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A PARTICULATE RESPIRATOR CERTIFICATION

TEST APPARATUS

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ABSTRACT

A device for testing particulate respirators for solid particulate aerosol % penetration with mass loading has been developed according to the ANSI Z88 Committee for Respiratory protection specifications presented to NIOSH as a revision to present respirator certification standards. A description of the test apparatus is given. Comparisons of the performance of present respiratory filter devices are done. Comparisons of the performance of filters on the new solid particulate test to the liquid particulate Q127 DOP penetrometer test are presented at different flowrates.

INTRODUCTION

In the past the need for the development of respirator tests were based on the prevalent industrial aerosols. Mortality rates in the mining and quarrying industries necessitated the development of a silica dust respirator test (Federal Register, 1972). Heavy metal poisoning in the metal industries inspired the development of the lead fume test (Federal Register, 1972). The need for a "worst case" most penetrating aerosol test for the growing nuclear industry and military applications brought forth the DOP test.

Concern over respirator testing in the United States has manifested itself in the formation of committees in professional societies and testing organizations: AIHA, ASTM, and ANSI, as examples. The Federal government, respirator user industries, and respirator manufacturers have all strongly contributed to resolving this concern through consensus on methods of testing for end use.

ANSI Z88 COMMITTEE RECOMMENDATIONS

The American National Standards Institute (ANSI) Z88 Committee for Respiratory Protection reviewed in great detail the efficiency testing of all types of particulate removing respirators. Their objective was to recommend to The National Institute for Occupational Safety and Health (NIOSH) revisions to present particulate respirator certification tests which would improve the methods of classifying particulate respirators into end use categories. A final report was submitted to NIOSH on January 29, 1982 (ANSI Z88 Committee, 1982).

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The committee concluded that current certification tests used for evaluation of respiratory efficiency were based on 1920-1930 technology. The committee also concluded that modification of these procedures would not yield a significant improvement in the ability of the tests to assess respirator performance. As a result, new concepts in respirator testing were to be developed and evaluated.

Shortcomings of the current tests according to the ANSI Z88 committee were:

1. Inability to ascertain the level of particle penetration of the filter media at any given time throughout the test.

Examples:

- a. Filters that have acceptable initial efficiencies, but, as particle loading progresses, have efficiencies which degrade to unacceptable levels.

- b. Filters with unacceptable initial efficiencies which only have acceptable efficiencies after a particulate challenge clogs them.

2. The silica and lead fume test aerosols used for certification, while representative of certain industrial aerosols, are not "worst case" test aerosols with the greatest ability to penetrate filter medias. These most highly penetrating aerosols (as described below) can be used to discriminate between filter medias in tests with good resolution and reproducibility.

Since existing literature (Lee and Liu, 1980) indicated that the most difficult particle size for a filter to remove lies between .1 and .3 microns, two test aerosols presently in use were considered for providing the data necessary for respirator classification.

- a. Solid Particulates: Sodium chloride having a particle size of approximately .12 microns diameter (transmission electron microscopy count geometric mean) and a geometric standard deviation less than 1.6.
- b. Liquid Particulate: Dioctyl phthalate (DOP) having a particle size of .3 microns diameter (optical wavelength, a particle sizing method which gives no geometric standard deviation).

Light scattering photometers were recommended for use as the method for measuring concentrations upstream and downstream of a challenged respirator filter to determine particulate percent penetration. With photometers, continuous filter penetration could be monitored throughout the test during particulate loading.

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Here is a condensation of the ANSI Z88 Committee Particulate Respirator Testing Procedural and Classification Recommendations to NIOSH (ANSI Z88 Committee, 1982):

1. Pre-condition respirators at 100°F, 85% RH for 24 hours previous to aerosol testing.
2. Particulate testing will be against 100 mg total loading of particulate at 32 lpm. Concentration is maintained at no more than 200 mg/m³ with a temperature of 25 ± 5°C and a RH of less than 30%.
3. ANSI performance recommendations are:

CLASS	% PENE. SHALL NOT EXCEED	INITIAL 85 LPM INHALATION RESISTANCE	INITIAL 85 LPM EXHALATION RESISTANCE	FINAL 85 LPM INHALATION RESISTANCE	FINAL 85 LPM EXHALATION RESISTANCE
1	5	50 mmH ₂ O	20 mmH ₂ O	90 mmH ₂ O	20 mmH ₂ O
2	1	50	20	90	20
3	.03	50	20	90	20

Other requirements dealt with rapid changes in efficiency with loading: If at the end of 100 mg aerosol challenge the penetration is increasing rapidly, loading shall continue until no further increase in penetration occurs.

LIQUID PARTICULATE TEST

The DOP test (Q127, Air Techniques, Inc.) for filters was designed and has been used for years not only to test high efficiency filters, but to grade flat filter medias of low efficiencies as well. I won't address its applicability to mist aerosol testing in this paper since it is already a well known test.

SOLID PARTICULATE TEST

The sodium chloride test apparatus (MDA Scientific, Inc.) was chosen as described in Shibata, et al, 1983. This equipment was manufactured by the Sibata Chemical Apparatus Company, LTD, Japan and consists of two parts: A sodium chloride generator and a filter % penetration test system (see Figure 1).

A. SODIUM CHLORIDE GENERATOR

The sodium chloride generator used to produce the solid particulate aerosol consists of four parts:

1. Mist Generator Stage: 10-20% NaCl aqueous solution is continuously fed to a glass nebulizer.

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2. Mist Classification Stage: using a low pass impactor with an 80% cutoff efficiency for .6 micron diameter particles.
3. Particle Formation Stage: the mist is mixed with clean, dry air and heated to 180°F to form dry NaCl particles.
4. Dilution Mixing Stage: for concentration control

On our unit, we have added a diffusion dryer to meet the Z88 Committee restrictions on % relative humidity and an aerosol electrostatic charge neutralizer to create a stable test aerosol.

The particle size depends on the method of analysis. Transmission electron microscopy image analysis gives a distribution of .12 microns count geometric mean diameter with a geometric standard deviation of less than 1.8. The TSI Model 3030 Electrical Aerosol Size Analyzer gives an equivalent Stokes count geometric mean diameter of .09 micrometer with a geometric standard deviation less than 1.6.

B. % PENETRATION DETECTION

A Sibata Series 63 filter efficiency test system (see Figure 1) uses upstream and downstream photometric detection. The signals from each of the photometers are processed automatically in a microprocessor and printed out in time-weighted percent penetration. Filter resistance is also continually monitored by pressure taps located upstream and downstream of the filter. Percent penetration and pressure drop can be measured over the duration of an aerosol loading test.

CLASSIFICATION OF RESPIRATORS INTO GROUPS

Since the ANSI Z88 Committee Guidelines separated particulate respirators into three distinct classes, tests were run using the sodium chloride tests to determine its usefulness in classifying respirators into these designated groups. The present Federal certification test standards already do divide certifications into three basic areas: DUST/MIST, DUST/FUME/MIST and HEPA.

3M selected respirators in these three present certification categories to be tested: Dust/Mist, Dust/Fume/Mist, and HEPA. Manufacturers included: Mine Safety Appliances, American Optical, Norton, Willson, Glendale, Pulmosan, 3M, and Scott.

The sodium chloride test was run according to the ANSI Z88 committee recommendations. For two element devices a challenge

rate of 16 1pm was used for each element. For one element units 32 1pm was used, Each device was challenged with particulate until the total loading specification was met. Percent penetration was recorded continuously.

In the following three graphs, the % NaCl penetration was recorded for each respirator or cartridge at NaCl total mass challenges of 3 mg, 33.3 mg, 66.6 mg and 100 mg. Each point represents the % penetration through a single respirator or cartridge at that loading. As the total mass challenge increased, the performance of each filter device changed. On some respirators, the % penetration increases with increasing particulate loading while on others the % penetration decreases. In each case the recommended NaCl % penetration limits are shown.

The great differences in filter device performance reflect the great difference in filter material design. The ability of a device to maintain its effectiveness when challenged with a worst case aerosol is the goal of the test.

CLASS I: 5% PENETRATION LIMIT

This test was limited to present dust/mist approved respirators. Graph 1 shows % NaCl penetration with time loading. Initial % penetrations were in 82% of the cases acceptable. As loading continued, however, 62% of the devices failed, probably electrostatic degradation with particle loading.

CLASS II: 1% PENETRATION LIMIT

This test was limited to present dust/fume/mist approved respirators. Graph 2 shows % NaCl penetration with time loading. Initial % penetrations and final % penetrations showed an even division of passes and failures: 45% passing initially and at final loading.

CLASS III: .03% PENETRATION LIMIT

This test was limited to present high efficiency approved respirators. Graph 3 shows % NaCl penetration with time loading. Surprisingly, 30% failures were encountered initially. The majority, however, passed with no problem.

COMPARISONS OF INITIAL % NACL PENETRATION WITH % DOP PENETRATION AT DIFFERENT FLOWRATES

Since both of the ANSI Z88 committees particulate test recommendations (solid and liquid aerosols) are meant to measure an initial percent penetration and the subsequent effects on percent penetration caused by their respective loading attributes, the relationship between the two aerosols on initial percent penetration should be strong. Both aerosols

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occupy the most penetrating particle size region for fibrous filters and their capture mechanisms should be very similar. Here is presented a derived theoretical relationship between the two tests and an actual empirical filter test correlation.

1. Theoretical Relationship - Initial % Penetration

The theoretical relationship between two aerosol % penetration tests on a flat, fibrous filter media is related to their respective single fiber efficiencies:

$$\frac{\% \text{ NaCl}}{\% \text{ DOP}} = \frac{100e^{-K(\text{SFE})_{\text{NaCl}}}}{100e^{-K(\text{SFE})_{\text{DOP}}}}$$

$$\frac{\ln(\% \text{ NaCl})}{\ln(\% \text{ DOP})} = \frac{-K(\text{SFE})_{\text{NaCl}}}{-K(\text{SFE})_{\text{DOP}}} = \frac{(\text{SFE})_{\text{NaCl}}}{(\text{SFE})_{\text{DOP}}}$$

$$\frac{(\text{SFE})_{\text{NaCl}}}{(\text{SFE})_{\text{DOP}}}$$

So, $\% \text{ NaCl} = (\% \text{ DOP})$

Where: K = constant related to filter structure
 $\% \text{ NaCl}$ = % NaCl Penetration
 $\% \text{ DOP}$ = % DOP Penetration
 $(\text{SFE})_{\text{NaCl}}$ = filter NaCl single fiber efficiency
 $(\text{SFE})_{\text{DOP}}$ = filter DOP single fiber efficiency

On log-log paper this equation is a straight line. Single fiber efficiency is also a function of filter face velocity. However, since this equation is related to a ratio of single fiber efficiencies, it should not be affected by changes in velocity as long as the same velocity is used on either test.

2. Empirical Correlation of the Tests

On eighteen flat filters representing a range of % DOP penetrations from .004 to 18, both initial % DOP and initial % NaCl penetrations were measured at three face velocities: 5.3 cm/s, 10.6 cm/s, and 21.2 cm/s. Curve fit results were:

$$\begin{aligned} & \text{at } 5.3 \text{ cm/g, } \% \text{ NaCl} = .52(\% \text{ DOP})^{1.05} \\ & \text{at } 10.6 \text{ cm/g, } \% \text{ NaCl} = .59(\% \text{ DOP})^{1.06} \\ & \text{at } 21.2 \text{ cm/g, } \% \text{ NaCl} = .46(\% \text{ DOP})^{1.09} \end{aligned}$$

All curves had linear correlation coefficients greater than .98.

A curvefit of all three populations massed together gives:

$$\% \text{ NaCl} = .53 (\% \text{ DOP})^{1.07}$$

Graph 4 shows the data points and this curve. The curve does not go through the 100% NaCl, 100% DOP point. It is assumed that in these upper % penetration ranges a non-linearity exists on one or both of the detection devices. Also, although % penetration on either test is affected by face velocity, there seems to be little affect on the relationship between the test penetration results, as expected.

CONCLUSIONS

The two tests selected by the ANSI Z88 committee do classify respirators into proposed certification groups. A strong correlation exists between them on initial % penetrations.

It is recommended that NIOSH change the proposed certification group % penetration limits according to the relationship between the two sets.

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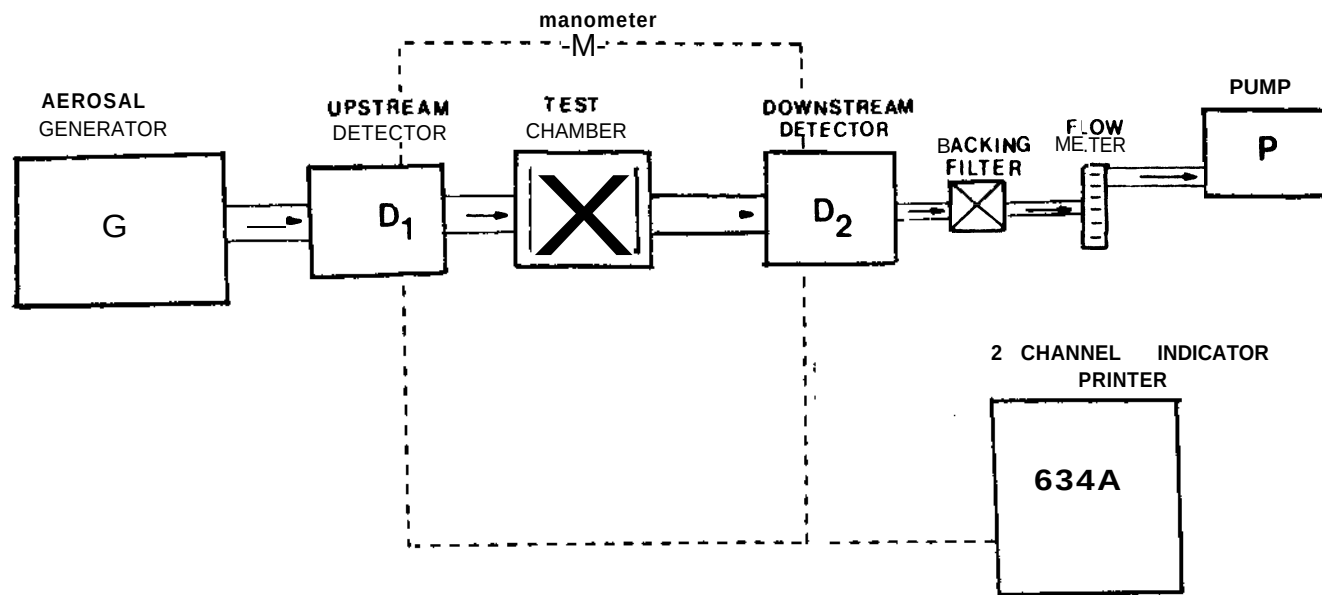
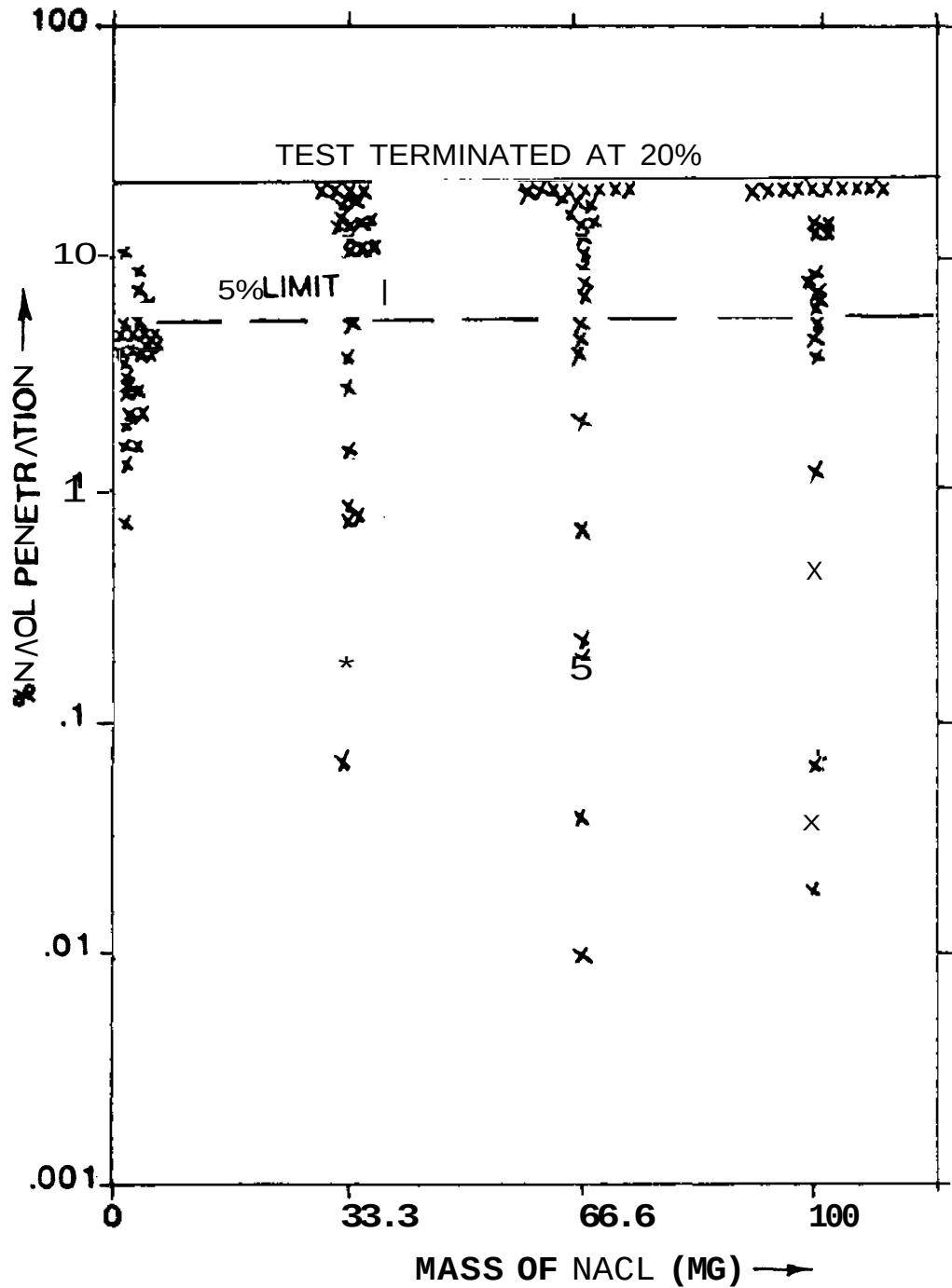


FIGURE 1.

SIBATA SERIES 63 FILTER EFFICIENCY TEST SYSTEM

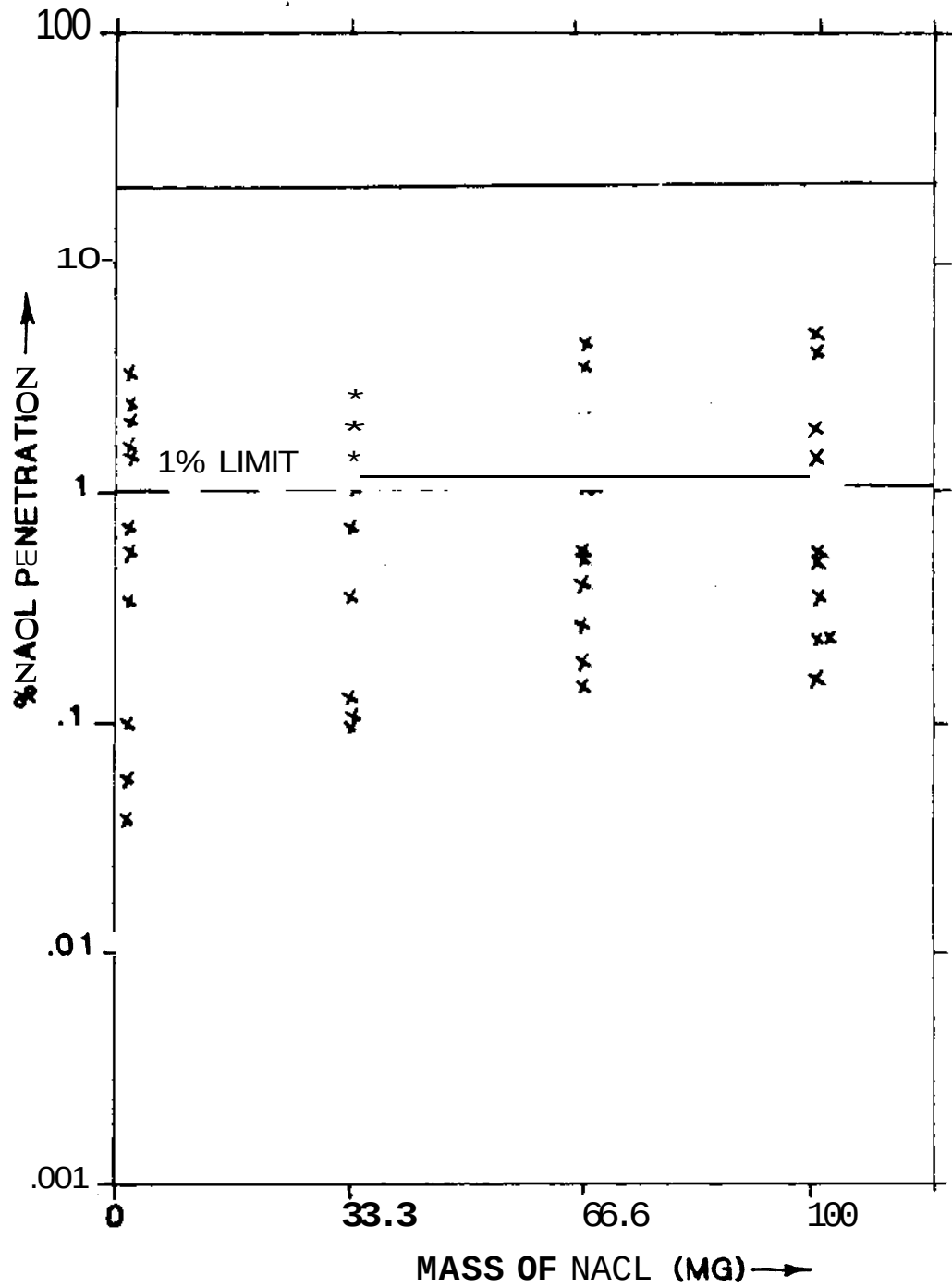
CLASS I: 5% NACL PENETRATION (DUST/MIST RESPIRATORS)



GRAPH 1

% NaCl PENETRATION VERSUS
NaCl MASS CHALLENGE (MG)

CLASS II:1% NACL PENETRATION
(DUST/FUME/MIST RESPIRATORS)

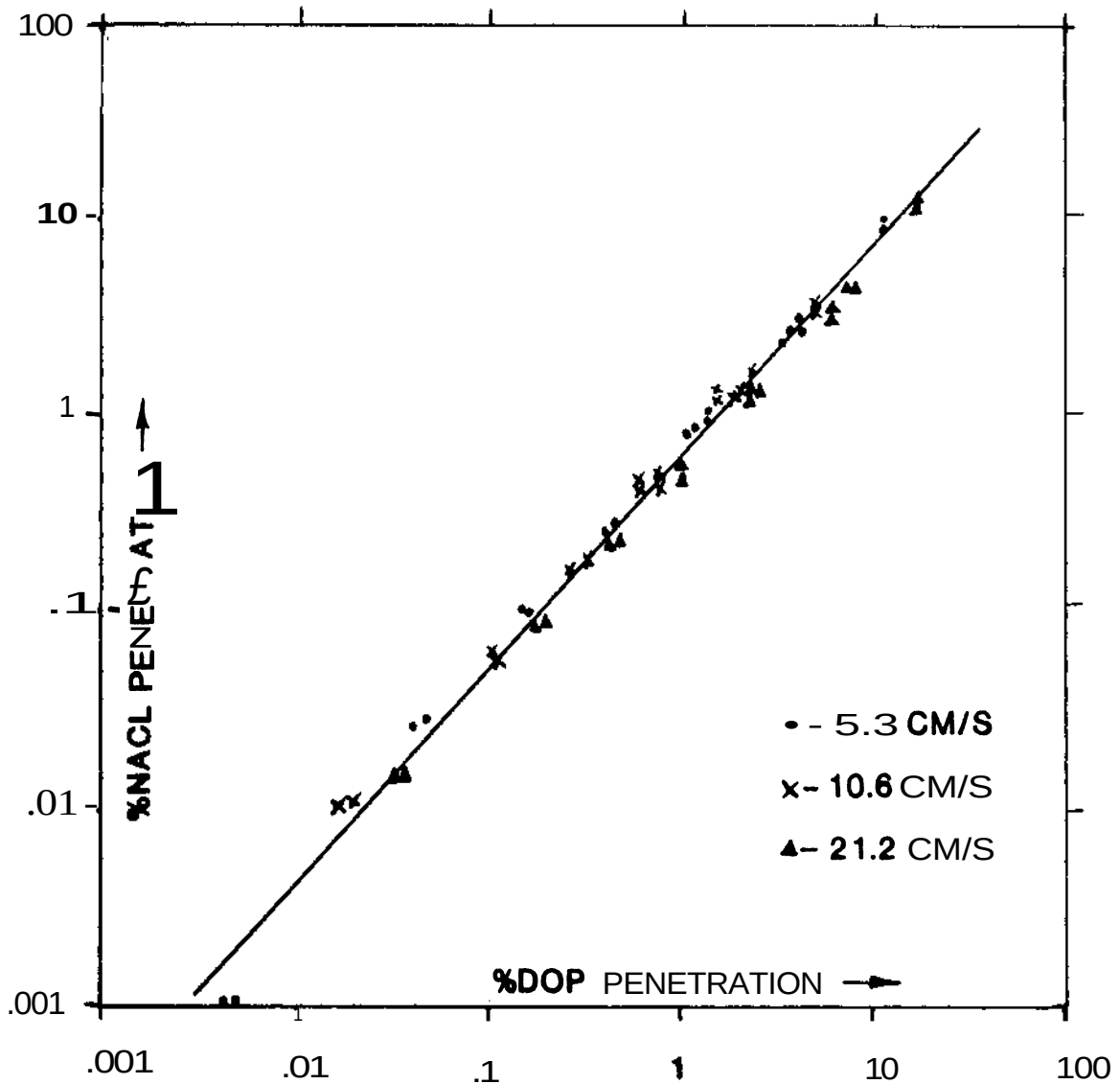


GRAPH 2

%NACL PENETRATION VERSUS
NACL MASS CHALLENGE (MG)



%NACL PENETRATION VERSUS NACL MASS CHALLENGE (MG)



GRAPH 4

**%NACL PENETRATION VERSUS
%DOP PENETRATION AT
THREE FACE VELOCITIES**