higher consumption rates under less carefully planned and executed procedures could easily increase the rate by a factor of two or three, making the procedure impractical if the water supply were marginal.

TABLE B.2

Physical and Radiological Properties of Fallout Simulant Batch No. 2 Having a Nominal Particle Size Range 177 μ to 350 μ

Sieve Size		Weight Analysis (%)		Radioactivity Analysis (%)
U.S. Mesh	Microns	Raw Material	Tagged Material	
40	417	0.4	0.6	0.4
45	350	1.5	2.6	1.3
50	295	8.1	9.3	5.3
60	246	22.7	25.7	16.4
80	177	41.9	45.1	40.3
100	149	17.8	12.0	22.8
Pan	-149	7.6	4.7	13.5
Totals		100.00	100.00	100.00
Date Batch Mixed		9/6/61		
Specific Activity (μc/g) at Mixing Time		6.9		

TABLE B.3

Physical and Radiological Properties of Fallout Simulant Batch No. 3 Having a Nominal Particle Size Range 88 μ to 177 μ

Sieve Size		Weight Analysis (%)		Radioactivity Analysis (%)
U.S. Mesh	Microns	Raw Material	Tagged Material	
70	208	0.9	0.8	0.9
80	177	1.3	1.3	1.8
100	149	10.6	28.6	25.7
120	124	25.6	25.8	21.1
170	88	52.8	40.7	42.2
200	74	7.9	2.6	7.3
Pan	-74	0.9	0.2	1.0
Totals		100.00	100.00	100.00

Date Batch Mixed 9/27/61

Specific Activity (μc/g) at Mixing Time 9.7

TABLE C-1

CORRECTED RAW DATA FOR MOTORIZED FLUSHING

TEST NO C-20-Y
DATE 10/21/61
SURFACE TYPE CONCRETE

INITIAL MASS 20.99 (g/Ft²)
ZERO TIME 9/27/1200
PARTICLE SIZE 88-177 (μ)
SPEED 6 mi (hr)
AREA SIZE 1395 (Ft²)

INITIAL READINGS (C/m)

183078	186259	ND	170024	162472	166456	154408	ND
△	△	△	△	△	△	△	△
129116	ND	ND	142727	139801	137311	148606	ND
△	△	△	△	△	△	△	△

CYCLE NO. 1 (C/m)

1204	1345	ND	1440	1651	736	975	ND
△	△	△	△	△	△	△	△
1615	ND	ND	2117	2544	2874	2196	ND
△	△	△	△	△	△	△	△

CYCLE NO. 2 (C/m)

1280	1386	ND	1356	1368	1072	850	ND
△	△	△	△	△	△	△	△
1636	ND	ND	1683	2457	3205	2091	ND
△	△	△	△	△	△	△	△

TEST NO A-20-Y
DATE 10/2-3/61
SURFACE TYPE ASPHALT

INITIAL MASS 22.13 (g/Ft²)
ZERO TIME 9/27/1200
SPEED 6 mi (hr)
PARTICLE SIZE 88-177 (μ)
AREA SIZE 1395 (Ft²)

INITIAL READINGS (C/m)

159816	159315	161172	152891	172562	176997	161987	191196
△	△	△	△	△	△	△	△
185793	190723	193410	173266	190066	184900	171423	186091
△	△	△	△	△	△	△	△

CYCLE NO. 1 (C/m)

4027	4821	4891	6217	6179	6477	4869	7661
△	△	△	△	△	△	△	△
6477	6550	2726	4484	9073	6604	3345	10760
△	△	△	△	△	△	△	△

CYCLE NO. 2 (C/m)

3468	4484	4434	4516	5177	5384	4276	5761
△	△	△	△	△	△	△	△
2941	3669	2121	2690	3797	2696	2181	3893
△	△	△	△	△	△	△	△

TABLE C-1

CORRECTED RAW DATA FOR MOTORIZED FLUSHING

TEST NO C-20-Z
DATE 10/12/61
INITIAL MASS 18,55 (g/Ft.²)
ZERO TIME 10/6/1200

SURFACE TYPE CONCRETE
PARTICLE SIZE 44-88 (μ)
SPEED 6 mi (hr)
AREA SIZE 1395 (Ft.²)

INITIAL READINGS (C/m)

164969 Δ 153819 Δ	164262 Δ ND Δ	ND Δ ND Δ	178519 Δ 143871 Δ	168033 Δ 136875 Δ	171762 Δ 135922 Δ	165710 Δ 125545 Δ	ND Δ ND Δ

CYCLE NO. 1 (C/m)

2260 Δ 2600 Δ	2133 Δ ND Δ	ND Δ ND Δ	2065 Δ 3082 Δ	2830 Δ 3751 Δ	1552 Δ 4304 Δ	2220 Δ 3119 Δ	ND Δ ND Δ

CYCLE NO. 2 (C/m)

2191 Δ 2185 Δ	2315 Δ ND Δ	ND Δ ND Δ	1734 Δ 2225 Δ	2154 Δ 3066 Δ	1503 Δ 3609 Δ	1649 Δ 2275 Δ	ND Δ ND Δ

TEST NO A-20-Z
DATE 10/11/61
INITIAL MASS 18,39 (g/Ft.²)
ZERO TIME 10/6/1200

SURFACE TYPE ASPHALT
SPEED 6 mi (hr)
PARTICLE SIZE 44-88 (μ)
AREA SIZE 1395 (Ft.²)

INITIAL READINGS (C/m)

132052 Δ 107467 Δ	130914 Δ 128367 Δ	105114 Δ 109029 Δ	90720 Δ 110952 Δ	127164 Δ 115516 Δ	130663 Δ 134868 Δ	119843 Δ 124913 Δ	134741 Δ 144015 Δ

CYCLE NO. 1 (C/m)

1395 Δ 2246 Δ	3130 Δ 4148 Δ	2979 Δ 5587 Δ	1670 Δ 3947 Δ	3210 Δ 3631 Δ	5426 Δ 4471 Δ	4507 Δ 2972 Δ	6198 Δ 3519 Δ

CYCLE NO. 2 (C/m)

731 Δ 1648 Δ	1951 Δ 2866 Δ	2095 Δ 3814 Δ	1169 Δ 3658 Δ	2748 Δ 3251 Δ	4349 Δ 3280 Δ	3327 Δ 2513 Δ	5059 Δ 2296 Δ

TABLE C-1

CORRECTED RAW DATA FOR MOTORIZED FLUSHING

TEST NO C-100-X-(C) dup.
DATE 8/17/60

SURFACE TYPE CONCRETE

INITIAL MASS 101.9 (g. Ft.^{2})

ZERO TIME 8/7/1200

PARTICLE SIZE 177-350 (μ)
SPEED 6 mi. (hr)
AREA SIZE 1395 (Ft.^{2})

INITIAL READINGS (C/m)

2910589 △ 3310747 △	2812092 △ ND △	ND △ ND △	2811081 △ 2996713 △	2757438 △ 2978785 △	2663442 △ 3292489 △	2602443 △ 3292489 △	ND △ ND △

CYCLE NO. 1 (C/m)

69772 △ 118511 △	84043 △ ND △	ND △ ND △	17126 △ 11048 △	10289 △ 18466 △	6989 △ 7050 △	3704 △ 5143 △	ND △ ND △

CYCLE NO. 2 (C/m)

6171 △ 10754 △	5209 △ ND △	ND △ ND △	7156 △ 7326 △	8348 △ 13615 △	5010 △ 4201 △	2880 △ 3689 △	ND △ ND △

TEST NO A-100-X (D) dup.
DATE 8/16/60

SURFACE TYPE ASPHALT

SPEED 6 mi. (hr)

INITIAL MASS 108.7 (g. Ft.^{2})
ZERO TIME 8/7/1200

PARTICLE SIZE 177-350 (μ)
AREA SIZE 1395 (Ft.^{2})

INITIAL READINGS (C/m)

3498044 △ 2939659 △	3841350 △ 3022256 △	3892894 △ 2957247 △	3760336 △ 2811350 △	3747781 △ 2821927 △	3761611 △ 3245749 △	3729143 △ 2663310 △	3732146 △ 3078872 △

CYCLE NO. 1 (C/m)

4227 △ 7950 △	12190 △ 25170 △	12208 △ 15052 △	13640 △ 14764 △	16034 △ 27588 △	18433 △ 142942 △	51119 △ 40960 △	378785 △ 116767 △

CYCLE NO. 2 (C/m)

2153 △ 1090 △	1763 △ 2806 △	4251 △ 2353 △	2343 △ 1341 △	0 △ 2714 △	0 △ 2513 △	0 △ 1470 △	4235 △ 0 △

APPENDIX D

STREET FLUSHER SPECIFICATIONS

Truck: GMC Model M73
6-cylinder gasoline engine, 97 hp at 3450 RPM
6-10.00X20 12 ply tires - single at front; dual at rear
13,500 lb gross weight empty
28,500 lb gross wt w/2000 gal water

Tank: 2000 gal capacity, oval cross-section, steel, electrically welded, flat front head, internally braced w/baffle plates
18 in. diameter manhole w/gasket
overload indicator float
3 in. diameter overflow
2-1/2 diameter firehose filler w/coupling and swivel connection

Power Pump Unit: Mounted between tank and truck cab, with engine choke, ignition and starter switch in cab
Engine: Continental, 6-cylinder, gasoline, water cooled 86 hp at 3250 RPM
Pump: Centrifugal, 500 GPM at 40 psi

Nozzles: Standard bronze 2-piece horizontally split slot type 2-1/2 in. flushing nozzles - swivel, adjustable and hand locked in position or angle of spray.
The two at front used in tests - one at left rear used for cleanup of test area side splash boards.
Special water broom brass type scaled up to 1-1/2 in. size from 1 in. firehose type developed by W. L. Owen of NRDL for firehose decontamination studies.

Valves: 2 in. size individually controlled by lever - cable system from cab for any operating combination.

Piping: 2-1/2 in. diameter manifolded from pump outlet through valves to nozzles.

Naval Radiological Defense Laboratory
USNRDL-TR-797
REMOVAL OF SIMULATED FALLOUT FROM PAVEMENTS BY CONVENTIONAL STREET FLUSHERS, by D. E. Clark, Jr., and W. C. Cobbin 18 June 1964 84 p. tables illus. 7 refs. UNCLASSIFIED

A conventional motorized street flusher was evaluated as a suitable decontamination tool to be used in the operational recovery of extensive paved areas contaminated with fallout from a land-surface nuclear detonation. The selection of fallout parameters such as particle size and initial mass levels was based on a theoretical fallout model.

The flusher nozzle orientation
(over)

1. Radioactive fallout.
2. Street cleaning apparatus.
3. Pavements.
4. Decontamination.
5. Cleaning.
6. Surface bursts.

I. Clark, D. E.
II. Cobbin, W. C.
III. Title.
IV.

UNCLASSIFIED

was adjusted for maximum decontamination effectiveness. This adjustment can be applied to any flusher to be used for similar purposes. Using a fixed set of flusher adjustments and constant-size test area, the effects of 4 particle size ranges, 3 mass levels, and 2 types of surfaces on removal effectiveness were determined.

The least effective removal by flushing (2.2 g/ft^2 residual mass) for a given expenditure of effort was obtained at high initial mass loadings (100 to 600 g/ft^2) on asphalt surface using small particles (44-88 μ and 88-177 μ). The best removal effectiveness by flushing (0.06 g/ft^2 residual mass) for the same expenditure of effort was obtained using low initial mass loading (20 g/ft^2) on concrete surface with 350 to 700 μ particle sizes.

A majority of the tests conducted were in agreement with previously developed theoretical equations describing decontamination in terms of residual mass as a function of expended effort.

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was adjusted for maximum decontamination effectiveness. This adjustment can be applied to any flusher to be used for similar purposes. Using a fixed set of flusher adjustments and constant-size test area, the effects of 4 particle size ranges, 3 mass levels, and 2 types of surfaces on removal effectiveness were determined.

The least effective removal by flushing (2.2 g/ft^2 residual mass) for a given expenditure of effort was obtained at high initial mass loadings (100 to 600 g/ft^2) on asphalt surface using small particles (44-88 μ and 88-177 μ). The best removal effectiveness by flushing (0.06 g/ft^2 residual mass) for the same expenditure of effort was obtained using low initial mass loading (20 g/ft^2) on concrete surface with 350 to 700 μ particle sizes.

A majority of the tests conducted were in agreement with previously developed theoretical equations describing decontamination in terms of residual mass as a function of expended effort.

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