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Particle Size Distribution on Surfaces in Clean Rooms

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30 April 1984

Final Report

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Experimental particle size distributions on surfaces in clean rooms, resulting from the gravity settling of airborne particulates (fallout), are presented and found to be significantly different from the distributions described by Military Standard 1246A. Theoretical surface size distributions, based on fallout from a Federal Standard 209B airborne particle distribution, are derived and show good correlation with experimental data. Further experimental data and analysis are

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provided to show that surface cleaning tends to make a particle size distribution resulting from fallout approach the MIL-STD-1246A distribution. Recommendations are made to limit the use of MIL-STD-1246A, when specifying surface cleanliness levels, to surfaces that have been cleaned after exposure to fallout.

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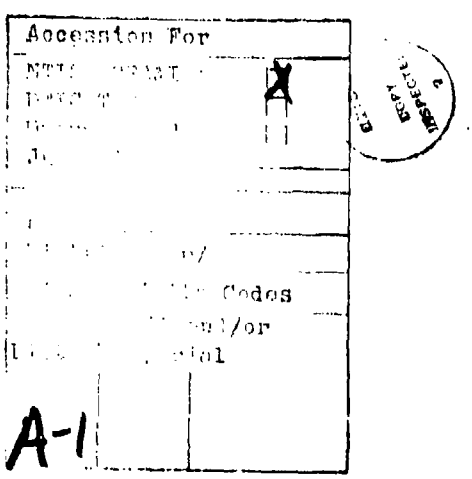

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I. INTRODUCTION

Military Standard 1246A, "Product Cleanliness Levels and Contamination Control Program," is used to specify surface particulate cleanliness level based on particle size distribution and count as shown in Fig. 1. The standard states that these particle size/count distributions are representative of naturally occurring surface contamination. Consequently, observers expect to measure such distributions on surfaces exposed to fallout in clean rooms. However, experiments by a number of contractors and agencies show that the particulate size distributions on surfaces exposed to such fallout diverge widely from MIL-STD-1246A distributions. This lack of agreement between the standard and measured distributions causes difficulties in specifying surface cleanliness levels and in performing predictive analysis of contamination-related parameters. The purpose of this study is to reconcile these differences on the basis of both theory and experimental data available.

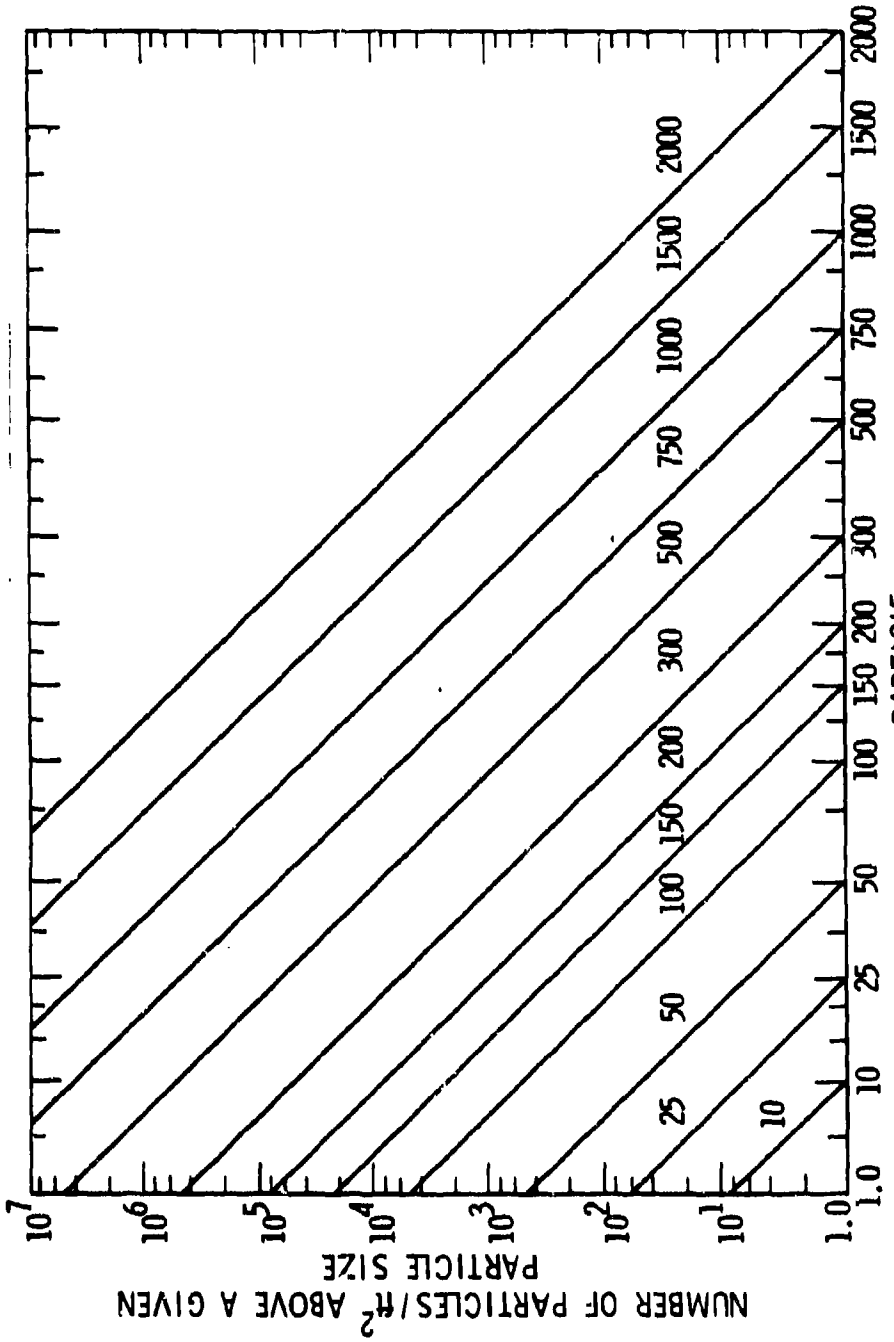

Fig. 1. MIL-STD-1246A

II. EXPERIMENTAL FALLOUT DATA

A number of aerospace contractors and government agencies have measured particle fallout size/count distributions in clean rooms used to process space vehicles. The following data present the measurements obtained and compare these with the size/count distribution exhibited in MIL-STD-1246A.

A. NASA KENNEDY SPACE CENTER EXPERIMENTAL RESULTS

In 1982, NASA published a report, "Relationship Between Air and Surface Cleanliness at Kennedy Space Center Processing Facilities."[1] Data collected in the report included airborne particle counts and particle fallout measurements at three Kennedy Space Center (KSC) Processing Facilities: the Vertical Processing Facility (VPF), the Payload Changeout Room (PCR) located at PAD 39A, and the Orbiter Processing Facility (OPF). Fallout data were also presented for a horizontal laminar flow clean room in Building AE at Cape Canaveral Air Force Station. The VPF is ~1 million ft^3 in volume with an air change rate of 8/hr through HEPA filters. The PCR has a volume of ~300,000 ft^3 with 15 air changes/hr through HEPA filters. The OPF with only four air changes/hr is not considered a true clean room. However, it is included in this study as representative of an airplane hangar-type facility. The laminar flow clean room in Building AE is ~1500 ft^3 in volume with 105 air changes/hr through a HEPA filter bank. The data for the four facilities examined are represented in Fig. 2.

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[1] Whitehead, V., et al., "Relationships Between Air and Surface Cleanliness Classes at Kennedy Space Center Processing Facilities," Seventh Inertial Guidance Community Contamination Control Seminar, 1982.

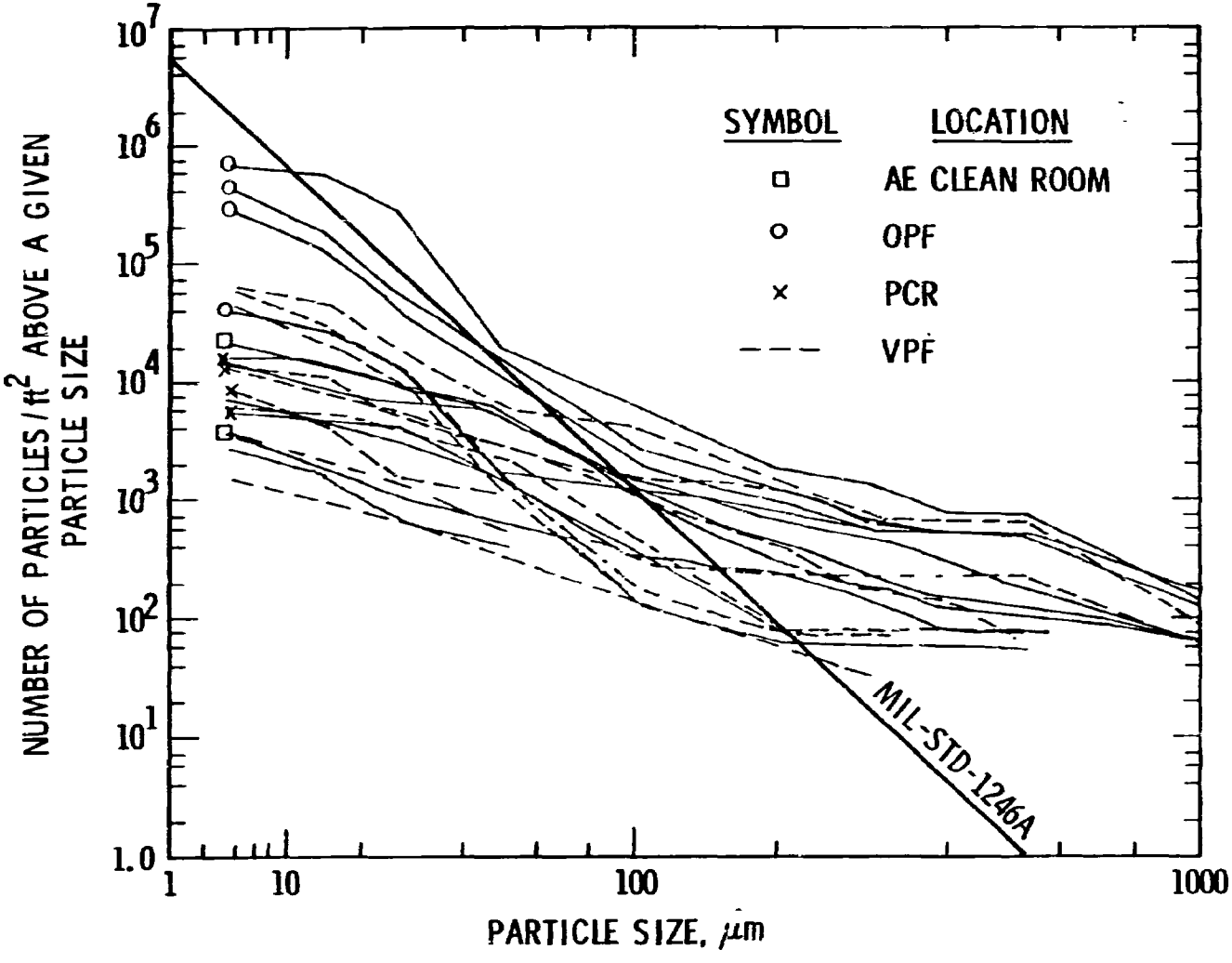

Fig. 2. NASA Experimental Data

B. THE AEROSPACE CORPORATION EXPERIMENTAL RESULTS

The Aerospace Corporation also published a study in 1982 titled "Shuttle Contamination Evaluation."[2] Fallout data were included for several KSC Processing Facilities. The data chosen for examination were from the same facilities as those examined by NASA: the VPF, the PCR, and the OPF.

The VPF was noted to be typical of FED-STD-209B Class 100,000 clean rooms. The PCR was noted to be less than FED-STD-209B Class 10,000 during most operations. Data collected from these facilities are given in Fig. 3. Included in the figure are particulate fallout data taken during various phases of the vertical installation of the cargo on STS-4, from the OPF to the PCR.

C. MARTIN MARIETTA EXPERIMENTAL RESULTS

A study was published in 1982 by Martin Marietta titled "Analysis of Prelaunch Particulate Contamination."[3] This study also dealt with particulate cleanliness of KSC Processing Facilities. The data examined included fallout results for non-operational conditions in the PCR (see Fig. 4).

D. TRW EXPERIMENTAL RESULTS

In 1970, TRW published a study, "A Forecasting Technique for Accumulated Particulate Contamination of Spacecraft Assemblies."[4] The clean rooms evaluated were nominal FED-STD-209B Class 1 million, 100,000, 10,000, and 100. Typical fallout distributions measured in these areas are shown in Fig. 5.

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[2]Borson, E. N., R. V. Peterson, and L. H. Rachal, "Shuttle Contamination Evaluation," Proceedings of the Aerospace Testing Seminar, Institute of Environmental Sciences, and The Aerospace Corporation, Oct. 1982.

[3]Pugel, N., "Analysis of Prelaunch Particulate Contamination," Int. Soc. Opt. Engrng., 338, 1982, p. 49.

[4]Reul, R. P., et al., "A Forecasting Technique for Accumulated Particulate Contamination of Spacecraft Assemblies," TRW Technical Report 82078A, 30 Oct., 1970.

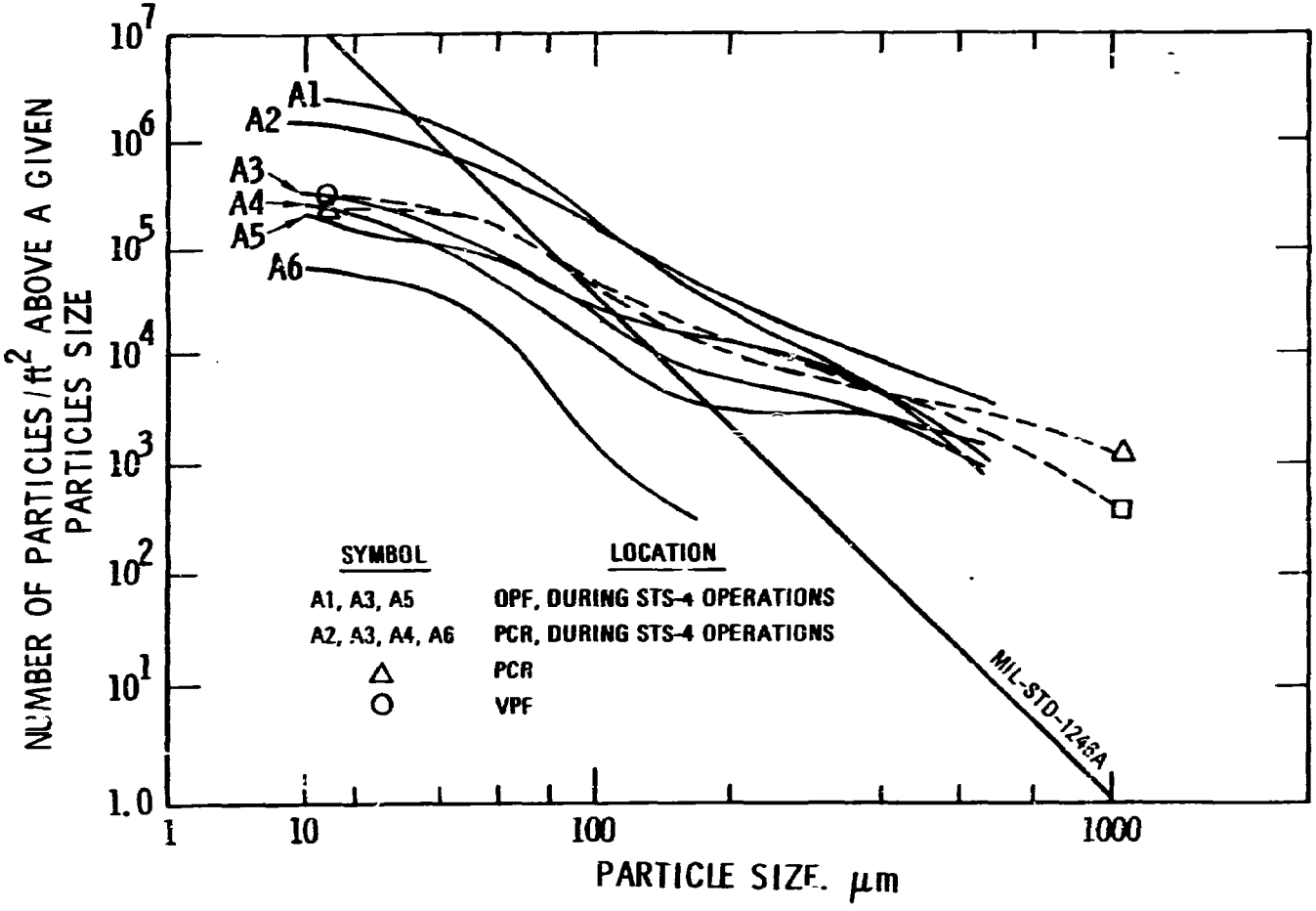

Fig. 3. The Aerospace Corporation Experimental Data

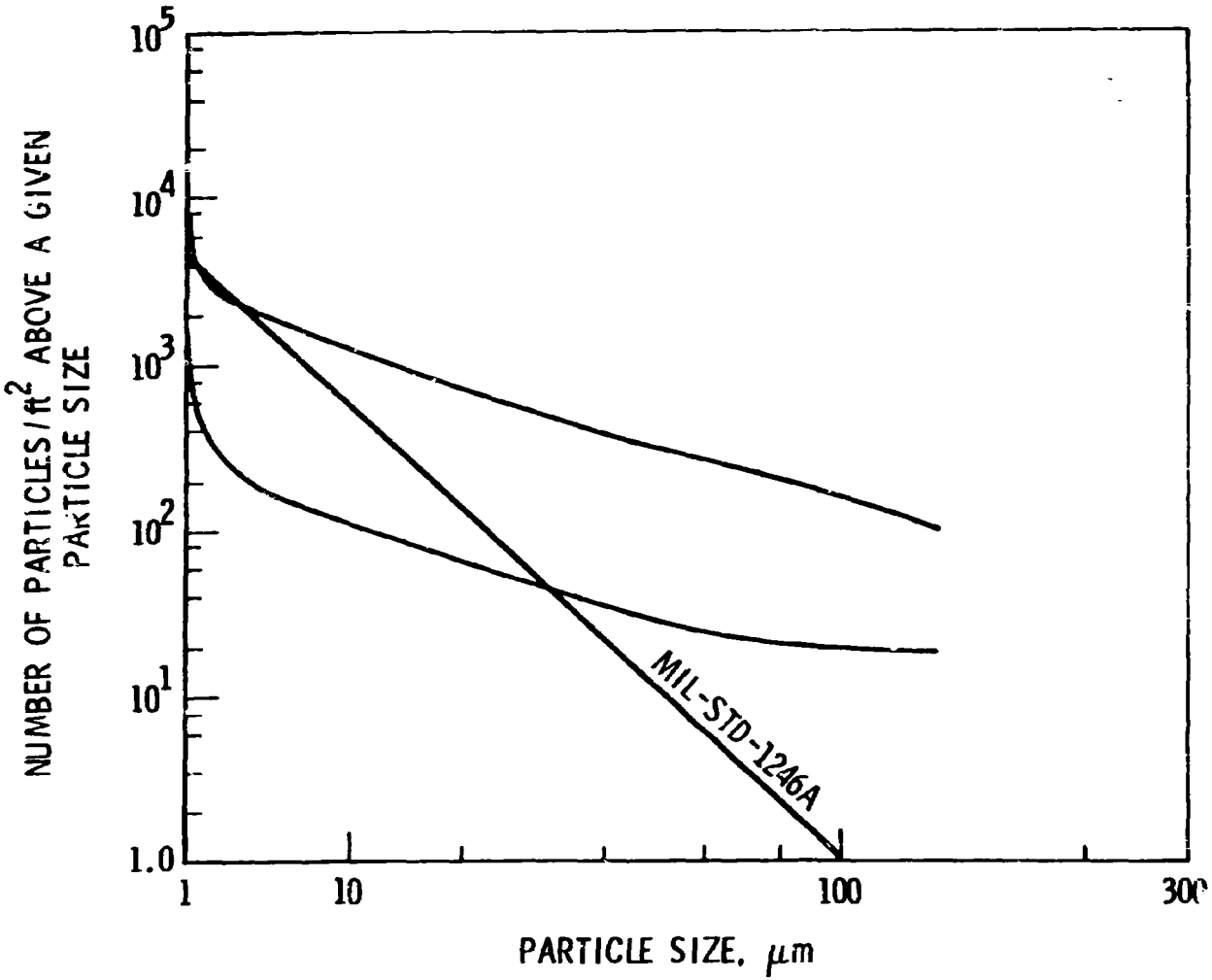

Fig. 4. Martin Marietta Experimental Data

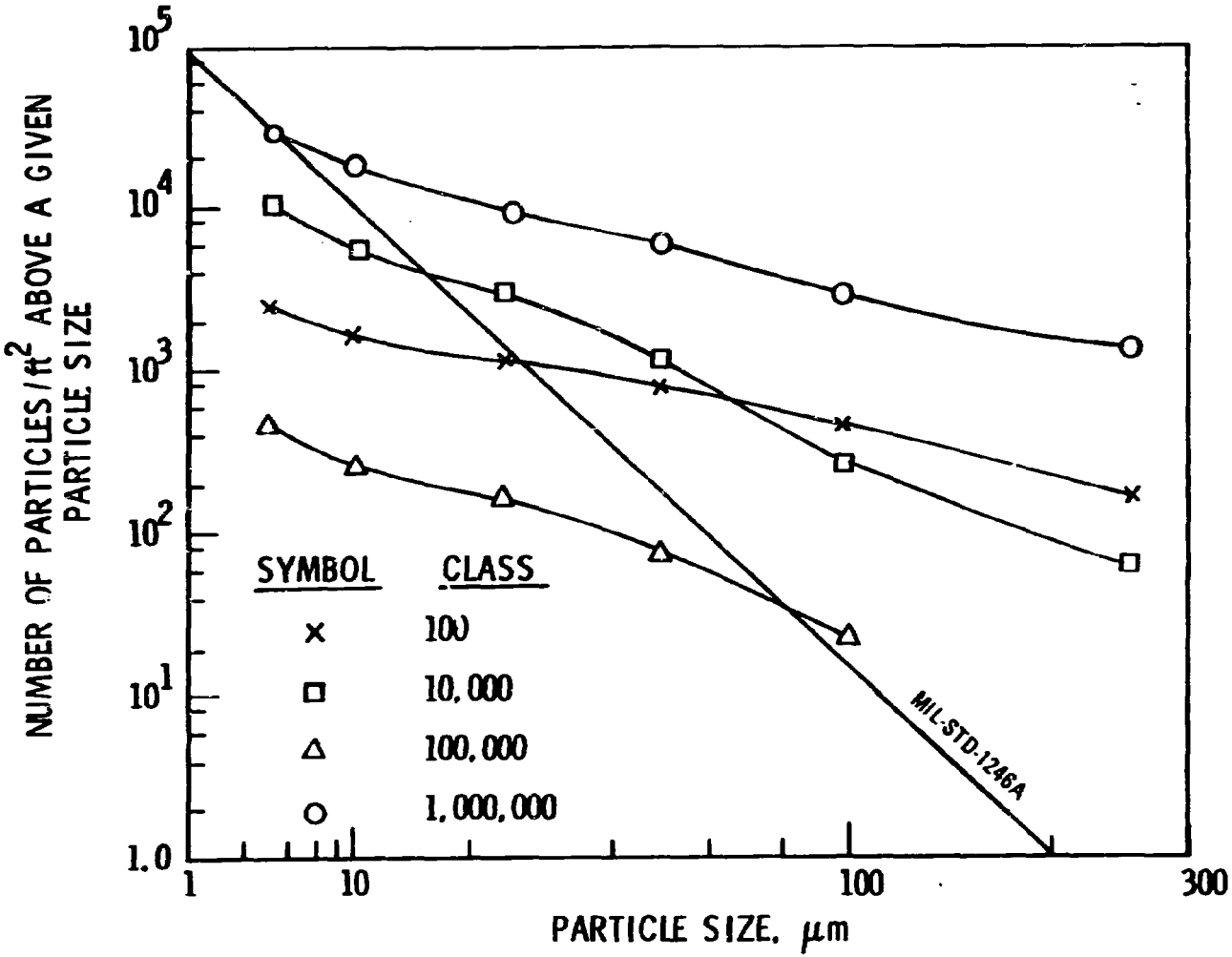

Fig. 5. TRW Experimental Data

E. JET PROPULSION LABORATORY EXPERIMENTAL RESULTS

Jet Propulsion Laboratory published a study in 1975 titled "Evaluation of Particulate Contamination for Unmanned Spacecraft Prelaunch Operations."[5] Particulate fallout was sampled from a Class 100,000 high bay room and from a laminar flow tent located within the high bay room. Both locations were affected by the activity of a spacecraft assembly and encapsulation operation. These data are presented in Fig. 6.

F. SUMMARY OF FALLOUT DISTRIBUTION DATA

Figure 7 shows the average particle size distribution from each of the sources previously mentioned in addition to the MIL-STD-1246A distribution on a normalized scale from 0.01 to 100 percent. In this figure all levels of MIL-STD-1246A are represented by a single line. Note that the particle sizes are plotted on a log square scale, similar to MIL-STD-1246A, in order to linearize the log-normal distribution. Table 1 provides a summary of the slopes from each of the sources.

Table 1. Slope of Surface Particle Size Distribution

Source	Average Slope
NASA/KSC Clean Rooms	-0.311
The Aerospace Corporation/ KSC Clean Rooms	-0.380
Martin Marietta/KSC Clean Rooms	-0.315
TRW/Factory Clean Rooms	-0.354
JPL/Eastern Test Range	-0.557
Average Slope, m	-0.383
Standard Deviation	-0.101
MIL-STD-1246A	-0.926

[5]Schneider, H. W., "Evaluation of Particulate Contamination for Unmanned Spacecraft Prelaunch Operations," J. Envir. Sci., Jan/Feb, 1975, p. 29.

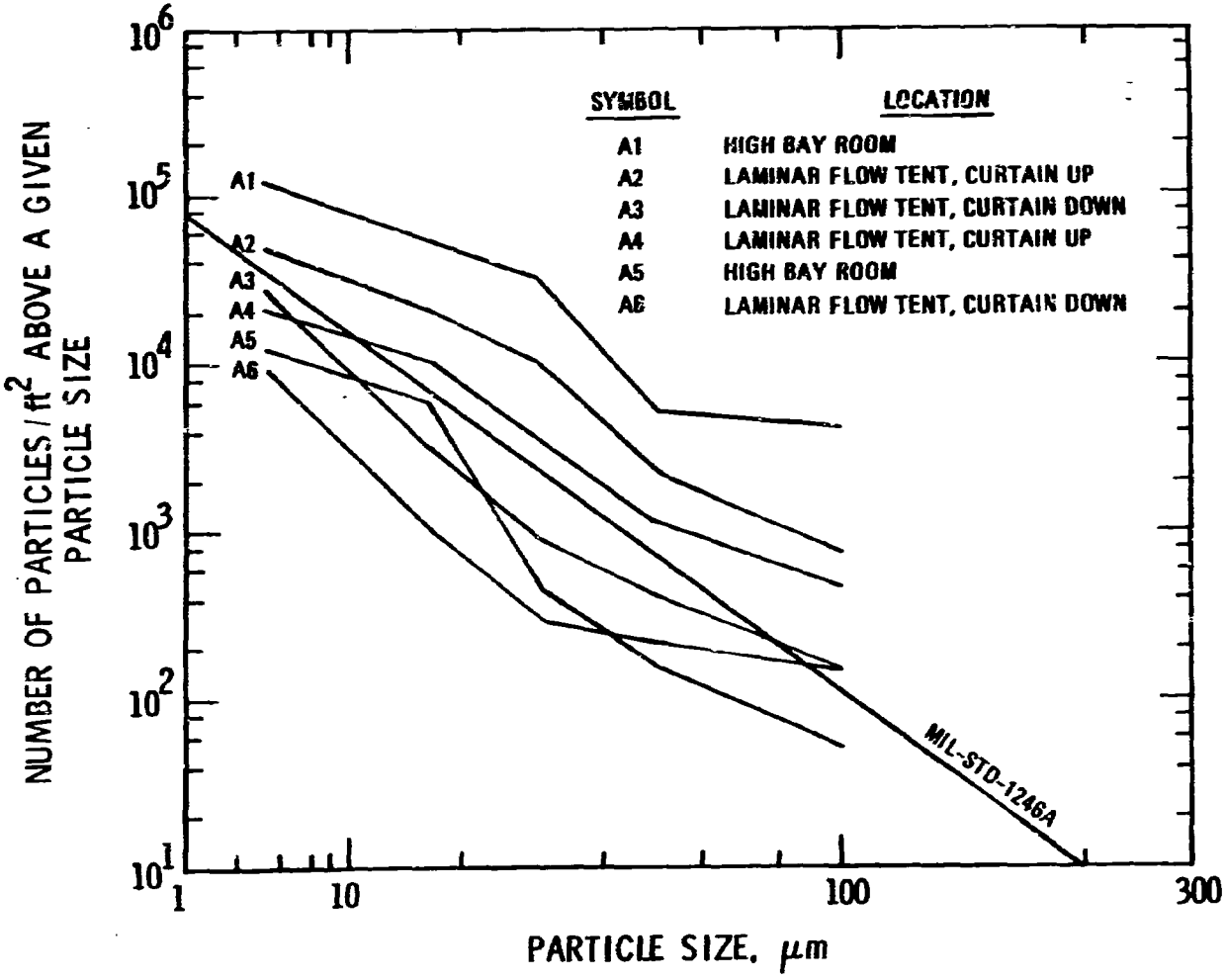

Fig. 6. JPL Experimental Data

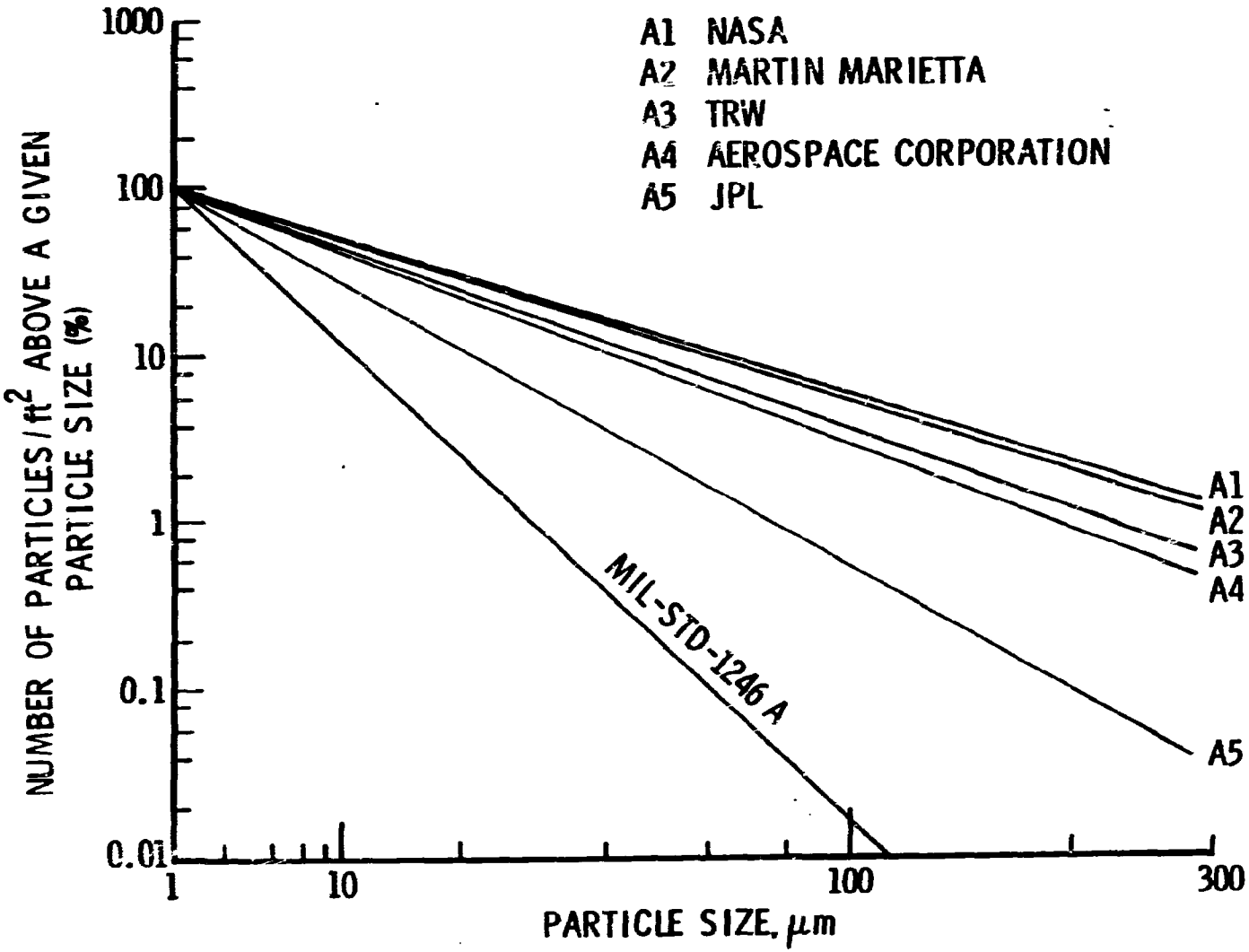

Fig. 7. Summary of Experimental Data and MIL-STD-1246A

III. THEORETICAL FALLOUT DATA

A theoretical size distribution resulting from fallout rates in still air can be developed, based on the terminal velocity of particles. Typically, the upper limit of particle sizes found in clean room air is approximately 200 μm. A lower particle size limit of 1 μm is selected for agreement with the lower limit, shown in MIL-STD-1246A. For this range of particle sizes, Stokes law is applicable. It is assumed that the clean room air has a constant FED-STD-209B distribution as shown by Fig. 8. Using this distribution, we may calculate fallout rates for various particle sizes as follows.

Per Stokes law, the terminal velocity of particles is

$$v = 0.0059SD^2 \qquad (1)$$

where

- D = particle diameter, μm
- s = particle specific gravity
- v = terminal velocity in air, ft/min

Fallout rates for incremental particle sizes may be calculated based on the relationship between terminal velocity and particle concentration in air as expressed by the formula

$$\dot{n} = vN_c \qquad (2)$$

where

- N_c = number of particles of diameter "D" per ft^3 of air
- v = terminal velocity of diameter "D" particles in air in ft/min
- $\dot{n}$ = settling rate of diameter "D" particles in air in particles/ft^2/min
- "D" = average diameter for equal logarithmic intervals derived from FED-STD-209B airborne particle distribution

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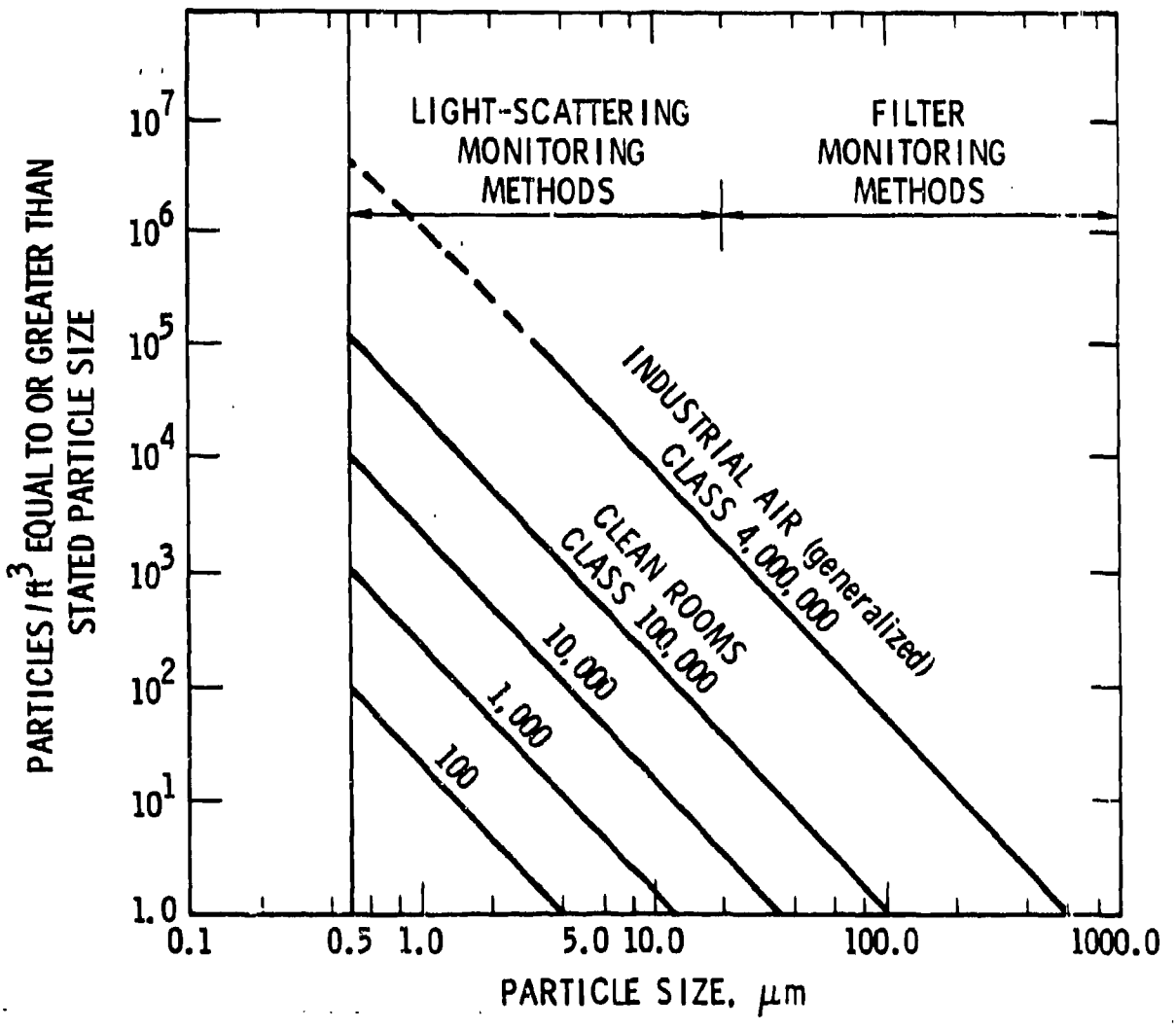

Fig. 8. FED-STD-209B

Table 2 shows the particulate surface distribution determined as a result of fallout from an FED-STD-209B Class 10,000 airborne particle concentration. Similar fallout distributions are derived using FED-STD-209B Class 100 and 100,000 airborne particle concentrations. The slope of the theoretical fallout distribution is not sensitive to the specific gravity or Class. For all FED-STD-209B distributions, the slope is calculated to be -0.28 which compares with an average slope of -0.38 for the experimental data as shown in Table 1. Note from Fig. 9 that the theoretical distribution compares more closely with the experimental data than does MIL-STD-1246A.

Table 2. Theoretical Fallout Results

ΔD (μ)	D_{MEAN} (μ)	v, s=1 (ft/min)	$\dot{n}$ $(ft^2/min)^{-1}$	Cumulative Settling Rate from 180 μ to D_{MEAN} $(ft^2/min)^{-1}$	Cumulative % of Particle Size $\frac{n}{N_o} \times 100\%$ (N_o = 960.5)
1.0- 1.3	1.15	0.01	74.91	960.47	100.0
1.3- 1.6	1.45	0.012	55.82	885.50	92.2
1.6- 2.0	1.80	0.02	59.26	829.68	86.4
2.0- 2.5	2.25	0.03	53.76	770.42	80.2
2.5- 3.2	2.85	0.05	62.30	715.66	74.6
3.2- 4.0	3.60	0.07	53.53	654.36	68.1
4.0- 5.0	4.60	0.12	43.70	600.83	62.6
5.0- 6.4	5.70	0.19	51.70	557.13	58.0
6.4- 8.0	7.2	0.31	45.88	505.37	52.6
8.0- 10.0	9.0	0.48	43.01	459.49	47.8
10.0- 13.0	11.5	0.78	46.04	416.48	43.4
13.0- 16.0	14.5	1.24	35.97	370.44	38.6
16.0- 20.0	18.0	1.91	38.23	334.47	34.8
20.0- 25.0	22.5	2.99	38.83	296.24	30.8
25.0- 32.0	28.5	4.79	36.90	257.41	26.8
32.0- 40.0	36.0	7.65	32.12	220.51	23.0
40.0- 50.0	46.0	12.48	33.71	188.39	19.6
50.5- 64.0	57.0	19.17	36.42	154.68	16.1
64.0- 80.0	72.0	30.59	27.53	118.26	12.3
80.0-100.0	90.0	47.79	25.78	90.73	9.4
100.0-130.0	115.0	78.03	23.58	64.95	6.8
130.0-160.0	145.0	124.05	21.58	41.37	4.3

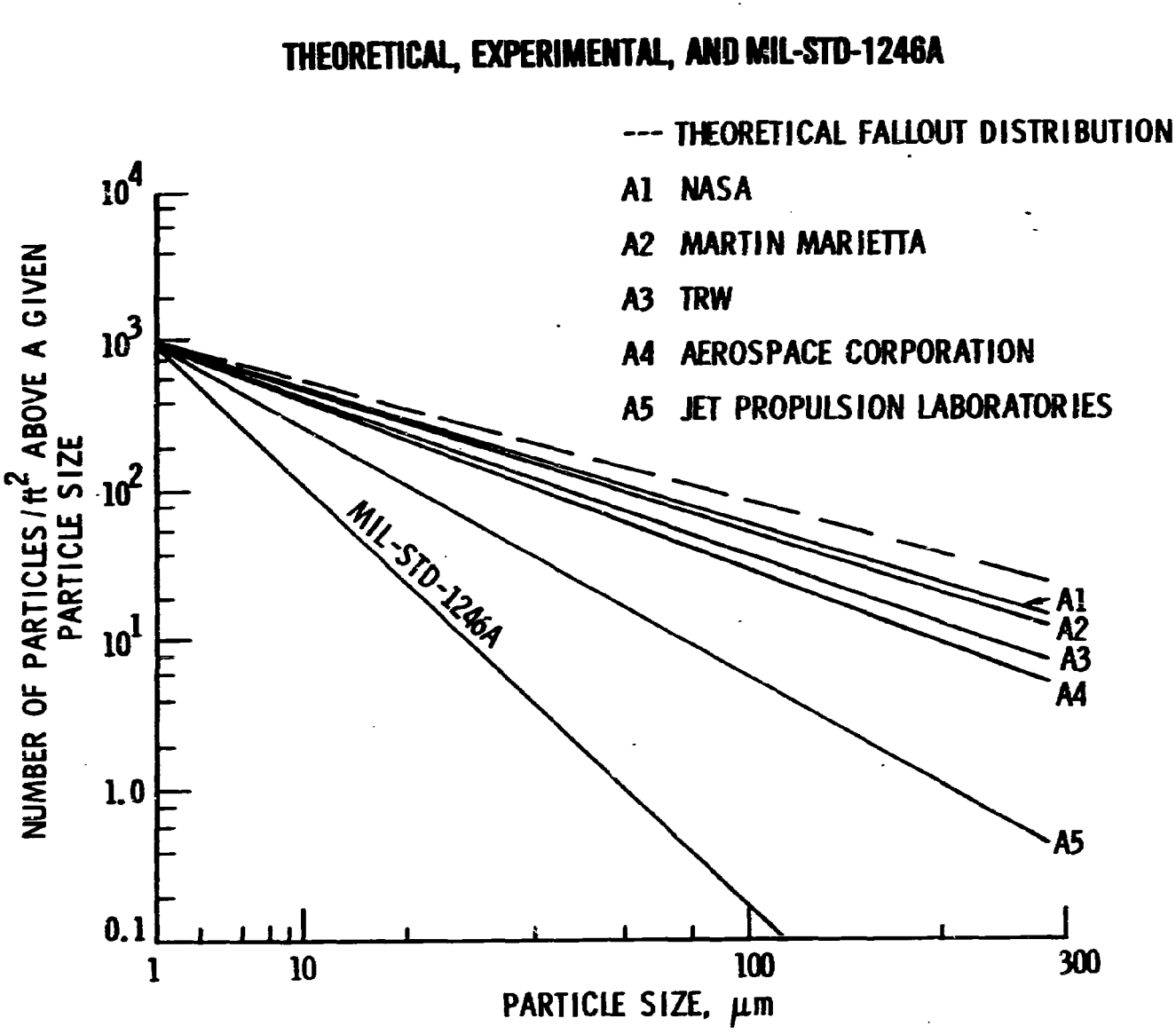

Fig. 9. Particle Size Distributions

IV. EFFECT OF SURFACE CLEANING ON PARTICLE SIZE DISTRIBUTIONS

In order to reconcile the differences between the size distributions shown by MIL-STD-1246A and the experimental plus theoretical data, the effect of cleaning on size distribution was considered. Many products exposed to fallout in clean rooms are cleaned of particulates during and after exposure. Final measurements are usually made just after final surface cleaning and, as a result, the particle size distribution reflects the effect of cleaning efficiencies.

A commonly employed technique used for removing particulate contaminants from surfaces is ultrasonic cleaning. Experimental results for ultrasonic cleaning with Freon, from Dupont Corporation,[6] were used to calculate the effect of cleaning on experimental data of fallout size distributions. The Dupont data, represented by curves of percent surface particles remaining after cleaning versus diameter, is given in Fig. 10.

As an example, the cleaning efficiency data from Dupont are utilized to model surface cleaning of a particulate fallout distribution of slope -0.383. A new fallout distribution may be calculated by numerical integration of particles remaining after cleaning as follows:

$$\sum_{D_a}^{D_b} N_2 = \sum_{D_a}^{D_b} N_1 \, (1 - e) \qquad (3)$$

where

N_2 = number of particles/ft^2 within increment of size D_a and D_b remaining after cleaning

N_1 = number of particles/ft^2 within increment of size D_a and D_b before cleaning

e = cleaning removal efficiency for increment of size D_a and D_b

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[6] Johnson, R. E., Dupont Corporation, personal communication

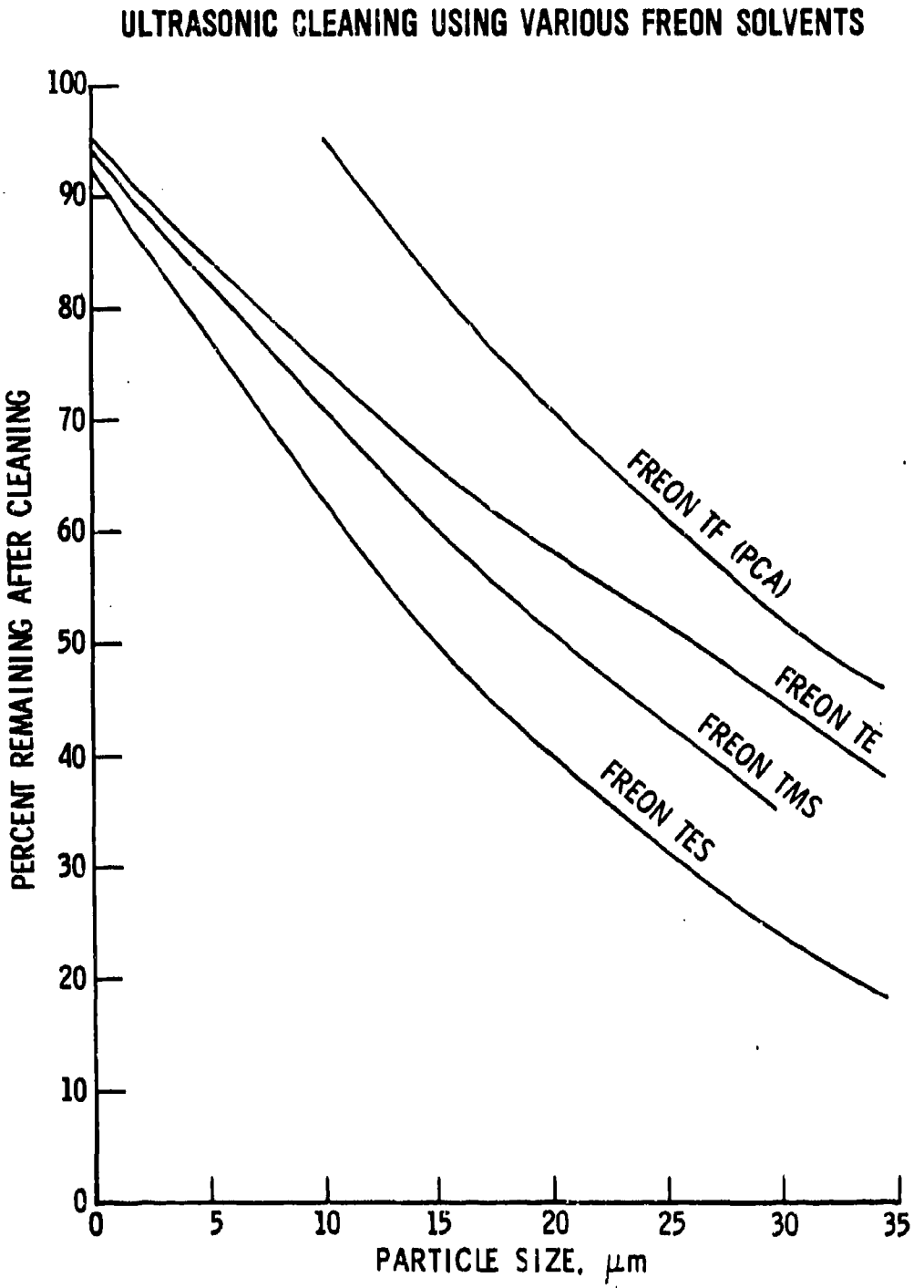

Fig. 10. Dupont Cleaning Efficiencies

Figure 11 illustrates before and after cleaning size distributions. Note that cleaning of surfaces exposed to relatively undisturbed fallout in clean rooms results in steeper size distributions. For this example, the slope of the size distribution after surface cleaning approaches the slope of the MIL-STD-1246A size distribution. Since most cleaning processes increase in efficiency with particle diameter, it can be predicted that the size distribution slope increases after cleaning, approaching or possibly exceeding the slope shown in MIL-STD-1246A. Consequently, in order to predict the particle size distribution on surfaces, it is necessary to know the initial distribution and the removal efficiency of the cleaning process for each particle size range.

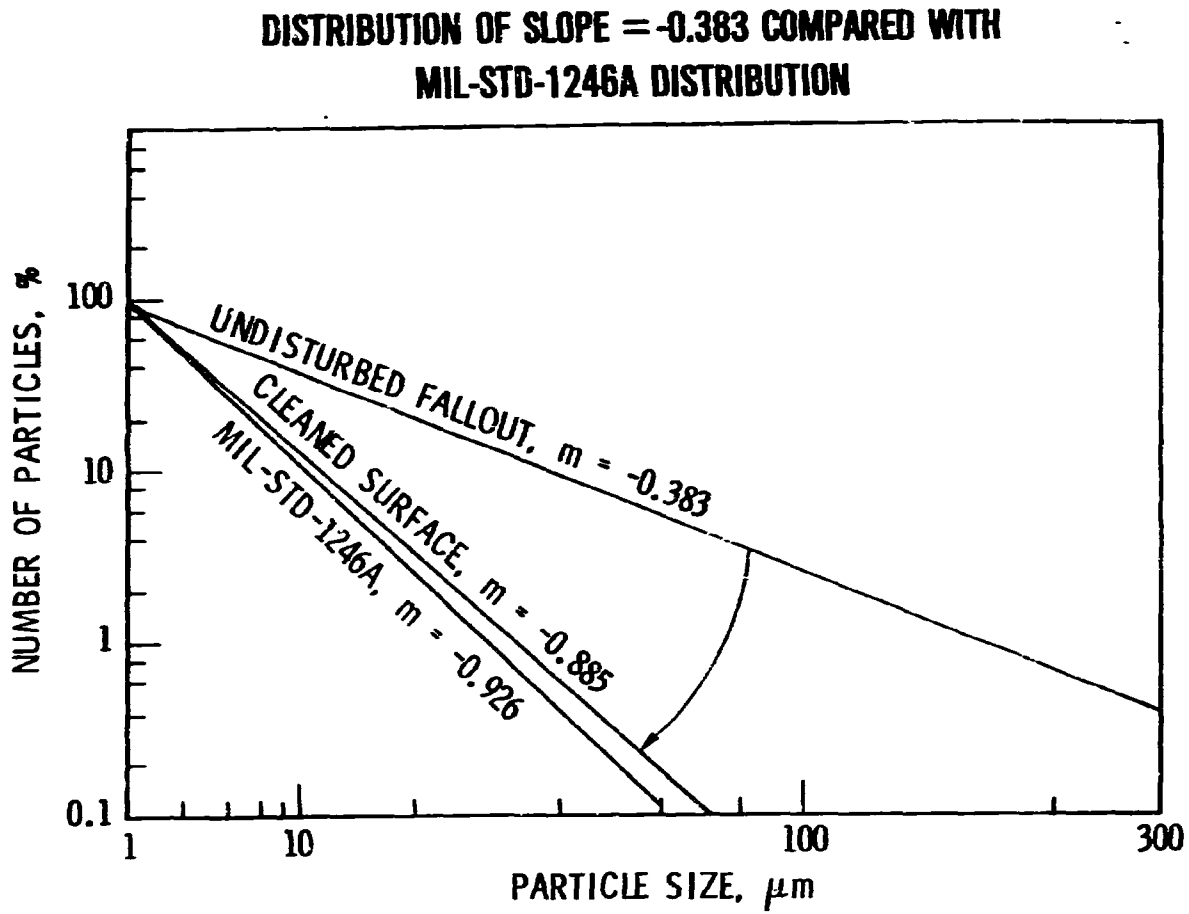

Fig. 11. Cleaning Effects on Particle Size Distribution

V. CONCLUSIONS AND RECOMMENDATIONS

Based on the experimental fallout data gathered by various contractors and agencies, it is concluded that the size distribution of particles on surfaces exposed to fallout in clean rooms can differ appreciably from the distribution shown in MIL-STD-1246A. For predictive purposes, an average size distribution slope of -0.38 has been calculated as a reasonable representation of the size distribution due to undisturbed fallout in a variety of clean rooms. Prediction of size distributions after surface cleaning requires a knowledge of initial size distribution and the removal efficiency of the cleaning process relative to size range. The slope of this size distribution increases after cleaning, approaching the slope of MIL-STD-1246A.

In order to specify the cleanliness levels of surfaces, it is recommended that the use of MIL-STD-1246A, in specifying surface cleanliness levels, be limited to surfaces that have been cleaned after exposure to fallout.

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