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# Core Analyses for Selected Samples from the Culebra Dolomite at the Waste Isolation Pilot Plant Site

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Prepared by Sandia National Laboratories Albuquerque, New Mexico 87185
and Livermore, California 94550 for the United States Department of Energy
under Contract DE-AC04-76DP00789

Printed November 1990

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SAND--90-7011
DE91 006752

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Unlimited Release
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# CORE ANALYSES FOR SELECTED SAMPLES FROM THE CULEBRA DOLOMITE AT THE WASTE ISOLATION PILOT PLANT SITE

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## ABSTRACT

Two groups of core samples from the Culebra Dolomite Member of the Rustler Formation at and near the Waste Isolation Pilot Plant were analyzed to provide estimates of hydrologic parameters for use in flow-and-transport modeling. Whole-core and core-plug samples were analyzed by helium porosimetry, resaturation porosimetry, mercury-intrusion porosimetry, electrical-resistivity techniques, and gas-permeability methods.

Seventy-nine (79) helium-porosity determinations indicated that the distribution of Culebra porosities was skewed toward lower porosity values with an arithmetic mean and standard deviation of 0.153 and 0.053, respectively.

The vertical heterogeneity of porosity was indicated by 21 pairs of helium-porosity determinations where each sample of the pair was separated by approximately 5 cm. The porosity differences between the samples in the pairs varied from 0.050 to 0.093.

Water-resaturation-porosimetry results showed a near 1-to-1 correlation with the results from helium-porosity determinations. In some cases, the resaturation porosities were slightly larger than the helium porosities, possibly due to mineral dissolution by the resaturation fluid (deionized water) or to the experimental reproducibility of the two measuring techniques.

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*The work described in this report was done for Sandia National Laboratories under Contract No. 32-1025.

Endpoint mercury pore-volume saturations for 25 samples ranged from 66.7% to 99.9%, with an average endpoint pore-volume saturation of 95.4%. The endpoint pressure was 207 MPa. The median pore-throat radius varied over an order of magnitude from 0.077 μm to 0.588 μm, with an arithmetic average value of 0.315 μm. Eighty-four percent of the pore-throat radii in the samples analyzed were between 0.1 μm and 0.5 μm. The average mercury-intrusion porosity was 0.148, as compared with the helium-porosity average of 0.154.

Seventy-three (73) grain-density measurements indicated a skewed distribution toward larger values of grain density with an arithmetic average of 2.82 g/cm$^3$ and a standard deviation of 0.019 g/cm$^3$. The most common value of grain density was 2.83 g/cm$^3$, which was also the median of the distribution.

Electrical-resistivity measurements of 15 saturated core plugs were used to calculate estimates of formation factor and tortuosity. Formation-factor values were log-normally distributed and values ranged from 12 to 407, with a geometric mean of 58.8. Tortuosity ranged from 0.04 to 0.33, with an arithmetic average of 0.14 and a median of 0.12. The results show a general trend of increasing tortuosity with increasing porosity. The diffusion porosities and diffusion tortuosities determined by Dykhuizen and Casey (1989) agree with the lower range of the values determined by this core-analysis study.

Sixty-six (66) horizontal-permeability measurements ranged from 7.9E-18 m$^2$ to 3.6E-13 m$^2$, and the distribution had an arithmetic average of 6.2E-15 m$^2$, a geometric mean of 4.5E-16 m$^2$, and a median of 2.7E-16 m$^2$. Twenty-six (26) vertical-permeability measurements ranged from 8.4E-18 m$^2$ to 5.2E-14 m$^2$, with an arithmetic mean of 5.1E-15 m$^2$, a geometric mean of 9.0E-16 m$^2$, and a median of 3.5E-16 m$^2$. Plots of the $\log_{10}$ of permeability versus porosity indicated a weak correlation between the $\log_{10}$ of permeability and porosity. A plot of $\log_{10}$ of horizontal permeability versus the median pore-throat radii determined for the same samples indicated that the $\log_{10}$ horizontal permeability is directly related to median pore-throat radius.

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## 1.0 INTRODUCTION AND FRAMEWORK FOR INVESTIGATION

The following report presents the results of the analysis of core samples from the Culebra Dolomite Member of the Rustler Formation obtained from drill holes at and near the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico (Figure 1.1). The WIPP is a U.S. Department of Energy research-and-development facility designed to demonstrate safe disposal of transuranic radioactive waste resulting from the United States' defense programs. The WIPP underground repository is being constructed in the bedded halite of the Salado Formation, approximately 655 meters below land surface. The core holes from which the core samples were obtained were drilled at the WIPP and the surrounding area from 1980 through 1984. The core holes were drilled as part of the hydrogeologic characterization of the Rustler Formation which overlies the Salado Formation. The core analyses were contracted by INTERA Inc. of Austin, Texas for and under the technical direction of Sandia National Laboratories (SNL) of Albuquerque, New Mexico.

The Culebra dolomite is the most transmissive confined unit above the proposed waste repository and therefore is considered the most likely transport path by which radionuclides could travel to the accessible environment over time spans of interest to regulatory agencies (Lappin et al., 1989). Because of the Culebra's importance as a possible transport pathway to the accessible environment, hydrogeologic and transport characterization of the Culebra forms a very important part of the overall site characterization of the WIPP. Hydrologic data from over 40 observation wells in the vicinity of the WIPP site (Cauffman et al., 1990) are being used to calibrate and validate a ground-water-flow model of the Culebra dolomite (LaVenue et al., 1990). Figure 1.1 shows the location of the observation-well network in the vicinity of the WIPP site.

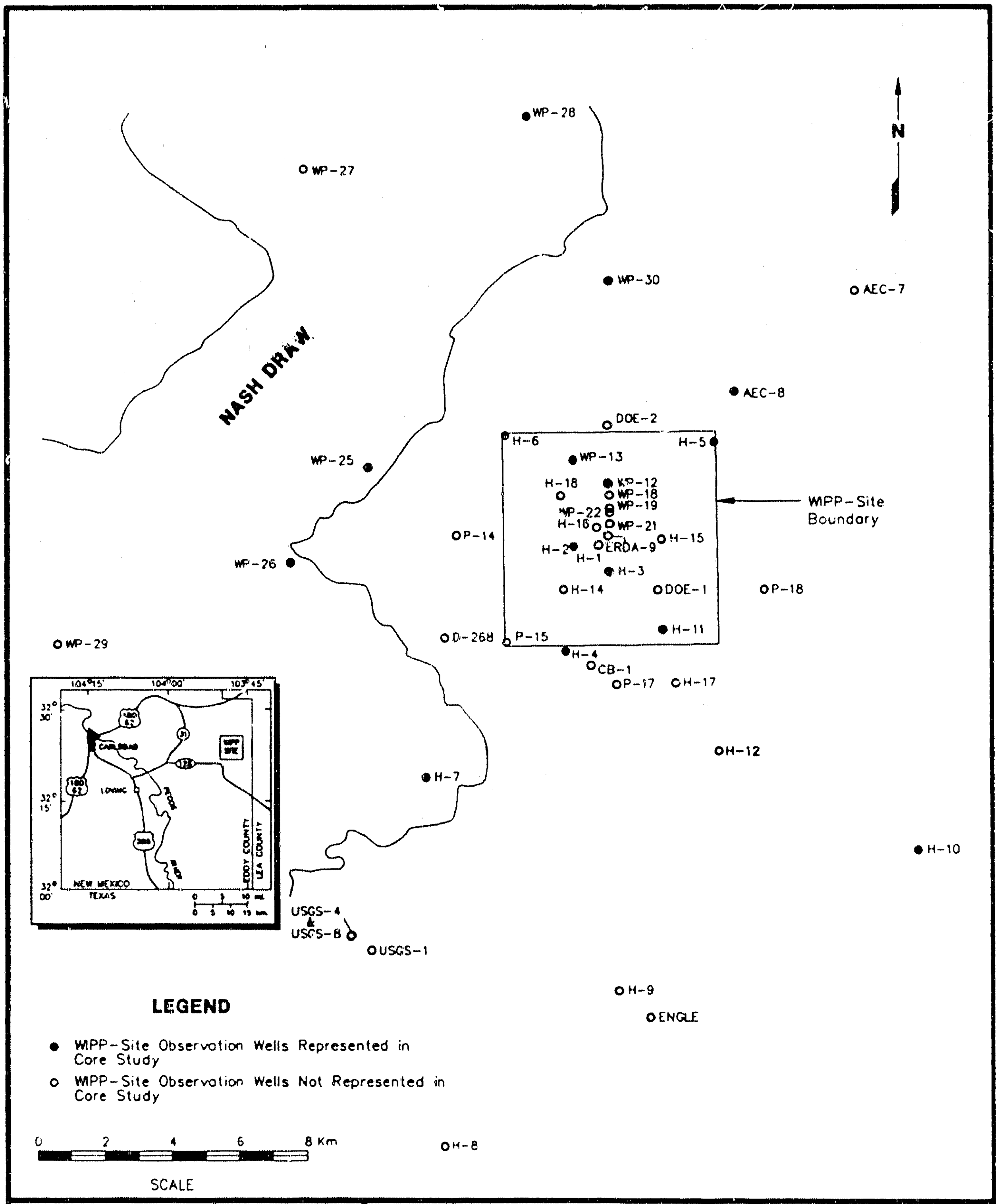
As part of SNL's WIPP-site characterization program, INTERA contracted two separate core-analysis studies of core samples from the Culebra dolomite.

The first study, performed in late 1985 to early 1986, is referred to as the Phase 1 core study. The second, more comprehensive study, which was performed from late 1987 to June 1988, is referred to as the Phase 2 core study. This report contains estimates of the physical properties of the Culebra dolomite from both Phase 1 and Phase 2. The Phase 1 core study was initiated to determine values of the Culebra matrix parameters, porosity and permeability, for transport and hydraulic-test interpretations. Using these data and hydraulic data from the WIPP site, Reeves et al. (1987) performed a parameter-sensitivity analysis of regional double-porosity transport within the Culebra. Under the conditions and assumptions of that study, it was concluded that matrix porosity was the most sensitive and important parameter governing double-porosity far-field transport in the Culebra. These results identified the need for a better understanding of the physical properties of the pore structure of the Culebra, specifically the porosity and tortuosity, and prompted the initiation of the Phase 2 core-characterization study.

The Culebra is a finely crystalline, vuggy dolomite which is often argillaceous and is fractured over a large part of the WIPP-site area (Beauheim, 1987). The Culebra is very heterogeneous, as indicated by the six order-of-magnitude variation in transmissivity estimates for this unit in the vicinity of the WIPP site. Beauheim (1987) states that the Culebra behaves hydraulically as a double-porosity medium for regions which have a transmissivity greater than $1 \times 10^{-6}$ $m^2/s$. Conservative tracer tests performed in these regions, including tests at the H-3 and H-11 hydropads (Figure 1.1), have also required double-porosity conceptualizations to model the observed tracer-breakthrough data (Kelley and Pickens, 1986; Saulnier et al., 1989). The estimated hydrologic travel pathways in the Culebra leading offsite from above the WIPP repository's waste-panel area are within that part of the Culebra characterized as a fractured, double-porosity formation (Reeves et al., 1987; Lappin et al., 1989). The matrix-parameter data base for the Culebra before the results presented in this report was extremely limited. This report augments the Culebra data base for site-characterization and performance-assessment studies.

Physical core parameters determined and presented in this report are porosity, formation factor, tortuosity, grain density, pore-size distributions, and gas permeability for selected samples. The matrix porosity and tortuosity are important parameters because of their direct effects upon solute transport. The grain density is also important because it is a parameter in the retardation equation.

Section 2 will briefly describe the methods used in determining the physical parameters of the Culebra core samples. In addition, the theoretical relationships from which these parameter determinations were derived will be presented. Section 3 identifies the samples which were analyzed and the analyses performed on each sample. In addition, Section 3 presents the rationale for sample and analysis selections. Section 4 presents the results from the Phase 1 and Phase 2 core studies and the appropriate parameter distributions and dependent-parameter relationships. Section 5 presents general conclusions based on the results of the core studies.



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| Checked by | G.S. | Date | 11/28/89 |
| Revisions | G.S. | Date | 10/10/90 |
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Site Location for the Waste Isolation Pilot Plant Showing the Observation-Well Network for Regional-Hydrogeologic-Characterization Studies

INTERA Technologies

Figure 1.1

## 2.0 METHODOLOGY AND THEORY FOR ANALYSES

Five different analyses were performed to characterize the physical properties of Culebra core samples. They were:

(1) Boyle's Law helium porosimetry;
(2) resaturation porosimetry;
(3) mercury-intrusion porosimetry;
(4) formation-factor determinations (to estimate tortuosities); and
(5) gas permeability.

Analyses (1) and (2) were used to determine the porosity of the samples. Because helium can access much smaller pore spaces than those which water can access, both techniques were used on selected core samples in an effort to characterize the differences between these methods. The porosity determinations also provided estimates of the grain density of the material in most samples. Mercury-intrusion porosimetry is designed to determine the pore-size distribution of a given sample. This type of data is very important when considering the effective porosity of a porous medium. The formation factor provides an empirical approach to determining the tortuosity of a porous medium. The appropriate relationships and their application are discussed fully in Section 2.3. Gas permeability was used to determine the intrinsic permeability of the dolomite matrix. Gas-permeability determinations were performed with standard, steady-state techniques for both horizontal and vertical permeabilities of selected samples.

The Phase 1 core study included Boyle's Law helium porosity and gas permeabilities of selected samples. These analyses were performed by Core Laboratories, Inc., Aurora, Colorado. During the Phase 2 study, all five of the above analyses were performed by Terra Tek Core Services, Salt Lake City, Utah, except the mercury-intrusion porosimetry, which was performed by K & A Laboratories, Tulsa, Oklahoma. The following sections will briefly discuss the techniques used for each analysis and the parameters determined using these methods.

## 2.1 Standard Porosimetry

The total porosity of a sample is equal to the total void volume divided by the total bulk volume. To calculate porosity, two of the three variables, bulk volume, pore volume, or grain volume must be determined. The effective porosity is defined as the connected void volume divided by the bulk volume. Because the size of the helium molecule is small, the helium method of determining porosity provides an approximate estimate of the total porosity. In addition to Boyle's Law helium-porosity determinations, water-resaturation porosities were measured for some of the samples. Resaturation porosities are considered to provide a better estimate of the connected porosity for ground-water-flow and solute-transport modeling, and also have the advantage of determining the void volume when the mineral samples are wet, as is the case in situ.

### 2.1.1 Helium Porosity

Boyle's Law helium porosimetry has the advantage of being: (1) very accurate; (2) fairly rapid except for extremely low-permeability ($< 1.0E-18$ m$^2$) samples; and (3) the method is non-destructive, allowing the samples to be reused for other analyses. However, Boyle's Law porosimetry can yield erroneously high porosity values when the permeating gas adsorbs on the rock surfaces. Helium is preferred for Boyle's Law porosimetry because helium is non-adsorbing and has a minimum deviation in behavior from that of an ideal gas. Boyle's Law porosimetry determines either the pore volume or the grain volume of a sample through either expansion of a gas out of, or compression of a gas into, the pores of the sample. The bulk volume of the sample is then calculated using caliper measurements or by displacement of the sample in a liquid of a known density. The grain density is calculated using the dry weight of the sample and the grain volume.

### 2.1.2 Water-Resaturation Porosity

Because gas-porosimetry measurements can yield erroneously high porosity estimates due to gas adsorption, the Phase 2 core study included analysis of both Boyle's Law helium porosity and resaturation porosity for selected samples to determine if these methods give significantly different values for the same sample. The resaturation technique also has the advantage of providing a porosity measurement under saturated conditions similar to those found in situ.

In resaturation porosimetry, the first step is calculation of the bulk volume and the dry weight of the sample. The pores of the sample are then filled with a fluid of a known density. The increase in the weight of the sample is divided by the fluid density to obtain the void volume. The void volume divided by the bulk volume yields porosity.

## 2.2 Mercury-Intrusion Porosimetry

Mercury-intrusion porosimetry was used on selected samples in the Phase 2 core study to define the sample pore-size distributions. The method requires enclosing a sample in an air-tight mercury chamber which is then evacuated to a low pressure. Mercury is then intruded into the sample's void spaces in successive steps of increased stabilized pressure and the amount of mercury injected into the core for each pressure step is recorded. The mercury-intrusion stage is referred to as the drainage cycle because the air in the sample is displaced by the non-wetting mercury. The K & A Laboratories mercury-intrusion apparatus can inject mercury up to a pressure of 207 MPa. At this pressure, the mercury invaded an average of 95.5% of the pore space for the 24 samples analyzed in the Phase 2 study.

Mercury-intrusion porosimetry results can also be used to estimate a sample's pore-diameter distribution. Knowing the physical properties of the non-wetting phase (mercury), one can calculate the average pore size. The theoretical pore diameter can be calculated from the Washburn equation (Walter, 1982):

$$d = 4 \, \tau \cos \theta \, / \, P \qquad (1)$$

where d is the theoretical pore diameter; $\tau$ is the surface tension of mercury (typically 484 dynes/cm); $\theta$ is the contact angle for mercury (typically 140°); and P is the mercury-intrusion pressure. Studies performed by Terra Tek Core Services indicate that the constants in this equation are ideal and quickly change in magnitude as the mercury comes in contact with the sample. The values used to calculate the results presented in this report were a contact angle of 180° and a surface tension value of 360 dynes/cm (Rakop and Little, 1988) (see Appendix D). Using the sample's initial void volume, the cumulative volume of mercury intruded into the sample can be used to calculate both the pore-size distribution of the sample and the cumulative pore-size distribution. Mercury-intrusion porosimetry determines the connected porosity, the correct porosity for transport calculations. The pore-size distribution is also used to determine the fraction of the sample pore space accessible to a diffusing solute. Dykhuizen and Casey (1989) have used mercury-intrusion-porosimetry results to provide complex pore-geometry models using data from diffusion experiments performed on core and excavated-rock samples of the Culebra.

## 2.3 Formation Factor

### 2.3.1 Formation-Factor Determinations

The electrical resistivity of a saturated porous medium is directly related to the resistivity of the fluid which saturates the porous medium. The constant of proportionality relating the resistivity of the formation and its saturating fluid is called the formation factor ($F \geq 1.0$) and is equal to

$$F = R_b / R_w \qquad (2)$$

where $R_b$ is equal to the resistivity of the porous media saturated with fluid of resistivity $R_w$. The fluid used to saturate the medium is usually a sodium-chloride (NaCl) solution with a concentration higher than 10 g/l (Bear, 1972). Values of formation factor were determined for 15 individual core plugs during the Phase 2 core study by Terra Tek Core Services. The samples were first saturated in a 100 g/l sodium-chloride solution of known electrical resistivity (Rw). Then the formation electrical resistivity of the saturated core plugs (Rb) was measured while the samples were placed under an ambient pressure of 1.4 MPa.

### 2.3.2 Tortuosity

The formation factor can be related to the physical properties of saturated porous media and, as derived from geophysical logging data, is a standard parameter used by the petroleum industry (Schlumberger, 1972). The electrical resistivity ($R_b$) of a saturated porous medium is controlled by the volume fraction of the pore cross section normal to current flow and by the connectivity of the pore volume (Touloukian et al., 1981). Because there are no analytical solutions for the concept of tortuosity, it has been described empirically. The best known description is the empirical relationship known as Archie's Law of total porosity:

$$F = C / \phi^m \qquad (3)$$

where C, sometimes called the tortuosity factor, and m, the cementation factor, are empirical constants which vary depending upon the porous medium's lithology, and $\phi$ is porosity expressed as a decimal fraction. The following table gives ranges of C and m for various lithologies (Katsube and Hume, 1987).

| Lithology | C | m |
|---|---|---|
| Carbonates | 1 | 2 |
| Unconsolidated sand | 0.62 | 2.15 |
| Typical sandstone | 1.45 | 1.54 |
| Shaly sandstone | 1.65 | 1.33 |
| Granites | 5.9E-3 | 2.21 |

All of the formation-factor formulas assume that the electrical current is conducted through the pores, and that surface conduction of the current on the pore walls is minimal. For rocks with varying degrees of clay, the clay may act as a highly conductive portion of the rock and reduce the bulk resistivity of the rock. In these cases, the formation factor represents more than the pore structure of the rock and the resistivity of the saturating fluid. In shale or shaly sands, surface conduction and cation-exchange capacity significantly modify Archie's equation (Hill and Milburn, 1956; Waxman and Smits, 1968). The factors complicating the measurement of formation factor are more easily controlled in the laboratory than when making in situ logging measurements in the field.

### 2.3.3 Formation Factor and Its Relation to Diffusive Flux in Porous Media

The effective molecular diffusion coefficient ($D_e$) in a porous medium is defined as:

$$D_e = D_o \phi' \tau \qquad (4)$$

where $D_o$ is the free-water diffusion coefficient evaluated at infinite dilution; $\phi'$ is the matrix porosity; and $\tau$ is the matrix tortuosity. Bear (1972) defines tortuosity as

$$\tau = (L / L_e)^2 \qquad (5)$$

where L is the sample length and $L_e$ is the actual tortuous flowpath length that a fluid particle would take passing through a sample of length L. The range of tortuosity is $0 < \tau \leq 1$, where a value of 1 would be a medium where all the pores were parallel capillary tubes. Another generally accepted expression for tortuosity is that defined by Collins (1961):

$$\tau = (L_e / L) \qquad (6)$$

Bear (1972) does not agree with this definition because it does not express tortuosity as affecting both the velocity and the driving force within a porous medium. This core-analysis report adopts the definition for porosity given by Equation (5). Because diffusion studies performed at SNL by Dykhuizen and Casey (1989) report tortuosity as defined by Equation (6), Figure 2.1 shows the relationship between the two definitions.

Another empirical geometrical variable which effectively decreases the free-water diffusivity in porous media is $\delta$, the constrictivity factor, ($0 < \delta \leq 1$) (van Brakel and Heertjes, 1974). Because tortuosity and constrictivity cannot be independently determined by experimental means, the following discussion lumps constrictivity with tortuosity.

Klinkenberg (1951) was the first to deduce that, from a theoretical viewpoint, the same factors that impede electrical conductance through a porous medium are also the same factors which impede diffusion of a conservative solute. Based upon the conclusion of Klinkenberg (1951) that diffusion should be analogous to conduction in a porous medium, an analogous equation to Equation (2) is

$$R_b = R_w (\tau \phi) \qquad (7)$$

From Equation (2), F can then be rewritten as

$$F = 1 / (\tau \phi) \qquad (8)$$

Therefore, by determining a medium's porosity and formation factor, the tortuosity can be estimated as

$$\tau = 1 / (F \phi) \qquad (9)$$

For Equation (9) to be appropriate, it is assumed that flow of the electrical current is only through the saturated void space. Using Equations (4) and (9), the formation factor can be used to calculate the effective molecular diffusion coefficient ($D_e$) of a porous medium. The formation factor becomes the reduction factor by which the free-water diffusion coefficient is divided to yield $D_e$. Therefore, expressing Equation (4) in terms of formation factor,

$$D_e = (D_o / F) \qquad (10)$$

Through diffusion studies, one can determine values for porosity and tortuosity which are often differentiated from those determined by other methods and can be referred to as diffusion porosity and diffusion tortuosity. From Equation (10) it becomes apparent that an effective diffusion formation factor can be calculated from diffusion studies. Other investigators (Skagius and Neretnieks, 1986; Katsube et al., 1986) have found that the formation factor determined from diffusion studies is generally higher than the formation factor determined through resistivity measurements. Skagius and Neretnieks (1986) found that the formation factor determined using values of electrical resistivity was not only a function of the rock, but also of the permeating ions. They recognized the importance of electrical resistivity as a tool to yield approximate formation factors with orders of magnitude less effort than through diffusion studies, which are susceptible to experimental difficulties and uncertainties.

## 2.4 Gas Permeability

Gas-permeability measurements were made on most core samples in both Phase 1 and Phase 2 studies. The measurements were made in a permeameter using standard steady-state techniques. The measurement of permeability utilizes a form of the Darcy equation which states that the flow through a porous medium of cross section (A) and length (L) is

$$Q = K\ A\ dh/dL \qquad (11)$$

where dh is the head (pressure) drop across the sample of length dL and K is the hydraulic conductivity of the medium. The hydraulic conductivity is dependent upon the fluid properties density ($\rho$) and viscosity ($\mu$), and can be expressed in terms of intrinsic permeability (k) by the relation

$$K = k\ \rho\ g\ /\ \mu \qquad (12)$$

Using Equations (11) and (12), where g is the acceleration due to gravity, the flow rate (Q) can be expressed in terms of intrinsic permeability by the expression

$$Q = k\ \rho\ g\ A\ dh\ /\ \mu\ dL \qquad (13)$$

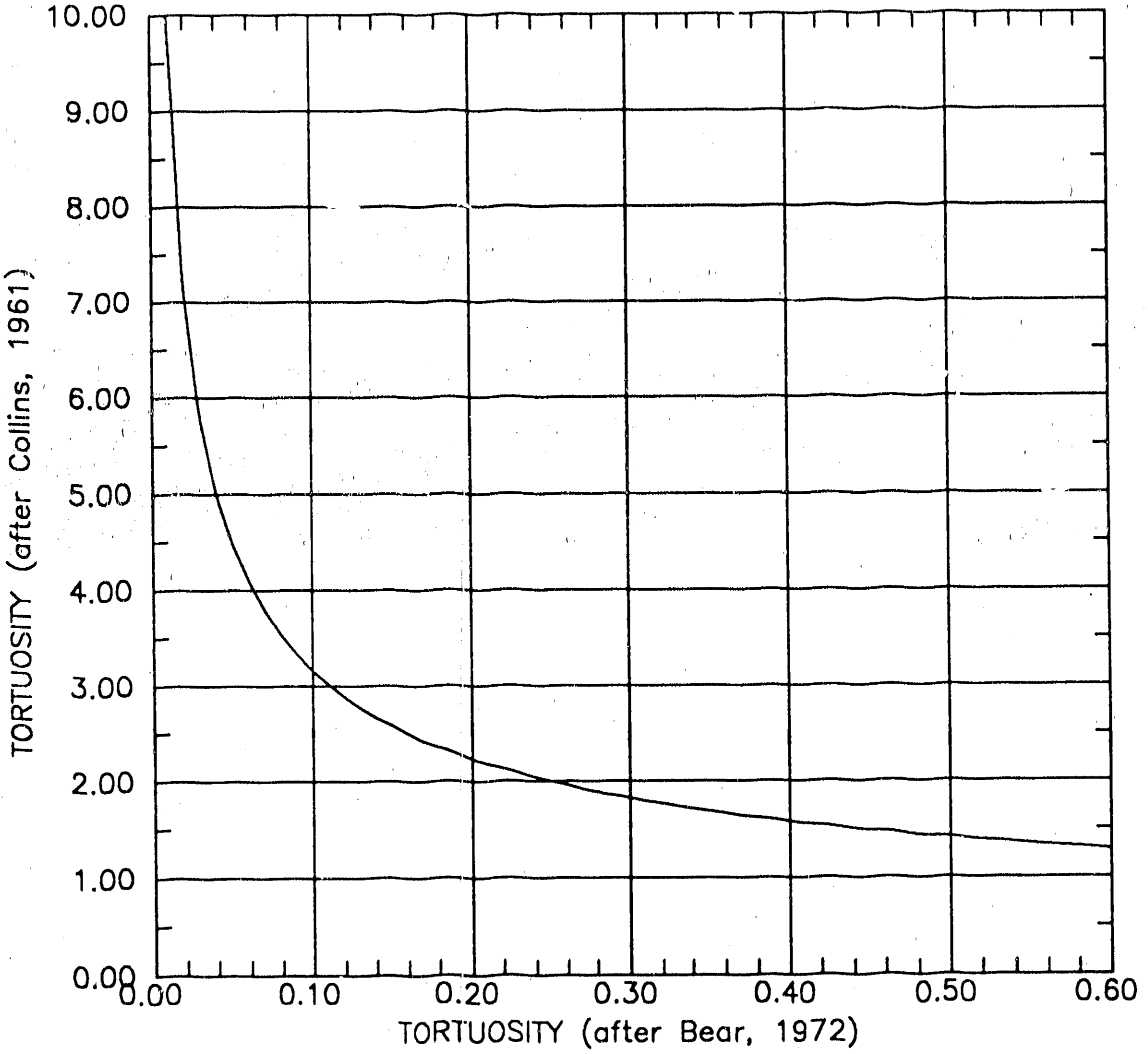
Using a permeameter, one can measure the downstream head, the upstream head, and the flow rate through the sample, and use the following relationship to calculate the intrinsic permeability:

$$k = Q\ \mu\ dL\ /\ \rho\ g\ A\ dh \qquad (14)$$

Gas-permeability measurements presented in this report were performed on intact (whole) core samples collected in the field, and on 2.5-cm diameter by 5-cm long cylindrical samples (core plugs) cored from the samples in the laboratory. Where possible, the permeability measurements in Phase 1 were made in both vertical and horizontal directions. In Phase 2, the gas permeability was measured in the direction coincident with the maximum dimension of the right-cylinder core plugs, thus corresponding to a horizontal-permeability measurement. For the whole-core samples, three measurements of permeability were obtained. The vertical measurement was made similar to the core-plug permeability determination. The horizontal-permeability measurements were made first in the estimated direction of the maximum or primary permeability axis (0°) and then in the estimated direction of the minimum permeability axis (90°).

For the permeability measurements made in Phase 1 and Phase 2, the permeating substance was helium gas. Gas-permeability measurements are generally performed under a confining pressure because: (1) the permeability of unconsolidated core material changes with confining pressure; (2) confining pressure retards sample bypass; and (3) confining pressure retards gas slippage. For well-cemented rocks, gas permeability is relatively insensitive to confining pressure with maximum deviations of 10% for confining pressures from atmospheric pressure to 14 MPa (Core Laboratories, 1973). Generally, a confining pressure is selected which is just enough to prevent sample bypass. The gas-permeability measurements for this report were performed under ambient conditions of 2.1 MPa net effective stress and 22.2°C.

The phenomenon known as gas slippage, or the Klinkenberg effect, causes the permeability determined using a gas to be larger than a liquid permeability. Gas slippage occurs when the diameter of the pores approaches the mean free path of the gas which is a function of the molecular weight and the kinetic energy of the gas. The kinetic energy is in turn a function of the mean pressure of the gas. Gas slippage causes the amount of flow through a sample to be greater than that predicted by Darcy's Law. The gas-slippage effect is decreased as the mean pressure on the gas is increased and the mean pore diameter of the sample is increased. Thus, the Klinkenberg effect becomes more pronounced as the permeability decreases. Klinkenberg corrections can be used to estimate what an equivalent liquid permeability would be for a sample. In the Phase 1 study, two Klinkenberg permeabilities were performed on two low-permeability core samples to assess the error inherent in gas-permeability determinations in low-permeability media. Typical liquid-to-helium permeability ratios for the range of permeabilities tested in this study are 0.6 to 0.8 (Core Laboratories, 1973).



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| INTERA Technologies | | Figure 2.1 |

# 3.0 SAMPLE SELECTION AND ANALYSES PERFORMED

## 3.1 Sample Selection and Sample Nomenclature

For all boreholes cored during the characterization of the WIPP site, the representative core samples were cataloged and stored in the WIPP Core Library located at the WIPP site. The goal of sample selection for the analyses presented in this report was to select objectively, from the available Culebra core samples, a complete distribution of Culebra physical textures. The factors which were used in deciding which borehole locations to sample were: (1) availability of core samples; and (2) whether or not the available core samples were sufficiently competent for analysis.

Core samples from 20 different boreholes were chosen for analysis. Hydropads H-2, H-3, H-4, H-5, H-6, H-7, and H-11 (see Figure 1.1) are locations which have at least three wells penetrating the Culebra. Core samples from one or more wells at hydropads H-2, H-3, H-7, and H-11 were analyzed for this report. Where possible, whole-core samples were analyzed. The majority of samples analyzed were 2.5-cm-diameter core plugs, 5 cm long. In Phase 1, 3 whole-core samples and 21 core plugs were analyzed. In Phase 2, whole-core samples from 10 different boreholes and 51 core plugs from 15 different locations were analyzed. Combining the results from Phase 1 and Phase 2, 15 whole-core samples and 72 core-plug samples were analyzed.

The Phase 1 core-analysis reports from Core Laboratories were not presented in a summary document, but were reported in three separate analysis summaries (Appendix B). Therefore, the sample numbers used in this report for Phase 1 represent an identifier designating the suite of analyses and the sample numbers used by Core Laboratories. For example, sample number 2-3 represents Core Laboratories sample 3, reported in the second results summary. Some samples were reanalyzed and are designated by two sample and result numbers, separated by a slash (i.e., 2-3/3-3). Thus, one sample may have two parameter estimates

The results of the Phase 2 core study were reported in summary reports from Terra Tek (Appendix C) and K & A Laboratories (Appendix D). These samples are designated with an alphanumeric well identifier followed by a number indicating the number of the sample chosen. For example, H2a-1 indicates that H2a is the well identifier and 1 is the sample identifier. Core plugs that were used to determine formation factor have an F following the sample identifier (i.e., W-26-1F). Because some whole core samples contained contrasting matrix textures, more than one core plug was obtained from the same core sample in order to study the small-scale vertical heterogeneity in the Culebra. For these paired core plugs, the sample numbers are differentiated from one another by the addition of a lower-case letter a or b (i.e., W-12-1a and W-12-1b). In the following sections, core samples will be described on an analysis-by-analysis basis. Tables 3.1 through 3.3 summarize which samples received what analysis during the Phase 1 and Phase 2 core studies.

## 3.2 Standard Porosimetry

### 3.2.1 Helium Porosity

Table 3.1 summarizes the analyses performed in the Phase 1 core study. Helium-porosity determinations were made for 3 whole-core samples, and 26 helium-porosity measurements were performed on 16 different core plugs. Table 3.1 shows that 12 different core plugs were reanalyzed. Six of the core plugs were reanalyzed at an ambient overburden stress of 2.4 MPa, and 6 were reanalyzed using the immersion method rather than the caliper method for determining bulk volume.

Tables 3.2 and 3.3 summarize the analyses performed in the Phase 2 core study. All of the 12 whole-core samples were analyzed for helium porosity, gas permeability, and resaturation porosity. Boyle's Law helium-porosity determinations were performed for 51 core plugs. Terra Tek performed 45 of these analyses, and K & A Laboratories analyzed 6 other core plugs which were not analyzed by Terra Tek. K & A Laboratories reanalyzed 18 of the Terra Tek samples as part of the mercury-intrusion tests. The 18 samples which were analyzed for helium porosity by both laboratories offer a comparison between laboratories, and an independent check of the Terra Tek results.

### 3.2.2 Water-Resaturation Porosity

For resaturation-porosity determinations, samples must be initially dry and then be saturated fully with a fluid of known density. Because all the core samples were stored dry in the WIPP Core Library, and because most samples have been in the library for years, drying of the core samples was judged unnecessary. However, the resaturation fluid choice was complicated.

The available Culebra core samples were all desaturated. The Culebra is composed predominantly of dolomite with lesser amounts of gypsum and halite (Core Laboratories, 1986), minerals which are susceptible to precipitation and dissolution. The possible choices of fluids used to resaturate the core were: (1) formation fluids from the wells from which the core samples were obtained; (2) an average Culebra formation fluid; (3) deionized water; or (4) some organic solvent such as tolulene or methanol. Ideally, one would use a formation fluid which would be at equilibrium with the minerals in each of the core samples. Because the core samples were obtained from a large number of locations with different formation-water chemistries, this approach was not considered to be practical because too many different fluids would be required. Also, a fluid with an average formation-water chemistry might not be at equilibrium in any of the samples and could affect results in an inconsistent manner. Organic solvents were considered to be undesirable because these liquids would not wet the minerals in the samples in the same manner as water would in the formation. Recognizing that none of these liquids would be ideal, it was decided that deionized water be used as the resaturation fluid for all samples because it would be the simplest procedure and provide a consistent fluid for all samples and would not provide additional contamination (F.J. Pearson, personal communication, 1987).

Resaturation porosity was not determined for any core samples from Phase 1 (Table 3.1). Resaturation porosity was determined for all 12 whole-core samples and 18 of the core plugs analyzed in the Phase 2 core study (Tables 3.2 and 3.3). Because helium porosities were also determined for all of these samples, 30 sample results are available to compare helium-porosity versus resaturation-porosity methods. In addition, 4 of these 18 core plugs were also analyzed by the mercury-intrusion method, thus giving a method of comparing the porosities determined by all three methods. While the sample group including all three porosimetry methods is too small to render quantitative conclusions, the comparison gives an intuitive grasp of the differences between the results of these methods. Mercury-intrusion porosimetry was not performed on more of the samples which had undergone resaturation testing because of the concern that the resaturation might have changed the pore structure of the sample through dissolution and/or precipitation.

## 3.3 Mercury-Intrusion Porosimetry

Mercury-intrusion porosimetry provides estimates of a sample's connected porosity and also yields the pore-throat-diameter distribution for a sample. In petroleum engineering, the results of mercury-intrusion porosimetry are used to define capillary-pressure curves for given formations. Twenty-four (24) core plugs were analyzed by the mercury-intrusion method by K & A Laboratories (Table 3.3). In many cases, core plugs from the same piece of core were analyzed to give an indication of the heterogeneity of pore-size distributions over vertical scales of a few centimeters.

## 3.4 Formation Factor

Formation factors were estimated from electrical-resistivity measurements for 15 core plugs in the Phase 2 core study (Table 3.3). The formation factor results were used to calculate 15 estimates of matrix tortuosity.

## 3.5 Gas Permeability

In the Phase 1 core study, gas-permeability determinations were performed for 3 whole-core samples (Table 3.1). In addition, 20 gas-permeability determinations were performed on 16 core plugs. In the Phase 2 core study, 12 whole-core samples were analyzed for gas permeability (Table 3.2). The whole-core samples were analyzed twice for horizontal permeability: once in the direction thought to have the maximum permeability (e.g., along a fracture), and once in the direction 90° from the maximum. Vertical gas permeabilities were also determined using core plugs from each of these same samples. In the Phase 2 core study, gas permeability was determined for 51 core plugs (Table 3.3).

|  |  |  |  | <======= Whole Core =======> |  | <======== Plug Core =======> |  |
|---|---|---|---|---|---|---|---|
| Well No. | Sample No. | Depth (m) | Length x Diameter(cm) | Gas Permeability | Helium Porosity | Gas Permeability | Helium Porosity |
| H-2b | 1-1 | 192 | 12.7 X 8.9 | 1 | 1 |  |  |
|  | 1-1H * | 192 | 12.7 X 8.9 |  |  | 1 (a) | (1) |
|  | 1-1V * | 192 | 12.[illegible] 8.9 |  |  | 1 (a) | (1) |
|  | 2-1/3-1 | 193.8-193.9 | 11.[illegible] 8.9 |  |  | 1 | 1, [1] |
|  | 1-2 | 194.3 | 6.4 X 8.9 |  |  | 1 | 1 |
|  | 2-2/3-2 | 195.0-195.1 | 12.7 X 8.9 |  |  | 1 | 1, [1] |
| H-3b2 | 1-3/3-3V | 207.6 | 7.6 X 8.9 |  |  | 1, (1) | 1, (1) |
|  | -4/3-4V | 210.1 | 10.2 X 8.9 |  |  | 1, (1) | 1, (1) |
| H-3b3 | 2-3/3-3 | 204.6-204.7 | 7.6 X 8.9 |  |  | 1 | 1, [1] |
|  | 2-4/3-4V | 204.7-204.8 | 7.6 X 8.9 |  |  | 1 | 1, [1] |
|  | 1-6/3-6V | 210.1 | 10.2 X 8.9 |  |  | 1, (1) | 1, (1) |
|  | 2-5/3-5 | 210.3-210.5 | 7.2 X 8.9 |  |  | 1 | 1, [1] |
| H-4b | 1-9 | 156.4 | na | 1 | 1 |  |  |
|  | 2-6/3-6V | 157.6-157.7 | 7.6 X 8.9 |  |  | 1 | 1, [1] |
| H-6b | 2-7 | 187.2-187.3 | 3.6 X 8.9 |  |  | 1 | 1 |
|  | 2-8 | 187.4-187.5 | 3.6 X 8.9 |  |  | 1 | 1 |
|  | 1-7 | 187.8 | na |  |  | 1 | 1 |
|  | 1-8/3-8V | 191.4-195.1 | na |  |  | 1, (1) | 1, (1) |

| | |
|---|---|
| 1 | Denotes that the analysis was performed for that sample. |
| * | Denotes that the sample is a subsample of the piece of core listed immediately above. |
| (a) | Klinkenberg permeability. |
| ( ) | Denotes an ambient stress of 350 psi during testing. |
| [ ] | Denotes a helium porosity measurement where the bulk volume is determined by fluid displacement. |

| | | |
|---|---|---|
| Drawn by | Date | Summary of Analyses Performed as Part of the Phase 1 Core Study |
| Checked by | Date | |
| Revisions | Date | |
| # 105000R019 | 12/7/89 | |
| INTERA Technologies | | Table 3.1 |

| Well No. | Sample No. | Depth (m) | Length x Diameter(cm) | <========= Whole Core Analyses ==========> | | |
|---|---|---|---|---|---|---|
| | | | | Gas Permeability | Boyle's Law Porosity | Resaturation Porosity |
| H-5b | H-5b-3 | 274.7-274.8 | 13.7 x 11.4 | 1 | 1 | 1 |
| H-7b2 | H-7b2-2 | 79.2-79.6 | 43.2 x 8.9 | 1 | 1 | 1 |
| H-10b | H-10b-3 | 423.1-.2 | 20.3 x 11.4 | 1 | 1 | 1 |
| H-11 | H-11-1 | 222.9-223.0 | 12.7 x 8.9 | 1 | 1 | 1 |
| H-11b3 | H-11b3-3 | 226.1-226.2 | 16.5 x 8.9 | 1 | 1 | 1 |
| WIPP-12 | WIPP-12-3 | 253.6-253.7 | 13.9 x 11.4 | 1 | 1 | 1 |
| WIPP-25 | WIPP-25-1 | 138.3-138.4 | 25.4 x 8.9 | 1 | 1 | 1 |
| WIPP-26 | WIPP-26-2 | 58.4-58.5 | 15.2 x 11.4 | 1 | 1 | 1 |
| WIPP-28 | WIPP-28-2 | 129.9-130 | 15.2 x 11.4 | 1 | 1 | 1 |
| | WIPP-28-3 | 130.4-130.5 | 15.2 x 11.4 | 1 | 1 | 1 |
| WIPP-30 | WIPP-30-1 | 197.4-197.5 | 10.2 x 11.4 | 1 | 1 | 1 |
| | WIPP-30-2 | ~194.6 | 10.2 x 11.4 | 1 | 1 | 1 |

1 Denotes that the analysis was performed for that sample.

| | | |
|---|---|---|
| Drawn by | Date | Summary of Whole-Core Analyses<br>Performed in the Phase 2 Core Study |
| Checked by | Date | |
| Revisions | Date | |
| #105000R019 | 10/18/90 | |
| INTERA Technologies | | Table 3.2 |

| Well No. | Sample No. | Depth (m) | Length x Diameter(cm) | Plug Core |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Gas Permeability | Boyle's Law Porosity | Resaturation Porosity | Mercury Intrusion | Formation Factor |
| H-2a | H2a-1 | 188.7 | 6.1 x 8.9 | 1 | 1 | 1 |  |  |
|  | H2a-2 | 189.6-189.7 | 12.9 x 8.9 | 1 | 1 |  | 1 |  |
| H-2b1 | H2b1-1 | 194.3-194.4 | 8.9 x 8.9 | 1 | 1 | 1 |  |  |
|  | H2b1-1F | 194.3-194.4 | 8.9 x 8.9 | 1 | 1 |  |  | 1 |
|  | H2b1-2 | ~195 | 9.9 x 8.9 | 1 | 1 |  | 1 |  |
|  | H2b1-3 | ~195.5 | 6.1 x 8.9 | 1 | 1 | 1 |  |  |
| H-5b | H-5b-1a | 275.2-275.3 | 17.8 x 11.4 | 1 | 1 |  | 1 |  |
|  | H-5b-1b | 275.2-275.3 | 17.8 x 11.4 | 1 | 1 |  | 1 |  |
|  | H-5b-2 | 278.3-278.6 | 11.4 x 11.4 | 1 | 1 | 1 |  |  |
|  | H-5b-2F | 278.3-278.6 | 11.4 x 11.4 | 1 | 1 |  |  | 1 |
| H-7b1 | H-7b1-1 | 76.6-76.7 | 8.9 x 11.4 | 1 | 1 | 1 |  |  |
|  | H-7b1-1F | 76.6-76.7 | 8.9 x 11.4 | 1 | 1 |  |  | 1 |
|  | H-7b1-2a | ~81.7 | 10.2 x 11.4 | 1 | 1 |  | 1 |  |
|  | H-7b1-2b | ~81.7 | 10.2 x 11.4 | 1 | 1 |  | 1 |  |
| H-7b2 | H-7b2-1 | ~83.8 | 10.2 x 8.9 | 1 | 1 | 1 | 1 |  |
| H-7c | H-7c-1a | 82.6-82.8 | 17.8 x 11.4 | 1 | 1 | 1 | 1 |  |
|  | H-7c-1b | 82.6-82.8 | 17.8 x 11.4 | 1 | 1 |  | 1 |  |
|  | H-7c-1F | 82.6-82.8 | 17.8 x 11.4 | 1 | 1 |  |  | 1 |
| H-10b | H-10b-1 | 425-.1 | 12.7 x 11.4 | 1 | 1 |  | 1 |  |
|  | H-10b-2 | 418.8-418.9 | 11.2 x 11.4 | 1 | 1 | 1 |  |  |
|  | H-10b-2F | 418.8-418.9 | 11.2 x 11.4 | 1 | 1 |  |  | 1 |
| H-11 | H-11-2 | NA | 8.9 x 8.9 | 1 | 1 | 1 | 1 |  |
|  | H-11-2F | NA | 8.9 X 8.9 | 1 | 1 |  |  | 1 |
| H-11b3 | H-11b3-1 | 230.5-230.6 | 8.4 x 8.9 | 1 | 1 | 1 | 1 |  |
|  | H-11b3-1F | 230.5-230.6 | 8.4 x 8.9 | 1 | 1 |  |  | 1 |
|  | H-11b3-2 | ~229.5 | 11.4 x 8.9 | 1 | 1 | 1 |  |  |
|  | H-11b3-2F | ~229.5 | 11.4 x 8.9 | 1 | 1 |  |  | 1 |
|  | H-11b3-4 | 226.9-227.2 | 9.9 x 8.9 | 1 | 1 |  | 1 |  |
|  | H-11b3-4F | 226.9-227.2 | 9.9 x 8.9 | 1 | 1 |  |  | 1 |

1 Denotes that the analyses was performed for that sample.

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Summary of Plug-Core Analyses Performed in the Phase 2 Core Study

Table 3.3

| Well No. | Sample No. | Depth (m) | Length x Diameter(cm) | Plug Core: Gas Permeability | Plug Core: Boyle's Law Porosity | Plug Core: Resaturation Porosity | Plug Core: Mercury Intrusion | Plug Core: Formation Factor |
|---|---|---|---|---|---|---|---|---|
| WIPP-12 | WIPP-12-1a | 250.4-250.5 | 15.2 x 11.4 | 1 | 1 | | 1 | |
| | WIPP-12-1b | 250.4-250.5 | 15.2 x 11.4 | 1 | 1 | | 1 | |
| | WIPP-12-2 | 254.3-254.4 | 14.7 x 11.4 | 1 | 1 | 1 | 1 | |
| | WIPP-12-2F | 254.3-254.4 | 14.7 x 11.4 | 1 | 1 | | | 1 |
| WIPP-13 | WIPP-13-1 | ~216.4 | 13.9 x 11.4 | 1 | 1 | 1 | | |
| | WIPP-13-2 | ~220.5 | 12.7 x 11.4 | 1 | 1 | 1 | | |
| | WIPP-13-2F | ~220.5 | 12.7 x 11.4 | 1 | 1 | | | 1 |
| | WIPP-13-3a | 215.6-215.8 | 22.9 x 11.4 | 1 | 1 | | 1 | |
| | WIPP-13-3b | 215.6-215.8 | 22.9 x 11.4 | 1 | 1 | | 1 | |
| WIPP-26 | WIPP-26-1 | 58.1-58.2 | 9.6 x 11.4 | 1 | 1 | 1 | | |
| | WIPP-26-1F | 58.1-58.2 | 9.6 x 11.4 | 1 | 1 | | | 1 |
| | WIPP-26-3 | ?58.5-59.1 | 12.7 x 11.4 | 1 | 1 | | 1 | |
| WIPP-28 | WIPP-28-1a | ~131.1 | 7.6 x 11.4 | 1 | 1 | | 1 | |
| | WIPP-28-1b | ~131.1 | 7.6 x 11.4 | 1 | 1 | | 1 | |
| | WIPP-28-3F | 130.4-130.5 | 15.2 x 11.4 | 1 | 1 | | | 1 |
| WIPP-30 | WIPP-30-3a | 194.1-194.2 | 15.2 x 11.4 | 1 | 1 | | 1 | |
| | WIPP-30-3b | 194.1-194.2 | 15.2 x 11.4 | 1 | 1 | 1 | 1 | |
| | WIPP-30-3F | 194.1-194.2 | 15.2 x 11.4 | 1 | 1 | | | 1 |
| | WIPP-30-4 | 193.6-193.7 | 10.2 x 11.4 | 1 | 1 | | 1 | |
| AEC-8 | AEC-8-1 | ~258.8 | 10.2 x 11.4 | 1 | 1 | 1 | | |
| | AEC-8-1F | ~258.8 | 10.2 x 11.4 | 1 | 1 | | | 1 |
| | AEC-8-2 | ~260.3 | 10.2 x 11.4 | 1 | 1 | 1 | | |

1 Denotes that the analysis was performed for that sample.

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Summary of Plug-Core Analyses Performed in the Phase 2 Core Study

Table 3.3 (con't.)

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# 4.0 CORE ANALYSIS RESULTS

A summary of the results of the analyses performed by Core Laboratories can be found in Appendix B. Laboratory reports from Terra Tek and K & A Laboratories are presented in Appendices C and D, respectively. An errata page with correct sample numbers is included with the Terra Tek report. The following section will discuss the analyses performed by these laboratories grouped by parameter estimated and test method. The presentation of the results will include discussions of parameter distributions and relationships between parameters when possible. Table 4.1 summarizes the results of the Phase 1 core study, Table 4.2 presents the results of the Phase 2 whole-core analyses, and Table 4.3 summarizes the Phase 2 plug-core results.

## 4.1 Standard Porosity Analyses

Helium porosity was determined for both whole-core and plug-core samples in both Phase 1 and Phase 2. Results from both studies will be reviewed separately and then combined to increase the sample size for statistical analysis. Data presented in Davis (1969) and Freeze (1975) indicate that porosity is a normally distributed parameter. To determine whether or not the porosity of the Culebra dolomite is also normally distributed, the porosity distributions of the analytical data from the Phase 1 and Phase 2 core-analysis studies are presented in the form of relative-frequency histograms. In some cases, cumulative-frequency distributions of porosity are also included in the discussion of the results.

### 4.1.1 Helium Porosity

Table 4.1 summarizes the results from the Phase 1 core study. Note that for some samples, more than one value is listed for porosity (see Section 3.0). In general, the bulk volume for most samples was determined by the caliper method and volumetric relationships. Because of concerns that the bulk volume of some samples might be in error because the samples were not perfect right cylinders, six samples (denoted in square brackets in Table 4.1) had bulk volumes determined by fluid displacement. Where this is the case, the two reported porosities determined for that sample have been averaged and the average value is used in the frequency distributions and other statistical analyses. For six other samples, porosity was determined with an ambient pressure of 2.4 MPa. All other Boyle's Law helium-porosity determinations (for both Phase 1 and Phase 2 core studies) were performed at atmospheric conditions. For well-consolidated rocks, the effect of overburden pressures is negligible (Core Laboratories, 1973). Because all other porosity measurements were performed without simulated overburden pressure, the measurements performed with a 2.4 MPa pressure (denoted with a set bracket) are not included with the other values when presenting distribution statistics.

In the Phase 1 core study, three samples were analyzed for whole-core porosity (Table 4.1). Of these three, sample 1-5, from H-3b3, is not representative of the Culebra dolomite because the sample is dominantly composed of gypsum. In addition, because the sample was excessively dried, some or all of the gypsum may have been converted to anhydrite, thus providing a non-representative porosity for the gypsum interval. Because there are only 2 whole-core porosities, they are lumped with the plug-core data. Excluding porosities determined with a simulated overburden pressure, there are 16 helium-porosity determinations from the Phase 1 core study. Figure 4.1 is a relative-frequency histogram of the Phase 1 helium porosities. The distribution in Figure 4.1 does not display a normal distribution. Given the low number of samples (N) used for the relative-frequency histogram (N = 16), it is not surprising that the distribution is non-ideal. The arithmetic mean ($\mu$) of the porosity data is 0.175 with a standard deviation ($\sigma$) of 0.057. Figure 4.2 is a cumulative relative-frequency curve for Phase 1 helium porosities. The median (Md) of a distribution is defined as that value having a cumulative relative frequency equal to 0.5, which indicates that one half of the observations has a value less than the median and one half of the observations has a value greater than the median. Figure 4.2 shows that the median of the Phase 1 helium porosities is 0.174.

The Culebra is a massive, laminated dolomite with pronounced vertical heterogeneity, as can be seen in core samples and on outcrops, such as at Culebra Bluff on the Pecos River, 20 miles west of the WIPP site. As part of the Phase 2 core study, multiple core plugs were obtained from some Culebra samples because of a lack of available core samples for the desired suite of analyses and to characterize heterogeneity between closely spaced samples (see Section 3.0). Twenty-one (21) pieces of Culebra core had two plugs cored over vertical distances of less than 10 cm. Figure 4.3 is a bar chart of helium-porosity data for core plugs from the same core sample. The helium porosity of one core plug is compared to the porosity of its close neighbor. The chart illustrates that differences in porosity measured in samples within 5 to 10 cm of each other vertically can be as small as 0.005 and as high as 0.093, and demonstrates the heterogeneity of porosity in the Culebra. Because of this heterogeneity, all of these 42 independent porosity measurements were treated as point values.

Eighteen of the 24 core plugs analyzed by K & A Laboratories using mercury-intrusion porosimetry were first cored and analyzed for porosity by Terra Tek using Boyle's Law helium porosimetry. These samples were shipped from Terra Tek to K & A Laboratories where helium porosity was remeasured, thus allowing a laboratory-to-laboratory comparison. Figure 4.4 plots K & A Laboratories helium porosity versus Terra Tek helium porosity for the 18 samples measured by both laboratories. In general, the porosity values are nearly identical with the $R^2$ of the linear regression of these data equal to 0.93. Figure 4.4 and Table 4.3 show that the K & A Laboratories porosities are usually 0.005 to 0.01 larger than the Terra Tek porosities, with a maximum observed difference of 0.056. This data gives an estimate of the reproducibility of the Boyle's Law helium porosity. The discrepancies are probably the result of difficulty in the precision of estimating bulk volume and possible differences in the techniques used by the two laboratories in estimating bulk volumes. Because the correct helium porosity cannot be discerned, the arithmetic average between the two reported porosities is the value used in further data reduction and reporting.

In the Phase 2 core study, 51 core plugs were analyzed for helium porosity by the Boyle's Law method. Figure 4.5 is a relative-frequency histogram of these porosity determinations. The distribution of porosities is not a normal distribution, and is skewed toward the lower values of the range of porosities determined during the Phase 2 core study. The arithmetic average of these determinations is equal to 0.149, and the standard deviation is equal to 0.055. Because the distribution is skewed, the mean does not coincide with the peak of the distribution (Figure 4.5). The median core-plug porosity for the helium porosities obtained in the Phase 2 study is 0.138.

Twelve whole-core helium-porosity measurements were performed in the Phase 2 core study. Figure 4.6 is a relative-frequency histogram combining all 63 helium-porosity measurements (whole-core and core-plug analyses combined) from the Phase 2 core study. The addition of the whole-core porosities did not significantly affect the distribution of plug-core porosities shown on Figure 4.5. Again, the distribution of porosity is not normal and skewed. The arithmetic mean is equal to 0.147 with a standard deviation of 0.051. Figure 4.7 is a cumulative relative-frequency curve for all the Phase 2 helium porosities. The median value is 0.134.

All helium porosities for the Culebra dolomite determined during both the Phase 1 and Phase 2 core studies using Boyle's Law techniques are summarized in Table 4.4. Table 4.4 also lists an arithmetic-average porosity value for any samples for which more than one determination was made. Figure 4.8 is a relative-frequency histogram combining all 79 helium porosities measured from both Phase 1 and Phase 2. Helium-porosity values are normally distributed and are slightly skewed toward the lower part of the range of porosities presented, with an arithmetic mean of 0.153 and a standard deviation of 0.053. The mean porosity does not coincide with the peak of the distribution, quantitatively confirming the skewed nature of the distribution. Figure 4.9 is a cumulative relative-frequency curve for both Phase 1 and Phase 2 helium porosities, and shows that the median porosity is 0.141.

Figure 4.10 compares the cumulative relative-frequency curves of the Phase 1 and Phase 2 helium-porosity results. Two differences between these curves are indicated. First, the Phase 2 results create a much smoother distribution, which is not surprising, considering that the sample size for the Phase 2 helium porosities was approximately 4 times greater than that of Phase 1. The second observation is that the median porosity for the Phase 1 helium porosities is 4% larger than that of the Phase 2 data.

It was noted in Section 1.0 of this report that two hydrologic regimes appear to be present in the vicinity of the WIPP site. One regime acts hydraulically as a fractured medium with transmissivities greater than or equal to 1.0E-6 $m^2/s$ and exhibits double-porosity behavior. The other hydrologic regime has transmissivities less than 1.0E-6 $m^2$ and fluid-pressure responses to hydraulic tests generally do not display double-porosity behavior (Beauheim, 1987). LaVenue et al., (1990) indicate that the estimated fastest travel path from the center of the WIPP site to the WIPP-site boundary includes the H-3 and H-11 hydropads. The average porosity for core samples from H-3 and H-11 is

0.173, or two percent higher than the overall average WIPP-site Culebra porosity of 0.153. Comparing the porosity values on Table 4.4 with the transmissivity data for the Culebra in WIPP-site wells shown in Beauheim (1987, Figure 6.1) indicates that some locations exhibiting higher permeability and double-porosity behavior have reported porosity values higher than the WIPP-site average Culebra porosity and lower permeability locations such as the H-2 hydropad, have porosity values less than the WIPP-site average Culebra porosity. However, data comparison also shows the heterogeneous distribution of porosity within the Culebra even at the hydropad scale. Thus, while the average WIPP-site Culebra porosity may underestimate the porosity of the fastest offsite flow path, general conclusions concerning the relationship between permeability and porosity are not warranted using the data presented in this report. The porosity and permeability data should be compared on a site-by-site or area-by-area basis for any particular area under investigation.

The quantity and quality of samples recovered during core drilling at WIPP-site wells contributes a further uncertainty to the relationship between Culebra permeability and porosity. For many WIPP-site wells, the large amount of lost core in apparently porous and fractured parts of the Culebra indicates that the most porous material may have been destroyed and not recovered during coring and is, therefore, not represented in the final porosity distribution. Thus, the parameter distributions shown on Figures 4.8 and 4.10 represent selected determinations for helium porosity of the Culebra in the vicinity of the WIPP site. The degree to which these distributions remain affected by sample selection is unquantifiable.

### 4.1.2 Water-Resaturation Porosity

As discussed in Section 3.2.2, deionized water was the fluid used to determine resaturation porosity. In an attempt to quantify the effect of using deionized water as the resaturation fluid, a pair of core plugs was removed from a single piece of core from well H-5b (sample H-5b-1). Helium porosities were measured for each sample and then compared to the resaturation porosities for each sample, one analyzed using deionized water, and one analyzed using a laboratory approximation of the H-5b formation fluid. The core from well H-5b was used in this study because well H-5b had a large number of core samples, a relatively high formation-fluid density (1.102 g/cm$^3$), and several dissolved-solid determinations with similar values (Robinson and Lambert, 1987).

Core-plug sample H-5b1-1a had a helium porosity of 0.1078 and a resaturation porosity of 0.1068 measured with deionized water. Core plug H-5b1-1b had a helium porosity of 0.1245 and a resaturation porosity of 0.1207 measured with formation fluid. It thus appears that the use of deionized water as the resaturation fluid can have minimal effects, although this does not imply that this result can be extrapolated to all the resaturation porosities.

All samples which were analyzed by resaturation techniques were examined after analysis for any outward signs of mineral dissolution. Eighteen (18) core plugs and 12 whole-core samples were analyzed. Of the 30 samples analyzed, 8 showed signs of mineral dissolution as a result of the resaturation-porosity determinations. Figure 4.11 is a plot of resaturation porosity versus the associated helium porosity for all 30 samples. The R$^2$ of the linear regression of these two sets of data is 0.99. The difference between the porosity measurements is only greater than 0.01 for two samples, with the average difference being less than 0.005. In general, the results of the resaturation porosimetry are similar to those obtained using Boyle's Law helium porosimetry. However, Figure 4.11 indicates that the resaturation porosities in the majority of these samples are larger than the helium porosities. The differences in these results can be explained by two arguments. Either dissolution was important and altered and enlarged the pore volume of the samples during analysis, or the experimental standard error for both methods is greater than the resolution of the results. The differences are likely best explained using both arguments. Because dissolution was not observed to be universally active on all samples, the experimental standard of error probably best explains the variation in the results.

### 4.1.3 Grain Density

In porosity calculations, two of the three sample parameters (bulk volume, pore volume, and grain volume) must be determined. For the porosity determinations discussed thus far, both bulk volume and pore volume were determined. From this data base, calculation of rock grain density is a standard procedure for the analyzing laboratories. Figure 4.12 is a relative-frequency histogram of 73 grain-density determinations from both Phase 1 and Phase 2 core studies. The distribution is skewed toward the larger values of grain density, with an arithmetic mean of 2.82 g/cm$^3$ and a standard deviation of 0.019 g/cm$^3$. The median of the distribution of grain densities is 2.83 g/cm$^3$. If grain density were a normally distributed parameter, one would expect the best estimate for grain density to be 2.82 g/cm$^3$. From viewing Figure 4.12, it is apparent that 2.83 g/cm$^3$ is the most common grain density, which is consistent with the non-normal, skewed nature of the distribution.

## 4.2 Mercury-Intrusion Porosimetry

K & A Laboratories used mercury-intrusion porosimetry to analyze 25 Culebra dolomite samples and determine endpoint mercury saturation, mercury-intrusion porosity, and pore-throat radii. The samples analyzed included 24 core plugs and one segment of a core plug, and the results are summarized in Table 4.5, along with the helium porosities determined by K & A Laboratories. The median pore-throat radii were calculated from cumulative-frequency plots of the K & A mercury-intrusion data. The core-plug segment was obtained from sample H-10b-1 and was analyzed because the analysis of the complete core sample indicated an anomalously low endpoint mercury saturation. The samples were subjected to incremental pressure changes up to 207 MPa. The K & A Laboratories report containing the complete set of results is presented in Appendix D, and includes relative-frequency histograms of pore-throat radius and capillary-pressure curves for each sample where mercury is the non-wetting fluid. The pore-size distributions determined using mercury-intrusion porosimetry are based on the simplified capillaric model, indicated by Equation (1), that does not rigorously satisfy the complex pore geometry of geologic media (Scheidegger, 1974).

Discussion of the mercury-intrusion-porosimetry determinations presented in this report is limited to a comparison between the porosities determined by the intrusion technique and to calculation of median pore-throat radii for each sample. All samples reached 50% mercury saturation at pressures less than or equal to 10.3 MPa. The helium porosities, endpoint saturations, median pore-throat radii, and mercury-intrusion porosities for the 25 samples analyzed are listed in Table 4.5. The mercury-intrusion porosity for each sample is calculated by multiplying the endpoint saturation by the helium porosity. The endpoint saturations range from a low of 66.7% to a high of 99.9%. The average endpoint mercury saturation at 207 MPa is 95.4%. The average helium porosity for these samples is 0.154 and the average mercury-intrusion porosity is 0.148. The low endpoint mercury saturation of 66.7% for sample H10-1b-1 when compared to the near-average value of 95.2% determined for a segment of this core plug (Table 4.5) could indicate that pore-throat sizes in this sample of the Culebra may be heterogeneously distributed (Appendix D). The air-permeability values determined for sample H10-1b-1 were also lower for the complete core sample than for the core-plug segment, a further indication of heterogeneity.

There are several possible explanations for the endpoint mercury saturations being less than 100% for most samples. The most obvious explanation is that all non-saturated pore spaces have radii less than the radius accessible to mercury at 207 MPa. Another possible explanation lies in the sequence of laboratory procedures. K & A Laboratories determined helium porosity before conducting mercury-intrusion porosimetry and then used that porosity to define sample pore volume. Figure 4.4 shows that K & A Laboratories consistently determined a higher helium porosity than Terra Tek when testing the same core-plug samples. If Terra Tek's values were actually more representative of the true porosity, this fact could explain the less than 100% endpoint mercury saturations reported. Alternatively, if large pore spaces were only accessible by extremely small pore radii, it is conceivable that the larger pores could not be accessed by mercury intrusion.

Median pore-throat radii calculated from the cumulative-frequency plots of the results of mercury-intrusion porosimetry range from a low of 0.077 $\mu$m to a high of 0.588 $\mu$m. The arithmetic mean of the calculated median pore-throat radii is 0.315 $\mu$m. Given the assumptions implicit to mercury-intrusion porosimetry, 50% of the pore-throat radii for the 25 samples are greater than 0.315 $\mu$m. The distributions of pore-throat radii for the samples analyzed by K & A Laboratories (Appendix D) indicate that the pore-throat radii are distributed differently between samples. However, most pore radii generally range between 0.05 and 0.6 $\mu$m and the median pore radii for all samples have a range of approximately one order of magnitude.

In the Phase 2 core study, some plug-core samples were taken from the same larger piece of core and were separated generally by 5 to 10 cm. These samples are those which have sample numbers which differ only by the addition of an (a) or a (b) at the end of the sample number, as indicated on Table 4.4. The variation in pore-throat-radius distribution between these closely spaced sample pairs can be as heterogeneous as samples taken from different wells. For example, the distributions of pore-throat radii for samples H-7b1-2a and H-7b1-2b are significantly different (Appendix D). The median pore radii of the two samples are different while the modal pore radii of the samples are the same. Also, sample H-7b1-2b has a significant percentage of its pore volume occupied by large-diameter pores that are immediately accessible to the external edges of the sample. For some pairs of samples, the variations in the distributions of pore-throat-radii are negligible and the median pore-throat radii are equal (samples H-5b1-1a and H-5b1-1b).

The results of mercury-intrusion porosimetry indicate the heterogeneous nature of porosity distribution in the Culebra dolomite. The values and variations in endpoint mercury saturation and the distribution of pore-throat radii between samples illustrate this heterogeneity. In general, the distribution of pores within the Culebra can vary significantly over small vertical distances. However, the values of the median pore-throat radii range over only one order of magnitude between all samples, and in the majority of samples, the range is much less.

## 4.3 Formation-Factor Results

Terra Tek Core Services determined formation factors for 15 separate core plugs (Table 4.6). Values range from a low of 12 to a high of 407. Figure 4.13 is a relative-frequency histogram showing the distribution of formation-factor values. Although a value of zero is represented on the abcissa of the histogram, the theoretical lower limit for formation factor is 1. The arithmetic mean of the formation-factor values is 96.1. The distribution appears to be log-normal. Figure 4.14 is a relative-frequency histogram of the log of the formation-factor values. The geometric mean of this distribution is 58.8, and the histogram approximates a log-normal distribution. Because the formation factor is a function of the pore geometry and non-normal pore-size distribution, it might be expected that the distribution of formation-factor values would be non-normal.

Table 4.6 presents tortuosity values calculated using formation-factor values for 15 samples using Equation (9). The formation-factor values in Table 4.6 were calculated with Equation (2) from electrical-resistivity data. Figure 4.15 is a relative-frequency histogram of the calculated tortuosity values. The distribution is not well-defined due to the small sample size. The arithmetic average of calculated tortuosity is 0.14, the standard deviation is 0.08, and the median is 0.12. The values of tortuosity ranged from 0.03 to 0.33. Table 4.6 lists the values of formation factor and tortuosity for each of the samples measured. Figure 4.16 is a plot of the helium porosity of each sample versus the tortuosity of the sample, and indicates a general trend of increasing tortuosity with decreasing porosity. It thus appears that as the fraction of pore space decreases, the intersection of these pore spaces also decreases.

Terra Tek (see Appendix C) calculated the constants for Archie's equation (Equation (3), Section 2.3.1). Using these results, the formation factor for the Culebra can be related to porosity by the relationship

$$F = 1.0 / \phi^{2.13} \qquad (15)$$

where 2.13 represents the cementation factor. Figure 4.17 plots the formation-factor values determined from electrical-resistivity measurements for each sample against the formation factor calculated for each sample using the sample porosity and Equation (15). The plotted data have an $R^2$ for the linear regression of 0.77.

The use of resistivity studies to determine matrix diffusivities has proven to be effective and results indicate that the formation factor determined using electrical-resistivity measurements is usually smaller than that determined by diffusion studies (Skagius and Neretnieks, 1986; Katsube et al., 1986). For example, Katsube et al. (1986) determined that the diffusion-flux formation factor for a crystalline granite was

1.9 times greater than the electrical-resistivity formation factor. The differences between these two methods used to estimate formation factor are most likely due to dead-end pore space, constrictivity, and grain-to-fluid interface phenomena.

Sandia National Laboratories (SNL) performed diffusion experiments on four samples of the Culebra dolomite, and the results have been released in a series of internal technical memorandums and a Sandia National Laboratories report (Casey and Stockman, 1988a; Casey and Stockman, 1988b; Casey and Stockman, 1988c; Casey and Stockman, 1989; Dykhuizen and Casey, 1989). Nine different diffusion experiments were performed on four different samples from three different locations. Four experiments were performed on a rock sample of the Culebra dolomite from core recovered from well WIPP-19 (sample WIPP-19). Three experiments were performed on one subsample of the Culebra dolomite from a slab of the Culebra dolomite from the WIPP-site exhaust shaft (sample ESM-143-2), and another experiment was performed on a different subsample of that slab (sample ESM-143-1). One experiment was performed on a rock sample of the Culebra dolomite from the WIPP-site air-intake shaft (sample AIS-SNL-16). The diffusion porosity and diffusion tortuosities were determined using methods described in Katsube et al. (1986) (Dykhuizen and Casey, 1989). Table 4.7 summarizes the results of these diffusion experiments. When calculating mean values from these data, if a rock sample was used for more than one diffusion experiment using different tracers, the results from all experiments on the same sample were averaged to give an average tortuosity and diffusion porosity for that rock sample. All experimental values were then averaged to arrive at a mean value for the four rock samples. This procedure incorporates the variation within one sample, yet prevents that variation or any one sample from dominating the average.

The results of the SNL diffusion experiments indicate a range in diffusion tortuosity of 0.03 to 0.17, with a mean value of 0.1 (N = 4).

The diffusion porosity ranged from 0.01 to 0.13, with a mean value of 0.07 (N = 4). The average diffusion formation factor is 239 (N = 4), which is nearly 2.5 times greater than the mean formation factor of 96.1 calculated from electrical-resistivity measurements. This result is not surprising, given that the porosities of the samples used in the diffusion experiment are on the average much less than the porosities of the samples from which the electrical-resistivity formation factors were calculated. Because of the limited sample sizes, no conclusions or correlations were developed between the results of the diffusion experiments and the results derived from electrical-resistivity calculations.

Figure 4.18 combines the results from the electrical-resistivity calculations and the diffusion experiments. The diffusion tortuosities are plotted as a function of both diffusion porosity (open symbols) and helium porosity (filled symbols). All experiments on the same sample are indicated by the same symbol to indicate the experimental uncertainty in the results for that sample. Figure 4.18 shows that the variability in results for a given sample is high but the results from the diffusion experiments generally fall within the scatter of the values derived from electrical-resistivity measurements. The data presented in Table 4.7 show that the diffusion porosity is generally less than porosity determined by other methods. Dykhuizen and Casey (1989) indicate that this difference is due to the inadequacies of simple versions of Fick's First Law of Diffusion for solutes in a porous medium. The differences may also be due to incomplete resaturation of the pore spaces with the fluid used in the diffusion experiments (Casey and Stockman, 1989) and the low number of samples (4). Also, heterogeneity can contribute significant differences in porosity over distances of several centimeters using various subsamples of a given rock sample, as shown on Figure 4.3.

## 4.4 Gas-Permeability Results

Freeze (1975) reported that permeabilities are log-normally distributed within a formation and presented many potential reasons for this distribution pattern. The most reasonable explanation for a log-normal distribution of permeability appears to be that permeability is dependent upon pore-size distributions, and pore-size distributions of rocks and sediments are frequently log-normally distributed. Because this study assumed a log-normal probability-distribution function of permeability and uniform two-dimensional flow, the average permeability was assumed to be equal to the geometric mean of the permeability data (Matheron, 1967). For a log-normal distribution, the geometric mean should coincide with the median. The geometric mean is defined as

$$G_m = \mathrm{Log}^{-1} \left( \left( \sum_{n}^{i=1} \mathrm{Log}\ k \right) / n \right) \qquad (16)$$

The permeabilities presented in this report appear to be, in most cases, representative of the matrix, as opposed to the formation as a whole, which may be fractured. Portions of the Culebra with transmissivities greater than 1.0E-6 $m^2/s$ are generally thought to be fractured (Beauheim, 1987). LaVenue et al. (1988) indicate that an intrinsic permeability of 1.3E-14 $m^2$ corresponds to a transmissivity of 1.0E-6 $m^2/s$, assuming a fluid density of 1000 $kg/m^3$, a viscosity of 0.001 Pa•s, a formation thickness of 7.7 m, and a vertically homogeneous formation. A few permeabilities greater than 1.3E-14 $m^2$ were measured during Phase 1 and Phase 2 core-analysis studies (see Tables 4.1 through 4.3), and will be used to calculate permeability averages and distributions in this report. Therefore, core-sample analyses yielded values of permeability in the range of values that have been attributed to the effects of fracturing according to well-test analyses.

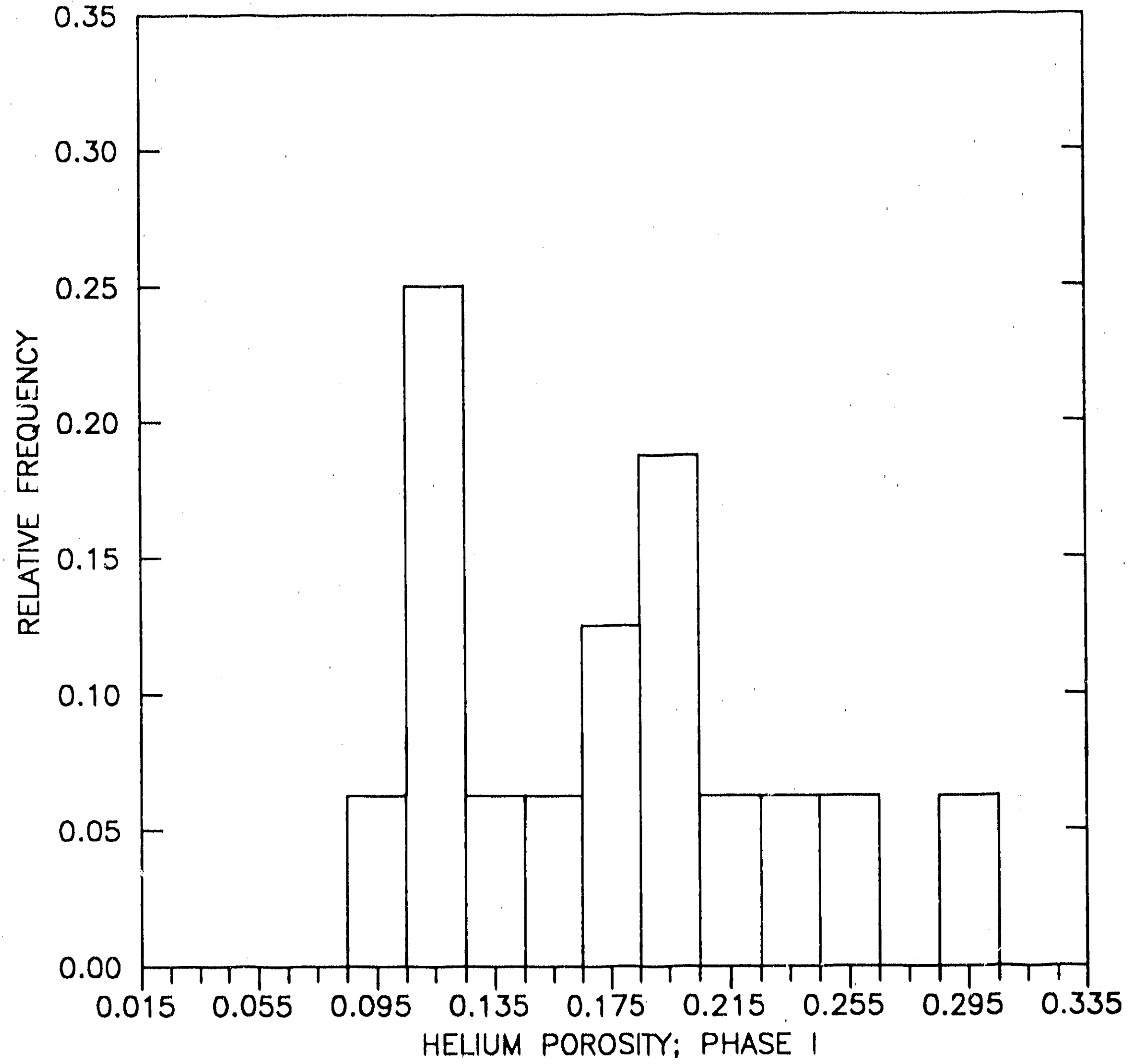
In the Phase 1 core study, 9 measurements of horizontal permeability were made. One measurement was performed on a whole-core sample, and the rest on plug cores. The values ranged from 7.9E-18 $m^2$ to 9.9E-15 $m^2$ (Table 4.1) for this small sample (N = 9). Analysis of these data indicated a non-normal distribution with a geometric mean of 1.6E-15 $m^2$ and a median permeability value of 7.9E-17 $m^2$. The Phase 1 core study included 14 measurements of vertical permeability (Table 4.1), 12 from plug cores, and 2 from whole-core samples. The permeabilities ranged from 8.4E-18 $m^2$ to 5.2E-14 $m^2$. Analysis of the vertical-permeability data indicated a more well-defined distribution than that for horizontal permeabilities because of the increased sample size. The distribution appears to approach a log-normal distribution, although the geometric mean is 4.8E-16 $m^2$ and does not equal the median, which was determined to be 5.4E-16 $m^2$.

In Phase 2, horizontal permeabilities were determined for 45 plug-core samples. The permeability ranged from a minimum of 2.0E-17 $m^2$ to a maximum of 5.7E-14 $m^2$ (Table 4.3), with a geometric mean of 3.7E-16 $m^2$ and a median of 2.6E-16 $m^2$. Figure 4.19 is a relative-frequency histogram of the $\log_{10}$ of all horizontal permeabilities measured in Phase 1 and Phase 2 (N = 66). For the 12 whole-core samples which had a maximum and a minimum horizontal permeability measured (Table 4.2), the arithmetic average between the two values was used. The lowest horizontal permeability measured was 7.9E-18 $m^2$ and the highest was 3.6E-13 $m^2$. The permeability distribution appears to be log-normal with an arithmetic mean of 6.2E-15 $m^2$, a geometric mean of 4.5E-16 $m^2$, and a median of 2.7E-16 $m^2$.

Figure 4.20 is a relative-frequency histogram of the $\log_{10}$ of all vertical permeabilities measured in both core studies (N = 26). The lowest vertical permeability measured was 8.4E-18 $m^2$ and the highest was 5.2E-14 $m^2$. The permeability distribution is log-normal with an arithmetic mean of 5.1E-15 $m^2$, a geometric mean of 9.0E-16 $m^2$, and a median of 3.5E-16 $m^2$.

Figure 4.21 is a plot of the $\log_{10}$ of 72 horizontal-permeability determinations from the Phase 1 and Phase 2 core studies versus the helium-porosity values for the same samples (Tables 4.1 to 4.3). The values plotted on Figure 4.21 include the results of both the plug-core and whole-core analyses. The horizontal permeability plotted for the whole-core samples is the arithmetic average of the two values shown on Table 4.2. Figure 4.21 shows that although the $\log_{10}$ of horizontal permeability tends to increase with porosity, higher-than-average permeability values were also determined for samples with average porosity values.

Figure 4.22 is a plot of the $\log_{10}$ of 25 vertical-permeability determinations from the Phase 1 and Phase 2 core studies versus the helium-porosity determinations for the same samples (Tables 4.1 to 4.3). (The vertical-permeability value for sample H-3b3 1-5 was not included in the plot because the porosity was considered to be unrepresentative as indicated on Table 4.1.) Figure 4.22 generally shows that the $\log_{10}$ of vertical permeability increases with increasing porosity. Figure 4.23 is a plot of the $\log_{10}$ of 23 horizontal-permeability determinations from Phase 2 plug-core samples versus the median pore-throat radii calculated from mercury-intrusion porosimetry for those same samples. Figure 4.23 shows that the $\log_{10}$ of horizontal permeability is apparently directly related to the median pore-throat radius. A comparison of Figures 4.21 and 4.23 indicates that the $\log_{10}$ of horizontal permeability appears to be more directly related to median pore-throat radius than to porosity.



Sample Size = 16
Arithmetic Mean = 0.175
Standard Deviation = 0.057

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Relative-Frequency Histogram for
Phase 1 Helium Porosities

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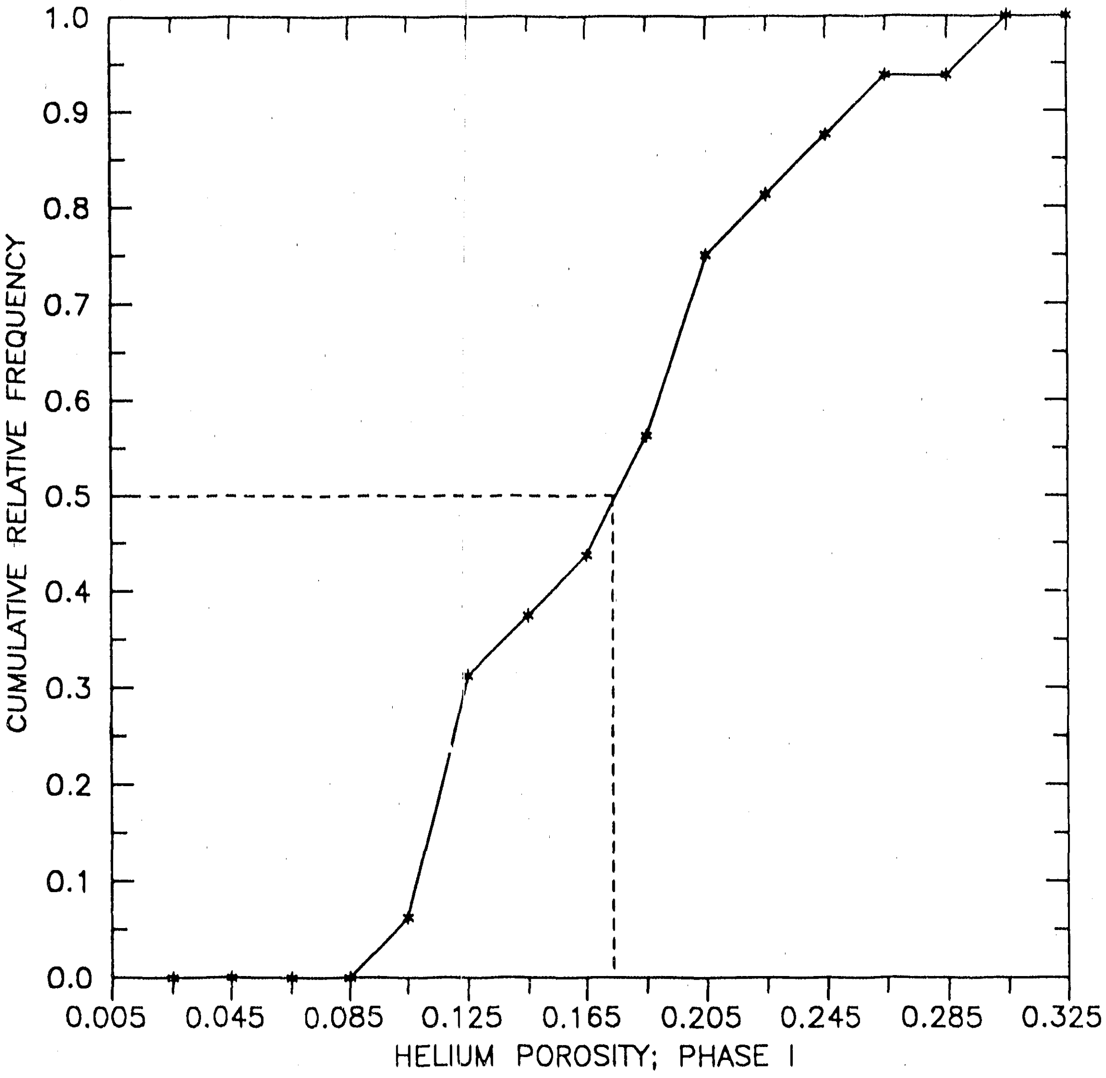
Figure 4.1



Sample Size = 16
Median = 0.174

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| #105000R019 | 12/6/89 |

Cumulative Relative-Frequency Curve for Phase 1 Helium Porosities

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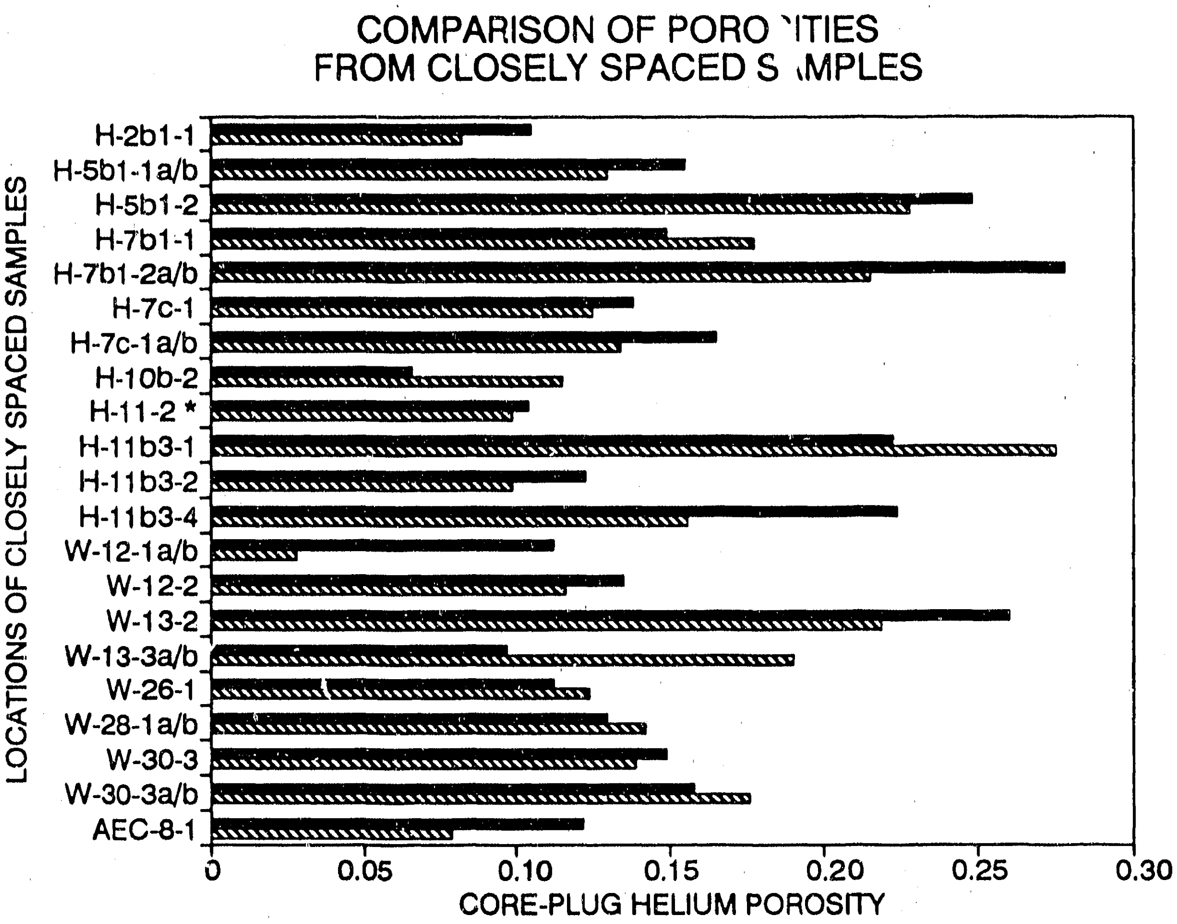
Figure 4.2



* H-11-2 is from H-11b3

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| Revisions | G.S. | Date | 10/10/90 |
| #105000R019 | | | 4/19/90 |

Comparison of Porosities Between Core-Plug Samples Taken in Close Vertical Proximity

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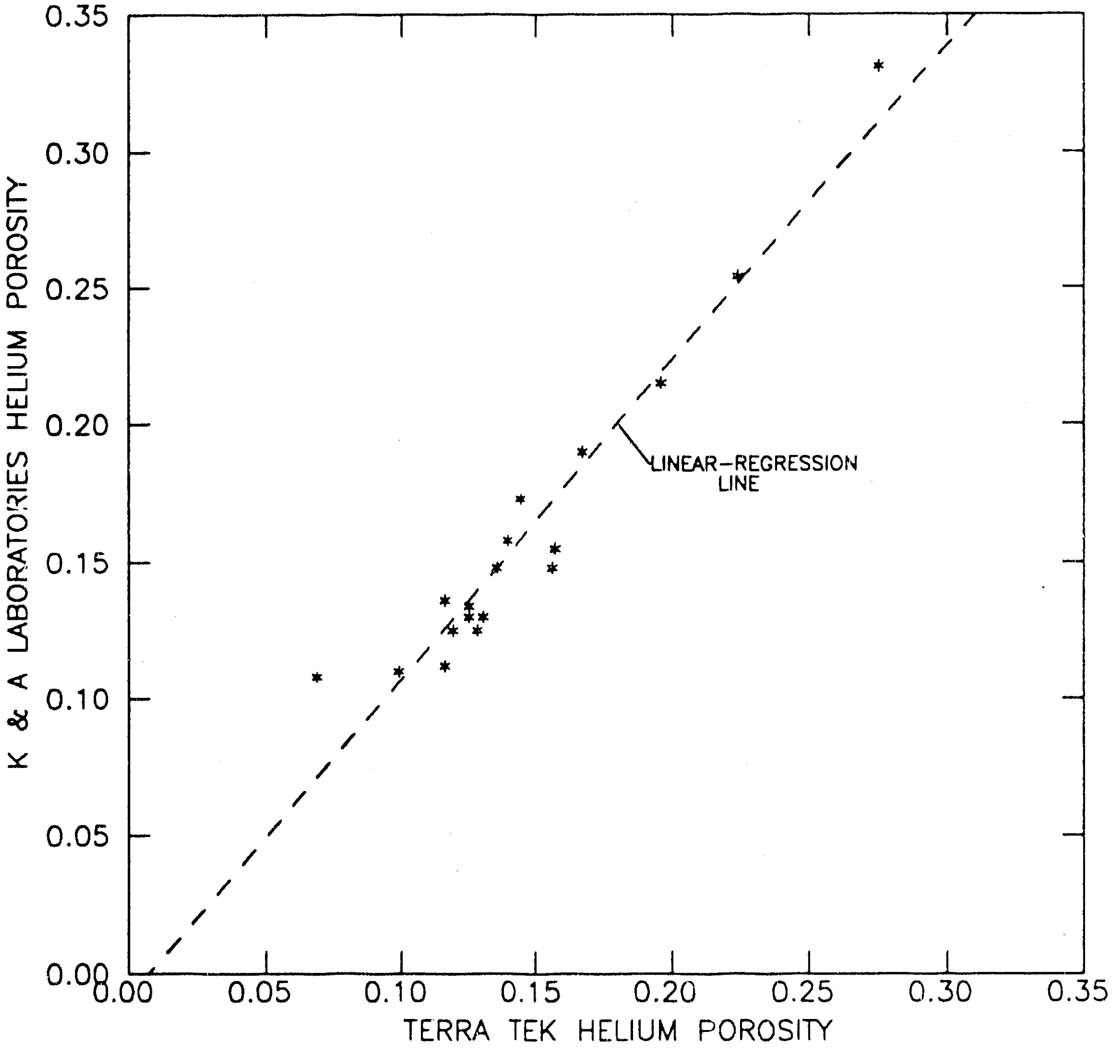
Figure 4.3



Sample Size = 18
Correlation Coefficient = 0.93

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| Checked by | G.S. | Date | 4/18/90 |
| Revisions | G.S. | Date | 10/10/90 |
| #105000R019 | | | 4/18/90 |

Laboratory Comparison of Helium Porosity
for Identical Samples

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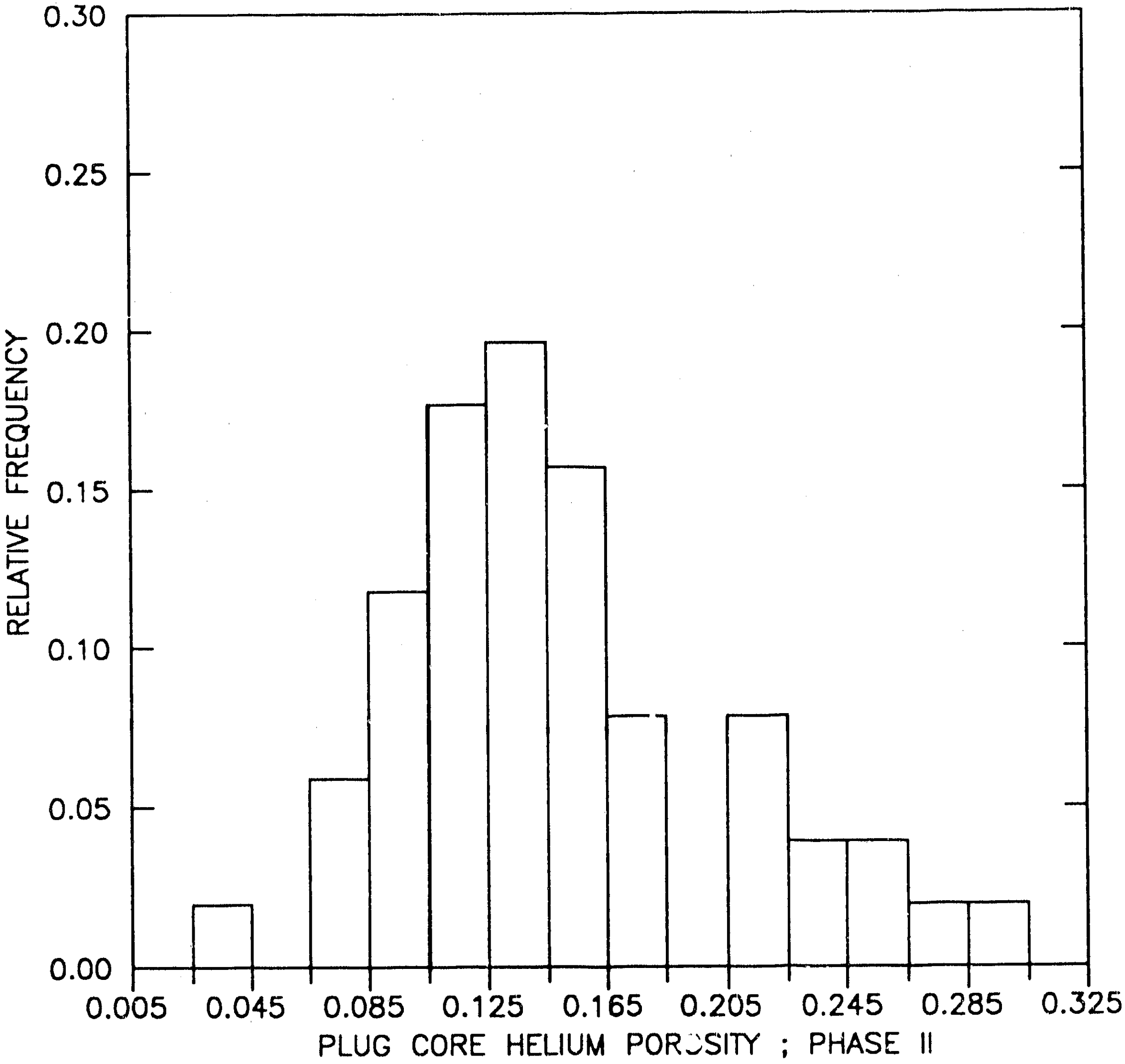
Figure 4.4



Sample Size = 51
Arithmetic Mean = 0.149
Standard Deviation = 0.055
Median = 0.138

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| #105000R019 | 12/6/89 |

Relative-Frequency Histogram for Phase 2
Core-Plug Helium Porosities

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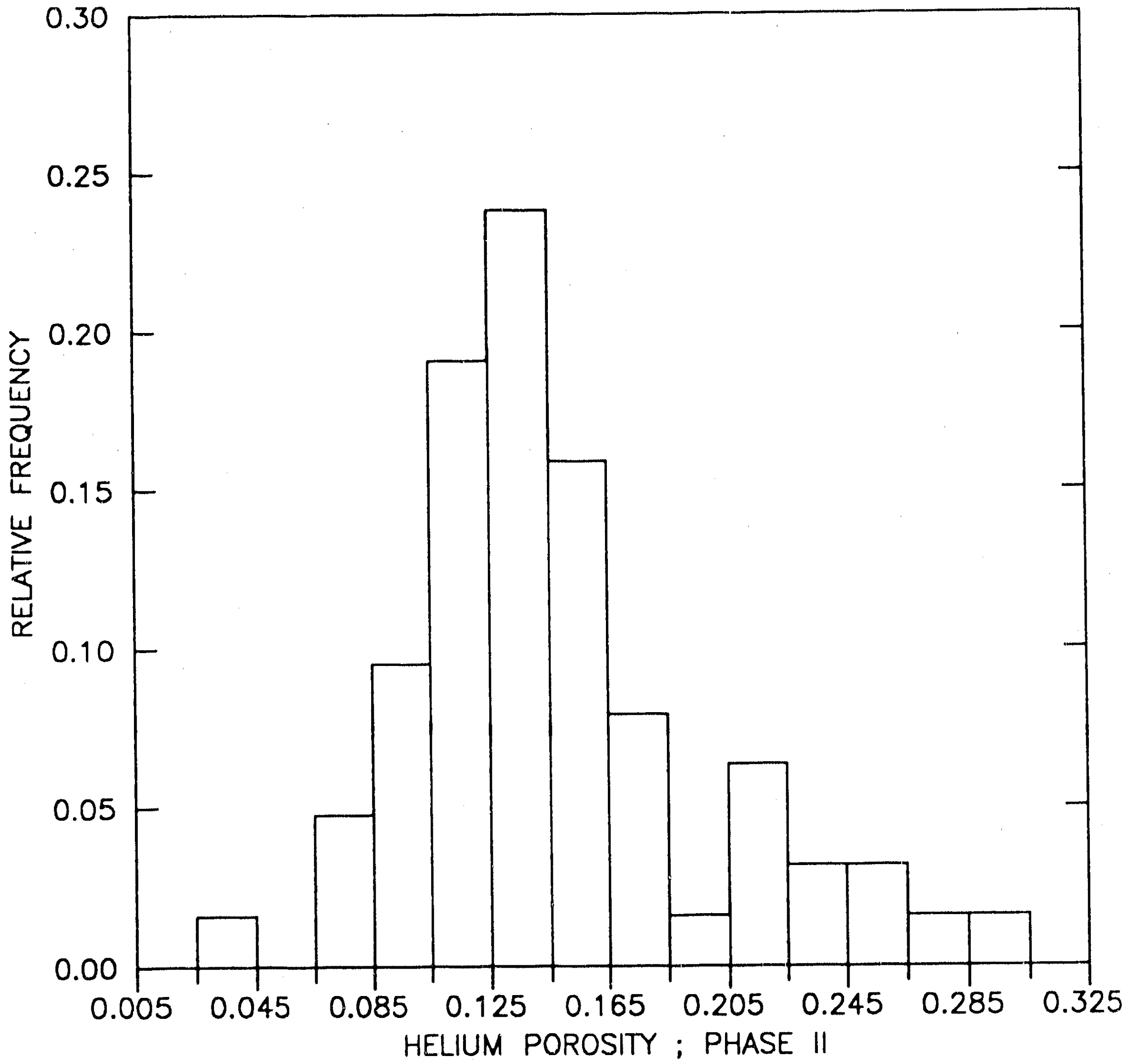
Figure 4.5



Sample Size = 63
Arithmetic Mean = 0.147
Standard Deviation = 0.051
Median = 0.134

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Relative-Frequency Histogram for Phase 2 Helium Porosities

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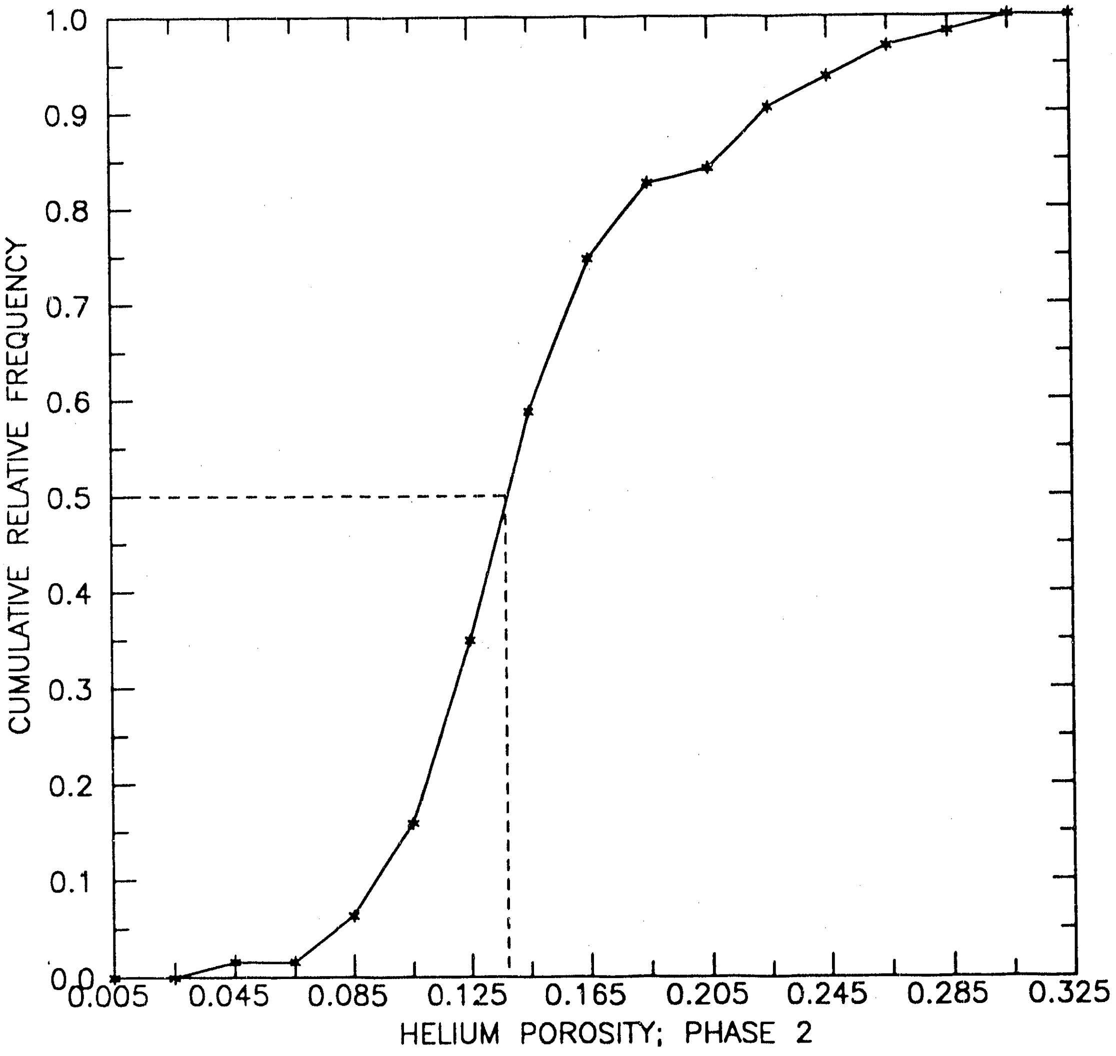
Figure 4.6



Sample Size = 63
Median = 0.134

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| Revisions | Date |
| #105000R019 | 12/6/89 |

Cumulative Relative-Frequency Curve for
Phase 2 Helium Porosities

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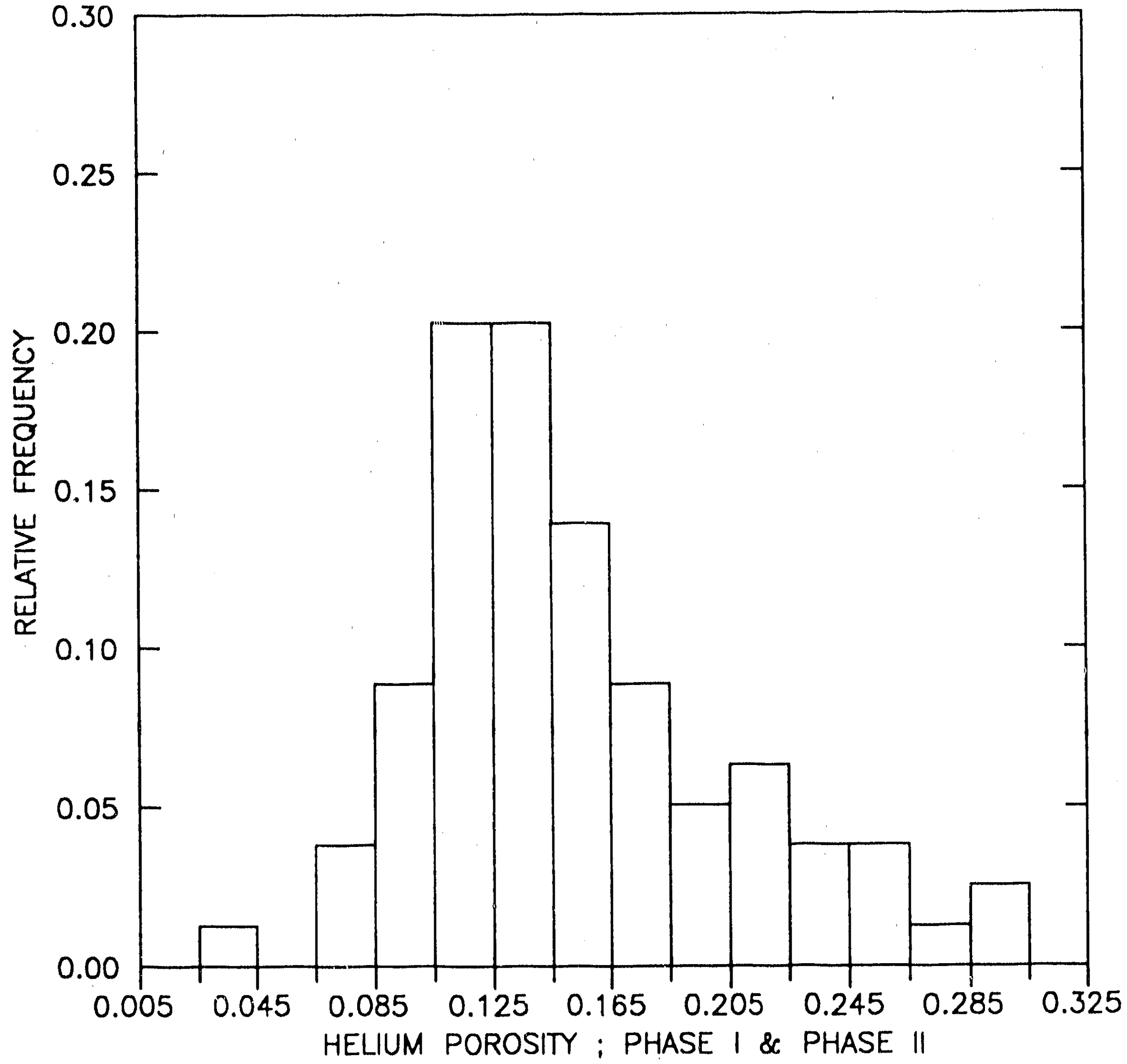
Figure 4.7



Sample Size = 79
Arithmetic Mean = 0.153
Standard Deviation = 0.053
Median = 0.141

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| Drawn by ABW | Date 12/6/89 | Relative-Frequency Histogram Phase 1 and Phase 2 Helium Porosities |
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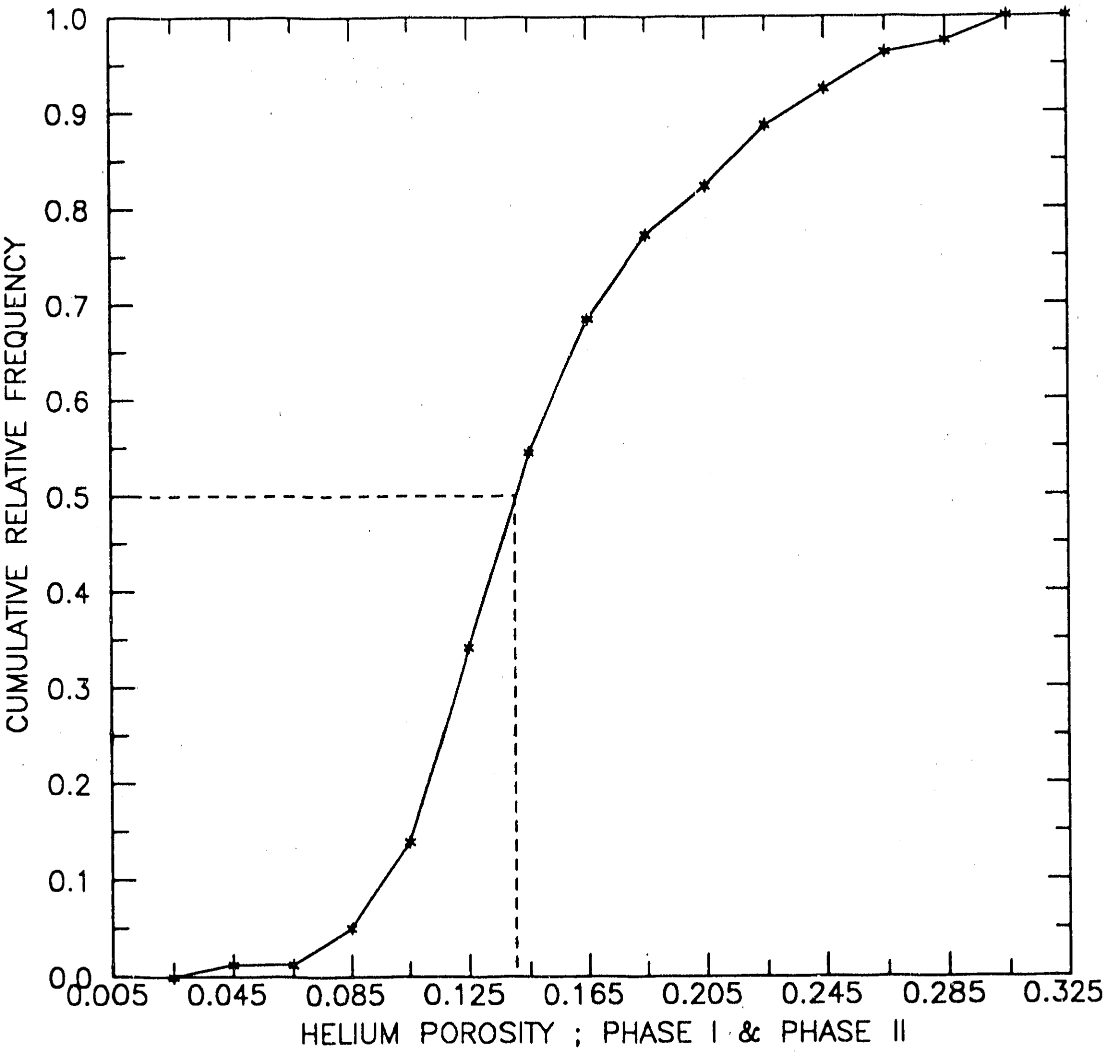
| INTERA Technologies | | Figure 4.8 |



Sample Size = 79
Median = 0.141

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| Drawn by ABW | Date 12/6/89 | Cumulative Relative-Frequency Curve for Phase 1 and Phase 2 Helium Porosities |
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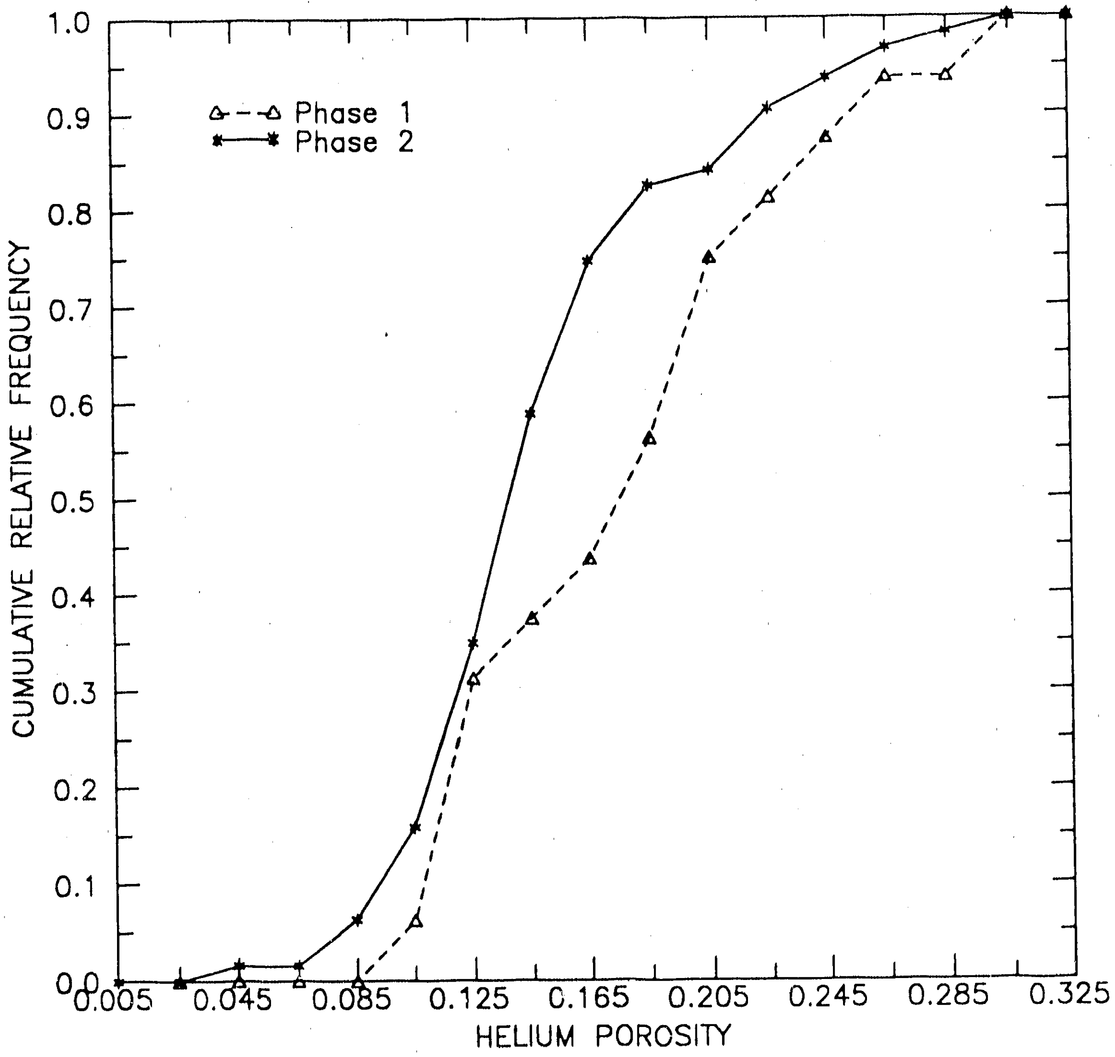
Figure 4.9



| | PHASE 1 | PHASE 2 |
|---|---|---|
| Sample Size | 16 | 63 |
| Arithmetic Mean | 0.175 | 0.147 |
| Standard Deviation | 0.057 | 0.051 |
| Median | 0.174 | 0.134 |

| | |
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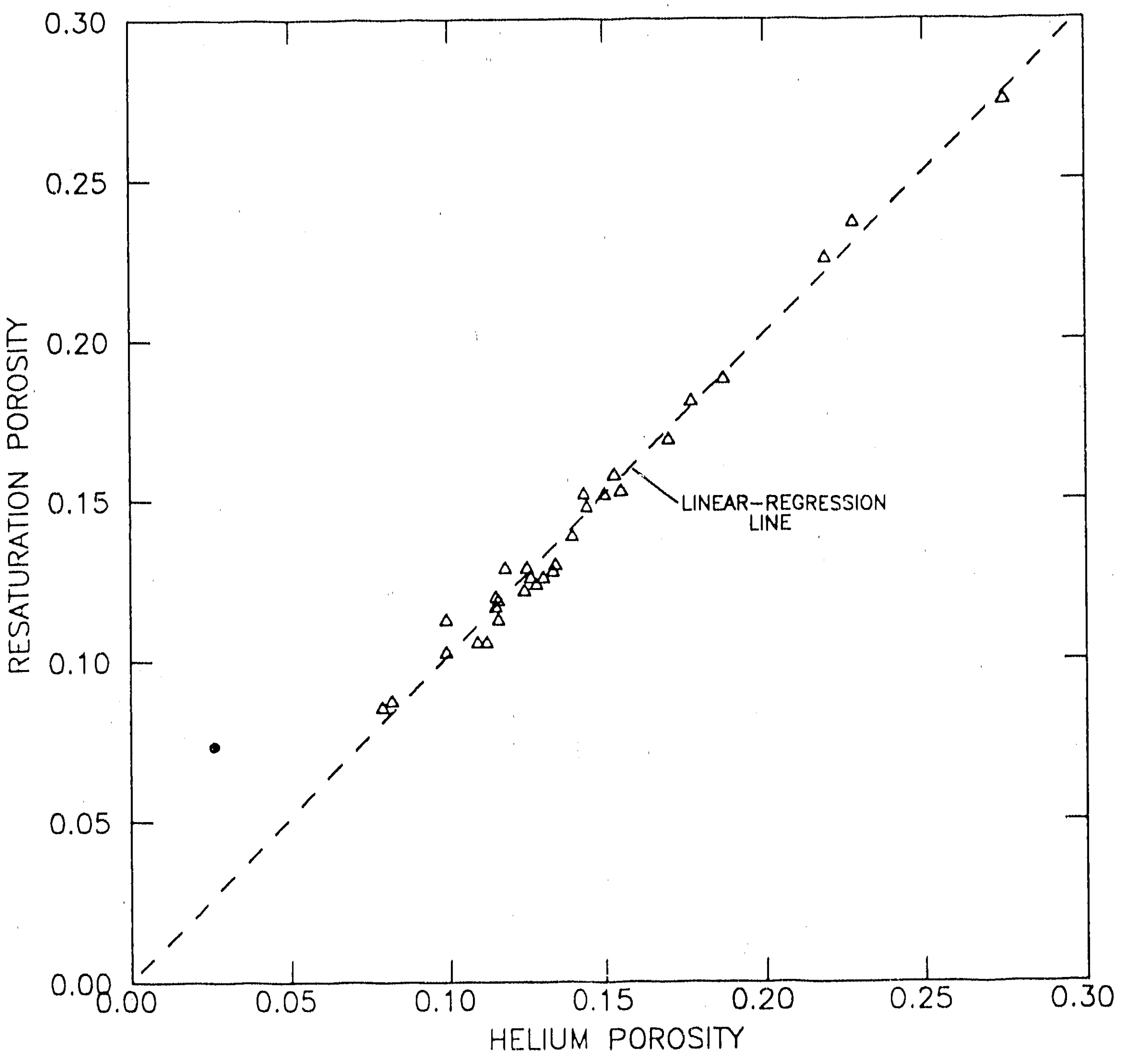
Comparison Between Phase 1 and Phase 2
Cumulative Relative-Frequency Curves
for Helium Porosity

INTERA Technologies

Figure 4.10



Sample Size = 30
Correlation Coefficient = 0.99

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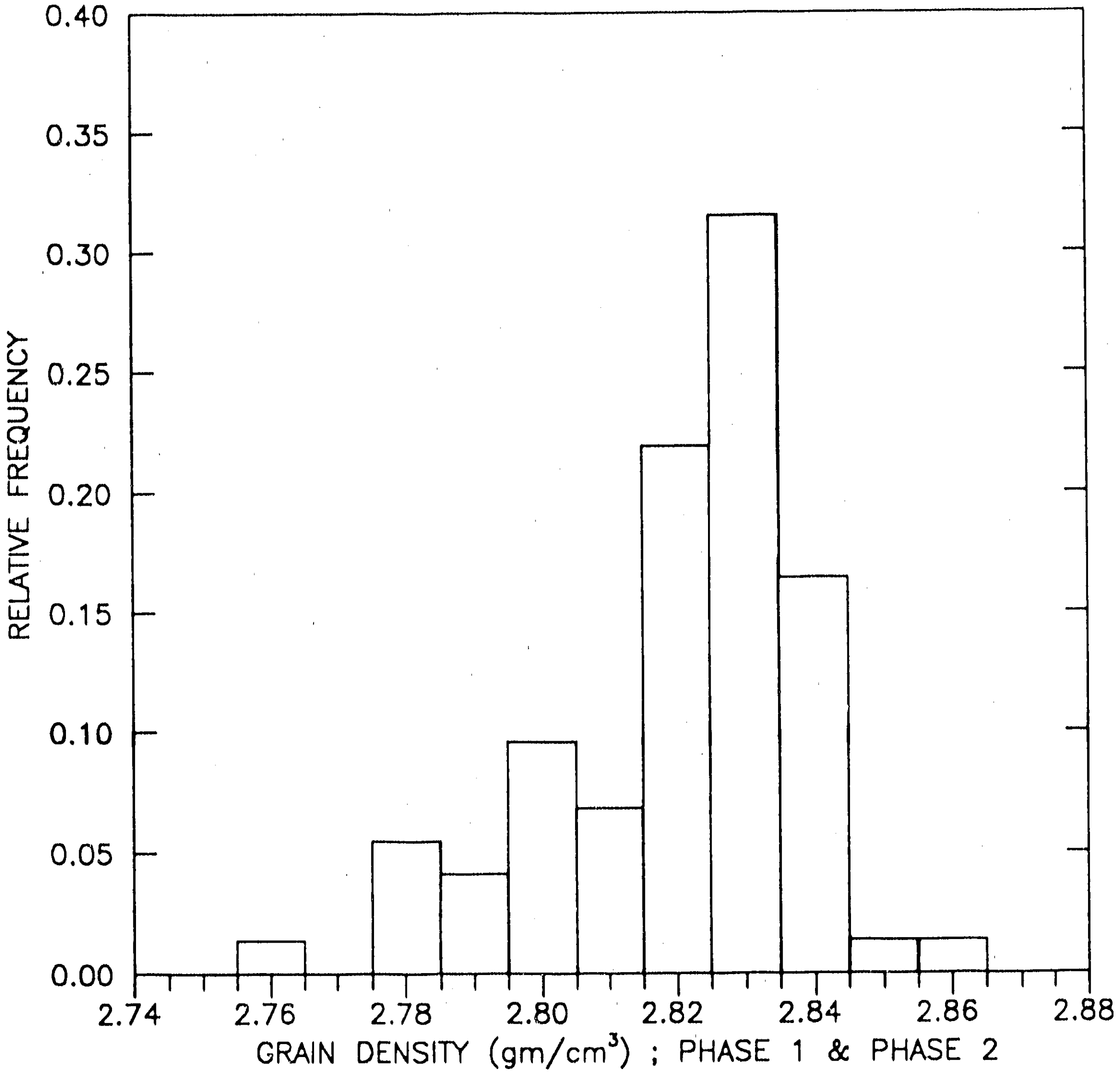
| Checked by | G.S. | Date | 4/18/90 |
| Revisions | G.S. | Date | 10/10/90 |
| #105000R019 | | | 4/18/90 |

Comparison Between Helium and Resaturation Porosities

INTERA Technologies

Figure 4.11



Sample Size = 73
Arithmetic Mean = 2.82 gm/cm$^3$
Standard Deviation = 0.019 gm/cm$^3$
Median = 2.83 gm/cm$^3$

| | | |
|---|---|---|
| Drawn by **ABW** | Date 12/6/89 | Relative-Frequency Histogram for<br>Sample Grain Density |
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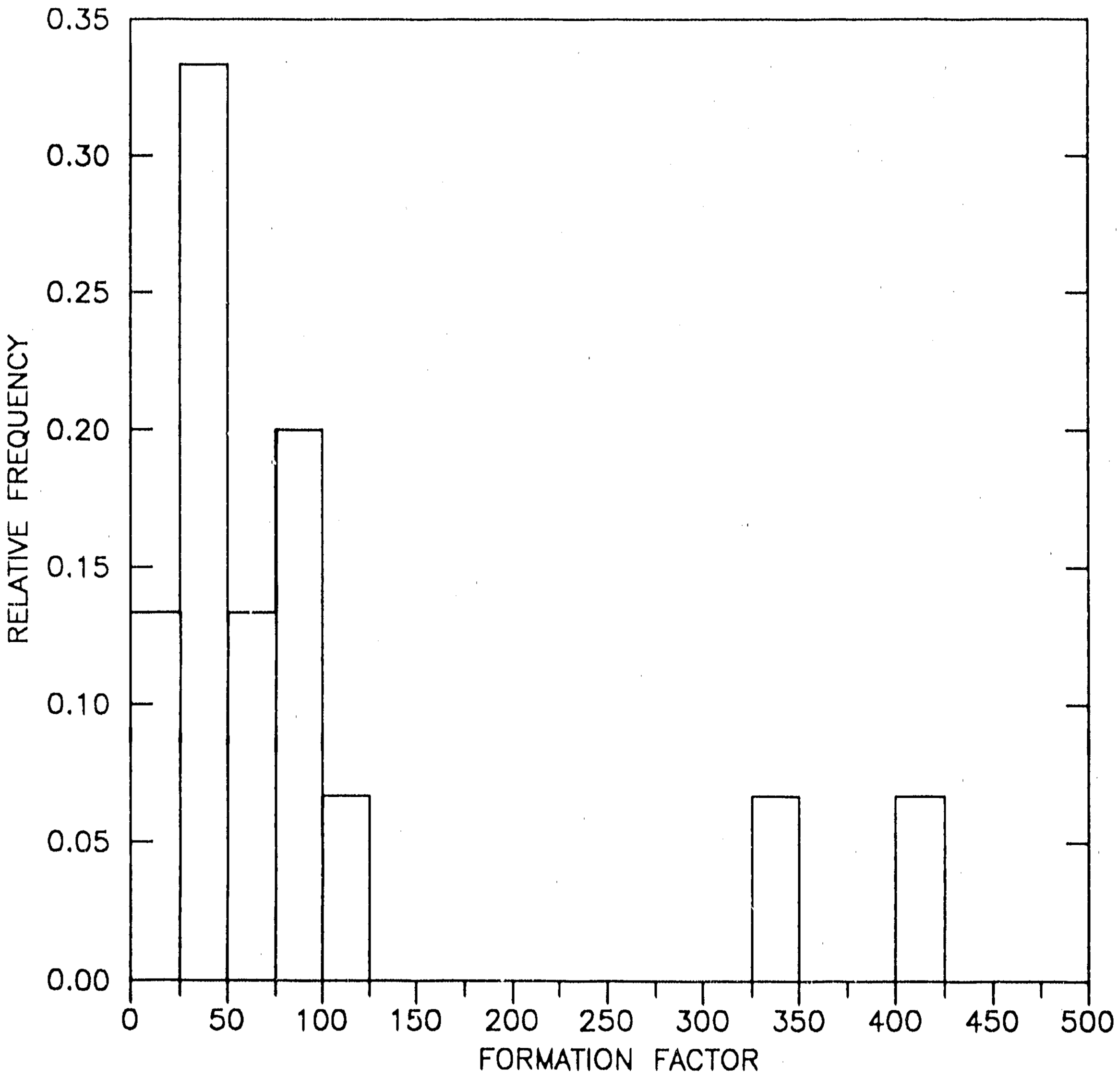
| Revisions | Date | |
| #105000R019 | 12/6/89 | |
| **INTERA Technologies** | | Figure 4.12 |



Sample Size = 15
Arithmetic Mean = 96.1

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| Checked by G.S. | Date 12/6/89 |
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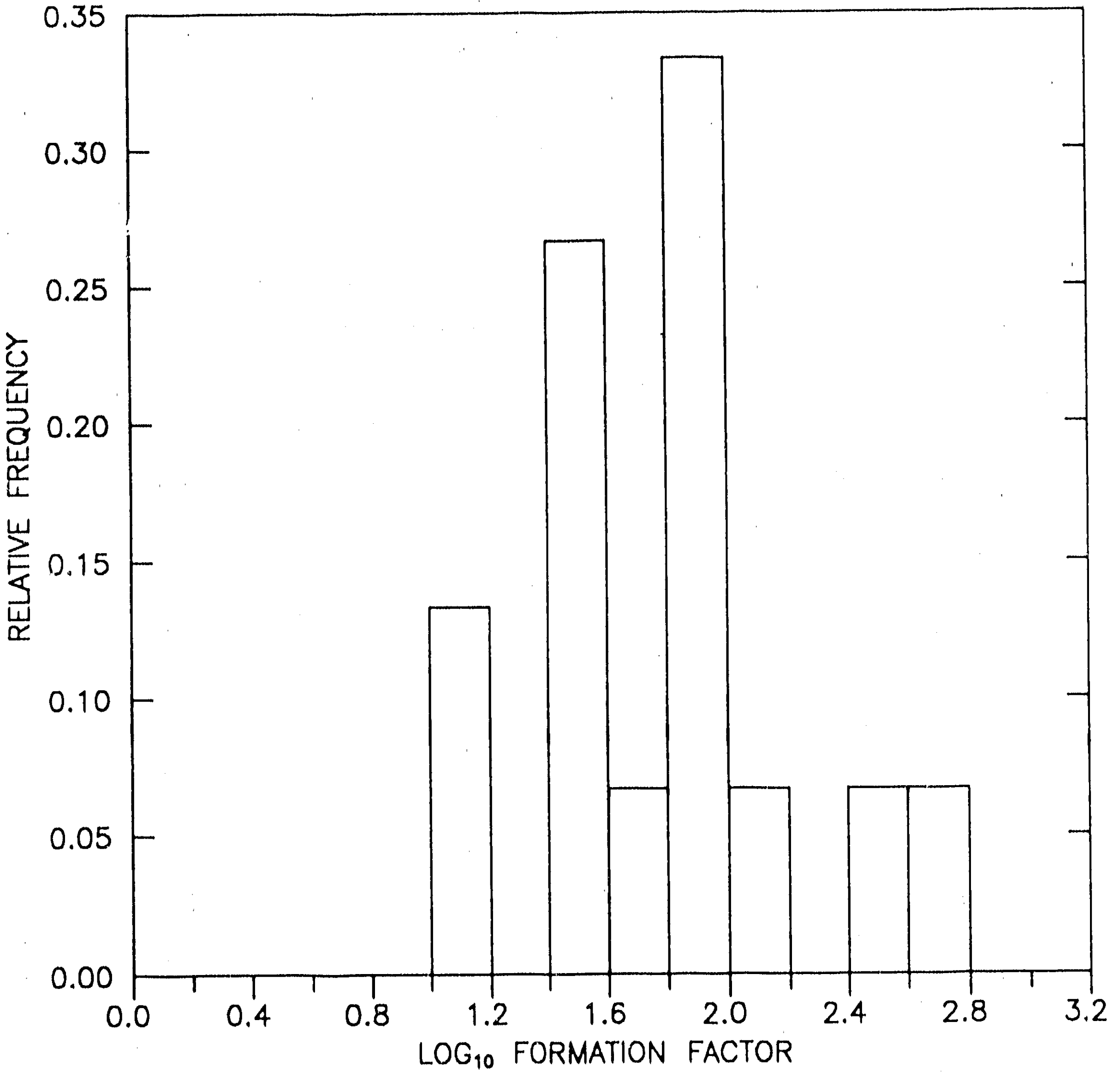
Relative-Frequency Histogram for Formation Factor Determined from Electrical-Resistivity Measurements

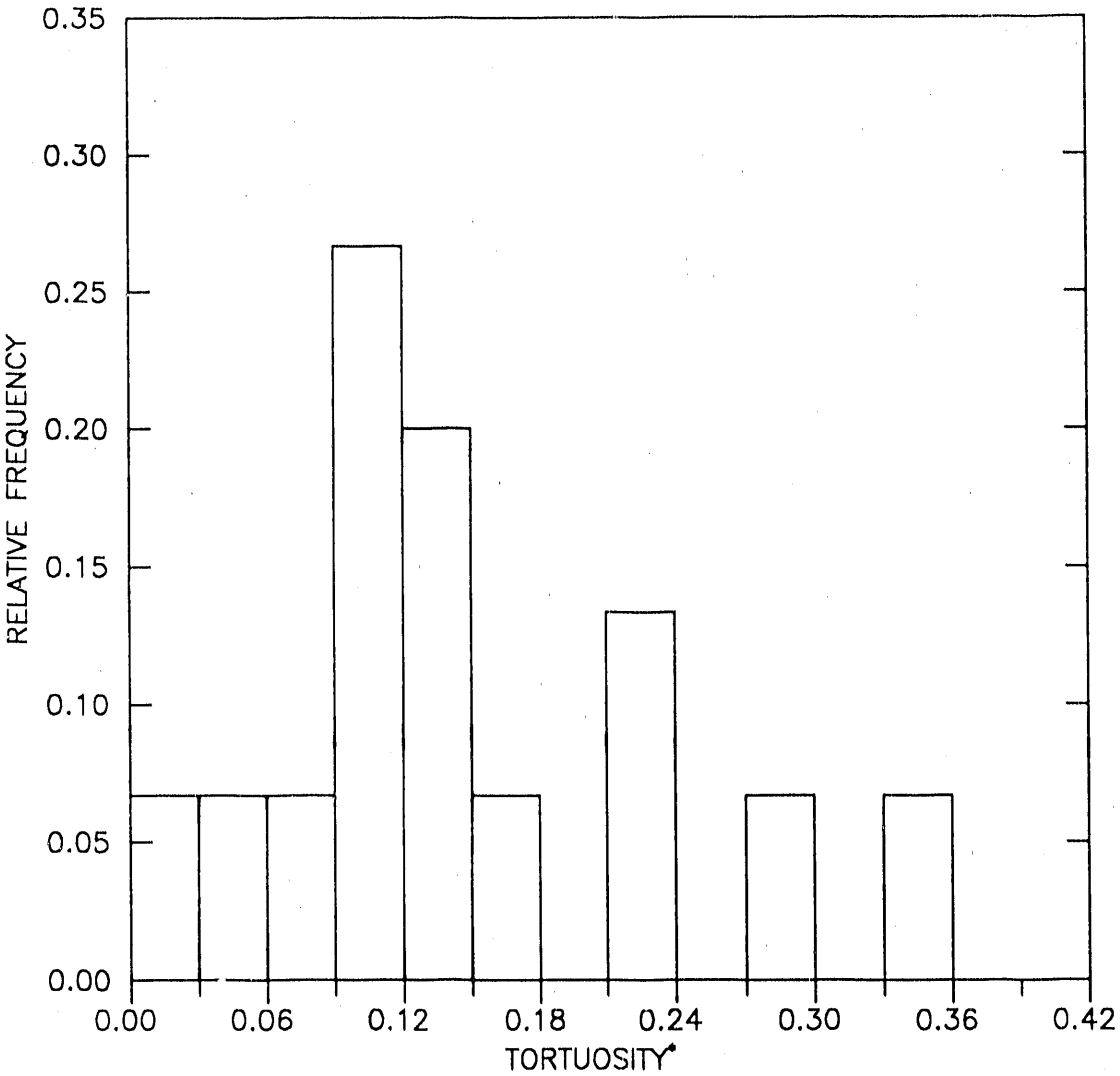
INTERA Technologies

Figure 4.13



Sample Size = 15
Geometric Mean = 58.8

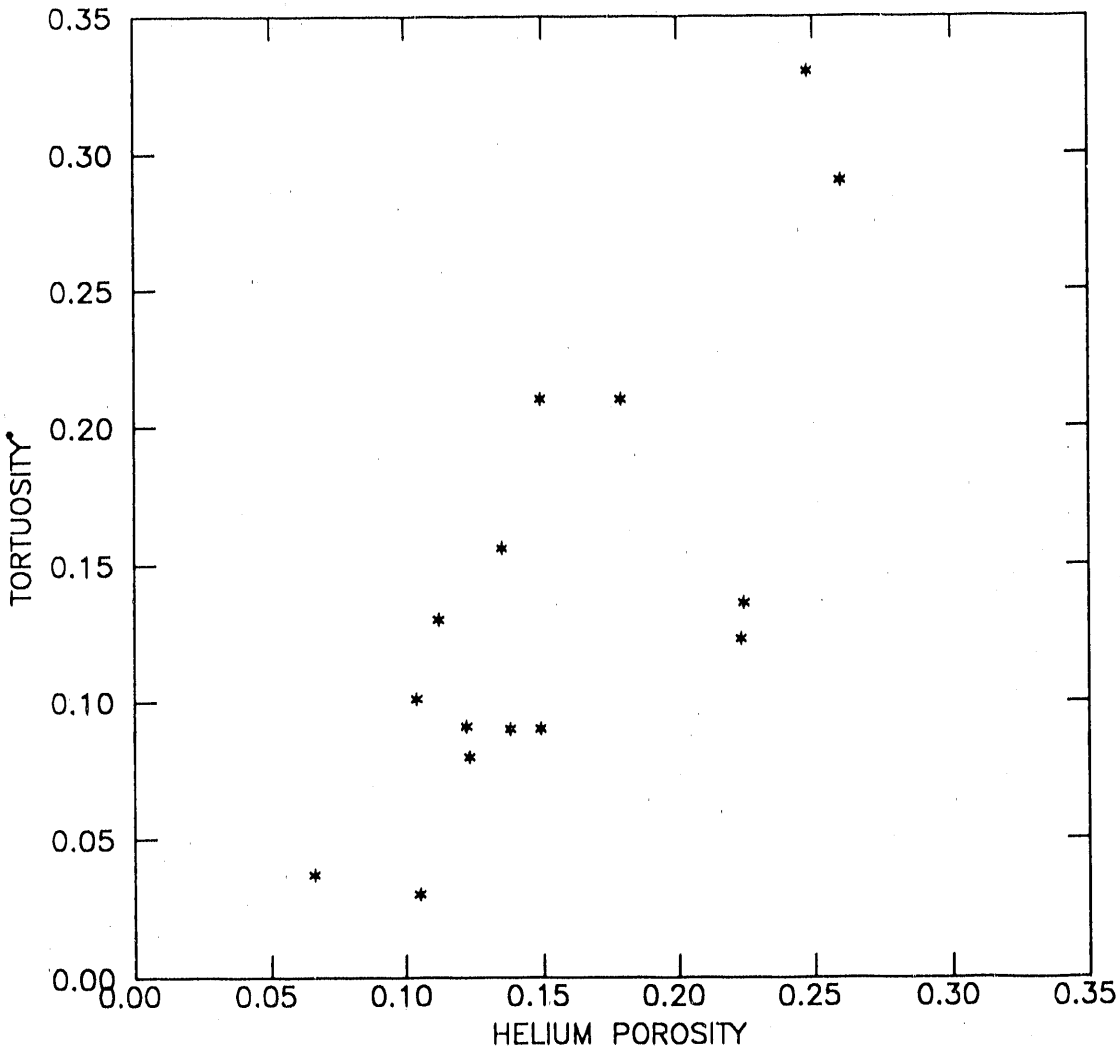
| | | |
|---|---|---|
| Drawn by ABW | Date 12/6/89 | Relative-Frequency Histogram for $\text{Log}_{10}$ of Formation Factor Determined from Electrical-Resistivity Measurements |
| Checked by G.S. | Date 12/6/89 | |
| Revisions | Date | |
| #105000R019 | 12/6/89 | |
| INTERA Technologies | | Figure 4.14 |



Sample Size = 15
Arithmetic Mean = 0.14
Standard Deviation = 0.08
Median = 0.12

* Tortuosity estimated using Formation Factor determined from electrical–resistivity measurements.

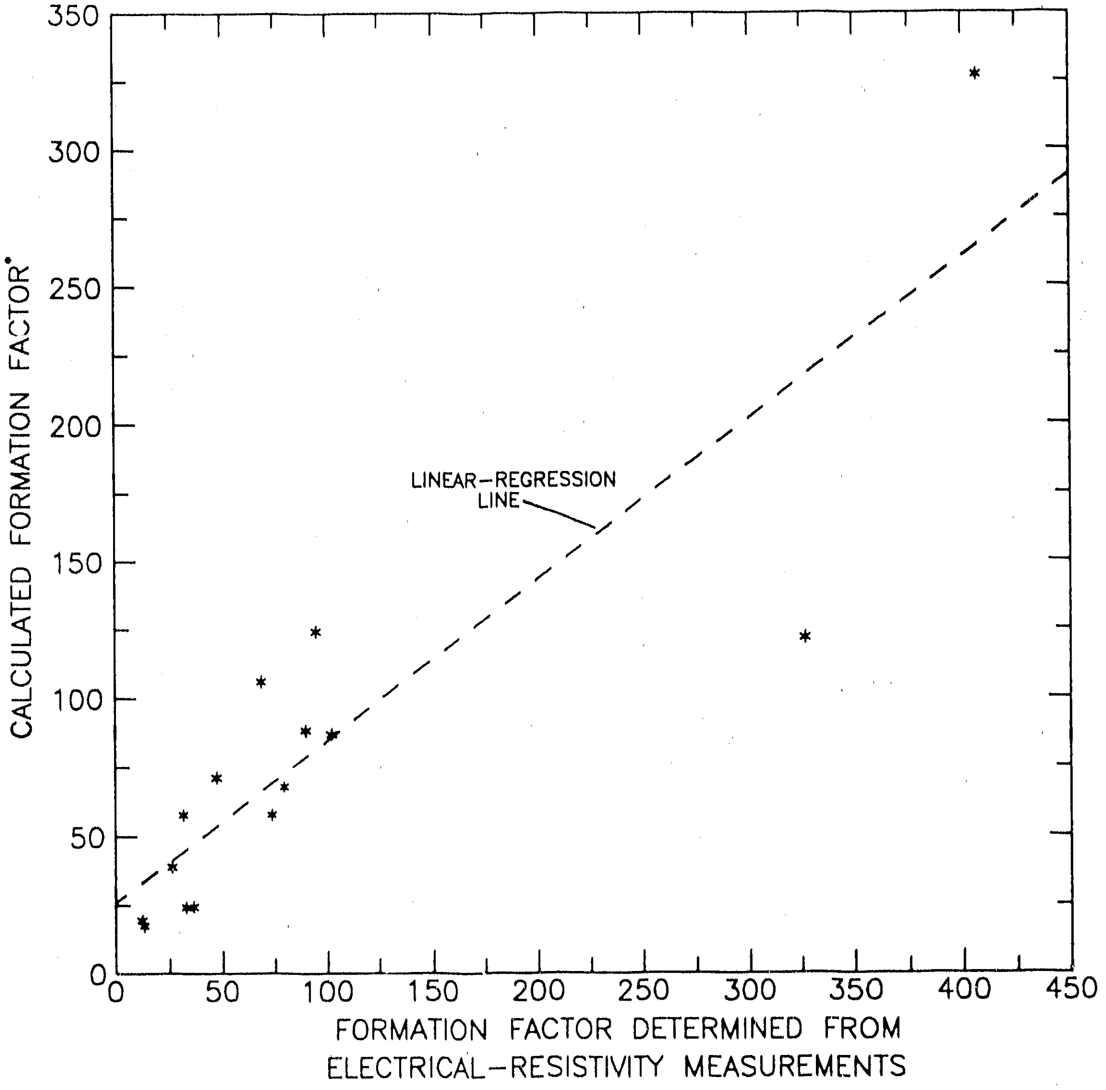
| | | |
|---|---|---|
| Drawn by ABW | Date 12/6/89 | **Relative – Frequency Histogram for Calculated Tortuosity Values** |
| Checked by G.S. | Date 12/6/89 | |
| Revisions | Date | |
| #105000R019 | 12/6/89 | |
| **INTERA Technologies** | | Figure 4.15 |



Sample Size = 15

* Tortuosity estimated using Formation factor determined from electrical-resistivity measurements

| | | |
|---|---|---|
| Drawn by ABW | Date 12/6/89 | Comparison Between Helium Porosity and Tortuosity Determined from Electrical-Resistivity Measurements |
| Checked by G.S. | Date 12/6/89 | |
| Revisions | Date | |
| #105000R019 | 12/6/89 | |
| INTERA Technologies | | Figure 4.16 |



Sample Size = 15
Correlation Coefficient = 0.77

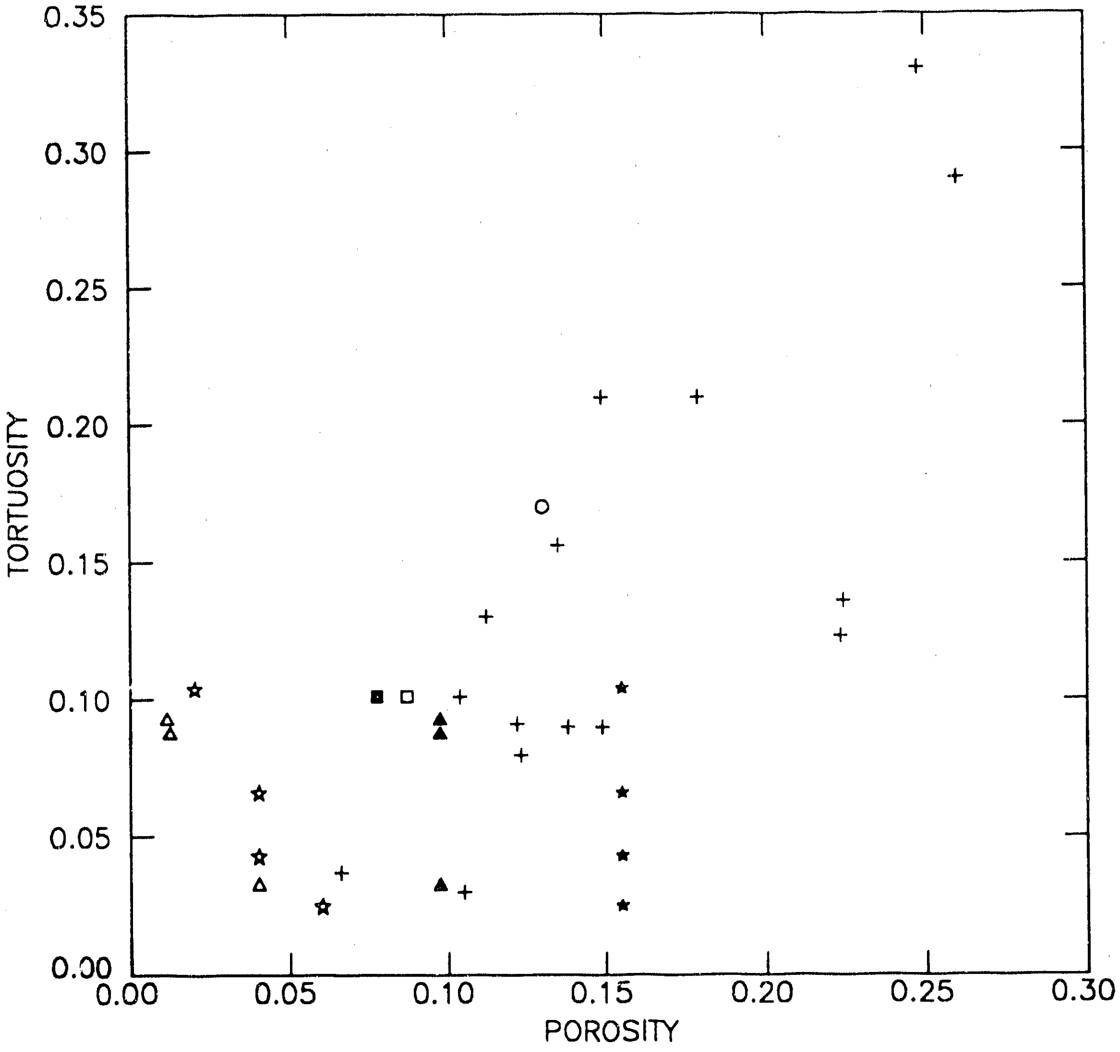
* Calculated F = $1/\phi^{2.13}$

| | | | |
|---|---|---|---|
| Drawn by | G.S. | Date | 4/19/90 |
| Checked by | G.S. | Date | 4/19/90 |
| Revisions | G.S. | Date | 10/10/90 |
| #105000R019 | | | 4/19/90 |

Comparison Between the Formation Factor Determined from Electrical-Resistivity Measurements and the Formation Factor Predicted by Archie's Equation

**INTERA Technologies**

Figure 4.17



\+ Electrical–Resistivity Results (N=15)
☆ Diffusion Sample WIPP–19 (N=4)
□ Diffusion Sample ESM–143–1 (N=1)
△ Diffusion Sample ESM–143–2 (N=3)
○ Diffusion Sample A1S–SNL–16 (N=1)

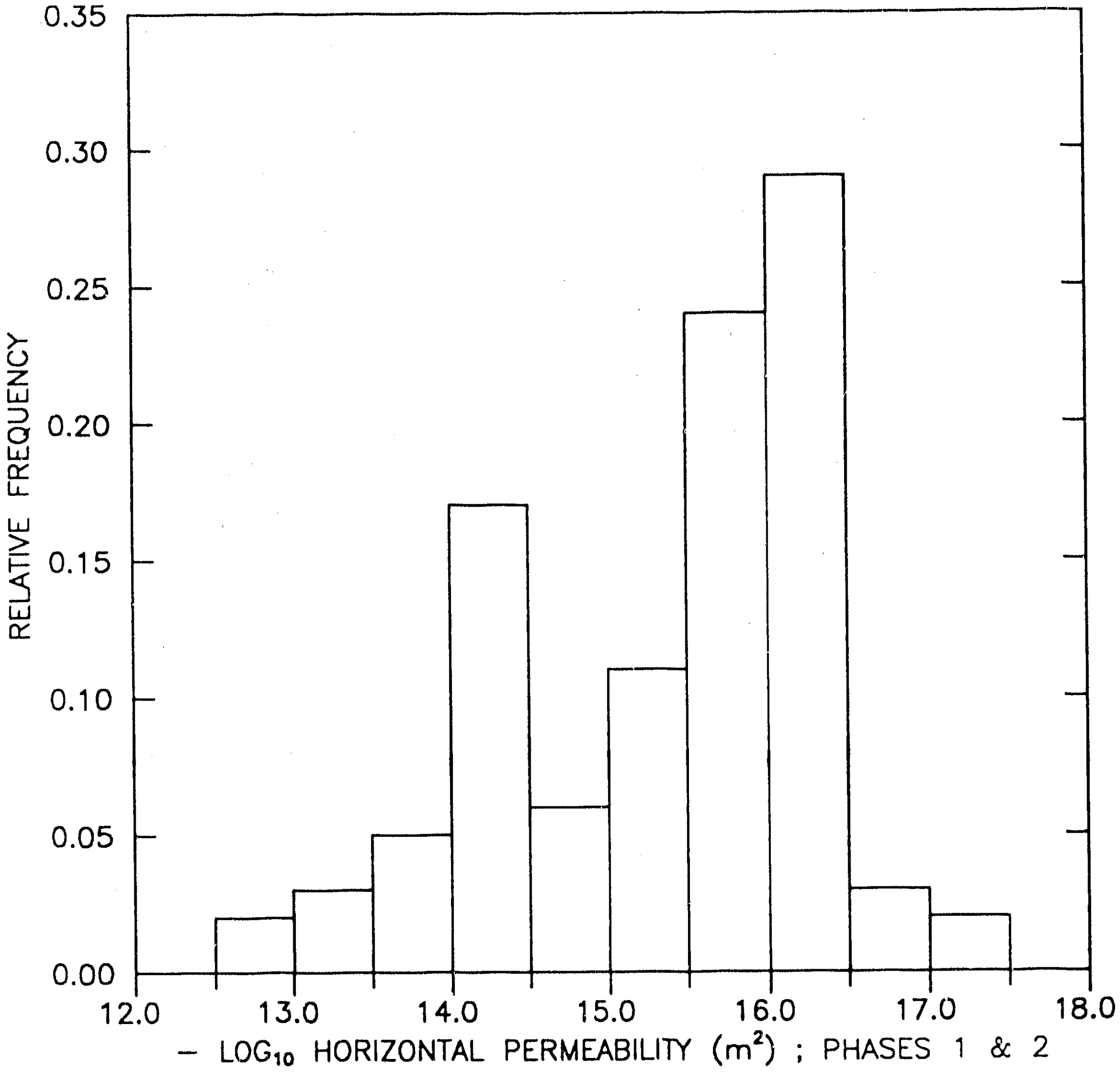
Note: Open Symbol = Diffusion Porosity
Closed Symbol = Helium Porosity
N = Number of Samples

| | | | |
|---|---|---|---|
| Drawn by | ABW | Date | 12/6/89 |
| Checked by | G.S. | Date | 12/6/89 |
| Revisions | | Date | |
| #105000R019 | | | 12/6/89 |

Comparison Between Tortuosity Determined
from Electrical-Resistivity Measurements
and Diffusion Tortuosity

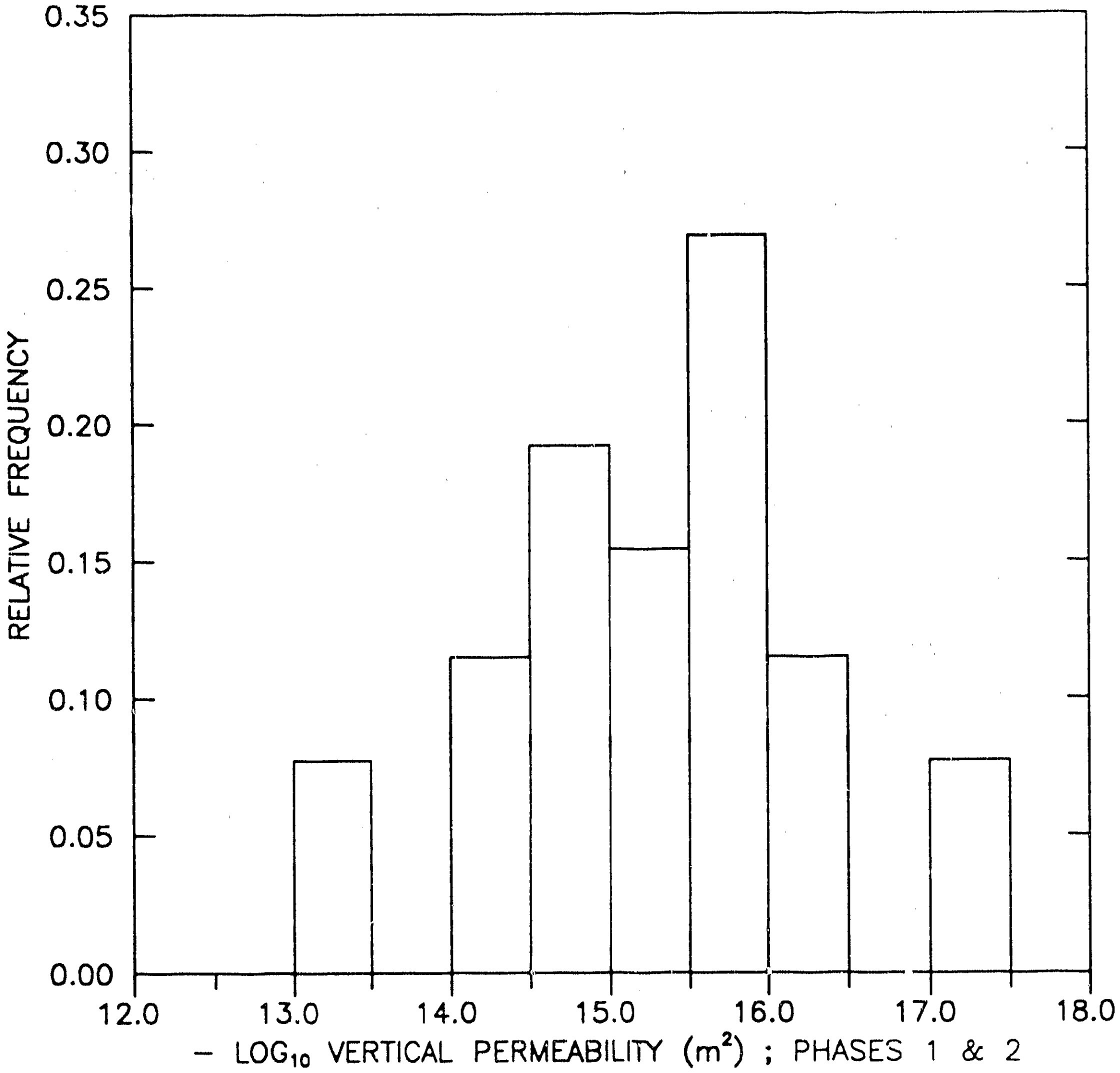
INTERA Technologies

Figure 4.18



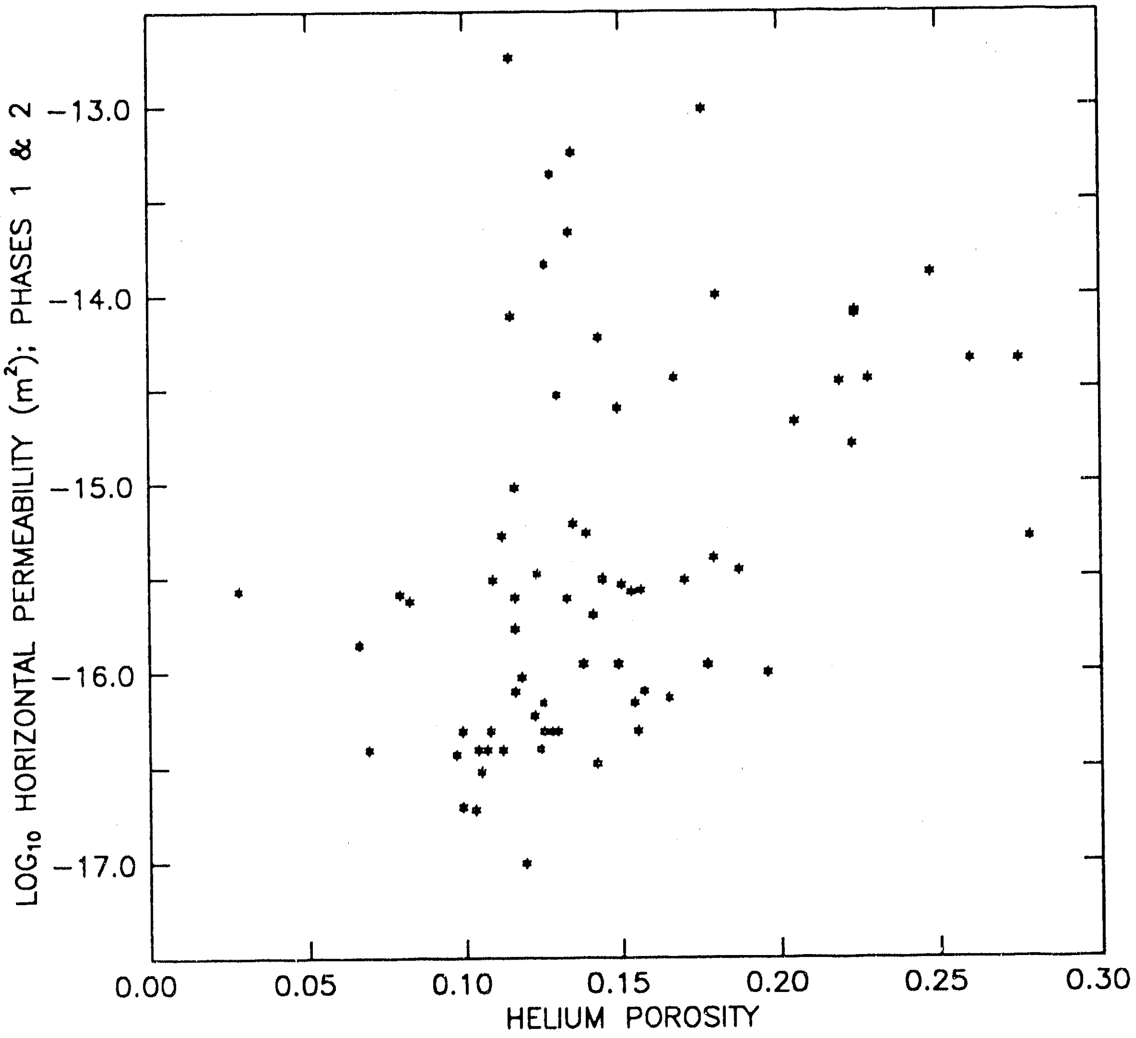
Sample Size = 66
Arithmetic Mean = 6.2E−15 $m^2$ (6.3 md)
Geometric Mean = 4.5E−16 $m^2$ (0.46 md)
Median = 2.7E−16 $m^2$ (0.27 md)

| | | |
|---|---|---|
| Drawn by ABW | Date 12/6/89 | Relative-Frequency Histogram for $\text{Log}_{10}$ Horizontal Permeability for Phase 1 and Phase 2 Core Studies |
| Checked by G.S. | Date 12/6/89 | |
| Revisions | Date | |
| #105000R019 | 12/6/89 | |
| INTERA Technologies | | Figure 4.19 |

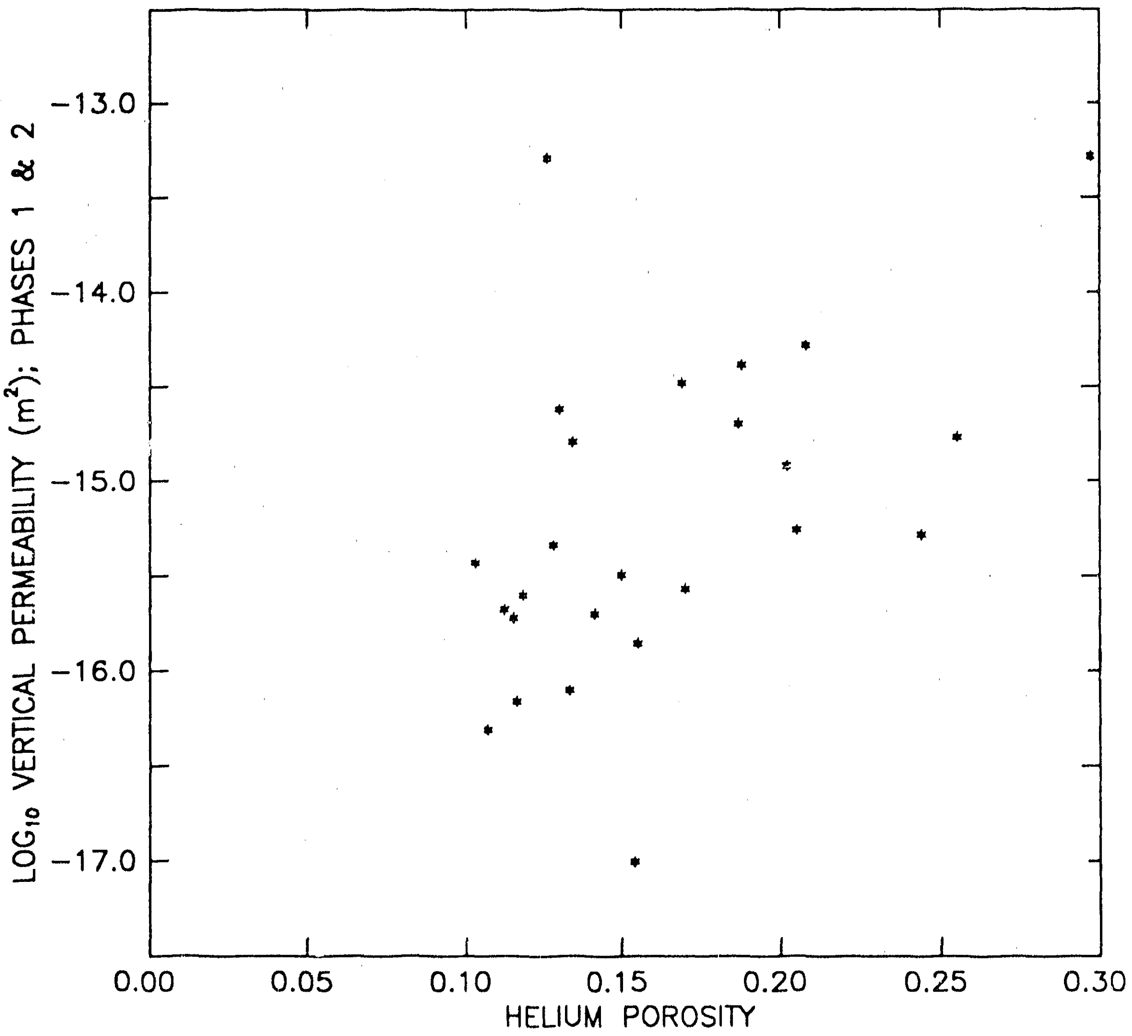


Sample Size = 26
Arithmetic Mean = 5.1E−15 m$^2$ (5.2 md)
Geometric Mean = 9.0E−16 m$^2$ (0.91 md)
Median = 3.5E−16 m$^2$ (0.35 md)

| | | |
|---|---|---|
| Drawn by ABW | Date 12/6/89 | Relative-Frequency Histogram for Log$_{10}$ Vertical Permeability for Phase 1 and Phase 2 Core Studies |
| Checked by G.S. | Date 12/6/89 | |
| Revisions | Date | |
| #105000R019 | 12/6/89 | |
| INTERA Technologies | | Figure 4.20 |



| | | |
|---|---|---|
| Drawn by GJS | Date 11/15/90 | Horizontal Permeability Versus Porosity for Phase 1 and Phase 2 Whole-Core and Plug-Core Analyses |
| Checked by | Date | |
| Revisions | Date | |
| # ID 5000R019 | 11/15/90 | |
| INTERA Technologies | | Figure 4.21 |

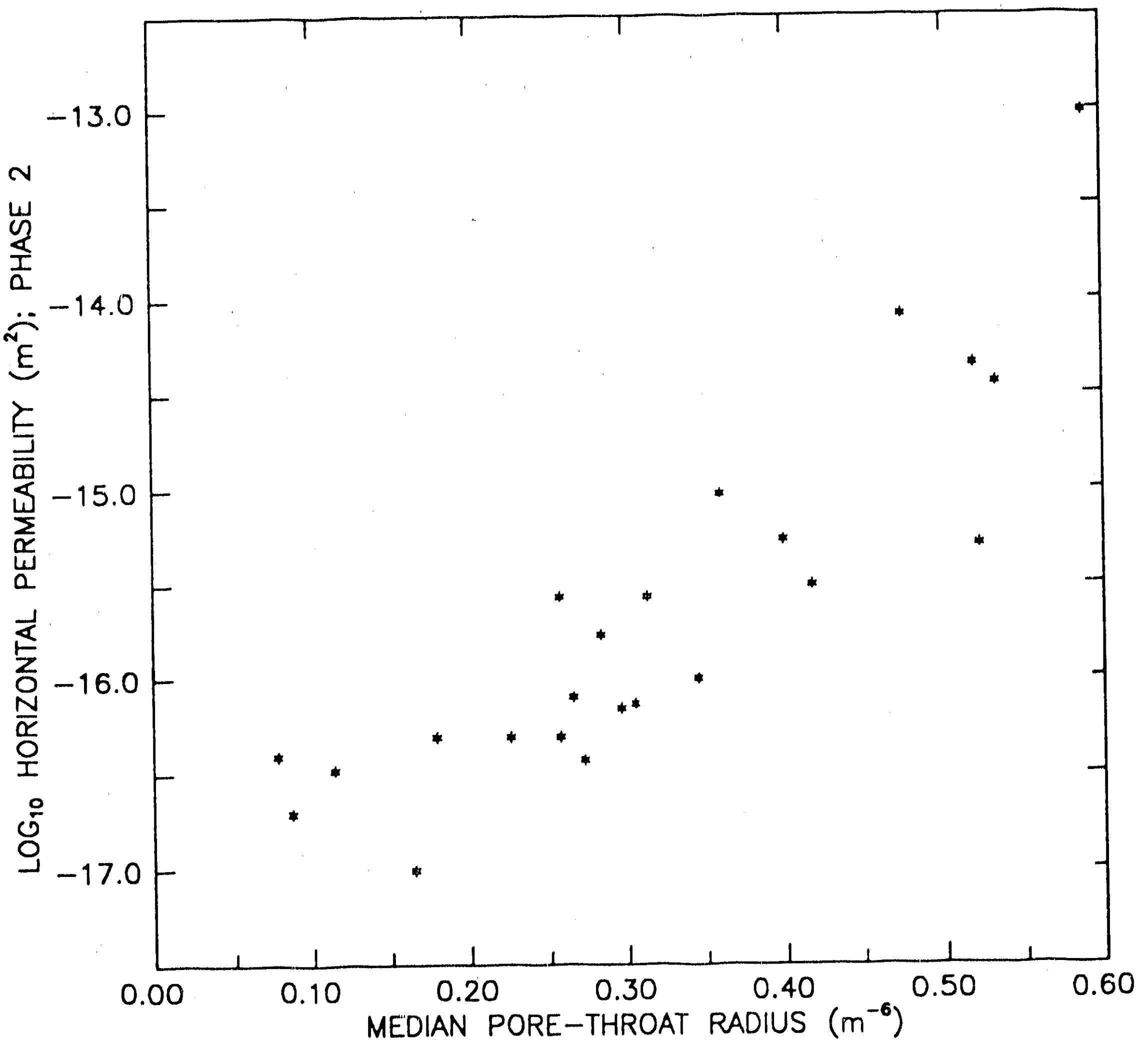


| | |
|---|---|
| Drawn by GJS | Date 11/15/90 |
| Checked by | Date |
| Revisions | Date |
| #105000R019 | 11/15/90 |

Vertical Permeability Versus Porosity for Phase 1 and Phase 2 Whole-Core and Plug-Core Analyses

INTERA Technologies

Figure 4.22



| | | |
|---|---|---|
| Drawn by GJS | Date 11/15/90 | Horizontal Permeability Versus Median Pore-Throat Radius for Phase 2 Plug-Core Samples |
| Checked by | Date | |
| Revisions | Date | |
| # 105000R019 | 11/15/90 | |
| INTERA Technologies | | Figure 4.23 |

| Well No. | Sample No. | Helium Porosity | Grain Density (g/cm3) | Gas Permeability (Horizontal) (m^2) | Gas Permeability (Vertical) (m^2) | Sample Type (1) | Report Date (mo-day-yr) |
|---|---|---|---|---|---|---|---|
| H-2b | 1-1 | 0.141 | 2.80 | 2.0E-16 | 2.0E-16 | WC | 11-13-85 |
| | 3-1H * | {0.115} | | 8.0E-18 (a) | | PC | 01-29-86 |
| | 3-1V * | {0.066} (0.073) | | | 8.4E-18 (a) | PC | 01-29-86 |
| | 2-1/3-1 | 0.165 [0.142] | 2.78 | 6.9E-17 | 9.9E-18 | PC | 12-9-85/1-29-86 |
| | 1-2 | 0.118 | 2.81 | | | PC | 11-13-85 |
| | 2-2/3-2 | 0.070 [0.136] | 2.78 | 1.9E-17 | 3.7E-16 | PC | 12-9-85/1-29-86 |
| H-3b2 | 1-3/3-3V | 0.188 {0.202} | 2.84 | | 4.1E-15 {4.4E-15} | PC | 11-13-85/1-29-86 |
| | 1-4/3-4V | 0.168 {0.113} | 2.79 | | 3.3E-15 {4.0E-15} | PC | 11-13-85/1-29-86 |
| H-3b3 | 1-5 (b) | 0.004 | 2.33 | <9.9E-18 | 2.0E-17 | WC | 11-13-85 |
| | 2-3/3-3 | 0.185 [0.174] | 2.83 | 9.9E-15 | | PC | 12-09-85/1-29-86 |
| | 2-4/3-4V | 0.209 [0.195] | 2.82 | | 1.2E-15 | PC | 12-09-85/1-29-86 |
| | 1-6/3-6V | 0.244 {0.241} | 2.82 | | 5.2E-16 {4.6E-16} | PC | 11-13-85/1-29-86 |
| | 2-5/3-5 | 0.213 [0.196] | 2.84 | 2.1E-15 | 5.5E-16 | PC | 12-09-85/1-29-86 |
| H-4b | 1-9 | 0.297 | 2.85 | | 5.2E-14 | WC | 11-13-85 |
| | 2-6/3-6V | 0.195 [0.220] | 2.84 | | 5.2E-15 | PC | 12-09-85/1-29-86 |
| H-6b | 2-7 | 0.108 | 2.83 | 4.9E-17 | | PC | 12-09-85 |
| | 2-8 | 0.116 | 2.83 | 7.9E-17 | 6.9E-17 | PC | 12-09-85 |
| | 1-7 | 0.107 | 2.83 | 3.9E-17 | 4.9E-17 | PC | 11-13-85 |
| | 1-8/3-8V | 0.255 {0.204} | 2.86 | | 1.7E-15 {1.6E-15} | PC | 11-13-85/1-29-86 |

(1) WC means whole-core sample, and PC means plug-core sample.

* Denotes that the sample is a subsample of the piece of core listed immediately above.

(a) Klinkenberg permeability.

(b) Mineralogic composition of this sample was Gypsum and, due to dehydration during testing, was converted to anhydrite. The porosity value is therefore considered to be unrepresentative.

{ } Denotes an ambient stress of 2.4 MPa during testing.

[ ] Denotes a helium porosity measurement where the bulk volume is determined by fluid displacement.

( ) Denotes a re-run.

| | |
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**Results from the Phase 1 Core Study**

INTERA Technologies

**Table 4.1**

| | | Whole Core | | | | | |
|---|---|---|---|---|---|---|---|
| | | Grain | Gas Permeability (m^2) | | | Boyle's Law | Resaturation |
| Well No. | Sample No. | Density (g/cm3) | Vertical | Horiz. (1) 0 degrees | Horiz. 90 degrees | Porosity | Porosity |
| H-5b | H-5b-3 | 2.82 | 7.9E-17 | 2.2E-16 | 2.7E-16 | 0.133 | 0.128 |
| H-7b2 | H-7b2-2 | 2.83 | 2.5E-16 | 9.9E-17 | 8.9E-17 | 0.118 | 0.129 |
| H-10b | H-10b-3 | 2.80 | 2.1E-16 | 6.2E-16 | 4.3E-16 | 0.112 | 0.106 |
| H-11 | H-11-1 | 2.83 | 1.4E-16 | 4.9E-17 | 4.9E-17 | 0.155 | 0.153 |
| H-11b3 | H-11b3-3 | 2.84 | 2.4E-15 | 5.8E-15 | 5.9E-17 | 0.130 | 0.126 |
| WIPP-12 | WIPP-12-3 | 2.82 | 1.6E-15 | 1.9E-14 | 2.4E-14 | 0.134 | 0.130 |
| WIPP-25 | WIPP-25-1 | 2.80 | 1.9E-16 | 3.6E-13 | 1.1E-16 | 0.115 | 0.120 |
| WIPP-26 | WIPP-26-2 | 2.82 | 5.1E-14 | 2.9E-14 | 6.9E-17 | 0.126 | 0.126 |
| WIPP-28 | WIPP-28-2 | 2.81 | 2.0E-15 | 3.6E-15 | 3.3E-15 | 0.187 | 0.188 |
| | WIPP-28-3 | 2.83 | 2.7E-16 | 3.0E-16 | 3.1E-16 | 0.170 | 0.169 |
| WIPP-30 | WIPP-30-1 | 2.83 | 4.6E-16 | 7.8E-14 | 9.2E-15 | 0.128 | 0.124 |
| | WIPP-30-2 | 2.83 | 3.2E-16 | 3.9E-16 | 1.9E-16 | 0.150 | 0.152 |

(1) The 0 degrees core orientation was chosen visually to be the maximum permeability direction. The 90 degrees orientation is measured 90 degrees to the 0 degrees orientation.

| | |
|---|---|
| Drawn by | Date |
| Checked by | Date |
| Revisions | Date |
| #105000R019 | 12/7/89 |

**Results from Whole-Core Samples, Phase 2 Core Study**

INTERA Technologies

Table 4.2

|  |  | <==================== Plug Core | ====================> |  |  |  |  |
|---|---|---|---|---|---|---|---|
| Well No. | Sample No. | Grain Density (g/cm3) | Gas Permeability (m^2) | Boyle's Law Porosity | Resaturation Porosity | Mercury Intrusion Porosity (1) | Formation Factor |
| H-2a | H2a-1 | 2.82 | 2.5E-16 | 0.116 | 0.113 |  |  |
|  | H2a-2 | 2.80 | 9.9E-18 [1.4E-16] | 0.119 [0.125] |  | 0.111 |  |
| H-2b1 | H2b1-1 | 2.82 | 2.4E-16 | 0.082 | 0.088 |  |  |
|  | H2b1-1F | 2.83 | 3.0E-17 | 0.105 |  |  | 326.77 |
|  | H2b1-2 | 2.78 | 6.1E-16 [1.2E-15] | 0.135 [0.148] |  | 0.148 |  |
|  | H2b1-3 | 2.82 | 2.7E-16 | 0.153 | 0.158 |  |  |
| H-5b | H-5b-1a | 2.82 | 4.9E-17 [4.1E-17] | 0.125 [0.130] |  | 0.124 |  |
|  | H-5b-1b | 2.83 | 7.9E-17 [6.8E-17] | 0.157 [0.155] |  |  |  |
|  | H-5b-2 | 2.81 | 3.6E-15 | 0.228 | 0.237 |  |  |
|  | H-5b-2F | 2.80 | 1.3E-14 | 0.248 |  |  | 12.20 |
| H-7b1 | H-7b1-1 | 2.84 | 1.1E-16 | 0.177 | 0.181 |  |  |
|  | H-7b1-1F | 2.84 | 9.9E-17 | 0.149 |  |  | 73.49 |
|  | H-7b1-2a | 2.84 | 9.9E-17 [1.1E-16] | 0.196 [0.215] |  | 0.197 |  |
|  | H-7b1-2b |  | [5.1E-16] | [0.278] |  | 0.277 |  |
| H-7b2 | H-7b2-1 | 2.83 | 3.1E-16 [2.9E-16] | 0.144 [0.173] | 0.148 | 0.167 |  |
| H-7c | H-7c-1a | 2.83 | 6.9E-17 [9.7E-17] | 0.125 [0.134] | 0.129 | 0.133 |  |
|  | H-7c-1b |  | [7.3E-17] | [0.165] |  |  |  |
|  | H-7c-1F | 2.83 | 1.1E-16 | 0.138 |  |  | 79.61 |
| H-10b | H-10b-1 | 2.80 | 3.9E-17 [1.2E-17] | 0.069 [0.108] |  | 0.072 |  |
|  | H-10b-2 | 2.76 | 7.7E-15 | 0.115 | 0.117 |  |  |
|  | H-10b-2F | 2.82 | 1.4E-16 | 0.066 |  |  | 406.78 |
| H-11 | H-11-2 | 2.78 | 2.0E-17 [3.8E-17] | 0.099 [0.11] | 0.113 | 0.103 |  |
|  | H-11-2F | 2.81 | 3.9E-17 | 0.104 |  |  | 94.82 |

(1) The mercury porosity is equal to the endpoint mercury saturation, expressed as a fraction, multiplied by the helium porosity of the sample.

[ ] Denotes additional permeability and helium porosity measurements performed by K & A Laboraotories as part of the mercury-intrusion porosimetry.

|  |  |  |
|---|---|---|
| Drawn by | Date | Results from Plug-Core Samples, Phase 2 Core Study |
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| Revisions | Date |  |
| #105000R019 | 12/7/89 |  |
| INTERA Technologies |  | Table 4.3 |

| | | Plug Core | | | | | |
|---|---|---|---|---|---|---|---|
| Well No. | Sample No. | Grain Density (g/cm3) | Gas Permeability (m^2) | Boyle's Law Porosity | Resaturation Porosity | Mercury Intrusion Porosity (1) | Formation Factor |
| H-11b3 | H-11b3-1 | 2.84 | 4.5E-15 [1.3E-15] | 0.275 [0.331] | 0.275 | 0.331 | |
| | H-11b3-1F | 2.84 | 1.6E-15 | 0.223 | | | 36.35 |
| | H-11b3-2 | 2.84 | 4.9E-17 | 0.099 | 0.103 | | |
| | H-11b3-2F | 2.83 | 3.3E-16 | 0.123 | | | 101.93 |
| | H-11b3-4 | 2.83 | 2.7E-16 [1.8E-16] | 0.156 [0.148] | | 0.148 | |
| | H-11b3-4F | 2.83 | 7.9E-15 | 0.224 | | | 32.74 |
| WIPP-12 | WIPP-12-1a | | [2.7E-16] | [0.028] | | | |
| | WIPP-12-1b | 2.79 | 1.7E-16 [8.5E-17] | 0.116 [0.112] | | 0.112 | |
| | WIPP-12-2 | 2.82 | 9.5E-16 [1.4E-15] | 0.116 [0.136] | 0.119 | 0.135 | |
| | WIPP-12-2F | 2.82 | 5.7E-14 | 0.135 | | | 47.30 |
| WIPP-13 | WIPP-13-1 | 2.83 | 5.9E-15 | 0.143 | 0.152 | | |
| | WIPP-13-2 | 2.84 | 3.5E-15 | 0.219 | 0.226 | | |
| | WIPP-13-2F | 2.84 | 4.5E-15 | 0.260 | | | 13.26 |
| | WIPP-13-3a | 2.83 | 3.6E-15 [4.9E-15] | 0.167 [0.190] | | 0.185 | |
| | WIPP-13-3b | | [3.7E-17] | [0.097] | | | |
| WIPP-26 | WIPP-26-1 | 2.82 | 3.9E-17 | 0.124 | 0.122 | | |
| | WIPP-26-1F | 2.81 | 3.9E-17 | 0.112 | | | 68.77 |
| | WIPP-26-3 | 2.82 | 4.9E-17 [3.8E-17] | 0.128 [0.125] | | 0.125 | |
| WIPP-28 | WIPP-28-1a | | [3.3E-17] | [0.142] | | | |
| | WIPP-28-1b | 2.83 | 4.9E-17 [3.8E-17] | 0.130 [0.130] | | 0.122 | |
| | WIPP-28-3F | 2.83 | 4.0E-16 | 0.179 | | | 26.30 |
| WIPP-30 | WIPP-30-3a | | [9.6E-15] | [0.176] | | 0.176 | |
| | WIPP-30-3b | 2.79 | 5.4E-16 [3.4E-15] | 0.139 [0.158] | 0.139 | 0.145 | |
| | WIPP-30-3F | 2.80 | 2.5E-15 | 0.149 | | | 31.49 |
| | WIPP-30-4 | 2.83 | 8.2E-15 [1.8E-14] | 0.224 [0.254] | | 0.245 | |

(1) The mercury porosity is equal to the endpoint mercury saturation, expressed as a fraction, multiplied by the helium porosity of the sample.

[ ] Denotes additional permeability and helium porosity measurements performed by K & A Laboraotories as part of the mercury-intrusion porosimetry.

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| Revisions | Date |
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INTERA Technologies

Results from Plug-Core Samples, Phase 2 Core Study

Table 4.3 (con't.)

| | | <========== Plug Core | ==========> | | | | |
|---|---|---|---|---|---|---|---|
| Well No. | Sample No. | Grain Density (g/cm3) | Gas Permeability (m^2) | Boyle's Law Porosity | Resaturation Porosity | Mercury Intrusion Porosity (1) | Formation Factor |
| AEC-8 | AEC-8-1 | 2.83 | 2.6E-16 | 0.079 | 0.086 | | |
| | AEC-8-1F | 2.82 | 5.9E-17 | 0.122 | | | 90.09 |
| | AEC-8-2 | 2.82 | 3.1E-16 | 0.109 | 0.106 | | |

(1) The mercury porosity is equal to the endpoint mercury saturation, expressed as a fraction, multiplied by the helium porosity of the sample.

[ ] Denotes additional permeability and helium porosity measurements performed by K & A Laboraotories as part of the mercury-intrusion porosimetry.

| | |
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| Revisions | Date |
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Results from Plug-Core Samples, Phase 2 Core Study

**INTERA Technologies**

Table 4.3 (con't.)

| Borehole Number | Sample Number | Porosity |
|---|---|---|
| H-2a | H-2a-1 | 0.116 |
| | H-2a-2 | 0.131 * |
| H-2b | 1-1 | 0.141 |
| | 2-1/3-1 | 0.154 ** |
| | 1-2 | 0.118 |
| | 2-2/3-2 | 0.103 ** |
| H-2b1 | H2b1-1 | 0.082 |
| | H2b1-1F | 0.105 |
| | H2b1-2 | 0.142 * |
| | H2b1-3 | 0.153 |
| H-3b2 | 1-3 | 0.188 |
| | 1-4 | 0.168 |
| H-3b3 | 2-3/3-3 | 0.180 ** |
| | 2-4/3-4V | 0.202 ** |
| | 1-6/3-6V | 0.244 |
| | 2-5/3-5 | 0.205 ** |
| H-4b | 1-9 | 0.297 |
| | 2-6/3-6V | 0.208 ** |
| H-5b | H-5b-1a | 0.128 * |
| | H-5b-1b | 0.155 |
| | H-5b-2 | 0.228 |
| | H-5b-2F | 0.248 |
| | H-5b-3 | 0.133 |
| H-6b | 2-7 | 0.108 |
| | 2-8 | 0.116 |
| | 1-7 | 0.107 |
| | 1-8/3-8V | 0.255 |
| H-7b1 | H-7b1-1 | 0.177 |
| | H-7b1-1F | 0.149 |
| | H-7b1-2a | 0.206 * |
| | H-7b1-2b | 0.278 |

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|---|---|
| Drawn by | Date |
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| Revisions | Date |
| # 105000R019 | 12/7/89 |

Summary of Porosities Determined Using Boyle's Law Technique on Culebra Core Samples During Phase 1 and Phase 2 Core Studies

INTERA Technologies

Table 4.4

| Borehole Number | Sample Number | Porosity |
|---|---|---|
| H-7b2 | H-7b2-1 | 0.159 * |
| | H-7b2-2 | 0.118 |
| H-7c | H-7c-1a | 0.130 * |
| | H-7c-1b | 0.165 |
| | H-7c-1F | 0.138 |
| H-10b | H-10b-1 | 0.089 * |
| | H-10b-2 | 0.115 |
| | H-10b-2F | 0.066 |
| | H-1-b-3 | 0.112 |
| H-11 | H-11-1 | 0.155 |
| | H-11-2 | 0.105 * |
| | H-11-2F | 0.104 |
| | H-11b3-1 | 0.303 |
| | H-11b3-1F | 0.223 |
| | H-11b3-2 | 0.099 |
| | H-11b3-2F | 0.123 |
| | H-11b3-3 | 0.130 |
| | H-11b3-4 | 0.152 * |
| | H-11b3-4F | 0.224 |
| WIPP-12 | W-12-1a | 0.028 |
| | W-12-1b | 0.114 * |
| | W-12-2 | 0.126 * |
| | W-12-2F | 0.135 |
| | W-12-3 | 0.134 |
| WIPP-13 | W-13-1 | 0.143 |
| | W-13-2 | 0.219 |
| | W-13-2F | 0.260 |
| | W-13-3a | 0.179 * |
| | W-13-3b | 0.097 |

| | |
|---|---|
| Drawn by | Date |
| Checked by | Date |
| Revisions | Date |
| # 105000R019 | 12/7/89 |

Summary of Porosities Determined Using
Boyle's Law Technique on Culebra Core Samples
During Phase 1 and Phase 2 Core Studies

INTERA Technologies

Table 4.4 (con't.)

| Borehole Number | Sample Number | Porosity |
|---|---|---|
| WIPP-25 | W-25-1 | 0.115 |
| WIPP-26 | W-26-1 | 0.124 |
| | W-26-1F | 0.112 |
| | W-26-2 | 0.126 |
| | W-26-3 | 0.127 * |
| WIPP-28 | W-28-1a | 0.142 |
| | W-28-1b | 0.130 * |
| | W-28-2 | 0.187 |
| | W-28-3 | 0.170 |
| | W-28-3F | 0.179 |
| WIPP-30 | W-30-1 | 0.128 |
| | W-30-2 | 0.150 |
| | W-30-3a | 0.176 |
| | W-30-3b | 0.149 * |
| | W-30-3F | 0.149 |
| | W-30-4 | 0.239 * |
| AEC-8 | AEC-8-1 | 0.079 |
| | AEC-8-1F | 0.122 |
| | AEC-8-2 | 0.109 |

Number of samples = 79
Average porosity = 0.153
Standard deviation = 0.053
Range = 0.028 - 0.303

* Represents an average value from porosity determinations from Terra Tek Laboratories and K & A Laboratories.

** Represents an average of porosity values determined using sample bulk volume estimated from pressured sample dimensions and from fluid displacement.

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Summary of Porosities Determined Using Boyle's Law Technique on Culebra Core Samples During Phase 1 and Phase 2 Core Studies

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Table 4.4 (con't.)

| Laboratory Sample Number | Sample No. | Helium Porosity | Endpoint Mercury Saturation (%) (1) | Mercury-Intrusion Porosity | Median Pore-Throat Radius (m x 10^-6) |
|---|---|---|---|---|---|
| 1 | H-2A-2 | 0.125 | 88.5 | 0.111 | 0.165 |
|  | H-2b1-2 | 0.148 | 99.7 | 0.148 | 0.376 |
|  | H-5b1-1a | 0.130 | 95.0 | 0.124 | 0.257 |
| 4 | H-5b1-1b | 0.155 | 95.3 | 0.148 | 0.265 |
| 5 | H-7b1-2a | 0.215 | 91.6 | 0.197 | 0.345 |
| 6 | H-7b1-2b | 0.278 | 99.5 | 0.277 | 0.521 |
| 7 | H-7b2-1 | 0.173 | 96.5 | 0.167 | 0.417 |
| 8 | H-7C-1b | 0.165 | 94.8 | 0.156 | 0.296 |
| 9 | H-7C-1a | 0.134 | 98.9 | 0.133 | 0.305 |
| 10 | H-10b-1 | 0.108 | 66.7 | 0.072 | 0.077 |
| 10a | H-10b-1 (2) | 0.090 | 95.2 | 0.086 | 0.245 |
| 11 | H-11-2 | 0.110 | 93.3 | 0.103 | 0.086 |
| 12 | H-11b3-1 | 0.331 | 99.9 | 0.331 | 0.518 |
| 13 | H-11b3-4 | 0.148 | 99.9 | 0.148 | 0.257 |
| 14 | W-12-1a | 0.028 | 98.2 | 0.027 | 0.313 |
| 15 | W-12-1b | 0.112 | 99.9 | 0.112 | 0.283 |
| 16 | W-12-2 | 0.136 | 99.4 | 0.135 | 0.359 |
| 17 | W-13-3a | 0.190 | 97.5 | 0.185 | 0.532 |
| 18 | W-13-3b | 0.097 | 99.6 | 0.097 | 0.272 |
| 19 | W-26-3 | 0.125 | 99.9 | 0.125 | 0.225 |
| 20 | W-28-1a | 0.142 | 95.3 | 0.135 | 0.114 |
| 21 | W-28-1b | 0.130 | 93.8 | 0.122 | 0.179 |
| 22 | W-30-3a | 0.176 | 99.8 | 0.176 | 0.588 |
| 23 | W-30-3b | 0.158 | 91.6 | 0.145 | 0.399 |
| 24 | W-30-4 | 0.254 | 96.3 | 0.245 | 0.474 |
|  | Mean = | 0.154 | 95.4 | 0.148 | 0.315 m x 10^-6 |
|  | Std. Dev.= | 0.062 |  | 0.063 | 0.137 m x 10^-6 |

(1) Endpoint Mercury saturation is evaluated at a maximum pressure of 207 MPa.

(2) This sample was analyzed twice due to the anomalous endpoint saturation.

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Summary of Endpoint Saturation and Median Pore-Throat Radii from Mercury-Intrusion Porosimetry

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Table 4.5

| Sample Number | Helium Porosity | Formation Factor | Tortuosity * |
|---|---|---|---|
| AEC-8-1F | 0.122 | 90.09 | 0.091 |
| H-2b1-1F | 0.105 | 326.77 | 0.029 |
| H-5b-2F | 0.248 | 12.2 | 0.331 |
| H-7b1-1F | 0.149 | 73.49 | 0.091 |
| H-7C-1F | 0.138 | 79.61 | 0.091 |
| H-10b-2F | 0.066 | 406.78 | 0.037 |
| H-11-2F | 0.104 | 94.82 | 0.101 |
| H-11b3-1F | 0.223 | 36.35 | 0.123 |
| H-11b3-2F | 0.123 | 101.93 | 0.080 |
| H-11b3-4F | 0.224 | 32.74 | 0.136 |
| W-12-2F | 0.135 | 47.3 | 0.157 |
| W-13-2F | 0.26 | 13.26 | 0.290 |
| W-26-1F | 0.112 | 68.77 | 0.130 |
| W-28-3F | 0.179 | 26.3 | 0.212 |
| W-30-3F | 0.149 | 31.49 | 0.213 |

* Tortuosity calculated from Equation (9) using formation factor determined from electrical-resistivity measurements.

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Summary of Formation-Factor and Tortuosity Results

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Table 4.6

| SAMPLE NUMBER | SAMPLE NAME | DATE REPORTED | TRACER ION | Do (cm2/s) | SAMPLE VOL (cm3) | HELIUM POROSITY | MERCURY POROSITY | DIFFUSION POROSITY | ERROR +/- | TORTUOSITY (BEAR) | TORTUOSITY (COLLINS) | DIFFUSION FORM. FACTOR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | WIPP-19 | 3/23/88(1) | 22 Na | 7.50E-06 | 19.68 | 0.1550 | 0.0860 | 0.040 | 0.020 | 0.043 | 4.80 | 577 |
|  | WIPP-19 | 3/23/88(1) | 3 H | 1.31E-05 | 19.68 | 0.1550 | 0.0860 | 0.060 | 0.020 | 0.025 | 6.30 | 409 |
|  | WIPP-19 | 3/23/88(1) | 129 I | 1.00E-05 | 19.68 | 0.1550 | 0.0860 | 0.020 | 0.006 | 0.104 | 3.10 | 625 |
|  | WIPP-19 | 3/23/88(1) | 22 Na | 7.50E-06 | 19.68 | 0.1550 | 0.0860 | 0.040 | 0.010 | 0.060 | 3.90 | 395 |
| 2 | ESM-143-1 | 6/23/88(2) | 22 Na | 7.50E-06 | 3.00 |  | 0.0777 | 0.087 | 0.060 | 0.101 | 3.15 | 107 |
| 3 | ESM-143-2 | 6/23/88(3) | 129 I | 1.00E-05 | 41.61 | 0.0975 | 0.0715 | 0.012 | 0.003 | 0.088 | 3.37 | 150 |
|  | ESM-143-2 | 6/23/88(3) | 22 Na | 7.50E-06 | 41.61 | 0.0975 | 0.0715 | 0.011 | 0.002 | 0.093 | 3.28 | 714 |
|  | ESM-143-2 | 11/21/88(1) | 3 H | 1.31E-05 | 41.61 | 0.0975 | 0.0715 | 0.040 | 0.005 | 0.033 | 5.50 | 437 |
| 4 | A1S-SNL-16 | 6/30/89(4) | 3 H | 1.31E-05 | 0.35 | 0.1950 | 0.1500 | 0.130 | 0.340 | 0.170 | 2.40 | 44 |

NOTE: Do = free-water diffusion coefficient.

The data were taken from (Casey and Stockman (1)1988a, (2)1988b, (3)1988c, (4)1989, and Dykhuizen and Casey 1989).

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Results from Diffusion Studies Performed on the Culebra by Sandia National Laboratories

Table 4.7

#105000R019 4/18/90

## 5.0 CONCLUSIONS

The Phase 1 and Phase 2 core studies of selected core samples of the Culebra dolomite from WIPP-site observation wells provided useful data in the parameterization of ground-water flow-and-transport modeling of the Culebra at the WIPP site. The samples were analyzed by helium porosimetry, resaturation porosimetry, mercury-intrusion porosimetry, electrical-resistivity techniques, and gas permeability. The analyses were conducted on whole-core and core-plug samples. This section presents general conclusions based on the combined results of these core studies.

The combined results from the 79 Phase 1 and Phase 2 helium-porosity determinations indicated that the distribution of Culebra porosities was skewed toward lower porosity values. The arithmetic mean and standard deviation of the 79 helium porosities are 0.153 and 0.053, respectively.

The vertical heterogeneity of porosity within the Culebra was evaluated using the results of core analysis of 21 pairs of core plugs, where each core plug in a pair was taken within about 5 to 10 cm of the other. The results using helium-porosity determinations showed that differences in porosity between the sample pairs ranged from as little as 0.05 to as high as 0.093. The paired data indicated significant vertical-permeability differences on this scale.

The water-resaturation-porosimetry results showed a near 1-to-1 correlation with the results from helium-porosity determinations. The linear correlation coefficient between helium porosity and resaturation porosity for 30 samples was 0.99. The correlation between the two sets of results was not expected to be good because water cannot normally access pore space as easily as helium. In some cases, the resaturation porosities were slightly larger than the helium porosities. It is possible that the results of the resaturation porosimetry may have been affected by mineral dissolution from the deionized water which was used as the resaturation fluid. It is also possible that the actual differences between the porosities determined by both methods were within the experimental reproducibility of the two measuring techniques.

The endpoint mercury pore-volume saturations for the 25 samples analyzed ranged from 66.7% to 99.9%, with an endpoint pressure of 207 MPa. The average endpoint pore-volume saturation was 95.4%. The median pore-throat radii varied over an order of magnitude from 0.077 μm to 0.588 μm with an arithmetic average value of 0.315 μm. Eighty-four percent of the pore-throat radii in the samples analyzed were between 0.1 μm and 0.5 μm. The average mercury-intrusion porosity was 0.148, as compared with the helium-porosity average of 0.154. The mercury-intrusion porosimetry analyses confirmed the heterogeneity of pore structure within the Culebra, even over vertical distances of 10 cm.

Seventy-three (73) grain-density measurements were made on the Culebra dolomite. The distribution of grain densities is skewed toward larger values of grain density with an arithmetic average of 2.82 g/cm$^3$ and a standard deviation of 0.019 g/cm$^3$. Because of the skewed grain-density distribution, the most common value of grain density is 2.83 g/cm$^3$, which is also the median of the distribution.

The results of electrical-resistivity measurements of saturated core plugs yielded 15 estimates of formation factor and tortuosity. The distribution of formation factor was log-normal and values ranged from 12 to 407 with a geometric mean of 58.8. The 15 values of tortuosity calculated from the formation-factor data ranged from 0.03 to 0.33 with an arithmetic average of 0.14. The median tortuosity was 0.12. The results show a general trend of increasing tortuosity with increasing porosity. The diffusion porosities and diffusion tortuosities determined for diffusion experiments on four rock samples by Dykhuizen and Casey (1989) agree with the lower range of the values determined by electrical-resistivity methods used in this core-analysis study.

Gas-permeability measurements were performed on plug-core samples in both the horizontal and vertical directions. Sixty-six (66) horizontal-permeability measurements were made in both Phase 1 and Phase 2 core studies. The permeability values ranged from 7.9E-18 $m^2$ to 3.6E-13 $m^2$, and the distribution had an arithmetic average of 6.2E-15 $m^2$, a geometric mean of 4.5E-16 $m^2$, and a median of 2.7E-16 $m^2$. Twenty-six (26) vertical-permeability measurements were made during both Phase 1 and Phase 2 core studies. The permeabilities ranged from 8.4E-18 $m^2$ to 5.2E-14 $m^2$, with an arithmetic mean of 5.1E-15 $m^2$, a geometric mean of 9.0E-16 $m^2$, and a median of 3.5E-16 $m^2$. Plots of the $\log_{10}$ of permeability versus porosity indicated a weak correlation between the $\log_{10}$ of permeability and porosity. In general, the $\log_{10}$ of vertical permeability appeared to be more directly correlated with porosity than did the $\log_{10}$ of horizontal permeability. A plot of the $\log_{10}$ of horizontal permeability versus median pore-throat radius indicated that the $\log_{10}$ of horizontal permeability is directly related to median pore-throat radius.

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# APPENDIX A

# SAMPLE DESCRIPTIONS

| Well No./ Sample No. | Depth (ft.) | Core-Sample Descriptions |
|---|---|---|
| H2b/1-1, 1-1H, 1-1V | 630.0 | finely vugular dolomite |
| H2b/2-3, 3-1 | 635.8-636.2 | very vuggy dolomite, some gypsum-filled fractures, some up to 15 mm. in diameter, some are gypsum filled |
| H2b/1-2 | 637.5 | finely porous and vuggy dolomite |
| H2b/2-2, 3-2 | 639.8-640.2 | finely vugular dolomite, some calcite fillings, has a brown silt (perhaps drilling mud) all over core, has a corroded appearance in areas. |
| H3b2/1-3, 3-3v | 681 | porous dolomite |
| H3b2/1-4, 3-4v | 689.2 | very vuggy and porous dolomite |
| H3b3/1-5 | 667.7-668.1 | massive gypsum |
| H3b3/2-3, 3-3 | 671.4-671.7 | finely vugular, finely fractured dolomite. Some (less than 10%) vugs and fractures are filled with gypsum. fractures are tight |
| H3b3/2-4, 3-4v | 671.7-672.0 | vuggy dolomite, tight vertical fracture, seems to be gypsum filled, some large voids, 20% or more are gypsum filled |
| H3b3/1-6, 3-6v | 689.3 | finely vugular, porous dolomite |
| H3b3/2-5, 3-5 | 690.0-690.6 | very finely vugular, porous core, large 25 by 40 mm gypsum fill |
| H4b/-9 | 513 | porous dolomite |
| H4b/2-6, 3-6v | 517.0-517.3 | very silty, finely porous dolomite, friable in sections |

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Core-Sample Descriptions for the Phase 1 Core Study

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Table A.1

| Well No./ Sample No. | Depth (ft.) | Core-Sample Descriptions |
|---|---|---|
| H6b/2-7 | 614.3-614.6 | massive dolomite |
| H6b/2-8 | 615.0-615.3 | very dense, massive dolomite, has brown spotty precip on outside, one noticeable void, open, ≃ 5 by 3 mm |
| H6b/1-7 | 616.0 | massive dolomite |
| H6b/1-8, 3-8v | 628-640 | very porous dolomite |

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Core-Sample Descriptions for the Phase 1 Core Study

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Table A.1 (cont.)

| Well No./ Sample No. | Depth (ft.) | Core-Sample Descriptions |
|---|---|---|
| H-2a-1 | 619 | irregular, tight dolomite, some microfractures, some filled vugs ≃6 cm. in length |
| H-2a-2 | 622-622.4 | tight, slightly vuggy dolomite; full length vertical frac, gypsum filled, irregular edges |
| H-2b1-1 | 637.6-637.8 | very vuggy dolomite, most unfilled, the remainder are gypsum-filled |
| H-2b1-2 | ≃ 640 | vuggy dolomite, some gypsum filled |
| H-2b-3 | ≃ 641.5 | slightly vuggy dolomite, vugs are not filled |
| H-5b-1 | 903-903.6 | massive dolomite with open vugs |
| H-5b-2 | 913 ≃ 914 | hairline horiz. fractures, finely vugular dolomite |
| H-5b-3 | 901.3-901.7 | massive dolomite, vuggy near top of sample |
| H-7b1-1 | 251.5-251.9 | open vugs, otherwise well-consolidated massive dolomite |
| H-7b1-2 | ≃ 268 | very vuggy dolomite, vugs are unfilled and average 1 cm diameter |
| H-7b2-1 | ≃ 275 | vuggy dolomite |
| H-7b2-2 | 260-261.25 | massive dolomite, some vertical fractures, and occasional isolated empty vugs |
| H-7c-1 | 271.1-271.7 | dolomite with large vugs, average diameter is approximately 2 cm |

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Core-Sample Descriptions for the Phase 2 Core Study

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Table A.2

| Well No./<br>Sample No. | Depth (ft.) | Core-Sample Descriptions |
|---|---|---|
| H-10b-1 | 1394.5-1395.1 | brecciated vuggy (filled) dolomite, contains a layer with fine clay infilling |
| H-10b-2 | 1374-1347.4 | consolidated dolostone, slightly fractured, contains fine vugs |
| H-10b-3 | 1388.1-.8 | vuggy dolomite |
| H-11-1 | 731.5-731.9 | competent dolomite with fine vugs which are not filled |
| H-11-2 | N/A | competent dolomite with filled hairline fracture, one gypsum-filled vug, ovoid in shape, 3cm. in diameter |
| H-11b-3-1 | 756.3-756.5 | silty dolomite, vuggy and very porous |
| H-11b3-2 | ≈ 753 | vuggy dolomite with hairline fractures, vugs are open. |
| H-11b3-3 | 741.8-742.3 | competent dolomite, a few vugs filled and not filled |
| H-11b3-4 | 744.46-745.33 | finely vugular dolomite, micro vugs not filled |
| WIPP-12-1 | 821.5-822 | vuggy, silty dolomite |
| WIPP-12-2 | 834.3-834.8 | vuggy dolomite, with some vugs filled with gypsum, also vertical fractures, some filled, others not |
| WIPP-12-3 | 832.3-832.8 | fractured dolomite with few vugs, fractures are tight |
| WIPP-13-1 | ≈ 710 | massive dolomite, a few open hairline fractures; core only 3/4 round so have to take plug sample |

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Core-Sample Descriptions for the Phase 2 Core Study

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Table A.2 (cont.)

| Well No./<br>Sample No. | Depth (ft.) | Core-Sample Descriptions |
|---|---|---|
| WIPP-13-2 | ≃ 723.5 | vuggy dolomite |
| WIPP-13-3 | 707.5-708.1 | vuggy silty dolomite |
| WIPP-25-1 | 454-454.8 | massive dolomite |
| WIPP-26-1 | 190.7-191 | massive dolomite with a few small-diameter, open vugs |
| WIPP-26-2 | 191.5-192 | massive dolomite with open vugs |
| WIPP-26-3 | ? | vuggy silty dolomite, vugs open, only good piece; all core below destroyed, hard to determine exact footage |
| WIPP-28-1 | ≃430 | finely vuggy dolomite |
| WIPP-28-2 | 426.5-427 | fragmented silty dolomite |
| WIPP-28-3 | 427.9-428.4 | massive silty dolomite, no obvious laminations or structure |
| WIPP-30-1 | 647.7-648 | vuggy dolomite with vertical fractures, some filled |
| WIPP-30-2 | ≃638.5 | finely vugular dolomite |
| WIPP-30-3 | 636.7-637.2 | very vuggy dolomite |
| WIPP-30-4 | 635.1-635.4 | vuggy, silty dolomite, vugs not filled with gypsum |
| AEC-8-1 | ≃849 | massive finely vugular dolomite |
| AEC-8-2 | ≃854 | massive dolomite with very large vugs |

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Core-Sample Descriptions for the Phase 2 Core Study

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Table A.2 (cont.)

# APPENDIX B

## SUMMARY OF RESULTS RECEIVED FROM CORE LABORATORIES, INC.

Note: Laboratory Sample Number 5 from the November 13, 1985 report is a sample of the Tamarisk Member of the Rustler Formation. Analyses performed on this sample are not included in the Culebra sample set presented in this report.

**CORE LABORATORIES, INC.**
*Petroleum Reservoir Engineering*
DALLAS, TEXAS

# CORE ANALYSIS REPORT

FOR

INTERRA TECHNOLOGIES

WIPP SITE

RECEIVED
15
JAN 27 1986
INTERA TECHNOLOGIES

# CORE LABORATORIES, INC.

*Petroleum Reservoir Engineering*

DALLAS, TEXAS

INTERRA TECHNOLOGIES
WIPP SITE

DATE : 13-NOV-85
FORMATION :
DRLG. FLUID:
LOCATION :

FILE NO. : 38060-7829
LABORATORY : AURORA, COLORA
API WELL NO.:
ELEVATION :

## CONVENTIONAL CORE ANALYSIS

| SAMPLE NUMBER | DEPTH FEET | PERM MD HORIZ Ka | PERM MD VERT Ka | He POR | GRAIN DEN M | DESCRIPTION |
|---|---|---|---|---|---|---|
| 1 | 630.0 | 0.02 | 0.02 | 14.1 | 2.80 | H2B |
| 2 | 637.5 | | ** | 11.8 | 2.81 | H2B |
| 3 | 681.0 | | 4.2 | 18.8 | 2.84 | H3B2 |
| 4 | 689.2 | | 3.3 | 16.8 | 2.79 | H3B2 |
| | 700.5 | | | | | UNSUITABLE FOR ANALYSIS |
| | 702.9- 3.5 | | | | | UNSUITABLE FOR ANALYSIS |
| 5 | 667.7-68.1 | <0.01 | 0.02 | 0.4 | 2.33 | H3B3 |
| 6 | 689.3 | | 0.53 | 24.4 | 2.82 | H3B3 |
| 7 | 616.0 | 0.04 | 0.05 | 10.7 | 2.83 | 6B |
| 8 | 628.0-40.0 | | 1.7 | 25.5 | 2.86 | 6B |
| 9 | 513.0 | | 53. | 29.7 | 2.85 | H4B |

**UNSUITABLE FOR PERMEABILITY MEASUREMENT

**CORE LABORATORIES, INC.**
*Petroleum Reservoir Engineering*
DALLAS, TEXAS

# CORE ANALYSIS REPORT

FOR

INTERRA TECHNOLOGIES

[redacted]C 20[redacted]
INTERRA TECHNOLOGIES

# CORE LABORATORIES, INC.

*Petroleum Reservoir Engineering*

DALLAS, TEXAS

PAGE 1

INTERRA TECHNOLOGIES

DATE : 09-DEC-85
FORMATION :
DRLG. FLUID:
LOCATION :

FILE NO. : 38060-7852
LABORATORY : AURORA, COLORADO
API WELL NO.:
ELEVATION :

## CONVENTIONAL CORE ANALYSIS

| SAMPLE NUMBER | DEPTH FEET | PERM MD HORIZ Ka | PERM MD VERT Ka | He POR | GRAIN DEN M | DESCRIPTION |
|---|---|---|---|---|---|---|
| 1 | 635.8-36.2 | 0.07 | <0.01 | 16.5 | 2.81 | H-2B |
| 2 | 639.8-40.2 | 0.19 | 0.37 | 7.0 | 2.78 | H-2B |
| 3 | 671.4-71.7 | 10. |  | 18.5 | 2.83 | H-3B3 [illegible] |
| 4 | 671.7-72.0 |  | 1.2 | 20.9 | 2.82 | H-3B3 |
| 5 | 690.0-90.6 | 2.1 | 0.56 | 21.3 | 2.84 | H-3B3 [illegible] |
| 6 | 517.0-17.3 |  | 5.3 | 19.5 | 2.84 | H-4B |
| 7 | 614.3-14.6 | 0.05 |  | 10.8 | 2.83 | H-6B [illegible] |
| 8 | 615.0-15.3 | 0.08 | 0.07 | 11.6 | 2.83 | H-6B [illegible] |

# SPECIAL CORE ANALYSIS STUDY

for

INTERA TECHNOLOGIES

WIPP SITE
FILE NUMBER: SCAL 203-850073

7501 STEMMONS FREEWAY, BOX 47547, • DALLAS, TEXAS 75247 • 214/631-8270

**CORE LABORATORIES, INC.**

Reply To:
10703 E. BETHANY DRIVE
AURORA, COLORADO 80014

January 29, 1986

Intera Technologies
6580 Austin Center Boulevard
Suite 300
Austin, TX 78731

Attention: Mr. George Saulnier:

Subject:

Special Core Analysis Study
WIPP Site
File Number: SCAL 203-850073

Gentlemen:

On December 12, 1985 Mr. George Saulnier of Intera Technologies requested the following special core analyses on core material recovered from the subject well:

1) Permeability to Air and Porosity.

2) Klinkenberg Permeability (Gas Slippage Corrected).

Enclosed are the final results of these analyses.

Six, one inch diameter core plugs were obtained from Intera Technologies for this study. Permeability to air and helium porosity values utilizing Boyle's Law technique were obtained with the resultant data presented on Pages 2 and 3. The samples are identified as to depth and are lithologically described on Page 1.

The Klinkenberg permeability (gas slippage corrected) was requested for sample numbers 1H, 1V, and 8V. These samples were measured at an effective overburden pressure of 350 psi by the non-steady state method. The results of this test are presented on Page 2 in conjunction with the permeability to air and porosity determinations.

A bibliographic reference for this procedure is:

Freeman, D. and Bush, D. Low Permeability Laboratory Measurements by Non-Steady State and Conventional Methods. SPE Technical Paper 10075.

An additional group of samples were examined after completion of the initial study. The core samples listed on Page 2 were re-examined for porosity measurements. A special procedure was utilized for more accurate porosity determination. The parameters used for porosity calculation are pore volume, grain volume and bulk volume. The vuggy nature of many of the core samples lends to erroneous bulk volume values by the length X area formula. As a result, all bulk volume values were remeasured using a different technique. Teflon tape was wrapped around each sample, isolating the vugs. A mercury bulk volume, and measurement was obtained. The teflon tape was removed and its bulk volume was determined and subtracted from the initial bulk volume value. Porosity was recalculated giving generally lower porosity values as compared to the original Conventional Core Analysis data.

It has been a pleasure working with Intera Technologies on this study. Should you have any questions pertaining to these test results or if we may be of further assistance, please do not hesitate to contact us at (303)751-9334.

Very truly yours,

CORE LABORATORIES, Inc.

Mercer L. Brugler

Mercer L. Brugler
Special Core Analysis Supervisor

MLB/sso
4 cc addressee

CORE LABORATORIES, INC.
*Special Core Analysis*

Page 1 of 3
File 203-850073

## IDENTIFICATION AND LITHOLOGICAL DESCRIPTION OF SAMPLES

Company: Intera Resources

Well: WIPP Site

| Sample Identification | Depth, feet | Lithological Description |
|---|---|---|
| 1H | 630.0 | DOL,bu,pkst,wl ind,slily lmy,vug,frac w/calc cmt |
| 1V | 630.0 | DOL,bu,pkst,wl ind,slily lmy,vug,frac w/calc cmt |
| 3V | 681.0 | DOL,bu,pkst,wl ind,slily lmy,vug,frac w/calc cmt |
| 4V | 689.2 | DOL,bu,pkst,wl ind,slily lmy,vug |
| 6V | 689.3 | DOL,bu,pkst,wl ind,slily lmy,vug w/cl inf |
| 8V | 682-640 | DOL,bu,pkst,wl ind,psool,slily lmy, vug |

## PERMEABILITY TO AIR, POROSITY AND KLINKENBERG PERMEABILITY AS A FUNCTION OF OVERBURDEN PRESSURE

Company: Intera Resources Well: WIPP Site

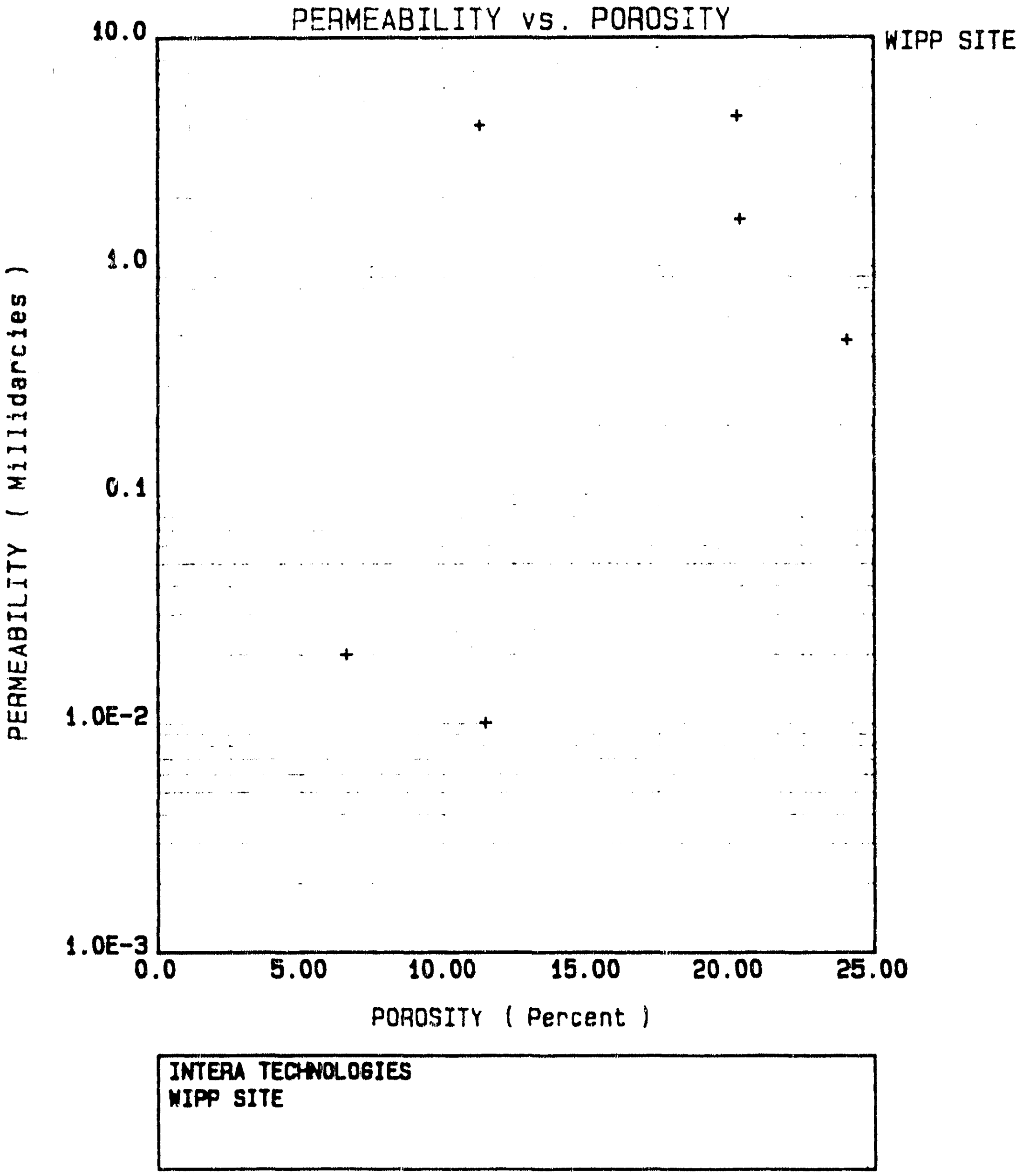
Effective Overburden Pressure, psi 350

| Sample I.D. | Depth, feet | Permeability to Air Millidarcys | Porosity Percent | Klinkenberg Permeability** Millidarcys |
|---|---|---|---|---|
| 1H | 630.0 | <0.01 | 11.5 | 0.00801 |
| 1V | 630.0 | 0.02 | 6.6 (7.3)*** | 0.00847 |
| 3V | 681.0 | 4.5 | 20.2 | * |
| 4V | 689.2 | 4.1 | 11.3 | * |
| 6V | 689.3 | 0.47 | 24.1 | * |
| 8V | 628-640 | 1.6 | 20.4 | 0.61229 |

### CONVENTIONAL CORE ANALYSIS DATA - FILE NO. 3806-7852

| Sample I.D. | Depth, feet | Porosity Percent |
|---|---|---|
| 1 | 635.8-36.2 | 14.2 |
| 2 | 639.8-40.2 | 13.6 |
| 3 | 671.4-71.7 | 17.4 |
| 4V | 671.7-72.0 | 19.5 |
| 5 | 690.0-90.6 | 19.6 |
| 6V | 517.0-17.3 | 22.0 |

* Indicates sample not requested for measurement.
** Permeability to Nitrogen
*** Remeasured value


PERMEABILITY vs. POROSITY
WIPP SITE
10.0
1.0
0.1
1.0E-2
1.0E-3
PERMEABILITY ( Millidarcies )
0.0
5.00
10.00
15.00
20.00
25.00
POROSITY ( Percent )
INTERA TECHNOLOGIES
WIPP SITE

# APPENDIX C

# TERRA TEK CORE SERVICES REPORT

## ERRATA

(Prepared by INTERA Inc.)

Some sample numbers are incorrect on some tables in the Terra Tek report. Refer to the following corrections when comparing these data to those presented in data tabulations in the report.

Table 1. H-2B-1F should read H-2B1-1F
H-5B-1 should read H-5B-1A
H-7B2-1F should read H-7C-1F
W-12-2B should read W-12-2

Table 2. H-5B1-3 should read H-5b-3

Table 4. H-5b1-2 should read H-5b-2
H-5b1-3 should read H-5b-3

Table 6. H-5b1-2F should read H-5b-2F

Final Report

# SPECIAL CORE ANALYSIS STUDY OF THE CULEBRA DOLOMITE

by

K. C. Rakop
T. Little

Submitted to:

INTERA TECHNOLOGIES, INC.
6850 Austine Center Boulevard
Suite 300
Austin, Texas 78731

Attn: Van A. Kelley

TR 88-48 R1
April, 1988

097B-00E-081

## PROGRAM SUMMARY

This program was designed to characterize core material from the Culebra dolomite formation. Information received indicated this formation to be naturally fractured with secondary, dissolution-type porosity.

The samples submitted for use in the characterization study were taken from various core holes throughout the reservoir. Information supplied with the cores indicated the core material to be predominantly dolomite with a gypsum content that averaged 2-3% with a high of approximately 18%. It was also reported that the cores contained low concentrations of several clays and about 2% halite. All of the cores were 3-5 years old and had not been subjected to any type of preservation procedure prior to storage.

Specific characterization tests requested included the following: 1) permeability, 2) helium porosity, 3) re-saturation porosity, and 4) formation factor. All of the testing was performed at ambient conditions. For the permeability and formation factor measurements, this is defined as 300 psi net effective stress and room temperature (approximately 72°F). For the porosity measurements, ambient is defined as atmospheric conditions and room temperature. X-ray diffraction analyses were also requested on three special samples.

Table 1 summarizes the characterization data, including permeability and helium porosity data, for the 1 inch diameter samples. Due to the vugular nature of the samples, all of the bulk volumes were determined using caliper measurements of the core dimensions. The helium porosity was measured by gas expansion using Boyle's law. The helium porosity values ranged from 6.6-27.5% with an average value of 14.9%. Permeability was measured using standard steady-state techniques and ranged from 0.02-58.0 md with an average value of

3.7 md even though approximately 70% of the samples had permeabilities less than 1 md.

Table 2 summarizes the characterization data, including the permeability and helium porosity data, for the whole core samples. Although these samples were whole core, not plugs, it should be noted that the diameter of the samples ranged from 2.25 to 4.25 inches. The bulk volumes were determined using caliper measurements of the length and diameter of the cores with three exceptions, samples H11-1, H11B3-3 and H7B2-2. These samples contained no secondary porosity (vugs), but each sample had deep scribe marks running the length of the core which needed to be omitted from both the bulk and pore volume measurements. For this reason, the bulk volumes were determined using an Archimedes technique with toluene. Toluene was used because of the presence of water sensitive clays and salts in the core. The helium porosity values for the whole core samples ranged from 11.2 to 18.7% with an average value of 13.8%.

Vertical permeability of the samples ranged from 0.081-52 md. The horizontal permeability of the samples varied from 0.046 to 368 md. All of the horizontal permeability measurements were performed using standard steady-state techniques with 90 degree screens placed on either side of the sample. According to Collins* and his comformal mapping code, the correction factor to account for the path of flow is 1.0. The location of the screens was chosen arbitrarily; although, where possible, the directions of maximum and minimum permeability were chosen. The presence of natural fractures was used to determine these directions. The observed high variation in horizontal perme-

---

*Collins, R.E., "Flow of Fluid Through Porous Media," The Petroleum Publishing Company, Tulsa, 1976.

ability is due primarily to the presence of these natural fractures in the core samples.

After the helium porosities and the gas permeabilities were measured, selected samples were to have their porosity remeasured using Archimedes resaturation technique. Intera Technologies requested that these measurements be performed with deionized water. This decision was based upon information that chemical analyses performed on various brine samples taken across the field revealed significant variations in brine composition. This problem was further complicated by the fact that Intera Technologies did not have brine samples from all of the zones of interest in this study, and could not supply brine or brine compositions for some of the zones from which the core samples were taken. In addition, because of the wide variation observed in brine composition, they did not feel comfortable in specifying a "generic" brine. Intera Technologies, therefore, decided to perform the porosity measurements by resaturation with deionized water.

Terra Tek was somewhat concerned about using deionized water in these tests due to the water sensitive clays and salts present in the reservoir. For this reason, it was suggested that a comparison be made between the performance of deionized water and simulated reservoir brine with some of the core samples to determine if any clay swelling or salt dissolution occurred with the deionized water. Table 3 details the data gathered from this test on twin plugs taken from the H5B1-1a and 1b samples. These samples were chosen by Intera Technologies because it came from an area of the reservoir for which a representative brine analysis was available. It should be noted in passing, however, that this sample may not be representative of most of the samples tested because it contained no obvious fractures or gypsum stringers. As can be seen, the sample saturated with deionized water had only a 0.1% difference in the porosities measured with helium and water. The important thing to note here, however, is that the resaturation porosity is less than the helium porosity. This is indicative of nominal salt dissolution. There is no indication of significant clay swelling either. The latter conclusion is based upon the small difference observed between the two measured porosity values. The resolution of the porosimeter used is ±1%; therefore, the difference in observed porosity is within experimental error.

On the other hand, the resaturation porosity measured using the simulated reservoir brine had a higher difference than the deionized water did, 0.4%. The simulated brine is representative of this reservoir section and should have no adverse reactions with the reservoir rock material. The difference observed between the performance of the deionized water and that of the simulated reservoir brine cannot be explained with the data available. Through discussions with Intera Technologies, it was decided that the remaining tests would be performed using deionized water.

Tables 4 and 5 detail the helium porosity and resaturation porosity values for both the plugs and the whole core, respectively. Also reported is whether or not any dissolution of the sample was observed. In most cases this dissolution was only slight, but in one case, W-28-2, it was severe. In those cases in which dissolution was observed, it appeared primarily in samples with obvious gypsum stringers or along fractures. It was not possible to determine dissolution of the interior of the samples by visual inspection. Although no dissolution was observed in the pilot brine/deionized water comparison tests on the H5B1 samples, there was also no obvious fractures or gypsum stringers in these samples. Based on the data from those tests, however, there was no evidence of adverse effects caused by the deionized water.

In approximately 57% of the samples, the resaturation porosity was greater than the helium porosity. This is not normally the trend observed in data of this type and is most likely due to dissolution of gypsum in those samples. Because of the small molecular size of helium, this gas can normally access more pore volume than water can. For this reason, as a general rule, the observed helium porosity is greater than the resaturuation porosity. The average deviation between the two measured values was 0.4%.

Table 6 and Figure 1 summarize the formation factor data for the 15 samples tested. The electrical samples were tested at ambient conditions saturated with a representative reservoir brine. The brine chemistry supplied was as follows:

| | |
|---|---|
| Calcium | 1,400 mg/l |
| Magnesium | 1,100 mg/l |
| Potassium | 720 mg/l |
| Sodium | 38,000 mg/l |
| Alkalinity $(HCO_3)^{-1}$ | 52 mg/l |
| Chloride | 65,000 mg/l |
| Sulfate | 6,100 mg/l |

The brine was made following the above chemistry with the exception of the sulfate. Since sulfate has the tendency to precipitate, it was omitted. The resistivity of the brine was 6.9 ohm-cm.

The cementation factor calculated for each individual sample was based on an intercept of 1/1 and the measured formation factor. The cementation factor ranged from 1.79 to 2.57. The composite cementation factor for the Culebra dolomite is 2.13. The variations observed in the cementation values are probably due to the various quantities of halite, gypsum and clays. The degree of secondary porosity will also contribute to the variations observed.

Results from tests on the three samples submitted for X-ray diffraction are summarized in Table 7. These data reveal that Samples 1 and 3 contain significant amounts of calcite, aragonite, and brucite. Sample 3 also contains a large amount of gypsum; Sample 1 contains none. The presence of brucite is not well understood. Brucite is a magnesium hydroxide clay mineral commonly associated with metamorphosed carbonate rocks. This sample may have come from the aquifer host rock. Sample 2 is dominantly halite with only minor amounts of gypsum and calcite.

The Appendix includes a copy of our Quality Assurance Manual. Also included is a one page summary of the specific quality control checks taken in the measurements performed in this program.

Table 1

Summary of Characterization Data
One Inch Diameter Samples

| Sample I.D. | Bulk Volume (cc) | Pore Volume (cc) | Porosity (%) | Grain Volume (gm/cc) | Permeability (md) |
|---|---|---|---|---|---|
| AEC-8-1 | 25.038 | 1.986 | 7.9 | 2.83 | 0.26 |
| AEC-8-1F | 25.261 | 3.082 | 12.2 | 2.82 | 0.06 |
| AEC-8-2 | 25.038 | 2.731 | 10.9 | 2.82 | 0.31 |
| H2A-1 | 22.307 | 2.594 | 11.6 | 2.82 | 0.25 |
| H2A-2 | 23.606 | 2.810 | 11.9 | 2.80 | 0.10 |
| H2B-1F | 25.191 | 2.645 | 10.5 | 2.83 | 0.03 |
| H2B1-1 | 23.592 | 1.939 | 8.2 | 2.82 | 0.24 |
| H2B1-2 | 23.558 | 3.182 | 13.5 | 2.78 | 0.62 |
| H2B1-3 | 23.606 | 3.615 | 15.3 | 2.82 | 0.27 |
| H-5B-1 | 21.893 | 2.726 | 12.5 | 2.82 | 0.05 |
| H-5B1-2 | 24.936 | 5.693 | 22.8 | 2.81 | 3.60 |
| H-5B1-2F | 25.151 | 6.237 | 24.8 | 2.80 | 13.00 |
| H-5B1-1B | 24.949 | 3.913 | 15.7 | 2.83 | 0.08 |
| H-7B1-1 | 24.811 | 4.385 | 17.7 | 2.84 | 0.11 |
| H-7B1-1F | 25.191 | 3.753 | 14.9 | 2.84 | 0.10 |
| H-7B1-2A | 24.924 | 4.873 | 19.6 | 2.84 | 0.10 |
| H-7B2-1 | 24.177 | 3.479 | 14.4 | 2.83 | 0.31 |
| H-7B2-1F | 18.882 | 2.606 | 13.8 | 2.83 | 0.11 |
| H-7C-1A | 25.038 | 3.134 | 12.5 | 2.83 | 0.07 |
| H-10B-1 | 24.949 | 1.728 | 6.9 | 2.80 | 0.04 |
| H-10B-2 | 24.936 | 2.879 | 11.5 | 2.76 | 7.80 |
| H-10B-2F | 25.191 | 1.663 | 6.6 | 2.82 | 0.14 |
| H-11-2 | 24.288 | 2.402 | 9.9 | 2.78 | 0.02 |
| H-11-2F | 25.201 | 2.621 | 10.4 | 2.81 | 0.04 |
| H-11B3-1 | 24.885 | 6.841 | 27.5 | 2.84 | 4.60 |
| H-11B3-1F | 25.152 | 5.609 | 22.3 | 2.84 | 1.60 |
| H-11B3-2 | 24.936 | 2.474 | 9.9 | 2.84 | 0.05 |
| H-11B3-2F | 25.201 | 3.100 | 12.3 | 2.83 | 0.33 |
| H-11B3-4 | 24.949 | 3.903 | 15.6 | 2.83 | 0.27 |
| H-11B3-4F | 25.191 | 5.643 | 22.4 | 2.83 | 8.00 |
| H-12-2F | 25.191 | 3.401 | 13.5 | 2.82 | 58.00 |
| W-12-1B | 23.488 | 2.727 | 11.6 | 2.79 | 0.17 |
| W-12-2B | 24.424 | 2.834 | 11.6 | 2.82 | 0.96 |
| W-13-1 | 25.676 | 3.678 | 14.3 | 2.83 | 6.00 |
| W-13-2 | 24.999 | 5.487 | 21.9 | 2.84 | 3.50 |
| W-13-2F | 25.191 | 6.550 | 26.0 | 2.84 | 4.60 |
| W-13-3A | 24.823 | 4.140 | 16.7 | 2.83 | 3.60 |
| W-26-1 | 25.050 | 3.095 | 12.4 | 2.82 | 0.04 |
| W-26-1F | 25.191 | 2.821 | 11.2 | 2.81 | 0.04 |
| W-26-3 | 25.766 | 3.295 | 12.8 | 2.82 | 0.05 |
| W-28-1B | 24.999 | 3.254 | 13.0 | 2.83 | 0.05 |
| W-28-3F | 25.191 | 4.509 | 17.9 | 2.83 | 0.41 |
| W-30-3B | 24.974 | 3.472 | 13.9 | 2.79 | 0.55 |
| W-30-3F | 25.191 | 3.753 | 14.9 | 2.80 | 2.50 |
| W-30-4 | 24.936 | 5.586 | 22.4 | 2.83 | 8.30 |

## Table 2

## Summary of Characterization Data
## Whole Core Samples

| Sample I.D. | Bulk Volume (cc) | Pore Volume (cc) | Porosity (%) | Grain Density (gm/cc) | Permeability (md) | | |
|---|---|---|---|---|---|---|---|
| | | | | | | Horizontal | |
| | | | | | Vertical | 0 | +90 |
| H11-1 | 219.33 | 33.99 | 15.5 | 2.83 | 0.14 | 0.05 | 0.05 |
| H-7B2-2 | 231.46 | 27.26 | 11.8 | 2.83 | 0.25 | 0.10 | 0.09 |
| H-11B3-3 | 256.29 | 33.32 | 13.0 | 2.84 | 2.47 | 5.88 | 0.06 |
| H-5B1-3 | 469.03 | 62.35 | 13.3 | 2.82 | 0.08 | 0.22 | 0.27 |
| H-10B-3 | 398.38 | 44.70 | 11.2 | 2.80 | 0.21 | 0.62 | 0.44 |
| W-25-1 | 260.70 | 29.92 | 11.5 | 2.80 | 0.19 | 367.62 | 0.11 |
| W-26-2 | 625.21 | 78.68 | 12.6 | 2.82 | 52.06 | 29.01 | 0.07 |
| W-28-2 | 466.14 | 87.21 | 18.7 | 2.81 | 2.06 | 3.61 | 3.36 |
| W-28-3 | 546.78 | 92.78 | 17.0 | 2.83 | 0.27 | 0.30 | 0.31 |
| W-30-1 | 626.85 | 80.52 | 12.8 | 2.83 | 0.47 | 79.16 | 9.30 |
| W-30-2 | 469.64 | 70.66 | 15.0 | 2.83 | 0.32 | 0.40 | 0.20 |
| W-12-3 | 937.92 | 125.31 | 13.4 | 2.82 | 1.65 | 19.32 | 24.21 |

## Table 3

## Summary of Re-Saturation Porosity Comparisons

| Sample I.D. | Saturating Fluid | Helium Porosity | Re-Saturation Porosity |
|---|---|---|---|
| H5B1-1a | Deionized Water | 10.78% | 10.68% |
| H5B1-1b | Formation Brine | 12.45% | 12.07% |

## Table 4

### Summary of Comparison Data for Helium ard Re-Saturation Porosities
### One Inch Diameter Samlpes

| Sample I.D. | Pore Volume<br>Helium (cc) | Pore Volume<br>Re-Saturation (cc) | Porosity<br>Helium (%) | Porosity<br>Re-Saturation (%) | Comments |
|---|---|---|---|---|---|
| AEC-8-1 | 1.986 | 2.142 | 7.9 | 8.6 | None |
| AEC-8-2 | 2.731 | 2.659 | 10.9 | 10.6 | None |
| H2A-1 | 2.594 | 2.528 | 11.6 | 11.3 | Gypsum Dissolution |
| H2B1-1 | 1.939 | 2.084 | 8.2 | 8.8 | Gypsum Dissolution |
| H2B1-3 | 3.615 | 3.717 | 15.3 | 15.8 | None |
| H-5B1-2 | 5.693 | 5.942 | 22.8 | 23.7 | None |
| H-7B1-1 | 5.385 | 4.459 | 17.7 | 18.1 | None |
| H-7B2-1 | 3.479 | 3.567 | 14.4 | 14.8 | None |
| H-7C-1A | 3.134 | 3.226 | 12.5 | 12.9 | None |
| H-10B-2 | 2.879 | 2.933 | 11.5 | 11.7 | None |
| H-11-2 | 2.402 | 2.726 | 9.9 | 11.3 | None |
| H-11B3-1 | 6.841 | 6.844 | 27.5 | 27.5 | None |
| H-11B3-2 | 2.474 | 2.575 | 9.9 | 10.3 | Sample Chipped |
| W-12-2 | 2.834 | 2.916 | 11.6 | 11.9 | Gypsum Dissolution |
| W-13-1 | 3.678 | 3.908 | 14.3 | 15.2 | None |
| W-13-2 | 5.487 | 5.639 | 21.9 | 22.6 | Sample Parted |
| W-26-1 | 3.095 | 3.036 | 12.4 | 12.2 | None |
| W-30-3B | 3.472 | 3.477 | 13.9 | 13.9 | Gypsum Dissolution |

## Table 5

### Summary of Comparison Data for Helium and Re-Saturation Porosities
### Whole Core Samlpes

| Sample I.D. | Pore Volume<br>Helium (cc) | Pore Volume<br>Re-Saturation (cc) | Porosity<br>Helium (%) | Porosity<br>Re-Saturation (%) | Comments |
|---|---|---|---|---|---|
| H-11-1 | 33.99 | 33.77 | 15.5 | 15.3 | None |
| H-7B2-2 | 27.26 | 29.59 | 11.8 | 12.9 | None |
| H-11B3-3 | 33.32 | 32.22 | 13.0 | 12.6 | None |
| W-25-1 | 29.92 | 31.15 | 11.5 | 12.0 | None |
| H-5B1-3 | 62.35 | 59.81 | 13.3 | 12.8 | None |
| H-10B-3 | 44.70 | 42.17 | 11.2 | 10.6 | Gypsum Dissolution |
| W-26-2 | 78 68 | 78.84 | 12.6 | 12.6 | None |
| W-28-2 | 87.21 | 87.55 | 18.7 | 18.8 | Severe Grain Loss |
| W-28-3 | 92.78 | 92.48 | 17.0 | 16.9 | None |
| W-30-1 | 80.52 | 77.49 | 12.8 | 12.4 | Gypsum Dissolution |
| W-30-2 | 70.66 | 71.22 | 15.0 | 15.2 | None |
| W-12-3 | 125.31 | 121.64 | 13.4 | 13.0 | Gypsum Dissolution |

## Table 6

## Summary of Formation Factor Data

| Sample I.D. | Helium Porosity | Formation Factor | Cementation Factor |
|---|---|---|---|
| AEC-8-1F | 12.2 | 90.09 | 2.14 |
| H-2B1-1F | 10.5 | 326.77 | 2.57 |
| H-5B1-2F | 24.8 | 12.20 | 1.79 |
| H-7B1-1F | 14.9 | 73.49 | 2.25 |
| H-7C-1F | 13.8 | 79.61 | 2.21 |
| H-10B-2F | 6.6 | 406.78 | 2.21 |
| H-11-2F | 10.4 | 94.82 | 2.01 |
| H-11B3-1F | 22.3 | 36.35 | 2.39 |
| H-11B3-2F | 12.3 | 101.93 | 2.21 |
| H-11B3-4F | 22.4 | 32.74 | 2.33 |
| W-12-2F | 13.5 | 47.30 | 1.93 |
| W-13-2F | 26.0 | 13.26 | 1.92 |
| W-26-1F | 11.2 | 68.77 | 1.93 |
| W-28-3F | 17.9 | 26.30 | 1.90 |
| W-30-3F | 14.9 | 31.49 | 1.81 |

Rw = 6.9 ohm-cm

## Table 7

## Summary of X-Ray Diffraction Analysis

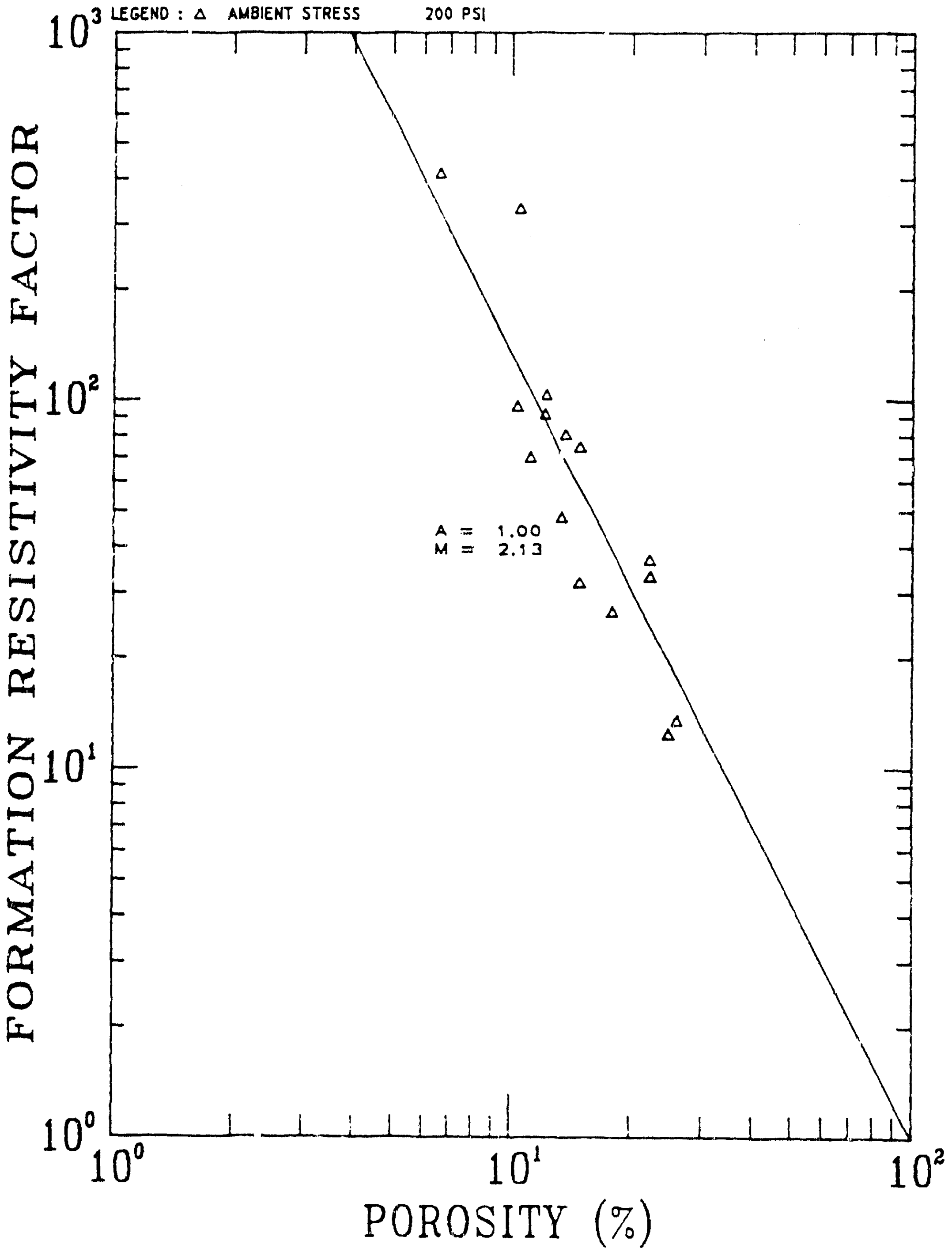
| Sample I.D. | #1 | #2 | #3 |
|---|---|---|---|
| Sample Depth (ft) | 735 | 805 | 723 |
| Calcite | 58 | 1 | 21 |
| Aragonite | 20 |  | 18 |
| Gypsum |  | 1 | 45 |
| Halite | 3 | 98 | 5 |
| Brucite* | 19 |  | 11 |

---

*NOTE: Brucite values shown are residual percentages left over after summing all other phases. No brucite standard; percentages must be considered approximate.

INTERA TECHNOLOGIES
FORMATION:
CULEBRA DOLAMITE
COMPOSTIE
14-APR-88

# FORMATION RESISTIVITY FACTOR VERSUS POROSITY



TERRATEK INC.
420 WAKARA WAY
SALT LAKE CITY
(801) 584-2400

# APPENDIX

# QUALITY CONTROL

## Porosimeter

1. The porosimeter is calibrated at the beginning of each shift or prior to each testing period which ever is applicable.
2. It is calibrated with a steel billet of known volume for repeatability within 1%.

## Bulk Volumes

1. The temperature of the test bath is monitored for correction of fluid density.
2. The scales are calibrated once a month by the Quality Assurance Laboratory which is maintained for government contract work.

## Dry Weights

1. Weight measurements are taken once a day until there is less than a 0.05 gm loss in a 24 hour period.

## Re-saturation Porosity

1. The scales used for wet and bouyant weights are calibrated once a month by the Quality Assurance Laboratory which is maintained for government contract work.
2. The porosity determined by this method is checked against routine helium porosity measurements by porosimeter.

## Permeability

1. The permeameter is checked for leaks by using a steel billet sample and applying a known pressure to the upstream side of the system.
2. The system is calibrated at the beginning of each shift or at the beginning of each test period as is applicable.
3. The system is calibrated using standards of generic rock types. These standards have been used for some time by a number of commercial and research test laboratories. Measured permeabilities must fall within 1% of the pre-determined permeability values of these standards.

## Resistivity Measurements

1. Performance of the system is checked by using a rock standard run with every project.
2. Values are checked against each other as testing progresses for a linear fit.
3. Saturations are checked at the end of the test program by comparing the volume of fluid expelled from the sample against the weight loss.

# QUALITY
# ASSURANCE
# MANUAL

TT-QA (Revision C)
May, 1985

# QUALITY ASSURANCE MANUAL

## Statement of Authority

The purpose of this document is to formalize the quality assurance program instituted by Terra Tek, Inc. The program implements the pertinent requirements described in SI/ASME N45.2-1977 and ANSI/ASME NQA-1-1983 "Quality Assurance Program Requirements for Nuclear Facilities" and addresses the 18 basic requirements contained in Appendix B of the code of Federal Regulations 10CFR Part 50 "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants". When quality assurance requirements are mandated, this Quality Assurance Manual (QAM) shall provide the minimum requirements to be followed in preparing an appropriate Quality Assurance Plan (QAP) for specific programs.

The Quality Assurance Administrator (QAA) has been delegated the authority and responsibility for implementation of the provision of this Quality Assurance Manual and the authority for assuring implementation. Changes to this manual must be documented and approved by the Quality Assurance Administrator.

Bennie G. Di Bona Date May 30, 1985

Bennie G. DiBona
Senior Vice President
Terra Tek, Inc.

**TerraTek**

**QUALITY ASSURANCE MANUAL**

**Title:** TABLE OF CONTENTS

**Section No.** 0 **Revision** C

**Effective Date** 5/85 **Page** 1 **of** 1

**Approved**

**Quality Assurance Administrator**

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| 7 | Control of Purchased Items and Services | C | 05/85 |
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| 11 | Test Control | B | 01/85 |
| 12 | Control of Measuring and Test Equipment | C | 05/85 |
| 13 | Handling, Storage and Shipping | B | 01/85 |
| 14 | Inspection, Test and Operating Status | C | 05/85 |
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| 16 | Corrective Action | C | 05/85 |
| 17 | Quality Assurance Records | C | 05/85 |
| 18 | Audits | C | 05/85 |

**TerraTek**

**QUALITY ASSURANCE MANUAL**

**Title:** ORGANIZATION

**Section No.** 1 **Revision** C

**Effective Date** 5/85 **Page** 1 **of** 6

**Approved**

**Quality Assurance Administrator**

## 1.0 SCOPE

To identify the organizational structures, functional responsibilities, levels of authority, and lines of communication for activities affecting quality assurance.

## 2.0 BASIC REQUIREMENTS

Persons or organizations responsible for assuring that an appropriate quality assurance program is established and verifying that activities affecting quality have been correctly performed shall have sufficient authority, access to work areas, and organizational freedom to: (1) identify quality problems; (2) initiate, recommend or provide solutions to quality problems through designated channels; (3) verify implementation of solutions; and (4) assure that further processing, delivery, installation, or use is controlled until proper disposition of a nonconformance, deficiency or unsatisfactory condition has occurred. Such persons or organization shall have direct access to responsible management at a level where appropriate actions can be effected. Such persons or organizations shall report to a management level such that required authority and organization freedom are provided, including sufficient independence from costs and schedule considerations.

## 3.0 ORGANIZATION STRUCTURES

### 3.1 Company

Terra Tek is a privately owned company with main offices located in Salt

Lake City, Utah. Terra Tek and its divisions specialize in geoscience research and testing.

3.2 Quality Assurance

The Quality Assurance (QA) organization is operated by the Research division of Terra Tek under the direction of the Senior Vice President of the Company and is ultimately responsible for all QA programs throughout the company. The organizational structure of a typical QA program is shown in Exhibit 1-1. The positions of Program Manager, Project Engineer, and Task Manager(s) may be staffed by personnel from other Terra Tek divisions depending on the nature of the program. Furthermore, where feasible, an individual shall be permitted to hold more than one position. The Quality Assurance Plan (QAP) for a specific program shall name the personnel and their position in the organization.

## 4.0 FUNCTIONAL RESPONSIBILITIES AND AUTHORITIES

### 4.1 Director

The director shall provide administrative and contractual support to the Program Manager and the QA staff. Conflicts due to costs, schedules and staffing shall be resolved by the Director.

### 4.2 Quality Assurance Administrator (QAA)

The QAA reports directly to the Senior Vice President of Terra Tek and has the authority necessary to verify and enforce implementation of the QA program.

**TerraTek**

**QUALITY ASSURANCE MANUAL**

**Title:** ORGANIZATION

**Section No.** 1 **Revision** C

**Effective Date** 5/85 **Page** 3 **of** 6

**Approved**

**Quality Assurance Administrator**

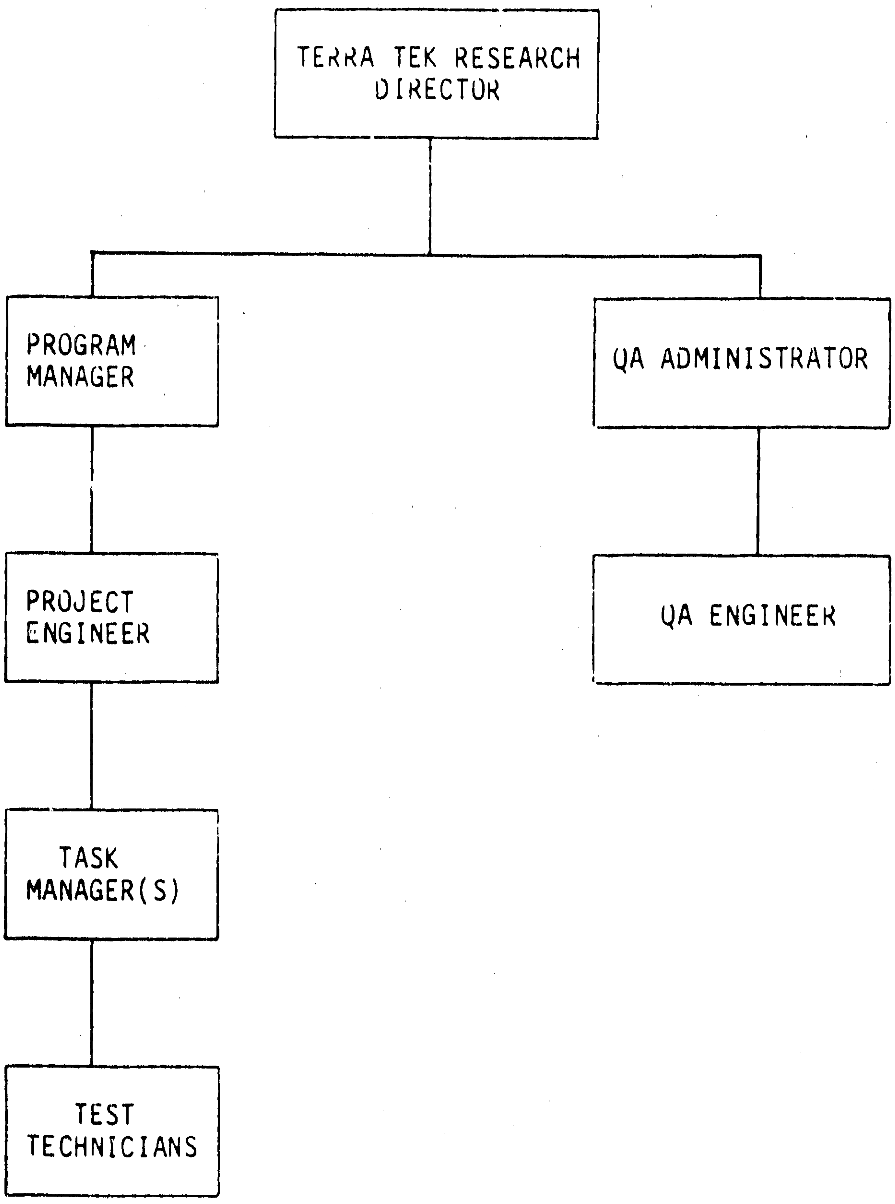

EXHIBIT 1-1

Because of limited personnel and resources, the QAA function is necessarily a part-time one. When conflicts due to schedules or responsibilities arise, the QAA shall be permitted to designate a qualified individual to act on his behalf during his absence. The QAA designee shall report to the QAA and has the authority to enforce the provisions of the QA program.

It shall be the responsibility of the QAA to: (1) review proposals with QA requirements and evaluate related costs, (2) review and approve the QA plan for each program, (3) review and approve changes to the QA Manual and control its distribution, (4) conduct timely audits to verify the implementation and effectiveness of active QA programs, (5) maintain a central QA file, (6) provide guidance to program personnel on QA related administrative and technical matters, and (7) report deficiencies to appropriate program personnel.

The QAA shall have the authority to enforce the provisions of the QA Manual and the QA Plan. Furthermore, the QAA shall have the authority to issue a Stop Work Order to a program which is found to be in gross violation of acceptable QA practices and procedures. Customer requests to stop work being performed by program personnel, or by a program supplier or subcontractor, shall be referred to the QAA for resolution.

### 4.3 Quality Assurance Engineer (QAE)

The QAE shall establish and maintain a system for the calibration of all measuring and test equipment used on QA programs. The system shall conform to the specifications contained in MIL-C-45662A, Calibration Systems Requirements.

The QAE shall maintain a listing of the applicable measurement standards, both reference and transfer, and shall provide nomenclature, identification numbers, and calibration interval and source. The standards shall be traceable to the National Bureau of Standards. The QAE shall insure that measurement and test equipment and measurement standards are calibrated at periodic intervals established on the basis of stability, purpose and degree of usage. Calibration records consisting of certificates, data sheets, reports, and calibration schedules shall be maintained by the QAE for the purpose of verification.

### 4.4 Program Manager (PM)

The PM shall have overall responsibility for: (1) contract negotiations, (2) QA Plan preparation, (3) liaison between the Company the the contracting agency, major suppliers, and Task Managers, and (4) administrative and technical management of the program. The PM shall also perform peer observations periodically to insure program personnel are complying with the provisions of the QAP.

### 4.5 Project Engineer (PE)

The PE shall be responsible for the technical aspects of the program including design, testing, and data reduction and reporting. The PE shall coordinate the efforts of the Task Managers and shall perform peer observations on a regular basis. Technical problems shall be referred to the PE for resolution.

4.6 Task Manager (TM)

The Task Manager(s) shall be responsible for the day-to-day activities of the program and shall insure that test personnel comply with the QA requirements and program technical objectives. The TM shall be responsible for training and certification of test personnel.

| | |
|---|---|
| **TerraTek** | **Section No.** 2 **Revision** C |
| **QUALITY ASSURANCE MANUAL** | **Effective Date** 5/85 **Page** 1 **of** 4 |
| **Title:** QUALITY ASSURANCE PROGRAM | **Approved** <br> **Quality Assurance Administrator** |

1.0 SCOPE

To define the Terra Tek Quality Assurance program and its implementation and application to attendant QA projects.

2.0 BASIC REQUIREMENTS

A documented Quality Assurance program shall be planned, implemented, and maintained in accordance with this manual, or portions thereof. The program shall identify the activities and items to which it applies. The establishment of the program shall include consideration of the technical aspects of the activities affecting quality. The program shall provide control over activities affecting quality to an extent consistent with their importance. The program shall be established at the earliest time consistent with the schedule for accomplishing the activities.

The program shall provide for the planning and accomplishment of activities affecting quality under suitably controlled conditions. Controlled conditions include the use of appropriate equipment, suitable environmental conditions for accomplishing the activity, and assurance that prerequisites for the given activity have been satisfied. The program shall provide for any special controls, processes, test equipment, tools, and skills to attain the required quality and for verification of quality.

The program shall provide for indoctrination and training as necessary, of personnel performing activities affecting quality to assure that suitable proficiency is achieved and maintained.

Management of those organizations implementing the quality assurance program, or portions thereof, shall regularly assess the adequacy of that part of the program for which they are responsible and shall assure its effective implementation.

## 3.0 APPLICATION

Projects which contain QA requirements shall structure their QA programs as described in this Quality Assurance Manual (QAM). This Terra Tek QAM is the top document upon which the individual project Quality Assurance Plans (QAP's) shall be based. In the event an Owner (customer) proposes QA requirements which exceed those contained in this manual, the QA Administrator shall review the proposed program for impact on the Company.

### 3.1 Quality Assurance Plan

A Quality Assurance Plan (QAP) shall be prepared at the onset of a project and prior to initiating technical work. The Program Manager shall have responsibility for the preparation and maintenance of the QAP. The QAP shall be approved by the Director, the QA Administrator, the Program Manager, and the Owner prior to release. The QAP shall be a controlled document.

The purpose of the QAP is to establish the procedures and structures of a project as they relate to quality assurance. As such, the QAP should address the following topics where feasible: 1) sections of the Terra Tek QA Manual invoked (sections 1 and 2 are mandatory); 2) QAP change procedures; 3) technical procedures; 4) special skill, equipment or procedure requirements; 5) the controlled documents list; 6) the project records list; 7) training requirements and schedules, 8) peer observations and audits, and 9) nonconformance reporting. As a minimum, the QAP shall implement those requirements placed on the Company by the Owner.

## 3.2 Training and Qualification

Personnel assigned to the project shall be qualified to perform their related work activity. Qualifications depend on past experience, training, and education. Where feasible, a training program shall be implemented using formal classroom training, on-the-job training, or a combination thereof. The qualifications of personnel should be reviewed yearly and certified in writing. The QAA shall maintain a file of personnel qualifications using Form TTQA-47.

Qualification requirements for project personnel are shown in Exhibit 2-1. These qualifications shall not be mandatory for every QA program, but are presented as a guideline for Program Managers. The QAP shall state the qualification requirements that are in effect for the specific project.

Exhibit 2-1

| Level | Job Title | Qualifications |
|---|---|---|
| I | Lab & Test Technician | Two years of related experience in an equivalent activity; or high school diploma plus six months of related experience; or Associate Degree in related discipline plus three months related experience. |
| II | Task Manager | One year of satisfactory performance as a Level I; or high school diploma plus three years related experience; or Associate Degree in related discipline plus one year of related experience; or four year college degree plus six months of related experience. |
| III | Project Engineer, Program Manager | Six years of satisfactory performance as a Level II; or high school diploma plus ten years of related experience; or Associate Degree in related discipline plus seven years of related experience; or four year college degree in related discipline plus four years of related experience. |

### 3.3 Program Assessment

Project management shall regularly assess the effectiveness of the associated QA program and effect changes as deemed necessary to insure correct and efficient operation.

| | |
|---|---|
| **TerraTek** | **Section No.** 3 **Revision** C |
| **QUALITY ASSURANCE MANUAL** | **Effective Date** 5/85 **Page** 1 **of** 7 |
| **Title:** DESIGN CONTROL | **Approved**<br>**Quality Assurance Administrato** |

## 1.0 SCOPE

To establish procedures for the definition, control and verification of design activities. For geologic investigations, design control encompasses all activities associated with: 1) the design of hardware components and systems, both production and prototypic, 2) experimental testing techniques, and 3) computer codes used for design analysis and data reduction. The intent of design control is to insure that the methodology used to achieve the final design is complete; i.e., that the design base is accurate, the performance and regulatory requirements are achieved, the documentation including codes and standards is correctly stated, interfaces are clearly defined, and approval by responsible personnel is met. The implementation of an approved design through procedures, drawings and specifications is the subject of Section 5, Instructions, Procedures, and Drawings.

## 2.0 BASIC REQUIREMENTS

The design shall be defined, controlled, and verified. Applicable design inputs shall be appropriately specified on a timely basis and correctly translated into design documents. Design interfaces shall be identified and controlled. Design adequacy shall be verified by persons other than those who designed the item. Design changes, including field changes, shall be governed by control measures commensurate with those applied to the original design.

## 3.0 APPLICATION

Originally, design control was written for the construction of nuclear power plants and facilities where safety was a primary concern. As applied to geologic work, design control generally translates to peer review since the more conventional verification/validation methods are not available and the unique application of an established or standard practice is in effect. Peer review is also invaluable when the work goes beyond the state-of-the-art and new or unusual experimental techniques are contemplated. The steps necessary to achieve adequate design control are presented below.

### 3.1 Responsibility

The Project Engineer (PE) shall be responsible for design control. Where a significant design effort is in effect, the PE shall coordinate the design activities of the design team. The PE shall insure that approval and verification criteria are established, implemented, and documented. Approval by the Owner shall be required for designs which compromise or otherwise restrict the application of the final product.

## 4.0 DESIGN INPUT

Applicable design inputs, such as design bases, performance requirements, regulatory requirements, codes, and standards, shall be identified and documented, and their selection reviewed and approved by the responsible design organization. Changes from approved design inputs, including the reason for the changes, shall be identified, approved, documented, and controlled.

## 5.0 DESIGN PROCESS

The responsible design organization shall prescribe and document the design activities on a timely basis and to the level of detail necessary to permit the design process to be carried out in a correct manner, and to permit verification that the design meets requirements. Appropriate quality standards shall be identified and documented, and their selection reviewed and approved. Design methods, materials, parts, equipment, and processes that are essential to the function of the final product, shall be selected and reviewed for suitability of application. The design output documents shall be relatable to the design input by documentation in sufficient detail to permit design verification, and shall identify assemblies and/or components that are part of the item being designed.

### 5.1 Design Analysis

Design analyses shall be performed in a planned, controlled, and documented manner. The design analytical documents shall be sufficiently detailed as to purpose, method, assumptions, design input, references, and units that a person technically qualified in the subject can review and understand the analyses and verify the adequacy of the results. Computer programs may be utilized for design analysis without individual verification of the program if they meet the requirements contained in paragraph 7.

## 6.0 DESIGN VERIFICATION

The approved design shall be verified as to adequacy through the use of design or peer reviews, alternate calculations, or the performance of qualification tests. The design method and results shall be identified and clearly documented. Design verification shall be performed by any competent individual(s) other than those who performed the original design. The extent of the design verification required is a function of the importance to safety of the item under consideration, the complexity of the design, the degree of standardization, the state-of-the-art, and the similarity with previously proven designs. The verification process need not be duplicated for identical designs except where a new application is in effect. Where changes to previously verified designs have been made, design verification shall be required for the changes, including evaluation of the effects of those changes on the overall design. Verification using computer models shall be permitted if they meet the requirements of paragraph 7.

## 7.0 COMPUTER CODES

The use of computer codes for design analysis, verification, data acquisition, and data reduction shall be permitted provided they meet the requirements below. Documentation for computer programs shall include the computer type, program name, revision number, and references to its verification and applicability. Source listings shall be made available to the Owner upon request provided the computer code is nonproprietary.

### 7.1 Design Analysis Programs

Computer programs may be utilized for design analysis without individual verification of the program for each application provided: 1) the computer program has been verified to show that it produces correct solutions for the encoded mathematical model within defined limits for each parameter employed; and 2) the encoded mathematical model has been shown to produce a valid solution to the physical problem associated with the particular application.

### 7.2 Design Verification Programs

Alternate calculations using computer programs shall be permitted as a method of verifying designs. The appropriateness of assumptions, input data, and mathematical model employed shall be documented and subject to review.

### 7.3 Data Acquisition Programs

Computer programs may be utilized to acquire data from test systems provided: 1) they make no irreversible calculations on channel data other than converting to engineering units; 2) the channel calibration data is maintained as part of the output file(s); and 3) pertinent information which would permit identifying the test at a later date is contained in the output file(s).

### 7.4 Data Reduction Programs

Programs used to reduce data shall be permitted provided: 1) the program has been verified to show that it produces correct solutions for the encoded mathematical model within defined limits for each parameter employed; and 2) the encoded mathematical model has been shown to produce a valid solution to the physical problem associated with the particular application. The use of benchmarks, standards, past experience, or a combination thereof shall be sufficient for demonstrating verification and application. Data reduction programs shall be controlled.

## 8.0 CHANGE CONTROL

Changes to final designs, including field changes, shall be justified and subjected to design control measures commensurate with those applied to the original design and approved by the same affected organizations which approved the original design. Where a significant design change is necessary because of an incorrect design, the design process and verification procedure shall be reviewed and modified as necessary.

## 9.0 INTERFACE CONTROL

Design efforts which involve more than one organization shall be coordinated by the Project Engineer. Design interfaces shall be identified and controlled. Interface control shall include assignment of responsibility and the establishment of procedures among participating design organizations for the review, approval, release, distribution, and revision of documents involving design interfaces. Design information transmitted across interfaces shall be documented and controlled. Where it is necessary to initially transmit design information orally or by some other informal means, the transmittal shall be confirmed promptly by a controlled document.

## 10.0 DOCUMENTATION AND RECORDS

Design documentation and records, which provide evidence that the design and design verification processes were performed in accordance with this QA manual and other applicable documents, shall be collected, stored, and maintained by the Program Manager or authorized designee. The documentation shall include not only the final design documents, such as drawings and specifications, and revisions thereto, but also documentation which identifies important steps, including sources of design inputs that support the final design.

**TerraTek**

**QUALITY ASSURANCE MANUAL**

**Title:** PROCUREMENT DOCUMENT CONTROL

**Section No.** 4 **Revision** C

**Effective Date** 5/85 **Page** 1 **of** 3

**Approved**

**Quality Assurance Administrato**

## 1.0 SCOPE

To define the documentation associated with the purchase of goods and services. Externally supplied goods and services are subject to the same quality assurance requirements as the program for which they are intended to be used. The documents authorizing purchase shall explicitly state these requirements where applicable.

## 2.0 BASIC REQUIREMENTS

Applicable design bases and other requirements necessary to assure adequate quality shall be included or referenced in documents for procurement of items and services. To the extent necessary, procurement documents shall require suppliers to have a quality assurance program consistent with the applicable requirements of this manual.

## 3.0 APPLICATION

### 3.1 QA Programs for Suppliers

A formal quality assurance program is not mandatory for all suppliers. In most cases, contractual documents must assure that required quality actions are implemented in compliance with the associated QA program. However, suppliers who furnish a critical component or service shall be required to certify that they have a QA program for the production of the item or service. The extent of the program required shall depend upon the type and use of the item or service being procured.

3.2 Technical Requirements

Where necessary, technical requirements shall be specified in the procurement documents. These requirements shall be specified by reference to specific drawings, specifications, codes, standards, regulations, procedures, or instructions, including revisions thereto that describe the items or services to be furnished. In general, commercial grace and off-the-shelf items are exempt from this requirement; a purchase order specifying part number or other identifying description is sufficient. Examples of the application of technical requirements would be unusual heat treatments, calibration services, exotic alloys, pressure vessels, and testing services.

3.3 Purchaser Inspection

Where technical requirements are in effect, it shall be the responsibility of the purchaser to inspect the furnished item or service for compliance with the QA program. Section 14 of this manual provides amplified instructions for inspection requirements.

3.4 Supplier Documents

Documents to be submitted by the supplier upon task completion shall be specified in the procurement documents. These submitted documents may range from a simple Certificate of Conformance, or Nonconformance, to an extensive history record of the item or service furnished. These documents shall be placed in the project record file and may be subject to the archival requirements as specified in the QA plan.

### 3.5 Change Control

Procurement document changes shall be subject to the same degree of control as utilized in the preparation of the original documents.

## 4.0 RESPONSIBILITY

It shall be the responsibility of the Program Manager (PM), or his designee as documented in the QA plan, for assuring conformance to this basic requirement. The QA Administrator (QAA) shall provide guidance as necessary.

**TerraTek**

**QUALITY ASSURANCE MANUAL**

**Title:** INSTRUCTIONS, PROCEDURES AND DRAWINGS

**Section No.** 5 **Revision** C

**Effective Date** 5/85 **Page** 1 **of** 4

**Approved**

**Quality Assurance Administrator**

## 1.0 SCOPE

To establish provisions for assuring that all activities affecting quality are prescribed by instructions, written procedures, drawings, or otherwise documented.

## 2.0 GENERAL INFORMATION

2.1 Policy with regard to quality is specified in the Statement of Authority for this QAM.

2.2 Quality assurance requirements and the procedural interfaces between organizations affecting quality are specified in the various sections of this QAM.

2.3 A Quality Assurance Plan (QAP) shall be prepared for each individual project, identifying applicable customer requirements, regulations, codes, and standards.

2.4 Instructions for work affecting quality shall provide appropriate acceptance criteria for the determination of accomplishment.

2.5 Instructions, procedures, and drawings shall be prepared, reviewed, and approved as indicated in Exhibit 5-2.

## 3.0 PROCEDURE

### 3.1 Quality Assurance Manual (QAM)

3.1.1 The various sections of the QAM contain the basic specifications of the quality assurance program for the Company. These sections and amendments thereto require approval signature of the QAA.

3.1.2 Requests for changes to the QAM shall be submitted to the QAA on Exhibit 5-1 (Form TT-QA03). If the request is rejected, a completed copy of the form shall be returned to the initiator; if approved, the revision will be implemented as soon as possible.

3.1.3 The QA staff will be responsible for maintenance of the QAM. This includes the following:

a) Distribution of the manuals and amendments.

b) Maintaining a current record of manual holders.

c) The resolution of request for changes.

d) The implementation of amendments resulting from requests, audits, or reviews.

## 3.2 Quality Assurance Plan (QAP)

3.2.1 A QAP shall be generated for each project requiring a formal QA effort. The QAP shall be prepared and approved by the assigned Project Manager (PM) and approved by the QAA. The QAP will contain the following:

a) The identification of appropriate sections of the QAM to be invoked.

b) Specify customer QA requirements not covered in the QAM.

c) Documentation requirements and documentation control procedures for the project.

d) Identification of assigned personnel and definition of responsibilities and authority relating to activities affecting quality of work to be performed on the project.

TT-OA03 (5/85)

Exhibit 5-1
Page 3 of 4

# Q A MANUAL CHANGE REQUEST

FROM:

TO: Quality Assurance Administrator DATE: ____________

It is requested that the following change be made to:

Section No.____________ Rev.______ Page________ Para.__________

REQUEST

Change to read:______________________________

______________________________

______________________________

______________________________

______________________________

Reason for change:______________________________

______________________________

-------CONTINUE ON REVERSE SIDE IF NECESSARY-------

RESPONSE

Disposition:______________________________

______________________________

______________________________

______________________________

______________________________

______________________ ______________________
(Signature) (Date)

Exhibit 5-2
Page 4 of 4
Rev. C

## Document Preparation Guidelines

| Document | QAM Section | Prepared by | Adequacy Reviewed by | Approved by |
|---|---|---|---|---|
| Drawings | 3 | Design Eng. | Draft Review Process | PM |
| Diagrams | 3 | Design Eng. | Draft Review Process | PM |
| Specifications | 3 | Design Eng. | Draft Review Process | PM |
| Test Procedures | 11 | Test Eng. | Eng. Supervisor | PM |
| Change Notice | 3 | Any Resp. Party | PM | PM |
| QAM Changes | 5 | QAS | QAA | QAA |
| QA Plan | 1&5 | PM | QAA | PM |
| Nonconformance Reports | 15 | Any Resp. Party | QAA | QAA/PM |
| Audit Reports | 6 | QAE | QAA | QAA/PM |

PM = Program Manager
QAS = Quality Assurance Staff
QAA = Quality Assurance Administrator
QAE = Quality Assurance Engineer

| | |
|---|---|
| **TerraTek** | **Section No.** 6 **Revision** C |
| **QUALITY ASSURANCE MANUAL** | **Effective Date** 5/85 **Page** 1 **of** 3 |
| **Title:** DOCUMENT CONTROL | **Approved** **Quality Assurance Administrator** |

## 1.0 SCOPE

To define controlled documents and establish procedures for document control. The basic intent of document control is to insure that activities affecting the quality of the final product are performed in an approved manner. This is accomplished by generating procedures or other quality affecting documents which are jointly approved by authorized individuals representing the concerned organizations. The approved documents then are released in a controlled fashion to the personnel performing the associated activity. Changes to the controlled documents are handled in a similar manner.

## 2.0 BASIC REQUIREMENT

The preparation, issue, and change of documents that specify quality requirements or prescribe activities affecting quality shall be controlled to assure that correct documents are being employed. Such documents, including changes thereto, shall be reviewed for adequacy and approved for release by authorized personnel.

## 3.0 APPLICATION

A controlled document is a document which defines procedures, specifies requirements, or releases data outside the Company. A controlled document has a unique control number and a distribution list. Examples of controlled documents are the Quality Assurance Manual (QAM), the Quality Assurance Plan (QAP), computer codes which reduce data, procurement documents, construction/assembly drawings, contracts, and published final reports or interim data released to the Owner. The QAP shall list those controlled documents applicable to the project.

3.1 Preparation

The originator of the controlled document shall be identified and should be proficient and knowledgeable in the subject of interest. A format should be established which is complete and concise. Review of the document by competent, uninterested personnel is desireable.

3.2 Approval

Controlled documents shall be approved by responsible management personnel prior to release. All controlled documents shall be approved by the QAA. Controlled documents particular to a project shall require approval by the Program Manager as well.

3.3 Distribution

A controlled distribution shall be established to assure that those personnel requiring the documents will have them where they need them and that all copies are updated when changes are made. The QAA shall be responsible for issuing a control number and for maintaining the control log. The Program Manager shall be responsible for determining the distribution list for project related documents. The control log and a copy of each controlled document shall be kept in the central QA file.

## 3.4 Changes

Changes to documents, other than those defined as minor changes in 3.4.1 below, are considered as major changes and shall be reviewed and approved by the same organizations that performed the original review and approval unless other organizations are specifically designated. The reviewing organization shall have access to pertinent background data or information upon which to base their approval.

### 3.4.1 Minor Changes

Minor changes to documents, such as inconsequential editorial corrections, shall not require that the revised documents receive the same review and approval as the original documents. To avoid a possible omission of a required review, all suspected minor changes shall be approved by the QAA.

**TerraTek**

**QUALITY ASSURANCE MANUAL**

**Title:** CONTROL OF PURCHASED ITEMS AND SERVICES

**Section No.** 7 **Revision** C

**Effective Date** 5/85 **Page** 1 **of** [illegible]

**Approved**

**Quality Assurance Administrator**

## 1.0 SCOPE

To define the procurement activities associated with the purchase of externally supplied goods and services. Just as procurement documents must be controlled to assure complete and correct requirements for the purchase of items and services (Section 4), so must the procurement process be controlled. All actions associated with procurement shall be documented so that the adequacy of items and services purchased can be verified prior to use, and after use should the necessity arise.

## 2.0 BASIC REQUIREMENTS

The procurement of items and services shall be controlled to assure conformance with specified requirements. Such control shall provide for the following, as appropriate: source evaluation and selection; evaluation of objective evidence of quality furnished by the supplier; source inspection; audit; and examination of items or services upon delivery or completion.

## 3.0 APPLICATION

### 3.1 Procurement Planning

Procurement activities shall be planned and documented to assure a systematic approach to the procurement process. Planning should provide for: 1) procurement document preparation; (2) selection of procurement sources; (3) evaluation and award; (4) purchaser control of supplier performance; (5) verification through surveillance, inspection or audit; (6) control of nonconformance;

(7) corrective action; (8) acceptance of item or service; and (9) quality assurance records.

3.2 Supplier Evaluation and Selection

The selection of suppliers shall be based on evaluation of their capability to provide items or services in accordance with the requirements of the procurement documents prior to contract award or purchase. Evaluation shall be based on: (1) technical considerations; (2) quality assurance requirements; (3) supplier's personnel; (4) supplier's production capability; (5) supplier's past performance; (6) alternates; and (7) exceptions.

3.3 Verification

The extent of verification activities shall be a function of the relative importance, complexity, and quantity of the item or services procured, and the supplier's quality performance. Source surveillance and inspections, audits, receiving inspections, nonconformances, dispositions, waivers, and corrective actions shall be documented. Activities performed to verify conformance to procurement documents shall be recorded. These documents shall be reviewed periodically to assess the effectiveness of the supplier's QA program.

3.4 Acceptance

Prior to offering the item or service for acceptance, the supplier shall verify that the item or service being furnished complies with the procurement regulations. Purchaser methods used to accept an item or related service from a supplier shall be supplier Certificate of Conformance, source verification, receiving inspection, or a combination thereof. In certain cases involving procurement of services only, acceptance shall be by any combination of: (1) technical verification of data produced; (2) surveillance and/or audit of the activity; and (3) review of objective evidence for conformance to the requirements specified in the procurement documents.

3.5 Control of Supplier Nonconformances

In the event an item or service fails to conform to the requirements of the procurement documents for any reason(s), the supplier shall submit a nonconformance report to purchaser. Supplier shall state nature of nonconformance and recommended disposition. Purchaser shall have ultimate control of disposition and verify implementation of disposition on the nonconformance report. The report shall be logged and entered in the project record file.

## 4.0 COMMERICAL GRADE ITEMS

Where the design utilizes commercial grade or off-the-shelf items, the following requirements are an acceptable alternate to other requirements of this section.

a) The commercial grade item is identified in an approved design output document or has independently been verified that it will perform the intended function and will meet design requirements.

b) Supplier evaluation and selection, where determined necessary by the purchaser based on complexity and importance to safety, shall be in accordance with paragraph 3.2 of this section.

c) Commercial grade item shall be identified in the purchase order by the manufacturer's published product description (for example, catalog number).

d) After receipt of a commercial grade item, the purchaser shall determine that: (1) damage was not sustained during shipment; (2) the item received was the item ordered; (3) inspection and/or testing is accomplished, as required by the purchaser, to assure conformance with the manufacturer's published requirements; and (4) documentation, as applicable to the item, was received and is acceptable.

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| **TerraTek** | **Section No.** 8 **Revision** C |
| **QUALITY ASSURANCE MANUAL** | **Effective Date** 5/85 **Page** 1 **of** 2 |
| **Title:** IDENTIFICATION AND CONTROL OF ITEMS | **Approved**<br>**Quality Assurance Administrator** |

## 1.0 SCOPE

To establish procedures to be used to identify and control materials, parts, and components in order to prevent the use of inappropriate or defective items.

## 2.0 GENERAL REQUIREMENTS

### 2.1 Applicability

These procedures apply to all materials received at Terra Tek for the purpose of testing.

### 2.2 Records

Records shall be maintained on material received for the purpose of testing. The record shall contain at least the following information on the material:

a) type

b) origin

c) purpose

d) subdivision or sampling

### 2.3 Identification

All materials received shall be identified in a manner to allow traceability to its origin. This applies to all samples taken for subsequent testing. All samples shall be legibly marked with a unique identification. If the identification interferes with the test to be performed, the sample shall be kept in an appropriate container containing the sample identification, at all times except when the sample is under test.

2.4 Responsibilities

The PM shall be reponsible for the identification and control of all materials and also the appropriate documentation thereof.

**TerraTek**

**QUALITY ASSURANCE MANUAL**

**Title:** CONTROL OF SPECIAL PROCESSES

**Section No.** 9 **Revision** C

**Effective Date** 5/85 **Page** 1 **of** 1

**Approved**

**Quality Assurance Administrator**

## 1.0 SCOPE

To describe the measures for assuring that special processes, such as the selection and preparation of test samples, are controlled and accomplished by qualified personnel.

## 2.0 GENERAL REQUIREMENTS

Special process requirements, control, qualifications and documentation shall be specified in the QAP for each project.

**TerraTek**

**QUALITY ASSURANCE MANUAL**

**Title:** INSPECTION

**Section No.** 10 **Revision** B

**Effective Date** 1/85 **Page** 1 **of** 1

**Approved**

**Quality Assurance Administrator**

To be added at a later date

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| **TerraTek** | **Section No.** 11 **Revision** B |
| **QUALITY ASSURANCE MANUAL** | **Effective Date** 1/85 **Page** 1 **of** 1 |
| **Title:** TEST CONTROL | **Approved**<br>**Quality Assurance Administrato** |

## 1.0 SCOPE

To establish the criterion for control of tests.

## 2.0 GENERAL REQUIREMENTS

### 2.1 Test Procedures

Test procedures shall be prepared by a cognizant engineer reviewed by an Engineer Supervisor and approved by the QAA, and made part of the QAP for each project. The test procedures shall address the following:

a) Objective (anticipated results).

b) Criteria for acceptance/rejection of test results.

c) Calibration requirements.

d) Personnel qualifications.

e) Documentation.

f) Review and certification.

### 2.2 Responsibilities

The assigned Test Group shall be responsible for the validity and documentation of all test procedures and data.

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| **TerraTek** | **Section No.** 12 **Revision** C |
| **QUALITY ASSURANCE MANUAL** | **Effective Date** 5/85 **Page** 1 **of** 1 |
| **Title:** CONTROL OF MEASURING AND TEST EQUIPMENT | **Approved**<br>**Quality Assurance Administrator** |

## 1.0 SCOPE

To describe the methods for control of measuring and test equipment.

## 2.0 MAINTENANCE AND CALIBRATION REQUIREMENTS

2.1 Equipment used to record test data shall be calibrated to manufacturers (or other written) specifications with standards traceable to the National Bureau of standards.

2.2 The calibration status shall be clearly displayed on calibrated item.

2.3 Equipment shall be repaired as necessary to maintain calibration capability.

2.4 The QAE shall establish a recall system to assure that equipment due for calibration is withdrawn from service. This system shall be implemented using a combination of file records and floor spot checks.

2.5 Any item subjected to abusive treatment such as overload, dropped, etc. shall be repaired as necessary and recalibrated.

2.6 The QAE shall maintain a calibration and maintenance record on all equipment.

2.7 A CAR Form TTQA-13 (Exhibit 15-1) shall be completed by the QAE on any failed equipment used to obtain pertinent test data.

**TerraTek**

**QUALITY ASSURANCE MANUAL**

**Title:** HANDLING, STORAGE, AND SHIPPING

**Section No.** 13 **Revision** B

**Effective Date** 1/85 **Page** 1 **of** 1

**Approved**

**Quality Assurance Administrato**

## 1.0 SCOPE

To describe the measures for assuring proper handling, storage, and shipping of materials, supplies, instruments, products, documents, etc. commended to the authority of Terra Tek.

## 2.0 GENERAL REQUIREMENTS

2.1 The QAP for each project shall identify the requirements for handling, storage, and shipping of items related to that project.

2.2 Specification, procedures, or drawings shall be prepared describing special requirements such as cleaning, packaging, preservation, etc.

2.3 Items not covered by special procedures shall be treated in accordance with sound industrial practices for handling, storage, and shipping.

## 3.0 RESPONSIBILITIES

It shall be the responsibility of the PM to insure that special handling, storage, and shipping procedures are documented. The QAA shall initiate audits to insure the documented procedures are adequate and are being executed.

**TerraTek**

**QUALITY ASSURANCE MANUAL**

**Title:** INSPECTION TEST AND OPERATING STATUS

**Section No.** 14 **Revision** C

**Effective Date** 5/85 **Page** 1 **of** 1

**Approved**

**Quality Assurance Administrato**

## 1.0 SCOPE

To specify the measures used to identify inspection, and test status of materials being tested at Terra Tek, Inc.

## 2.0 GENERAL REQUIREMENTS

2.1 Test samples shall be inspected prior to testing to insure that the quality is sufficient for test validation.

2.2 A CAR (see Section 15, Exhibit 15-1) shall be completed on all rejected samples. The rejected sample and CAR shall be conveyed to the QAE.

2.3 The PM (or other technically knowledgeable personnel) shall review all test sample CAR's and make the final decision on the disposition of test samples in question.

2.4 Special requirements for identification of inspection and test status shall be included in the QAP for individual projects, and in general is to be included as part of the test specifications.

## 3.0 RESPONSIBILITIES

3.1 The Task Manager shall be responsible for the generation and implementation of test status procedures for tests performed under his jurisdiction.

3.2 The PM shall review and approve all test status procedures.

3.3 The QAA shall initiate audits to insure adequacy and implementation of all procedures.

**TerraTek**

**QUALITY ASSURANCE MANUAL**

**Title:** NONCONFORMING ITEMS

**Section No.** 15 **Revision** C

**Effective Date** 5/85 **Page** 1 **of** 6

**Approved**

**Quality Assurance Administrator**

## 1.0 SCOPE

To define nonconforming items and to establish procedures for the reporting, control, and disposition of nonconformances.

## 2.0 BASIC REQUIREMENTS

Items that do not conform to specified requirements shall be controlled to prevent inadvertent installation or use. Controls shall provide for identification, documentation, evaluation, segregation when practical, disposition of nonconforming items, and notification to affected organizations.

## 3.0 APPLICATION

In the broadest sense, a nonconformance is a design or implementation discrepancy in an established procedure, specification or part which jeopardizes the quality of the delivered product. For geologic investigations, nonconforming items are defined to include data, samples, geologic environment, and prototypic hardware. Examples of nonconforming items are: use of samples not meeting specified tolerances; test data acquired with a transducer whose calibration date has expired; testing with a controlled parameter at the wrong value; data reduced using nonstandard techniques; and improper documentation. Once a nonconformance is identified, it must be reported to appropriate personnel, controlled by marking and/or segregating, and disposed of in a manner consistent with its impact on the activity.

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| **TerraTek** | **Section No.** 15 **Revision** C |
| **QUALITY ASSURANCE MANUAL** | **Effective Date** 5/85 **Page** 2 **of** 5 |
| **Title:** NONCONFORMING ITEMS | **Approved**<br>**Quality Assurance Administrator** |

## 4.0 REPORTING OF NONCONFORMANCES

### 4.1 Responsibility

It shall be the responsibility of all project personnel to report nonconforming items that are clearly in violation of established procedures or specifications. Most nonconformances are found during the normal performance of work. Other common methods are through audits, surveillances, peer reviews, inspections, statistical trends, and calibration activities.

### 4.2 Procedure

Nonconformances shall be reported by filling out a Nonconformance/Incident and Corrective Action Report (CAR) form TTQA-13 (Exhibit 15-1). The partially completed form shall be submitted to the QA Engineer who logs the CAR and assigns it a number. The QAE in turn submits a copy of the CAR to the associated Program Manager for control and eventual disposition.

## 5.0 CONTROL OF NONCONFORMING ITEMS

Nonconforming items shall be controlled to prevent their inadvertent use in subsequent activities. If use of the nonconforming item is absolutely critical to the program, or if its impact is considered minimal, then use shall be permitted under controlled conditions pending evaluation and final disposition. The QAE shall be responsible for identification and storage of the item until disposition has been determined.

Form TT(QA13) 4/85 Rev B

## NONCONFORMANCE / INCIDENT AND CORRECTIVE ACTION REPORT

TO: ____________________ CAR # __________

FROM: ____________________ Date: __________

Discrepant Condition:

Cause (If known)

____________________
Signature/Position/Date

Corrective Action, including action to prevent recurrence:

____________________
Signature/Position/Date

Comments by QA Representative:

Approved Disapproved

____________________
Signature/Position/Date

5.1 Identification

Identification of nonconforming items shall be by marking, tagging, or other methods which shall not adversely affect the end use of the item. If identification of each nonconforming item is not practical, the container, package or segregated area, as appropriate, shall be identified. The identification should include the associated CAR number.

5.2 Segregation

Nonconforming items shall be segregated, when practical, by placing them in a clearly identified and designated hold area until properly dispositioned. When segregation is impractical or impossible due to physical conditions or access limitations, other precautions shall be employed to preclude inadvertent use of a nonconforming item.

## 6.0 DISPOSITION PROCEDURES

Nonconforming characteristics of the item shall be reviewed and recommended dispositions shall be proposed and approved in accordance with procedures defined below.

6.1 Responsibility

The Program Manager shall have final authority for disposition of nonconforming items. Where significant impact to the program or validity of the data is in question, approval from the Owner shall be required. Final disposition shall be coordinated by the QAA.

### 6.1 Evaluation

Personnel performing evaluations to determine a disposition shall have demonstrated competence in the specific area they are evaluating, have an adequate understanding of the requirements, and have access to pertinent background information. A peer review process shall be used, when justified, to assure technical adequacy of the evaluations.

### 6.2 Final Disposition

The final disposition, such as use-as-is, reject, repair, or rework, of nonconforming items shall be identified on the CAR. The technical justification for the acceptability of a nonconforming item, dispositioned repair/rework, or use-as-is shall be documented on the CAR. The as-built records, if such records are required, shall reflect the accepted deviation.

### 6.3 Repaired or Reworked Items

Repaired or reworked items shall be reexamined in accordance with applicable procedures and with the original acceptance criteria unless the nonconforming item disposition has established alternate criteria.

## 7.0 DOCUMENTATION

Nonconformance documentation shall consist of the completed CAR and log maintained by the QAE. Completed CAR's shall be filed in the central QA file.

**TerraTek**

**QUALITY ASSURANCE MANUAL**

**Title:** CORRECTIVE ACTION

**Section No.** 16 **Revision** C

**Effective Date** 5/85 **Page** 1 **of** 2

**Approved**

**Quality Assurance Administrator**

## 1.0 SCOPE

To specify the requirements and establish Quality Assurance corrective action procedures.

## 2.0 GENERAL REQUIREMENTS

2.1 QA corrective action procedures shall provide:

a) Prompt identification and correction of conditions that may have an adverse effect on quality of services provided by Terra Tek, Inc.

b) Documentation on problem, cause, and action taken.

c) Follow-up measures to assess the effectveness of the corrective action taken.

2.2 The appropriate provisions of Section 15, "Nonconforming Items", and Section 18, "Audits" shall be considered part of the QA corrective action procedures.

2.3 The QAA is responsible for the implementation of QA corrective action procedures, and shall initiate steps necessary to insure their effectiveness.

## 3.0 PROCEDURES

3.1 A Corrective Action Request (CAR, Exhibit 15-1) shall be initiated by any knowledgeable person who recognizes a QA deficiency.

3.2 A "CAR", regardless of origin, shall be submitted to the QAE to be logged and redistributed.

3.3 A "CAR" shall be initiated on any unresolved nonconformance item; refer to

Section 15.

3.4 Customer corrective action requests shall be forwarded to the QAA for investigation, disposition, and reply.

3.5 The QAA shall maintain a log and follow-up status on all active "CAR's".

3.6 QA deficiencies revealed as a result of quality audits shall be resolved in accordance with the provisions of Section 18.

**TerraTek**

**QUALITY ASSURANCE MANUAL**

**Title:** QUALITY ASSURANCE RECORDS

**Section No.** 17 **Revision** C

**Effective Date** 5/85 **Page** 1 **of** 2

**Approved**

**Quality Assurance Administrato**

## 1.0 SCOPE

To establish procedures for generation, review, and approval, control and maintenance of quality assurance records.

## 2.0 GENERAL REQUIREMENTS

2.1 A Project Record List (PRL) shall be prepared for each project and shall be part of the Quality Assurance Plan (QAP) for each project.

2.2 Procedures for generation, review and approval of Records shall be those delineated in Sections 5 and 6.

2.3 A central file facility shall be provided that offers protection against fire and theft.

2.4 All Quality Assurance Records (QA Records) shall be legible, identifiable, and retrievable.

2.5 Test records shall, as a minimum, identify the date, test personnel, results, acceptability, and action taken on noted deficiencies.

2.6 The retention and disposition of QA Records shall be established by the customer. Any and all records listed on the PRL shall be transmitted upon customer's request.

3.0 RESPONSIBILITIES

3.1 The PM shall maintain the project QA records and is responsible for the technical content of documents generated on a project under his control.

3.2 The QAA shall initiate audits to assure that: (a) the QA records are maintained in accordance with written procedures, (b) the procedures are responsive to the customer's QA requirements.

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| **TerraTek** | **Section No.** 18 **Revision** C |
| **QUALITY ASSURANCE MANUAL** | **Effective Date** 5/85 **Page** 1 **of** 2 |
| **Title:** AUDITS | **Approved**<br>**Quality Assurance Administrator** |

## 1.0 SCOPE

To establish auditing procedures to verify compliance and effectiveness of Terra Tek's QAP.

## 2.0 GENERAL REQUIREMENTS

Audits shall be performed to:

a) Provide an objective evaluation of compliance with established requirements, methods, and procedures.

b) Assess progress.

c) Determine adequacy of the QAP.

d) Verify implementation of recommended corrective action.

## 3.0 PROCEDURES

3.1 Audits shall be performed in accordance with written procedures or check lists.

3.2 Audits shall be conducted by the QAA or his designated representative.

3.3 Audit results shall be documented by the auditing personnel.

3.4 Audit reports shall be reviewed by management having responsibility in the area audited.

3.5 An Audit Schedule for each project shall be prepared and maintained by the QAA. The schedule may be periodic and/or keyed to project milestones.

3.6 Unscheduled audits are recommended when:

a) Significant changes are made in the QAP.

b) It is suspected that there is a deficiency in the quality of services being provided.

c) it is considered necessary to verify implementation of recommended corrective actions.

4.0 AUDIT FOLLOW-UP

4.1 An Audit Report shall be prepared and routed to the appropriate management for review.

4.2 A Corrective Action Request (CAR - see Exhibit 15-1) shall be completed on discrepancies revealed as a result of an audit.

# TERMS AND DEFINITIONS

Acceptance Criteria: Specified limits placed on characteristics of an item, process, or service defined in codes, standards, or other requirement documents.

Audit: A planned and documented activity performed to determine by investigation, examination, or evaluation of objective evidence the adequacy of and compliance with established procedures, instructions, drawings, and other applicable documents, and the effectiveness of implementation. An audit should not be confused with surveillance or inspection activities performed for the sole purpose of process control or product acceptance.

Certificate of Conformance: A document signed by an authorized individual certifying the degree to which items or services meet specified requirements.

Certification: The act of determining, verifying, and attesting in writing to the qualifications of personnel, processes, procedures, or items in accordance with specified requirements.

Characteristic: Any property or attribute of an item, process, or service that is distinct, describable, and measurable.

Condition Adverse to Quality: An all inclusive term used in reference to any of the following: failures, malfunctions, deficiencies, defective items, and nonconformances. A significant condition adverse to quality is one which, if uncorrected, could have a serious effect on safety or operability.

Corrective Action: Measures taken to rectify conditions adverse to quality and, where necessary, to preclude repetition.

Design Input: Those criteria, parameters, bases, or other design requirements upon which detailed final design is based.

Design Output: Documents, such as drawings, specifications, and other documents, defining technical requirements of structures, systems, and components.

Design Process: Technical and management processes that commence with identification of design input and that lead to and include the issuance of design output documents.

Deviation: A departure from specified requirements.

Document: Any written or pictorial information describing, defining, specifying, reporting, or certifying activities, requirements, procedures, or results. A document is not considered to be a Quality Assurance Record until it satisfies the definition of a Quality Assurance Record as defined in this Supplement.

External Audit: An audit of those portions of another organization's quality assurance program not under the direct control or within the organizational structure of the auditing organization.

Final Design: Approved design output documents and approved changes thereto.

Guideline: A suggested practice that is not mandatory in programs intended to comply with a standard. The word should denotes a guideline; the word shall denotes a requirement.

Inspector: A person who performs inspection activities to verify conformance to specific requirements.

Inspection: Examination or measurement to verify whether an item or activity conforms to specified requirements.

Internal Audit: An audit of those portions of an organization's quality assurance program retained under its direct control and within its organizational structure.

Item: An all inclusive term used in place of any of the following: appurtenance, assembly, component, equipment, material, module, part, structure, subassembly, subsystem, system, or unit.

Measuring and Test Equipment (M & TE): Devices or systems used to calibrate, measure, gage, test, or inspect in order to control or to acquire data to verify conformance to specified requirements.

Nonconformance: A deficiency in characteristic, documentation, or procedure that renders the quality of an item or activity unacceptable or indeterminate.

Objective Evidence: Any documented statement of fact, other information, or record, either quantitative or qualitative, pertaining to the quality of an item or activity, based on observations, measurements, or tests which can be verified.

Owner: The person, group, company, agency, or corporation who has or will have title to the final product.

Procedure: A document that specifies or describes how an activity is to be performed.

Procurement Document: Purchase requisitions, purchase orders, drawings, contracts, specifications, or instructions used to define requirements for purchase.

Purchaser: The organization responsible for establishment of procurement requirements and for issuance, administration, or both, of procurement documents.

Qualification (Personnel): The characteristics or abilities gained through education, training, or experience, as measured against established requirements, such as standards or tests, that qualify an individual to perform a required function.

Qualified Procedures: An approved procedure that has been demonstrated to meet the specified requirements for its intended purpose.

Quality Assurance (QA): All those planned and systematic actions necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily in service. For geologic investigations, all those planned and systematic actions necessary to provide adequate confidence that data are valid, have integrity, and are preserved and retrievable.

Quality Assurance Record: A completed document that furnishes evidence of the quality of items and/or activities affecting quality.

Receiving: Taking delivery of an item at a designated location.

Repair: The process of restoring a nonconforming characteristic to a condition such that the capability of an item to function reliably and safely is unimpaired, even though that item still does not conform to the original requirement.

Rework: The process by which an item is made to conform to original requirements by completion or correction.

Right of Access: The right of a Purchaser or designated representative to enter the premises of a Supplier for the purpose of inspection, surveillance, or quality assurance audit.

Service: The performance of activities such as design, fabrication, inspection, nondestructive examination, repair, or installation.

Special Process: A process, the results of which are highly dependent on the control of the process or the skill of the operators, or both, and in which the specified quality cannot be readily determined by inspection or test of the product.

Supplier: Any individual or organization who furnishes items or services in accordance with a procurement document. An all inclusive term used in place of any of the following: vendor, seller, contractor, subcontractor, fabricator, consultant, and their subtier levels.

Surveillance: The act of monitoring or observing to verify whether an item or activity conforms to specified requirements.

Testing: An element of verification for the determination of the capability of an item to meet specified requirements by subjecting the item to a set of physical, chemical, environmental, or operating conditions.

Traceability: The ability to trace the history, application, or location of an item and like items or activities by means of recorded identification.

Use-as-is: A disposition permitted for a nonconforming item when it can be established that the item is satisfactory for its intended use.

Verification: The act of reviewing, inspecting, testing, checking, auditing, or otherwise determining and documenting whether items, processes, services, or documents conform to specified requirements.

Waiver: Documented authorization to depart from specified requirements.

# APPENDIX D

# K & A LABORATORIES REPORT

# Intera Technologies, Inc.
# Final Results of High Pressure Mercury Injection Capillary Pressure Tests

**K & A**
LABORATORIES

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2
JUL - 7 [illegible]
(3)
INTERA TECHNOLOGIES

July 5, 1988

Intera Technologies, Inc.
6850 Austin Center Blvd.
Suite 300
Austin, Texas 78731

Attention: Mr. Van Kelley

Re: Revised Final Report:
Mercury Injection Capillary
Pressure Tests
Job Number 88-1056-14

Gentlemen:

This report presents the revised final results of the high pressure mercury injection capillary pressure tests performed on core samples supplied by Intera Technologies, Inc. These tests indicated a final mercury saturation ranging from 66.7 to 100.0 and averaged 95.4 percent pore volume. Although Sample No. 10 showed a lower final mercury saturation, 66.7 percent pore volume, it does correlate to the lower air permeability of the sample. Sample No. 10A, an endpiece of this same sample was also tested. These results showed a higher final mercury saturation of 95.2 percent pore volume, however note that the air permeability in Sample No. 10A is significantly higher than the original test sample. These differences may suggest a heterogeneous distribution of pore throat sizes within this core sample. Final results also yielded a mean pore throat diameter (at 30,000 psi injection pressure) of 0.00717 μm using a air/mercury contact angle of 140°. As requested, pore surface area summmaries (appendix 1), plus additional tabular pore size data (appendix 2) have been included in this report. The test procedures used are described below.

Following trimming of the samples to the required one-inch length, the samples were placed in a vacuum for 24 hours and then stored in a dessicator. Air permeabilities and porosities were then measured on the dried core samples. Mercury was then injected into each sample using pressures that ranged from 0.5 psia to 30,000 psia. Note Sample No. 10A was injected to a pressure of 20,000 psia. Pore throat size histograms were calculated from these results, using the typical contact angle and surface tension for histogram I, and for histogram II, a surface tension of 360 dynes/cm and a contact angle of 180° was used. Capillary pressure relationships were also calculated from these data. Final results are presented in graphical and tabular form.

The conditions under which this report is presented are described immediately following this report. We request that the report be used in its entirety if reproductions are to be made. Please contact us if you have any questions concerning these data, or if we may be of further service.

Respectfully submitted,

K & A LABORATORIES

JMC:ch

K & A Laboratories

## SUMMARY OF HIGH PRESSURE MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

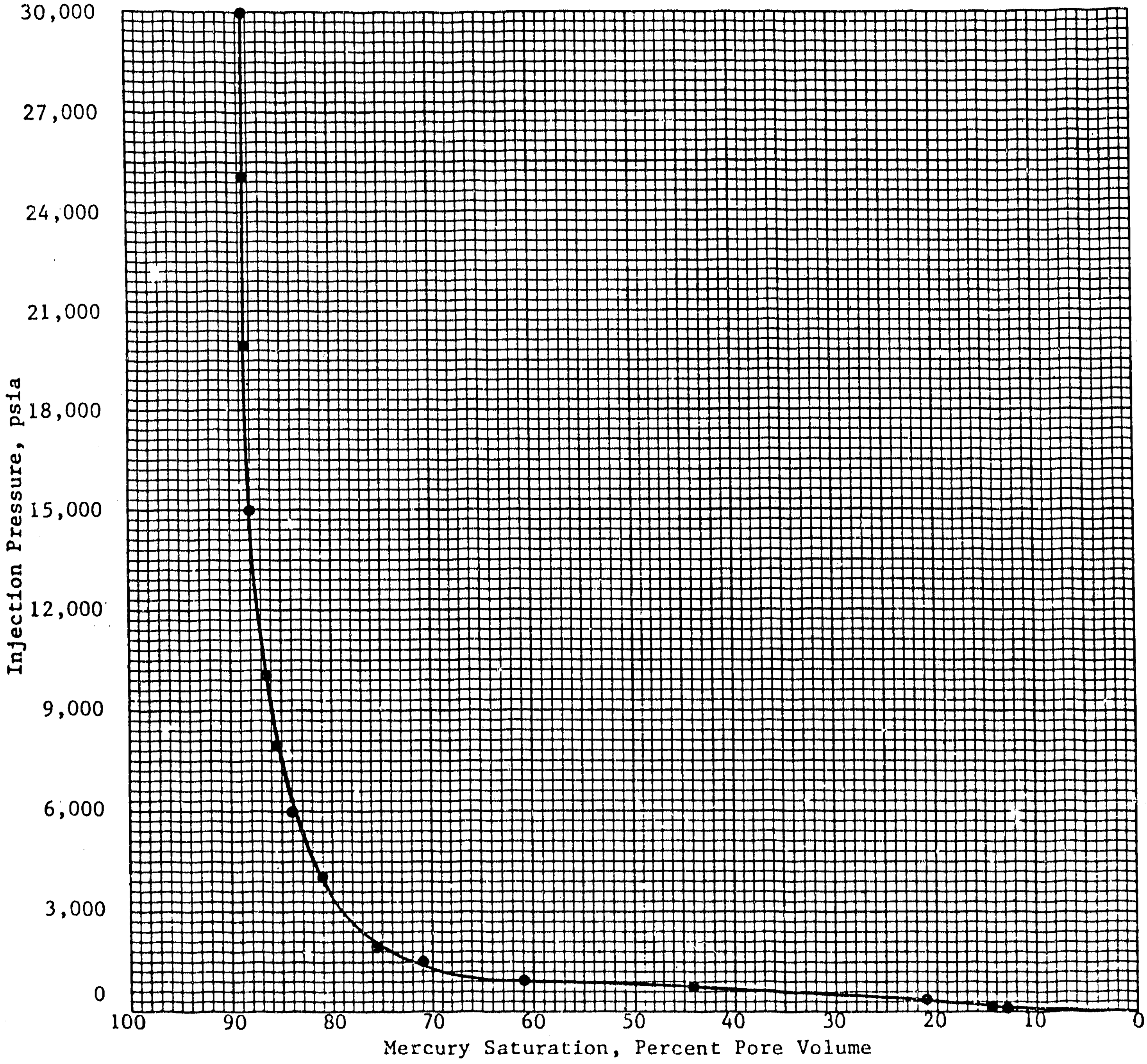
| Sample Number | Identification Number | Porosity, Percent | Air Permeability, md | Endpoint Mercury Saturation @ 30,000 psi, Percent |
|---|---|---|---|---|
| 1 | H2A-2 | 12.5 | 0.143 | 88.5 |
| 2 | H2B1-2 | 14.8 | 1.18 | 99.7 |
| 3 | H5B1-1a | 13.0 | 0.042 | 95.0 |
| 4 | H5B1-1b | 15.5 | 0.069 | 95.3 |
| 5 | H7B1-2a | 21.5 | 0.108 | 91.6 |
| 6 | H7B1-2b | 27.8 | 0.521 | 99.5 |
| 7 | H7B2-1 | 17.3 | 0.294 | 96.5 |
| 8 | H7C-1b | 16.5 | 0.074 | 94.8 |
| 9 | H7C-1a | 13.4 | 0.098 | 98.9 |
| 10 | H10B-1 | 10.8 | 0.012 | 66.7 |
| 10A | H10B-1 | 9.0 | 0.174 | 95.2 |
| 11 | H11-2 | 11.0 | 0.038 | 93.3 |
| 12 | H11B3-1 | 33.1 | 1.33 | 99.9 |
| 13 | H11B3-4 | 14.8 | 0.186 | 99.9 |
| 14 | W-12-1a | 2.8 | 0.270 | 98.2 |
| 15 | W-121b1 | 11.2 | 0.086 | 99.9 |
| 16 | W-12-2 | 13.6 | 1.38 | 99.4 |
| 17 | W-13-3a | 19.0 | 4.94 | 97.5 |
| 18 | W-13-3b | 9.7 | 0.037 | 99.6 |
| 19 | W-26-3 | 12.5 | 0.039 | 99.9 |
| 20 | W-28-1a | 14.2 | 0.033 | 95.3 |
| 21 | W-28-1b | 13.0 | 0.038 | 93.8 |
| 22 | W-30-3a | 17.6 | 9.68 | 99.8 |
| 23 | W-30-3b | 15.8 | 3.48 | 91.6 |
| 24 | W-30-4 | 25.4 | 18.6 | 96.3 |

# MERCURY INJECTION TEST RESULTS

## INTERA TECHNOLOGIES, INC.

## SAMPLE NUMBER 1

Air Permeability = 0.143 md Porosity = 12.5%



**K & A**
LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM

## INTERA TECHNOLOGIES INC.

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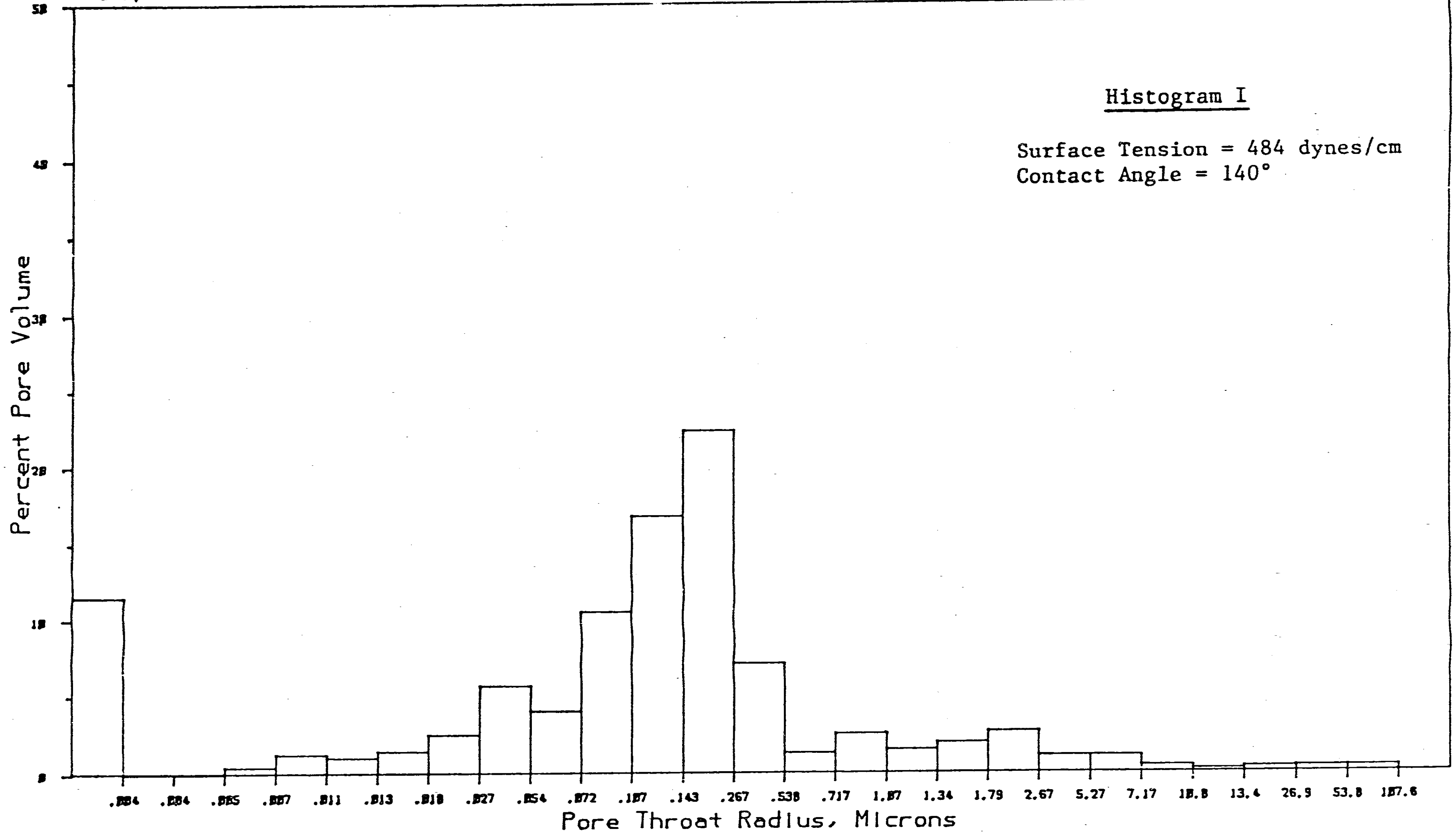
File 88-1056-14

Sample Number 1

Air Permeability = .143 md

Porosity = 12.5%



**K & A**
LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM
## INTERA TECHNOLOGIES INC.

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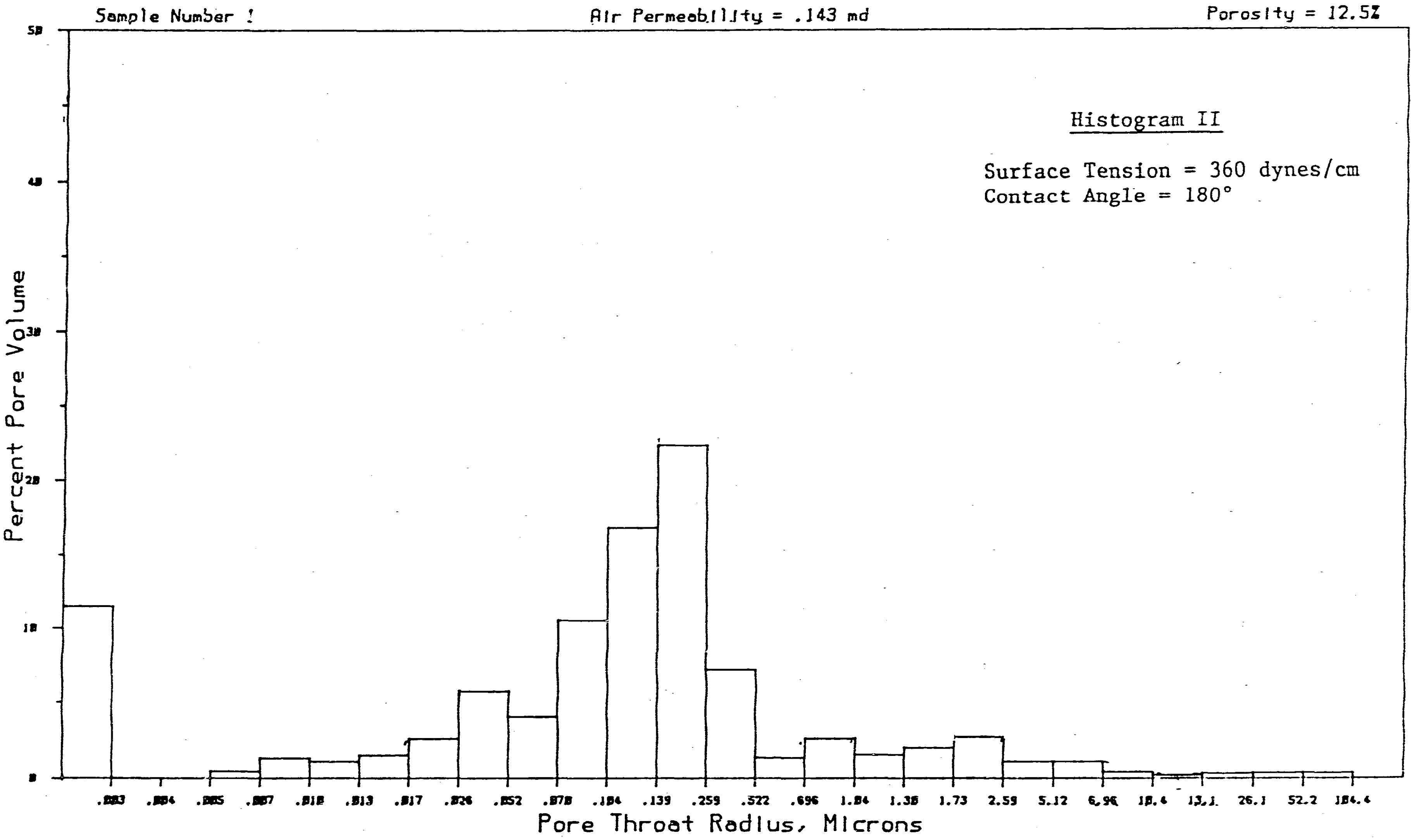
File 88-1056-14

Sample Number 1

Air Permeability = .143 md

Porosity = 12.5%



Histogram II

Surface Tension = 360 dynes/cm
Contact Angle = 180°

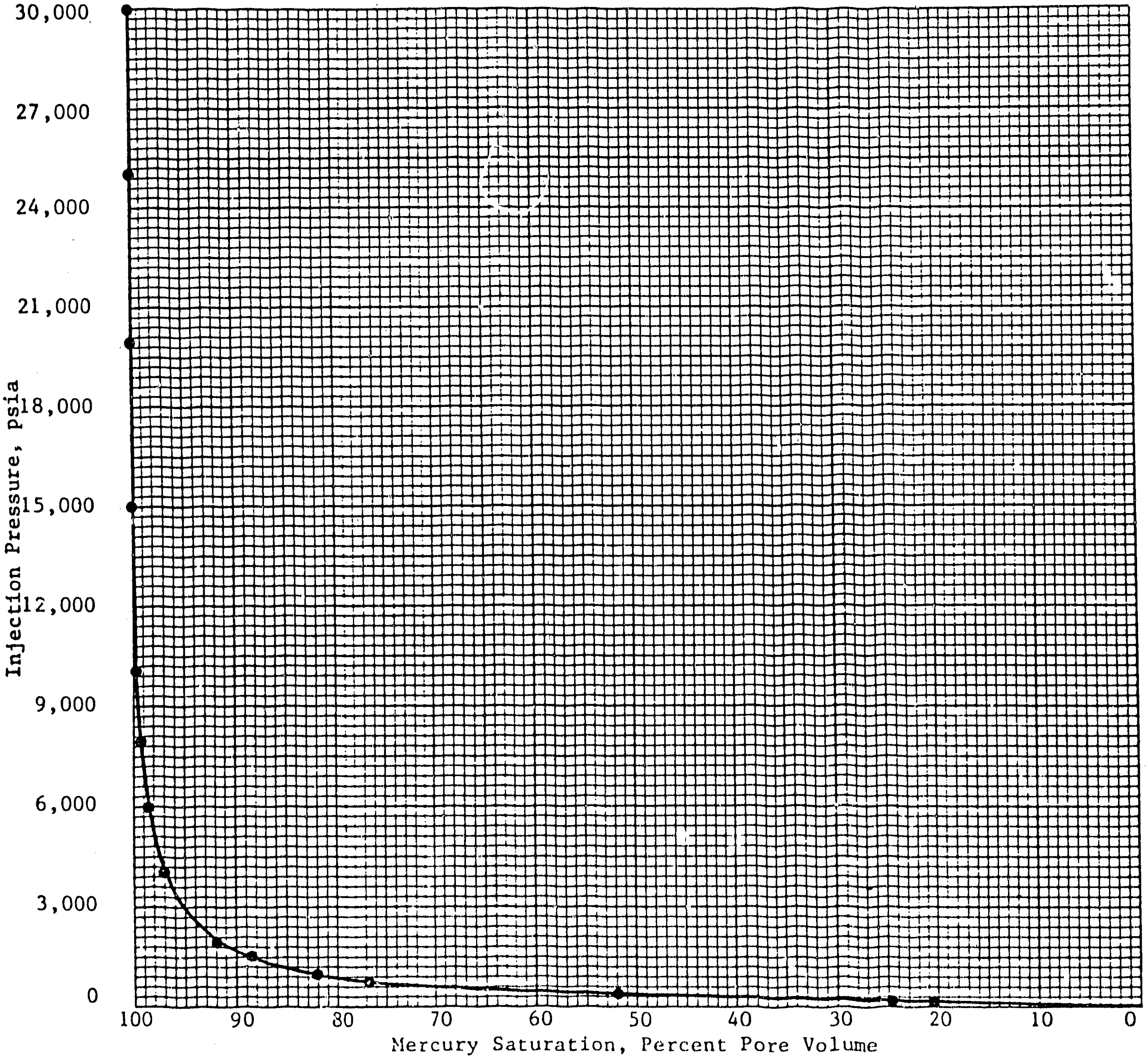
# MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 2

Air Permeability = 1.18 md

Porosity = 14.8%



**K & A**
LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM
INTERA TECHNOLOGIES INC.

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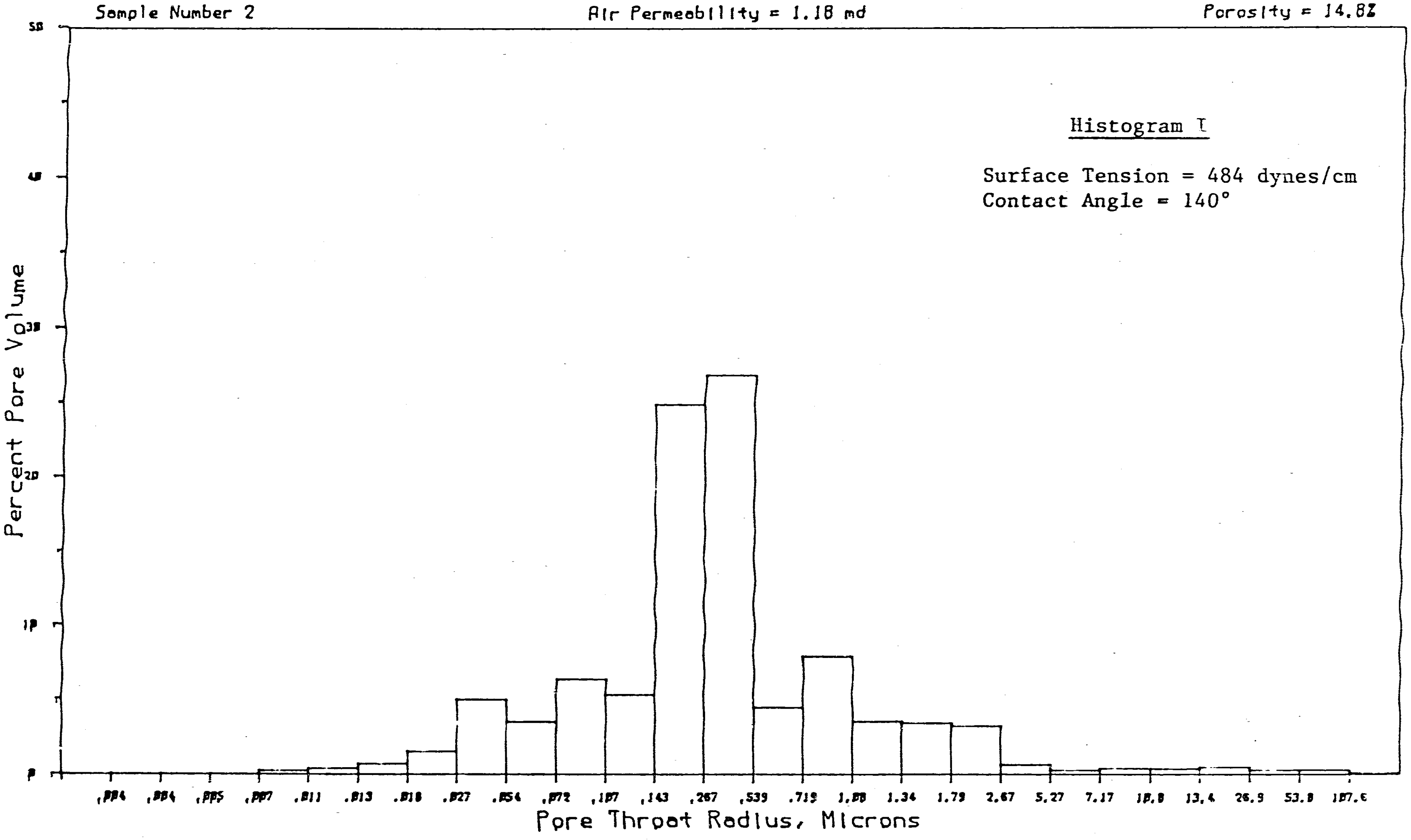

**K & A**
LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM

## INTERA TECHNOLOGIES INC.

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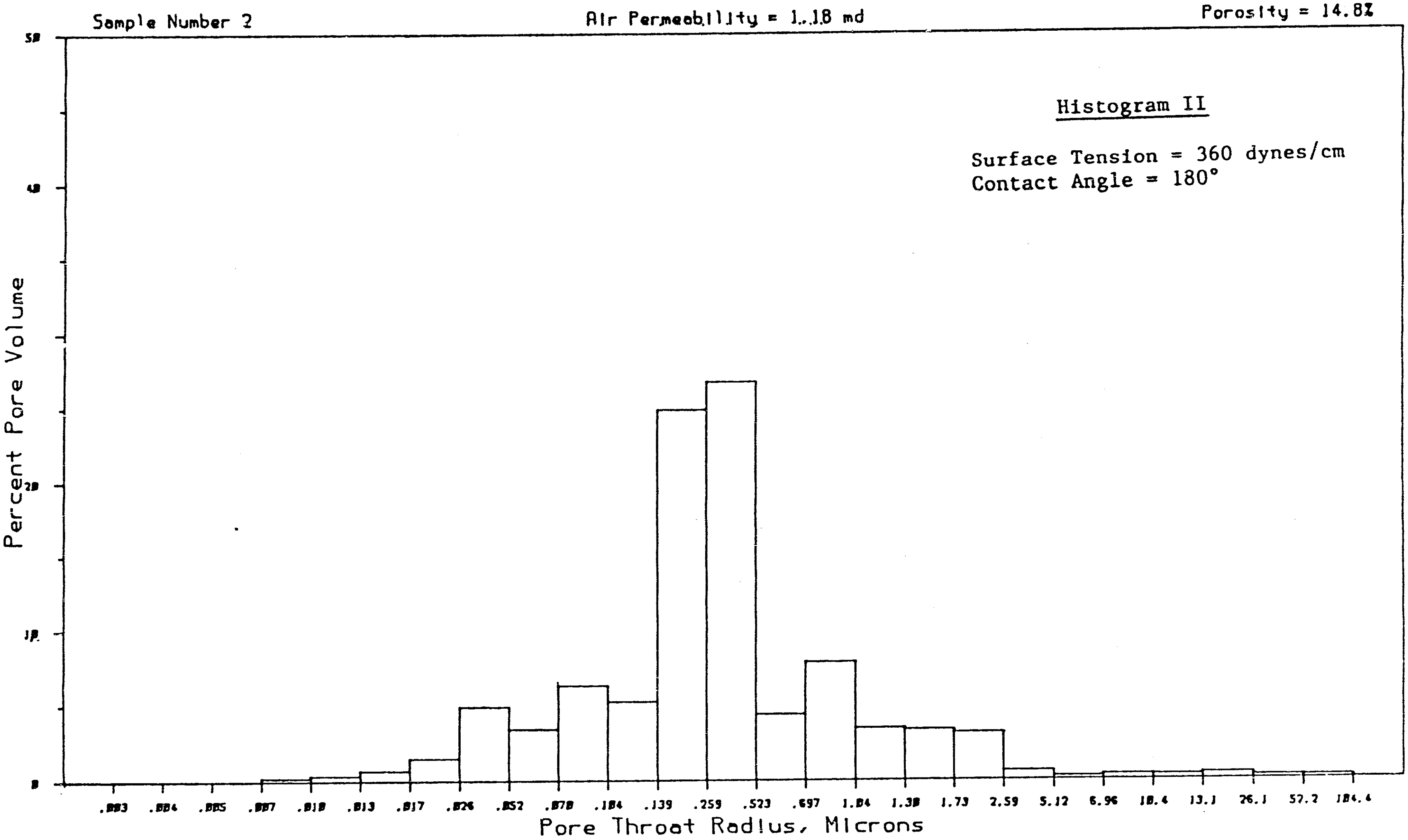
Sample Number 2

Air Permeability = 1.18 md

Porosity = 14.8%



Histogram II

Surface Tension = 360 dynes/cm
Contact Angle = 180°

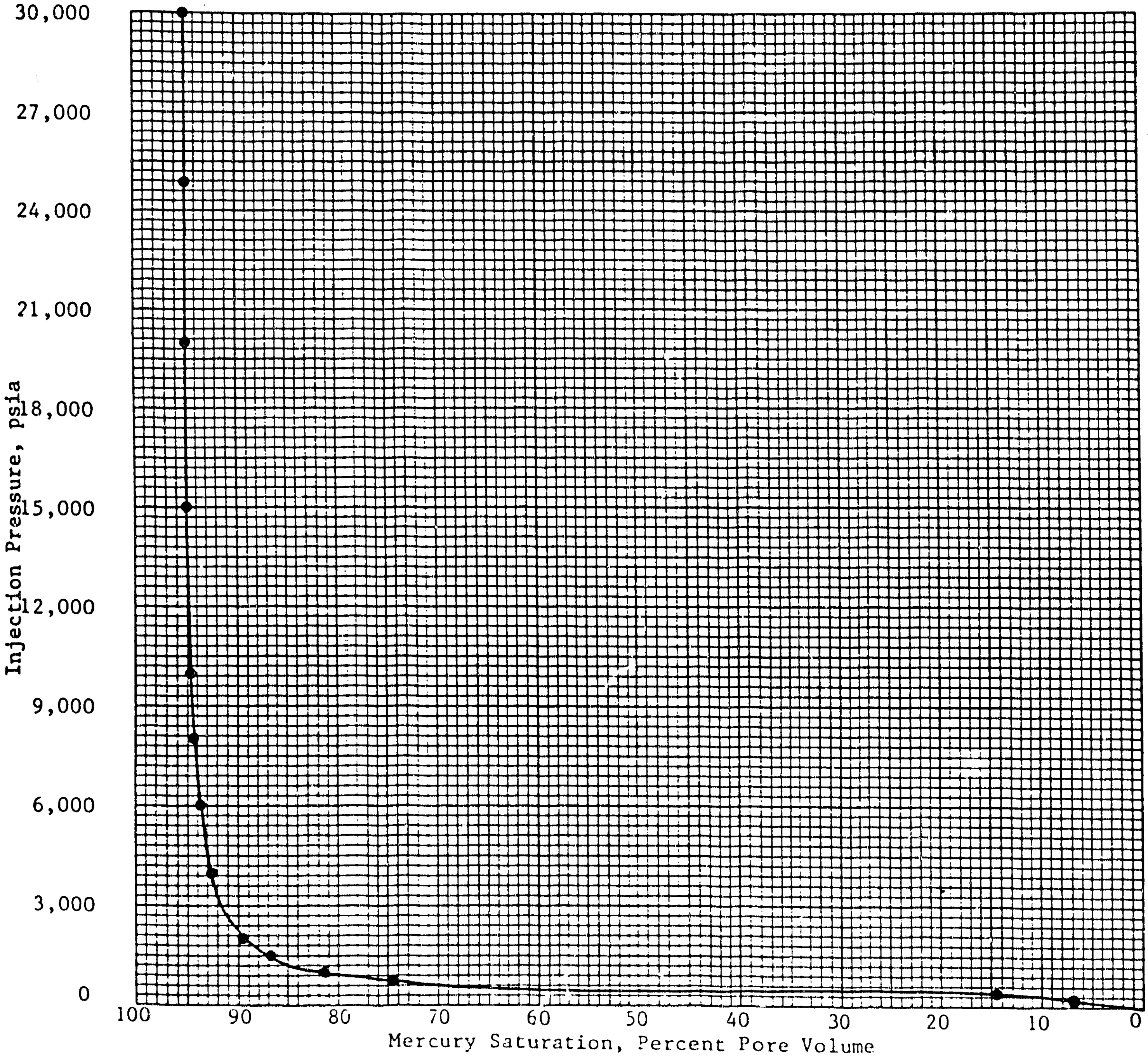
## MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 3

Air Permeability = 0.042 md

Porosity = 13.0%



**K & A**
LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM

## INTERA TECHNOLOGIES INC.

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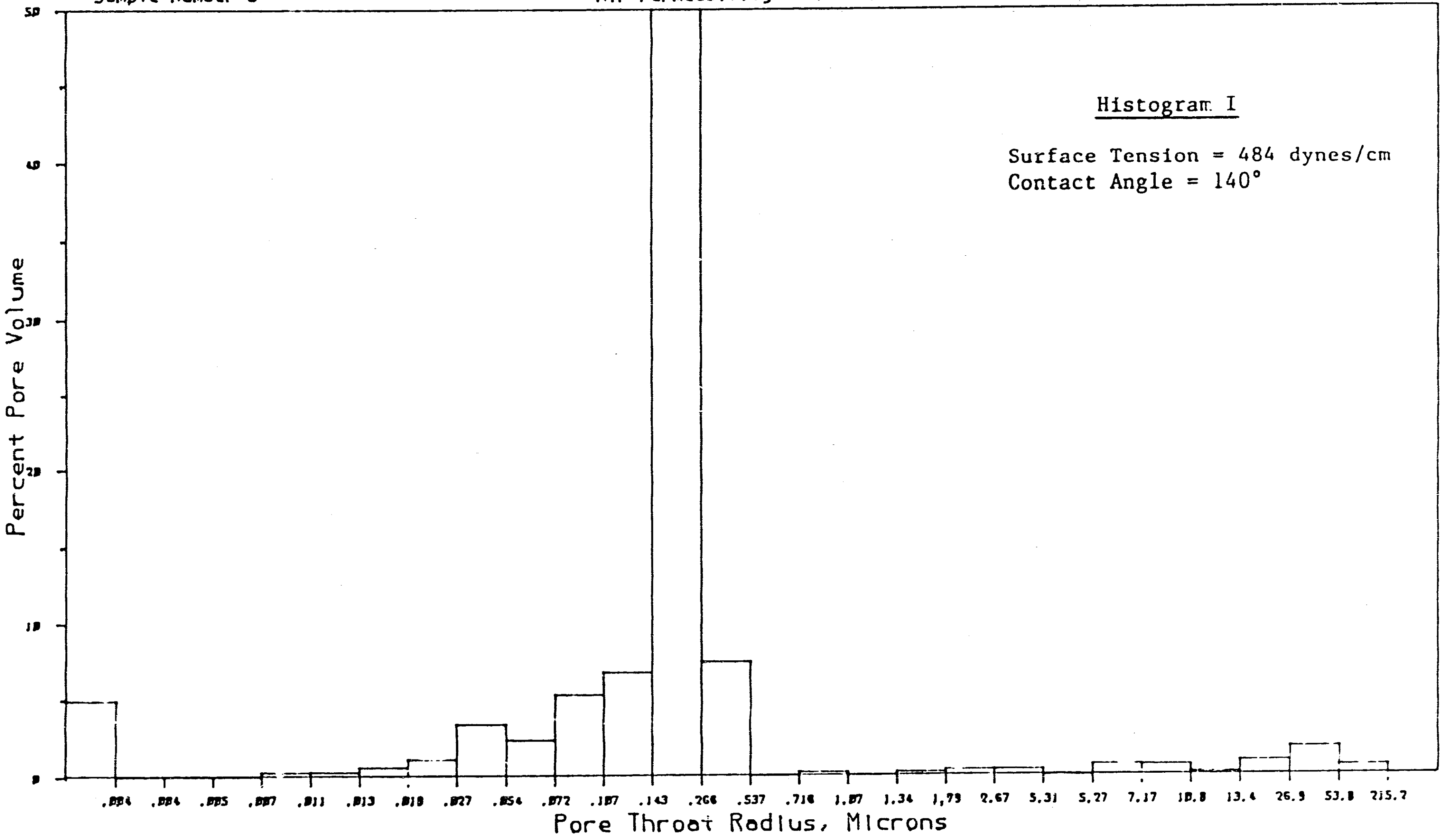
File 88-1056-14

Sample Number 3 Air Permeability = 0.042 md Porosity = 13.0%

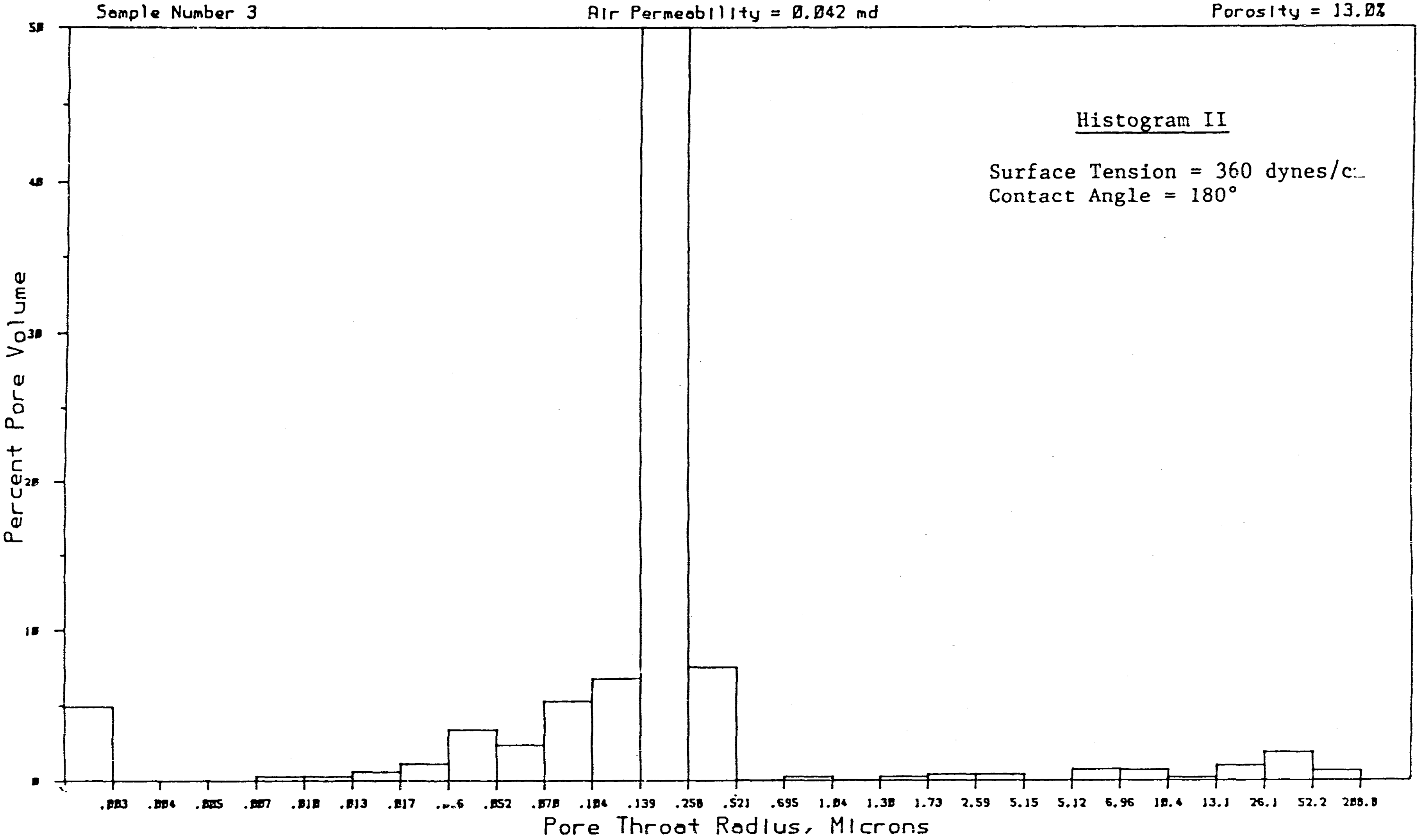


Histogram I

Surface Tension = 484 dynes/cm
Contact Angle = 140°

# COMPUTED PORE SIZE HISTOGRAM

## INTERA TECHNOLOGIES INC.



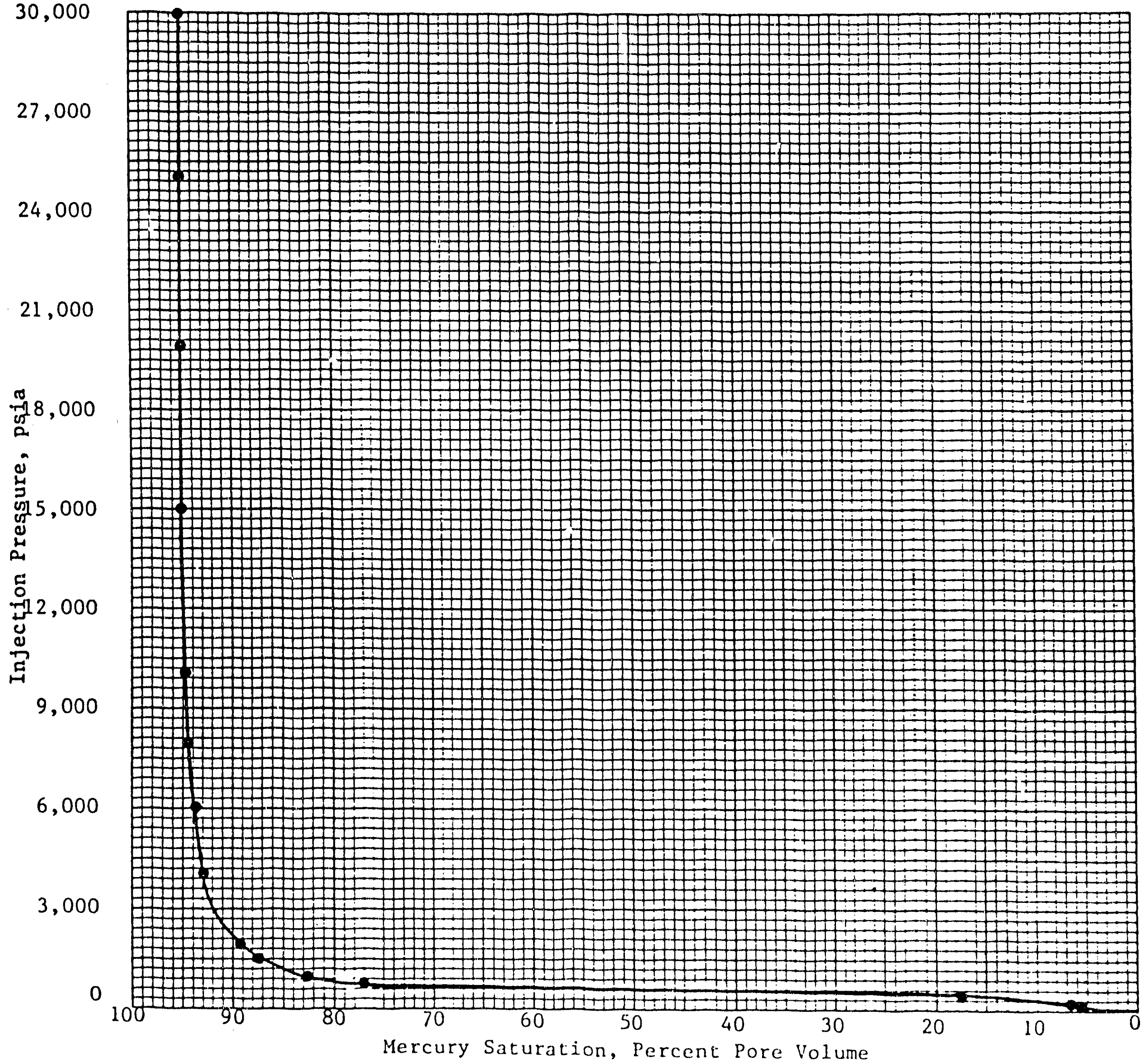
## MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 4

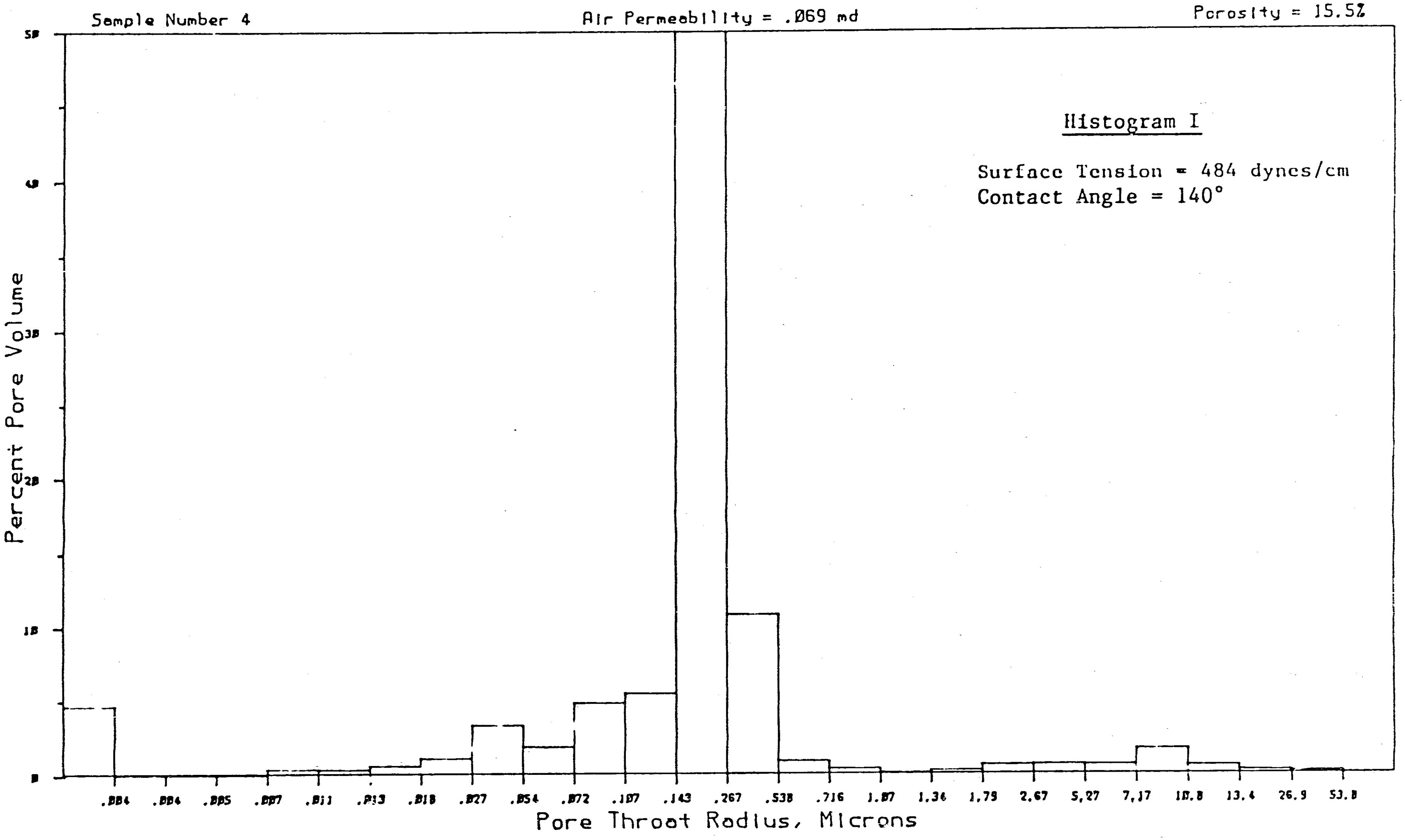
Air Permeability = 0.069 md

Porosity = 15.5%



# COMPUTED PORE SIZE HISTOGRAM

INTERA TECHNOLOGIES INC.



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LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM
INTERA TECHNOLOGIES INC.

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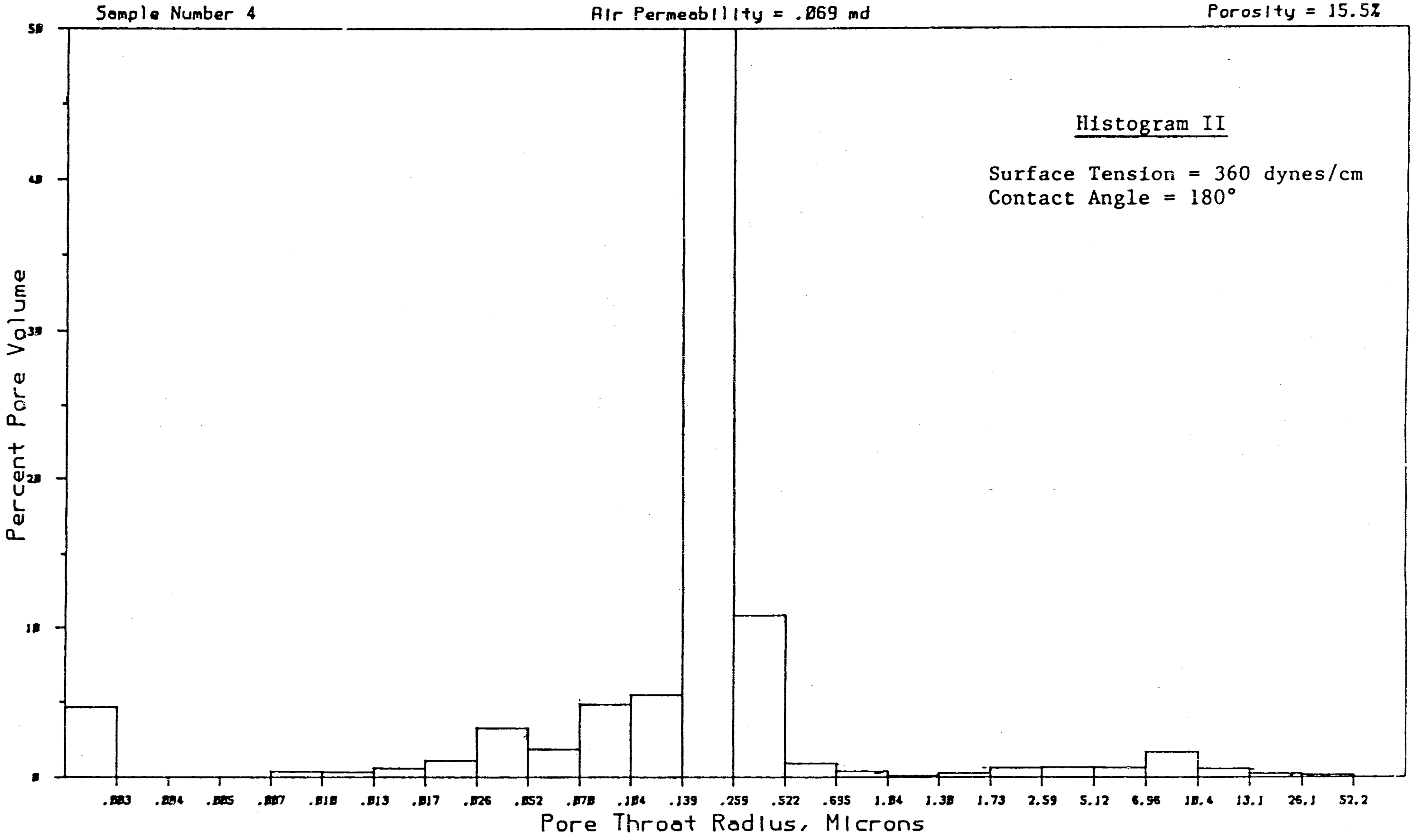


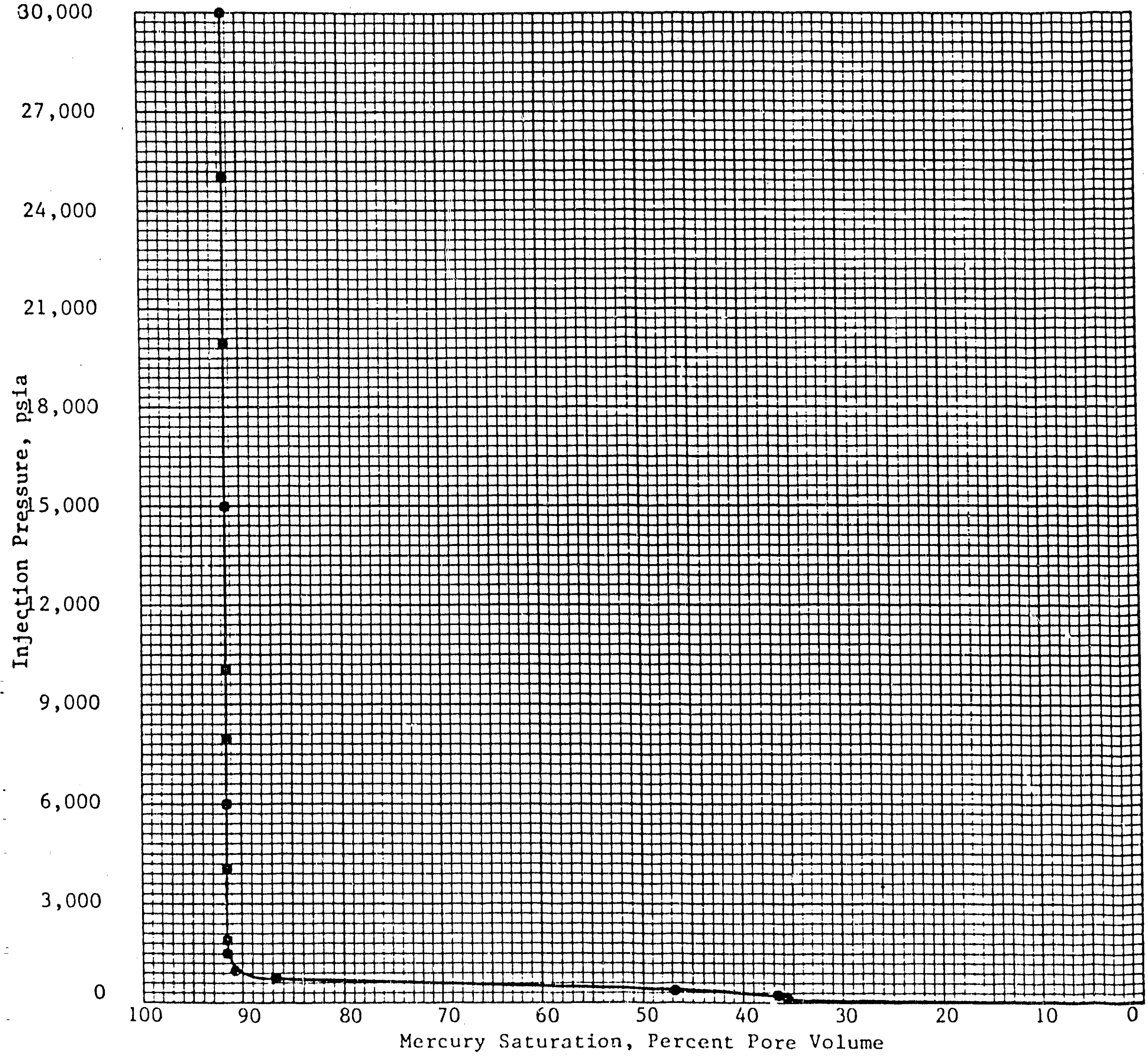
## MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 5

Air Permeability 0.108 md

Porosity = 21.5%



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# COMPUTED PORE SIZE HISTOGRAM

INTERA TECHNOLOGIES INC.

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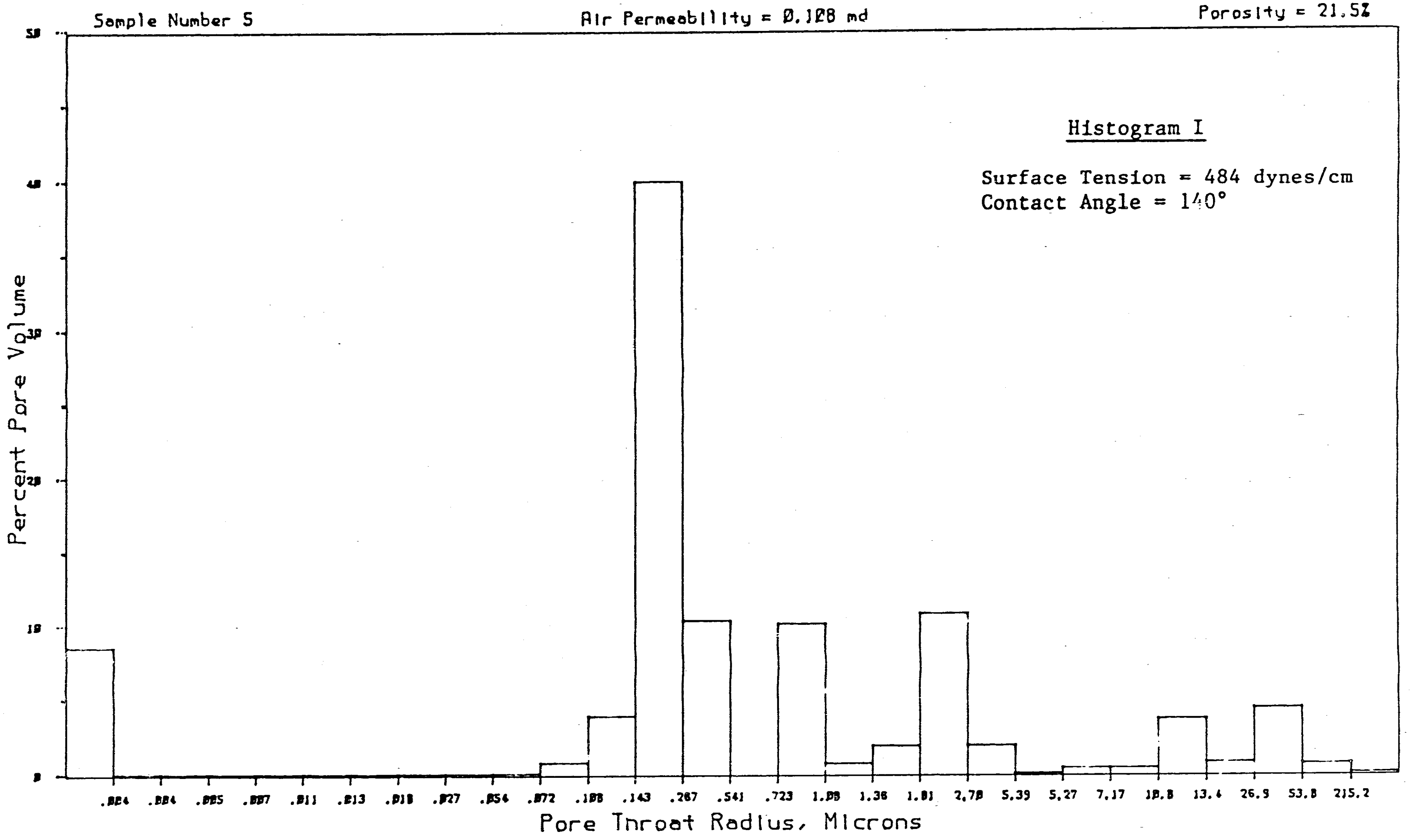
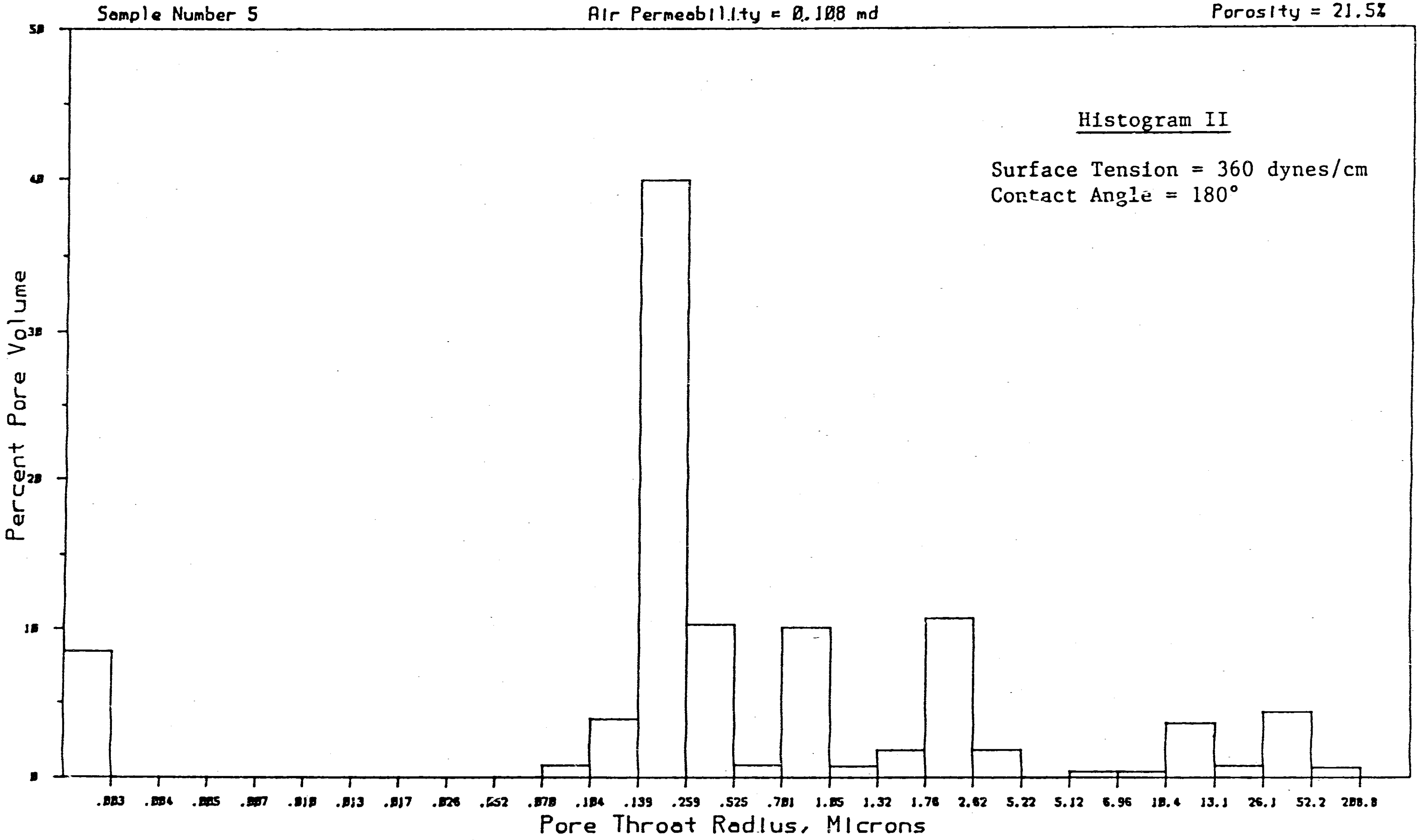
Sample Number 5 Air Permeability = 0.108 md Porosity = 21.5%



# COMPUTED PORE SIZE HISTOGRAM

INTERA TECHNOLOGIES INC.



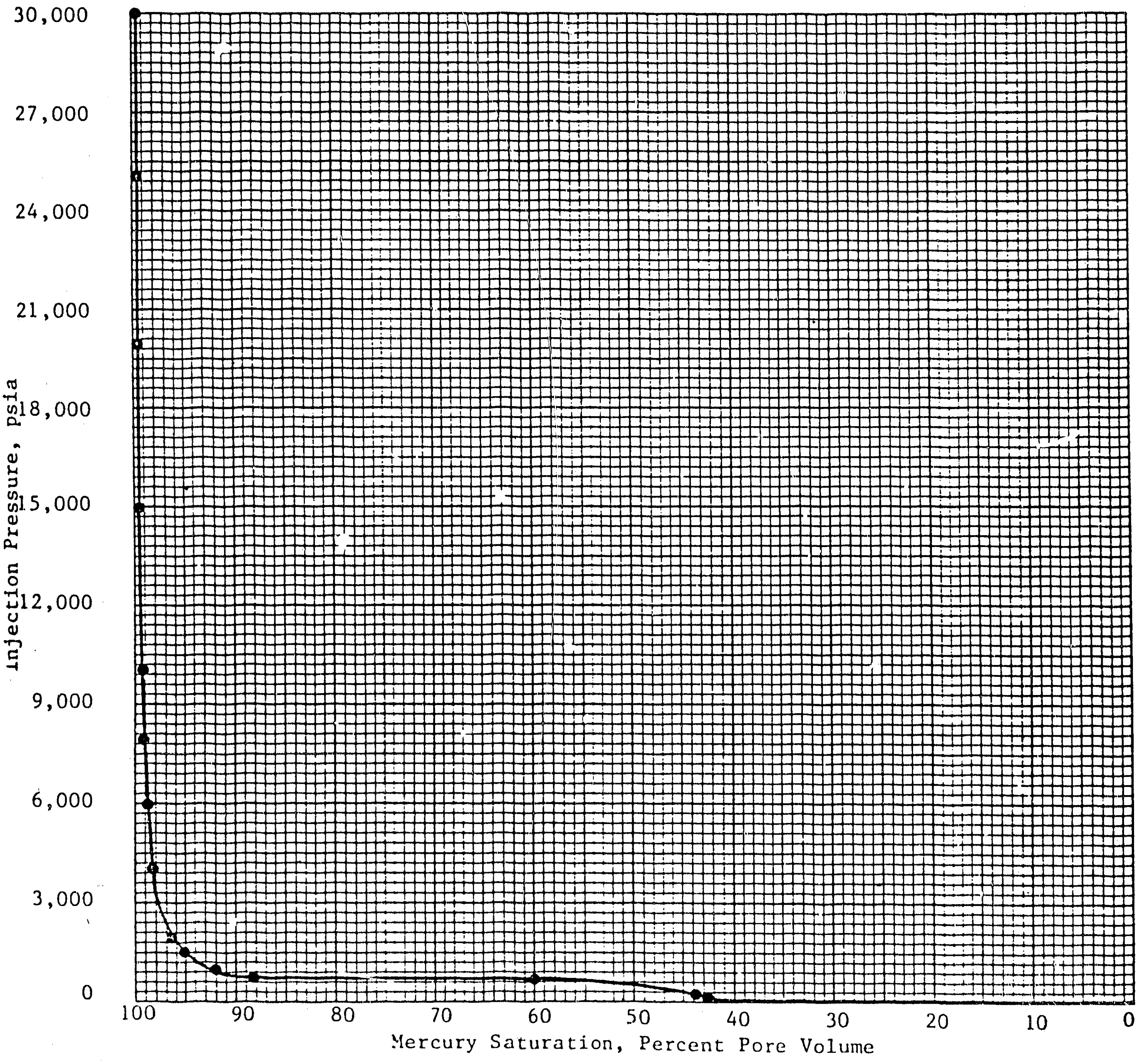
# MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 6

Air Permeability = 0.521 md

Porosity = 27.8%



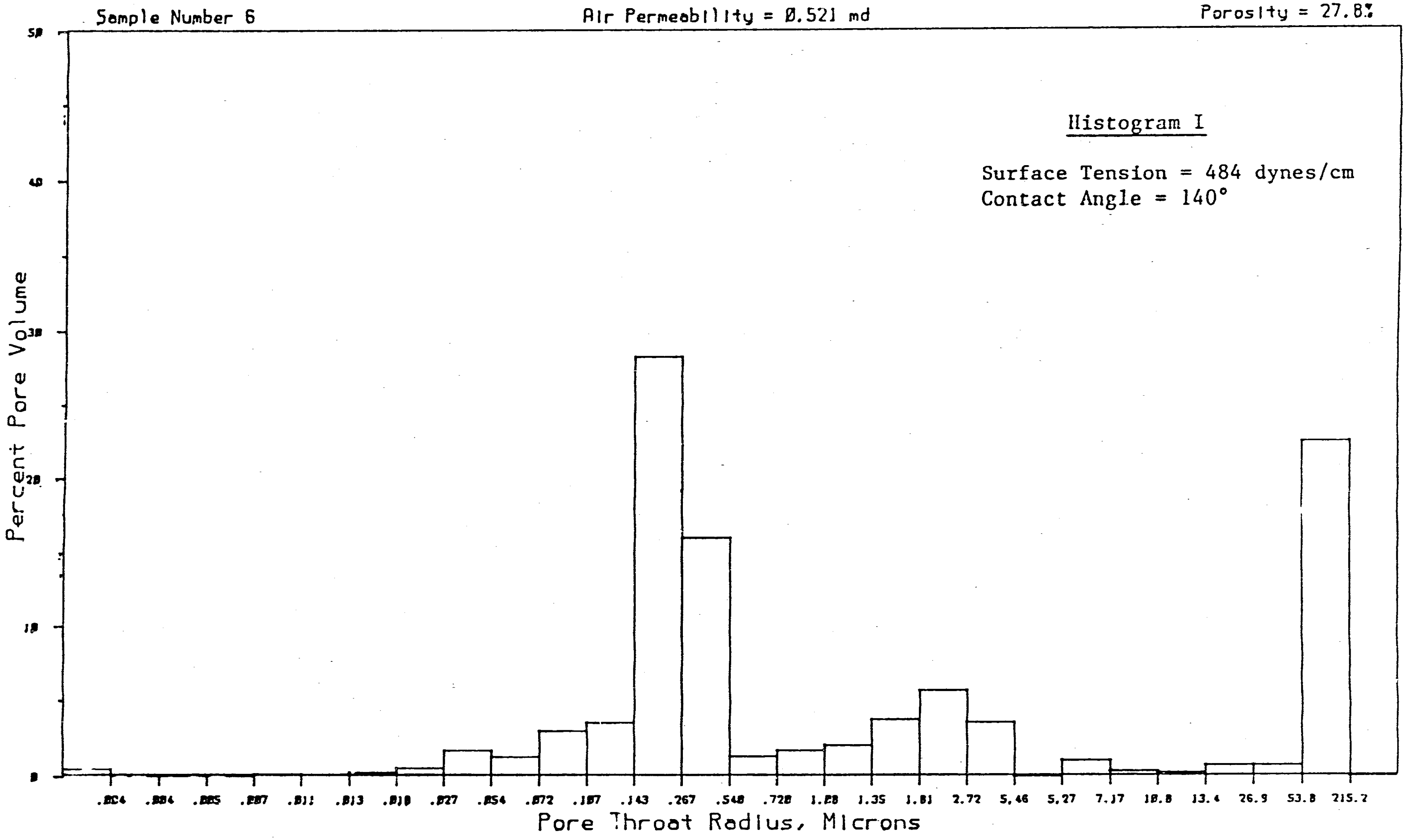
# COMPUTED PORE SIZE HISTOGRAM

INTERA TECHNOLOGIES INC.

Sample Number 6

Air Permeability = 0.521 md

Porosity = 27.8%



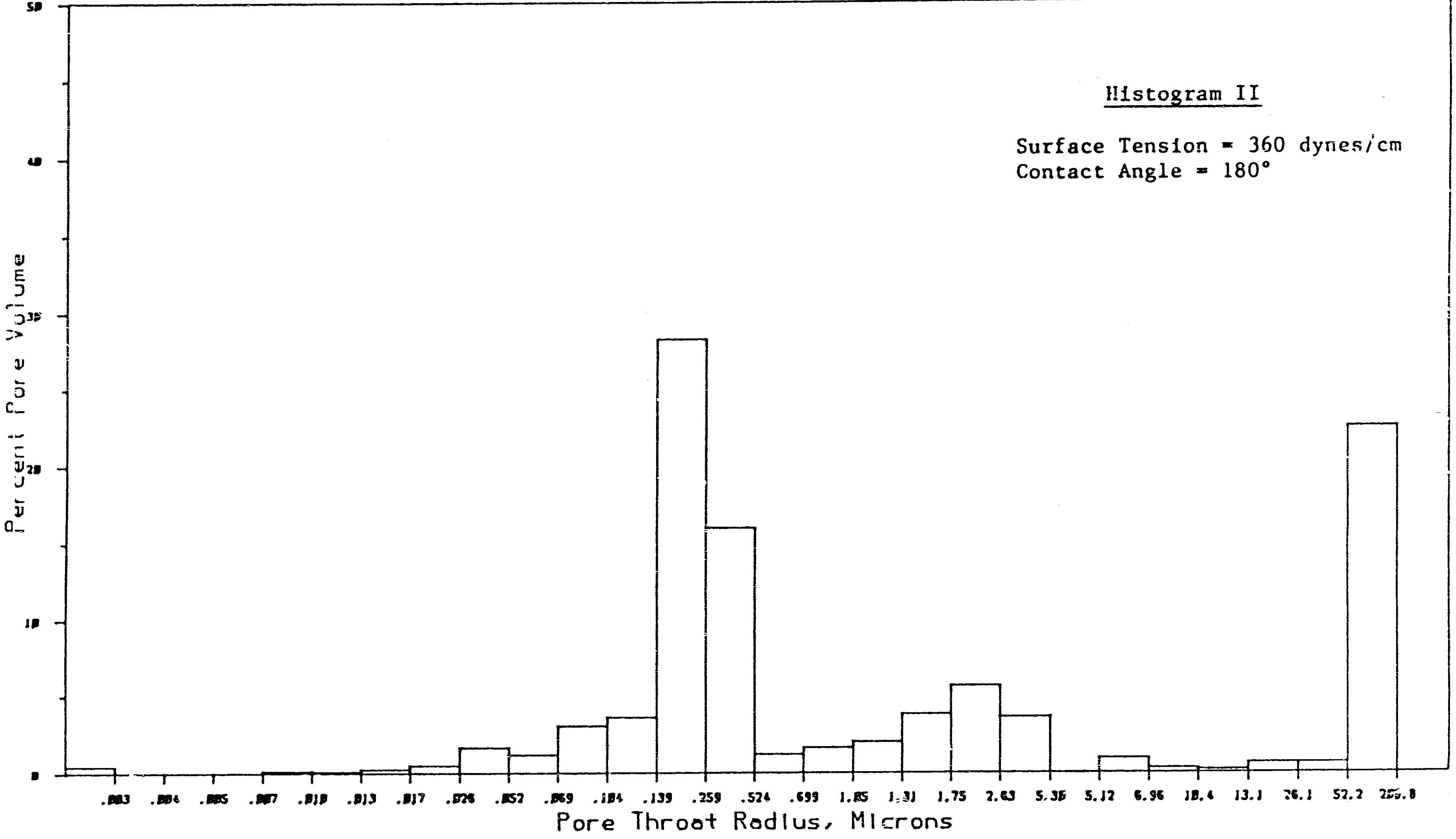
Histogram I

Surface Tension = 484 dynes/cm
Contact Angle = 140°

# COMPUTED PORE SIZE HISTOGRAM

## INTERA TECHNOLOGIES INC.

Sample Number 6 Air Permeability = 0.521 md Porosity = 27.8%



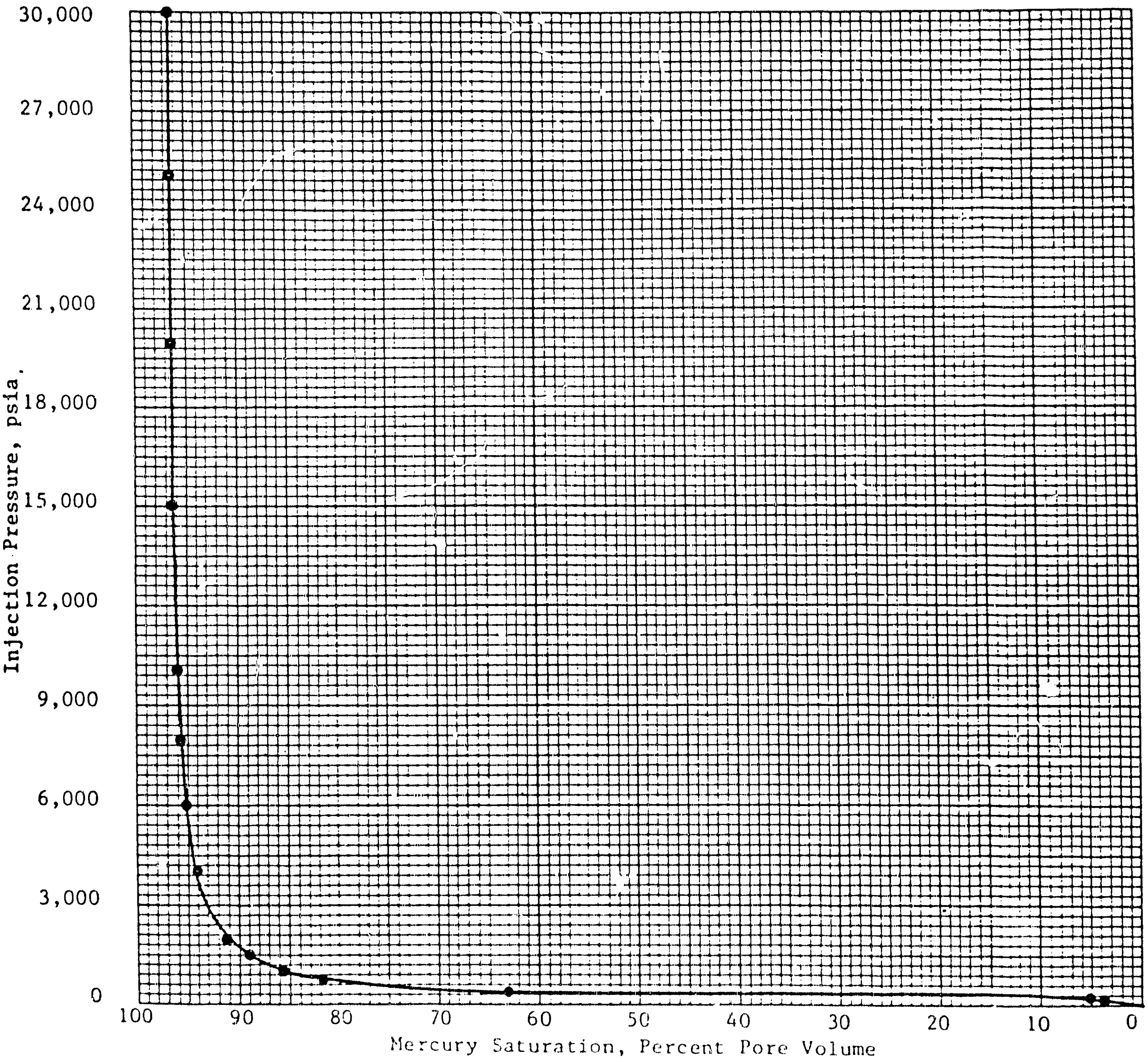
## MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 7

Air Permeability = 0.294 md

Porosity = 17.3%



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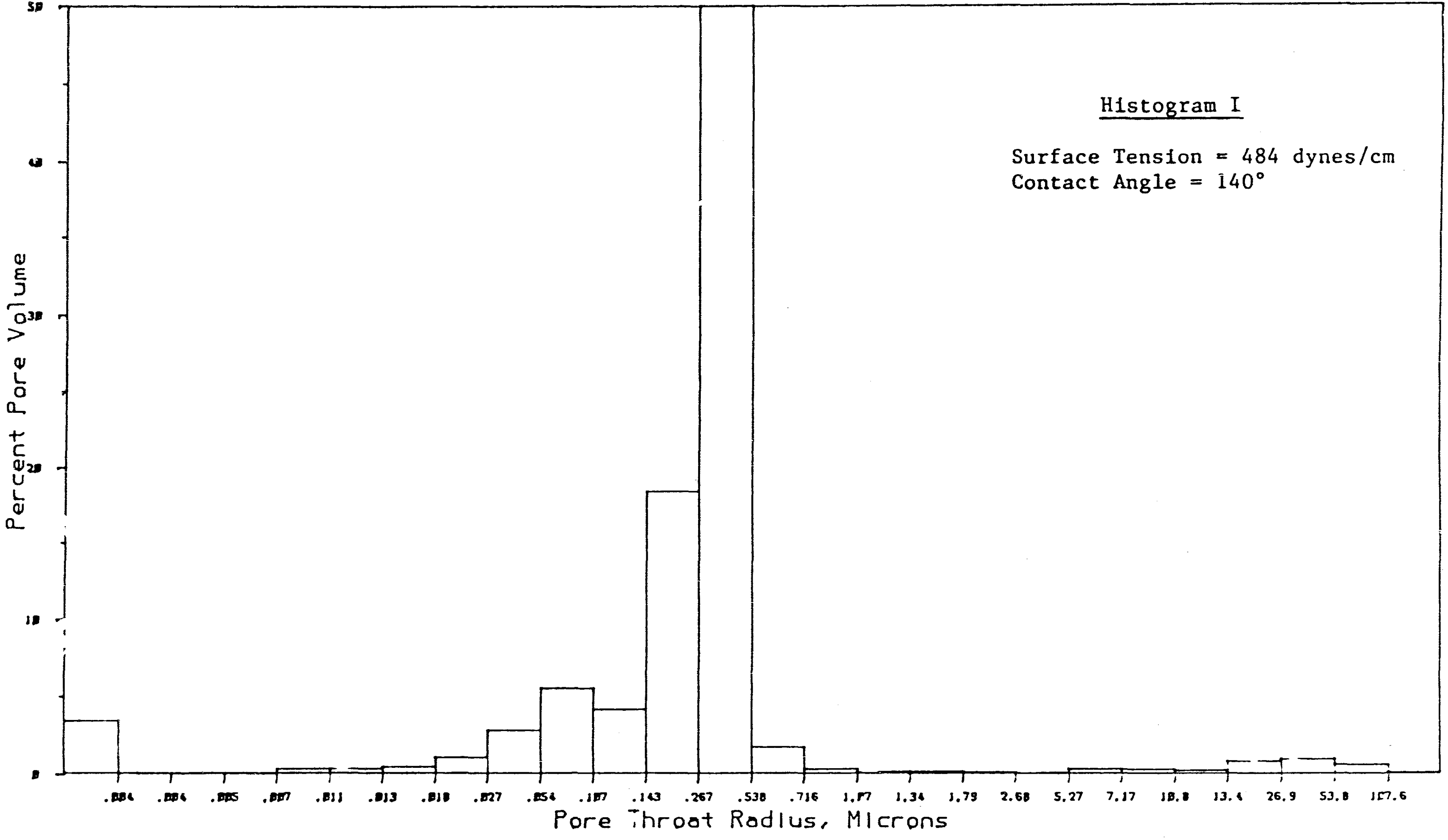
**LABORATORIES**

# COMPUTED PORE SIZE HISTOGRAM

## INTERA TECHNOLOGIES INC.

Sample Number 7 Air Permeability = 0.294 md Porosity = 17.3%



Histogram I

Surface Tension = 484 dynes/cm
Contact Angle = 140°

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# COMPUTED PORE SIZE HISTOGRAM
INTERA TECHNOLOGIES INC.

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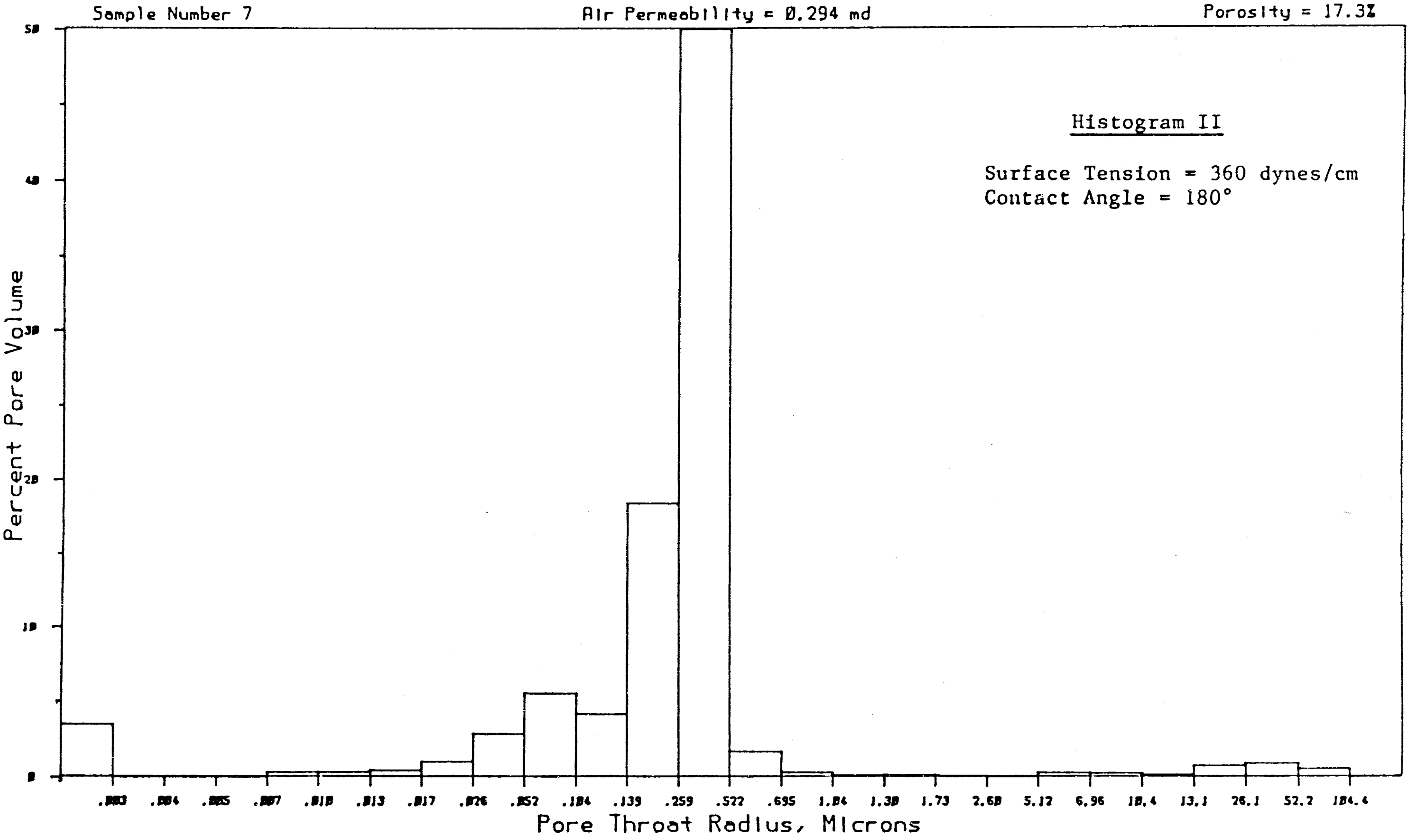


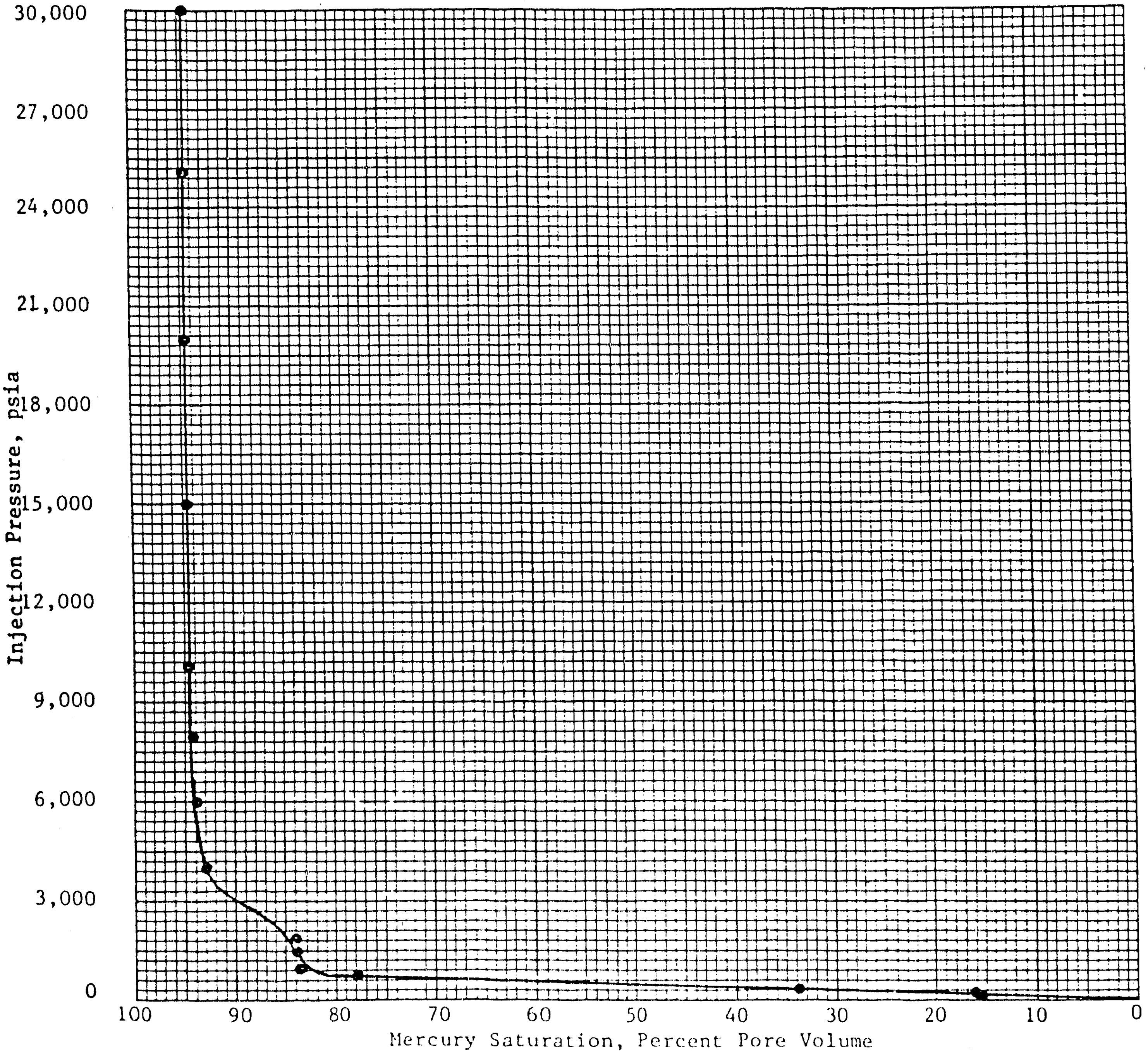
## MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 8

Air Permeability = 0.074 md

Porosity = 16.5%



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**LABORATORIES**

# COMPUTED PORE SIZE HISTOGRAM

## INTERA TECHNOLOGIES INC.

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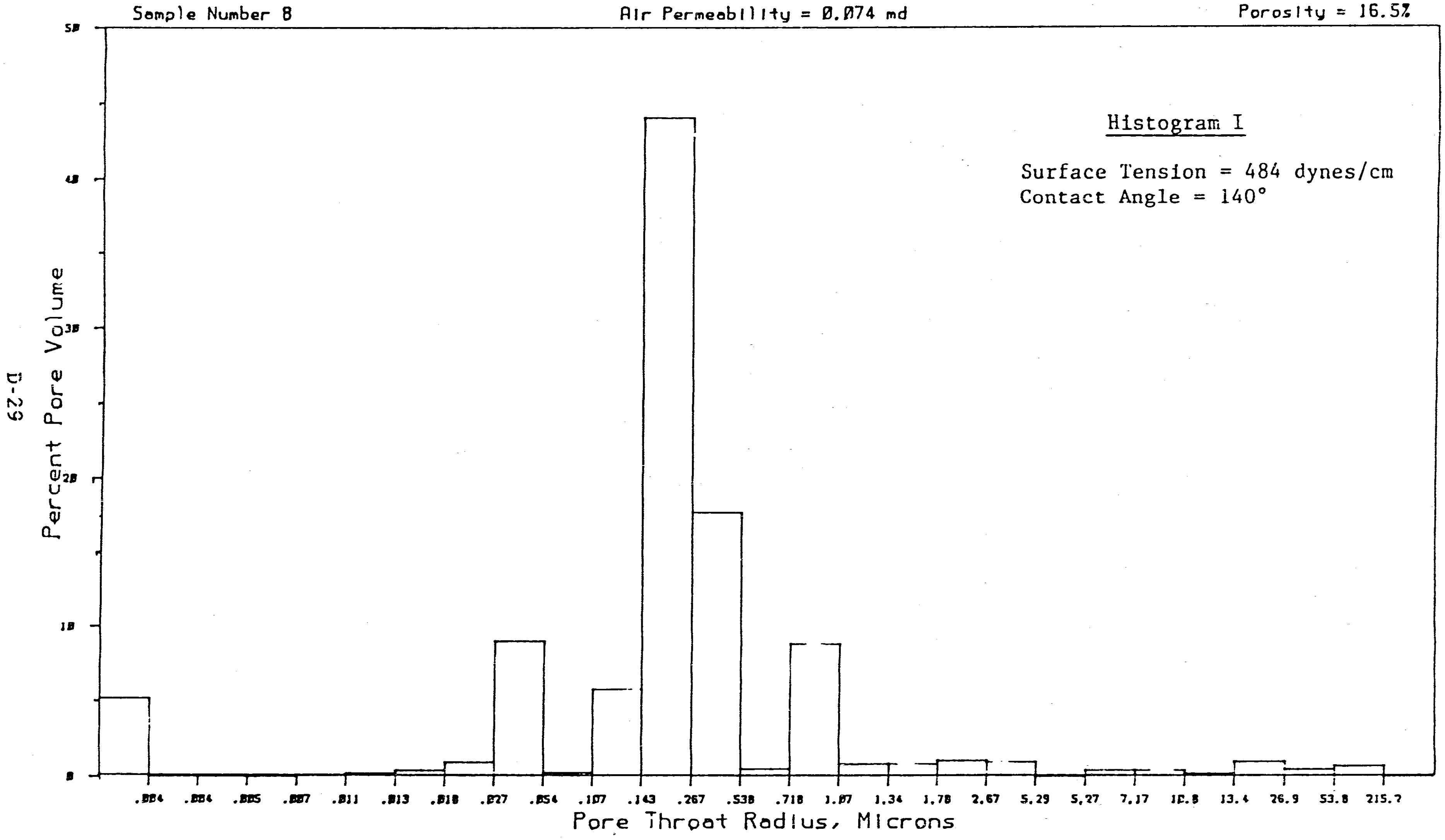
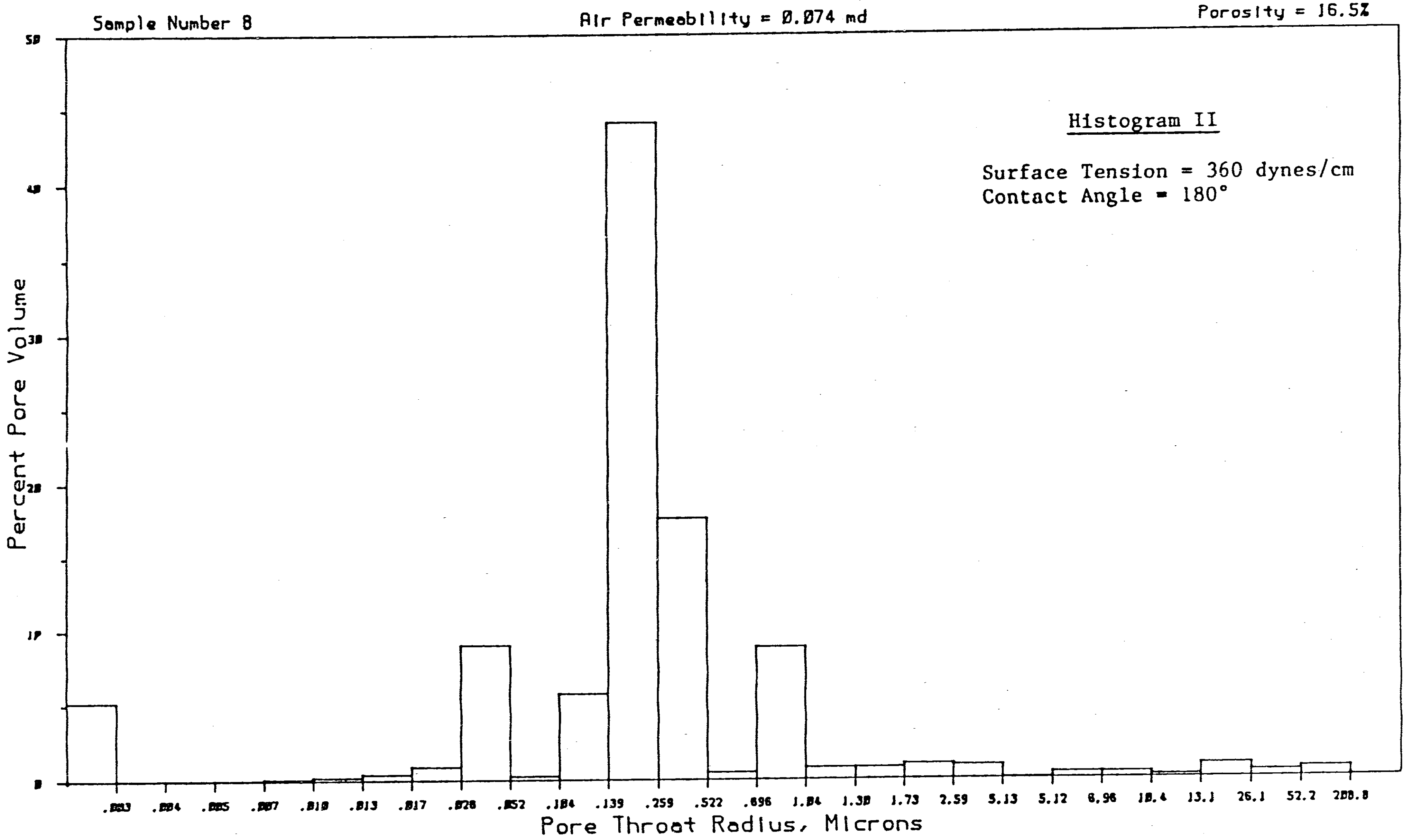

Sample Number 8 Air Permeability = 0.074 md Porosity = 16.5%

Histogram I

Surface Tension = 484 dynes/cm
Contact Angle = 140°

# COMPUTED PORE SIZE HISTOGRAM
## INTERA TECHNOLOGIES INC.



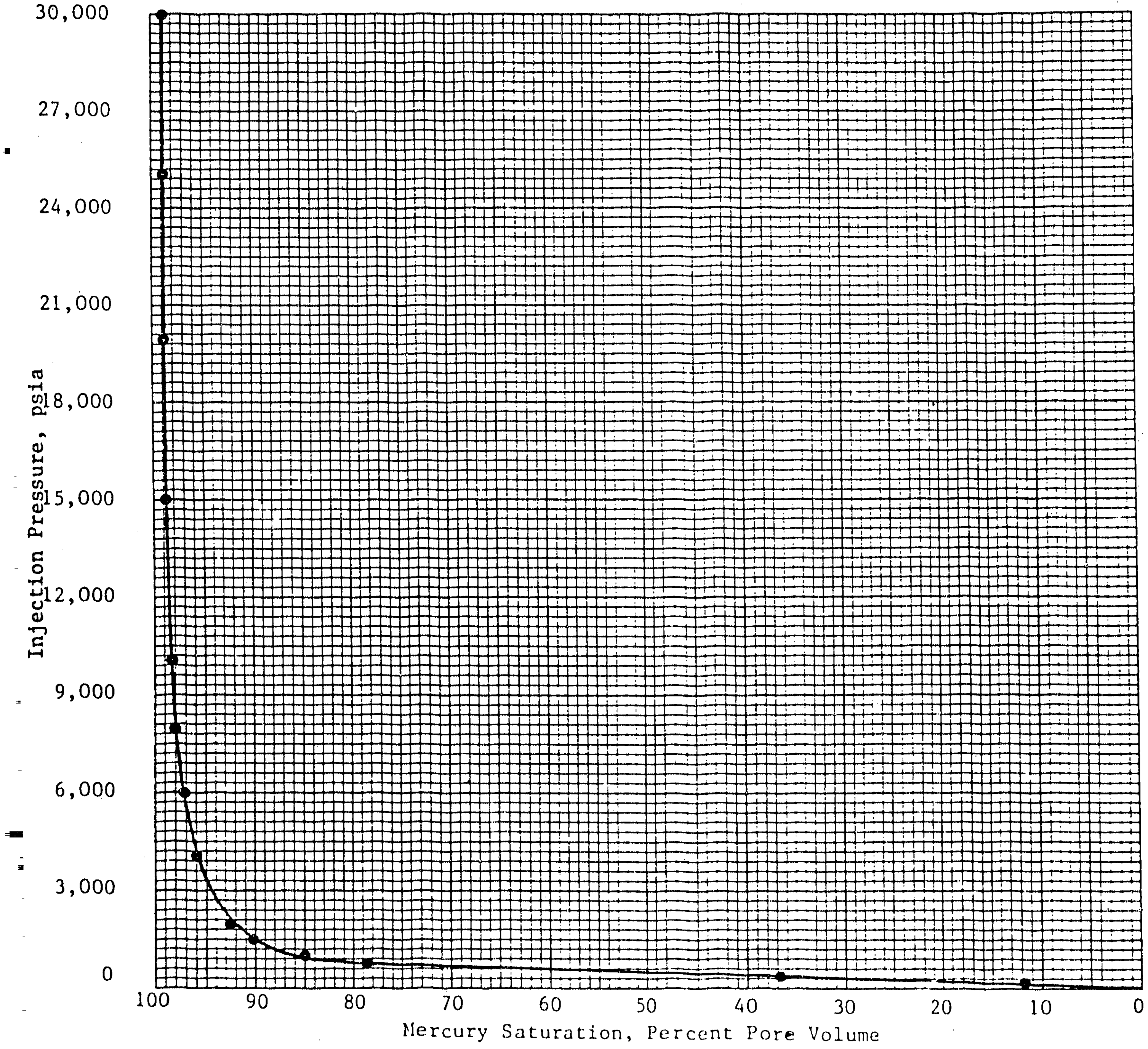
## MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 9

Air Permeability = 0.098 md

Porosity = 13.4%



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LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM
INTERA TECHNOLOGIES INC.

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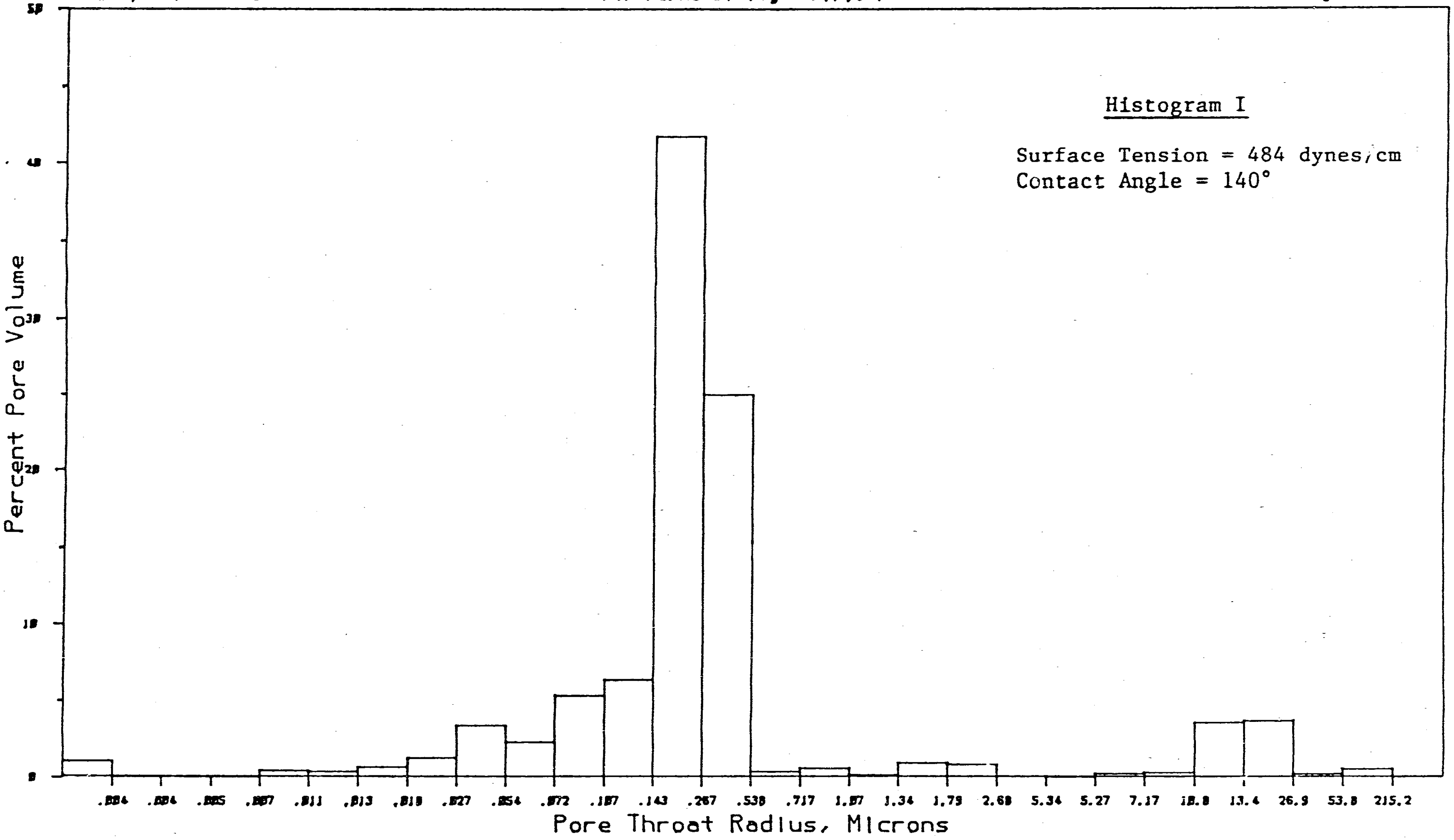
Sample Number 9 Air Permeability = 0.098 md Porosity = 13.4%



Histogram I

Surface Tension = 484 dynes/cm
Contact Angle = 140°

**K & A**
LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM
## INTERA TECHNOLOGIES INC.

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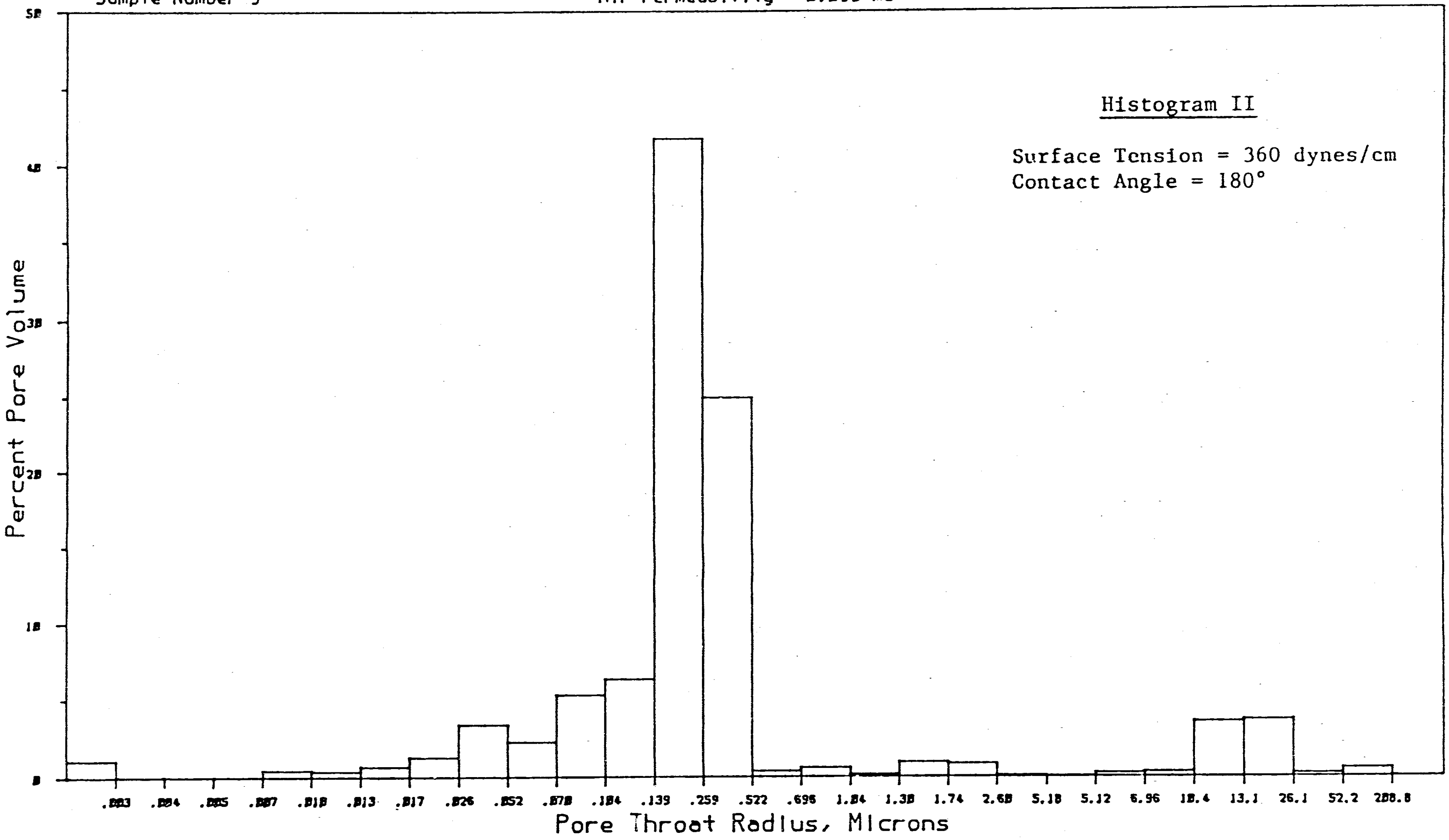
Sample Number 9

Air Permeability = 0.098 md

Porosity = 13.4%



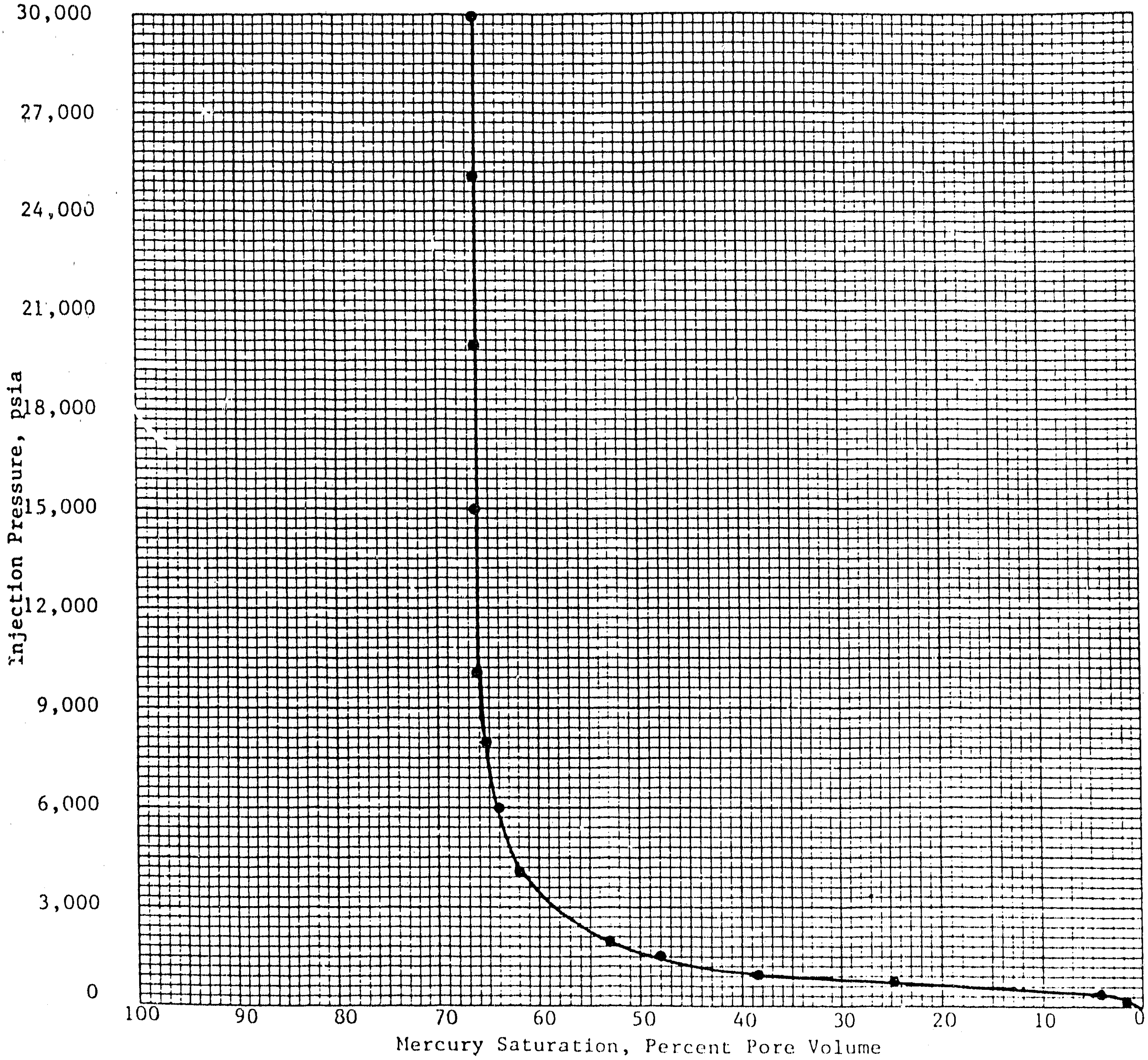
## MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 10

Air Permeability = 0.012 md

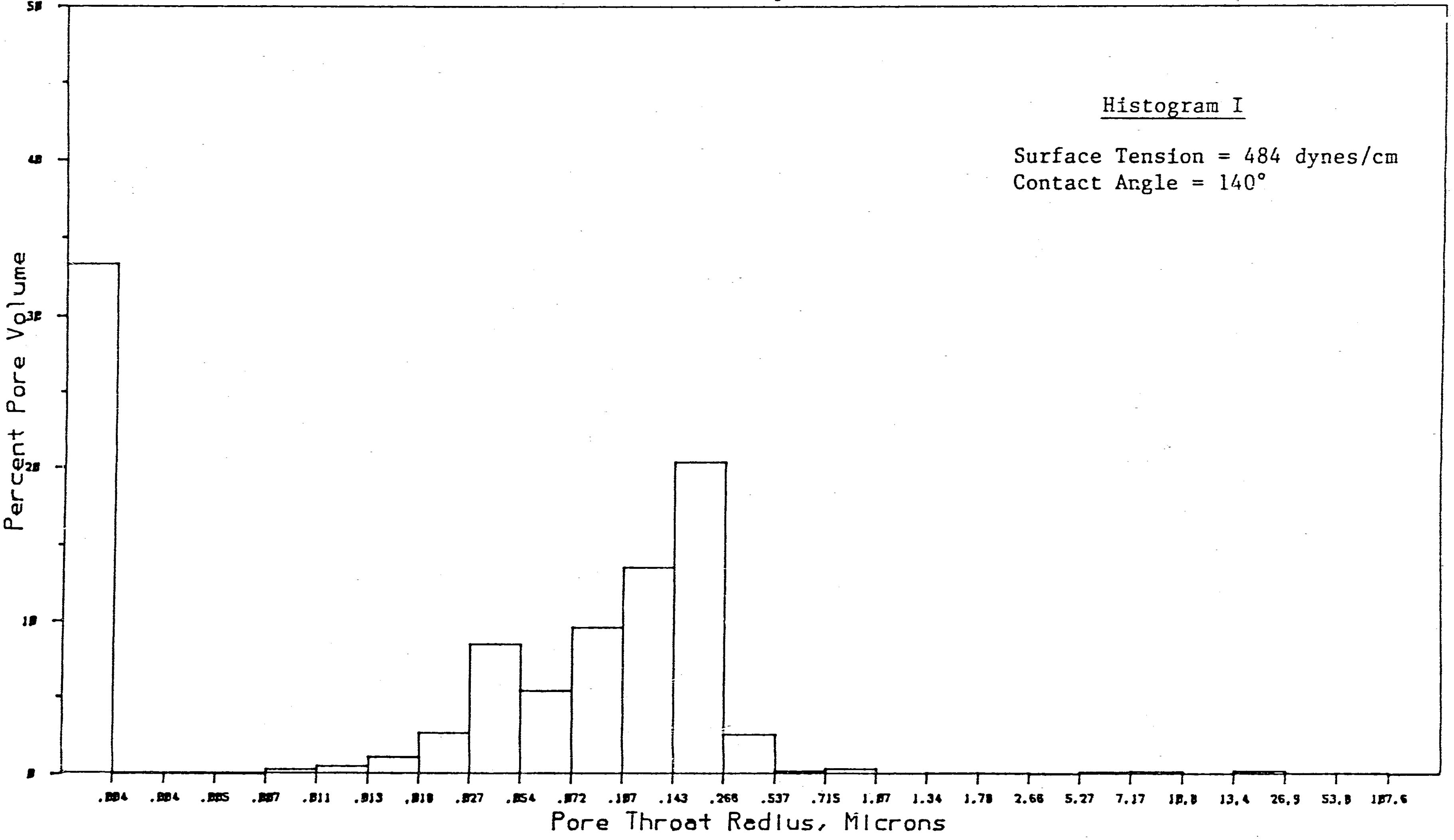
Porosity = 10.8%



# COMPUTED PORE SIZE HISTOGRAM

## INTERA TECHNOLOGIES INC.

Sample Number 10 Air Permeability = 0.012 md Porosity = 10.8%



Histogram I

Surface Tension = 484 dynes/cm
Contact Angle = 140°

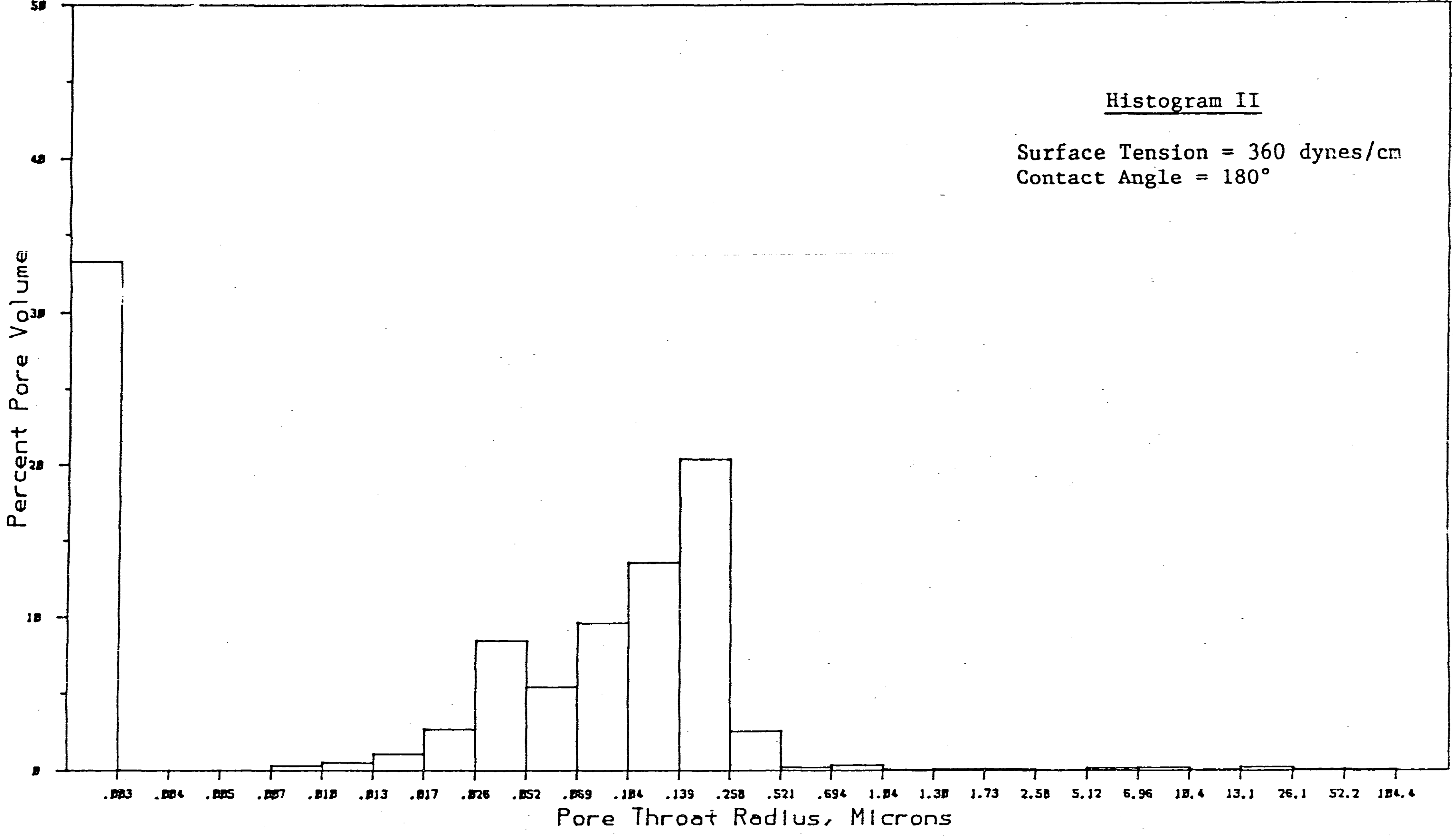
# COMPUTED PORE SIZE HISTOGRAM

INTERA TECHNOLOGIES INC.

Sample Number 10

Air Permeability = 0.012 md

Porosity = 10.8%



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**LABORATORIES**

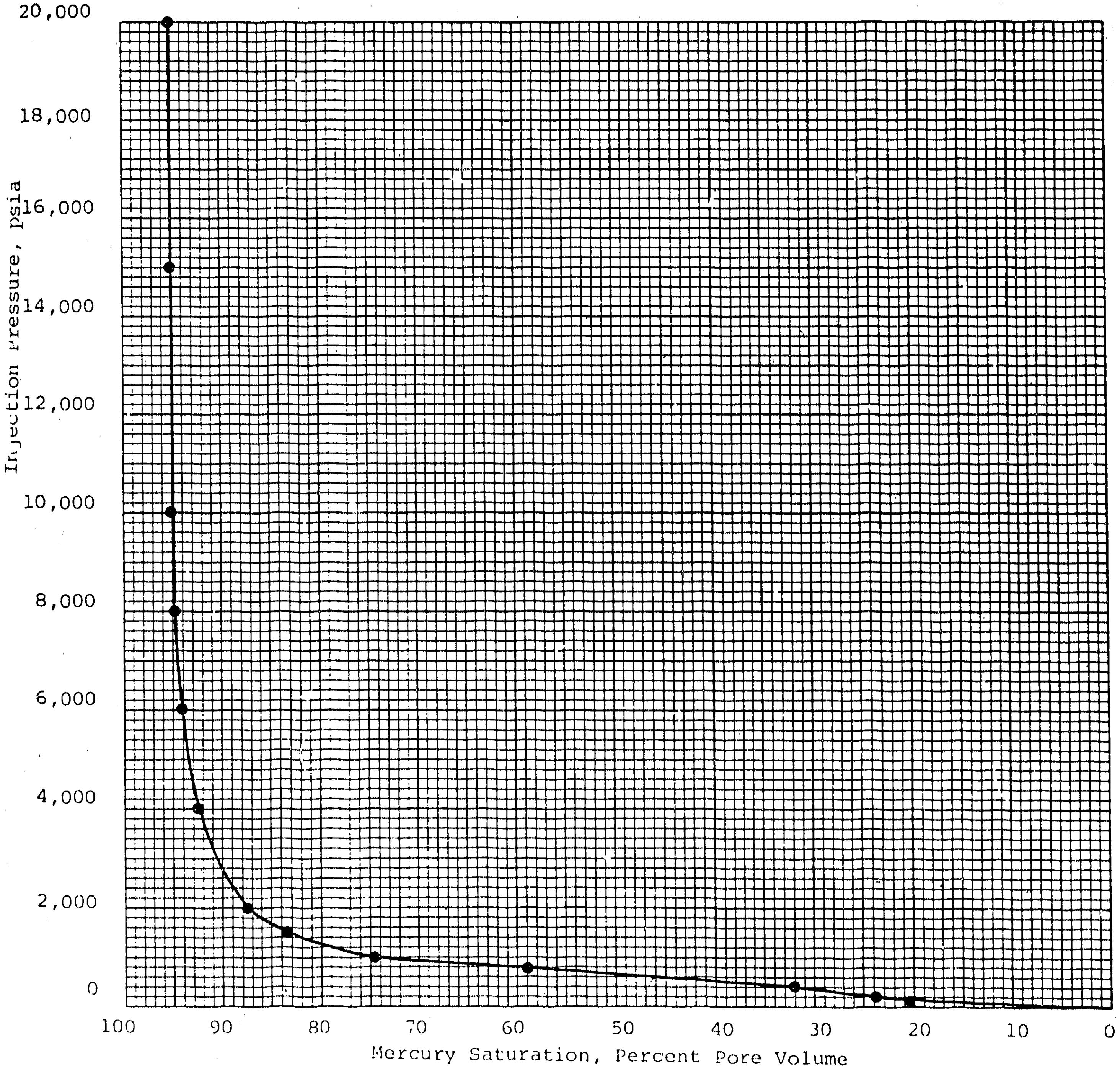
# MERCURY/INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 10A

Air Permeability = .174 md

Porosity = 9.0%



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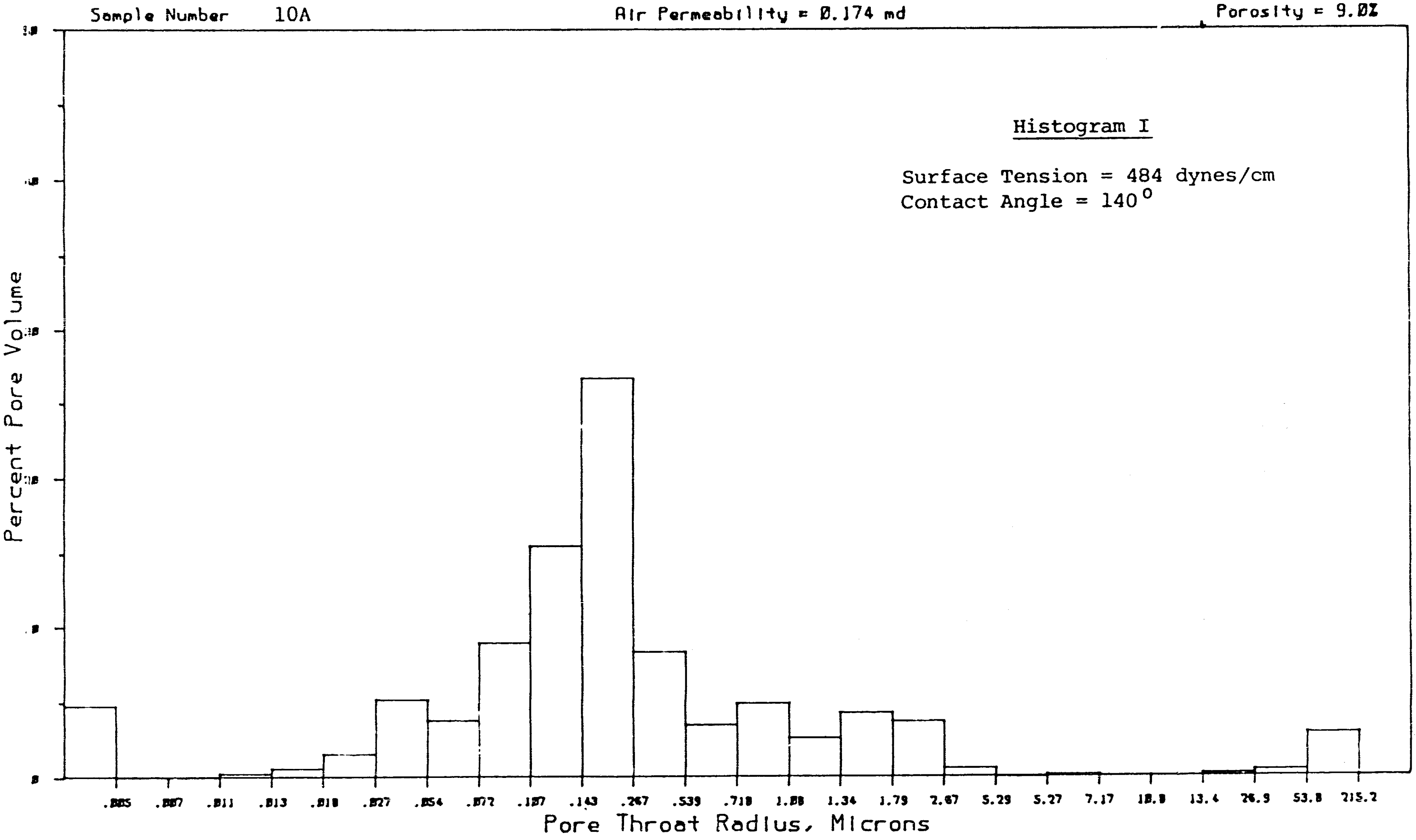
**K & A**
**LABORATORIES**

# COMPUTED PORE SIZE HISTOGRAM

## INTERA TECHNOLOGIES INC



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LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM
## INTERA TECHNOLOGIES INC

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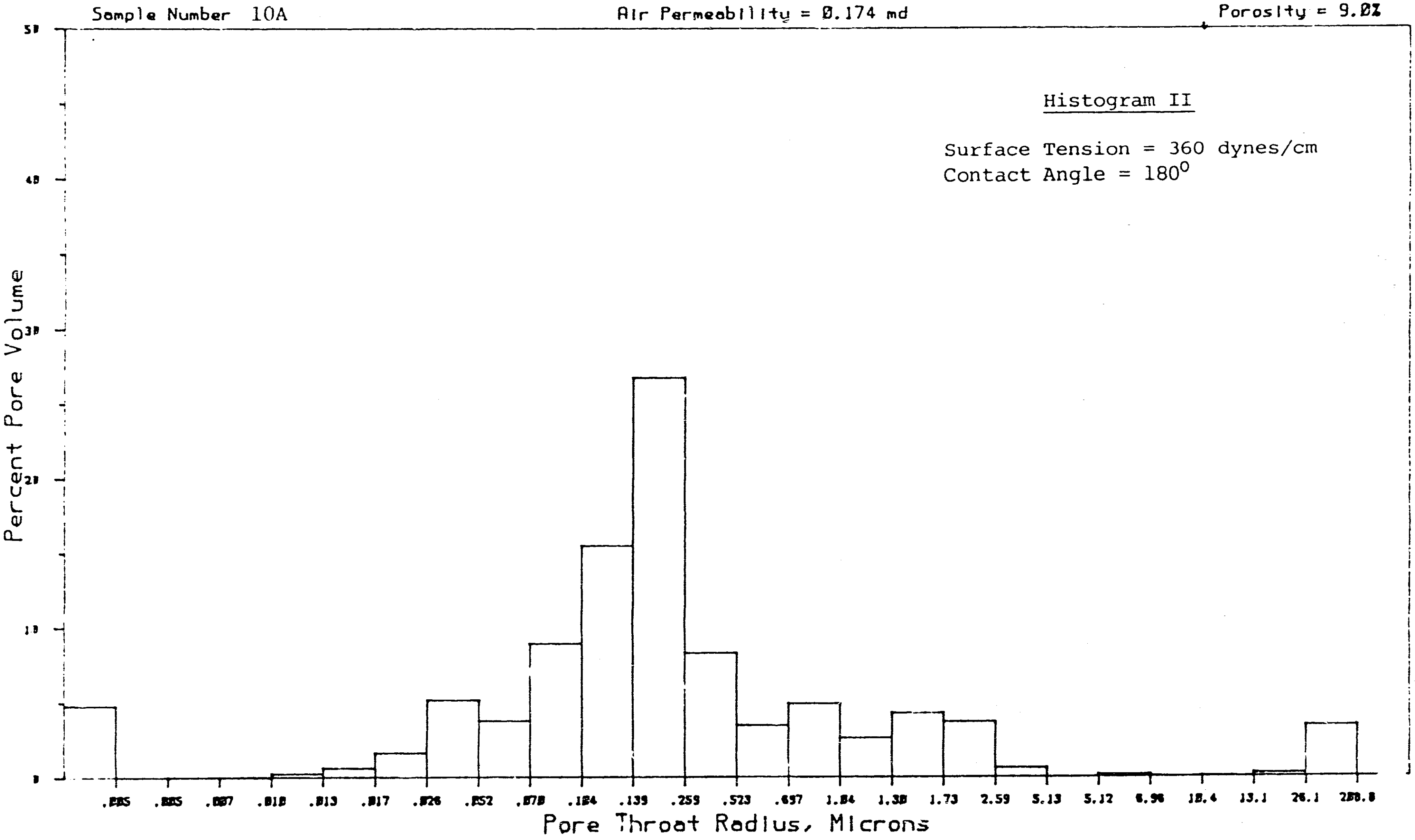


**K & A**
**LABORATORIES**

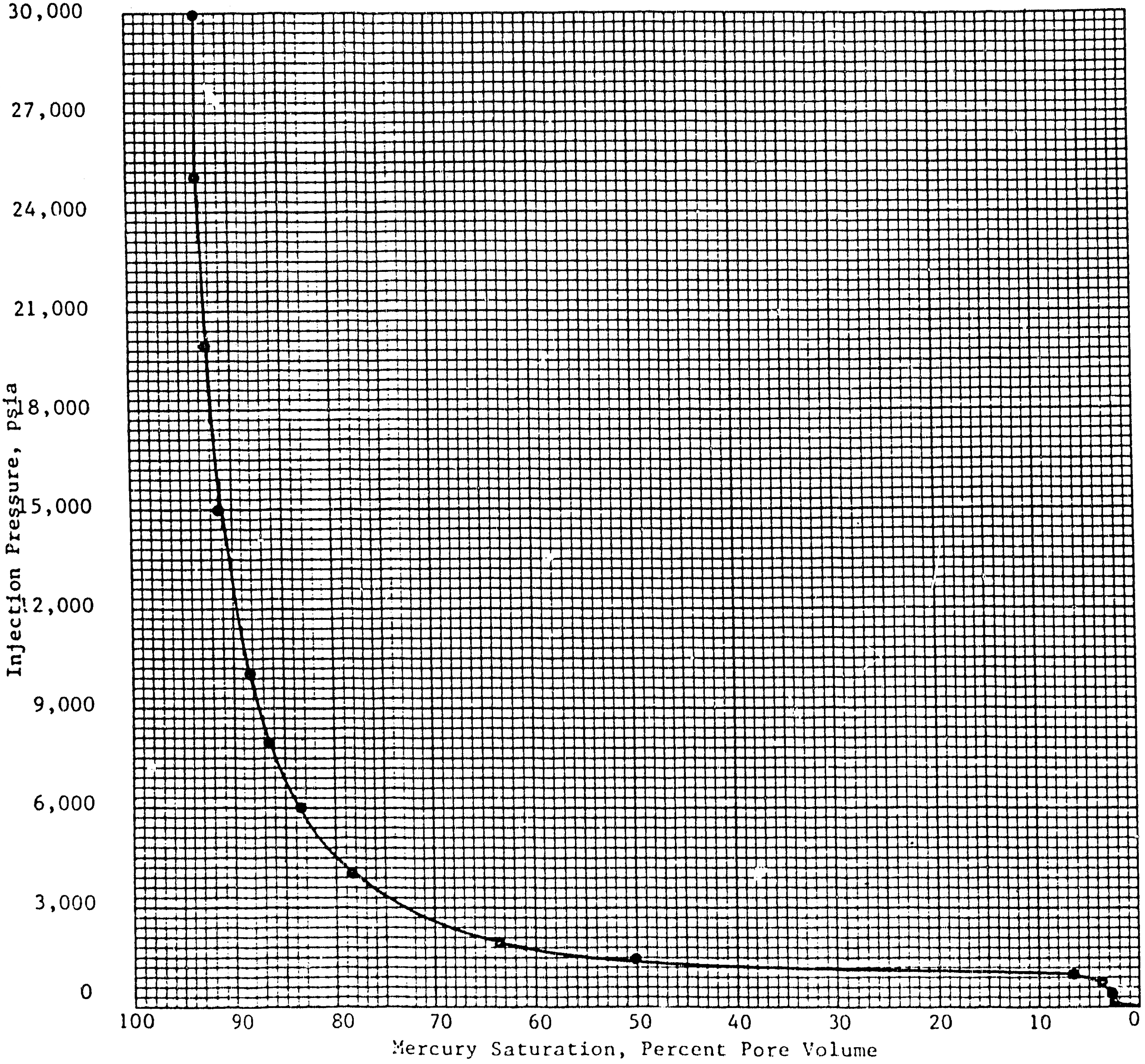
## MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 11

Air Permeability = 0.038 md

Porosity = 11.0%



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LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM

INTERA TECHNOLOGIES INC.

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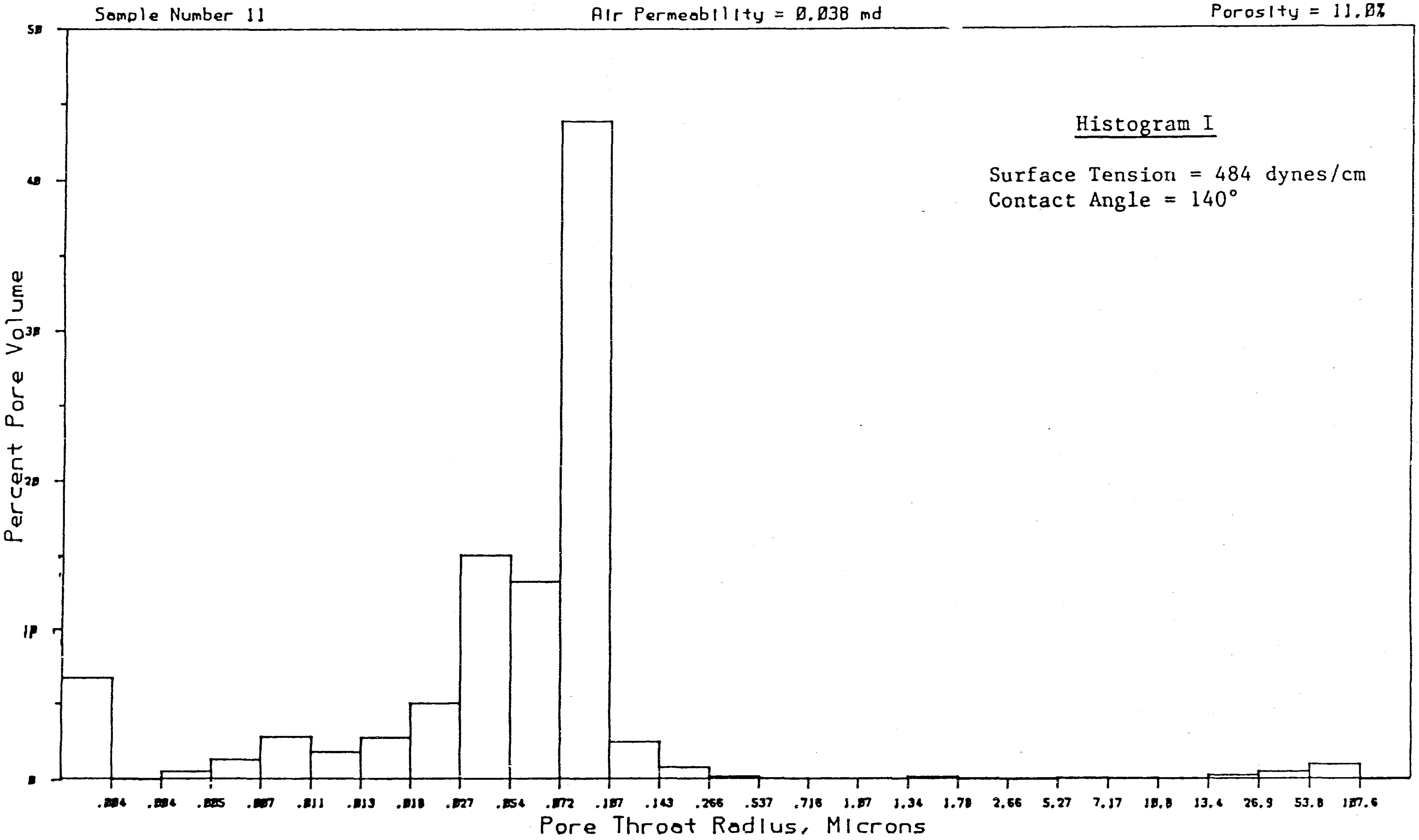
Sample Number 11

Air Permeability = 0.038 md

Porosity = 11.0%

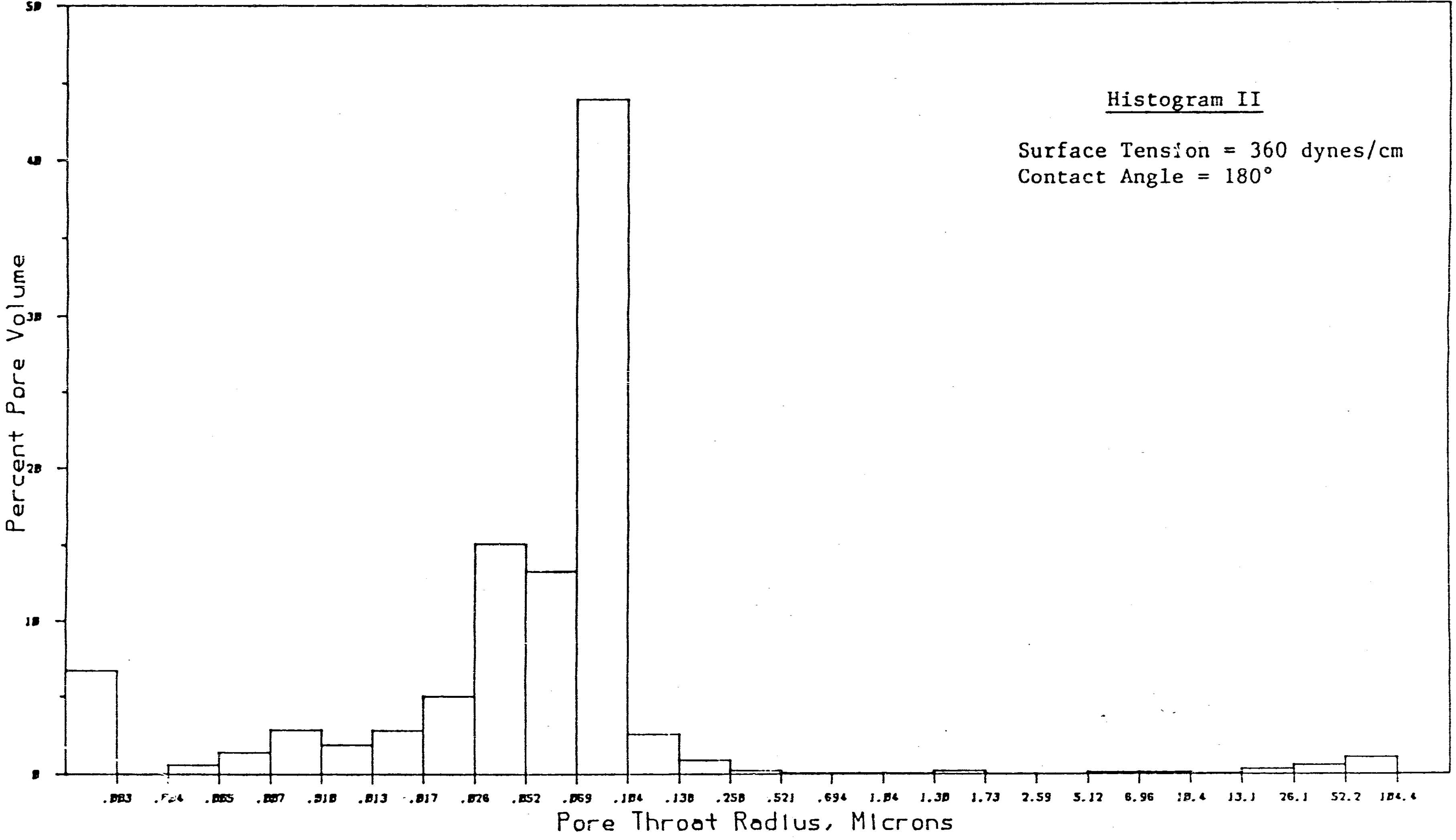


# COMPUTED PORE SIZE HISTOGRAM
## INTERA TECHNOLOGIES INC.

Sample Number 11

Air Permeability = 0.038 md

Porosity = 11.0%



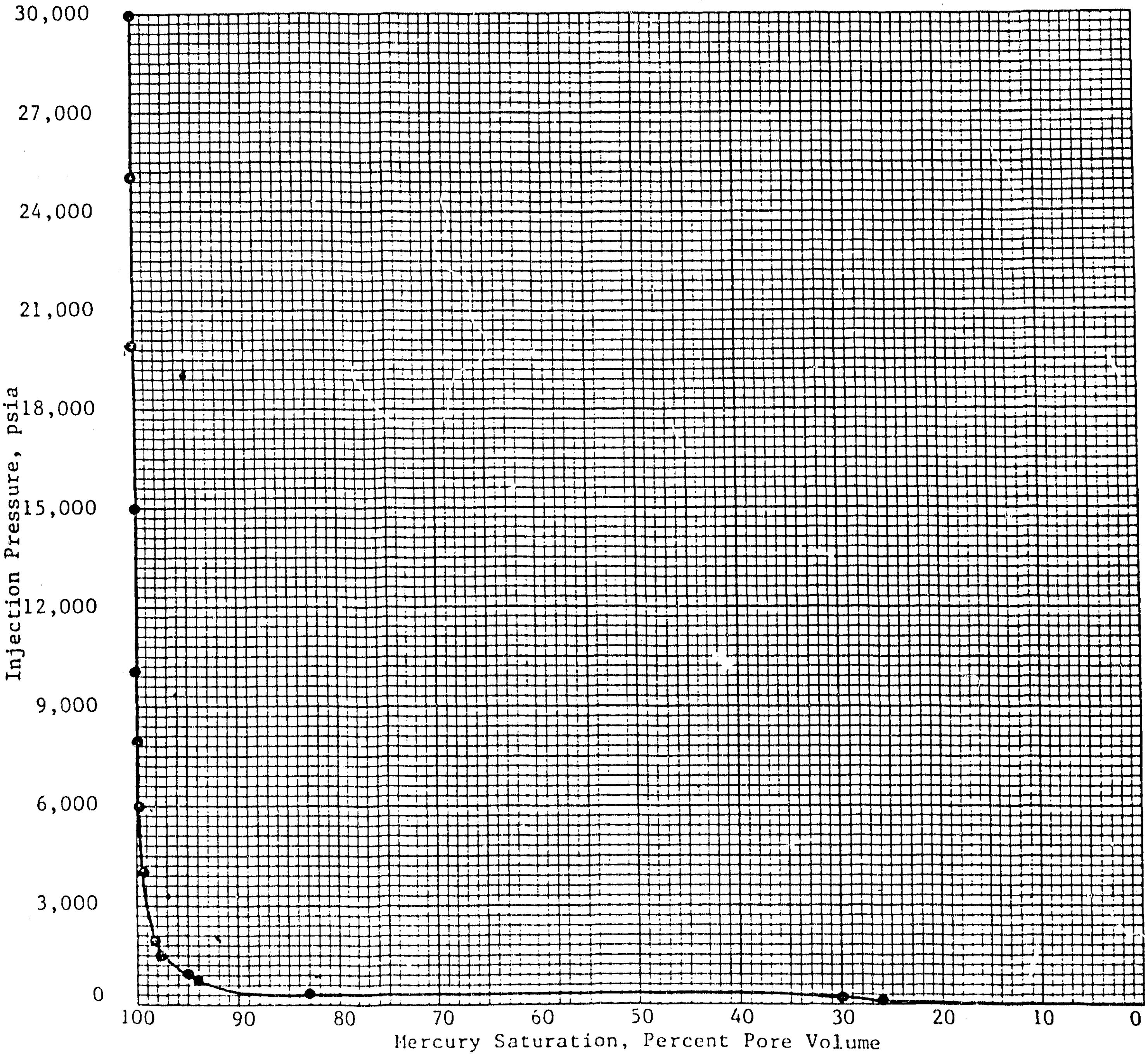
# MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 12

Air Permeability = 1.33 md

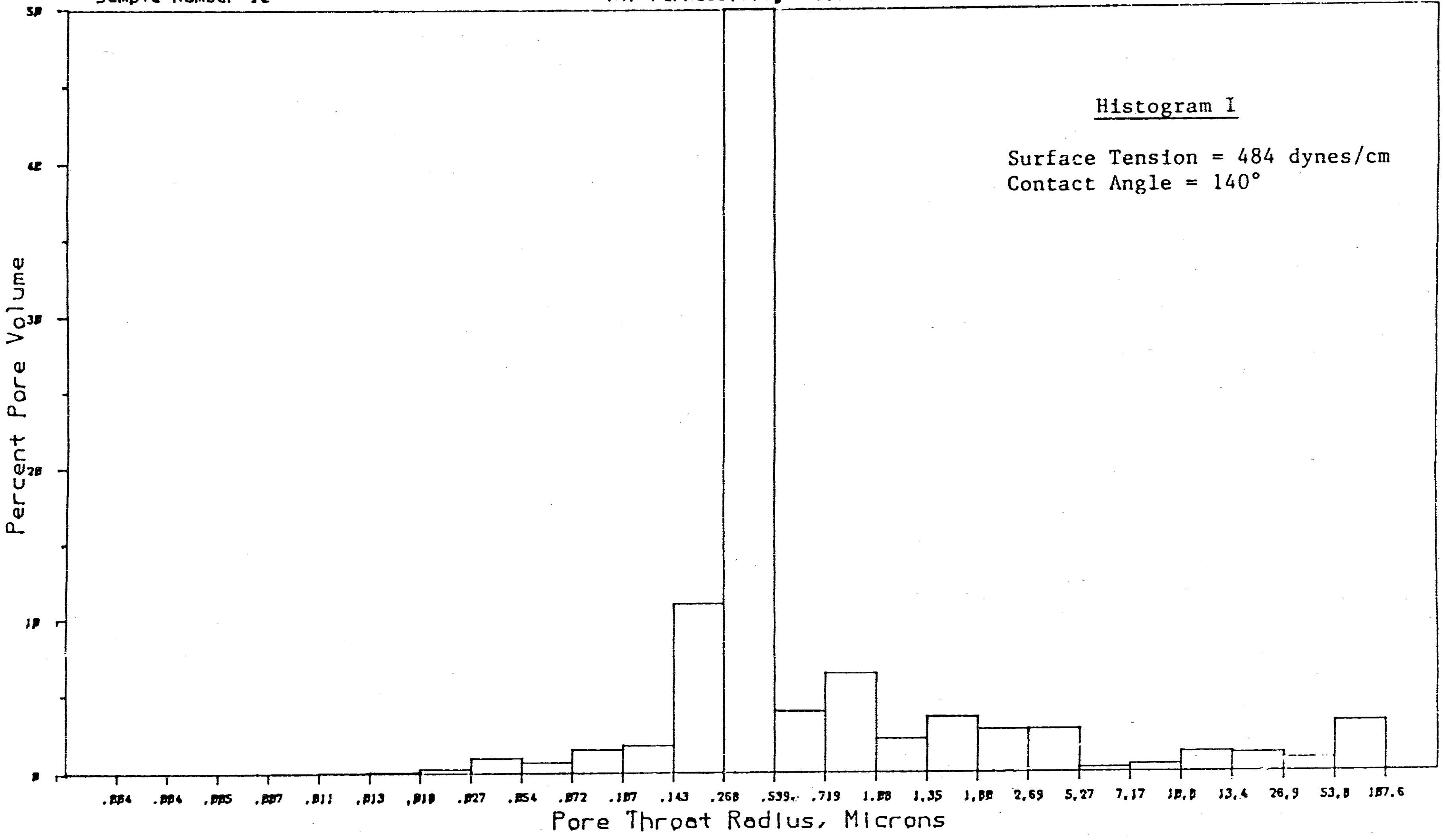
Porosity = 33.1%



# COMPUTED PORE SIZE HISTOGRAM

INTERA TECHNOLOGIES INC.

Sample Number 12 Air Permeability = 1.33 md Porosity = 33.1%



Histogram I

Surface Tension = 484 dynes/cm
Contact Angle = 140°

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LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM

INTERA TECHNOLOGIES INC.

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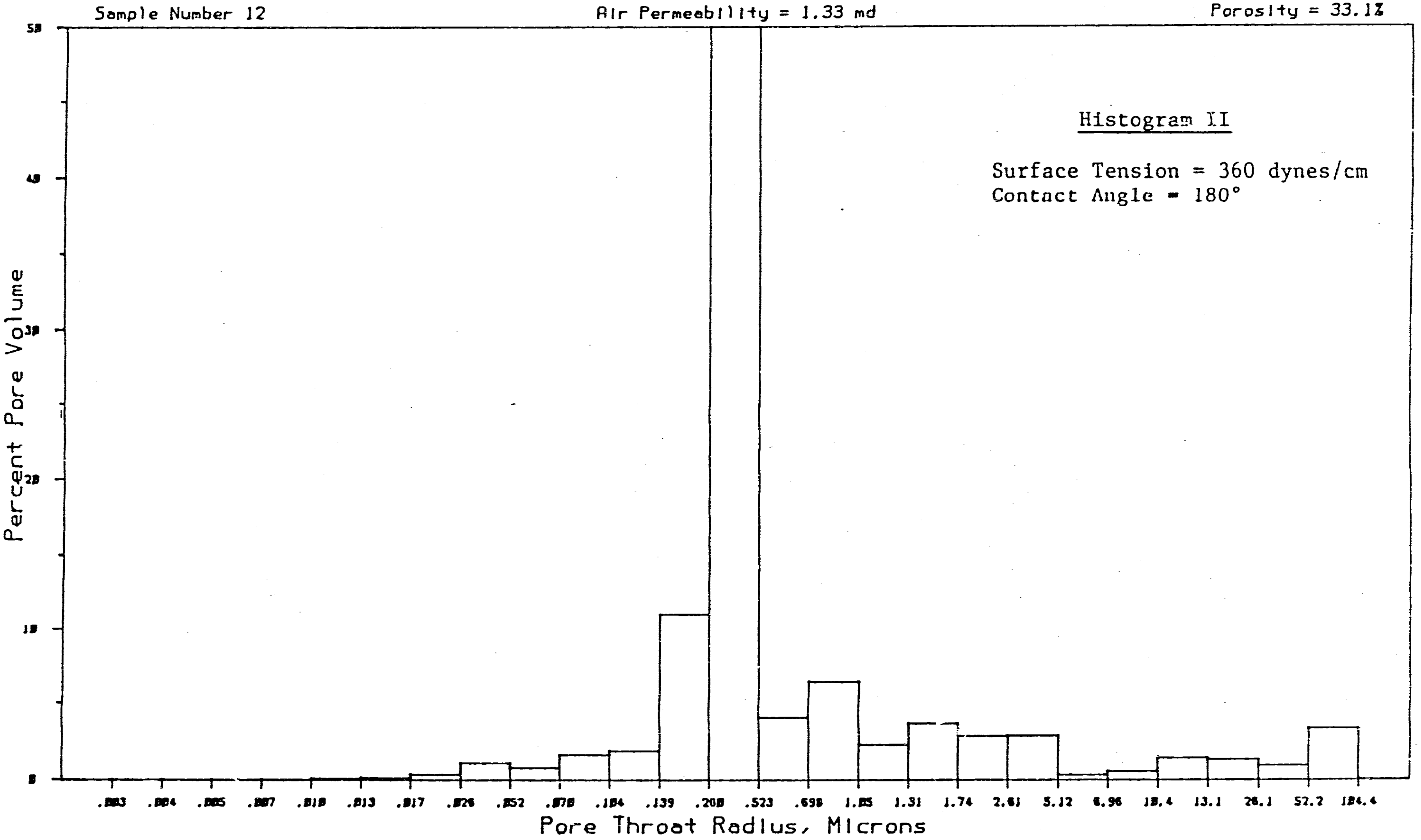

Sample Number 12

Air Permeability = 1.33 md

Porosity = 33.1%

Histogram II

Surface Tension = 360 dynes/cm
Contact Angle = 180°

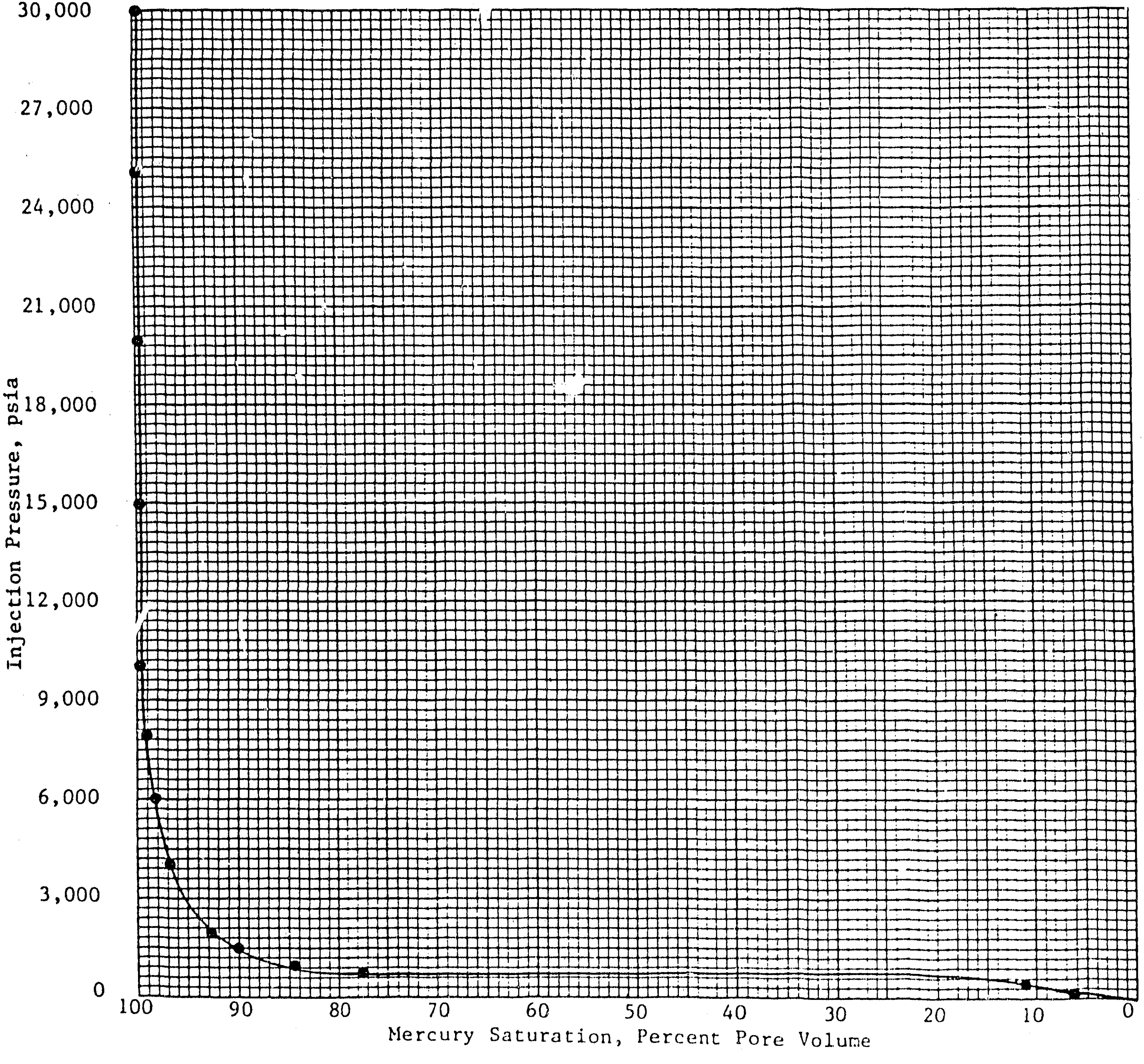
## MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

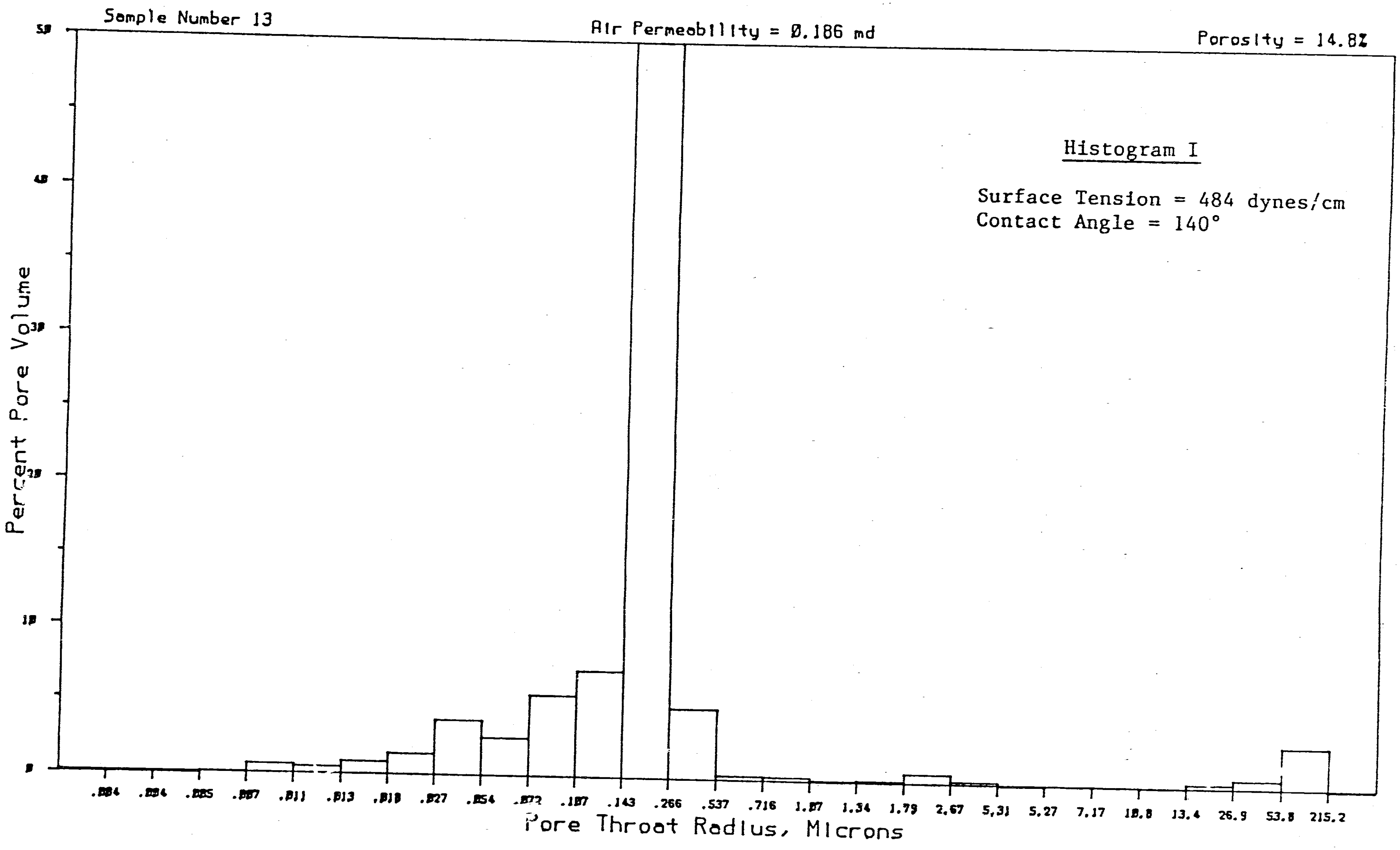
SAMPLE NUMBER 13

Air Permeability = 0.186 md

Porosity = 14.8%

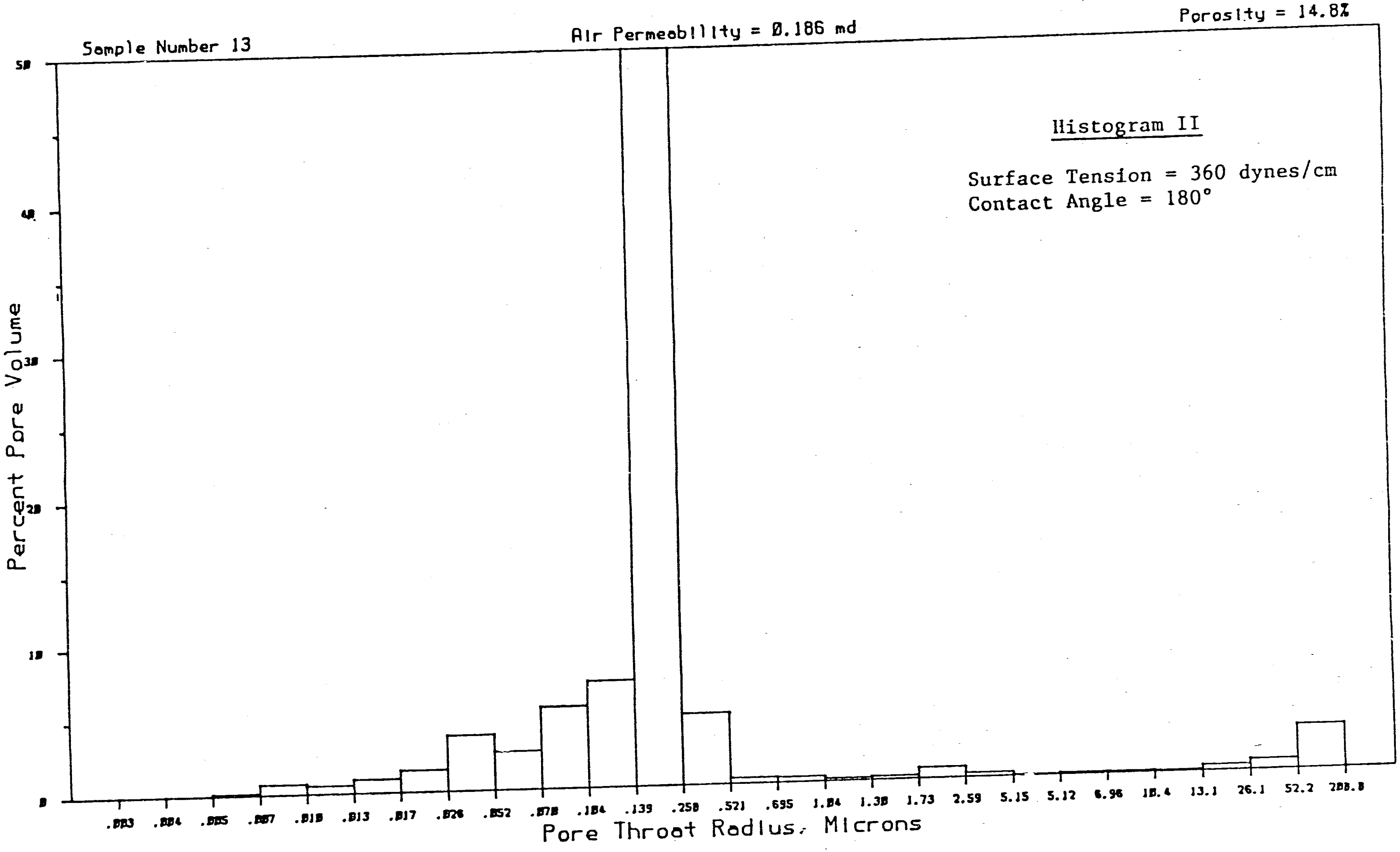


# COMPUTED PORE SIZE HISTOGRAM
## INTERA TECHNOLOGIES INC.



**K & A**
**LABORATORIES**

# COMPUTED PORE SIZE HISTOGRAM
## INTERA TECHNOLOGIES INC.



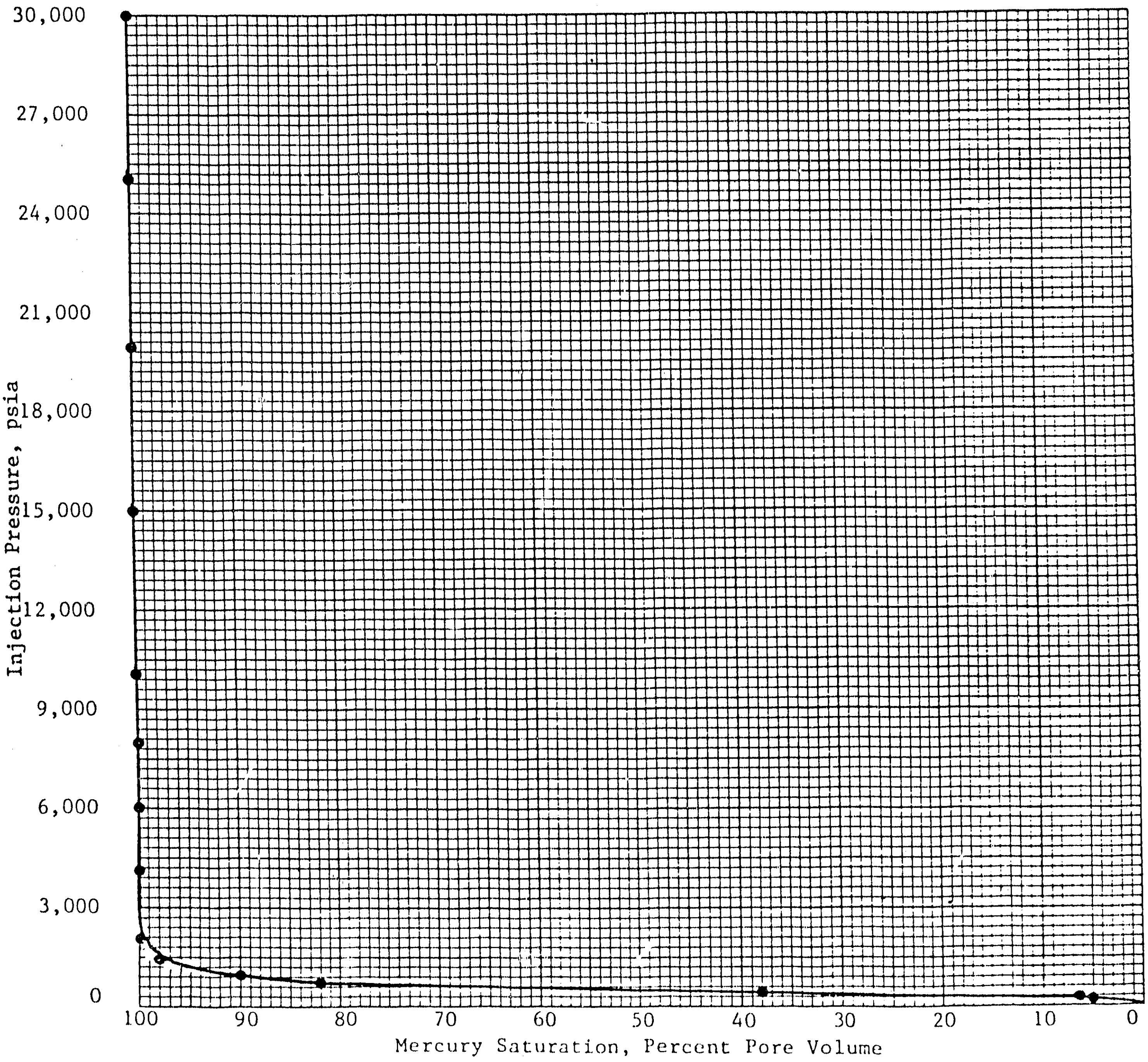
## MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 14

Air Permeability = 0.270 md

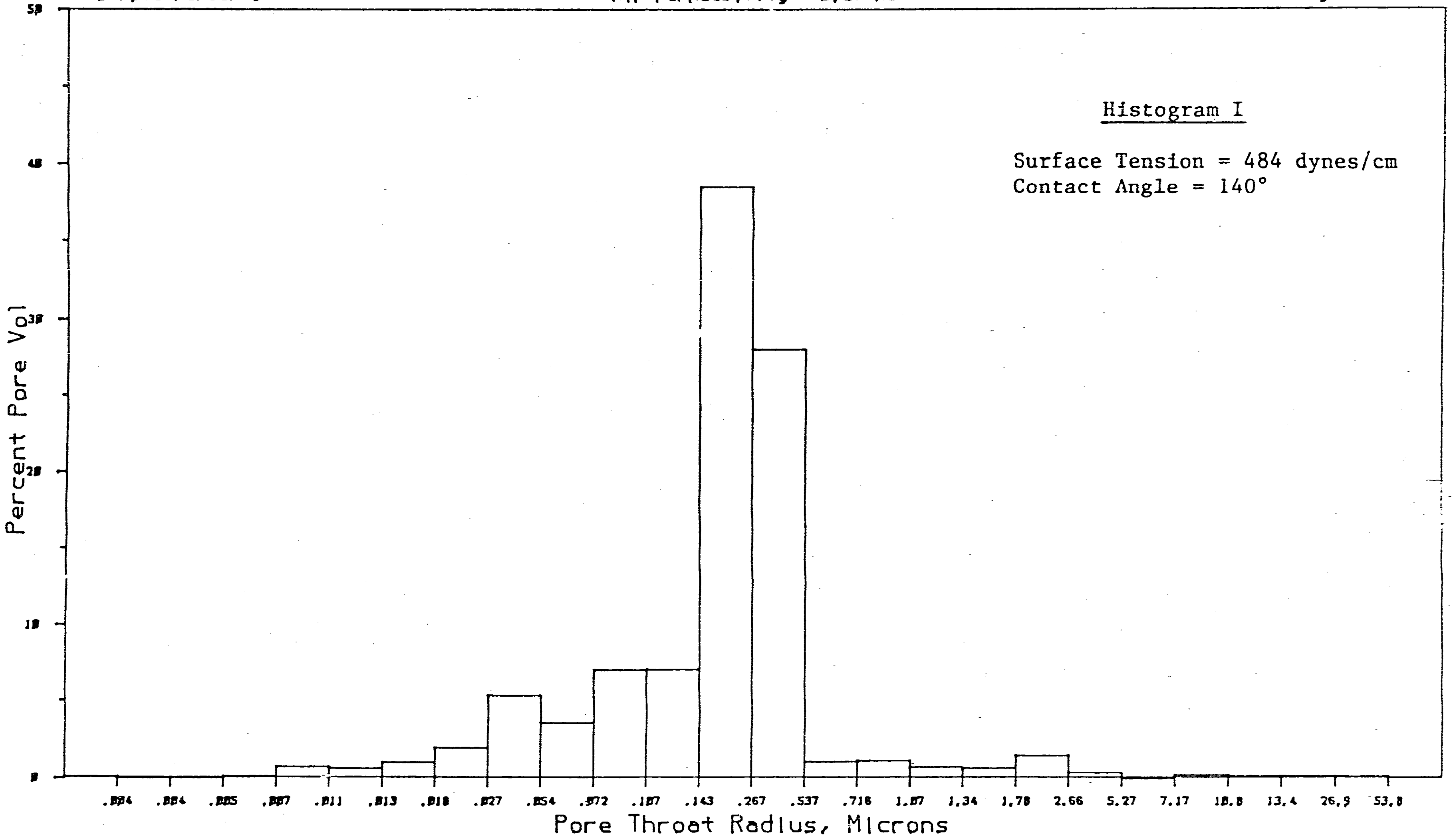
Porosity = 2.8%



COMPUTED PORE SIZE HISTOGRAM

INTERA TECHNOLOGIES INC.

Sample Number 14 Air Permeability = 0,27 md Porosity = 2.8 %

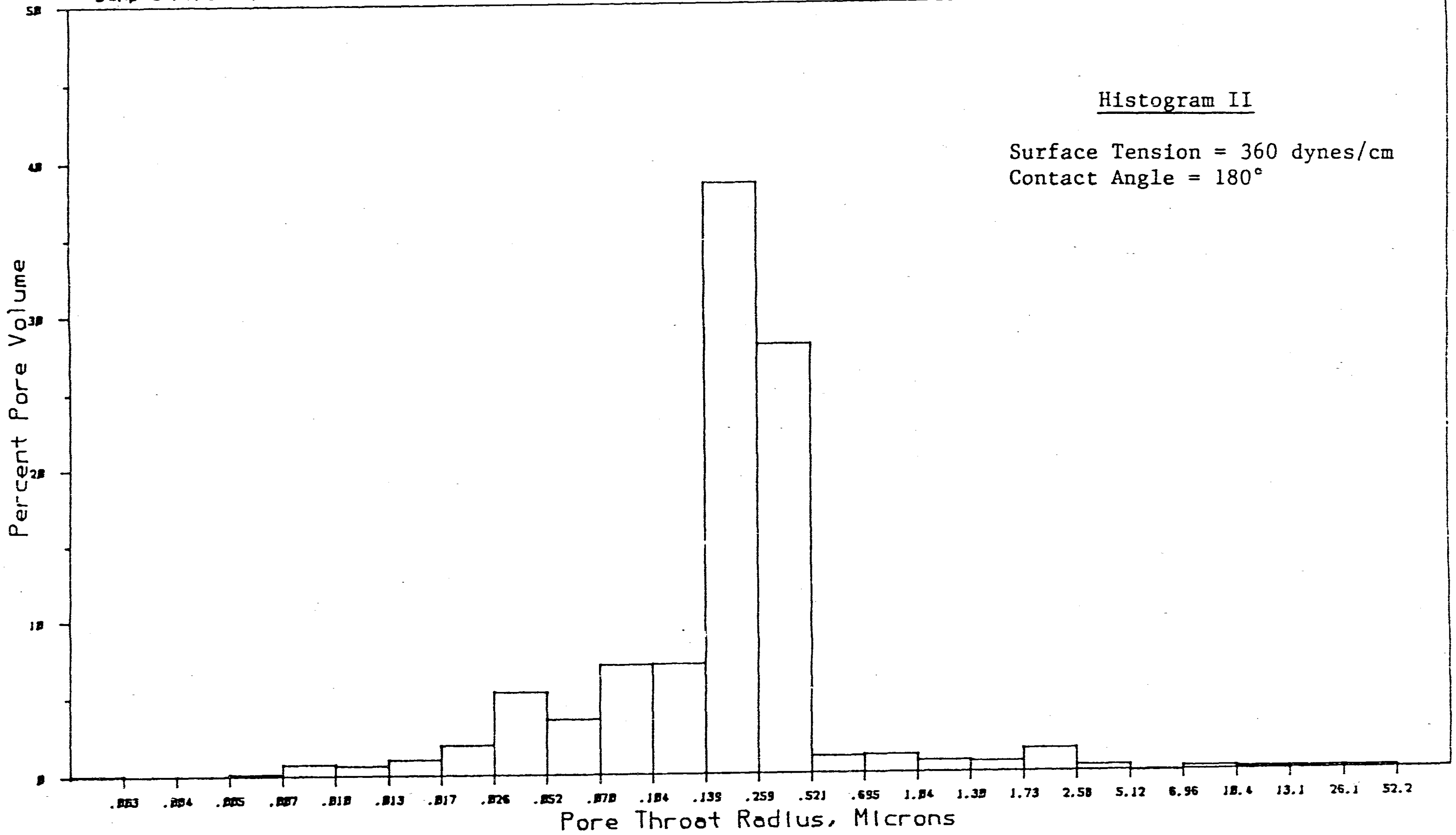


# COMPUTED PORE SIZE HISTOGRAM
## INTERA TECHNOLOGIES INC.

Sample Number 14

Air Permeability = 0.27 md

Porosity = 2.8 %



Histogram II

Surface Tension = 360 dynes/cm
Contact Angle = 180°

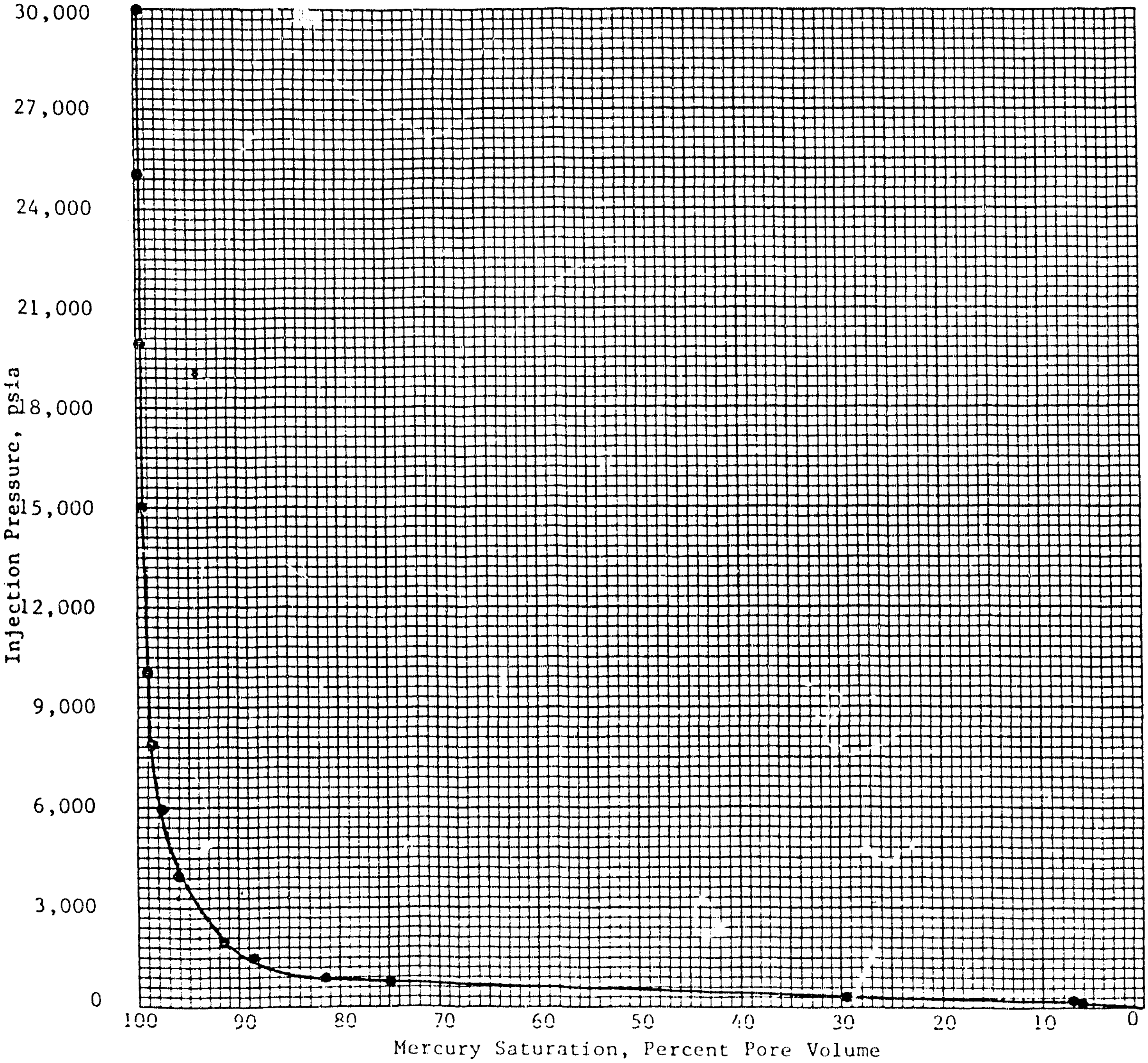
# MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 15

Air Permeability = 0.086 md

Porosity = 11.2%



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LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM

## INTERA TECHNOLOGIES INC.

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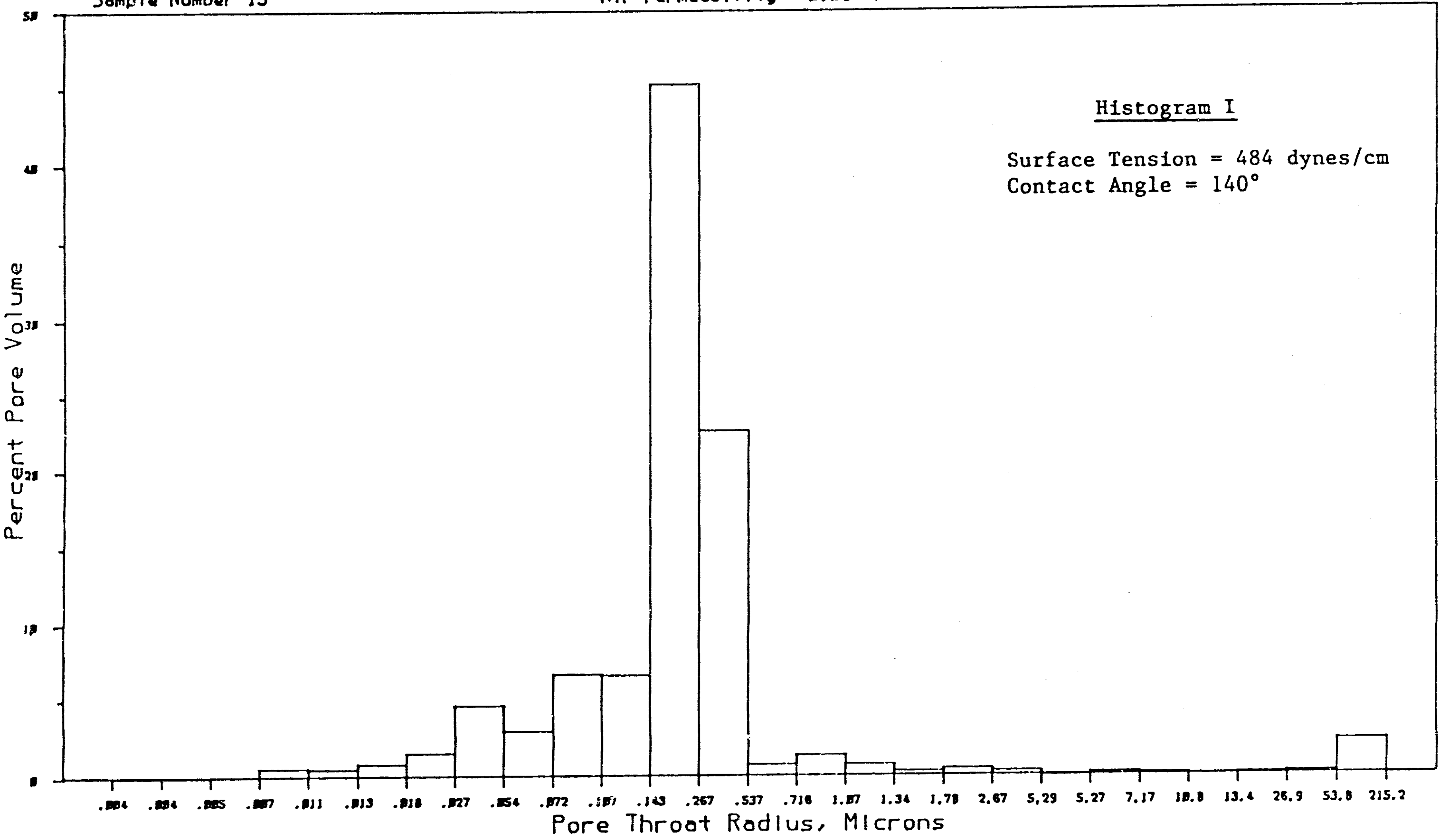
Sample Number 15

Air Permeability = 0.086 md

Porosity = 11.2%



Histogram I

Surface Tension = 484 dynes/cm
Contact Angle = 140°

**K & A**
LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM

INTERA TECHNOLOGIES INC.

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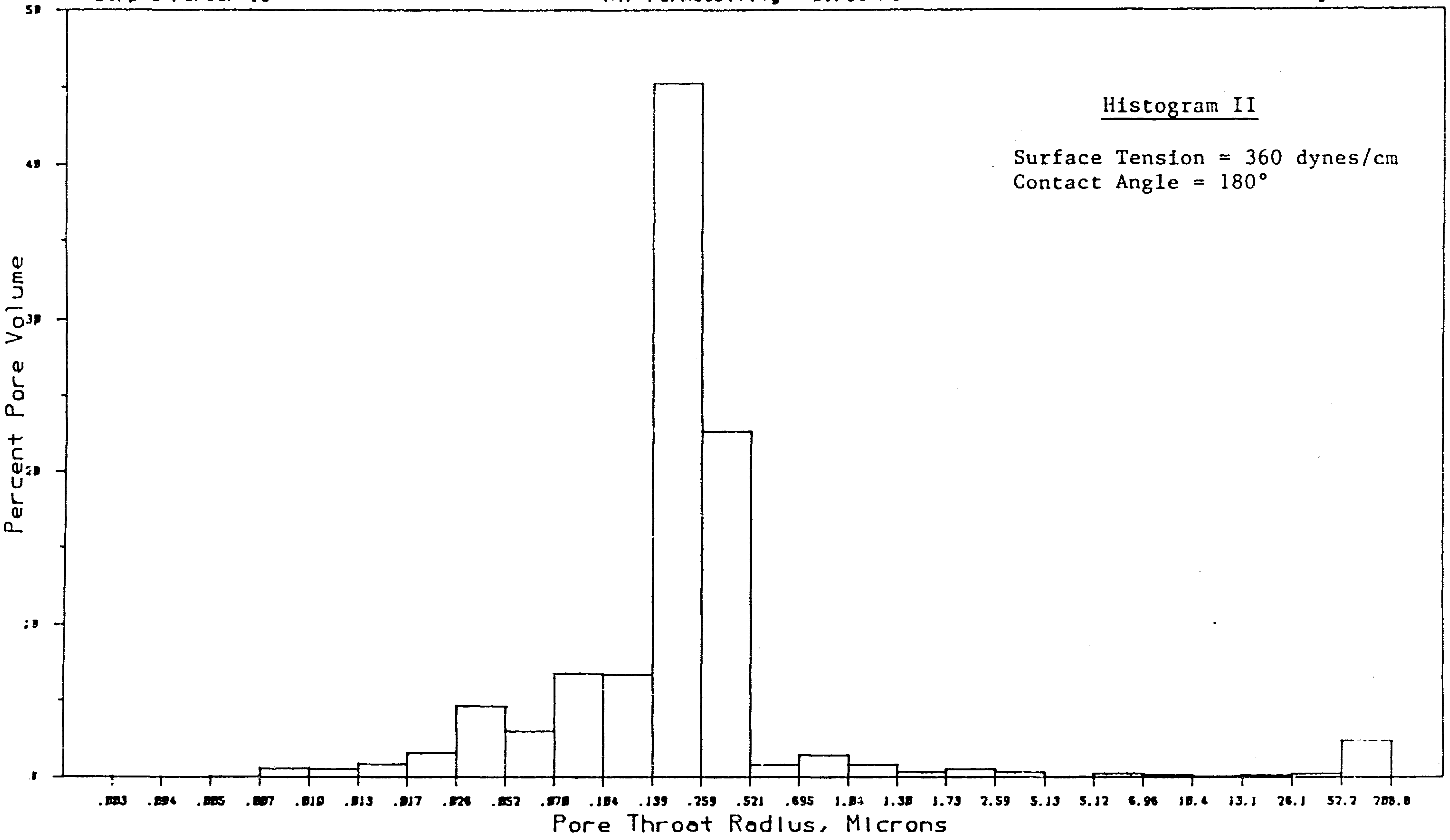
Sample Number 15    Air Permeability = 0.086 md    Porosity = 11.2%



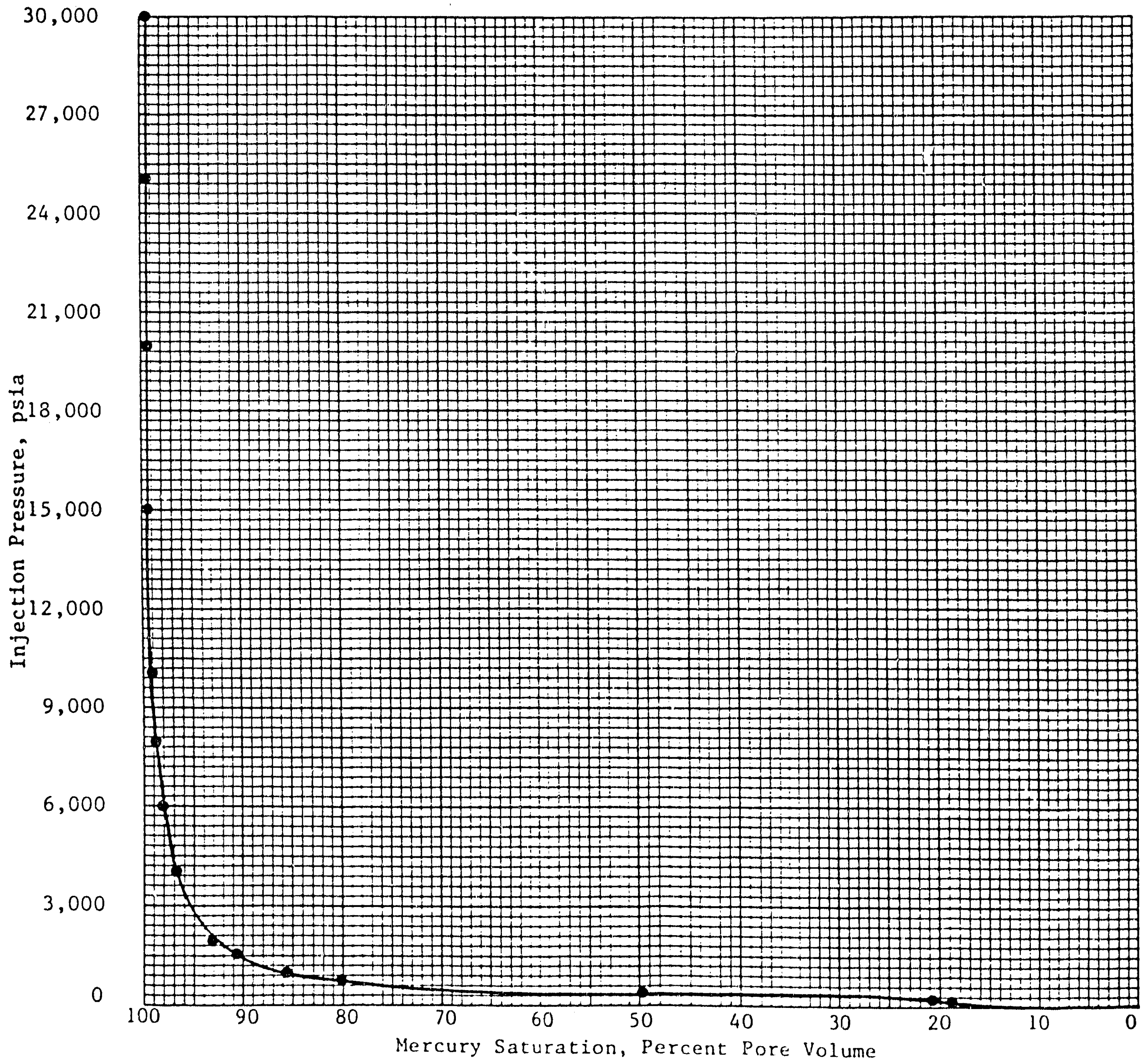
## MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 16

Air Permeability = 1.38 md

Porosity = 13.6%



**K & A**
**LABORATORIES**

# COMPUTED PORE SIZE HISTOGRAM
## INTERA TECHNOLOGIES INC.

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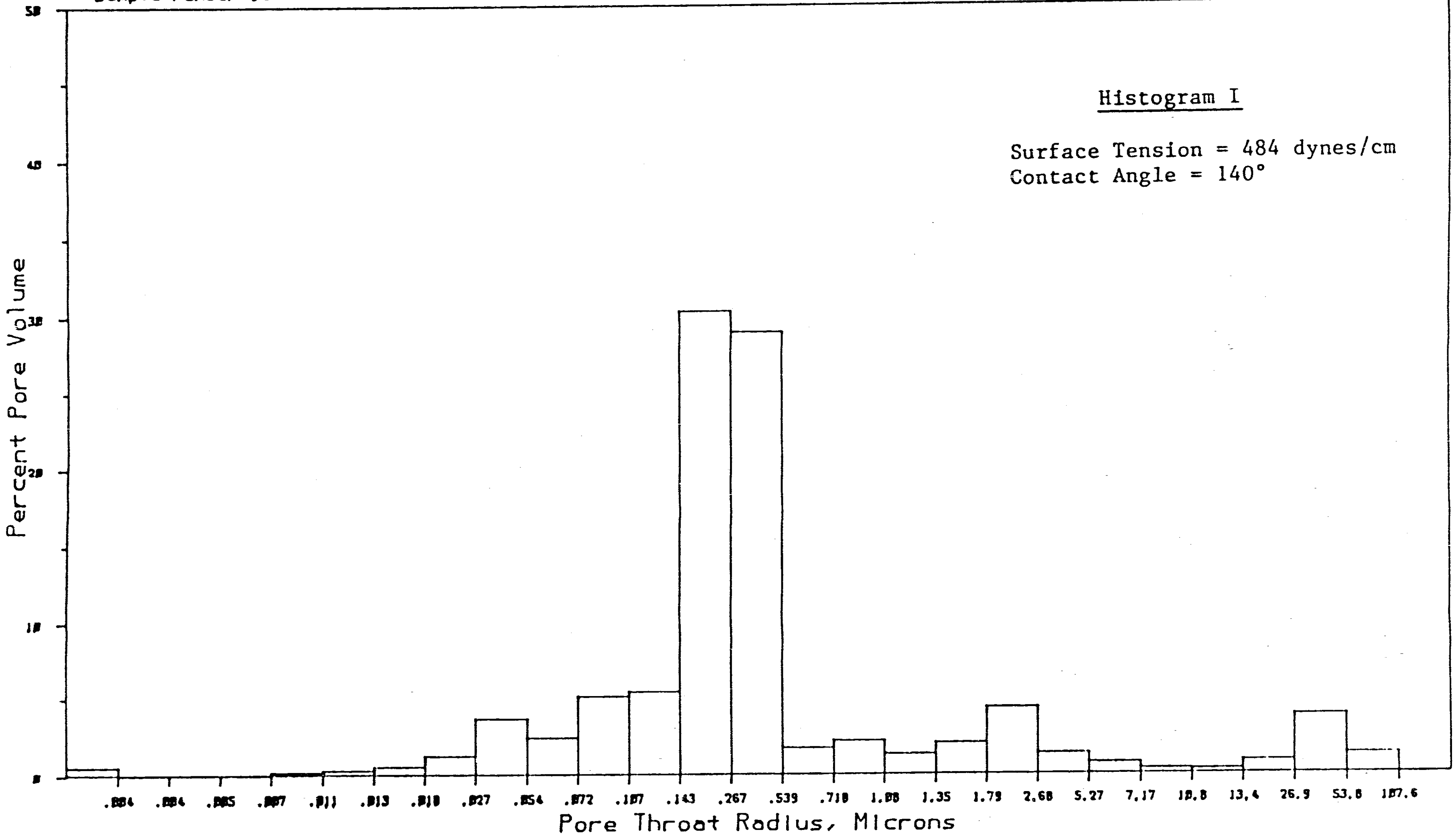
File 88-1056-14

Sample Number 16

Air Permeability = 1.38 md

Porosity = 13.6%



**K & A**
LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM

INTERA TECHNOLOGIES INC.

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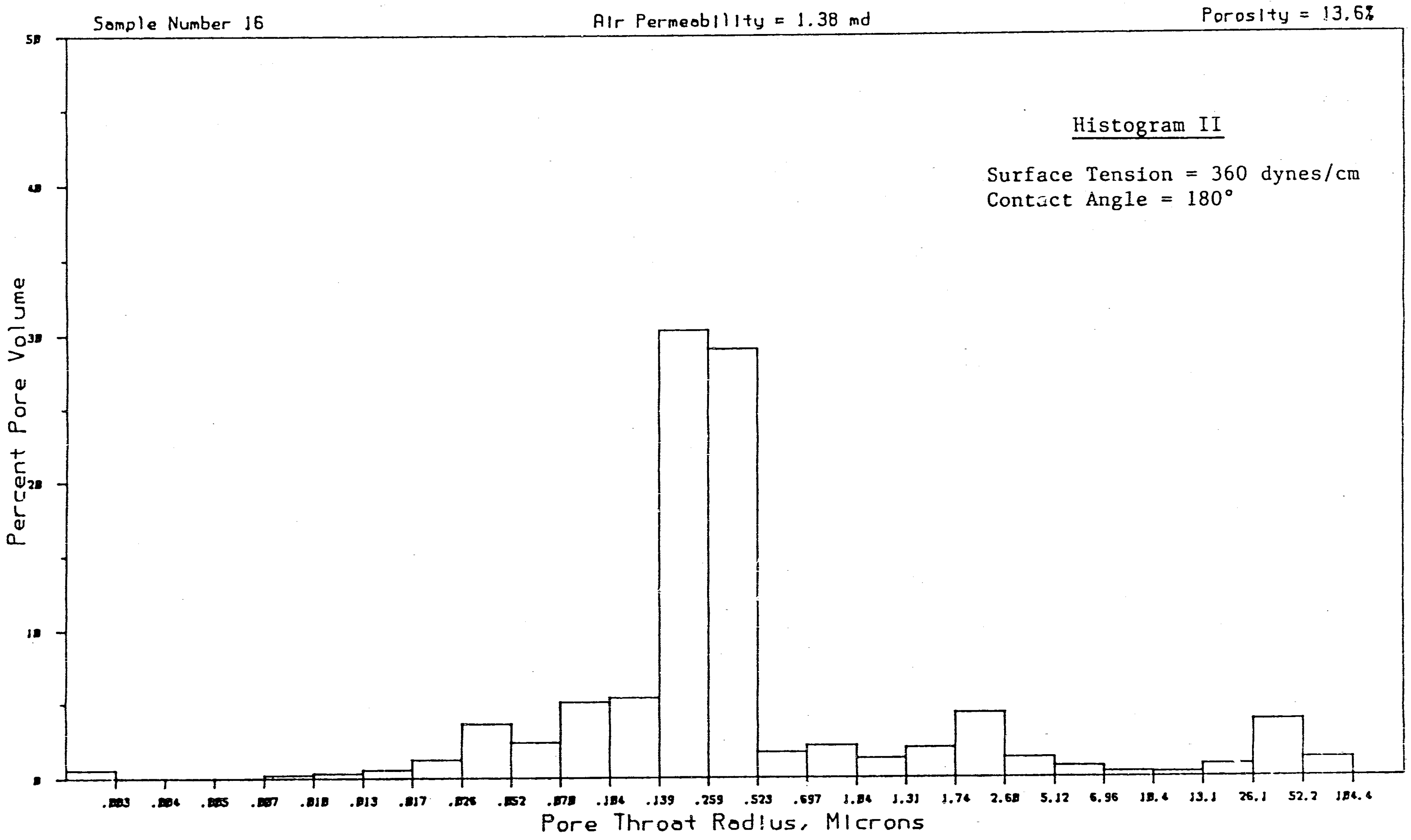


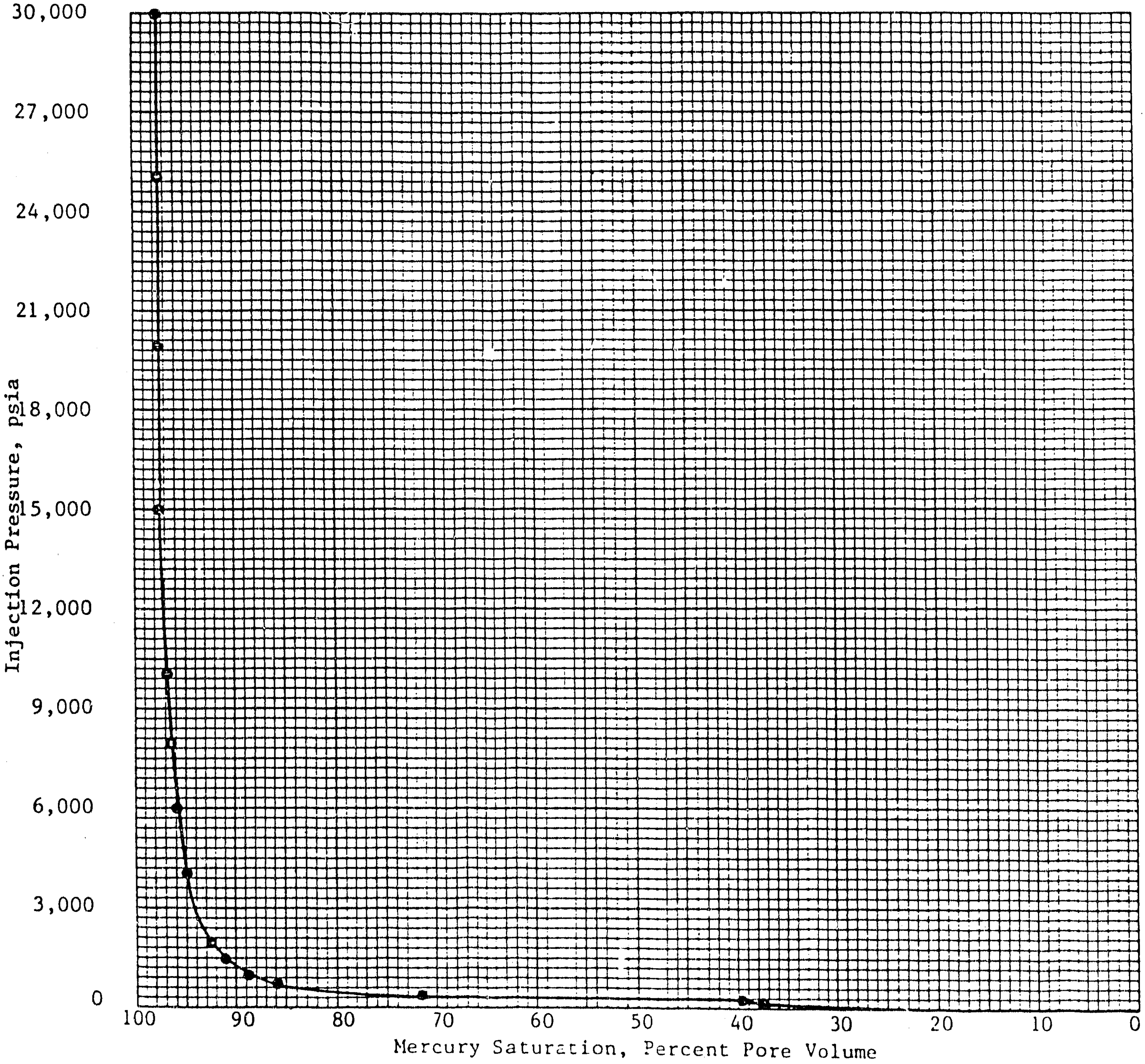
## MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 17

Air Permeability = 4.94 md

Porosity = 19.0%



**K & A**
LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM

## INTERA TECHNOLOGIES INC.

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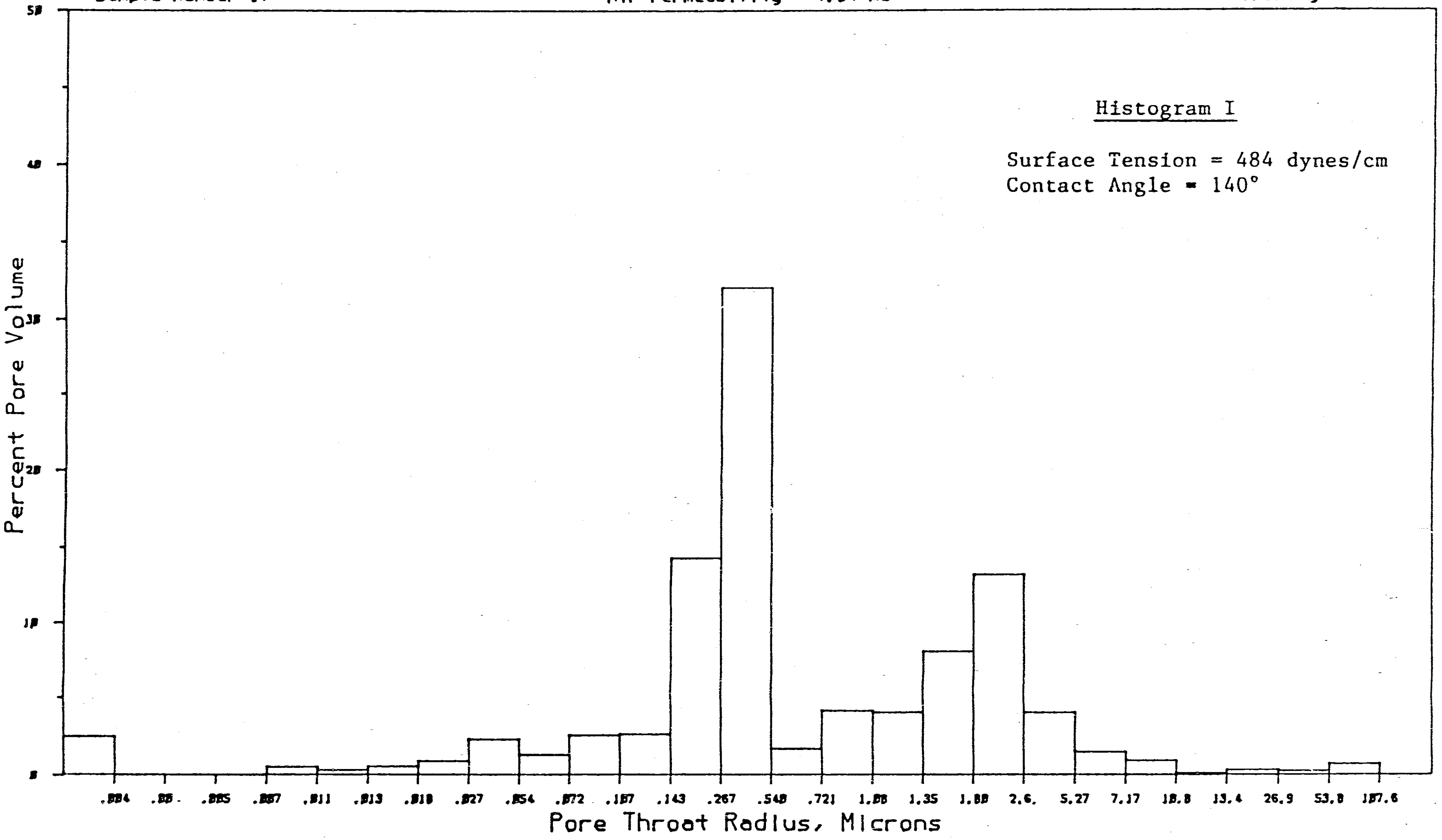
File 88-1056-14

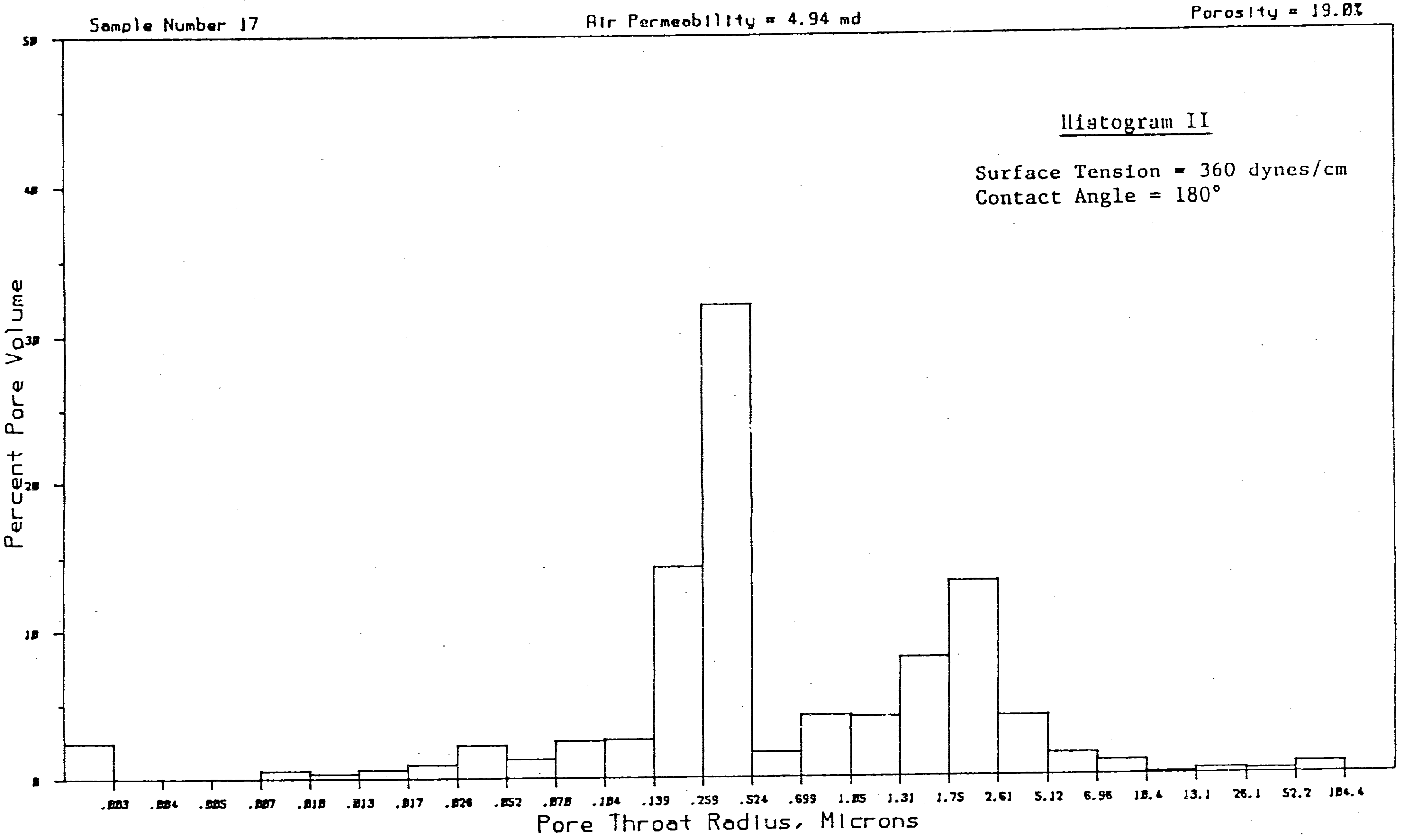
Sample Number 17 Air Permeability = 4.94 md Porosity = 19.0%



**K & A**
LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM

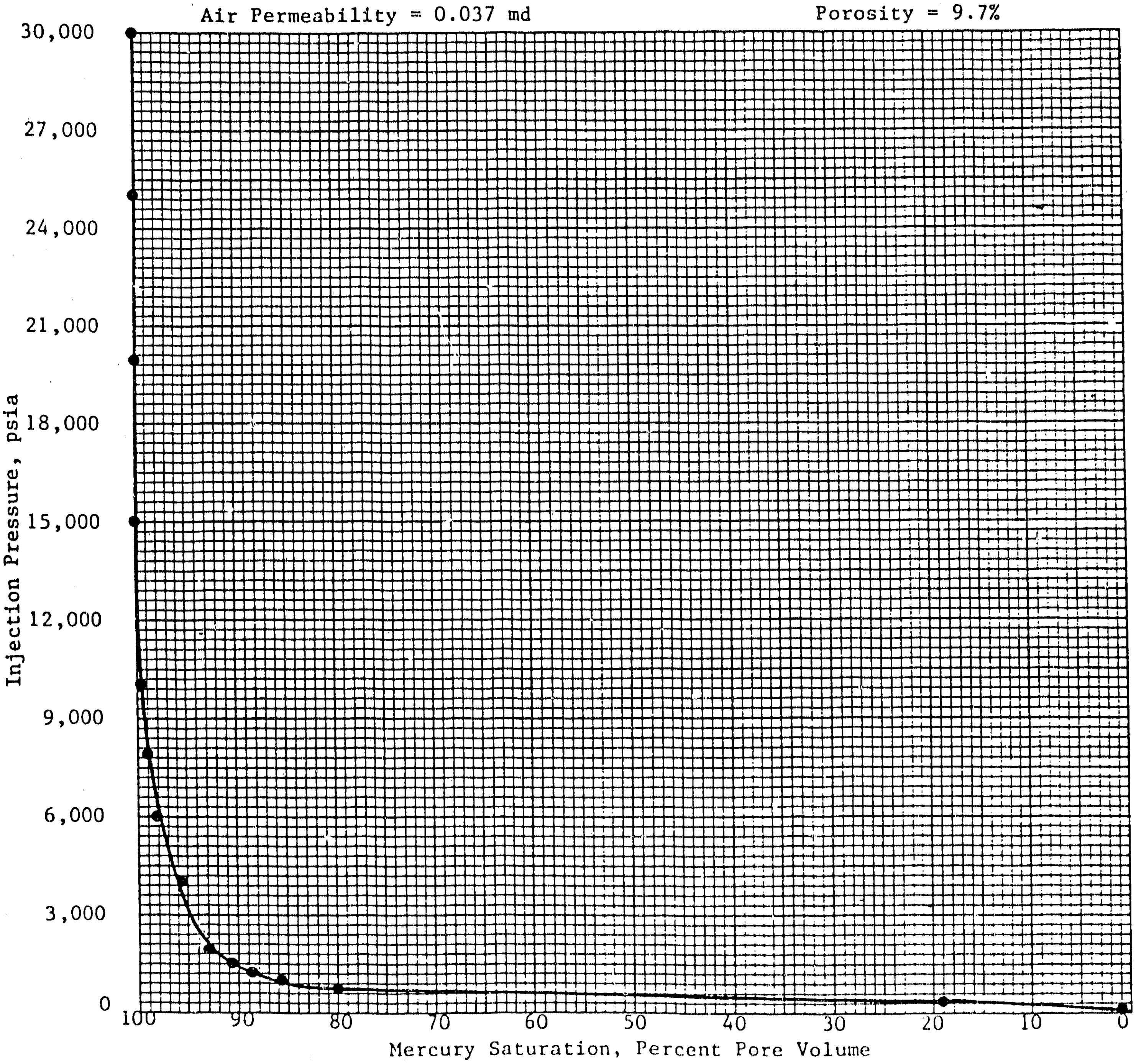
INTERA TECHNOLOGIES INC.



# MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 18



**K & A**
LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM

## INTERA TECHNOLOGIES

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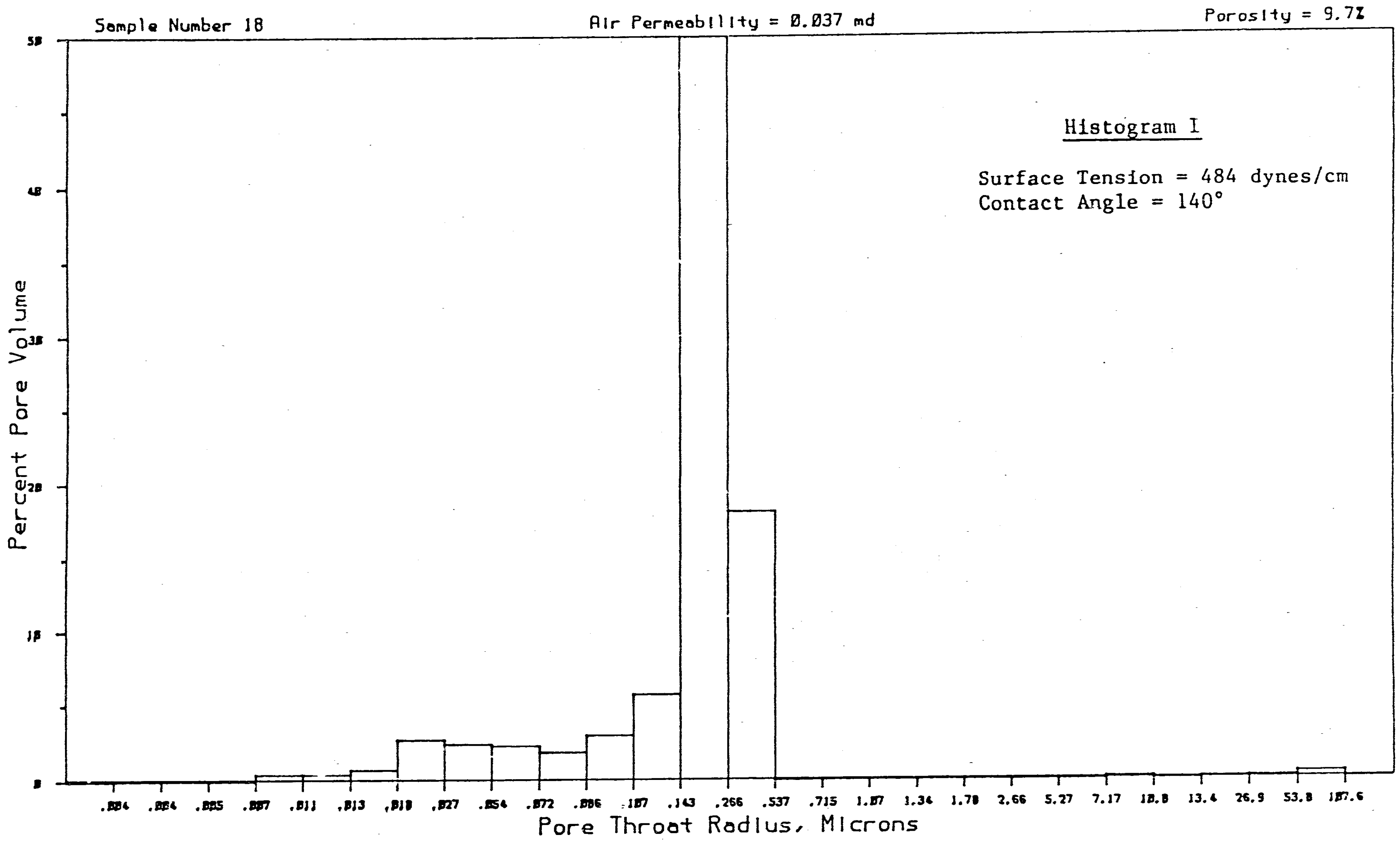
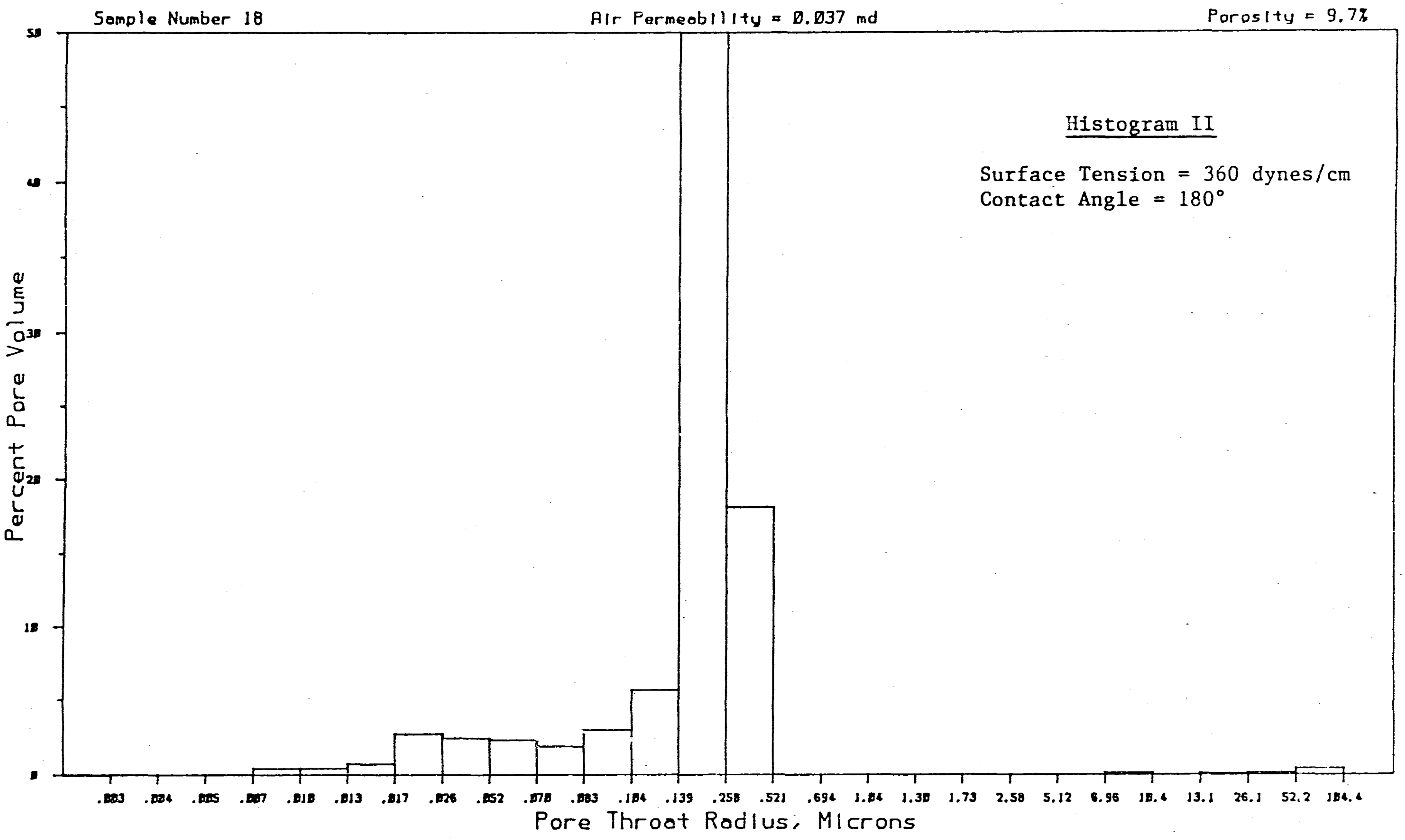


# COMPUTED PORE SIZE HISTOGRAM

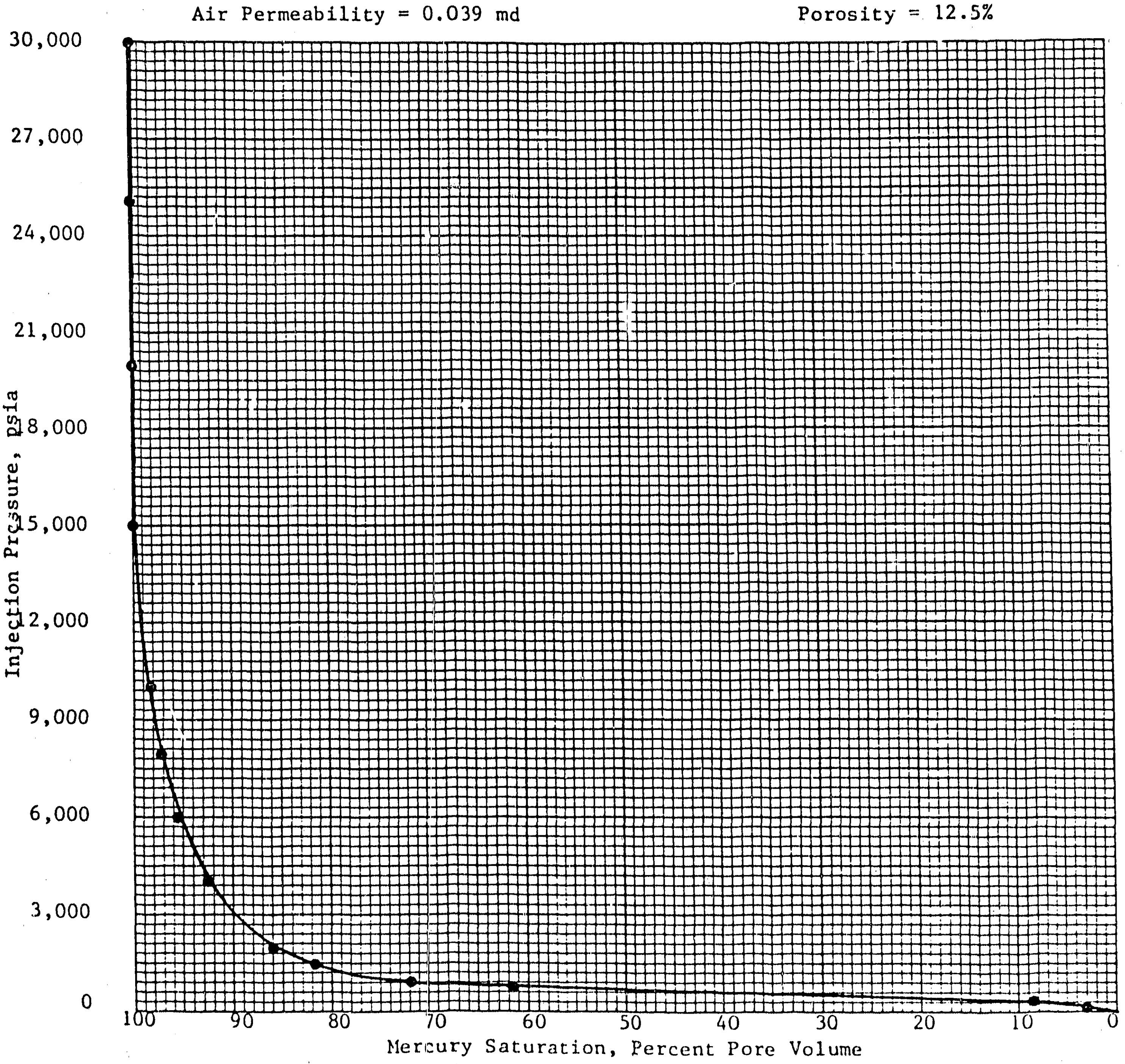
## INTERA TECHNOLOGIES



# MERCURY INJECTION TEST RESULTS

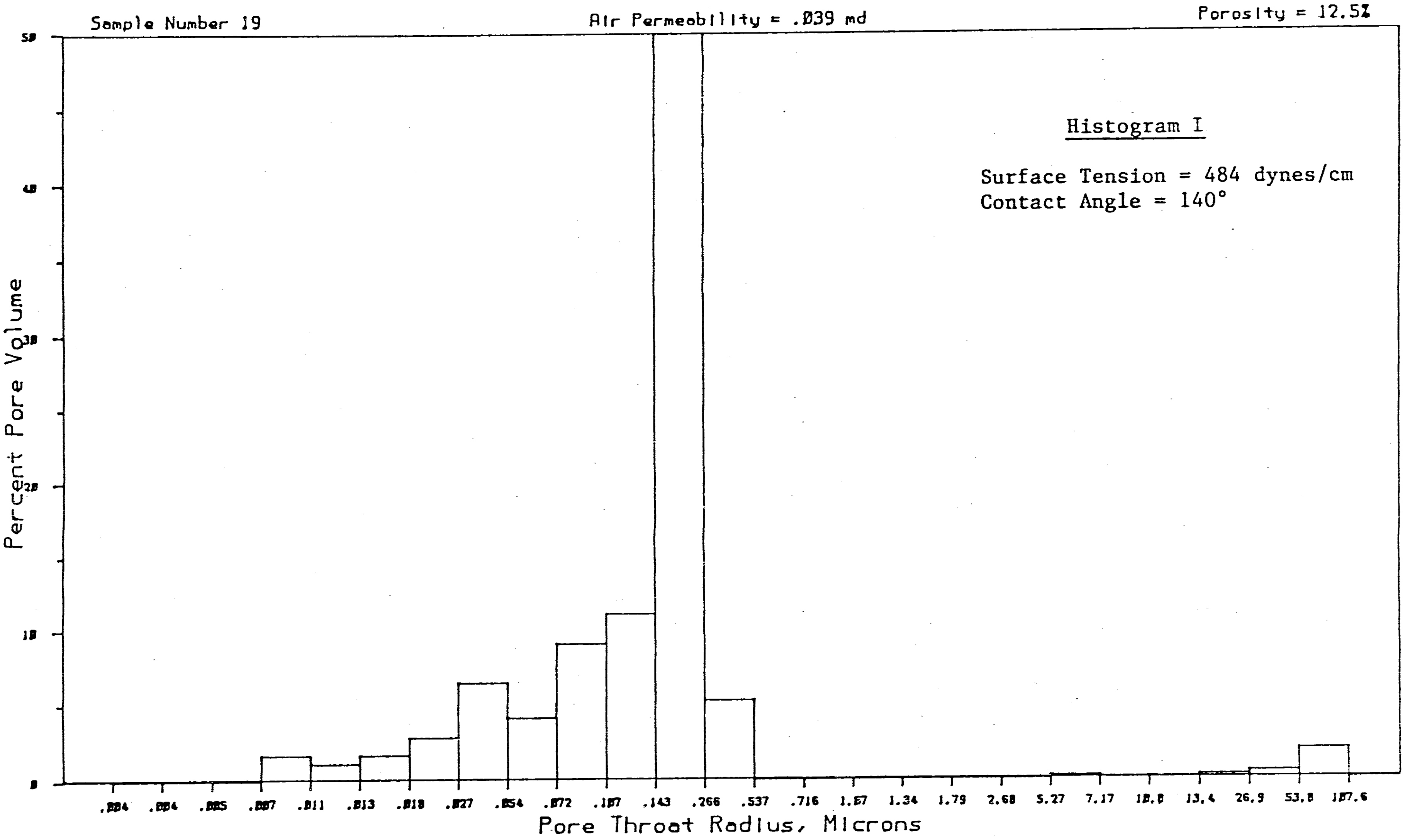
INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 19



# COMPUTED PORE SIZE HISTOGRAM

INTERA TECHNOLOGIES INC.



**K & A**
LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM
INTERA TECHNOLOGIES INC.

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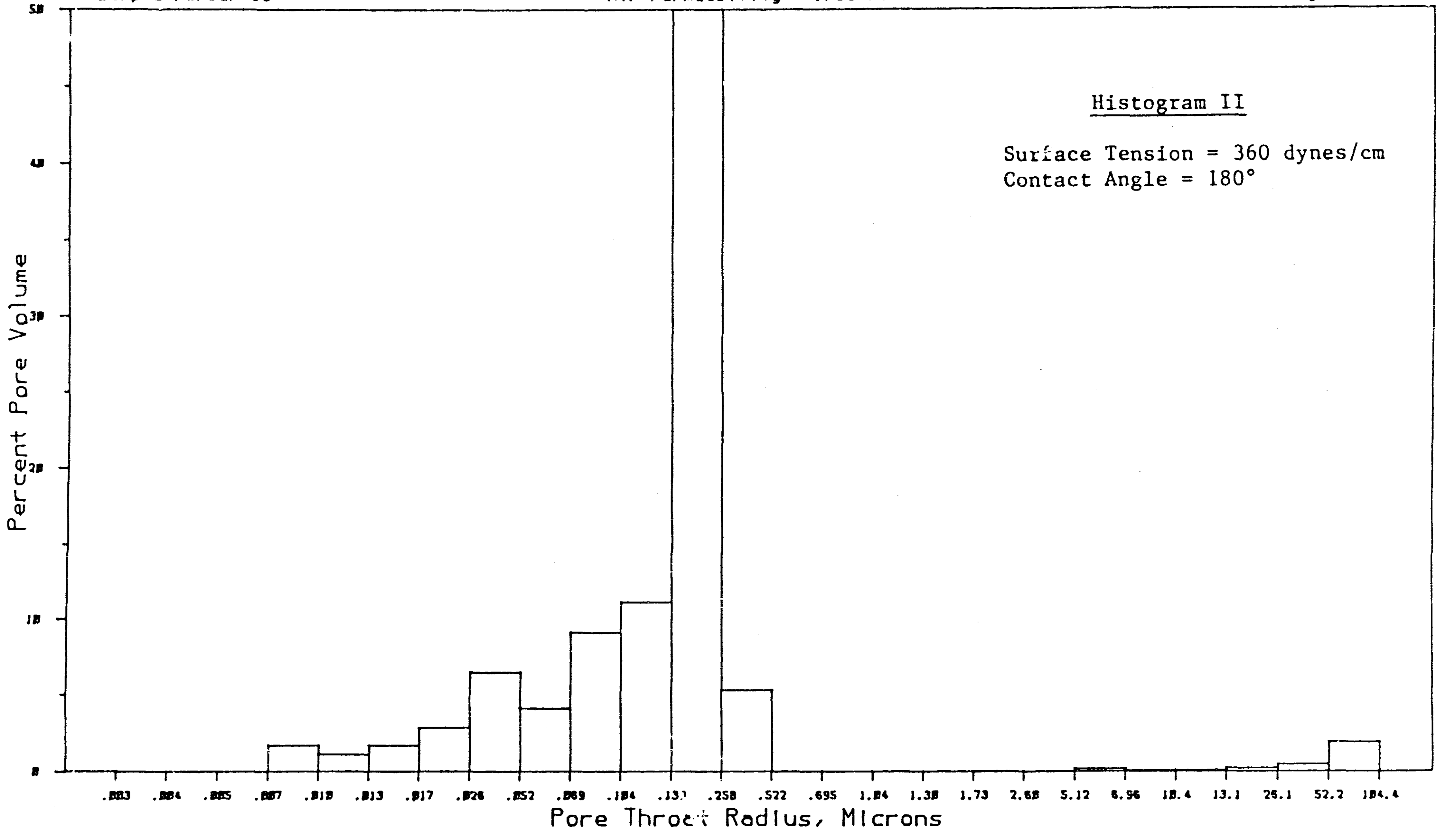
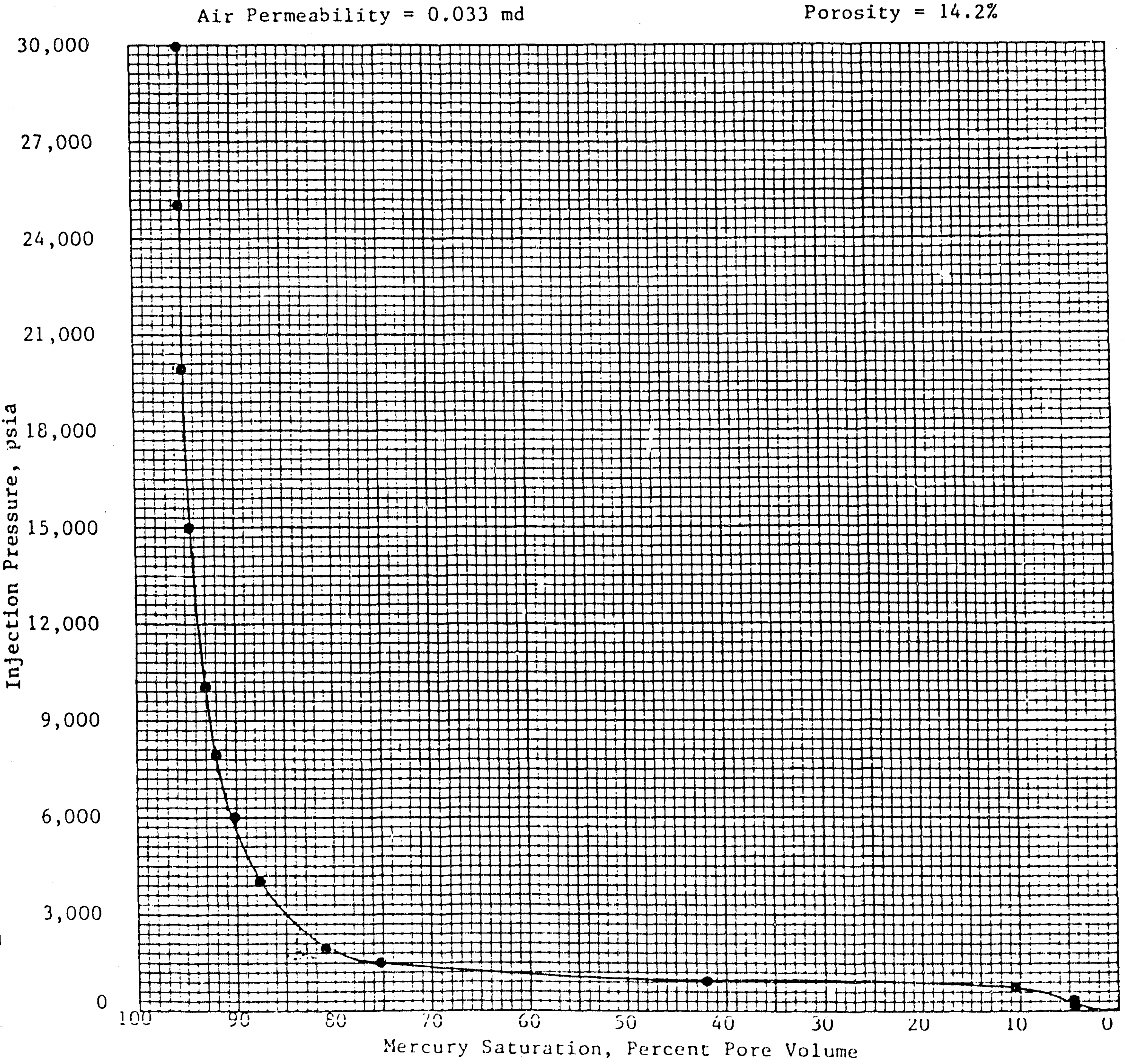
Sample Number 19 Air Permeability = .039 md Porosity = 12.5%



## MERCURY INJECTION TEST RESULTS

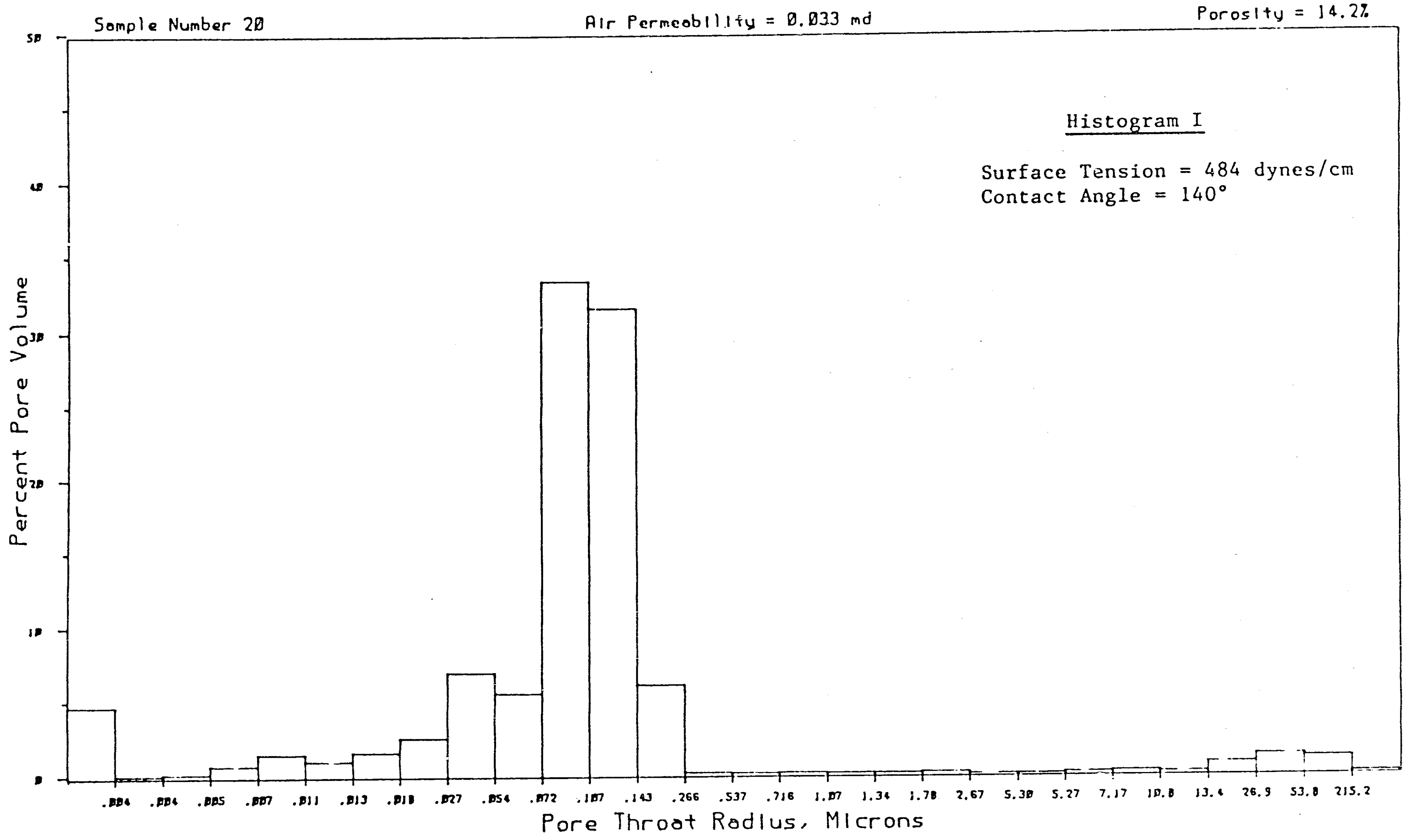
INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 20



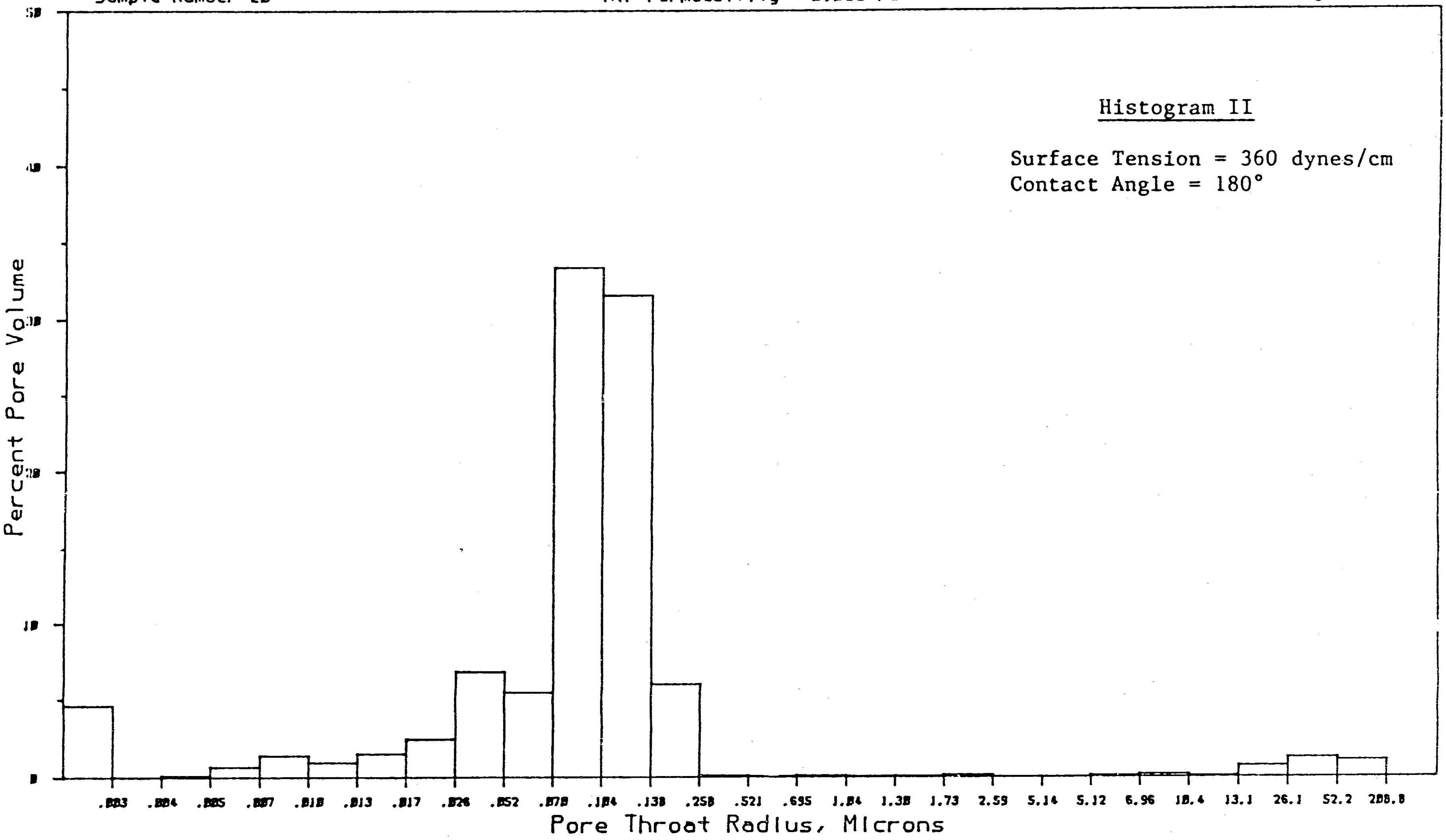
# COMPUTED PORE SIZE HISTOGRAM

INTERA TECHNOLOGIES INC.



# COMPUTED PORE SIZE HISTOGRAM
## INTERA TECHNOLOGIES INC.

Sample Number 20 Air Permeability = 0.033 md Porosity = 14.2%



Histogram II

Surface Tension = 360 dynes/cm
Contact Angle = 180°

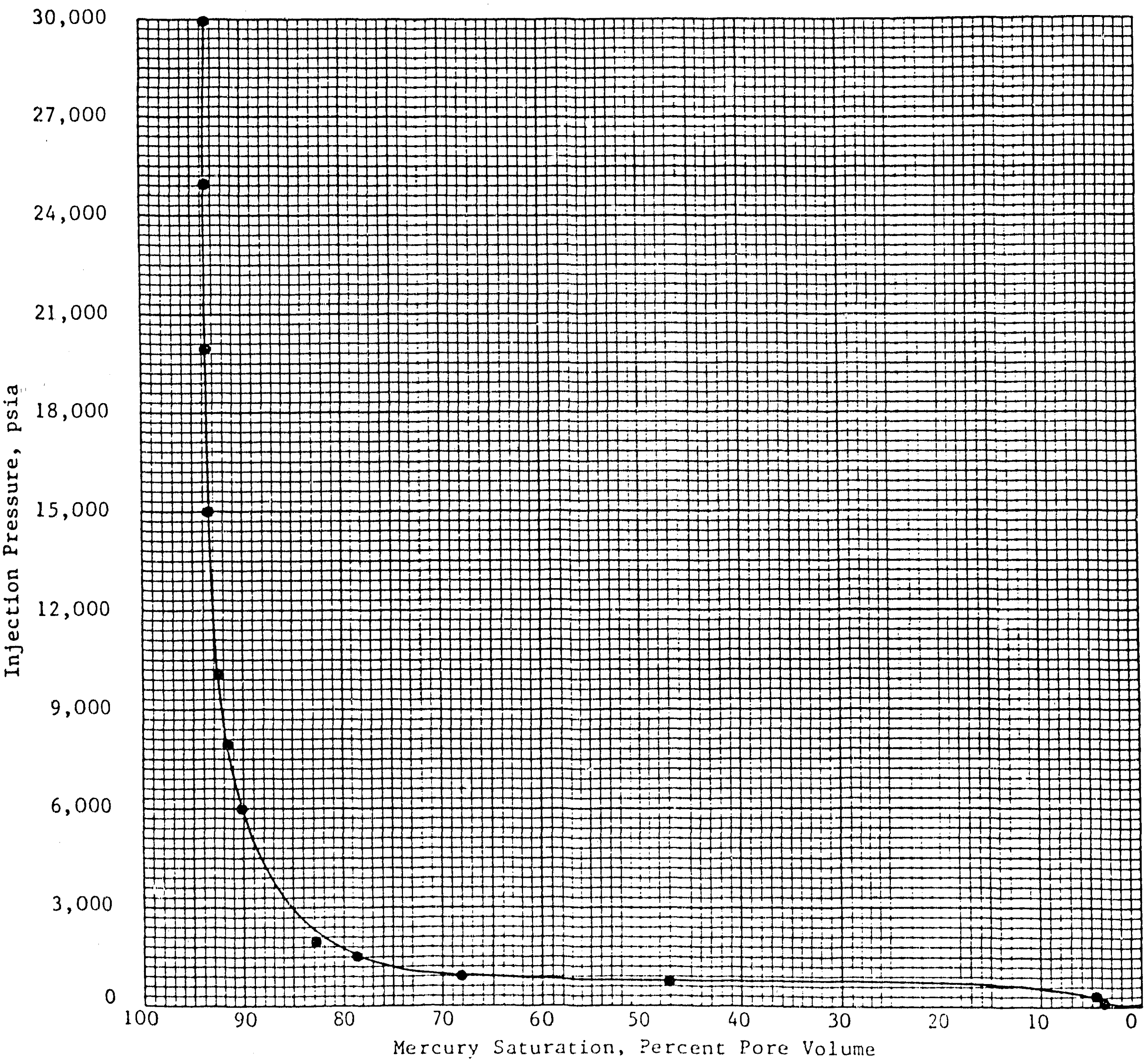
MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 21

Air Permeability = 0.038 md

Porosity = 13.0%



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**LABORATORIES**

# COMPUTED PORE SIZE HISTOGRAM

INTERA TECHNOLOGIES INC.

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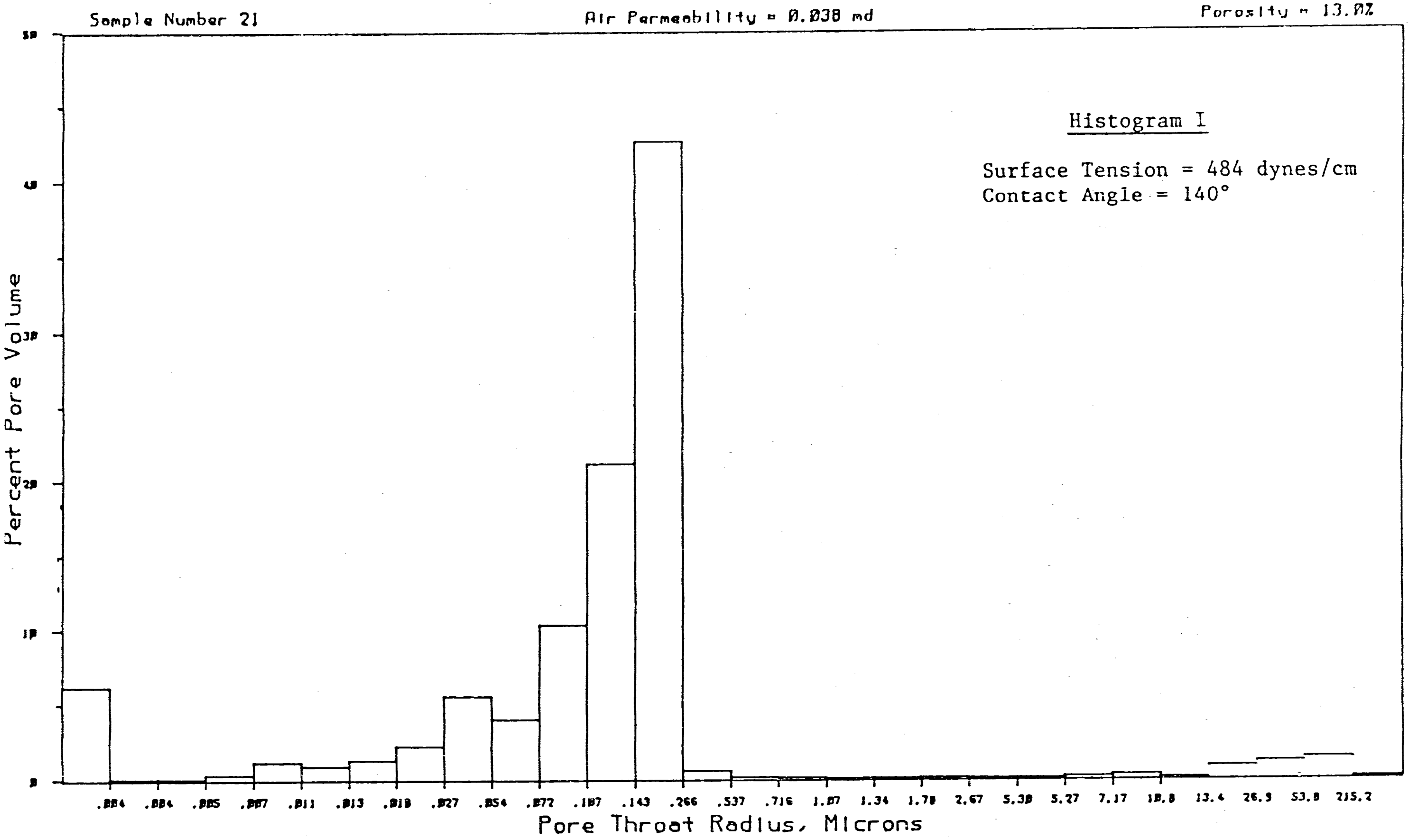
Sample Number 21 Air Permeability = 0.038 md Porosity = 13.0%



Histogram I

Surface Tension = 484 dynes/cm
Contact Angle = 140°

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**LABORATORIES**

# COMPUTED PORE SIZE HISTOGRAM

## INTERA TECHNOLOGIES

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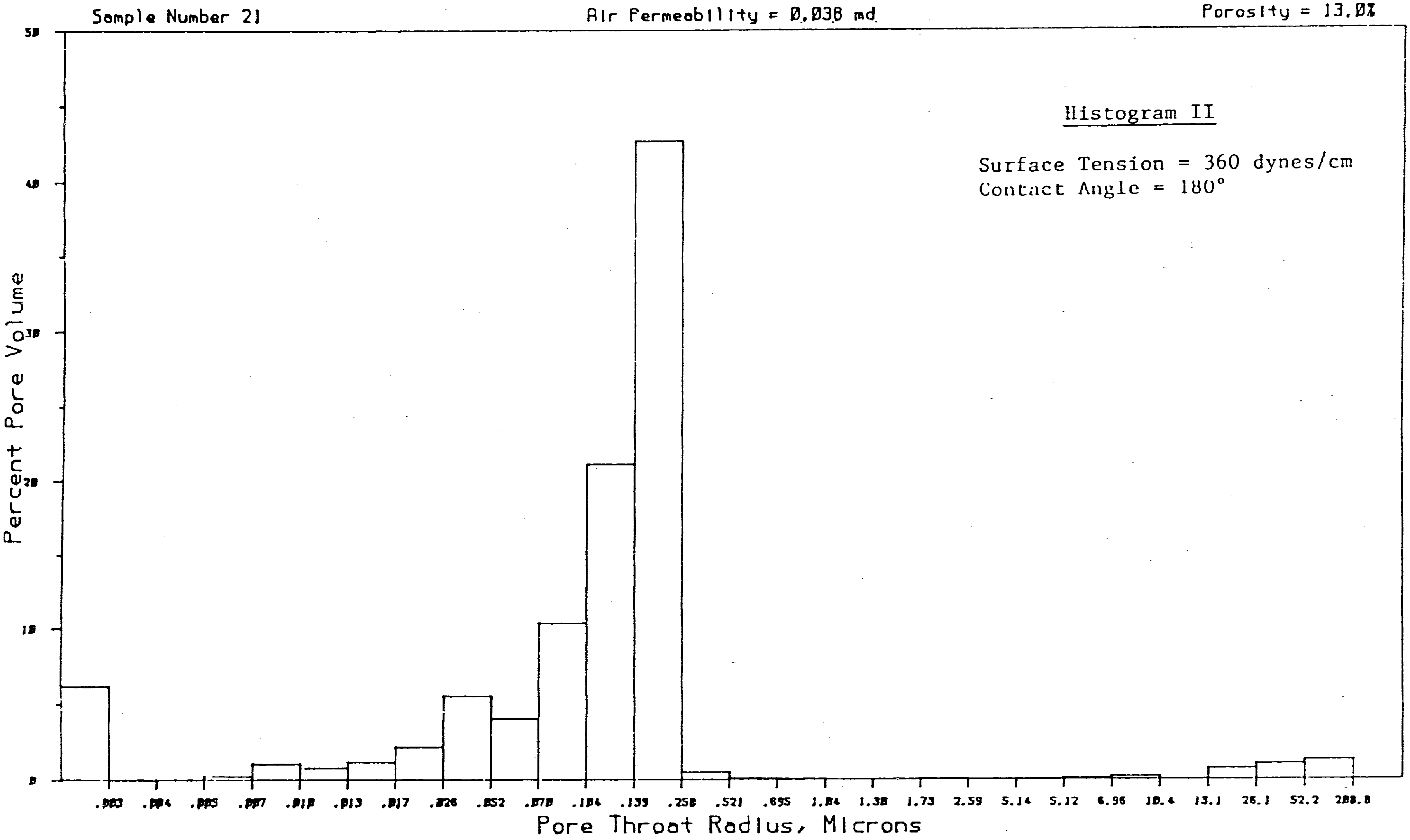


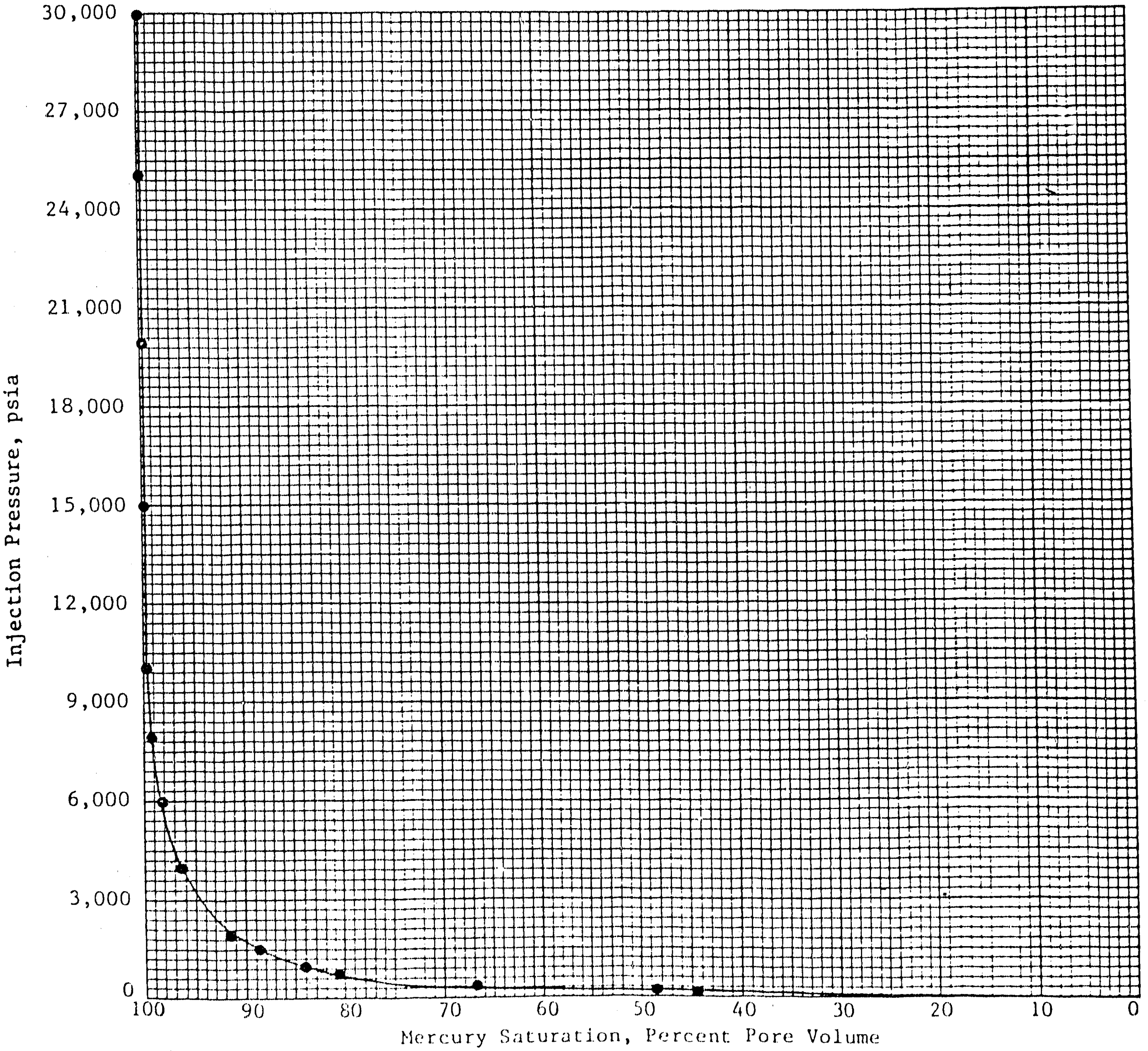
## MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 22

Air Permeability = 9.68 md

Porosity = 17.6%



**K & A**
LABORATORIES

# COMPUTED PORE SIZE HISTOGRAM

INTERA TECHNOLOGIES

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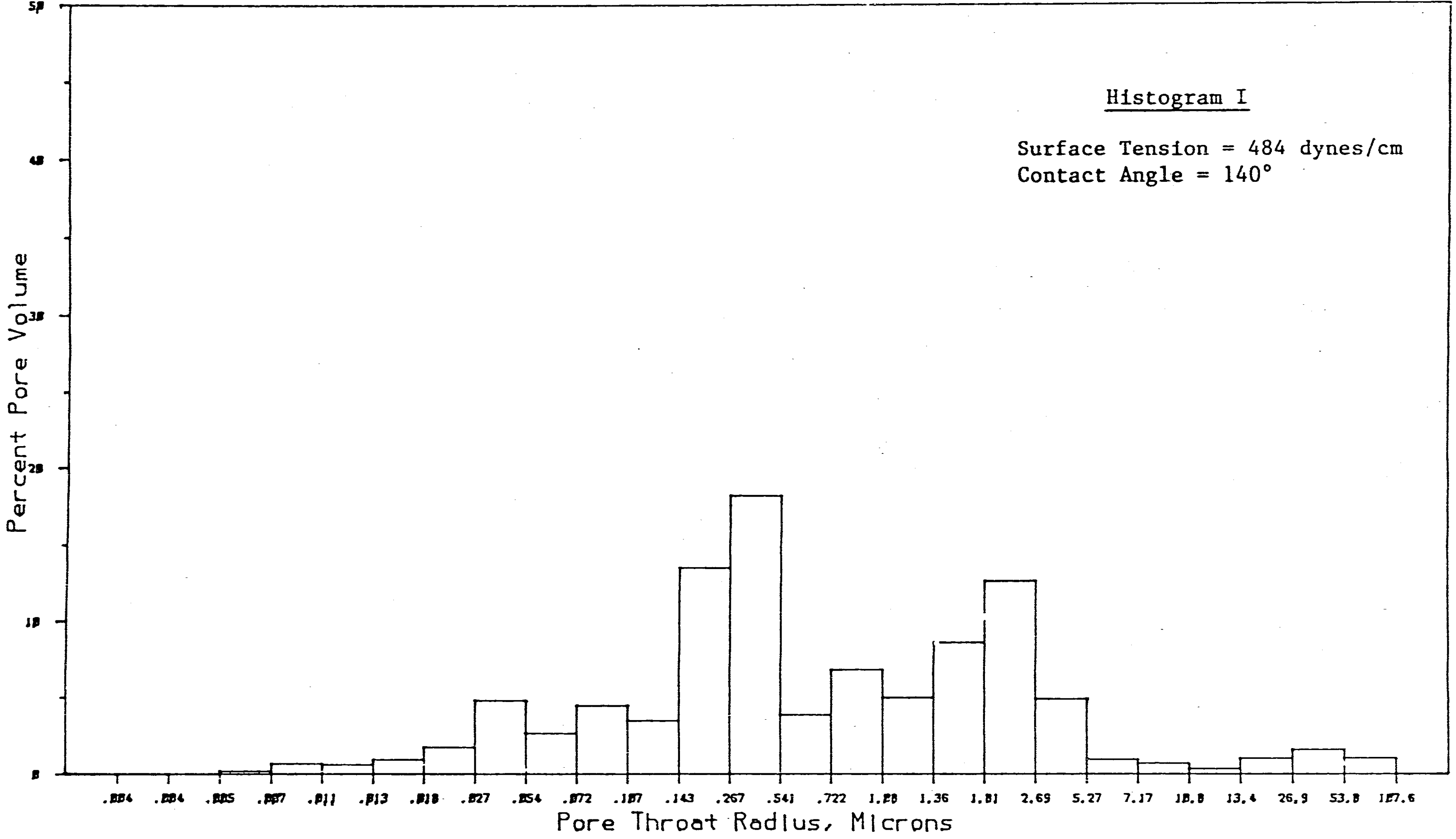
Sample Number 22

Air Permeability = 9.68 md

Porosity = 17.6%



**K & A**
**LABORATORIES**

# COMPUTED PORE SIZE HISTOGRAM
INTERA TECHNOLOGIES INC.

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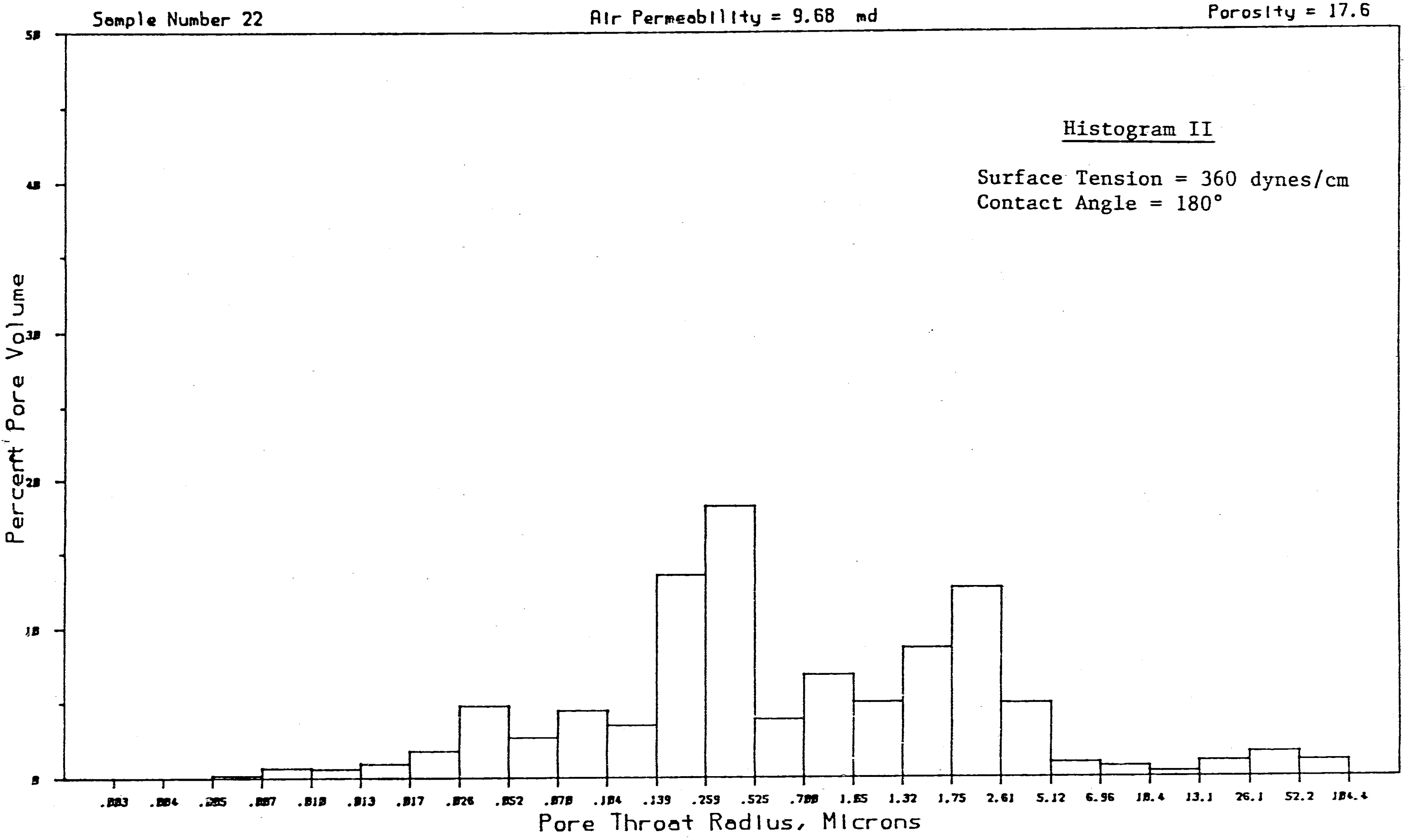
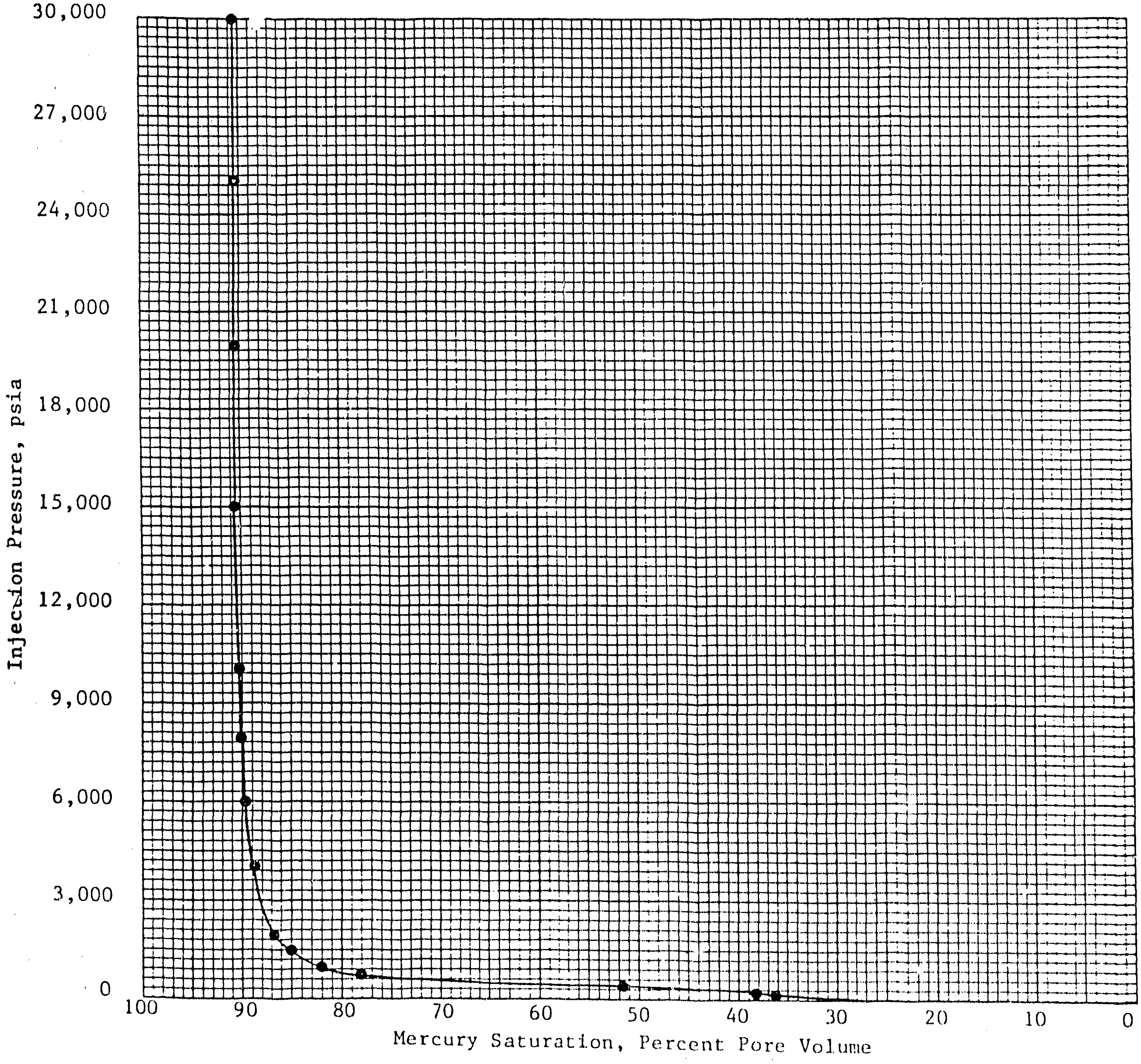


## MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 23

Air Permeability = 3.48 md Porosity = 15.8%



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**LABORATORIES**

# COMPUTED PORE SIZE HISTOGRAM
## INTERA TECHNOLOGIES

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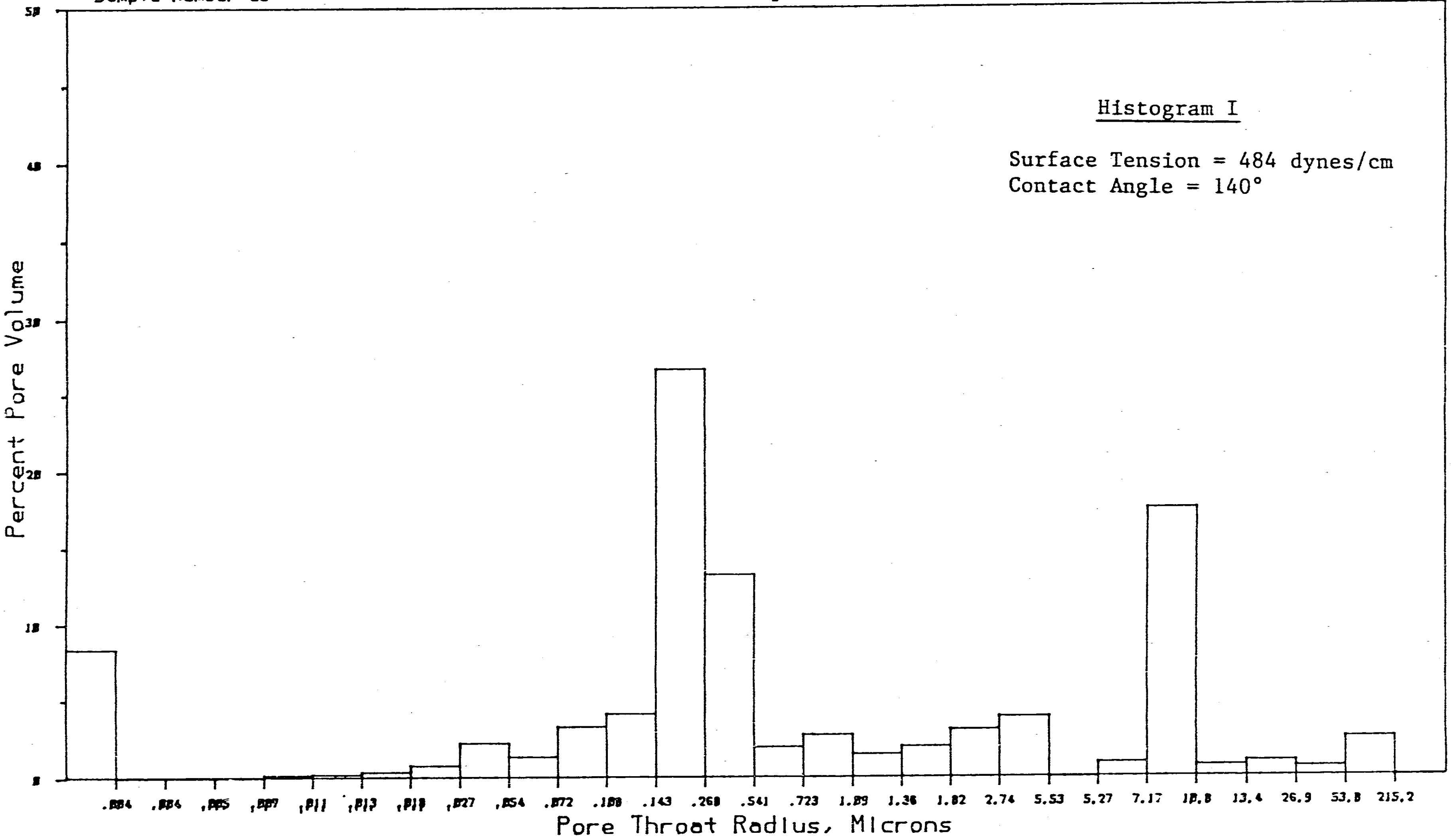
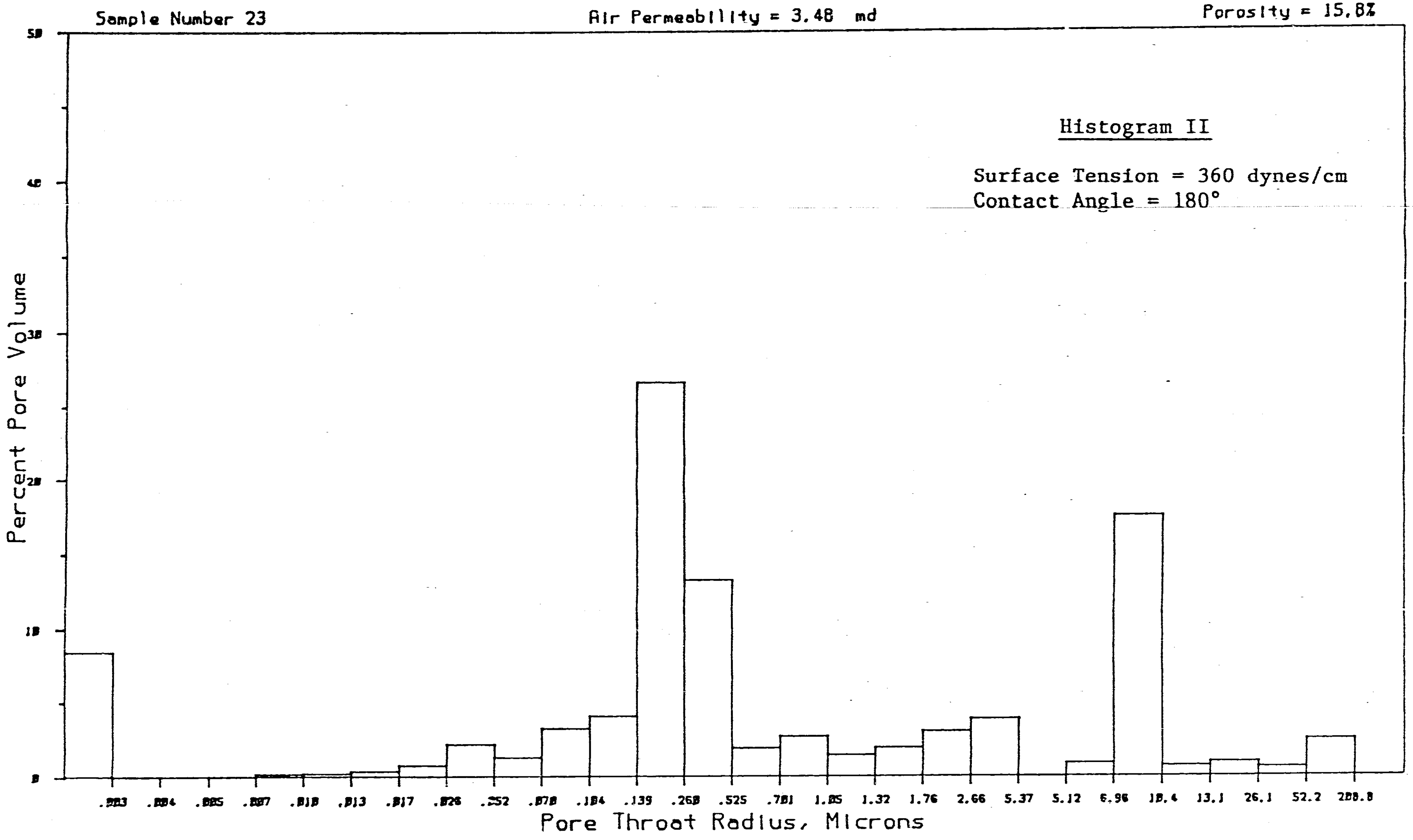
Sample Number 23 Air Permeability = 3.48 md Porosity = 15.8%



# COMPUTED PORE SIZE HISTOGRAM

## INTERA TECHNOLOGIES



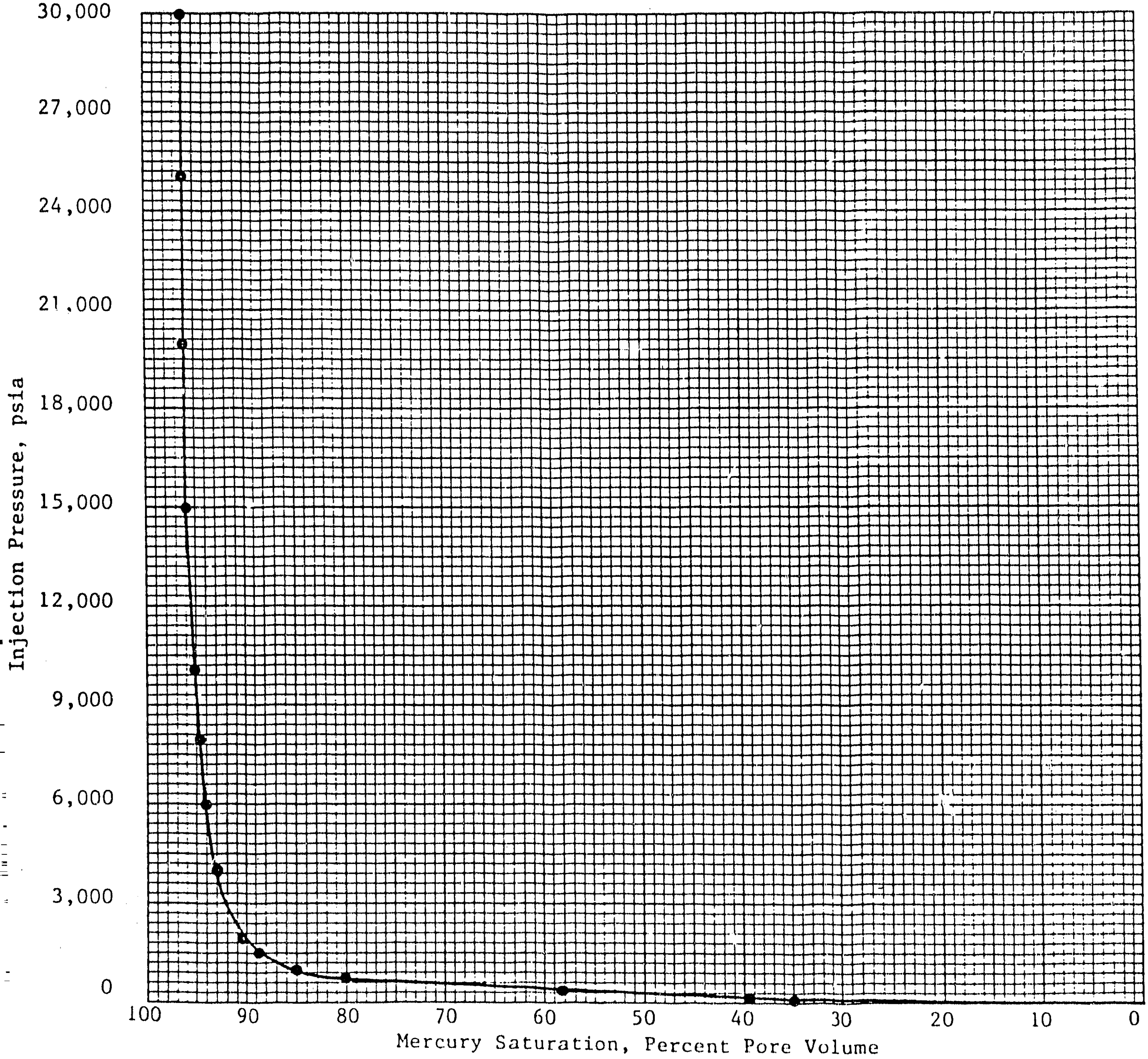
## MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

SAMPLE NUMBER 24

Air Permeability = 18.6 md

Porosity = 25.4%



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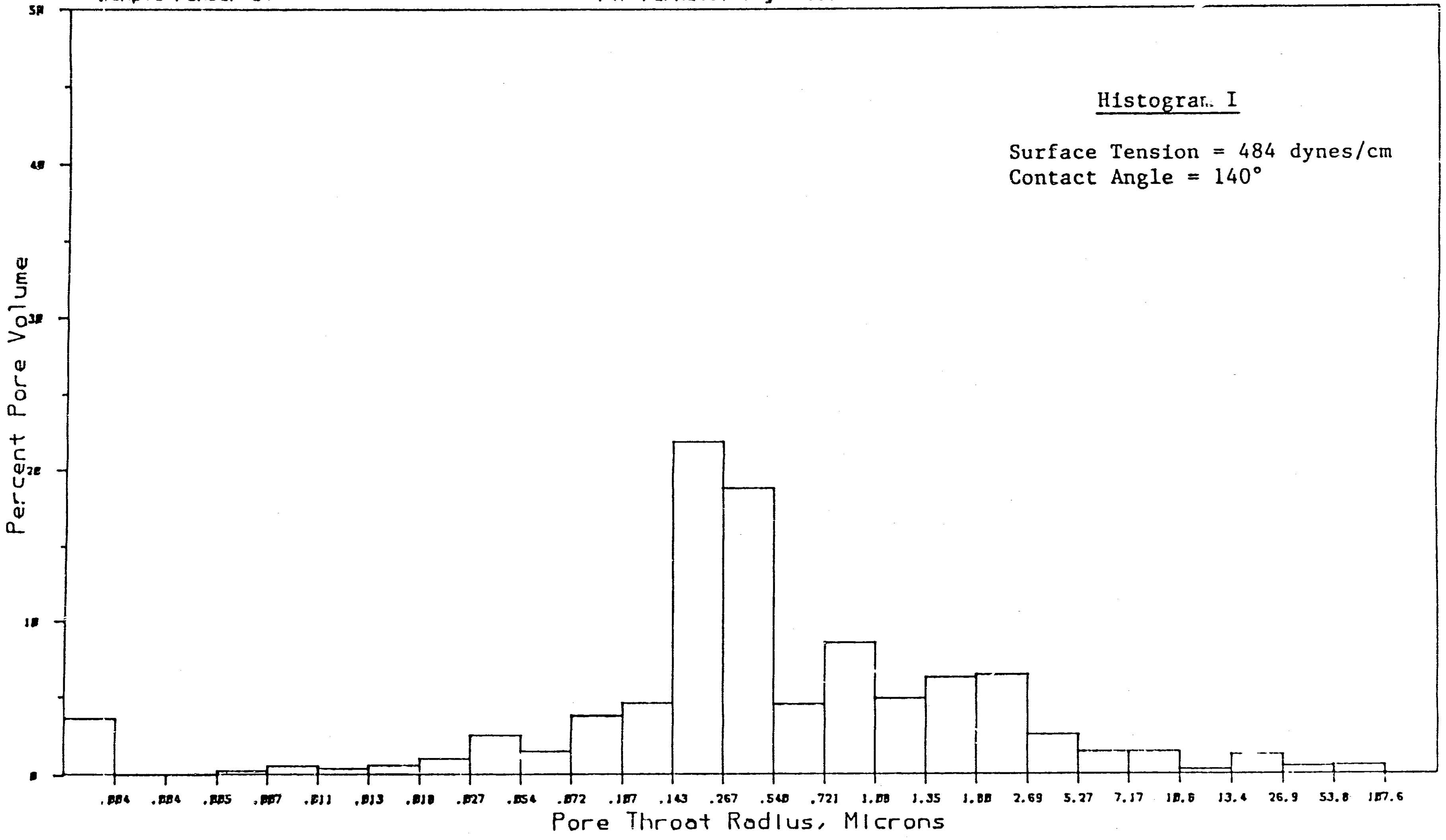
**LABORATORIES**

# COMPUTED PORE SIZE HISTOGRAM
## INTERA TECHNOLOGIES

Sample Number 24 Air Permeability = 18.6 md Porosity = 25.4%



Histogram I

Surface Tension = 484 dynes/cm
Contact Angle = 140°

**K & A**
LABORATORIES

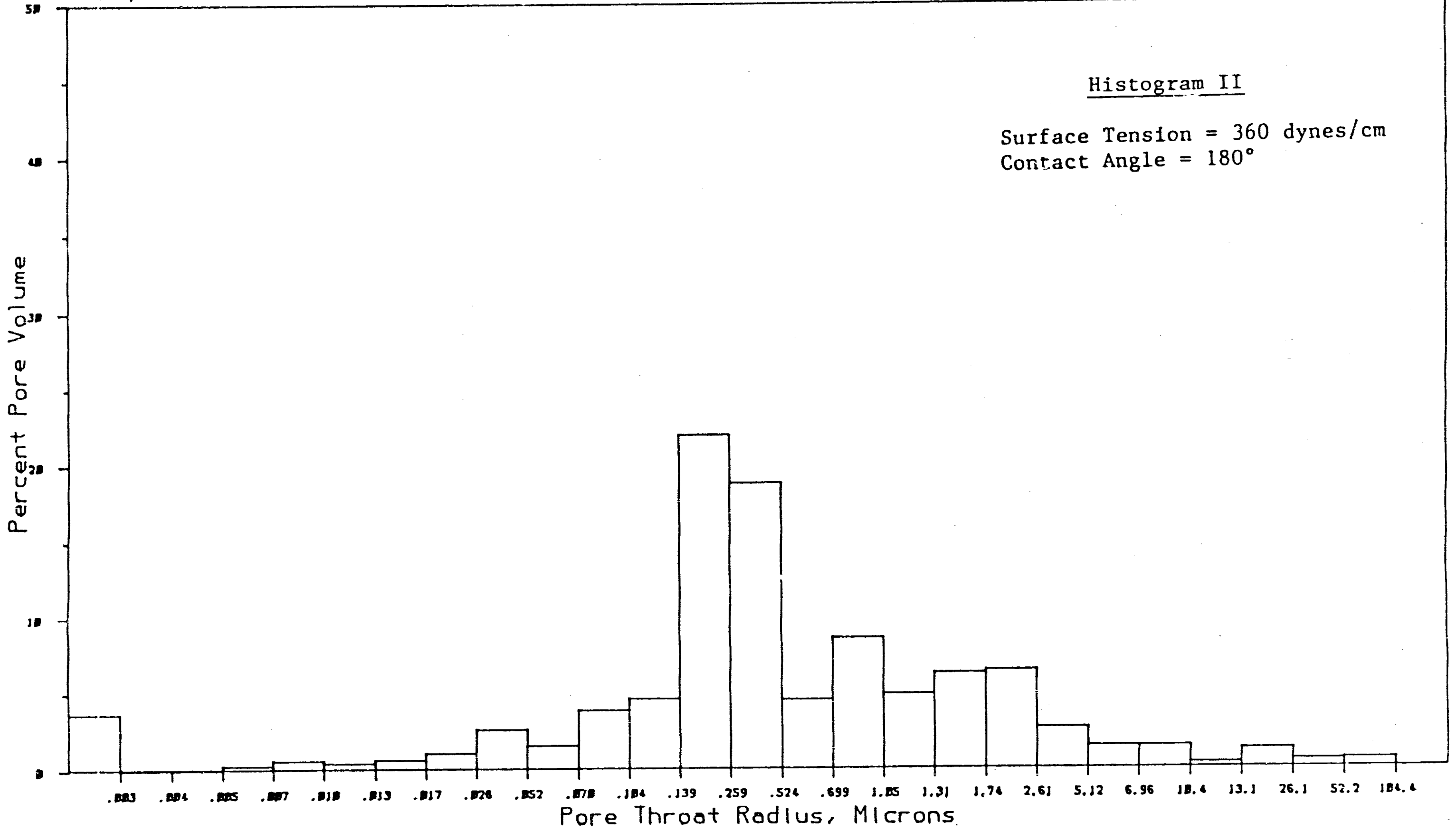
# COMPUTED PORE SIZE HISTOGRAM

## INTERA TECHNOLOGIES

Sample Number 24

Air Permeability = 18.6 md

Porosity = 25.4%



## HIGH PRESSURE MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

| Sample Number: | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Sample Identification Number: | H2A-2 | H2B1-2 | H5B1-1a | H5B1-1b |
| Air Permeability, md: | 0.143 | 1.18 | 1.18 | 0.042 |
| Porosity, Percent: | 12.5 | 14.8 | 13.0 | 15.5 |
| Injection Pressure, psia | Mercury Saturation, Percent Pore Volume | | | |
| 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1 | 0.0 | 0.0 | 0.3 | 0.0 |
| 2 | 0.4 | 0.2 | 0.7 | 0.0 |
| 4 | 0.9 | 0.4 | 2.6 | 0.2 |
| 8 | 1.3 | 0.9 | 3.6 | 0.4 |
| 10 | 1.5 | 1.2 | 3.8 | 1.0 |
| 15 | 1.9 | 1.6 | 4.5 | 2.8 |
| 20.4 | 3.1 | 1.9 | 5.3 | 3.5 |
| 40 | 4.2 | 2.5 | 5.8 | 4.3 |
| 60 | 6.9 | 5.7 | 6.2 | 4.9 |
| 80 | 9.0 | 9.1 | 6.5 | 5.3 |
| 100 | 10.6 | 12.6 | 6.6 | 5.3 |
| 150 | 13.2 | 20.5 | 6.9 | 5.8 |
| 200 | 14.6 | 24.9 | 7.0 | 6.7 |
| 400 | 21.8 | 51.8 | 14.5 | 17.6 |
| 750 | 44.2 | 76.8 | 74.6 | 77.0 |
| 1,000 | 61.1 | 82.1 | 81.4 | 82.5 |
| 1,500 | 71.6 | 88.5 | 86.7 | 87.4 |
| 2,000 | 75.6 | 92.0 | 89.1 | 89.4 |
| 4,000 | 81.4 | 97.0 | 92.5 | 92.7 |
| 6,000 | 84.0 | 98.5 | 93.7 | 93.9 |
| 8,000 | 85.5 | 99.3 | 94.4 | 94.5 |
| 10,000 | 86.6 | 99.7 | 94.7 | 94.9 |
| 15,000 | 88.0 | 99.7 | 95.0 | 95.3 |
| 20,000 | 88.5 | 99.7 | 95.0 | 95.3 |
| 25,000 | 88.5 | 99.7 | 95.0 | 95.3 |
| 30,000 | 88.5 | 99.7 | 95.0 | 95.3 |

## HIGH PRESSURE MERCURY INJECTION TEST RESULTS

### INTERA TECHNOLOGIES, INC.

| Sample Number: | 5 | 6 | 7 | 8 |
|---|---|---|---|---|
| Sample Identification Number: | H7B1-2a | H7B1-2b | H7B2-1 | H7C-1b |
| Air Permeability, md: | 0.108 | 0.521 | 0.294 | 0.074 |
| Porosity, Percent: | 21.5 | 27.8 | 17.3 | 16.5 |
| Injection Pressure, psia | Mercury Saturation, Percent Pore Volume | | | |
| 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1 | 0.4 | 1.5 | 0.0 | 0.4 |
| 2 | 0.7 | 22.5 | 0.6 | 0.7 |
| 4 | 5.0 | 23.3 | 1.5 | 1.2 |
| 8 | 5.8 | 24.0 | 2.3 | 2.2 |
| 10 | 9.5 | 24.2 | 2.5 | 2.3 |
| 15 | 9.9 | 24.6 | 2.7 | 2.7 |
| 20.4 | 10.3 | 25.6 | 3.0 | 3.2 |
| 40 | 12.2 | 29.3 | 3.1 | 4.1 |
| 60 | 23.0 | 35.0 | 3.1 | 5.2 |
| 80 | 24.9 | 38.8 | 3.3 | 6.0 |
| 100 | 25.6 | 41.0 | 3.4 | 6.8 |
| 150 | 35.7 | 42.7 | 3.7 | 15.7 |
| 200 | 36.5 | 44.1 | 5.4 | 16.2 |
| 400 | 46.8 | 60.1 | 63.2 | 33.9 |
| 750 | 86.7 | 88.4 | 81.7 | 77.9 |
| 1,000 | 90.7 | 92.1 | 85.9 | 83.8 |
| 1,500 | 91.5 | 95.2 | 89.0 | 83.9 |
| 2,000 | 91.6 | 96.5 | 91.4 | 84.0 |
| 4,000 | 91.6 | 98.3 | 94.2 | 93.1 |
| 6,000 | 91.6 | 98.8 | 95.3 | 94.0 |
| 8,000 | 91.6 | 99.2 | 95.8 | 94.4 |
| 10,000 | 91.6 | 99.3 | 96.2 | 94.7 |
| 15,000 | 91.6 | 99.5 | 96.5 | 94.8 |
| 20,000 | 91.6 | 99.5 | 96.5 | 94.8 |
| 25,000 | 91.6 | 99.5 | 96.5 | 94.8 |
| 30,000 | 91.6 | 99.5 | 96.5 | 94.8 |

## HIGH PRESSURE MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

| | | | | |
|---|---|---|---|---|
| Sample Number: | 9 | 10 | 11 | 12 |
| Sample Idenitifcation Number: | H7C-1c | H10B-1 | H11-2 | H11B3-1 |
| Air Permeability, md: | 0.098 | 0.012 | 0.038 | 1.33 |
| Porosity, Percent: | 13.4 | 10.8 | 11.0 | 33.1 |

| Injection Pressure, psia | Mercury Saturation, Percent Pore Volume | | | |
|---|---|---|---|---|
| 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1 | 0.3 | 0.0 | 0.0 | 0.0 |
| 2 | 0.6 | 0.1 | 1.1 | 3.3 |
| 4 | 0.8 | 0.2 | 1.6 | 4.2 |
| 8 | 4.5 | 0.5 | 2.0 | 5.5 |
| 10 | 8.1 | 0.6 | 2.0 | 7.0 |
| 15 | 8.5 | 0.8 | 2.2 | 7.5 |
| 20.4 | 8.7 | 1.0 | 2.3 | 7.8 |
| 40 | 8.8 | 1.0 | 2.3 | 10.7 |
| 60 | 9.7 | 1.1 | 2.4 | 13.5 |
| 80 | 10.6 | 1.2 | 2.6 | 17.2 |
| 100 | 10.8 | 1.3 | 2.6 | 19.5 |
| 150 | 11.4 | 1.6 | 2.6 | 26.0 |
| 200 | 11.8 | 1.8 | 2.7 | 30.0 |
| 400 | 36.8 | 4.4 | 2.9 | 83.0 |
| 750 | 78.6 | 24.8 | 3.8 | 94.1 |
| 1,000 | 85.0 | 38.4 | 6.4 | 96.0 |
| 1,500 | 90.3 | 48.1 | 50.3 | 97.6 |
| 2,000 | 92.6 | 53.5 | 63.5 | 98.3 |
| 4,000 | 96.0 | 62.0 | 78.6 | 99.4 |
| 6,000 | 97.3 | 64.7 | 83.7 | 99.7 |
| 8,000 | 98.0 | 65.8 | 86.5 | 99.9 |
| 10,000 | 98.4 | 66.4 | 88.4 | 99.9 |
| 15,000 | 98.9 | 66.7 | 91.3 | 99.9 |
| 20,000 | 98.9 | 66.7 | 92.7 | 99.9 |
| 25,000 | 98.9 | 66.7 | 93.3 | 99.9 |
| 30,000 | 98.9 | 66.7 | 93.3 | 99.9 |

## HIGH PRESSURE MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

| | | | | |
|---|---|---|---|---|
| Sample Number: | 13 | 14 | 15 | 16 |
| Sample Idenitifcation Number: | H11B3-4 | W-12-1a | W-12-1b1 | W-12-2b |
| Air Permeability, md: | 0.186 | 0.270 | 0.086 | 1.38 |
| Porosity, Percent: | 14.8 | 2.8 | 11.2 | 13.6 |

| Injection Pressure, psia | Mercury Saturation, Percent Pore Volume | | | |
|---|---|---|---|---|
| 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1 | 1.8 | 0.0 | 2.0 | 0.0 |
| 2 | 2.9 | 0.0 | 2.4 | 1.3 |
| 4 | 3.6 | 0.2 | 2.6 | 5.2 |
| 8 | 4.0 | 0.3 | 2.7 | 6.0 |
| 10 | 4.1 | 0.5 | 2.8 | 6.3 |
| 15 | 4.1 | 0.7 | 2.9 | 6.7 |
| 20.4 | 4.3 | 0.7 | 3.1 | 7.4 |
| 40 | 4.5 | 1.0 | 3.4 | 8.8 |
| 60 | 5.2 | 2.6 | 4.0 | 13.2 |
| 80 | 5.5 | 3.4 | 4.3 | 15.3 |
| 100 | 5.6 | 4.1 | 5.0 | 16.7 |
| 150 | 5.9 | 5.4 | 6.5 | 18.9 |
| 200 | 6.3 | 6.6 | 7.3 | 20.7 |
| 400 | 11.1 | 38.4 | 29.9 | 49.8 |
| 750 | 77.0 | 82.1 | 75.2 | 80.1 |
| 1,000 | 84.2 | 90.2 | 81.9 | 85.6 |
| 1,500 | 89.7 | 98.2 | 88.6 | 90.7 |
| 2,000 | 92.4 | 98.2 | 91.6 | 93.2 |
| 4,000 | 96.2 | 98.2 | 96.3 | 96.9 |
| 6,000 | 97.7 | 98.2 | 97.9 | 98.1 |
| 8,000 | 98.6 | 98.2 | 98.8 | 98.8 |
| 10,000 | 99.2 | 98.2 | 99.3 | 99.1 |
| 15,000 | 99.9 | 98.2 | 99.9 | 99.4 |
| 20,000 | 99.9 | 98.2 | 99.9 | 99.4 |
| 25,000 | 99.9 | 98.2 | 99.9 | 99.4 |
| 30,000 | 99.9 | 98.2 | 99.9 | 99.4 |

## HIGH PRESSURE MERCURY INJECTION TEST RESULTS

### INTERA TECHNOLOGIES, INC.

| | | | | |
|---|---|---|---|---|
| Sample Number: | 17 | 18 | 19 | 20 |
| Sample Idenitifcation Number: | W-13-3a | W-13-3b | W-26-3 | W-28-1a |
| Air Permeability, md: | 4.94 | 0.037 | 0.039 | 0.033 |
| Porosity, Percent: | 19.0 | 9.7 | 12.5 | 14.2 |

| Injection Pressure, psia | Mercury Saturation, Percent Pore Volume | | | |
|---|---|---|---|---|
| 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1 | 0.0 | 0.0 | 0.0 | 0.7 |
| 2 | 0.8 | 0.4 | 1.9 | 1.2 |
| 4 | 1.1 | 0.6 | 2.4 | 2.5 |
| 8 | 1.4 | 0.7 | 2.7 | 3.3 |
| 10 | 1.6 | 0.8 | 2.8 | 3.4 |
| 15 | 2.5 | 0.9 | 2.9 | 3.6 |
| 20.4 | 4.1 | 1.0 | 3.2 | 3.7 |
| 40 | 8.2 | 1.0 | 3.2 | 3.7 |
| 60 | 21.5 | 1.0 | 3.2 | 3.9 |
| 80 | 29.5 | 1.0 | 3.2 | 4.0 |
| 100 | 33.6 | 1.0 | 3.2 | 4.1 |
| 150 | 37.9 | 1.0 | 3.2 | 4.3 |
| 200 | 39.6 | 1.0 | 3.2 | 4.4 |
| 400 | 71.6 | 19.2 | 8.5 | 4.5 |
| 750 | 85.9 | 80.1 | 61.6 | 10.6 |
| 1,000 | 88.6 | 85.8 | 72.7 | 42.1 |
| 1,500 | 91.3 | 90.8 | 81.8 | 75.4 |
| 2,000 | 92.6 | 93.1 | 86.0 | 81.0 |
| 4,000 | 95.0 | 95.6 | 92.5 | 87.9 |
| 6,000 | 95.9 | 98.3 | 95.4 | 90.4 |
| 8,000 | 96.5 | 99.1 | 97.1 | 92.0 |
| 10,000 | 96.9 | 99.6 | 98.2 | 93.0 |
| 15,000 | 97.5 | 99.6 | 99.9 | 94.5 |
| 20,000 | 97.5 | 99.6 | 99.9 | 95.2 |
| 25,000 | 97.5 | 99.6 | 99.9 | 95.3 |
| 30,000 | 97.5 | 99.6 | 99.9 | 95.3 |

## HIGH PRESSURE MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

| | | | | |
|---|---|---|---|---|
| Sample Number: | 21 | 22 | 23 | 24 |
| Sample Idenitifcation Number: | W-28-1b | W-30-3a | W-30-3b | W-30-4 |
| Air Permeability, md: | 0.038 | 9.68 | 3.48 | 18.6 |
| Porosity, Percent: | 13.0 | 17.6 | 15.8 | 25.4 |

| Injection Pressure, psia | Mercury Saturation, Percent Pore Volume | | | |
|---|---|---|---|---|
| 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1 | 0.8 | 0.0 | 1.8 | 0.0 |
| 2 | 1.4 | 1.1 | 2.6 | 0.6 |
| 4 | 2.5 | 2.7 | 3.2 | 1.2 |
| 8 | 3.2 | 3.8 | 4.2 | 2.5 |
| 10 | 3.3 | 4.1 | 4.9 | 2.8 |
| 15 | 3.5 | 4.8 | 22.5 | 4.3 |
| 20.4 | 3.7 | 5.8 | 23.5 | 5.8 |
| 40 | 3.7 | 10.8 | 27.4 | 8.5 |
| 60 | 3.7 | 23.5 | 30.5 | 15.1 |
| 80 | 3.8 | 32.2 | 32.5 | 21.4 |
| 100 | 3.8 | 37.3 | 34.0 | 26.3 |
| 150 | 3.8 | 44.2 | 36.8 | 35.0 |
| 200 | 3.9 | 48.1 | 38.8 | 39.5 |
| 400 | 4.5 | 66.4 | 52.1 | 58.4 |
| 750 | 47.2 | 80.0 | 78.8 | 80.3 |
| 1,000 | 68.3 | 83.5 | 83.0 | 85.0 |
| 1,500 | 78.6 | 88.1 | 86.3 | 88.9 |
| 2,000 | 82.7 | 90.8 | 87.6 | 90.5 |
| 4,000 | 88.2 | 95.7 | 89.9 | 93.1 |
| 6,000 | 90.4 | 97.5 | 90.7 | 94.2 |
| 8,000 | 91.6 | 98.5 | 91.1 | 94.9 |
| 10,000 | 92.4 | 99.1 | 91.4 | 95.3 |
| 15,000 | 93.5 | 99.8 | 91.6 | 96.0 |
| 20,000 | 93.8 | 99.8 | 91.6 | 96.3 |
| 25,000 | 93.8 | 99.8 | 91.6 | 96.3 |
| 30,000 | 93.8 | 99.8 | 91.6 | 96.3 |

## HIGH PRESSURE MERCURY INJECTION TEST RESULTS

INTERA TECHNOLOGIES, INC.

Sample Number: 10A
Sample Identification Number: H10B-1
Air Permeability, md: 0.174
Porosity, Percent: 9.0%

| Injection Pressure, psia | Mercury Saturation, Percent Pore Volume |
|---|---|
| 0.5 | 0.0 |
| 1 | 0.3 |
| 2 | 3.0 |
| 4 | 3.5 |
| 8 | 3.7 |
| 10 | 3.8 |
| 15 | 3.8 |
| 20.4 | 4.0 |
| 40 | 4.6 |
| 60 | 8.4 |
| 80 | 12.7 |
| 100 | 15.4 |
| 150 | 20.4 |
| 200 | 23.9 |
| 400 | 32.2 |
| 750 | 59.0 |
| 1,000 | 74.6 |
| 1,500 | 83.6 |
| 2,000 | 87.4 |
| 4,000 | 92.6 |
| 6,000 | 94.2 |
| 8,000 | 94.9 |
| 10,000 | 95.2 |
| 15,000 | 95.2 |
| 20,000 | 95.2 |

## CONDITIONS AND QUALIFICATIONS

K&A Laboratories will endeavor to provide accurate and reliable laboratory measurements of the cores provided by the client. The results of any core analysis are necessarily affected by the condition in which the core is received and the selection of the samples to be analyzed. In the absence of direction by the client, K&A Laboratories will utilize their best geological and engineering judgment in selecting the samples to be analyzed. It should be recognized that most cores do not have uniform properties and that selection of truly representative samples is rarely possible. Unless otherwise directed, the samples will normally be selected from the highest quality segments. Thus, use of the properties measured in this report in reservoir calculations could result in an overestimation in reservoir volume and/or deliverability. K&A Laboratories assumes no responsibility nor offers any guarantee of the productivity or performance of any oil or gas well or hydrocarbon recovery process based upon the data presented in this report.

## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 1 |
| Sample Identification Number: | (H2A-2) |
| Air Permeability, md: | .143 |
| Porosity, Percent: | 12.5% |
| Dry Sample Weight (gm): | 27.00 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2$/g) | Surface Area (%) |
|---|---|---|---|---|
| 1 | 0 | 215. | 0 | 0 |
| 2 | .0058 | 71.7 | 7.25 E-6 | 511. E-6 |
| 4 | .0114 | 35.9 | 21.3 E-6 | .00150 |
| 8 | .0167 | 17.9 | 47.8 E-6 | .00337 |
| 10 | .0195 | 12.0 | 68.8 E-6 | .00485 |
| 15 | .0256 | 8.61 | 132. E-6 | .00733 |
| 20.4 | .0406 | 6.08 | 354. E-6 | .0249 |
| 40 | .0556 | 3.56 | 731. E-6 | .0515 |
| 60 | .0924 | 2.15 | .00226 | .160 |
| 80 | .1196 | 1.54 | .00385 | .271 |
| 100 | .1405 | 1.20 | .00542 | .382 |
| 150 | .1761 | .861 | .00913 | .643 |
| 200 | .1945 | .615 | .0118 | .833 |
| 400 | .2899 | .359 | .0357 | 2.51 |
| 750 | .5878 | .187 | .178 | 12.6 |
| 1000 | .8121 | .123 | .342 | 24.1 |
| 1500 | .9520 | .0861 | .488 | 34.4 |
| 2000 | 1.006 | .0615 | .566 | 39.9 |
| 4000 | 1.0822 | .0359 | .757 | 53.4 |
| 6000 | 1.1170 | .0215 | .902 | 63.6 |
| 8000 | 1.1376 | .0154 | 1.02 | 72.0 |
| 10000 | 1.1523 | .0120 | 1.13 | 79.8 |
| 15000 | 1.1704 | .00861 | 1.32 | 93.1 |
| 20000 | 1.1771 | .00615 | 1.42 | 100. |
| 25000 | 1.1771 | .00478 | 1.42 | 100. |
| 30000 | 1.1771 | .00391 | 1.42 | 100. |

## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 2 |
| Sample Identification Number: | (H2B1-2) |
| Air Permeability, md: | 1.180 |
| Porosity, Percent: | 14.8% |
| Dry Sample Weight (gm): | 26.40 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 1 | 0. | 215. | 0. | 0. |
| 2 | .0036 | 71.7 | 4.6 E-6 | 468. E-6 |
| 4 | .0067 | 35.9 | 12.5 E-6 | .00127 |
| 8 | .0139 | 17.9 | 49.3 E-6 | .00502 |
| 10 | .0189 | 12.0 | 87.7 E-6 | .00892 |
| 15 | .0248 | 8.61 | 151. E-6 | .0153 |
| 20.4 | .0284 | 6.08 | 205. E-6 | .0208 |
| 40 | .0376 | 3.56 | 442. E-6 | .0449 |
| 60 | .0865 | 2.15 | .00253 | .257 |
| 80 | .1385 | 1.54 | .00563 | .573 |
| 100 | .1925 | 1.20 | .00977 | .994 |
| 150 | .3133 | .861 | .0226 | 2.30 |
| 200 | .3814 | .615 | .0328 | 3.34 |
| 400 | .7926 | .359 | .138 | 14.0 |
| 750 | 1.1737 | .187 | .325 | 33.0 |
| 1000 | 1.255 | .123 | .385 | 39.2 |
| 1500 | 1.3526 | .0861 | .489 | 49.8 |
| 2000 | 1.4063 | .0615 | .569 | 57.9 |
| 4000 | 1.4825 | .0359 | .764 | 77.8 |
| 6000 | 1.5067 | .0215 | .867 | 88.2 |
| 8000 | 1.5181 | .0154 | .935 | 95.2 |
| 10000 | 1.5243 | .0120 | .983 | 100. |
| 15000 | 1.5284 | .00861 | .983 | 100. |
| 20000 | 1.5284 | .00615 | .983 | 100. |
| 25000 | 1.5284 | .00478 | .983 | 100. |
| 30000 | 1.5284 | .00391 | .983 | 100. |

## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 3 |
| Sample Identification Number: | (H5B1-1A) |
| Air Permeability, md: | .042 |
| Porosity, Percent: | 13.0% |
| Dry Sample Weight (gm): | 27.75 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| .5 | 0. | 430. | 0. | 0. |
| 1 | .0039 | 143. | 2.37 E-6 | 245. E-6 |
| 2 | .0097 | 71.7 | 9.43 E-6 | 975. E-6 |
| 4 | .0373 | 35.9 | 76.6 E-6 | .00792 |
| 8 | .0523 | 17.9 | .00015 | .0155 |
| 10 | .0554 | 12.0 | .000172 | .0178 |
| 15 | .0659 | 8.61 | .000279 | .0288 |
| 20.4 | .0773 | 6.08 | .000442 | .0457 |
| 40 | .0840 | 3.56 | .000606 | .0627 |
| 60 | .0910 | 2.15 | .00089 | .0921 |
| 80 | .0951 | 1.54 | .00112 | .116 |
| 100 | .0960 | 1.20 | .00119 | .123 |
| 150 | .1004 | .861 | .00163 | .169 |
| 200 | .1015 | .615 | .00179 | .185 |
| 400 | .2114 | .359 | .0285 | 2.95 |
| 750 | 1.0886 | .187 | .437 | 45.3 |
| 1000 | 1.1879 | .123 | .508 | 52.6 |
| 1500 | 1.2661 | .0861 | .587 | 60.8 |
| 2000 | 1.3009 | .0615 | .637 | 65.9 |
| 4000 | 1.3509 | .0487 | .758 | 78.4 |
| 6000 | 1.3682 | .0215 | .828 | 85.7 |
| 8000 | 1.3776 | .0154 | .882 | 91.2 |
| 10000 | 1.3827 | .0120 | .919 | 95.1 |
| 15000 | 1.3874 | .00861 | .967 | 100. |
| 20000 | 1.3874 | .00615 | .967 | 100. |
| 25000 | 1.3874 | .00478 | .967 | 100. |
| 30000 | 1.3874 | .00391 | .967 | 100. |

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## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 4 |
| Sample Identification Number: | (H5B1-1B) |
| Air Permeability, md: | .042 |
| Porosity, Percent: | 13.0% |
| Dry Sample Weight (gm): | 26.85 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 2 | 0. | 108. | 0. | 0. |
| 4 | .0031 | 35.9 | 7.79 E-6 | 674. E-6 |
| 8 | .0075 | 17.9 | 29.9 E-6 | .00259 |
| 10 | .0178 | 12.0 | 108. E-6 | .0093 |
| 15 | .0479 | 8.61 | 423. E-6 | .0366 |
| 20.4 | .0598 | 6.08 | 599. E-6 | .0518 |
| 40 | .0723 | 3.56 | 916. E-6 | .0792 |
| 60 | .0840 | 2.15 | .00141 | .122 |
| 80 | .0893 | 1.54 | .00172 | .148 |
| 100 | .0907 | 1.20 | .00182 | .158 |
| 150 | .0979 | .861 | .00258 | .223 |
| 200 | .1143 | .615 | .00498 | .431 |
| 400 | .2991 | .359 | .0514 | 4.45 |
| 750 | 1.3087 | .187 | .538 | 46.5 |
| 1000 | 1.4027 | .123 | .607 | 52.5 |
| 1500 | 1.4859 | .0861 | .694 | 60.0 |
| 2000 | 1.5190 | .0615 | .743 | 64.2 |
| 4000 | 1.5754 | .0359 | .884 | 76.4 |
| 6000 | 1.5955 | .0215 | .969 | 83.7 |
| 8000 | 1.6069 | .0154 | 1.040 | 89.5 |
| 10000 | 1.6130 | .012 | 1.08 | 93.5 |
| 15000 | 1.6202 | .00861 | 1.16 | 100. |
| 20000 | 1.6202 | .00615 | 1.16 | 100. |
| 25000 | 1.6202 | .00478 | 1.16 | 100. |
| 30000 | 1.6202 | .00391 | 1.16 | 100. |

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## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 5 |
| Sample Identification Number: | (H7B1-2A) |
| Air Permeability, md: | .108 |
| Porosity, Percent: | 21.5% |
| Dry Sample Weight (gm): | 25.02 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 0.5 | 0. | 430. | 0. | |
| 1 | .0078 | 143. | 5.26 E-6 | 948. E-6 |
| 2 | .0122 | 71.7 | 11.2 E-6 | .00202 |
| 4 | .0940 | 35.9 | 232. E-6 | .0418 |
| 8 | .1088 | 17.9 | 312. E-6 | .0562 |
| 10 | .1769 | 12. | 863. E-6 | .155 |
| 15 | .1850 | 8.61 | 954. E-6 | .172 |
| 20.4 | .1928 | 6.08 | .00108 | .195 |
| 40 | .2284 | 3.56 | .00204 | .368 |
| 60 | .4295 | 2.15 | .0111 | 2.00 |
| 80 | .4652 | 1.54 | .0133 | 2.40 |
| 100 | .4788 | 1.20 | .0144 | 2.59 |
| 150 | .6677 | .861 | .0357 | 6.43 |
| 200 | .6833 | .615 | .0381 | 6.86 |
| 400 | .8755 | .359 | .0900 | 16.2 |
| 750 | 1.6222 | .187 | .476 | 85.5 |
| 1000 | 1.6954 | .123 | .534 | 96.2 |
| 1500 | 1.7107 | .0861 | .551 | 99.3 |
| 2000 | 1.7120 | .0615 | .553 | 99.6 |
| 4000 | 1.7126 | .0359 | .555 | 100. |
| 6000 | 1.7126 | .0215 | .555 | 100. |
| 8000 | 1.7126 | .0154 | .555 | 100. |
| 10000 | 1.7126 | .0120 | .555 | 100. |
| 15000 | 1.7126 | .00861 | [illegible] | 100. |
| 20000 | 1.7126 | .00615 | .555 | 100. |
| 25000 | 1.7126 | .00478 | .555 | 100. |
| 30000 | 1.7126 | .00391 | .555 | 100. |

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## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 6 |
| Sample Identification Number: | (H7B1-2B) |
| Air Permeability, md: | 0.521 |
| Porosity, Percent: | 27.8% |
| Dry Sample Weight (gm): | 22.98 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 0.5 | 0. | 430. | 0. | |
| 1 | .0303 | 143. | 22.3 E-6 | .00248 |
| 2 | .4500 | 71.7 | 639. E-6 | .0711 |
| 4 | .4644 | 35.9 | 681. E-6 | .0758 |
| 8 | .4793 | 17.9 | 768. E-6 | .0854 |
| 10 | .4838 | 12.0 | 808. E-6 | .0899 |
| 15 | .4903 | 8.61 | 888. E-6 | .0988 |
| 20.4 | .5117 | 6.08 | .00126 | .140 |
| 40 | .5848 | 3.56 | .00342 | .380 |
| 60 | .6986 | 2.15 | .00899 | 1.00 |
| 80 | .7758 | 1.54 | .0143 | 1.59 |
| 100 | .8182 | 1.20 | .0180 | 2.00 |
| 150 | .8534 | .861 | .0223 | 2.48 |
| 200 | .8799 | .615 | .0269 | 2.99 |
| 400 | 1.2009 | .359 | .121 | 13.5 |
| 750 | 1.7661 | .187 | .439 | 48.8 |
| 1000 | 1.8395 | .123 | .502 | 55.8 |
| 1500 | 1.9012 | .0861 | .578 | 64.3 |
| 2000 | 1.9271 | .0615 | .622 | 69.2 |
| 4000 | 1.9626 | .0359 | .726 | 80.8 |
| 6000 | 1.9740 | .0215 | .782 | 87.0 |
| 8000 | 1.9802 | .0154 | .825 | 91.8 |
| 10000 | 1.9833 | .012 | .852 | 94.8 |
| 15000 | 1.9871 | .00861 | .899 | 100. |
| 20000 | 1.9871 | .00615 | .899 | 100. |
| 25000 | 1.9871 | .00478 | .899 | 100. |
| 30000 | 1.8971 | .00391 | .899 | 100. |

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## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 7 |
| Sample Identification Number: | (H7B2-1) |
| Air Permeability, md: | 0.294 |
| Porosity, Percent: | 17.3% |
| Dry Sample Weight (gm): | 25.99 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 1 | 0. | 215. | 0. | 0. |
| 2 | .0076 | 71.7 | 9.87 E-6 | .00127 |
| 4 | .0209 | 35.9 | 44.4 E-6 | .00573 |
| 8 | .0318 | 17.9 | 101. E-6 | .013 |
| 10 | .0341 | 12.0 | 119. E-6 | .0154 |
| 15 | .0378 | 8.61 | 159. E-6 | .0205 |
| 20.4 | .0421 | 6.08 | 225. E-6 | .029 |
| 40 | .0424 | 3.56 | 233. E-6 | .030 |
| 60 | .0434 | 2.15 | 276. E-6 | .0356 |
| 80 | .0454 | 1.54 | 397. E-6 | .0513 |
| 100 | .0467 | 1.20 | 498. E-6 | .0643 |
| 150 | .0507 | .861 | 931. E-6 | .120 |
| 200 | .0749 | .615 | .00460 | .593 |
| 400 | .8760 | .359 | .213 | 27.4 |
| 750 | 1.1314 | .187 | .340 | 43.9 |
| 1000 | 1.1894 | .123 | .384 | 49.5 |
| 2000 | 1.2659 | .0717 | .488 | 62.9 |
| 4000 | 1.3053 | .0359 | .581 | 74.9 |
| 6000 | 1.3202 | .0215 | .645 | 83.3 |
| 8000 | 1.3269 | .0154 | .686 | 88.5 |
| 10000 | 1.3318 | .0120 | .724 | 93.4 |
| 15000 | 1.3365 | .00861 | .775 | 100. |
| 20000 | 1.3365 | .00615 | .775 | 100. |
| 25000 | 1.3365 | .00478 | .775 | 100. |
| 30000 | 1.3365 | .00391 | .775 | 100. |

## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 8 |
| Sample Identification Number: | (H7C-1B) |
| Air Permeability, md: | .074 |
| Porosity, Percent: | 16.5% |
| Dry Sample Weight (gm): | 26.67 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 0.5 | 0. | 430. | 0. | 0. |
| 1 | .0053 | 143. | 3.35 E-6 | 392. E-6 |
| 2 | .0095 | 71.7 | 8.67 E-6 | .00101 |
| 4 | .0159 | 35.9 | 24.9 E-6 | .00291 |
| 8 | .0289 | 17.9 | 90.7 E-6 | .0106 |
| 10 | .0312 | 12.0 | 108. E-6 | .0126 |
| 15 | .0367 | 8.61 | 166. E-6 | .0194 |
| 20.4 | .0426 | 6.08 | 254. E-6 | .0297 |
| 40 | .0551 | 3.56 | 573. E-6 | .067 |
| 60 | .0693 | 2.15 | .00117 | .137 |
| 80 | .0801 | 1.54 | .00181 | .212 |
| 100 | .0912 | 1.20 | .00265 | .310 |
| 150 | .2098 | .861 | .0152 | 1.77 |
| 200 | .2164 | .615 | .0161 | 1.89 |
| 400 | .4524 | .359 | .0759 | 8.87 |
| 750 | 1.0413 | .187 | .362 | 42.3 |
| 1000 | 1.1189 | .123 | .419 | 49.0 |
| 2000 | 1.1225 | .0717 | .423 | 49.5 |
| 4000 | 1.2433 | .0359 | .729 | 85.3 |
| 6000 | 1.2558 | .0215 | .782 | 91.5 |
| 8000 | 1.2616 | .0154 | .816 | 95.5 |
| 10000 | 1.2647 | .0120 | .840 | 98.2 |
| 15000 | 1.2660 | .00861 | .853 | 99.8 |
| 20000 | 1.2661 | .00615 | .855 | 100. |
| 25000 | 1.2661 | .00478 | .855 | 100. |
| 30000 | 1.2661 | .00391 | .855 | 100. |

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## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 9 |
| Sample Identification Number: | (H7C-1A) |
| Air Permeability, md: | .098 |
| Porosity, Percent: | 13.4% |
| Dry Sample Weight (gm): | 27.63 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 0.5 | 0. | 430. | 0. | 0. |
| 1 | .0045 | 143. | 2.75 E-6 | 318. E-6 |
| 2 | .0075 | 71.7 | 6.41 E-6 | 741. E-6 |
| 4 | .0103 | 35.9 | 13.3 E-6 | .00153 |
| 8 | .0606 | 17.9 | 259. E-6 | .0299 |
| 10 | .1091 | 12.0 | 614. E-6 | .0710 |
| 15 | .1138 | 8.61 | 662. E-6 | .0766 |
| 20.4 | .1171 | 6.08 | 710. E-6 | .0821 |
| 40 | .1177 | 3.56 | 725. E-6 | .0838 |
| 60 | .1294 | 2.15 | .0012 | .139 |
| 80 | .1424 | 1.54 | .00194 | .225 |
| 100 | .1441 | 1.2 | .00207 | .239 |
| 150 | .1525 | .861 | .00292 | .338 |
| 200 | .1577 | .615 | .00366 | .423 |
| 400 | .4927 | .359 | .0855 | 9.89 |
| 750 | 1.0527 | .187 | .348 | 40.2 |
| 1000 | 1.1384 | .123 | .409 | 47.3 |
| 1500 | 1.2099 | .0861 | .482 | 55.7 |
| 2000 | 1.2408 | .0615 | .526 | 60.8 |
| 4000 | 1.2867 | .0359 | .638 | 73.7 |
| 6000 | 1.3042 | .0215 | .709 | 82.0 |
| 8000 | 1.3137 | .0154 | .763 | 83.2 |
| 10000 | 1.3187 | .0120 | .800 | 92.5 |
| 15000 | 1.3251 | .00861 | .865 | 100. |
| 20000 | 1.3251 | .00615 | .865 | 100. |
| 25000 | 1.3251 | .00478 | .865 | 100. |
| 30000 | 1.3251 | .00391 | .865 | 100. |

## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 10 |
| Sample Identification Number: | (H-10B-1) |
| Air Permeability, md: | .012 |
| Porosity, Percent: | 10.8% |
| Dry Sample Weight (gm): | 29.65 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 1 | 0. | 215. | 0. | 0. |
| 2 | .0014 | 71.7 | 1.59 E-6 | 172. E-6 |
| 4 | .0028 | 35.9 | 4.78 E-6 | 515. E-6 |
| 8 | .0061 | 17.9 | 19.8 E-6 | .00213 |
| 10 | .0070 | 12.0 | 26.0 E-6 | .00279 |
| 15 | .0095 | 8.61 | 49.7 E-6 | .00535 |
| 20.4 | .0117 | 6.08 | 79.2 E-6 | .00853 |
| 40 | .0117 | 3.56 | 79.2 E-6 | .00853 |
| 60 | .0128 | 2.15 | 121. E-6 | .0130 |
| 80 | .0142 | 1.54 | 195. E-6 | .0210 |
| 100 | .0150 | 1.20 | 250. E-6 | .0269 |
| 150 | .0195 | .861 | 677. E-6 | .0729 |
| 200 | .0220 | .615 | .00101 | .109 |
| 400 | .0531 | .359 | .00809 | .871 |
| 750 | .2980 | .187 | .115 | 12.4 |
| 1000 | .4607 | .123 | .223 | 24.0 |
| 1500 | .5767 | .0861 | .333 | 35.9 |
| 2000 | .6421 | .0615 | .420 | 45.2 |
| 4000 | .7442 | .0359 | .652 | 70.2 |
| 6000 | .7767 | .0215 | .776 | 83.5 |
| 8000 | .7898 | .0154 | .845 | 91.0 |
| 10000 | .7962 | .0120 | .889 | 95.7 |
| 15000 | .8004 | .00861 | .929 | 100. |
| 20000 | .8004 | .00615 | .929 | 100. |
| 25000 | .8004 | .00478 | .929 | 100. |
| 30000 | .8004 | .00391 | .929 | 100. |

## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 10A |
| Sample Identification Number: | (H10B-1) |
| Air Permeability, md: | .174 |
| Porosity, Percent: | 9.0% |
| Dry Sample Weight (gm): | 33.07 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| .5 | 0 | 430. | 0 | |
| 1 | .0036 | 143. | 1.84 E-6 | .000285 |
| 2 | .0339 | 71.7 | 32.8 E-6 | .00507 |
| 4 | .0398 | 35.9 | 44.8 E-6 | .00694 |
| 8 | .0426 | 17.9 | 56.2 E-6 | .00871 |
| 10 | .0434 | 12.0 | 61.1 E-6 | .00947 |
| 15 | .0442 | 8.61 | 67.9 E-6 | .0105 |
| 20.4 | .0462 | 6.08 | 92. E-6 | .0143 |
| 40 | .0534 | 3.56 | 240. E-6 | .0372 |
| 60 | .0965 | 2.15 | .00171 | .264 |
| 80 | .1466 | 1.54 | .00409 | .634 |
| 100 | .1772 | 1.20 | .00597 | .924 |
| 150 | .2345 | .861 | .0108 | 1.68 |
| 200 | .2751 | .615 | .0157 | 2.43 |
| 400 | .3708 | .359 | .0352 | 5.45 |
| 750 | .6788 | .187 | .156 | 24.1 |
| 1000 | .8577 | .123 | .262 | 40.6 |
| 1500 | .9612 | .0861 | .350 | 54.3 |
| 2000 | 1.0051 | .0615 | .402 | 62.4 |
| 4000 | 1.0649 | .0359 | .525 | 81.3 |
| 6000 | 1.0836 | .0215 | .588 | 91.1 |
| 8000 | 1.0914 | .0154 | .625 | 96.9 |
| 10000 | 1.0947 | .0120 | .646 | 100 |
| 15000 | 1.0947 | .0120 | .646 | 100 |
| 20000 | 1.0947 | .0120 | .646 | 100 |

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## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 11 |
| Sample Identification Number: | (H11-2) |
| Air Permeability, md: | .038 |
| Porosity, Percent: | 11.0% |
| Dry Sample Weight (gm): | 27.92 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 1 | 0. | 215. | 0. | |
| 2 | .0131 | 71.7 | 15.8 E-6 | 610. E-6 |
| 4 | .0200 | 35.9 | 32.5 E-6 | .00125 |
| 8 | .0242 | 17.9 | 52.8 E-6 | .00204 |
| 10 | .0250 | 12.0 | 58.6 E-6 | .00226 |
| 15 | .0267 | 8.61 | 75.8 E-6 | .00293 |
| 20.4 | .0284 | 6.08 | 100. E-6 | .00386 |
| 40 | .0287 | 3.56 | 107. E-6 | .00413 |
| 60 | .0289 | 2.15 | 115. E-6 | .00444 |
| 80 | .0314 | 1.54 | 256. E-6 | .00988 |
| 100 | .0320 | 1.20 | 300. E-6 | .0116 |
| 150 | .0325 | .861 | 350. E-6 | .0135 |
| 200 | .0331 | .615 | 435. E-6 | .0168 |
| 400 | .0359 | .359 | .00111 | .0429 |
| 750 | .0465 | .187 | .00602 | .232 |
| 1000 | .0782 | .123 | .0284 | 1.10 |
| 1500 | .6182 | .0861 | .572 | 22.1 |
| 2000 | .7815 | .0615 | .803 | 31.0 |
| 4000 | .9670 | .0359 | 1.25 | 48.3 |
| 6000 | 1.0293 | .0215 | 1.50 | 57.9 |
| 8000 | 1.0644 | .0154 | 1.70 | 65.6 |
| 10000 | 1.0872 | .0120 | 1.87 | 72.2 |
| 15000 | 1.1231 | .00861 | 2.23 | 86.1 |
| 20000 | 1.1401 | .00615 | 2.47 | 95.4 |
| 25000 | 1.1470 | .00478 | 2.59 | 100. |
| 30000 | 1.1470 | .00391 | 2.59 | 100. |

## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 12 |
| Sample Identification Number: | (H11B3-1) |
| Air Permeability, md: | 1.330 |
| Porosity, Percent: | 33.1% |
| Dry Sample Weight (gm): | 21.41 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 1 | 0. | 215. | 0. | 0. |
| 2 | .0779 | 71.7 | 123. E-6 | .0137 |
| 4 | .0990 | 35.9 | 189. E-6 | .0212 |
| 8 | .1289 | 17.9 | 378. E-6 | .0423 |
| 10 | .1621 | 12.0 | 692. E-6 | .0775 |
| 15 | .1743 | 8.61 | 852. E-6 | .0954 |
| 20.4 | .1813 | 6.08 | 982. E-6 | .110 |
| 40 | .2485 | 3.56 | .00312 | .349 |
| 60 | .3153 | 2.15 | .00663 | .742 |
| 80 | .4007 | 1.54 | .0129 | 1.45 |
| 100 | .4546 | 1.20 | .0180 | 2.02 |
| 150 | .6063 | .861 | .0379 | 4.25 |
| 200 | .6999 | .615 | .0551 | 6.17 |
| 400 | 1.9365 | .359 | .445 | 49.8 |
| 750 | 2.1938 | .187 | .600 | 67.2 |
| 1000 | 2.2379 | .123 | .641 | 71.8 |
| 1500 | 2.2756 | .0861 | .691 | 77.3 |
| 2000 | 2.2925 | .0615 | .722 | 80.8 |
| 4000 | 2.3175 | .0359 | .800 | 89.6 |
| 6000 | 2.3258 | .0215 | .844 | 94.5 |
| 8000 | 2.3289 | .0154 | .867 | 97.1 |
| 10000 | 2.3314 | .012 | .891 | 99.7 |
| 15000 | 2.3316 | .00861 | .893 | 100. |
| 20000 | 2.3316 | .00615 | .893 | 100. |
| 25000 | 2.3316 | .00478 | .893 | 100. |
| 30000 | 2.3316 | .00391 | .893 | 100. |

**K & A**
**LABORATORIES**

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## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 13 |
| Sample Identification Number: | (H11B3-4) |
| Air Permeability, md: | .186 |
| Porosity, Percent: | 14.8% |
| Dry Sample Weight (gm): | 26.90 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 0.5 | 0. | 430. | 0. | 0. |
| 1 | .0303 | 143. | 19.0 E-6 | .00138 |
| 2 | .0484 | 71.7 | 41.7 E-6 | .00303 |
| 4 | .0601 | 35.9 | 71.1 E-6 | .00517 |
| 8 | .0665 | 17.9 | 103. E-6 | .00751 |
| 10 | .0673 | 12.0 | 109. E-6 | .00794 |
| 15 | .0687 | 8.61 | 124. E-6 | .00901 |
| 20.4 | .0707 | 6.08 | 153. E-6 | .0112 |
| 40 | .0751 | 3.56 | 265. E-6 | .0192 |
| 60 | .0871 | 2.15 | 766. E-6 | .0557 |
| 80 | .0907 | 1.54 | 977. E-6 | .0711 |
| 100 | .0929 | 1.20 | .00114 | .0831 |
| 150 | .0985 | .861 | .00173 | .126 |
| 200 | .1049 | .615 | .00267 | .194 |
| 400 | .1847 | .359 | .0227 | 1.65 |
| 750 | 1.2781 | .187 | .549 | 39.9 |
| 1000 | 1.3977 | .123 | .636 | 46.3 |
| 1500 | 1.4898 | .0861 | .732 | 53.3 |
| 2000 | 1.5334 | .0615 | .796 | 57.9 |
| 4000 | 1.5963 | .0359 | .954 | 69.4 |
| 6000 | 1.6213 | .0215 | 1.06 | 77.0 |
| 8000 | 1.6369 | .0154 | 1.15 | 83.5 |
| 10000 | 1.6461 | .0120 | 1.22 | 88.7 |
| 15000 | 1.6575 | .00861 | 1.34 | 97.3 |
| 20000 | 1.6600 | .00615 | 1.37 | 100. |
| 25000 | 1.6600 | .00478 | 1.37 | 100. |
| 30000 | 1.6600 | .00391 | 1.37 | 100. |

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## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 14 |
| Sample Identification Number: | (W-12-1A) |
| Air Permeability, md: | .270 |
| Porosity, Percent: | 2.8% |
| Dry Sample Weight (gm): | 28.27 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 2 | 0 | 108 | 0 | 0 |
| 4 | .0022 | 35.9 | 5.25 E-6 | .0004 |
| 8 | .0047 | 17.9 | 17.2 E-6 | .00131 |
| 10 | .0067 | 12.0 | 31.5 E-6 | .0024 |
| 15 | .0100 | 8.61 | 64.3 E-6 | .0049 |
| 20 | .0092 | 6.08 | 53.1 E-6 | .00404 |
| 40 | .0145 | 3.56 | 180.E-6 | .0138 |
| 60 | .0378 | 2.15 | .00111 | .0844 |
| 80 | .0481 | 1.54 | .00168 | .128 |
| 100 | .0593 | 1.20 | .00248 | .189 |
| 150 | .0776 | .861 | .0043 | .328 |
| 200 | .0949 | .615 | .00671 | .512 |
| 400 | .5494 | .359 | .115 | 8.78 |
| 750 | 1.1743 | .187 | .401 | 30.6 |
| 1000 | 1.2892 | .123 | .481 | 36.7 |
| 1500 | 1.4038 | .0861 | .595 | 45.4 |
| 2000 | 1.4617 | .0615 | .676 | 51.5 |
| 4000 | 1.5462 | .0359 | .882 | 67.2 |
| 6000 | 1.5793 | .0215 | 1.01 | 76.7 |
| 8000 | 1.5960 | .0154 | 1.10 | 83.8 |
| 10000 | 1.6058 | .0120 | 1.17 | 89.1 |
| 15000 | 1.6175 | .00861 | 1.29 | 98. |
| 20000 | 1.6194 | .00615 | 1.31 | 100. |
| 25000 | 1.6194 | .00478 | 1.31 | 100. |
| 30000 | 1.6194 | .00391 | 1.31 | 100. |

## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 15 |
| Sample Identification Number: | (W-12-1B-1) |
| Air Permeability, md: | .086 |
| Porosity, Percent: | 11.2% |
| Dry Sample Weight (gm): | 24.80 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 0.5 | 0. | 430. | 0. | 0. |
| 1 | .0248 | 143. | 16.9 E-6 | .00161 |
| 2 | .0295 | 71.7 | 23.3 E-6 | .00221 |
| 4 | .0320 | 35.9 | 30.1 E-6 | .00286 |
| 8 | .0337 | 17.9 | 39.3 E-6 | .00374 |
| 10 | .0345 | 12.0 | 45.9 E-6 | .00436 |
| 15 | .0362 | 8.61 | 65.1 E-6 | .0062 |
| 20.4 | .0387 | 6.08 | 105. E-6 | .0100 |
| 40 | .0426 | 3.56 | 212. E-6 | .0202 |
| 60 | .0490 | 2.15 | 502. E-6 | .0478 |
| 80 | .0526 | 1.54 | 731. E-6 | .0696 |
| 100 | .0623 | 1.2 | .00152 | .145 |
| 150 | .0798 | .861 | .00351 | .334 |
| 200 | .0896 | .615 | .00506 | .482 |
| 400 | .3697 | .359 | .0813 | 7.74 |
| 750 | .9286 | .187 | .373 | 35.5 |
| 1000 | 1.0110 | .123 | .438 | 41.7 |
| 1500 | 1.0944 | .0861 | .533 | 50.7 |
| 2000 | 1.1317 | .0615 | .592 | 56.4 |
| 4000 | 1.1893 | .0359 | .749 | 71.3 |
| 6000 | 1.2091 | .0215 | .839 | 79.8 |
| 8000 | 1.2199 | .0154 | .907 | 86.3 |
| 10000 | 1.2263 | .0120 | .950 | 91.3 |
| 15000 | 1.2335 | .00861 | 1.04 | 99.1 |
| 20000 | 1.2341 | .00615 | 1.05 | 100. |
| 25000 | 1.2341 | .00478 | 1.05 | 100. |
| 30000 | 1.2341 | .00391 | 1.05 | 100. |

## PORE SURFACE AREA SUMMARY

## INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 16 |
| Sample Identification Number: | (W-12-2) |
| Air Permeability, md: | 1.380 |
| Porosity, Percent: | 13.6% |
| Dry Sample Weight (gm): | 27.67 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2$/g) | Surface Area (%) |
|---|---|---|---|---|
| 1 | 0. | 215. | 0. | 0. |
| 2 | .0172 | 71.7 | 21. E-6 | .00274 |
| 4 | .0684 | 35.9 | 146. E-6 | .0191 |
| 8 | .0796 | 17.9 | 201. E-6 | .0262 |
| 10 | .0835 | 12.0 | 229. E-6 | .0300 |
| 15 | .0882 | 8.61 | 277. E-6 | .0362 |
| 20.4 | .0982 | 6.08 | 421. E-6 | .0550 |
| 40 | .1166 | 3.56 | 873. E-6 | .114 |
| 60 | .1744 | 2.15 | .00322 | .422 |
| 80 | .2023 | 1.54 | .00481 | .629 |
| 100 | .2201 | 1.20 | .00611 | .800 |
| 150 | .2501 | .861 | .00916 | 1.2 |
| 200 | .2737 | .615 | .0125 | 1.64 |
| 400 | .6568 | .359 | .106 | 13.9 |
| 750 | 1.0572 | .187 | .293 | 38.3 |
| 1000 | 1.1295 | .123 | .345 | 45.1 |
| 1500 | 1.1974 | .0861 | .414 | 54.1 |
| 2000 | 1.2296 | .0615 | .459 | 60.1 |
| 4000 | 1.2786 | .0359 | .579 | 75.7 |
| 6000 | 1.2956 | .0215 | .648 | 84.8 |
| 8000 | 1.3036 | .0154 | .694 | 90.7 |
| 10000 | 1.3087 | .0120 | .731 | 95.6 |
| 15000 | 1.3120 | .00861 | .765 | 100. |
| 20000 | 1.3120 | .00615 | .765 | 100. |
| 25000 | 1.3120 | .00478 | .765 | 100. |
| 30000 | 1.3120 | .00391 | .765 | 100. |

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# PORE SURFACE AREA SUMMARY

## INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 17 |
| Sample Identification Number: | (W-13-3A) |
| Air Permeability, md: | 4.940 |
| Porosity, Percent: | 19.0% |
| Dry Sample Weight (gm): | 26.74 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 1 | 0. | 215. | 0. | 0. |
| 2 | .0146 | 71.7 | 18.4 E-6 | .00212 |
| 4 | .0199 | 35.9 | 31.8 E-6 | .00366 |
| 8 | .0268 | 17.9 | 66.6 E-6 | .00767 |
| 10 | .0292 | 12.0 | 84.8 E-6 | .00977 |
| 15 | .0477 | 8.61 | 279. E-6 | .0322 |
| 20.4 | .0769 | 6.08 | 714. E-6 | .0822 |
| 40 | .1534 | 3.56 | .00266 | .306 |
| 60 | .4019 | 2.15 | .0131 | 1.51 |
| 80 | .5533 | 1.54 | .022 | 2.54 |
| 100 | .6298 | 1.20 | .0278 | 3.2 |
| 150 | .7090 | .861 | .0362 | 4.16 |
| 200 | .7418 | .615 | .0410 | 4.72 |
| 400 | 1.3414 | .359 | .192 | 22.1 |
| 750 | 1.6098 | .187 | .322 | 37.1 |
| 1000 | 1.6601 | .123 | .359 | 41.4 |
| 1500 | 1.7095 | .0861 | .411 | 47.3 |
| 2000 | 1.7344 | .0615 | .448 | 51.6 |
| 4000 | 1.7784 | .0359 | .559 | 64.4 |
| 6000 | 1.7970 | .0215 | .637 | 73.4 |
| 8000 | 1.8082 | .0154 | .703 | 81.0 |
| 10000 | 1.8149 | .0120 | .754 | 86.8 |
| 15000 | 1.8258 | .00861 | .869 | 100. |
| 20000 | 1.8258 | .00717 | .869 | 100. |
| 25000 | 1.8258 | .00478 | .869 | 100. |
| 30000 | 1.8258 | .00391 | .869 | 100. |

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## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 18 |
| Sample Identification Number: | (W-13-3B) |
| Air Permeability, md: | .037 |
| Porosity, Percent: | 9.7% |
| Dry Sample Weight (gm): | 29.59 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 1 | 0. | 215. | 0. | 0. |
| 2 | .0050 | 71.7 | 5.7 E-6 | 727. E-6 |
| 4 | .0070 | 35.9 | 10.3 E-6 | .00131 |
| 8 | .0083 | 17.9 | 16.2 E-6 | .00207 |
| 10 | .0086 | 12.0 | 18.2 E-6 | .00233 |
| 15 | .0106 | 8.61 | 37.3 E-6 | .00475 |
| 20.4 | .0108 | 6.08 | 40. E-6 | .0051 |
| 40 | .0108 | 3.56 | 40. E-6 | .0051 |
| 60 | .0108 | 2.15 | 40. E-6 | .0051 |
| 80 | .0108 | 1.54 | 40. E-6 | .0051 |
| 100 | .0108 | 1.20 | 40. E-6 | .0051 |
| 150 | .0111 | .861 | 68.5 E-6 | .00873 |
| 200 | .0111 | .615 | 68.5 E-6 | .00873 |
| 400 | .2173 | .359 | .0471 | 6.01 |
| 750 | .9075 | .187 | .349 | 44.5 |
| 1000 | .9723 | .123 | .392 | 50.0 |
| 1250 | 1.0071 | .0956 | .422 | 53.8 |
| 1500 | 1.0285 | .0783 | .444 | 56.7 |
| 2000 | 1.0549 | .0615 | .479 | 61.1 |
| 4000 | 1.0828 | .0359 | .543 | 69.3 |
| 6000 | 1.1142 | .0215 | .662 | 84.5 |
| 8000 | 1.1231 | .0154 | .710 | 90.5 |
| 10000 | 1.1284 | .0120 | .746 | 95.2 |
| 15000 | 1.1334 | .00861 | .784 | 100. |
| 20000 | 1.1334 | .00717 | .784 | 100. |
| 25000 | 1.1334 | .00478 | .784 | 100. |
| 30000 | 1.1334 | .00391 | .784 | 100. |

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# PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 19 |
| Sample Identification Number: | (W-26-3) |
| Air Permeability, md: | .039 |
| Porosity, Percent: | 12.5% |
| Dry Sample Weight (gm): | 28.60 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 1 | 0. | 215. | 0. | 0. |
| 2. | .0282 | 71.7 | 33.3 E-6 | .00211 |
| 4 | .0354 | 35.9 | 50.3 E-6 | .00319 |
| 8 | .0394 | 17.9 | 69.2 E-6 | .00439 |
| 10 | .0408 | 12.0 | 79.1 E-6 | .00502 |
| 15 | .0424 | 8.61 | 94.8 E-6 | .00602 |
| 20.4 | .0457 | 6.08 | 141. E-6 | .00894 |
| 40 | .0457 | 3.56 | 141. E-6 | .00894 |
| 60 | .0457 | 2.15 | 141. E-6 | .00894 |
| 80 | .0457 | 1.54 | 141. E-6 | .00894 |
| 100 | .0457 | 1.20 | 141. E-6 | .00894 |
| 150 | .0457 | .861 | 141. E-6 | .00894 |
| 200 | .0461 | .615 | 196. E-6 | .0124 |
| 400 | .1236 | .359 | .0185 | 1.17 |
| 750 | .8915 | .187 | .357 | 22.7 |
| 1000 | 1.0529 | .123 | .482 | 30.6 |
| 1500 | 1.1851 | .0861 | .612 | 38.8 |
| 2000 | 1.2457 | .0615 | .695 | 44.1 |
| 4000 | 1.3398 | .0359 | .917 | 58.2 |
| 6000 | 1.3815 | .0215 | 1.08 | 68.7 |
| 8000 | 1.4064 | .0154 | 1.22 | 77.4 |
| 10000 | 1.4223 | .0120 | 1.33 | 84.6 |
| 15000 | 1.4471 | .00861 | 1.57 | 100. |
| 20000 | 1.4471 | .00717 | 1.57 | 100. |
| 25000 | 1.4471 | .00478 | 1.57 | 100. |
| 30000 | 1.4471 | .00391 | 1.57 | 100. |

## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 20 |
| Sample Identification Number: | (W-28-1A) |
| Air Permeability, md: | .033 |
| Porosity, Percent: | 14.2% |
| Dry Sample Weight (gm): | 27.14 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area ($m^2/g$) | Surface Area (%) |
|---|---|---|---|---|
| 0.5 | 0. | 430. | 0. | 0. |
| 1 | .0106 | 143. | 6.59 E-6 | 294. E-6 |
| 2 | .0184 | 71.7 | 16.3 E-6 | 727. E-6 |
| 4 | .0395 | 35.9 | 68.8 E-6 | .00307 |
| 8 | .0520 | 17.9 | 131. E-6 | .00584 |
| 10 | .0537 | 12.0 | 144. E-6 | .00641 |
| 15 | .0537 | 8.61 | 144. E-6 | .00641 |
| 20.4 | .0595 | 6.08 | 229. E-6 | .0102 |
| 40 | .0595 | 3.56 | 229. E-6 | .0102 |
| 60 | .0626 | 2.15 | 357. E-6 | .0159 |
| 80 | .0640 | 1.54 | 438. E-6 | .0196 |
| 100 | .0654 | 1.20 | 543. E-6 | .0242 |
| 150 | .0676 | .861 | 771. E-6 | .0344 |
| 200 | .0693 | .615 | .00102 | .0454 |
| 400 | .0712 | .359 | .00149 | .0665 |
| 750 | .1680 | .187 | .0476 | 2.13 |
| 1000 | .6693 | .123 | .411 | 18.4 |
| 1500 | 1.1996 | .0861 | .961 | 42.9 |
| 2000 | 1.2878 | .0615 | 1.09 | 48.6 |
| 4000 | 1.3974 | .0359 | 1.36 | 60.7 |
| 6000 | 1.4380 | .0215 | 1.53 | 68.3 |
| 8000 | 1.4631 | .0154 | 1.68 | 74.8 |
| 10000 | 1.4786 | .0120 | 1.79 | 79.9 |
| 15000 | 1.5020 | .00861 | 2.03 | 90.7 |
| 20000 | 1.5131 | .00615 | 2.19 | 97.9 |
| 25000 | 1.5156 | .00478 | 2.24 | 100. |
| 30000 | 1.5156 | .00391 | 2.24 | 100. |

## PORE SURFACE AREA SUMMARY

INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 21 |
| Sample Identification Number: | (W-28-1B) |
| Air Permeability, md: | .038 |
| Porosity, Percent: | 13.0% |
| Dry Sample Weight (gm): | 27.60 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area (m$^2$/g) | Surface Area (%) |
|---|---|---|---|---|
| 0.5 | 0. | 430. | 0. | |
| 1 | .0117 | 143. | 7.15 E-6 | 476. E-6 |
| 2 | .0198 | 71.7 | 17.1 E-6 | .00114 |
| 4 | .0359 | 35.9 | 56.4 E-6 | .00376 |
| 8 | .0473 | 17.9 | 112. E-6 | .00747 |
| 10 | .0476 | 12.0 | 114. E-6 | .00760 |
| 15 | .0515 | 8.61 | 154. E-6 | .0103 |
| 20.4 | .0534 | 6.08 | 182. E-6 | .0121 |
| 40 | .0534 | 3.56 | 182. E-6 | .0121 |
| 60 | .0542 | 2.15 | 214. E-6 | .0143 |
| 80 | .0548 | 1.54 | 248. E-6 | .0165 |
| 100 | .0551 | 1.20 | 270. E-6 | .0180 |
| 150 | .0562 | .861 | 383. E-6 | .0255 |
| 200 | .0576 | .615 | 582. E-6 | .0388 |
| 400 | .0657 | .359 | .00256 | .171 |
| 750 | .6885 | .187 | .295 | 19.7 |
| 1000 | .9973 | .123 | .515 | 34.3 |
| 1500 | 1.1481 | .0861 | .668 | 44.5 |
| 2000 | 1.2071 | .0615 | .753 | 50.2 |
| 4000 | 1.2881 | .0359 | .951 | 63.4 |
| 6000 | 1.3198 | .0215 | 1.08 | 72.0 |
| 8000 | 1.3376 | .0154 | 1.18 | 78.7 |
| 10000 | 1.3493 | .0120 | 1.27 | 84.7 |
| 15000 | 1.3654 | .00861 | 1.43 | 95.3 |
| 20000 | 1.3699 | .00615 | 1.50 | 100. |
| 25000 | 1.3699 | .00478 | 1.50 | 100. |
| 30000 | 1.3699 | .00391 | 1.50 | 100. |

## PORE SURFACE AREA SUMMARY

## INTERA TECHNOLOGIES, INC.

| | |
|---|---|
| Sample Number: | 22 |
| Sample Identification Number: | (W-30-3A) |
| Air Permeability, md: | 9.680 |
| Porosity, Percent: | 17.6% |
| Dry Sample Weight (gm): | 25.18 |

| Injection Pressure, psia | Cumulative Volume Injected cc | Pore Throat Radius, um | Cumulative Surface Area $(m^2/g)$ | Surface Area (%) |
|---|---|---|---|---|
| 1 | 0. | 215. | 0. | 0. |
| 2 | .0212 | 71.7 | 28.4 E-6 | .00202 |
| 4 | .0543 | 35.9 | 117. E-6 | .00831 |
| 8 | .0752 | 17.9 | 229. E-6 | .0163 |
| 10 | .0818 | 12.0 | 282. E-6 | .02 |
| 15 | .0961 | 8.61 | 442. E-6 | .0314 |
| 20.4 | .1156 | 6.08 | 750. E-6 | .0532 |
| 40 | .2147 | 3.56 | .00342 | .243 |
| 60 | .4691 | 2.15 | .0148 | 1.05 |
| 80 | .6427 | 1.54 | .0256 | 1.82 |
| 100 | .7438 | 1.20 | .0338 | 2.4 |
| 150 | .8813 | .861 | .0491 | 3.49 |
| 200 | .9601 | .615 | .0615 | 4.36 |
| 400 | 1.3245 | .359 | .159 | 11.3 |
| 750 | 1.5965 | .187 | .299 | 21.2 |
| 1000 | 1.6671 | .123 | .354 | 25.1 |
| 1500 | 1.7579 | .0861 | .456 | 32.3 |
| 2000 | 1.8122 | .0615 | .540 | 38.3 |
| 4000 | 1.9096 | .0359 | .802 | 56.9 |
| 6000 | 1.9461 | .0215 | .965 | 68.4 |
| 8000 | 1.9656 | .0154 | 1.09 | 77.1 |
| 10000 | 1.9779 | .0120 | 1.19 | 84.1 |
| 15000 | 1.9914 | .00861 | 1.34 | 94.8 |
| 20000 | 1.9961 | .00615 | 1.41 | 100. |
| 25000 | 1.9961 | .00478 | 1.41 | 100. |
| 30000 | 1.9961 | .00391 | 1.41 | 100. |

INTERA TECHNOLOGIES

Sample No: 1

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 107.6 | .0 |
| 53.8 | .4 |
| 26.9 | .9 |
| 13.5 | 1.3 |
| 10.8 | 1.5 |
| 7.17 | 1.9 |
| 5.27 | 3.1 |
| 2.67 | 4.2 |
| 1.79 | 6.9 |
| 1.34 | 9.0 |
| 1.07 | 10.6 |
| .717 | 13.2 |
| .538 | 14.6 |
| .267 | 21.8 |
| .143 | 44.2 |
| .107 | 61.1 |
| .072 | 71.6 |
| .054 | 75.6 |
| .027 | 81.4 |
| .018 | 84.0 |
| .013 | 85.5 |
| .011 | 86.6 |
| .007 | 88.0 |
| .005 | 88.5 |
| .004 | 88.5 |
| .004 | 88.5 |

Sample No: 2

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 107.6 | .0 |
| 53.8 | .2 |
| 26.9 | .4 |
| 13.5 | .9 |
| 10.8 | 1.2 |
| 7.17 | 1.6 |
| 5.27 | 1.9 |
| 2.67 | 2.5 |
| 1.79 | 5.7 |
| 1.34 | 9.1 |
| 1.07 | 12.6 |
| .719 | 20.5 |
| .539 | 24.9 |
| .267 | 51.8 |
| .143 | 76.8 |
| .107 | 82.1 |
| .072 | 88.5 |
| .054 | 92.0 |
| .027 | 97.0 |
| .018 | 98.5 |
| .013 | 99.3 |
| .011 | 99.7 |
| .007 | **** |
| .005 | **** |
| .004 | **** |
| .004 | **** |

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## INTERA TECHNOLOGIES

Sample No: 3

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 215.2 | .0 |
| 107.6 | .3 |
| 53.8 | .7 |
| 26.9 | 2.6 |
| 13.5 | 3.6 |
| 10.8 | 3.8 |
| 7.17 | 4.5 |
| 5.27 | 5.3 |
| 2.67 | 5.8 |
| 1.79 | 6.2 |
| 1.34 | 6.5 |
| 1.07 | 6.6 |
| .716 | 6.9 |
| .538 | 7.0 |
| .266 | 14.5 |
| .143 | 74.6 |
| .107 | 81.4 |
| .072 | 86.7 |
| .054 | 89.1 |
| .027 | 92.5 |
| .018 | 93.7 |
| .013 | 94.4 |
| .011 | 94.7 |
| .007 | 95.0 |
| .005 | 95.0 |
| .004 | 95.0 |
| .004 | 95.0 |

Sample No: 4

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 53.8 | .0 |
| 26.9 | .2 |
| 13.5 | .4 |
| 10.8 | 1.0 |
| 7.17 | 2.8 |
| 5.27 | 3.5 |
| 2.67 | 4.3 |
| 1.79 | 4.9 |
| 1.34 | 5.3 |
| 1.07 | 5.3 |
| .716 | 5.8 |
| .538 | 6.7 |
| .267 | 17.6 |
| .143 | 77.0 |
| .108 | 82.5 |
| .072 | 87.4 |
| .054 | 89.4 |
| .027 | 92.7 |
| .018 | 93.9 |
| .013 | 94.5 |
| .011 | 94.9 |
| .007 | 95.3 |
| .005 | 95.3 |
| .004 | 95.3 |
| .004 | 95.3 |

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## INTERA TECHNOLOGIES

Sample No: 5

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 215.2 | .0 |
| 107.6 | .4 |
| 53.8 | .7 |
| 26.9 | 5.0 |
| 13.5 | 5.8 |
| 10.8 | 9.5 |
| 7.17 | 9.9 |
| 5.27 | 10.3 |
| 2.70 | 12.2 |
| 1.81 | 23.0 |
| 1.36 | 24.9 |
| 1.08 | 25.6 |
| .723 | 35.7 |
| .541 | 36.5 |
| .267 | 46.8 |
| .143 | 86.7 |
| .108 | 90.7 |
| .072 | 91.5 |
| .054 | 91.6 |
| .027 | 91.6 |
| .018 | 91.6 |
| .013 | 91.6 |
| .011 | 91.6 |
| .007 | 91.6 |
| .005 | 91.6 |
| .004 | 91.6 |
| .004 | 91.6 |

Sample No: 6

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 215.2 | .0 |
| 107.6 | 1.5 |
| 53.8 | 22.5 |
| 26.9 | 23.3 |
| 13.5 | 24.0 |
| 10.8 | 24.2 |
| 7.17 | 24.6 |
| 5.27 | 25.6 |
| 2.72 | 29.3 |
| 1.81 | 35.0 |
| 1.35 | 38.8 |
| 1.08 | 41.0 |
| .721 | 42.7 |
| .540 | 44.1 |
| .267 | 60.1 |
| .143 | 88.4 |
| .107 | 92.1 |
| .072 | 95.2 |
| .054 | 96.5 |
| .027 | 98.3 |
| .018 | 98.8 |
| .013 | 99.2 |
| .011 | 99.3 |
| .007 | 99.5 |
| .005 | 99.5 |
| .004 | 99.5 |
| .004 | 99.5 |

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## INTERA TECHNOLOGIES

**Sample No:** 7

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 107.6 | .0 |
| 53.8 | .6 |
| 26.9 | 1.5 |
| 13.5 | 2.3 |
| 10.8 | 2.5 |
| 7.17 | 2.7 |
| 5.27 | 3.0 |
| 2.68 | 3.1 |
| 1.79 | 3.1 |
| 1.34 | 3.3 |
| 1.07 | 3.4 |
| .717 | 3.7 |
| .538 | 5.4 |
| .267 | 63.2 |
| .143 | 81.7 |
| .107 | 85.9 |
| .054 | 91.4 |
| .027 | 94.2 |
| .018 | 95.3 |
| .013 | 95.8 |
| .011 | 96.2 |
| .007 | 96.5 |
| .005 | 96.5 |
| .004 | 96.5 |
| .004 | 96.5 |

**Sample No:** 8

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 215.2 | .0 |
| 107.6 | .4 |
| 53.8 | .7 |
| 26.9 | 1.2 |
| 13.5 | 2.2 |
| 10.8 | 2.3 |
| 7.17 | 2.7 |
| 5.27 | 3.2 |
| 2.68 | 4.1 |
| 1.79 | 5.2 |
| 1.34 | 6.0 |
| 1.07 | 6.8 |
| .718 | 15.7 |
| .538 | 16.2 |
| .267 | 33.9 |
| .143 | 77.9 |
| .107 | 83.8 |
| .054 | 84.0 |
| .027 | 93.1 |
| .018 | 94.0 |
| .013 | 94.4 |
| .011 | 94.7 |
| .007 | 94.8 |
| .005 | 94.8 |
| .004 | 94.8 |
| .004 | 94.8 |

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## INTERA TECHNOLOGIES

Sample No: 9

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 215.2 | .0 |
| 107.6 | .3 |
| 53.8 | .6 |
| 26.9 | .8 |
| 13.5 | 4.5 |
| 10.8 | 8.1 |
| 7.17 | 8.5 |
| 5.27 | 8.7 |
| 2.68 | 8.8 |
| 1.79 | 9.7 |
| 1.34 | 10.6 |
| 1.07 | 10.8 |
| .717 | 11.4 |
| .538 | 11.8 |
| .267 | 36.8 |
| .143 | 78.6 |
| .107 | 85.0 |
| .072 | 90.3 |
| .054 | 92.6 |
| .027 | 96.0 |
| .018 | 97.3 |
| .013 | 98.0 |
| .011 | 98.4 |
| .007 | 98.9 |
| .005 | 98.9 |
| .004 | 98.9 |
| .004 | 98.9 |

Sample No: 10

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 107.6 | .0 |
| 53.8 | .1 |
| 26.9 | .2 |
| 13.5 | .5 |
| 10.8 | .6 |
| 7.17 | .8 |
| 5.27 | 1.0 |
| 2.66 | 1.0 |
| 1.78 | 1.1 |
| 1.34 | 1.2 |
| 1.07 | 1.3 |
| .715 | 1.6 |
| .537 | 1.8 |
| .266 | 4.4 |
| .143 | 24.8 |
| .107 | 38.4 |
| .072 | 48.1 |
| .054 | 53.5 |
| .027 | 62.0 |
| .018 | 64.7 |
| .013 | 65.8 |
| .011 | 66.4 |
| .007 | 66.7 |
| .005 | 66.7 |
| .004 | 66.7 |
| .004 | 66.7 |

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INTERA TECHNOLOGIES

Sample No: 10A

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 215.2 | .0 |
| 107.6 | .3 |
| 53.8 | 3.0 |
| 26.9 | 3.5 |
| 13.5 | 3.7 |
| 10.8 | 3.8 |
| 7.17 | 3.8 |
| 5.27 | 4.0 |
| 2.67 | 4.6 |
| 1.79 | 8.4 |
| 1.34 | 12.7 |
| 1.08 | 15.4 |
| .718 | 20.4 |
| .539 | 23.9 |
| .267 | 32.2 |
| .143 | 59.0 |
| .107 | 74.6 |
| .072 | 83.6 |
| .054 | 87.4 |
| .027 | 92.6 |
| .018 | 94.2 |
| .013 | 94.9 |
| .011 | 95.2 |
| .007 | 95.2 |
| .005 | 95.2 |

## INTERA TECHNOLOGIES

Sample No: 11

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 107.6 | .0 |
| 53.8 | 1.1 |
| 26.9 | 1.6 |
| 13.5 | 2.0 |
| 10.8 | 2.0 |
| 7.17 | 2.2 |
| 5.27 | 2.3 |
| 2.66 | 2.3 |
| 1.78 | 2.4 |
| 1.34 | 2.6 |
| 1.07 | 2.6 |
| .716 | 2.6 |
| .537 | 2.7 |
| .266 | 2.9 |
| .143 | 3.8 |
| .107 | 6.4 |
| .072 | 50.3 |
| .054 | 63.5 |
| .027 | 78.6 |
| .018 | 83.7 |
| .013 | 86.5 |
| .011 | 88.4 |
| .007 | 91.3 |
| .005 | 92.7 |
| .004 | 93.3 |
| .004 | 93.3 |

Sample No: 12

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 107.6 | .0 |
| 53.8 | 3.3 |
| 26.9 | 4.2 |
| 13.5 | 5.5 |
| 10.8 | 7.0 |
| 7.17 | 7.5 |
| 5.27 | 7.8 |
| 2.69 | 10.7 |
| 1.80 | 13.5 |
| 1.35 | 17.2 |
| 1.08 | 19.5 |
| .719 | 26.0 |
| .539 | 30.0 |
| .268 | 83.0 |
| .143 | 94.1 |
| .107 | 96.0 |
| .072 | 97.6 |
| .054 | 98.3 |
| .027 | 99.4 |
| .018 | 99.7 |
| .013 | 99.9 |
| .011 | **** |
| .007 | **** |
| .005 | **** |
| .004 | **** |
| .004 | **** |

## INTERA TECHNOLOGIES

**Sample No: 13**

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 215.2 | .0 |
| 107.6 | 1.8 |
| 53.8 | 2.9 |
| 26.9 | 3.6 |
| 13.5 | 4.0 |
| 10.8 | 4.1 |
| 7.17 | 4.1 |
| 5.27 | 4.3 |
| 2.67 | 4.5 |
| 1.79 | 5.2 |
| 1.34 | 5.5 |
| 1.07 | 5.6 |
| .716 | 5.9 |
| .538 | 6.3 |
| .266 | 11.1 |
| .143 | 77.0 |
| .108 | 84.2 |
| .072 | 89.7 |
| .054 | 92.4 |
| .027 | 96.2 |
| .018 | 97.7 |
| .013 | 98.6 |
| .011 | 99.2 |
| .007 | 99.9 |
| .005 | **** |
| .004 | **** |
| .004 | **** |

**Sample No: 14**

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 53.8 | .0 |
| 26.9 | .2 |
| 13.5 | .3 |
| 10.8 | .5 |
| 7.17 | .7 |
| 5.27 | .6 |
| 2.66 | 1.0 |
| 1.78 | 2.6 |
| 1.34 | 3.4 |
| 1.07 | 4.1 |
| .716 | 5.4 |
| .537 | 6.6 |
| .267 | 38.4 |
| .143 | 82.1 |
| .108 | 90.2 |
| .072 | 98.2 |
| .054 | **** |
| .027 | **** |
| .018 | **** |
| .013 | **** |
| .011 | **** |
| .007 | **** |
| .005 | **** |
| .004 | **** |
| .004 | **** |

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## INTERA TECHNOLOGIES

**Sample No:** 15

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 215.2 | .0 |
| 107.6 | 2.0 |
| 53.8 | 2.4 |
| 26.9 | 2.6 |
| 13.5 | 2.7 |
| 10.8 | 2.8 |
| 7.17 | 2.9 |
| 5.27 | 3.1 |
| 2.67 | 3.4 |
| 1.78 | 4.0 |
| 1.34 | 4.3 |
| 1.07 | 5.0 |
| .716 | 6.5 |
| .537 | 7.3 |
| .267 | 29.9 |
| .143 | 75.2 |
| .107 | 81.9 |
| .072 | 88.6 |
| .054 | 91.6 |
| .027 | 96.3 |
| .018 | 97.9 |
| .013 | 98.8 |
| .011 | 99.3 |
| .007 | 99.9 |
| .005 | 99.9 |
| .004 | 99.9 |
| .004 | 99.9 |

**Sample No:** 16

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 107.6 | .0 |
| 53.8 | 1.3 |
| 26.9 | 5.2 |
| 13.5 | 6.0 |
| 10.8 | 6.3 |
| 7.17 | 6.7 |
| 5.27 | 7.4 |
| 2.68 | 8.8 |
| 1.79 | 13.2 |
| 1.35 | 15.3 |
| 1.08 | 16.7 |
| .718 | 18.9 |
| .539 | 20.7 |
| .267 | 49.8 |
| .143 | 80.1 |
| .1[illegible] | 85.6 |
| .0[illegible] | 90.7 |
| .0[illegible] | 93.2 |
| .027 | 96.9 |
| .018 | 98.1 |
| .013 | 98.8 |
| .011 | 99.1 |
| .007 | 99.4 |
| .005 | 99.4 |
| .004 | 99.4 |
| .004 | 99.4 |

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## INTERA TECHNOLOGIES

**Sample No:** 17

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 107.6 | .0 |
| 53.8 | .8 |
| 26.9 | 1.1 |
| 13.5 | 1.4 |
| 10.8 | 1.6 |
| 7.17 | 2.5 |
| 5.27 | 4.1 |
| 2.69 | 8.2 |
| 1.80 | 21.5 |
| 1.35 | 29.5 |
| 1.08 | 33.6 |
| .721 | 37.9 |
| .540 | 39.6 |
| .267 | 71.6 |
| .143 | 85.9 |
| .107 | 88.6 |
| .072 | 91.3 |
| .054 | 92.6 |
| .027 | 95.0 |
| .018 | 95.9 |
| .013 | 96.5 |
| .011 | 96.9 |
| .007 | 97.5 |
| .005 | 97.5 |
| .004 | 97.5 |
| .004 | 97.5 |

**Sample No:** 18

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 107.6 | .0 |
| 53.8 | .4 |
| 26.9 | .6 |
| 13.5 | .7 |
| 10.8 | .8 |
| 7.17 | .9 |
| 5.27 | 1.0 |
| 2.66 | 1.0 |
| 1.78 | 1.0 |
| 1.34 | 1.0 |
| 1.07 | 1.0 |
| .715 | 1.0 |
| .537 | 1.0 |
| .266 | 19.2 |
| .143 | 80.1 |
| .107 | 85.8 |
| .086 | 88.9 |
| .072 | 90.8 |
| .054 | 93.1 |
| .027 | 95.6 |
| .018 | 98.3 |
| .013 | 99.1 |
| .011 | 99.6 |
| .007 | **** |
| .005 | **** |
| .004 | **** |
| .004 | **** |

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## INTERA TECHNOLOGIES

Sample No: 19

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 107.6 | .0 |
| 53.8 | 1.9 |
| 26.9 | 2.4 |
| 13.5 | 2.7 |
| 10.8 | 2.8 |
| 7.17 | 2.9 |
| 5.27 | 3.2 |
| 2.68 | 3.2 |
| 1.79 | 3.2 |
| 1.34 | 3.2 |
| 1.07 | 3.2 |
| .716 | 3.2 |
| .538 | 3.2 |
| .266 | 8.5 |
| .143 | 61.1 |
| .107 | 72.7 |
| .072 | 81.8 |
| .054 | 86.0 |
| .027 | 92.5 |
| .018 | 95.4 |
| .013 | 97.1 |
| .011 | 98.2 |
| .007 | 99.9 |
| .005 | 99.9 |
| .004 | 99.9 |
| .004 | 99.9 |
| .004 | 95.3 |

Sample No: 20

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 215.2 | .0 |
| 107.6 | .7 |
| 53.8 | 1.2 |
| 26.9 | 2.5 |
| 13.5 | 3.3 |
| 10.8 | 3.4 |
| 7.17 | 3.6 |
| 5.27 | 3.7 |
| 2.67 | 3.7 |
| 1.78 | 3.9 |
| 1.34 | 4.0 |
| 1.07 | 4.1 |
| .716 | 4.3 |
| .537 | 4.4 |
| .266 | 4.5 |
| .143 | 10.6 |
| .107 | 42.1 |
| .072 | 75.4 |
| .054 | 81.0 |
| .027 | 87.9 |
| .018 | 90.4 |
| .013 | 92.0 |
| .011 | 93.0 |
| .007 | 94.5 |
| .005 | 95.2 |
| .004 | 95.3 |
| .004 | 95.3 |

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## INTERA TECHNOLOGIES

Sample No: 21

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 215.2 | .0 |
| 107.6 | .8 |
| 53.8 | 1.4 |
| 26.9 | 2.5 |
| 13.5 | 3.2 |
| 10.8 | 3.3 |
| 7.17 | 3.5 |
| 5.27 | 3.7 |
| 2.67 | 3.7 |
| 1.78 | 3.7 |
| 1.34 | 3.8 |
| 1.07 | 3.8 |
| .716 | 3.8 |
| .537 | 3.9 |
| .266 | 4.5 |
| .143 | 47.2 |
| .107 | 68.3 |
| .072 | 78.6 |
| .054 | 82.7 |
| .027 | 88.2 |
| .018 | 90.4 |
| .013 | 91.6 |
| .011 | 92.4 |
| .007 | 93.5 |
| .005 | 93.8 |
| .004 | 93.8 |
| .004 | 93.8 |

Sample No: 22

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 107.6 | .0 |
| 53.8 | 1.1 |
| 26.9 | 2.7 |
| 13.5 | 3.8 |
| 10.8 | 4.1 |
| 7.17 | 4.8 |
| 5.27 | 5.8 |
| 2.69 | 10.8 |
| 1.81 | 23.5 |
| 1.36 | 32.2 |
| 1.08 | 37.3 |
| .722 | 44.2 |
| .541 | 48.1 |
| .267 | 66.4 |
| .143 | 80.0 |
| .107 | 83.5 |
| .072 | 88.1 |
| .054 | 90.8 |
| .027 | 95.7 |
| .018 | 97.5 |
| .013 | 98.5 |
| .011 | 99.1 |
| .007 | 99.8 |
| .005 | **** |
| .004 | **** |
| .004 | **** |

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## INTERA TECHNOLOGIES

Sample No: 23

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 215.2 | .0 |
| 107.6 | 1.8 |
| 53.8 | 2.6 |
| 26.9 | 3.2 |
| 13.5 | 4.2 |
| 10.8 | 4.9 |
| 7.17 | 22.5 |
| 5.27 | 23.5 |
| 2.74 | 27.4 |
| 1.82 | 30.5 |
| 1.36 | 32.5 |
| 1.09 | 34.0 |
| .723 | 36.8 |
| .541 | 38.8 |
| .268 | 52.1 |
| .143 | 78.8 |
| .108 | 83.0 |
| .072 | 86.3 |
| .054 | 87.6 |
| .027 | 89.9 |
| .018 | 90.7 |
| .013 | 91.1 |
| .011 | 91.4 |
| .007 | 91.6 |
| .005 | 91.6 |
| .004 | 91.6 |
| .004 | 91.6 |

Sample No: 24

| Radius of Pore Apertures | Mercury Saturation (% Pore Volume) |
|---|---|
| 107.6 | .0 |
| 53.8 | .6 |
| 26.9 | 1.2 |
| 13.5 | 2.5 |
| 10.8 | 2.8 |
| 7.17 | 4.3 |
| 5.27 | 5.8 |
| 2.69 | 8.5 |
| 1.80 | 15.1 |
| 1.35 | 21.4 |
| 1.08 | 26.3 |
| .721 | 35.0 |
| .540 | 39.5 |
| .267 | 58.4 |
| .143 | 80.3 |
| .107 | 85.0 |
| .072 | 88.9 |
| .054 | 90.5 |
| .027 | 93.1 |
| .018 | 94.2 |
| .013 | 94.9 |
| .011 | 95.3 |
| .007 | 96.0 |
| .005 | 96.3 |
| .004 | 96.3 |
| .004 | 96.3 |

# END

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