A SOLUTION FOR FULLY DEVELOPED TURBULENT HEAT TRANSFER IN A CIRCULAR TUBE WITH UNIFORM WALL TEMPERATURE, USING A CONTINUOUS VELOCITY PROFILE

by

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ABSTRACT

Heat transfer coefficients and temperature profiles for fully developed turbulent pipe flow with uniform wall temperature are predicted for $Pr \leq 1$. The continous and differentiable velocity profile of Pai (1)[1] is used to integrate the energy equation numerically. Turbulent pipe flow is assumed to be steady, and thermally and hydrodynamically fully developed. The ratio of the eddy diffusivities is taken to be unity. Axial conduction is neglected, and the flow is assumed to be axisymmetric with constant fluid properties. The results obtained are presented as curves and tables. Three correlating equations are given which predict the Nusselt number for liquid-metals and for gases.

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[1]Numbers in brackets designate References at the end.

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NOMENCLATURE

a	constant to be evaluated in Eq. (40)
b	" " " " " " "
c	" " " " " " "
d	" " " " " " "
D	pipe diameter
C_p	specific heat at constant pressure
f	fanning friction factor
$f(\eta)$	function defined by Eq. (42)
$F(\eta)$	function defined by Eq. (36)
h	heat transfer coefficient
n	empirical constant defined by Eq. (20)
k	thermal conductivity
p	pressure
(q/A)	heat flux
$(q/A)_o$	heat flux at the wall
r	radius within the wall
r_o	radius of pipe
s	empirical constant defined by Eq. (17)
T	time-mean local temperature
T_o	wall temperature

T_m bulk mean temperature

t time

u radial component of time-mean velocity

w axial component of time-mean velocity

W mean value of w

y^+ dimensionless distance from wall in universal velocity profile

y distance from wall

z axial position in the pipe

Greek Letters

α thermal molecular diffusivity, $k/\rho c_p$

ϵ_h thermal turbulent diffusivity

ϵ_m momentum turbulent diffusivity

ν momentum molecular diffusivity, μ/ρ

η dimensionless radius within the pipe

θ dimensionless local temperature

μ dynamic viscosity

ρ mass density

τ transfer of z-directional momentum in r direction

τ_0 shear stress at the wall

Dimensionless Parameters

Nu	Nusselt number, hD/k
Pe	Peclet number, (Re) (Pr)
Pr	Prandtl number, $Cp\mu/k$
Re	Reynolds number, WD/μ

Subscripts

H	the constant heat flux value
T	" " wall temperature value
h	thermal value
m	momentum value, mean value
lam	laminar value
app	turbulent value
o	value at the wall
c	value at the center line
r	radial value

Superscripts

′	fluctuating component
–	time-mean value

I. INTRODUCTION

Seban and Shimizaki (2) made the first attempt to investigate the rate of heat transfer to fluids flowing turbulently in a pipe with the wall at uniform temperature. They followed an analytical method in which the universal velocity profile was used to obtain a solution for the Nusselt number. The eddy diffusivities were assumed to be equal. Momentum transfer by eddy diffusion in the laminar sublayer, and momentum transfer by molecular diffusion in the turbulent core were neglected. Martinelli's uniform heat flux solution was used as the first approximation for temperature distribution. The authors were the first to point out the difference between the heat transfer rates with uniform wall temperature and uniform heat flux, especially at low Prandtl numbers. The ratio between the heat transfer coefficients for the two cases was shown to have a maximum value of 1.37, with the coefficient for the uniform wall temperature case being the smaller of the two. For Prandtl numbers less than 0.1, their results were correlated with the following empirical relation

$$Nu = 5.0 + 0.025\ (Pe)^{0.8}$$

for which the maximum deviation is 6 percent.

Sleicher and Tribus (3) investigated the case of uniform wall temperature in the thermal entry region, from which other solutions can be obtained by the method of superposition. Their solution degenerates asyptotically to the fully-developed solution. They used the method of separation of variables to solve the energy equation. The resulting eigenvalues and constants were evaluated by using an analog computer. The ratio of eddy diffusivities suggested by Jenkins (4) was used after correction based on the experimental results of Sleicher (5). For Prandtl numbers less than 0.05, the results of uniform wall temperature are predicted within 2 percent by

$$Nu = 6.3 + 0.016\ (Pe)^{0.91}\ (Pr)^{0.30}\ .$$

The authors also present a plot of the ratio between the Nusselt numbers for constant wall temperature and constant heat flux versus Reynolds number.

The present analysis is aimed to predict the heat transfer coefficients for fully developed turbulent pipe flow under condition of uniform wall temperature, and is similar to the work of Seban and Shimizaki (2). The principle difference is that the present analysis uses the Pai velocity profile, whereas Seban and Shimizaki use the universal velocity profile.

The Pai velocity profile, to be discussed in detail later, is continously differentiable over the entire pipe cross section and fits the physical boundry conditions. Because of its algebraic simplicity, all physical variables may be maintained in the analysis. The Pai profile was also used by Haberstroh and Baldwin (6) for the uniform heat flux case. Their results are in good agreement with some well known analogies.

The energy equation is numerically integrated by means of an iterative method using a digital computer. The turbulent pipe flow is assumed to be steady, and thermally and hydrodynamically fully developed. The ratio of the eddy diffusivities is taken to be unity. Axial conduction is neglected, and the flow is assumed to be axisymmetric with constant fluid properties.

Since the solution of the energy equation requires the momentum results, the Pai profile is presented next.

II. THE MOMENTUM EQUATION

A. The Pai Profile

The laminar momentum equation for steady, fully developed, two dimensional, constant property flow is

$$\frac{d}{dr}\left(r\frac{dw}{dr}\right)=\frac{r}{\mu}\frac{dp}{dz} .$$

Transfer of z-directional momentum in the radial direction is by definition

$$\tau_{lam}=-\mu\frac{dw}{dz} .$$

Therefore

$$\frac{d}{dr}\left(r\tau_{lam}\right)=-r\frac{dp}{dz} .$$

The shear stress at wall is defined as

$$(\tau_o)_{lam}=-(\tau_{lam})_{r=r_o} .$$

From the momentum equation

$$(\tau_{lam})_{r=r_o}=\frac{r_o}{2}\frac{dp}{dz} .$$

Then the laminar momentum equation becomes

$$\frac{d}{dr}(r\tau_{lam}) = 2(\tau_o)_{lam}\frac{r}{r_o} \,. \tag{1}$$

The turbulent momentum equation may now be put down by analogy as

$$\frac{d}{dr}(r\tau_{app}) = 2(\tau_o)_{tur}\frac{r}{r_o} \tag{2}$$

where the apparent momentum transfer is

$$\tau_{app} = \tau_{mol} + \tau_{eddy}$$

or

$$\tau_{app} = -\left(\mu\frac{d\bar{w}}{dr} - \rho\,\overline{v'w'}\right) .$$

Eddy diffusivity for momentum is defined as

$$\epsilon_m \equiv -\frac{\overline{w'v'}}{\frac{d\bar{w}}{dr}} \,.$$

Therefore

$$\tau_{app} = -\rho\left(\nu\frac{d\bar{w}}{dr} + \epsilon_m\frac{d\bar{w}}{dr}\right) . \tag{3}$$

The bar on the mean velocity, w, will now be dropped for the sake of simplicity. The momentum equation can be rewritten as

$$-\frac{d}{dr}\left[r\rho(\nu+\epsilon_m)\frac{dw}{dr}\right] = 2\,(\tau_o)_{tur}\frac{r}{r_o}\,. \tag{4}$$

Integrating Eq. (4) once

$$-r\rho\,(\nu+\epsilon_m)\frac{dw}{dr} = (\tau_o)_{tur}\,\frac{r^2}{r_o} + c\,.$$

Using the boundry condition

$$r = 0 \qquad \frac{dw}{dr} = 0$$

the constant c vanishes, giving

$$-\rho(\nu+\epsilon_m)\frac{dw}{dr} = (\tau_o)_{tur}\,\frac{r}{r_o}\,.$$

Introducing the dimensionless radius $\eta = \frac{r}{r_o}$

$$\rho\,(\nu+\epsilon_m)\frac{dw}{d\eta} = -\,(\tau_o)_{tur}\,r_o\,\eta\,. \tag{5}$$

Since there are two unknowns in Eq. (5), namely the eddy diffusivity of momentum and the velocity gradient, it is not possible to obtain a unique solution from the momentum equation. Pai (1) assumed the velocity profile to have the following form

$$\frac{w}{w_c} = \left[1 - c_1\eta^2 - c_2\eta^{2n}\right] \tag{6}$$

which satisfies the condition of symmetry at the center line, and is forced to satisfy the other physical conditions at the wall as follows

$$\eta = 1 \qquad w = 0 \tag{7-a}$$

$$\eta = 1 \qquad \epsilon_m = 0. \tag{7-b}$$

The empirical constants c_1 and c_2 can be determined from Eqs. (7-a and b). To satisfy the first condition

$$1 - c_1 - c_2 = 0. \tag{8}$$

Substituting c_2 from Eq. (8) into Eq. (6) yields

$$\frac{w}{w_c} = \left[1 - \eta^{2n} + c_1(\eta^{2n} - \eta^2)\right].$$

The second condition can be satisfied by differentiating Eq. (6) and evaluating for $\eta = 1$

$$\left(\frac{dw}{d\eta}\right)_{\eta=1} = 2w_c\left[c_1(n-1) - n\right]. \tag{9}$$

Differentiating Eq. (5) and evaluating for $\eta = 1$

$$\left(\frac{du}{d\eta}\right)_{\eta=1} = - \frac{(\tau_0)_{tur}}{\mu} r_0 . \tag{10}$$

Equating (9) and (10) gives

$$2\omega_c \left[c_1(n-1) - n\right] = - \frac{(\tau_0)_{tur}}{\mu} r_0 .$$

Therefore

$$c_1 = \frac{n - \frac{(\tau_0)_{tur} r_0}{2\omega_c \mu}}{n - 1} .$$

The shear stress at the wall in laminar flow is given by

$$(\tau_0)_{lam} = \frac{2\omega_c \mu}{r_0} . \tag{11}$$

If we define

$$S \equiv \frac{(\tau_0)_{tur} r_0}{2\omega_c \mu}$$

then

$$S = \frac{(\tau_0)_{tur}}{(\tau_0)_{lam}} . \tag{12}$$

We now have

$$c_1 = \frac{n - s}{n - 1} \tag{13}$$

and

$$c_2 = 1 - c_1 = 1 - \frac{n - s}{n - 1} = \frac{s - 1}{n - 1} \tag{14}$$

The resulting dimensionless Pai profile is then

$$\frac{w}{w_c} = 1 - \frac{n - s}{n - 1}\eta^2 - \frac{s - 1}{n - 1}\eta^{2n} . \tag{15}$$

The parameters n and s are empirically determined functions of the Reynolds number alone, as will be shown later.

B. Features of the Pai Profile

The Pai profile is continous over the whole section. It satisfies the following three physical boundry conditions

$$\eta = 0 \qquad \frac{dw}{d\eta} = 0$$

$$\eta = 1 \qquad w = 0$$

$$\eta = 1 \qquad \epsilon_{r\eta} = 0 .$$

The first boundry condition implies that the slope is zero at the center line. This condition is not met by the universal velocity profile which has a finite slope at the center line and hence a discontinuity. The universal velocity profile has two more discontinuities, one between the turbulent core and the buffer zone and another between the buffer zone and the laminar sublayer.

Since the constant s represents the ratio between the turbulent and laminar wall shear stresses, when the two wall shear stresses are equal, the profile degenerates to the laminar profile. Thus with s = 1.0

$$\frac{w}{w_c} = 1 - \eta^2 . \tag{16}$$

1. Determination of Parameters s and n

The parameters s can be expressed as a function of Reynolds number only, as follows

$$s = \frac{(\tau_o)_{tur}}{(\tau_o)_{lam}} = \frac{(\tau_o)_{tur}\, r_o}{2 w_c \mu} = \frac{(\tau_o)_{tur}}{\frac{1}{2}\rho W^2} \; \frac{2 r_o W}{\nu} \; \frac{W}{w_c}$$

$$= \frac{f}{8} (Re) \frac{W}{w_c} . \tag{17}$$

It can be shown that the parameter n is also a function of Reynolds number only. The mean velocity over the cross section is given by

$$W = 2\int_0^1 w\eta\, d\eta . \tag{18}$$

Substituting for w from Eq. (15) and integrating gives

$$\frac{W}{w_c} = \frac{n+s}{2(n+1)} . \tag{19}$$

Solving for n and substituting for s from Eq. (17)

$$n = \frac{\frac{f}{16}(Re) - 1}{1 - \frac{1}{2}\frac{w_c}{W}} . \tag{20}$$

With two experiments, one for the friction factor and one for the mean-to-maximum velocity ratio, the parameters n and s may be easily determined. Brodkey (7) calculated the values of n and s from experimental data. He notes that for the higher Reynolds numbers, the value of the Pai velocity profile near the wall becomes higher than the experimental value. The maximum deviation occurs at about a y^+ of 75 for Reynolds numbers greater than 10^5. He also remarks that the Pai profile represents the velocity distribution over most of the turbulent core at all Reynolds numbers. Haberstroh and Baldwin (6) compare the Pai velocity profile to experimental profiles and conclude that the universal velocity profile is in general a better approximation than the Pai profile.

Brodkey (7) gives a plot of the parameters n and s versus Reynolds number. He also suggests the following correlations:

$$s = 0.585 + 3.172 \times 10^{-3} (Re)^{0.833} \qquad Re < 2800$$

$$s = 2.417 \times 10^{-12} (Re)^{3.51} \qquad 2040 < Re < 2800$$

$$s = 1 \qquad Re < 2040$$

$$n = - 0.617 + 8.211 \times 10^{-3} (Re)^{0.786}.$$

The first two equations have average deviations of 2.3 and 5.1 percent respectively and the last one has an average deviation of 2.9 percent.

The values of n and s suggested by Haberstroh and Baldwin (6) were used in the present analysis. These values are given in Table 1.

2. The Eddy Diffusivity for Momentum

The Pai assumes zero eddy diffusivity for momentum at the wall, as indicated before. This compares to an eddy diffusivity of momentum of zero for the whole laminar

Re	n	s
Laminar	-	1.00
2000	9.25	1.04
3000	3.31	2.86
8000	9.00	6.43
10000	10.93	7.56
30000	26.51	17.60
50000	39.91	26.62
70000	52.18	35.04
100000	69.27	46.97
300000	165.12	116.40
500000	247.00	177.83

Table 1 The values of the flow parameters for the Pai velocity profile

sublayer of the universal velocity profile. The eddy-to-molecular momentum transfer ratio can be determined from the Pai profile. Combining Eq. (5) with Eq. (11) and Eq. (12) gives

$$\left(1+\frac{\epsilon_m}{\nu}\right)\frac{1}{w_c}\frac{dw}{d\eta} = -2s\eta . \tag{21}$$

Differentiating the velocity profile and combining with Eq. (21) yields

$$\frac{\epsilon_m}{\nu} = \frac{s(n-1)}{n-s+n(s-1)\eta^{2n-1}} - 1 \tag{22}$$

which has the following values at the wall and the center line

$$\eta = 1 \qquad \frac{\epsilon_m}{\nu} = 0$$

$$\eta = 0 \qquad \frac{\epsilon_m}{\nu} = \frac{n(s-1)}{n-s} .$$

The eddy diffusivity of momentum for the universal profile becomes discontinous at $y^+=5$ and goes to minus 1 at the center line; whereas the eddy diffusivity of momentum for the Pai profile is continous over the whole pipe section and has a non-negative value at the center line.

III. THE ENERGY EQUATION

A. Laminar and Turbulent Energy Equations

The laminar energy equation for a steady, two dimensional, constant property flow is

$$\frac{k}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + k\frac{\partial^2 T}{\partial z^2} = \rho\, c_p\, w\, \frac{\partial T}{\partial z}$$

where the axial conduction term, $k\frac{\partial^2 T}{\partial z^2}$, is usually neglected. The Fourier's law of heat conduction gives

$$\frac{\partial T}{\partial r} = -\frac{1}{k}\,(q/A)_{lam} \; . \qquad (23)$$

With Eq. (23) and with the axial conduction term neglected, the energy equation becomes

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\,(q/A)_{lam}\right) = -\rho\, c_p\, w\, \frac{\partial T}{\partial z} \; .$$

The turbulent energy equation may now be put down by analogy, as

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\,(q/A)_{app}\right) = -\rho\, c_p\, \bar{w}\, \frac{\partial \bar{T}}{\partial z} \qquad (24)$$

where the apparent heat flux is given by

$$(q/A)_{app} = (q/A)_{mol} + (q/A)_{eddy} = -\left(k\frac{\partial \bar{T}}{\partial r} - \rho C_p \overline{u'T'}\right)$$

Eddy diffusivity for heat is defined as

$$\epsilon_h \equiv - \frac{\overline{u'T'}}{\frac{\partial \bar{T}}{\partial r}} . \tag{25}$$

Then

$$(q/A)_{app} = -\left(k\frac{\partial \bar{T}}{\partial r} + \rho c_p \epsilon_h \frac{\partial \bar{T}}{\partial r}\right) = -\rho C_p (\alpha + \epsilon_h)\frac{\partial \bar{T}}{\partial r}$$

combining with Eq. (24) gives

$$\frac{1}{r}\frac{\partial}{\partial r}\left((\alpha + \epsilon_h) r \frac{\partial \bar{T}}{\partial r}\right) = \omega \frac{\partial \bar{T}}{\partial z} . \tag{26}$$

The bar on the mean quantities, w and T, will be dropped hereafter. The boundry conditions are

$$r = 0 \qquad \frac{\partial T}{\partial r} = 0 \tag{27-a}$$

$$r = r_0 \qquad T = T_0 \ \text{(constant)}. \tag{27-b}$$

B. Thermally Fully Developed Flow

Thermally fully developed flow is defined as

$$\theta = \frac{T_o - T}{T_o - T_m} = \theta(\eta, \text{only}) . \tag{28}$$

Then

$$\frac{\partial}{\partial z}\left(\frac{T_o - T}{T_o - T_m}\right) = 0$$

or

$$\frac{1}{T_o - T_m}\frac{\partial T_o}{\partial z} - \frac{1}{T_o - T_m}\frac{\partial T}{\partial z} - \frac{T_o - T}{(T_o - T_m)^2}\left[\frac{\partial T_o}{\partial z} - \frac{\partial T_m}{\partial z}\right] = 0 . \tag{29}$$

Since wall temperature constant

$$\frac{\partial T_o}{\partial z} = 0$$

and Eq. (29) becomes

$$\frac{\partial T}{\partial z} = \frac{T_o - T}{T_o - T_m}\frac{\partial T_m}{\partial z} = \theta\,\frac{\partial T_m}{\partial z} . \tag{30}$$

$\frac{\partial T_m}{\partial z}$ is not a function of radius, r, and ordinary derivatives may be used for this term instead of partial derivatives. The energy equation now becomes

$$\frac{d}{dr}\left[(\alpha + \epsilon_h) r \frac{dT}{dr}\right] = r\,\omega\,\theta\,\frac{dT_m}{dz} .$$

C. Integration of the Energy Equation

The energy equation can be put in dimensionless form as follows

$$\frac{1}{r_o}\frac{d}{dr/r_o}\left[(\alpha+\epsilon_h)(T_o-T_m)\frac{r}{r_o}\frac{d\left(\frac{T-T_o}{T_o-T_m}\right)}{dr/r_o}\right] = r_o\,\frac{r}{r_o}\,w\theta\,\frac{dT_m}{dz}$$

or

$$\frac{d}{d\eta}\left[\left(1+\frac{\epsilon_h}{\alpha}\right)\eta\,\frac{d\theta}{d\eta}\right] = -\frac{r_o^2\,w\,\theta\,\eta\,\frac{dT_m}{dz}}{\alpha(T_o-T_m)} \qquad (31)$$

From an energy balance

$$(q/A)_o\,2\pi r_o\,dz = C_p\,(\rho W \pi r_o^2)\,dT_m$$

or

$$\frac{dT_m}{dz} = \frac{2\,(q/A)_o}{\rho\,C_p\,W\,r_o} \qquad (32)$$

substituting Eq. (32) into Eq. (31), and using

$$h \equiv \frac{(q/A)_o}{T_o-T_m},$$

one obtains

$$\frac{d}{d\eta}\left[\left(1+\frac{\epsilon_h}{\alpha}\right)\eta\frac{d\theta}{d\eta}\right] = -\,Nu\,\frac{w_c}{W}\,\frac{w}{w_c}\,\eta\,\theta\,. \tag{33}$$

The boundry conditions become

$$\eta = 0 \qquad \frac{d\theta}{d\eta} = 0$$

$$\eta = 1 \qquad \theta = 0\,.$$

Integrating Eq. (33) once yields

$$\frac{d\theta}{d\eta} = -\,\frac{Nu}{W/w_c}\,\frac{\int_0^\eta \theta\left(\frac{w}{w_c}\right)\eta\,d\eta}{\eta\left(1+\epsilon_h/\alpha\right)}\,.$$

A second integration gives

$$\theta = \frac{Nu}{W/w_c}\int_\eta^1 \frac{\int_0^\eta \theta\left(\frac{w}{w_c}\right)\eta\,d\eta}{\eta\left(1+\epsilon_h/\alpha\right)}\,d\eta\,. \tag{34}$$

Now the Pai momentum results are used together with the assumption of equal eddy diffusivities for heat and momentum. From Eq. (22)

$$\frac{\epsilon_m}{\nu} = \frac{\epsilon_h}{\nu} = \frac{s(n-1)}{n-s+n(s-1)\eta^{2n-2}} - 1\,,$$

and from Eq. (19)

$$\frac{W}{w_c} = \frac{n+s}{2(n+1)}$$

substituting into Eq. (34) gives

$$\theta = Nu\int_{\eta}^{1} \frac{\frac{2(n+1)}{n+s}\int_0^{\eta}\left(1-\frac{n-s}{n-1}\eta^2-\frac{s-1}{n-1}\eta^{2n}\right)\eta\theta\, d\eta}{\eta\left[1+Pr\left[\frac{s(n-1)}{n-s+n(s-1)\eta^{2n-2}}-1\right]\right]}\, d\eta . \tag{35}$$

If the integral on the right hand side of Eq. (35) is called F (η),

$$F(\eta) = \int_{\eta}^{1} \frac{\frac{2(n+1)}{n+s}\int_0^{\eta}\left(1-\frac{n-s}{n-1}\eta^2-\frac{s-1}{n-1}\eta^{2n}\right)\eta\theta\, d\eta}{\eta\left[1+Pr\left[\frac{s(n-1)}{n-s+n(s-1)\eta^{2n-2}}-1\right]\right]}\, d\eta , \tag{36}$$

then

$$\theta = Nu\, F(\eta) . \tag{37}$$

Since F (η) contains the unknown, θ, an iterative procedure must be used for the solution of Eq. (37). Once a value of θ is assumed, Nu number can be calculated as follows

$$Nu = \frac{hD}{k} = \frac{2\,(q/A)_o\, r_o}{(T_o-T_m)k}$$

and since

$$(q/A)_o = -\frac{k}{r_o}(T_o-T_m)\left(\frac{d\theta}{d\eta}\right)_{\eta=1},$$

$$Nu = -2\left(\frac{d\theta}{d\eta}\right)_{\eta=1} . \tag{38}$$

The next approximation to θ can be found by Eq. (37) after the integral F (η) is evaluated. The iteration continues until the difference between successive Nusselt numbers becomes insignificant. The procedure for the evaluation of the integral F (η) is presented in the next section.

IV. THE COMPUTER PROGRAM

A. Procedure

In the computer program a somewhat different iteration procedure was followed. In this method, the mean value of the dimensionless temperature profile is first calculated.

1. The Mean Value of the Dimensionless Temperature Distribution

By definition

$$\theta_m = \frac{T_o - T_m}{T_o - T_m} = 1$$

and also

$$\theta_m = \frac{\int_0^1 \theta \omega 2\pi \eta \, d\eta}{\int_0^1 \omega 2\pi \eta \, d\eta} = 1$$

substituting the equivalent of θ from Eq. (37)

$$\frac{Nu \int_0^1 F(\eta) \frac{\omega}{\omega_c} \eta \, d\eta}{\int_0^1 \frac{\omega}{\omega_c} \eta \, d\eta} = 1 .$$

Substituting the Pai velocity profile from Eq. (15)

$$\frac{Nu \int_0^1 F(\eta) \frac{w}{w_c} \eta \, d\eta}{\int_0^1 \left(1 - \frac{n-s}{n-1}\eta^2 - \frac{s-1}{n-1}\eta^{2n}\right)\eta \, d\eta} = 1,$$

integrating the denominator and solving for Nu gives

$$Nu = \frac{\frac{n+s}{n+1}}{4\int_0^1 F(\eta) \frac{w}{w_c} \eta \, d\eta} . \tag{39}$$

2. Integration of F (η)

First a dimensionless temperature profile of the form

$$\theta = a + b\eta + c\eta^2 + d\eta^3 \tag{40}$$

was assumed. For the lowest Reynolds number used, this starting temperature profile was a third degree polynomial approximation of the laminar temperature profile for the case of constant heat flux. For the higher Reynolds numbers, the temperature profile of the previous case was used as the starting profile. The first integral in Eq. (36) was integrated in closed form and called f (η), giving

$$F(\eta) = \int_\eta^1 \frac{\frac{2(n+1)}{n+s} f(\eta)\, d\eta}{\eta\left[1 + Pr\left[\frac{s(n-1)}{n-s+n(s-1)\eta^{2n-2}} - 1\right]\right]} \tag{41}$$

where

$$f(\eta) = \int_0^{\eta} (a + b\eta + c\eta^2 + d\eta^3)\left(1 - \frac{n-s}{n-1}\eta^2 - \frac{s-1}{n-1}\eta^{2n}\right)\eta\, d\eta$$

$$= a\left(\frac{\eta^2}{2} - \frac{n-s}{4(n-1)}\eta^4 - \frac{s-1}{(n-1)(2n+2)}\eta^{2n+2}\right) +$$

$$b\left(\frac{\eta^3}{3} - \frac{n-s}{5(n-1)}\eta^5 - \frac{s-1}{(n-1)(2n+3)}\eta^{2n+3}\right) +$$

$$c\left(\frac{\eta^4}{4} - \frac{n-s}{6(n-1)}\eta^6 - \frac{s-1}{(n-1)(2n+4)}\eta^{2n+4}\right) +$$

$$d\left(\frac{\eta^5}{5} - \frac{n-s}{7(n-1)}\eta^7 - \frac{s-1}{(n-1)(2n+5)}\eta^{2n+5}\right) . \qquad (42)$$

The Simpson rule was used to integrate Eq. (41) numerically for given Prandtl and Reynolds numbers, the later determining the values of n and s. Since the lower limit of the integral is not definite, it was necessary to integrate F (η) for a sufficient number of different values of the lower limit. This resulted in a set of values rather than a unique value, the set giving the temperature profile after multiplying by the Nusselt number according to Eq. (37). The values assigned to the lower limit varied between zero and unity, since $0 \leq \frac{r}{r_0} = \eta \leq 1$. After completing a set of calculations, the number of values used as the lower limit was doubled, and Nusselt number recalculated. This procedure was repeated until the difference between successive Nusselt numbers was less than 0.01. A similar procedure was used in connection with the number of integration increments used in the numerical integration of F (η). Thus the total number of increments used were equal to the product of the number of lower limit intervals and the number of integration increments. This total number became so large for high values of Prandtl and Reynolds numbers that it was not possible to cover Reynolds number greater than 5×10^5.

For the purpose of using in the calculation of the temperature profile and the Nusselt number, as described in the next section, a third degree polynomial was fitted through those values obtained from the numerical integration of F (η), in the form

$$F(\eta) = a_1 + b_1\eta + c_1\eta^2 + d_1\eta^3. \qquad (43)$$

A third degree polynomial was chosen because it gives the least root mean square for all Pr numbers used. This polynomial turns out to be almost exact for Prandtl numbers less than 0.1. For Prandtl numbers larger than

0.5, a higher degree polynomial would have been a better choice, but since the region of major interest is the liquid metal range, the same degree polynomial was used for all cases.

3. Calculation of the Nusselt Number and the Temperature Profile

After combining Eq. (15) with Eq. (39) and substituting F (η) in polynomial form one obtains

$$Nu = \frac{\frac{n+s}{n+1}}{4\int_0^1 (a_1+b_1\eta+c_1\eta^2+d_1\eta^3)\left(1-\frac{n-s}{n-1}\eta^2-\frac{s-1}{n-1}\eta^{2n}\right)\eta\, d\eta} \quad (44)$$

Carrying out integration gives

$$Nu = \frac{\frac{1}{4}\,\frac{n+s}{n+1}}{a_1\left[\frac{n+s}{4(n+1)}\right]+b_1\left[\frac{4n+6s}{15(2n+3)}\right]+c_1\left[\frac{n+2s}{12(n+2)}\right]+d_1\left[\frac{4n+10s}{35(2n+5)}\right]} \quad (45)$$

The first approximation was obtained for the Nusselt number by using Eq. (45) and the temperature profile was adjusted according to Eq. (37). The adjusted profile was then used for the next evaluation of F (η) and the Nusselt number. This iteration scheme was continued until the Nusselt numbers of successive iterations differed by no more than 0.1 percent.

4. Reduction to the Laminar Case

It was before shown that the Pai velocity profile degenerates to the laminar velocity profile

$$\frac{w}{w_c} = 1 - \eta^2$$

at a Reynolds number of 2000. Other laminar relations can be obtained by setting s equal to unity in Eqs. (42), (41), and (39), giving

$$f(\eta) = a\left(\frac{\eta^2}{2} - \frac{\eta^4}{4}\right) + b\left(\frac{\eta^3}{3} - \frac{\eta^5}{5}\right) + c\left(\frac{\eta^4}{4} - \frac{\eta^6}{6}\right) + d\left(\frac{\eta^5}{5} - \frac{\eta^7}{7}\right), \quad (46)$$

$$F(\eta) = 2\int_0^1 \frac{f(\eta)}{\eta}\, d\eta , \quad (47)$$

and

$$Nu = \frac{1}{4\int_0^1 (1-\eta^2) F(\eta)\eta\, d\eta} . \quad (48)$$

The computer calculations gave a Nusselt number of 3.656 for the laminar case compared to the accepted value 3.658. The difference between the two values is less than 0.1 percent.

B. Evaluation of the Program

The number of intervals used for the lower limit of the integral and the number of increments of the numerical integration were doubled and the effect on the results checked. In this manner, use of a sufficient number of increments was insured. Once the number of increments was decided for a particular case, the convergence of Nusselt number to its true value was obtained by iteration. Iteration was continued until the Nusselt numbers of successive iterations differed by not more than 0.1 percent. The laminar solution obtained on the computer, which showed good agreement with accepted results, is a measure of the validity of the computer program.

V. THE RESULTS

The calculated values of the Nusselt numbers are shown in Table 2. The range of Prandtl numbers was chosen to be between zero and unity. Since for large Prandtl numbers the difference between the Nusselt numbers of uniform wall and heat flux cases is not significant, Prandtl numbers larger than unity were not condisered. As the Reynolds number increases the required number of integration increments also increases, and numerical integration becomes very tedious. Therefore Reynolds numbers larger than 5×10^5 were not covered.

The calculated values of Nusselt number versus Reynolds number are plotted in Fig. 1. The convergence of Nusselt number to its laminar value at a Reynolds number of 2000 is a consequence of the Pai profile used. The general behaviour of the curves is similar to the behavior of those for constant heat flux given by Haberstroh and Baldwin (6). The following empirical equations may be used to predict the calculated values of Nusselt number. In each case, the average deviation is shown in parantheses.

For $0.5 \leq Pr \leq 1.$ (Gases)

$$Nu = 0.176\ Re^{0.817}\ Pr^{0.55} \qquad (2.0\ \%) \qquad (49)$$

For $Pr \leq 0.05$ (Liquid metals)

$$Nu = 4.44 + 0.0233\ ((Re - 1000)Pr)^{0.837} \qquad (3.3\ \%) \qquad (50)$$

or

$$Nu = 4.88 + 0.0056\ Re\ Pr \qquad (6.6\ \%). \qquad (51)$$

The Nusselt numbers predicted by these equations, and the corresponding percent deviations are given in Tables 3 through 8.

The present solution and the solutions of Seban-Shimizaki (2) and Sleicher-Tribus (3) are compared in the liquid metal range in Fig 2. The first two solutions are in good agreement except for very high Reynolds numbers. The discrepancy at high Reynolds numbers may be a results of high velocities predicted by the Pai profile at high Reynolds numbers at a short distance from the wall. The results of the last solution differ from the results of the first two solutions. This disagreement may be due to the fact that the first two solutions assume the ratio of eddy diffusivities to be unity whereas the last solution assumes this ratio to be different than unity.

For the liquid metal range the Peclet number which is equal to the product of the Reynolds and Prondtl numbers, alone is a good correlating parameter, as indicated in Fig. 3. Eq. (51) is based on this observation. However, at large Peclet numbers the effect of Prandtl number becomes significant. In Fig. 3, the prediction of Kays (8), as given by

$$Nu = 4.8 + 0.003\ (Re\ Pr) \qquad (52)$$

is also plotted. The difference between the present solution and Eq. (52) increases as the Peclet number increases.

In Fig. 4, the present results are compared with the experimental data of Colborn-Coughlan (9) and the results of references (2 and 8) for a Prandtl number of 0.5. Agreement between the data and the present calculations is particularly good at transition Reynolds numbers.

The ratio between Nusselt numbers for uniform heat flux and for uniform wall temperature is plotted in Fig. 5. The results of Haberstroh and Baldwin (6) for uniform heat flux were used to calculate this ratio, as they also employed the Pai velocity profile. It should be noted that the ratios all converge to the laminar value which is

$$\frac{Nu_H}{Nu_T} = \frac{4.364}{3.658} = 1.19$$

For fluids of large Prandtl number the two Nusselt numbers tend to become equal as Reynolds number increases. Seban and Shimizaki (2) give the following discussion of this behaviour:

> " Since, for the same heat-transfer rate, the heat-transfer coefficient depends on the difference between wall and mean-temperature values, the difference in the heat-transfer coefficients for the cases considered depends upon the magnitude of this temperature difference. For fluids of large Prandtl number, the change in temperature between wall and fluid is localized in the sublayer region immediately adjacent to the wall, and the temperature is almost constant across the entire turbulent core. Thus the magnitude of the mean temperature is but insignificantly affected by variation in the temperature of the wall. "

This effect at large Prandtl numbers is clearly seen in temperature profiles presented in Appendix A.

On the other hand, in the liquid metal range the difference between the two Nusselt numbers is quite significant; and the Nusselt number ratio can become even larger than in the case of laminar flow. As Prandtl number approaches zero, molecular diffusion of heat predominates over eddy diffusion regardless of the level of turbulence, and the temperature profile does not become flat in the turbulent core as in the case of higher Prandtl numbers. The effect of increased turbulence (as Reynolds number increases) now amounts to a flatter velocity profile, which, one may assume, approaches a uniform value over the cross section (plug flow) as a limit. On the basis of such an idealized model, that of plug flow with heat transfer by molecular diffusion only (i.e. laminar flow), it is possible to calculate a maximum value for the Nusselt number ratio of uniform heat flux to uniform wall temperature. Such a calculation gives

$$\frac{Nu_H}{Nu_T} = \frac{8}{5.8} = 1.37 .$$

Fig. 5 shows that the calculated ratio for $Pr = 0$ approaches this limiting value asymptotically as Reynolds number increases.

The curves of Fig. 5 are qualitatively in good agreement with similar curves presented by Sleicher and Tribus (3).

Numerical values of the Nusselt number ratios are given in Table 9. Base on the numerical values, the curves of Fig. 5 have a maximum error of 4 percent.

The temperature profiles for all cases considered are presented in Appendix A. It was before pointed out that as the liquid metal region is of primary interest, a third degree polynomial approximation was used for all cases even through a higher degree would have been better for $Pr = 0.5$ and $Pr = 1$. This explains the seatles observed in the temperature profiles at those two Prandtl numbers.

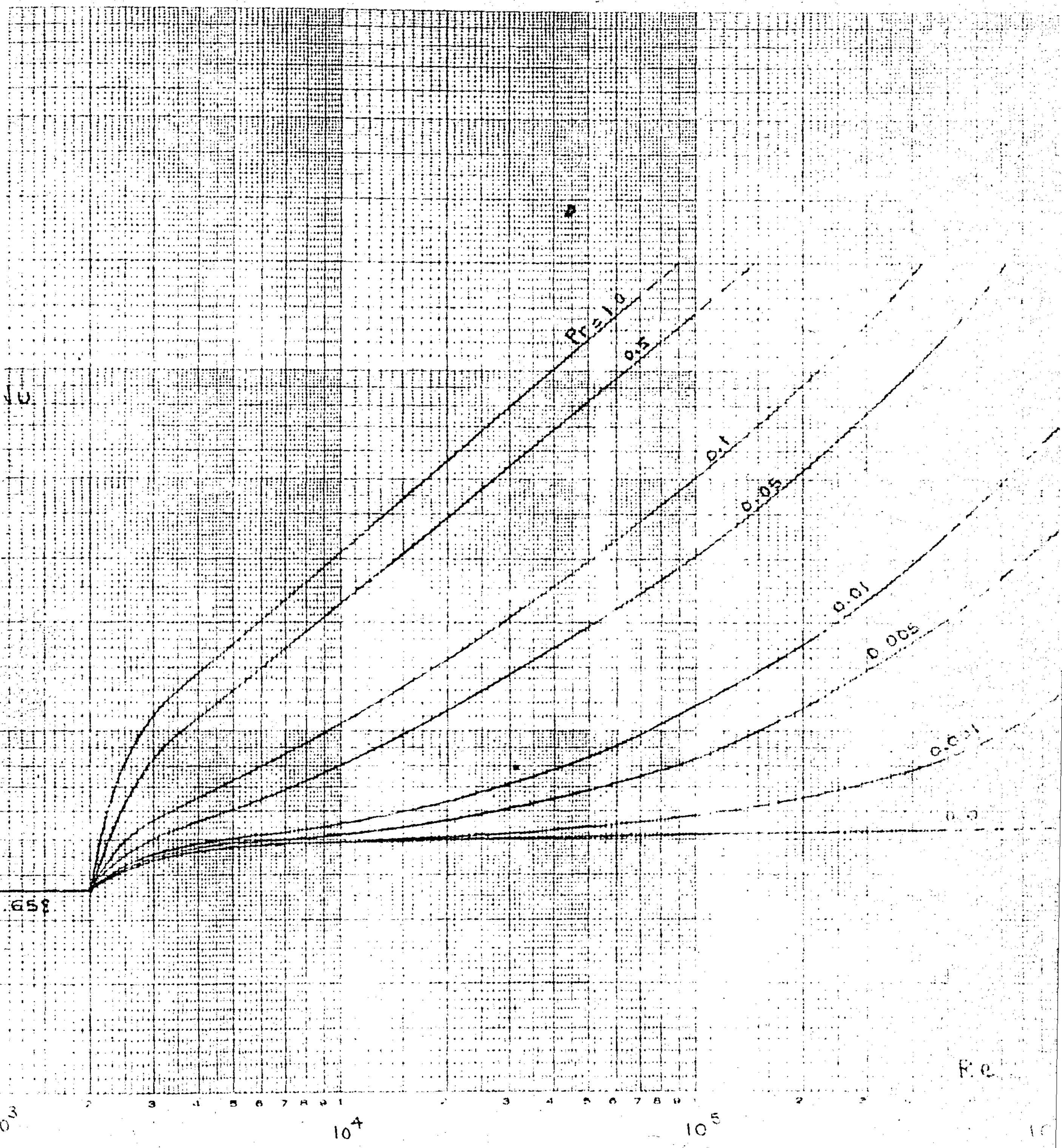


Fig 1 Calculated values of the Nusselt number versus Reynolds number

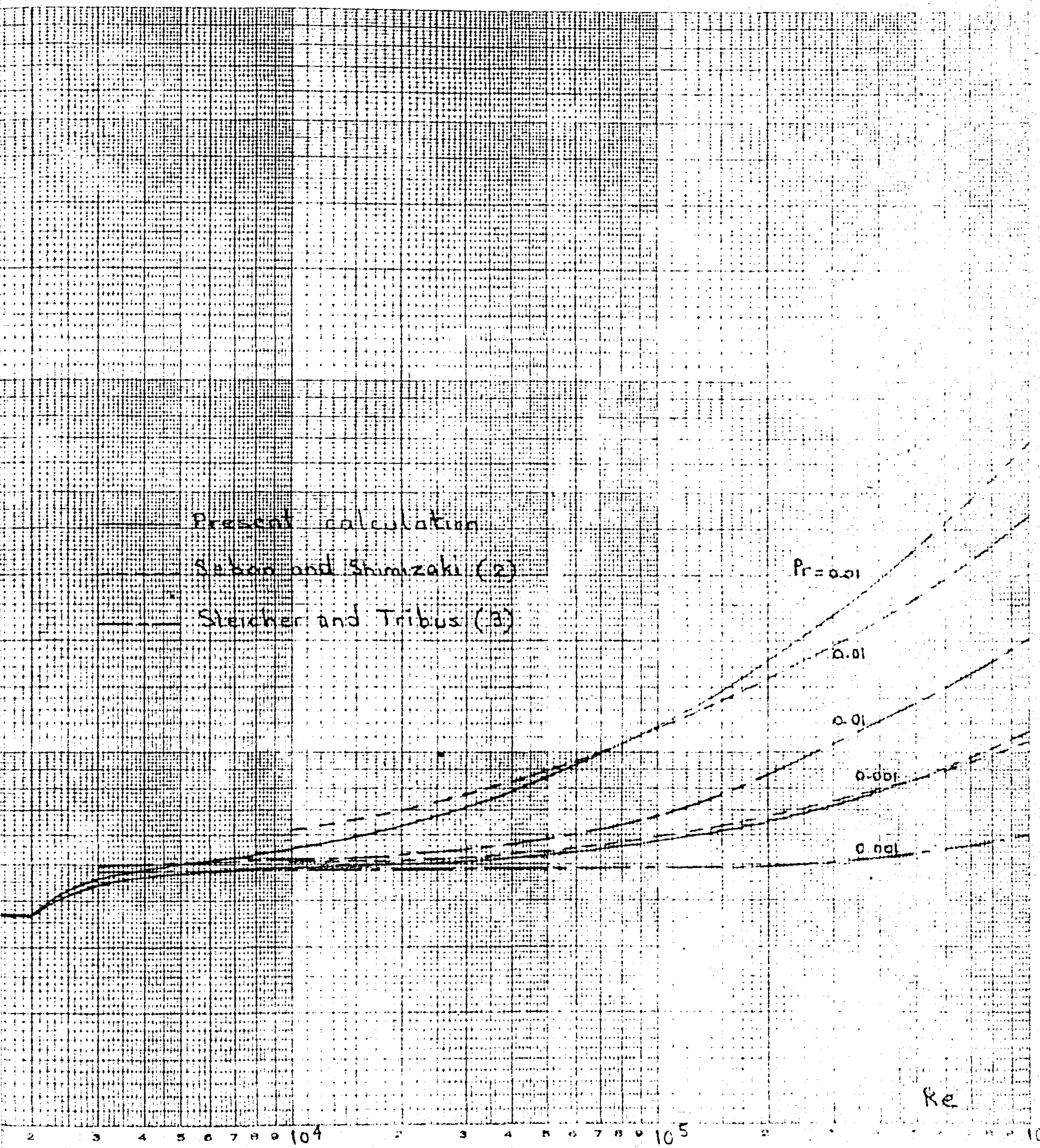


Fig 2 Comparison of the present solution with other solutions in the liquid metal region

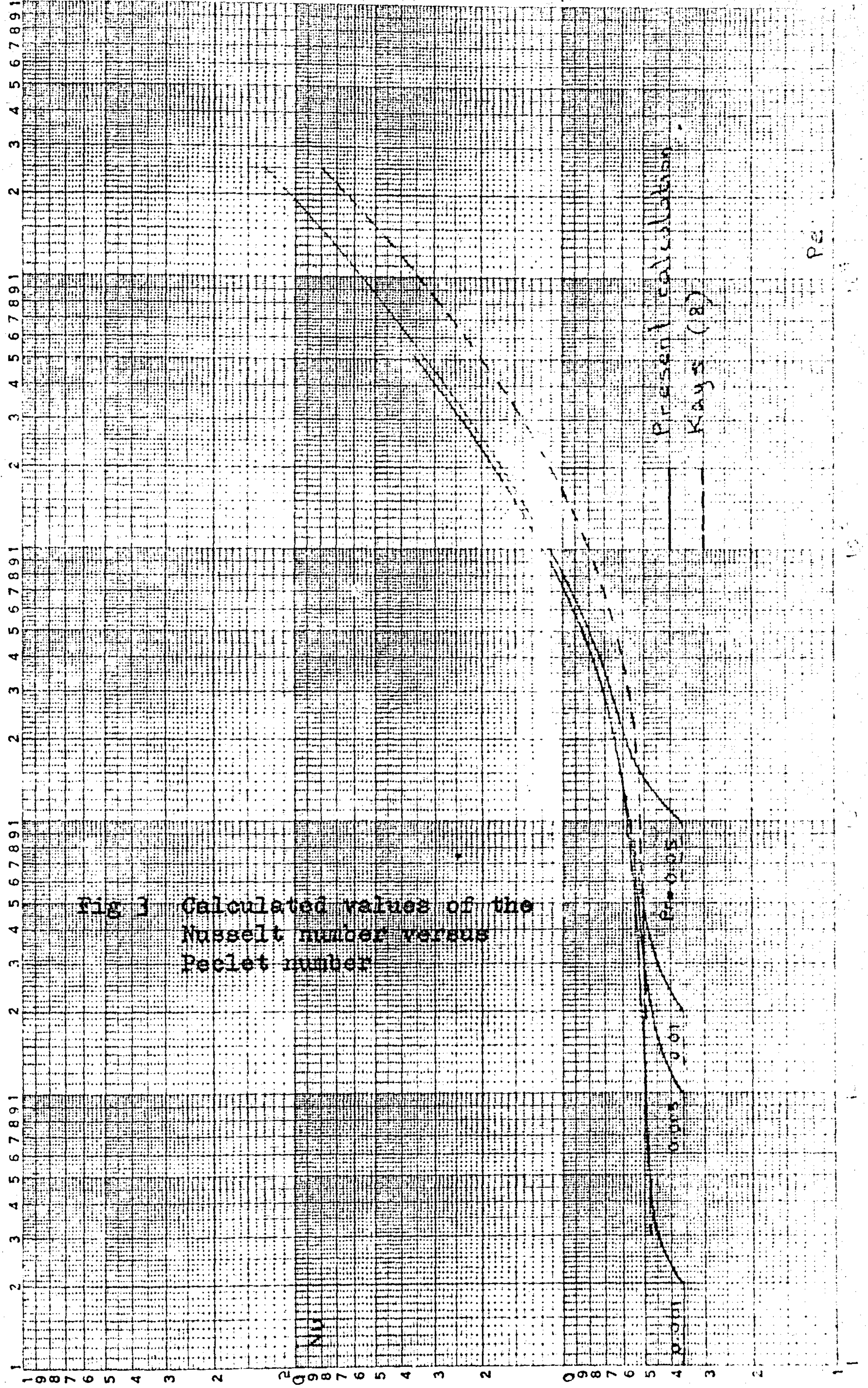


Fig 3 Calculated values of the Nusselt number versus Peclet number

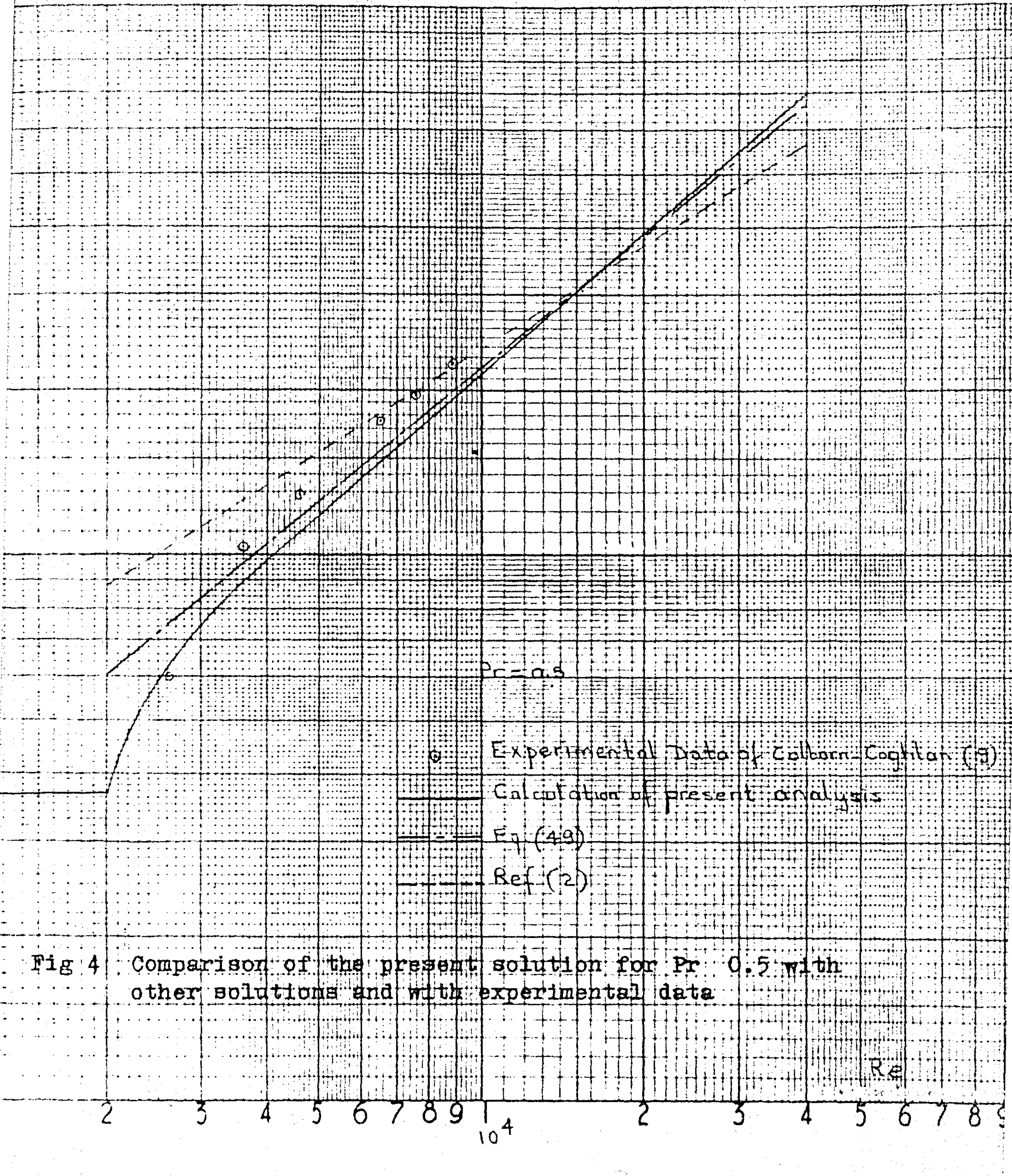
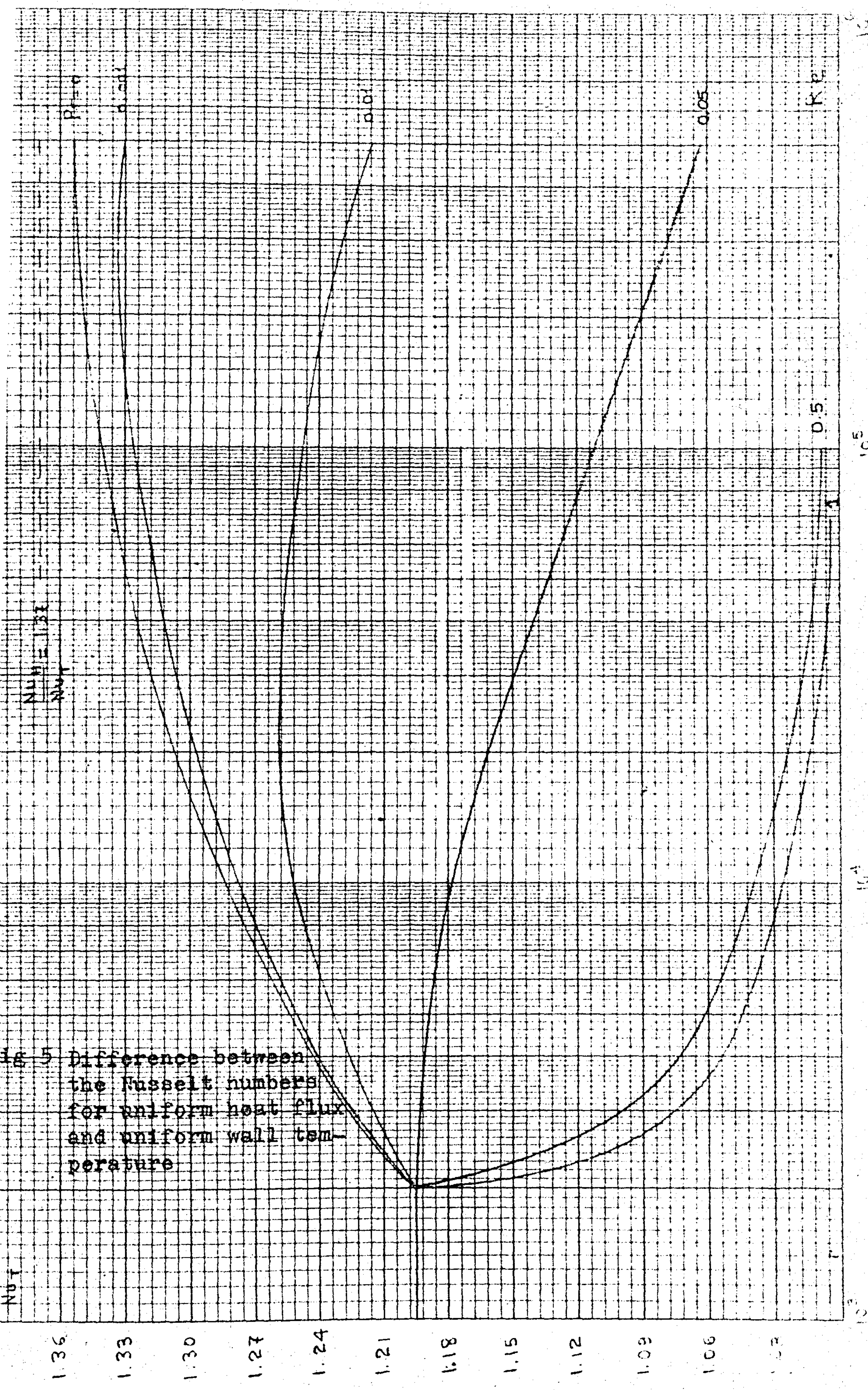


Fig 4 Comparison of the present solution for Pr 0.5 with other solutions and with experimental data



ig 5 Difference between the Nusselt numbers for uniform heat flux and uniform wall temperature

r	0.	0.001	0.005	0.01	0.05	0.1	0.5	1.0
0	3.658	3.658	3.658	3.658	3.658	3.658	3.658	3.658
0	4.429	4.446	4.512	4.592	5.144	5.705	8.663	11.276
0	4.805	4.862	5.098	5.381	7.323	9.274	19.439	27.393
00	4.842	4.913	5.196	5.539	7.913	10.341	22.595	32.960
00	5.016	5.233	6.095	7.143	14.472	20.429	52.984	79.699
00	5.078	5.438	6.854	8.549	19.701	28.888	81.159	122.473
00	5.113	5.605	7.515	9.807	25.743	38.542	106.354	161.137
00	5.148	5.844	8.574	11.549	31.711	50.836	143.817	
00	5.237	7.197	14.957	23.358	81.13	136.91		
00	5.275	8.520	20.878	35.663	131.22			

2 Calculated values of Nusselt number

Re/Pr	0.5	1.0
3000	8.320	12.187
8000	18.536	27.151
10000	22.241	32.578
30000	54.555	79.911
50000	82.798	121.281
70000	108.985	159.638
100000	145.840	–

Table 3 Values of Nusselt number predicted by Eq. (49)

Re/Pr	0.5	1.0
3000	0.039	-0.080
8000	0.046	0.008
10000	0.015	0.011
30000	-0.029	-0.002
50000	-0.020	0.009
70000	-0.024	0.009
100000	-0.014	–

Table 4 Percent deviations for Eq. (49)

Re/Pr	0.001	0.005	0.01	0.05
3000	4.481	4.600	4.726	5.542
8000	4.559	4.897	5.257	7.585
10000	4.586	5.005	5.449	8.322
30000	4.831	5.944	7.127	14.778
50000	5.046	6.773	8.609	20.477
70000	5.248	7.548	9.992	25.797
100000	5.533	8.644	11.951	33.333
300000	7.197	15.046	23.386	77.319
500000	8.673	20.723	33.528	116.329

Table 5 Values of Nusselt number predicted by Eq. (50)

Re/Pr	0.001	0.005	0.01	0.05
3000	-0.008	-0.019	-0.029	-0.077
8000	0.062	0.039	0.022	-0.035
10000	0.066	0.036	0.016	-0.051
30000	0.076	0.024	0.002	-0.021
50000	0.071	0.011	-0.007	-0.039
70000	0.063	-0.004	-0.018	-0.002
100000	0.053	-0.008	-0.034	-0.051
300000	0.000	-0.005	-0.001	0.046
500000	-0.017	0.007	0.059	0.113

Table 6 Percent deviations for Eq. (50)

Re/Pr	0.001	0.005	0.01	0.05
3000	4.897	4.964	5.048	5.720
8000	4.925	5.104	5.328	7.120
10000	4.936	5.160	5.440	7.680
30000	5.048	5.720	6.560	13.280
50000	5.160	6.280	7.680	18.880
70000	5.272	6.840	8.800	24.480
100000	5.440	7.680	10.480	32.880
300000	6.560	13.280	11.680	88.880
500000	7.680	18.880	32.880	144.880

Table 7 Values of Nusselt number predicted by Eq. (51)

Re/Pr	0.001	0.005	0.01	0.05
3000	-0.101	-0.100	-0.099	-0.111
8000	-0.012	-0.001	0.009	0.027
10000	0.004	0.006	0.017	0.029
30000	0.035	0.061	0.081	0.082
50000	0.051	0.083	0.101	0.041
70000	0.059	0.089	0.102	0.049
100000	0.069	0.104	0.092	-0.036
300000	0.088	0.112	0.071	-0.095
500000	0.098	0.095	0.078	-0.104

Table 8 Percent deviations for Eq. (51)

Re/Pr	0.	0.001	0.01	0.05	0.5	1.0
2000	1.19	1.19	1.19	1.19	1.19	1.19
3000	1.227	1.225	1.215	1.180	1.090	1.070
10000	1.282	1.280	1.254	1.180	1.051	1.032
30000	1.32	1.304	1.250	1.110	1.030	1.019
50000	1.325	1.315	1.243	1.125	1.012	1.005
70000	1.335	1.321	1.250	1.090	1.010	1.004
100000	1.34	1.323	1.265	1.130	1.005	-
300000	1.35	1.335	1.255	1.090	-	-
500000	1.351	1.330	1.215	1.034	-	-

Table 9 Values of Nu_H/Nu_T

VI. SUMMARY AND CONCLUSIONS

Once the empirical constant s and n are know, the Pai velocity profile may be used to integrate the turbulent energy equation.

With the assumption of equal eddy diffusivities of heat and momentum, the energy equation may be numerically integrated to give the temperature profile and the Nusselt number.

The Pai velocity profile is continous and fits the physical boundry conditions. But it has the disadvantage of predicting high velocity values for Reynolds numbers larger than 10^5. Therefore in the region of high Reynolds numbers the present predictions are higher than the predictions of those analysis employing the universal velocity profile, which correlates experimental data more accurately in this region.

The present calculations are in agreement with experimental data for Pr = 0.5. For other Prandtl numbers, the correlation between the present predictions and experimental data is to be determined.

The following equations may be used to obtain the calculated Nusselt numbers, with average deviations as indicated.

For $0.5 \leq Pr \leq 1$ (Gases)

$$Nu = 0.176\ Re^{0.817}\ Pr^{0.55} \qquad (2.0\ \%)$$

For $Pr \leq 0.05$ (Liquid metals)

$$Nu = 4.44 + 0.0233\ ((Re - 1000)Pr)^{0.837} \qquad (3.3\ \%)$$

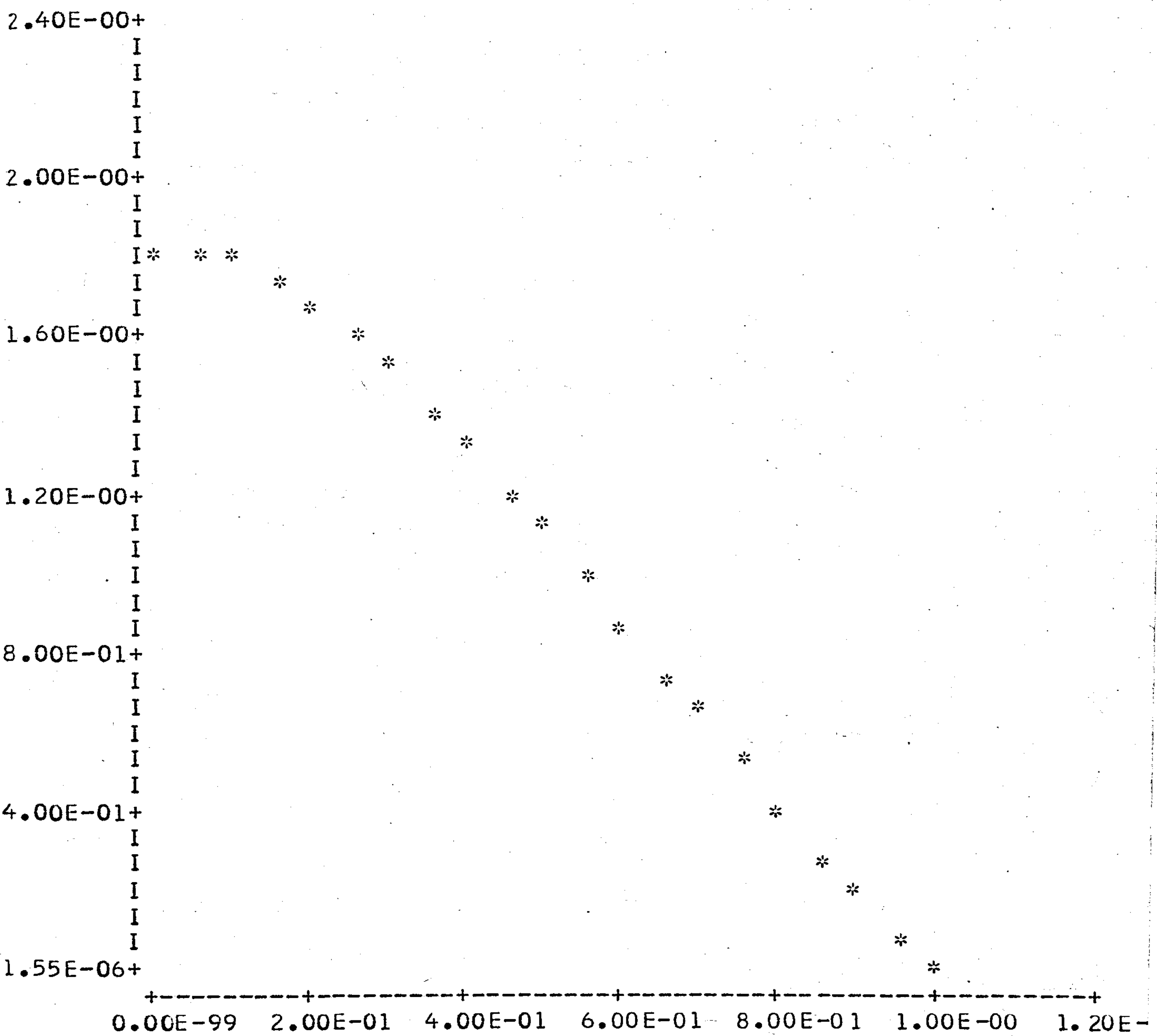
or

$$Nu = 4.88 + 0.0056\ Pe \qquad (6.6\ \%)$$

APPENDIX A

THE TEMPERATURE PROFILES

(abscissa: dimensionless radius, η
ordinate: dimensionless temperature, θ)



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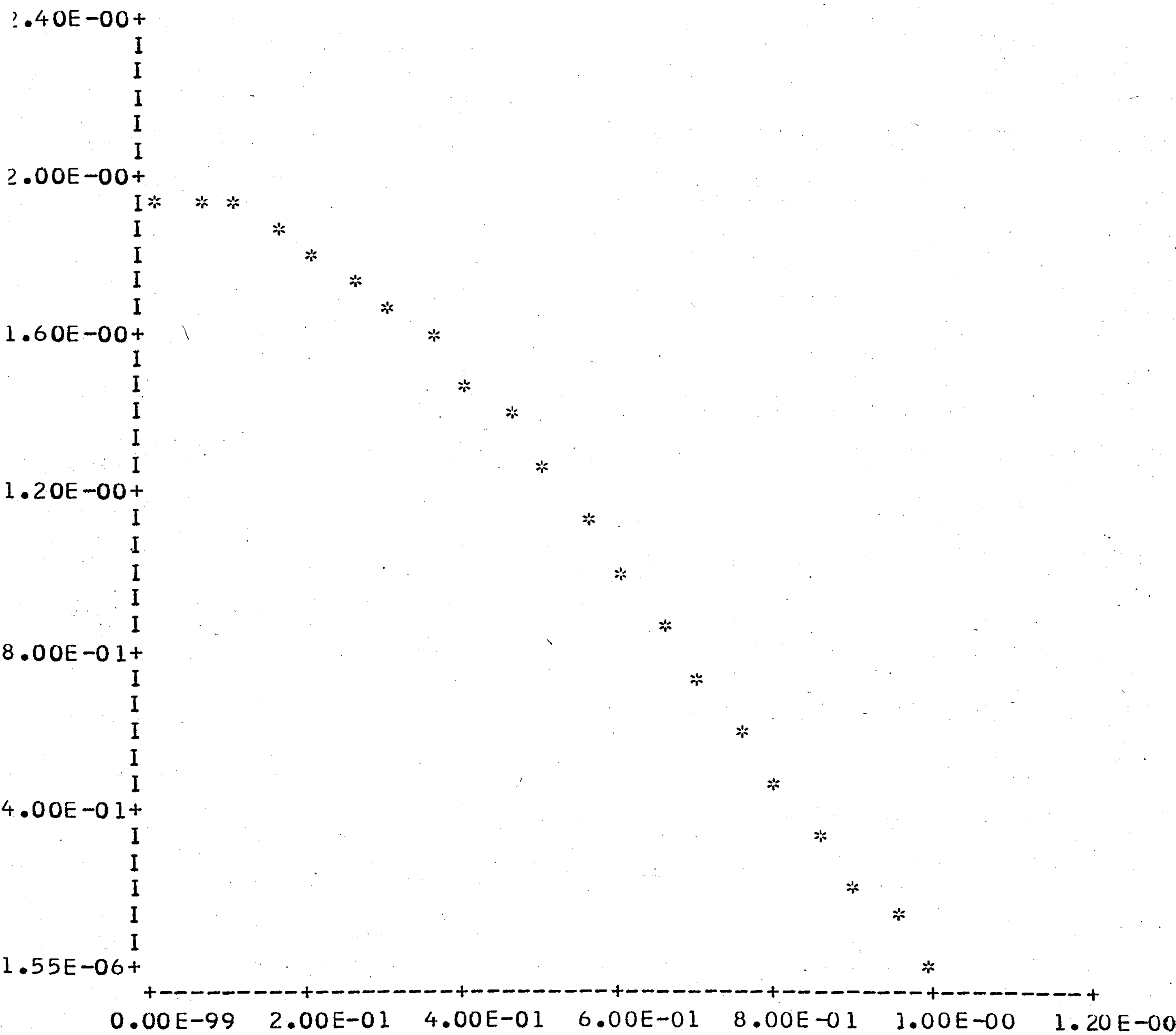

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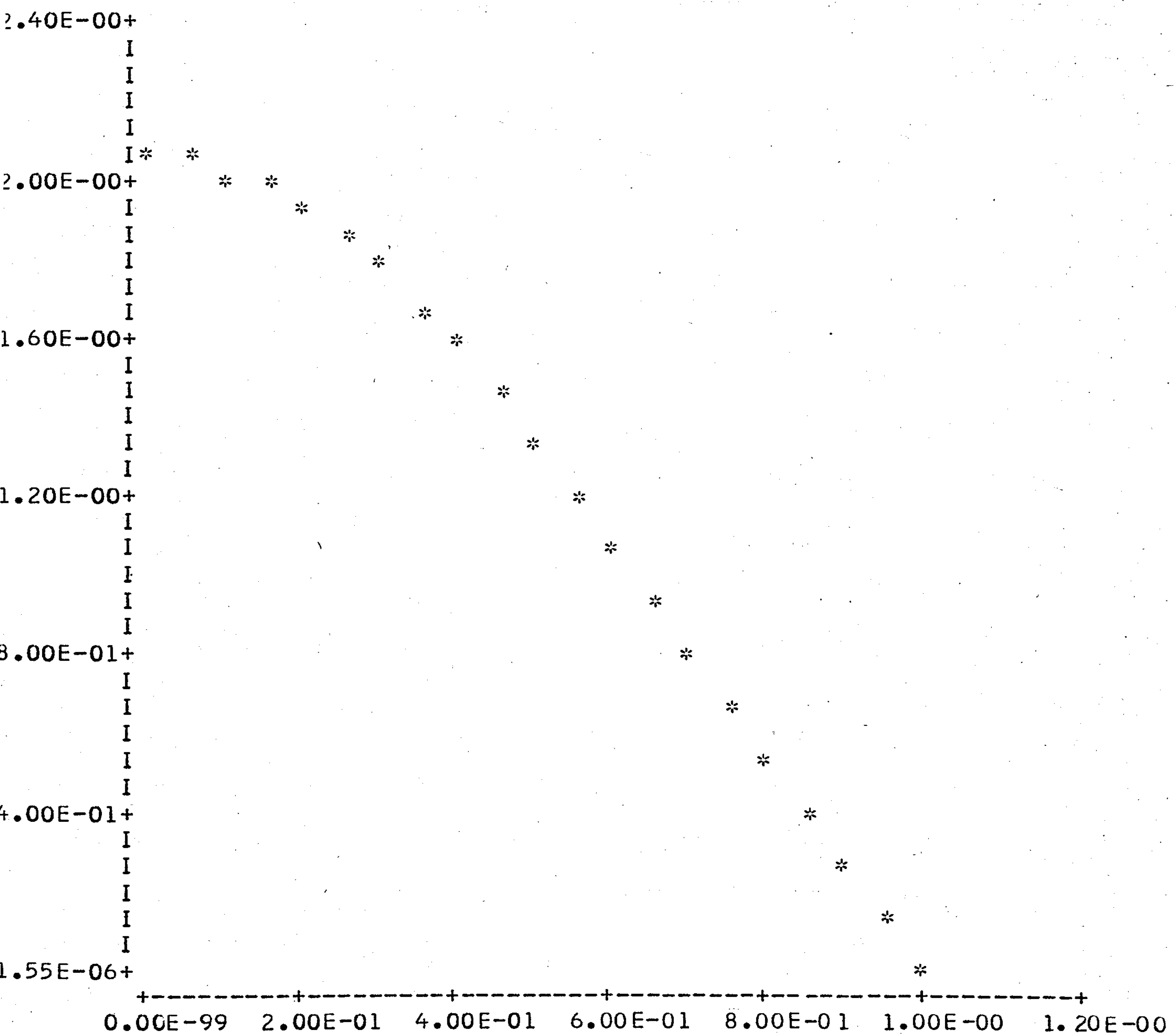

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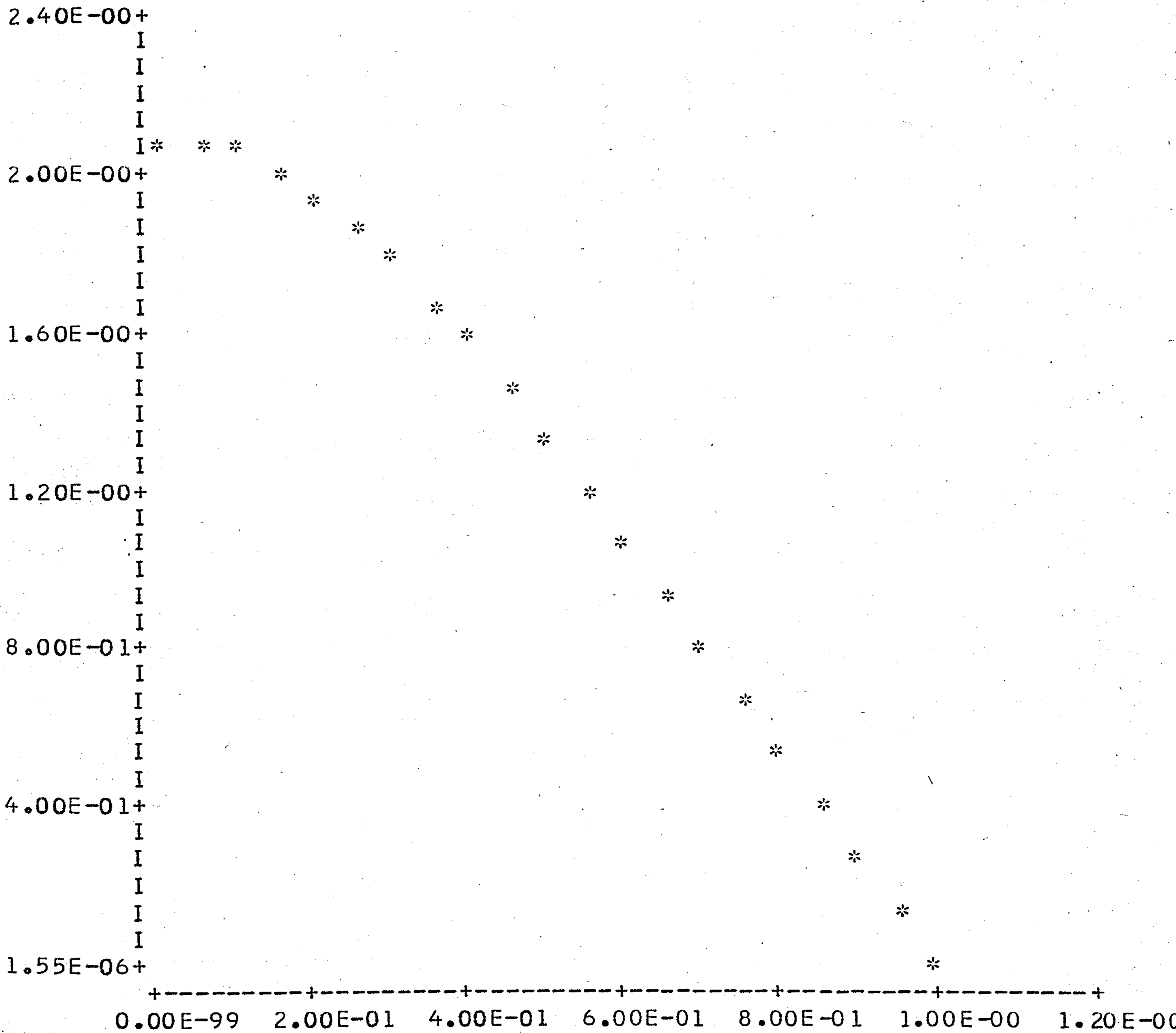

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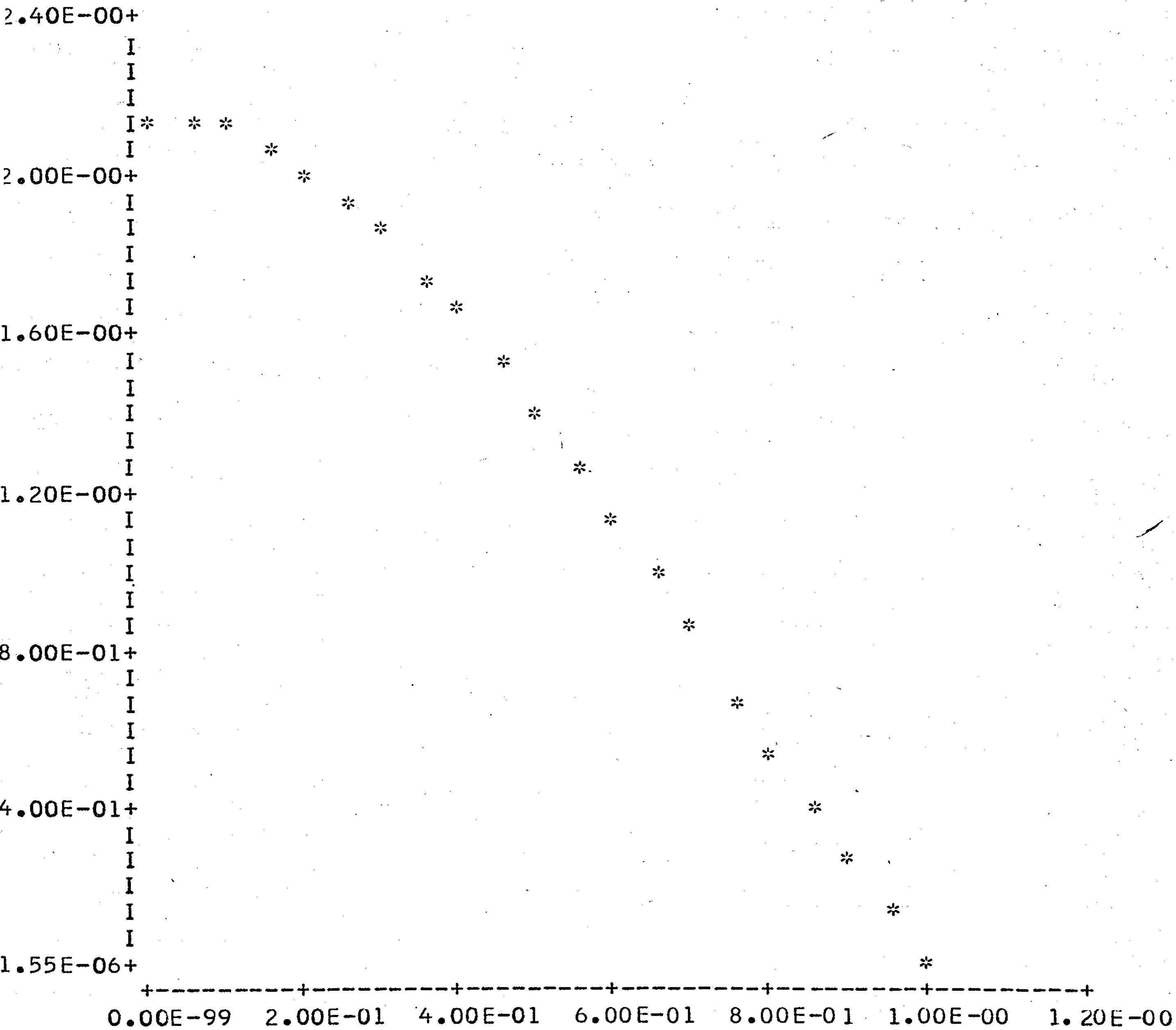

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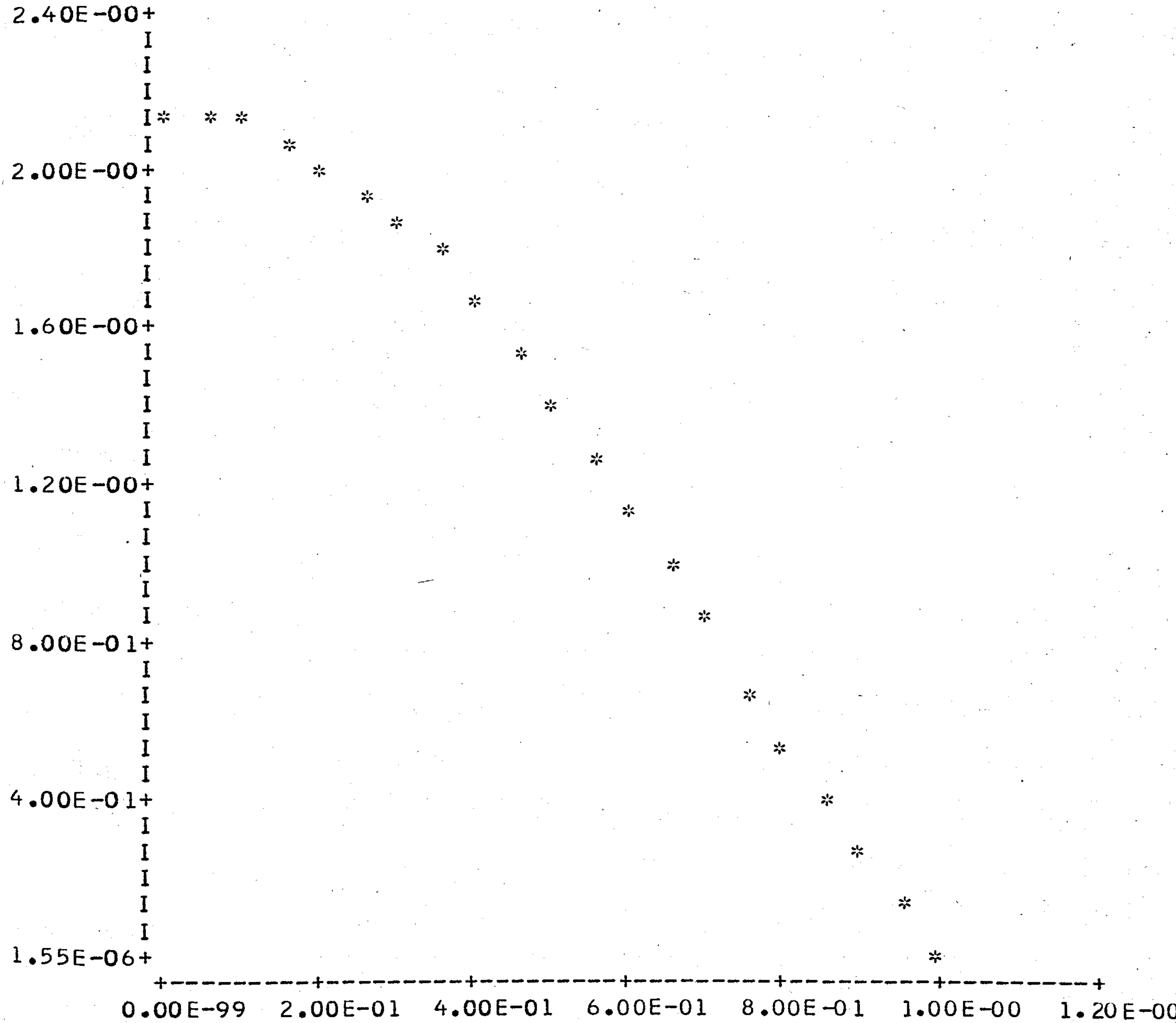

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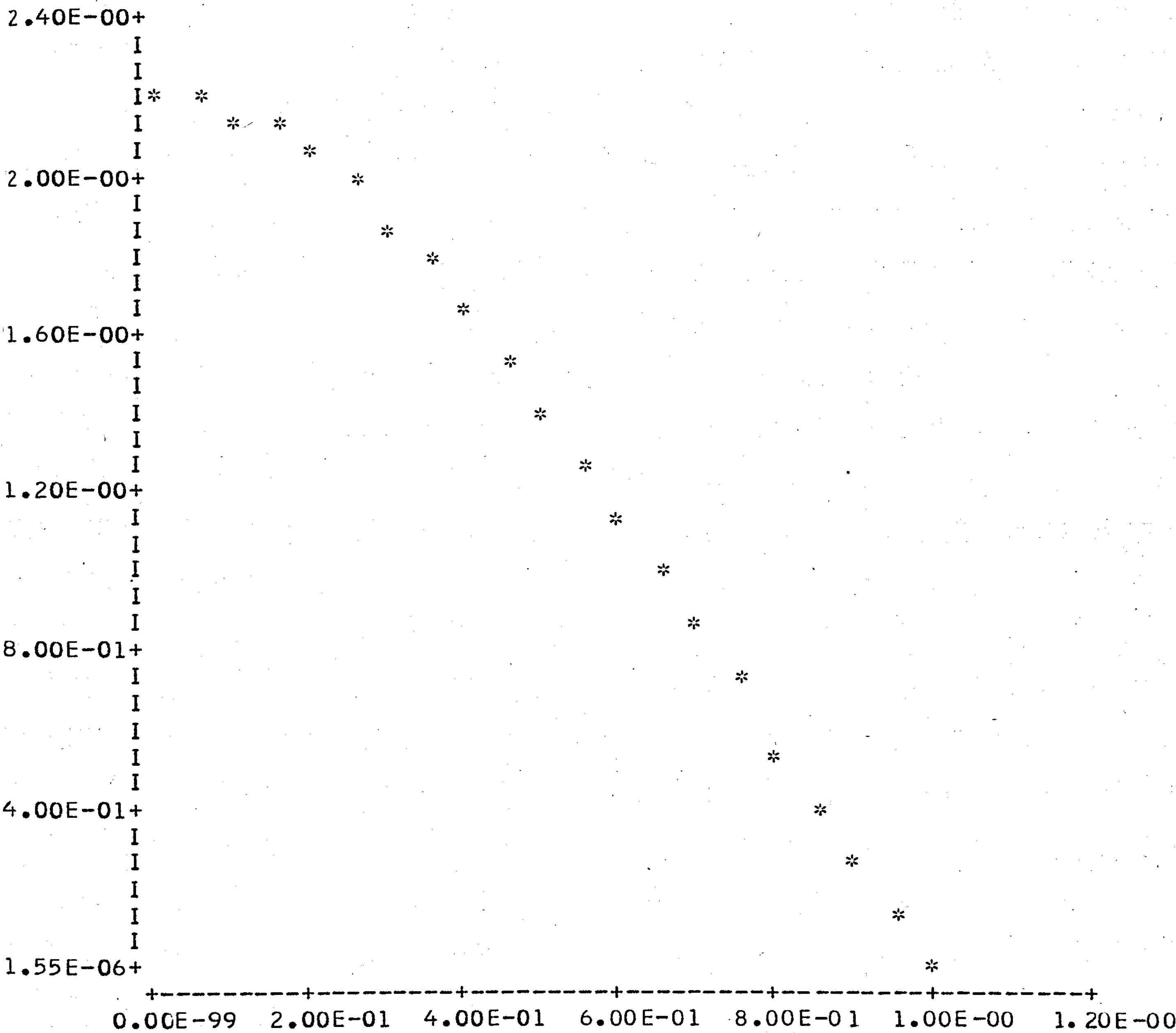

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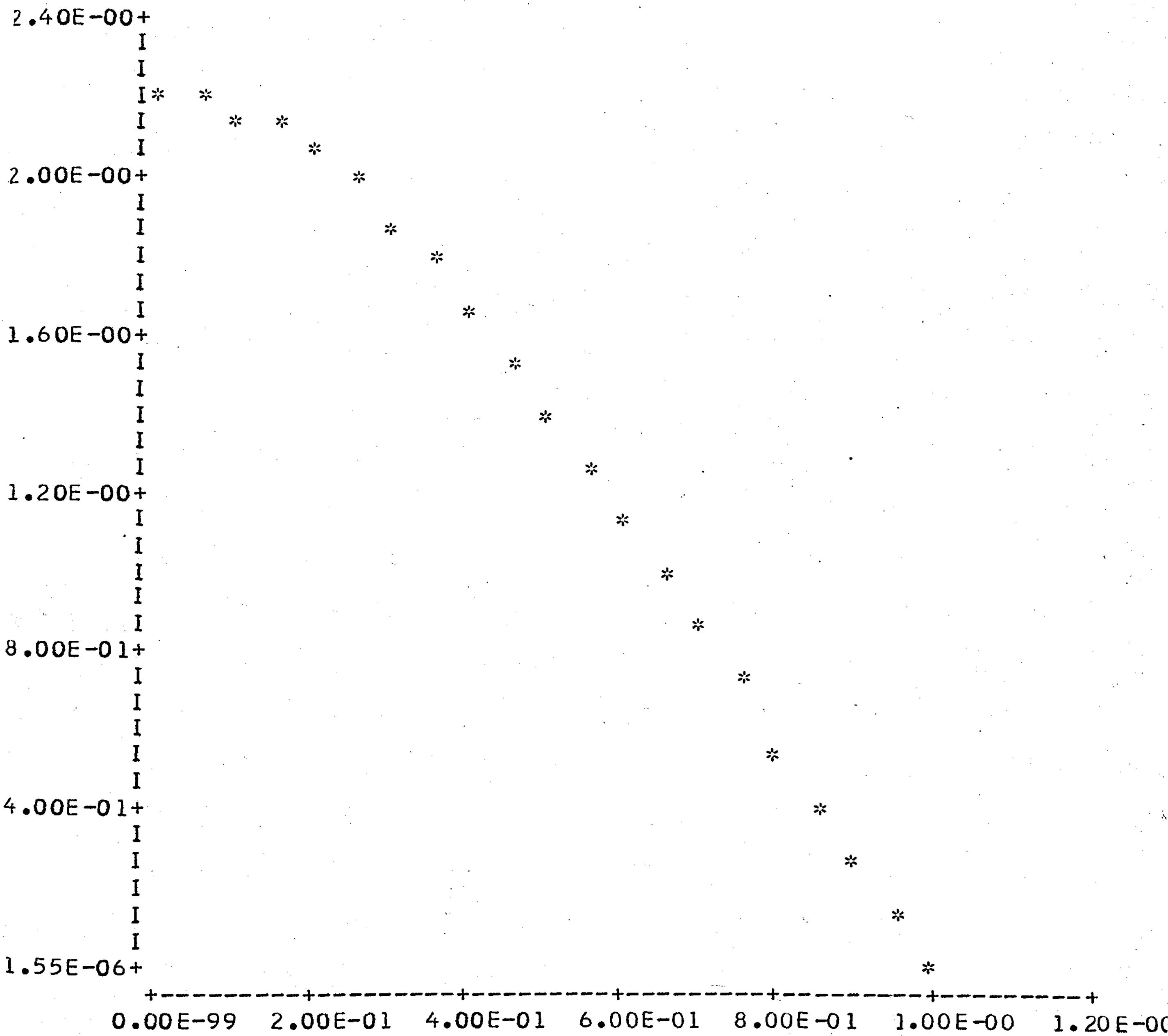

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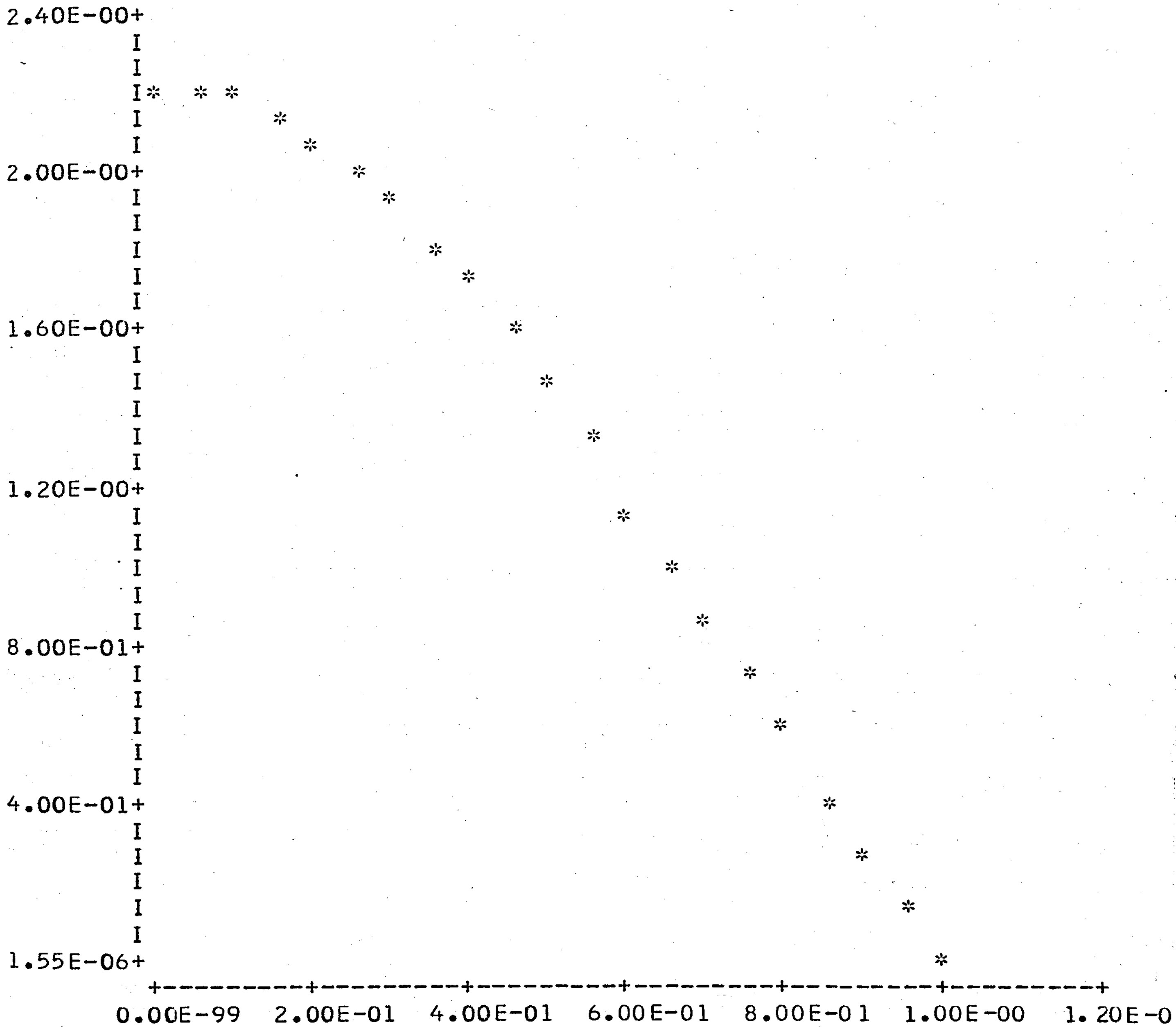

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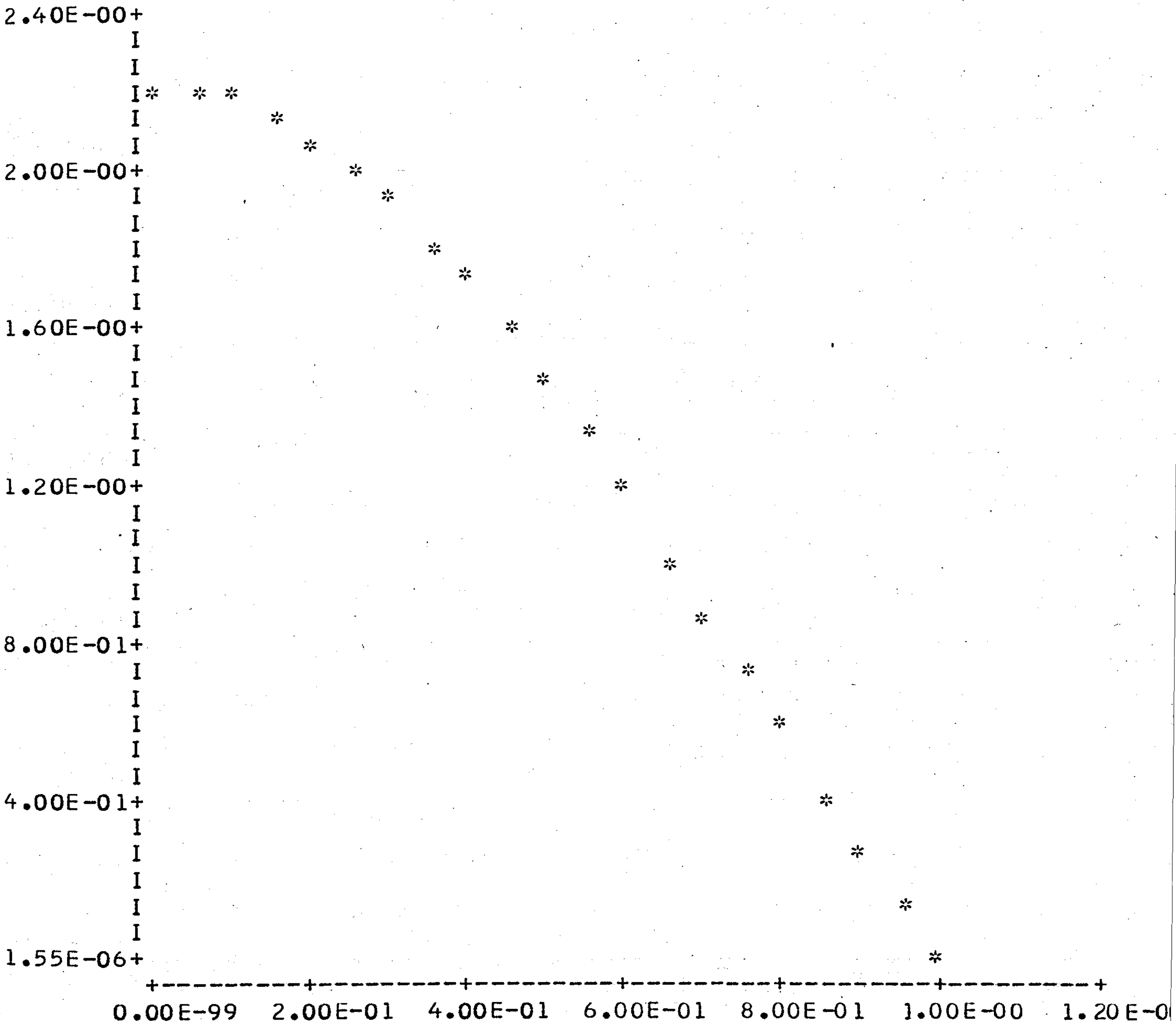

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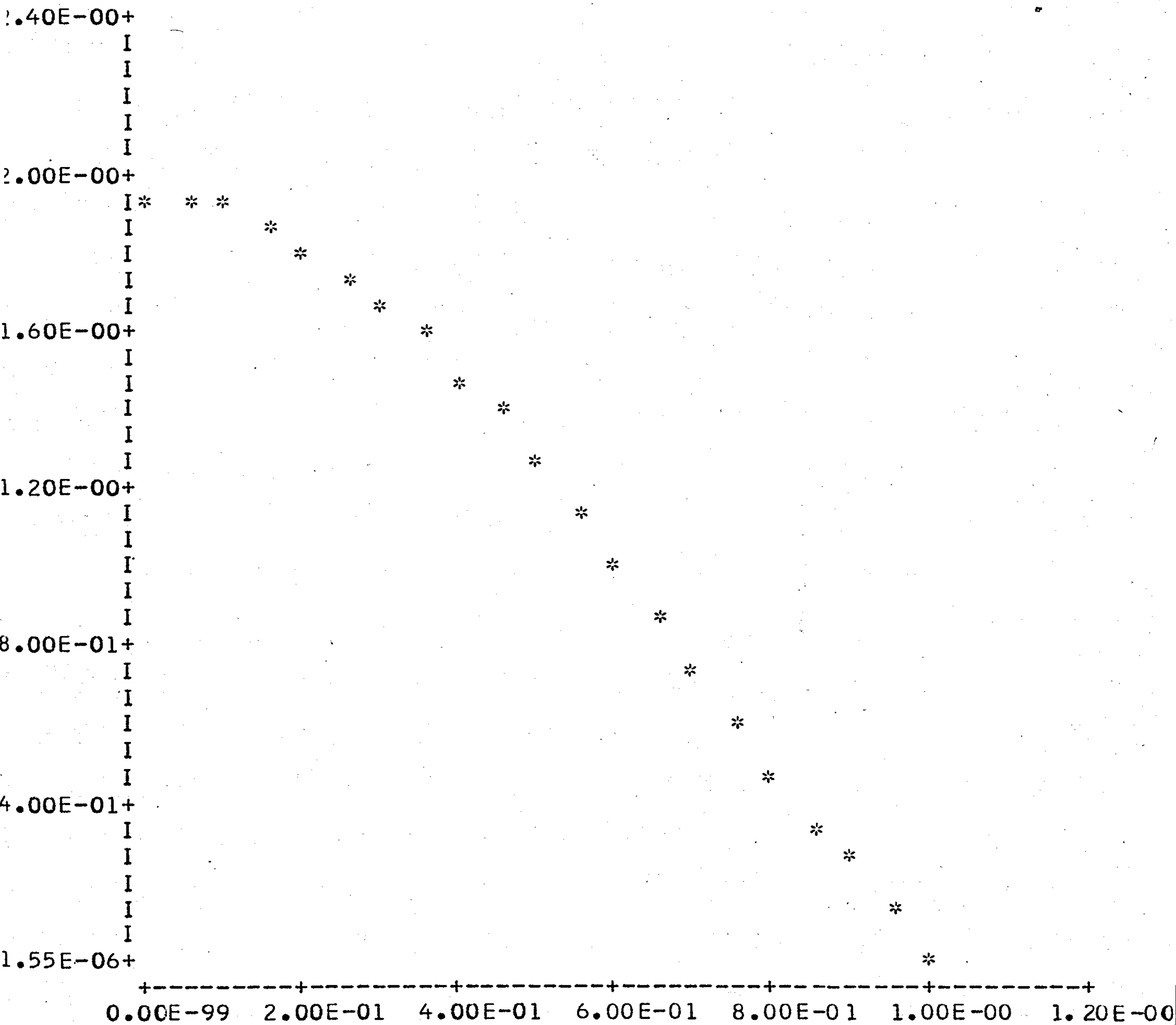

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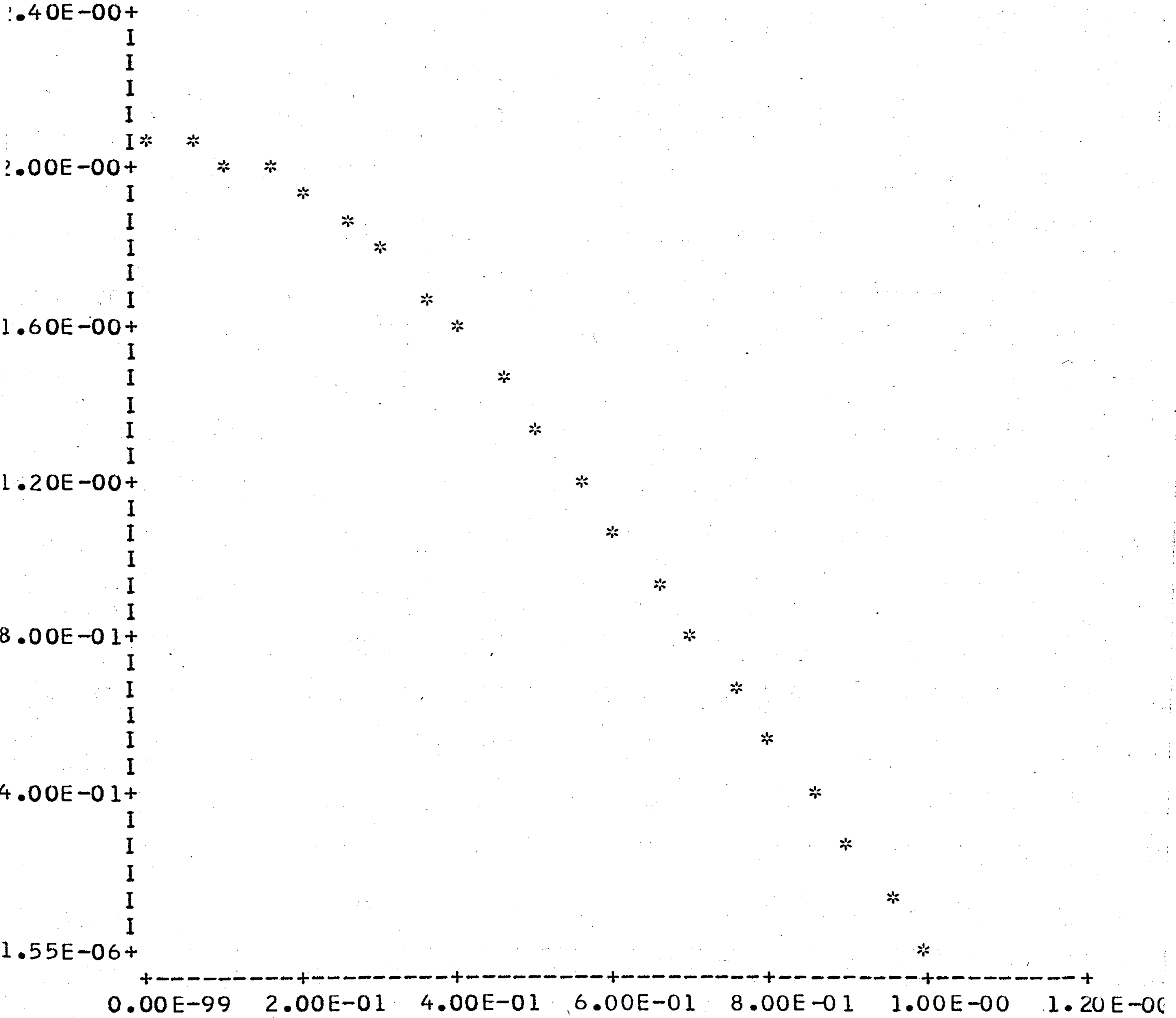

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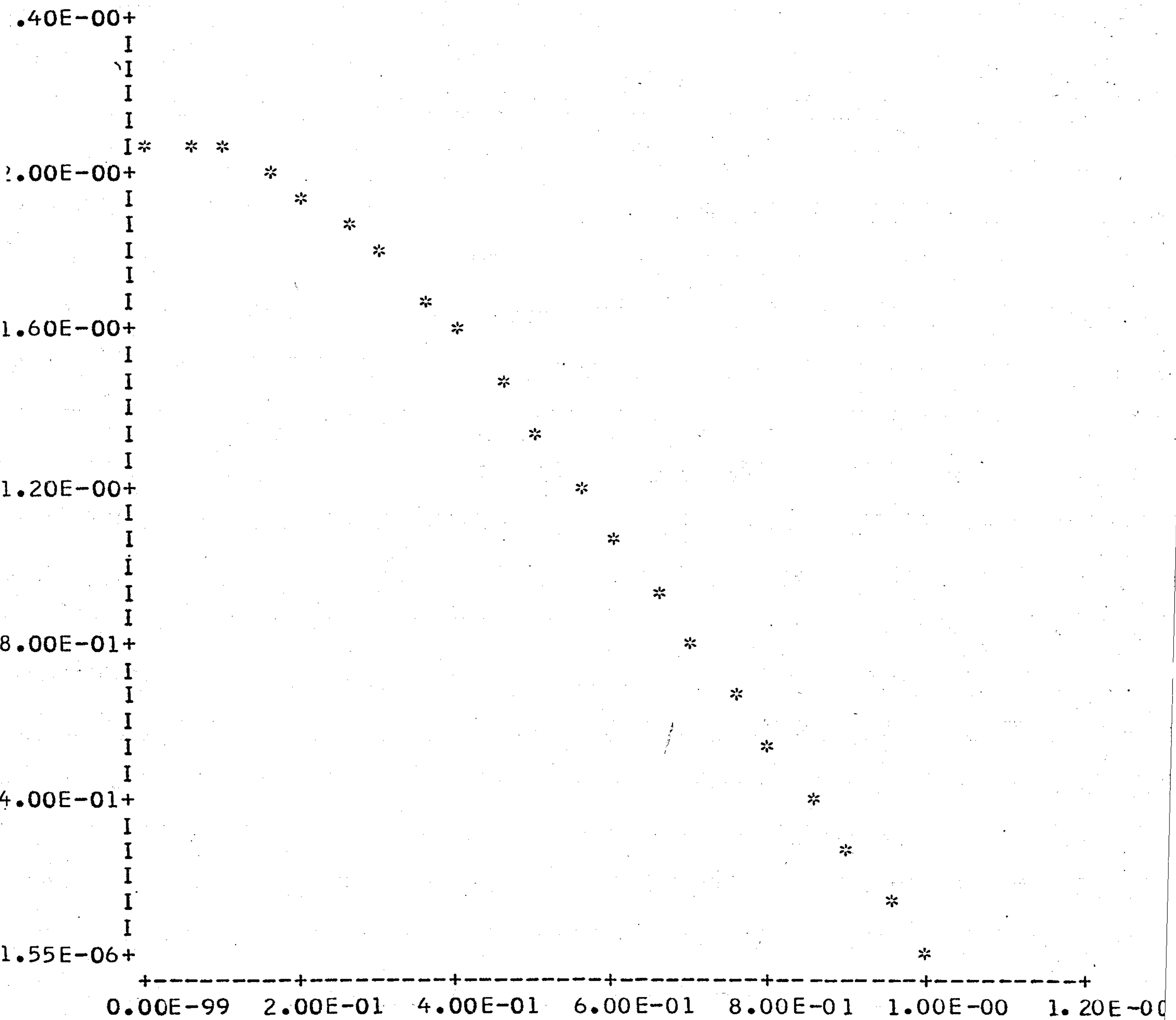

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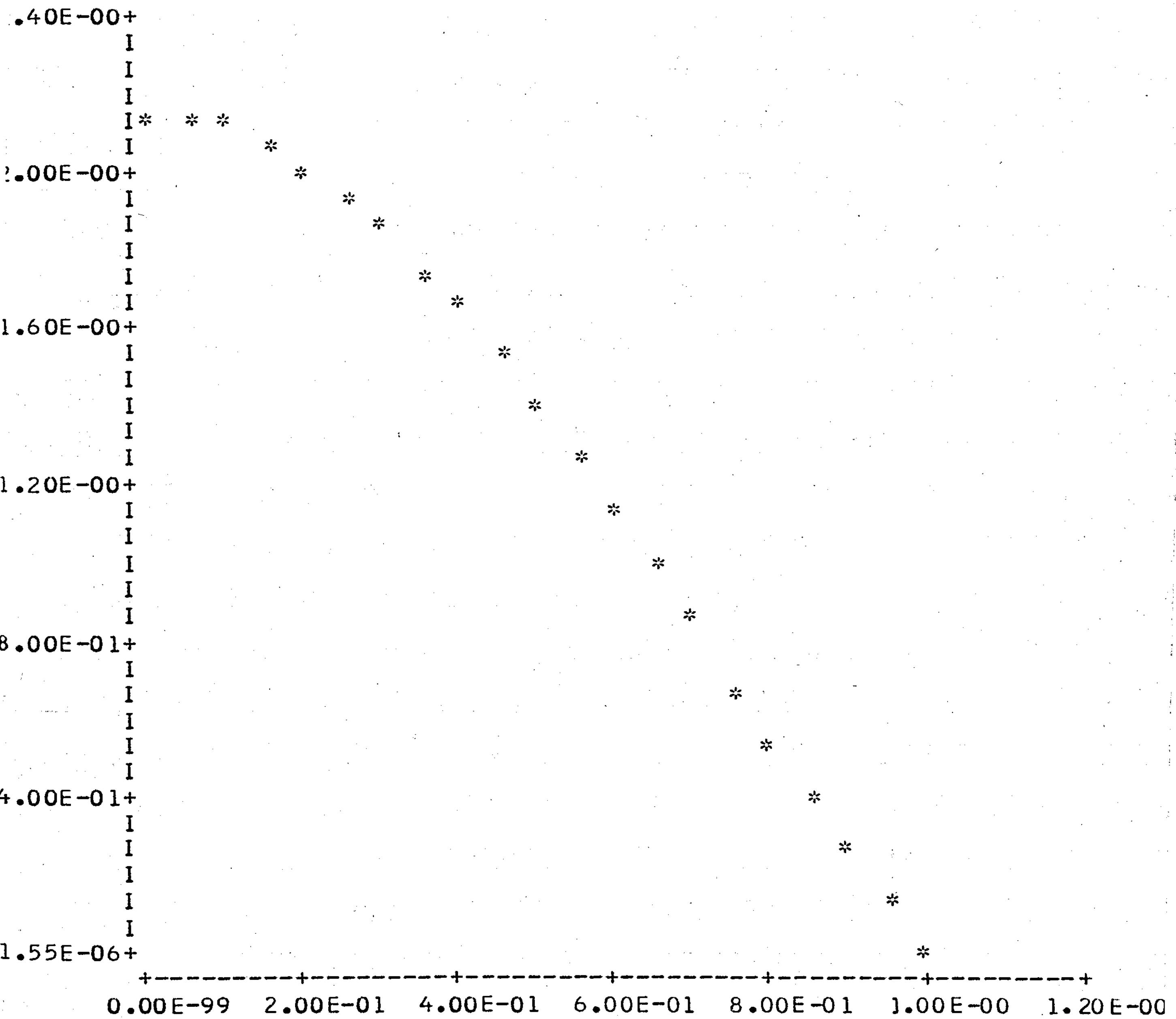

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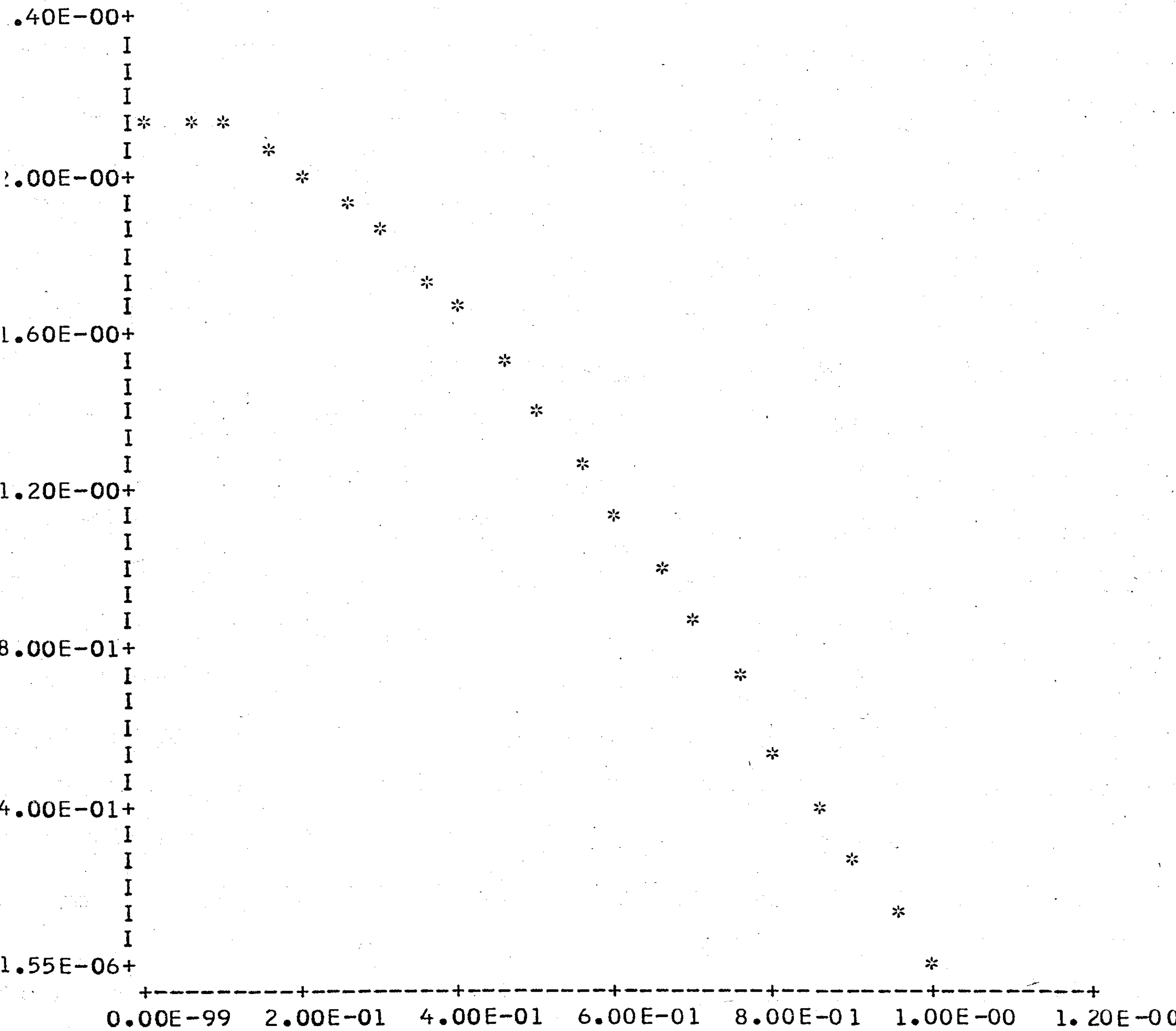

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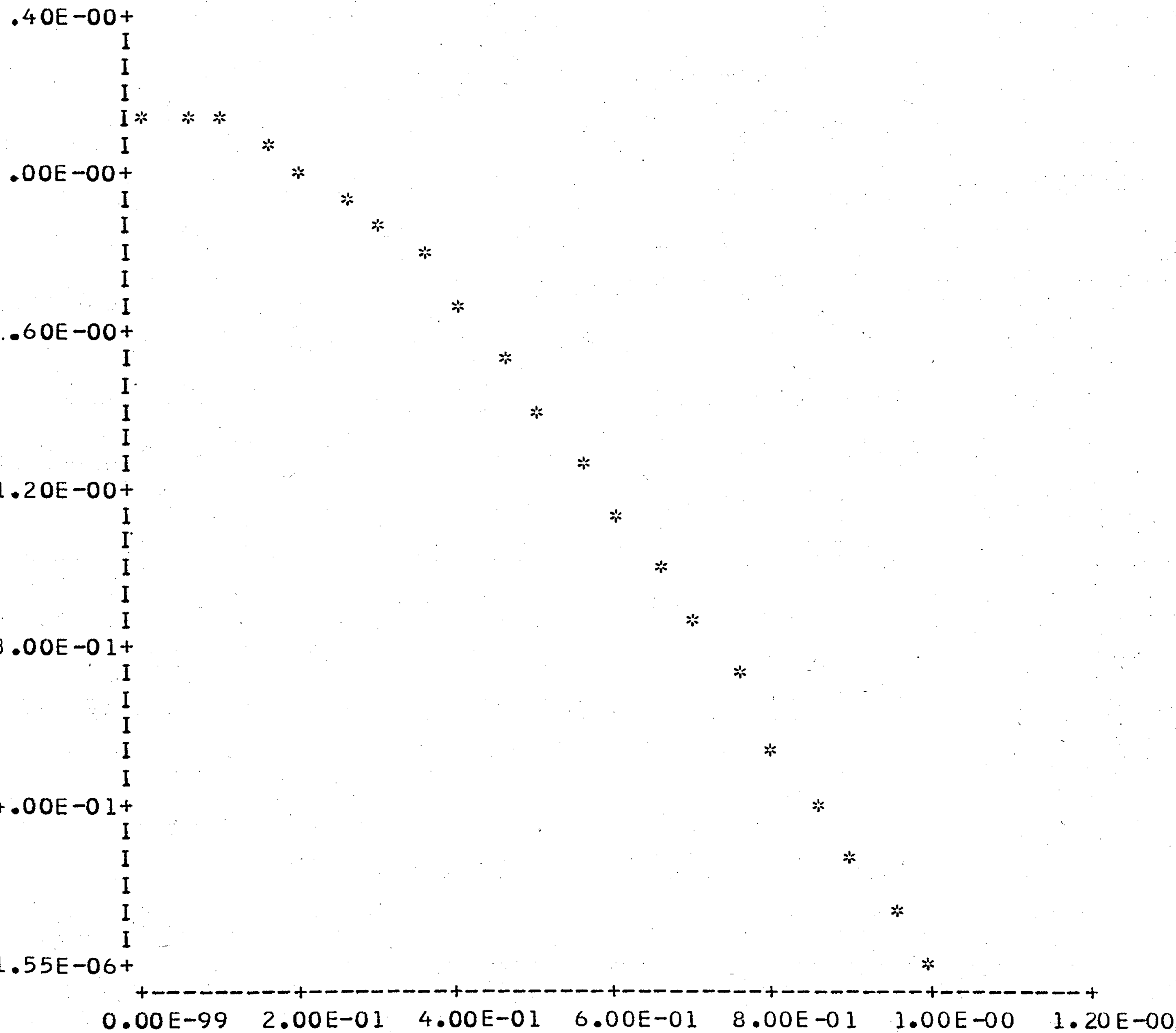

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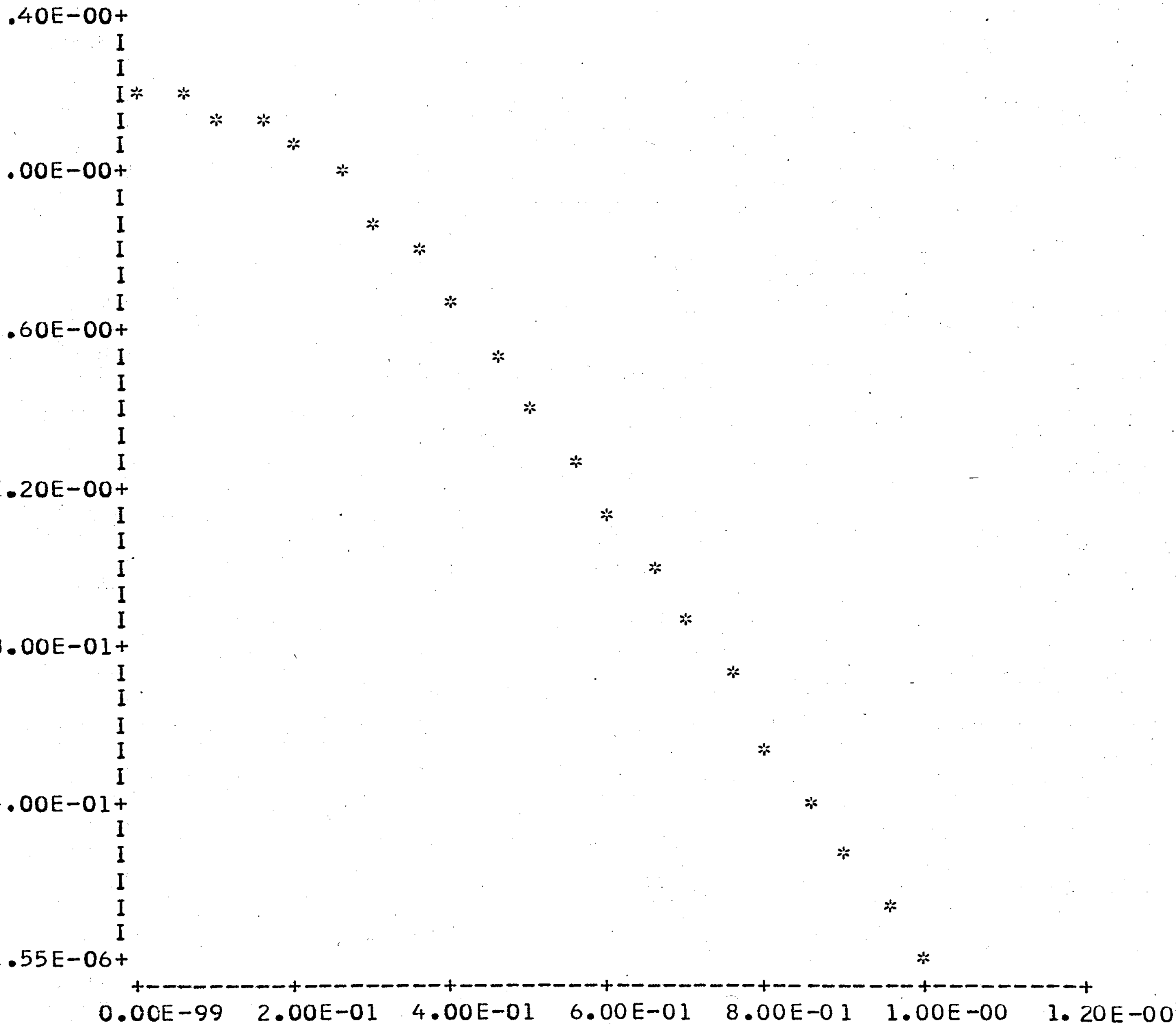

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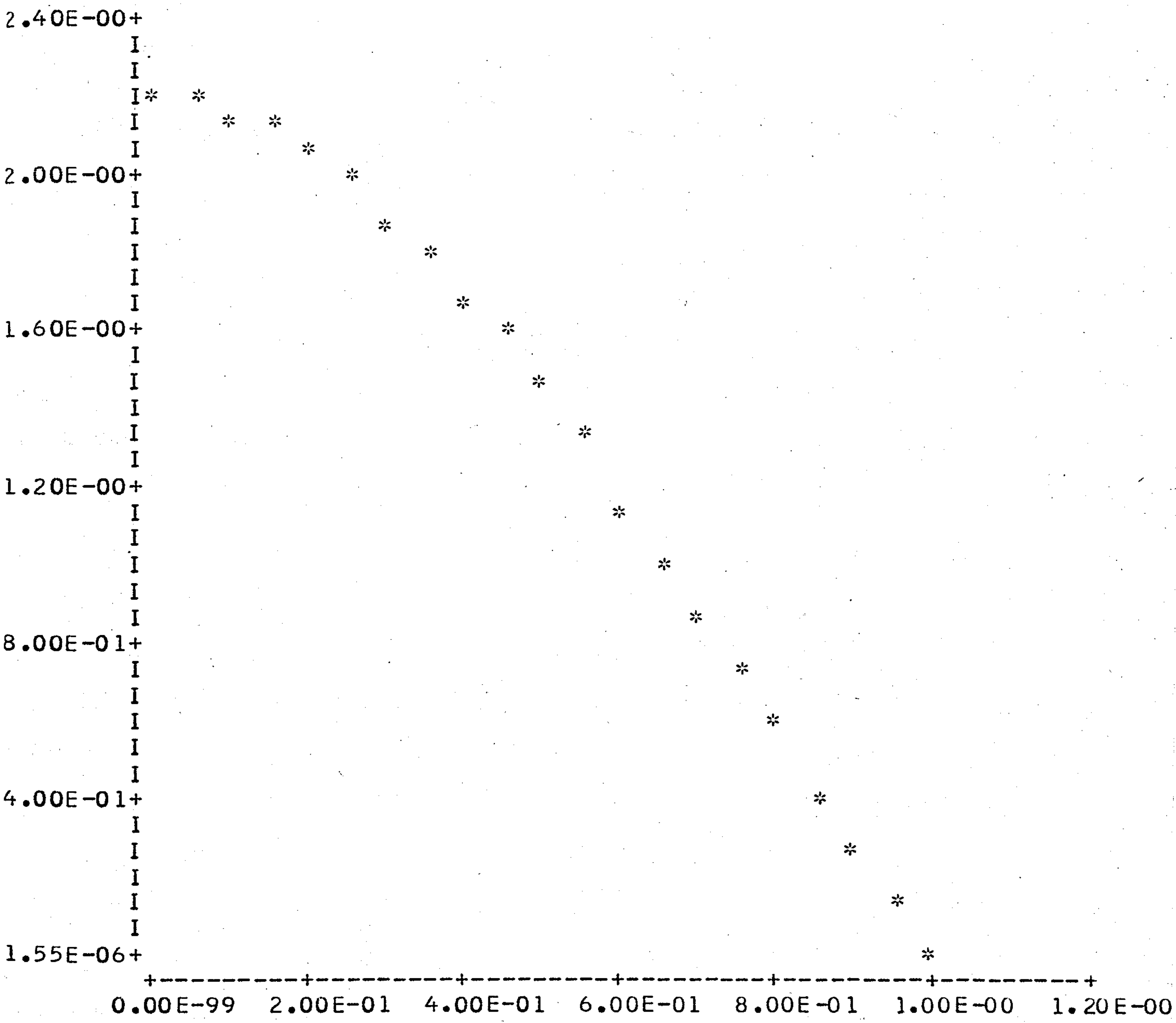

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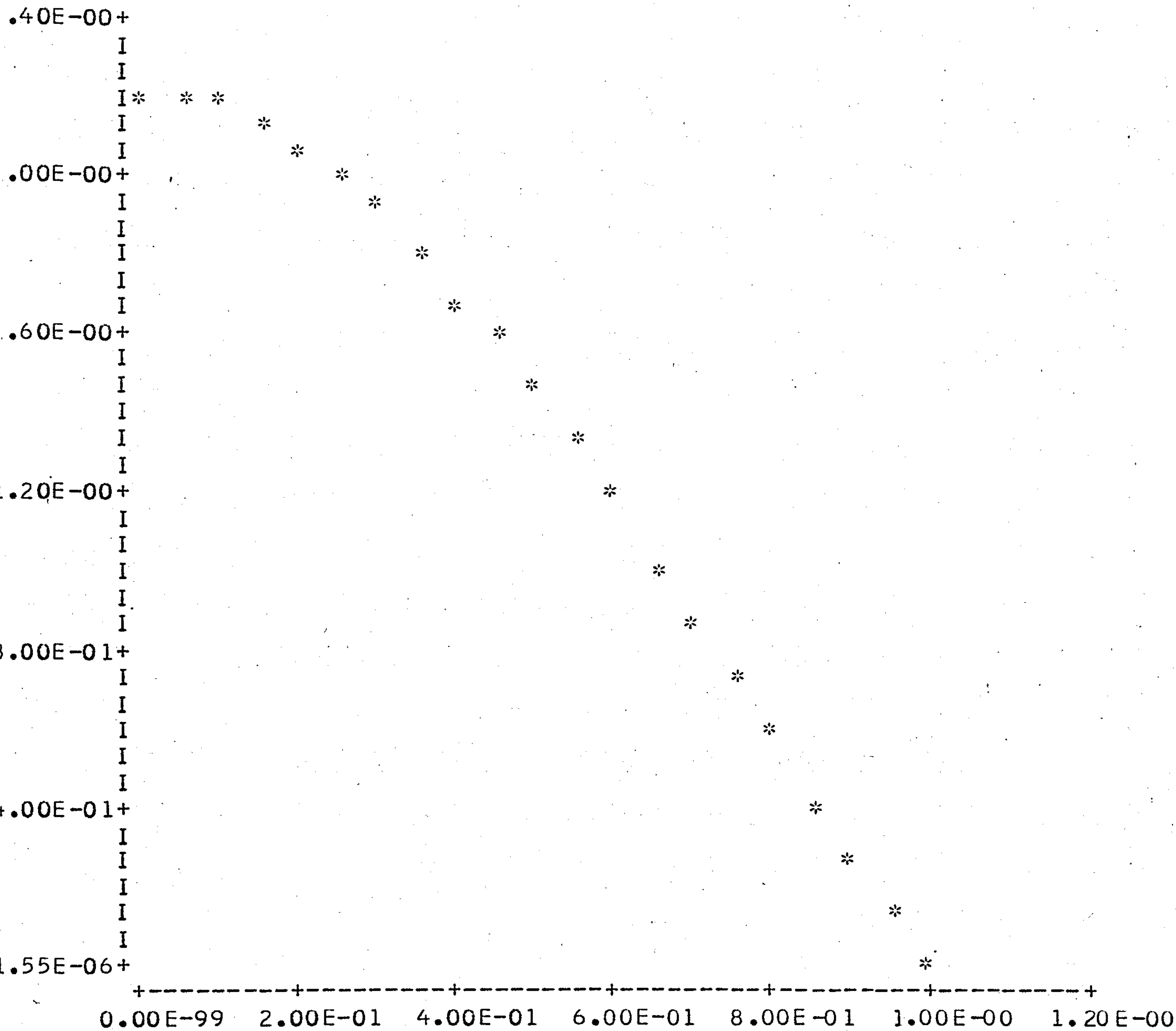

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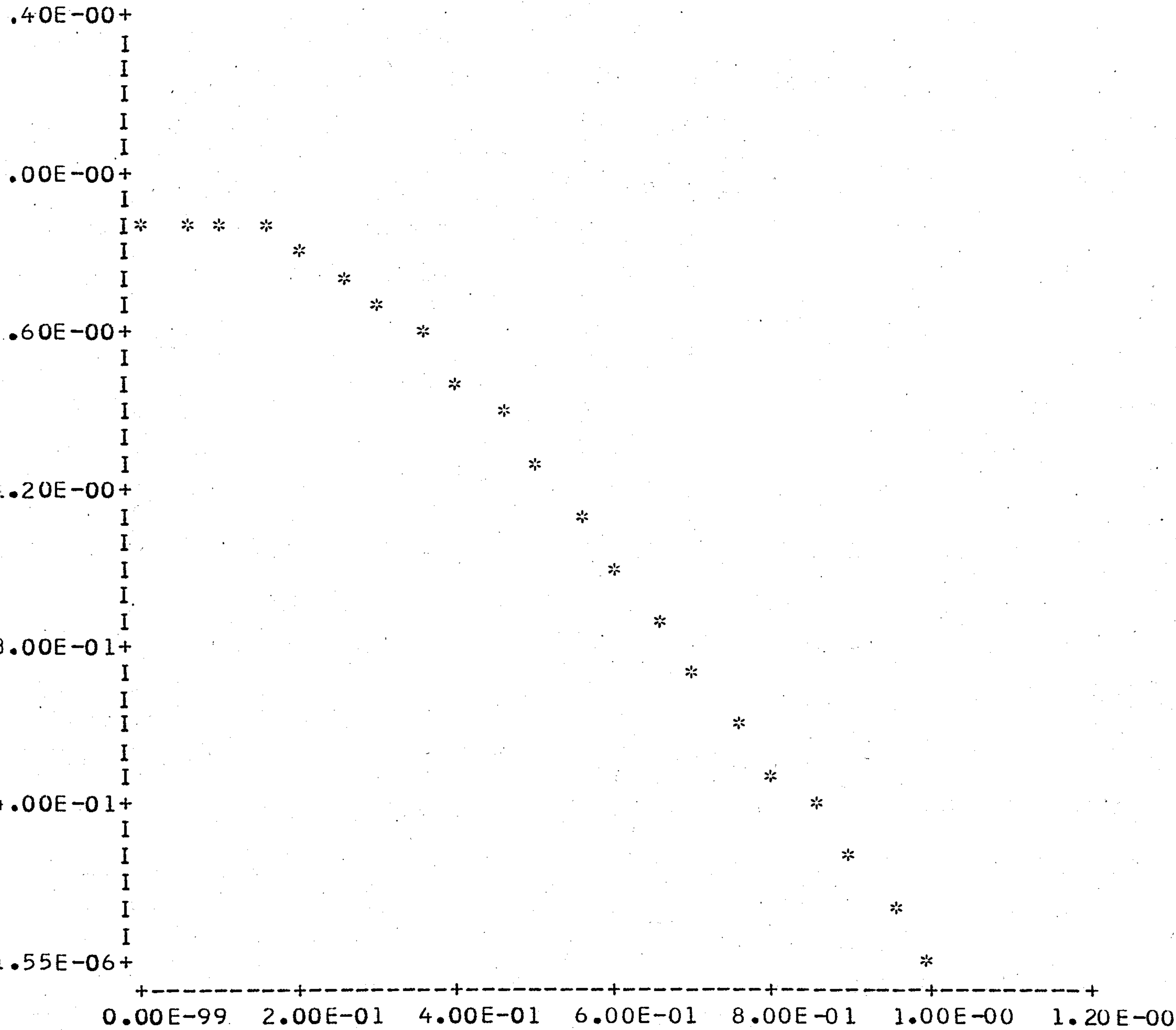

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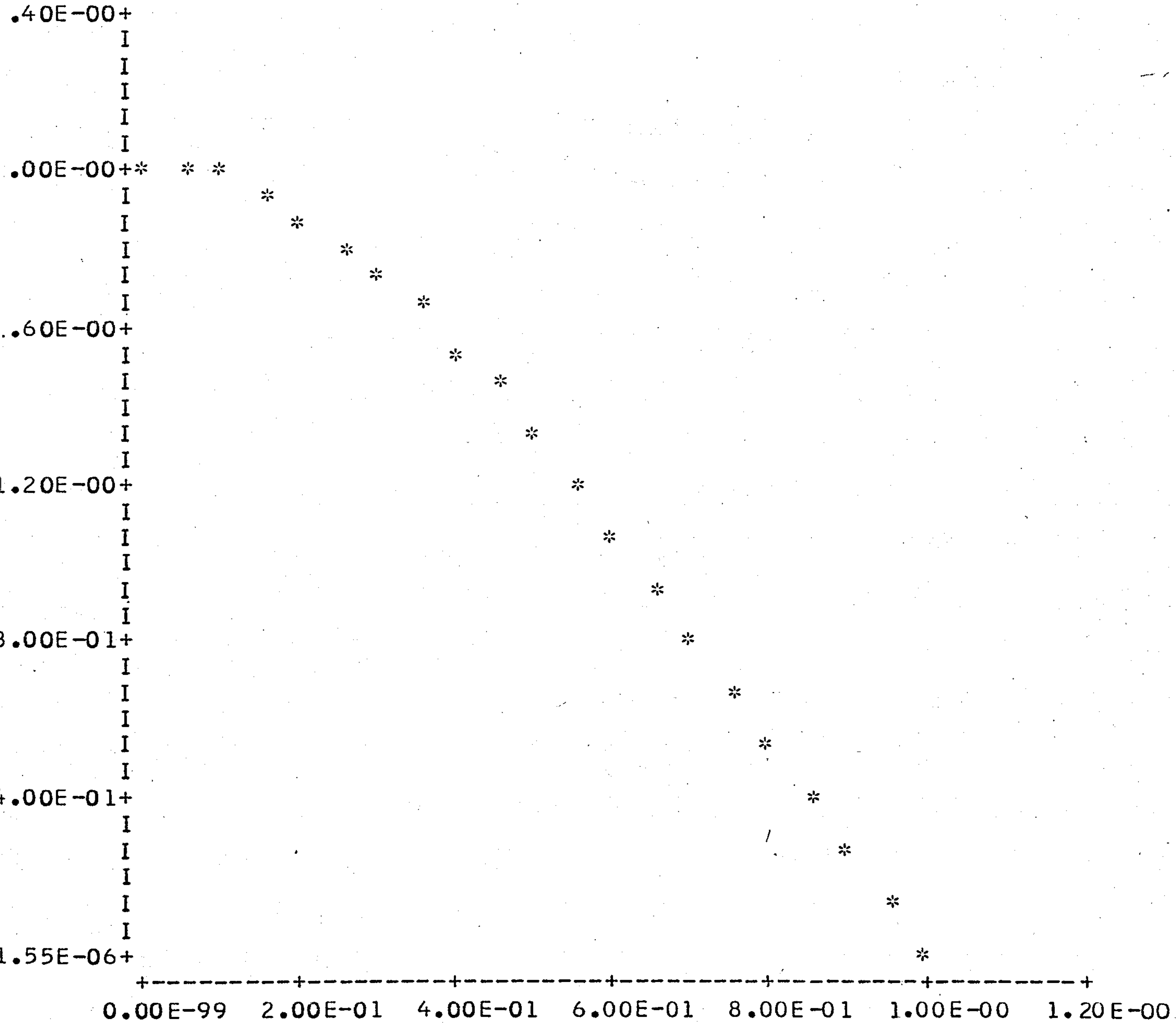

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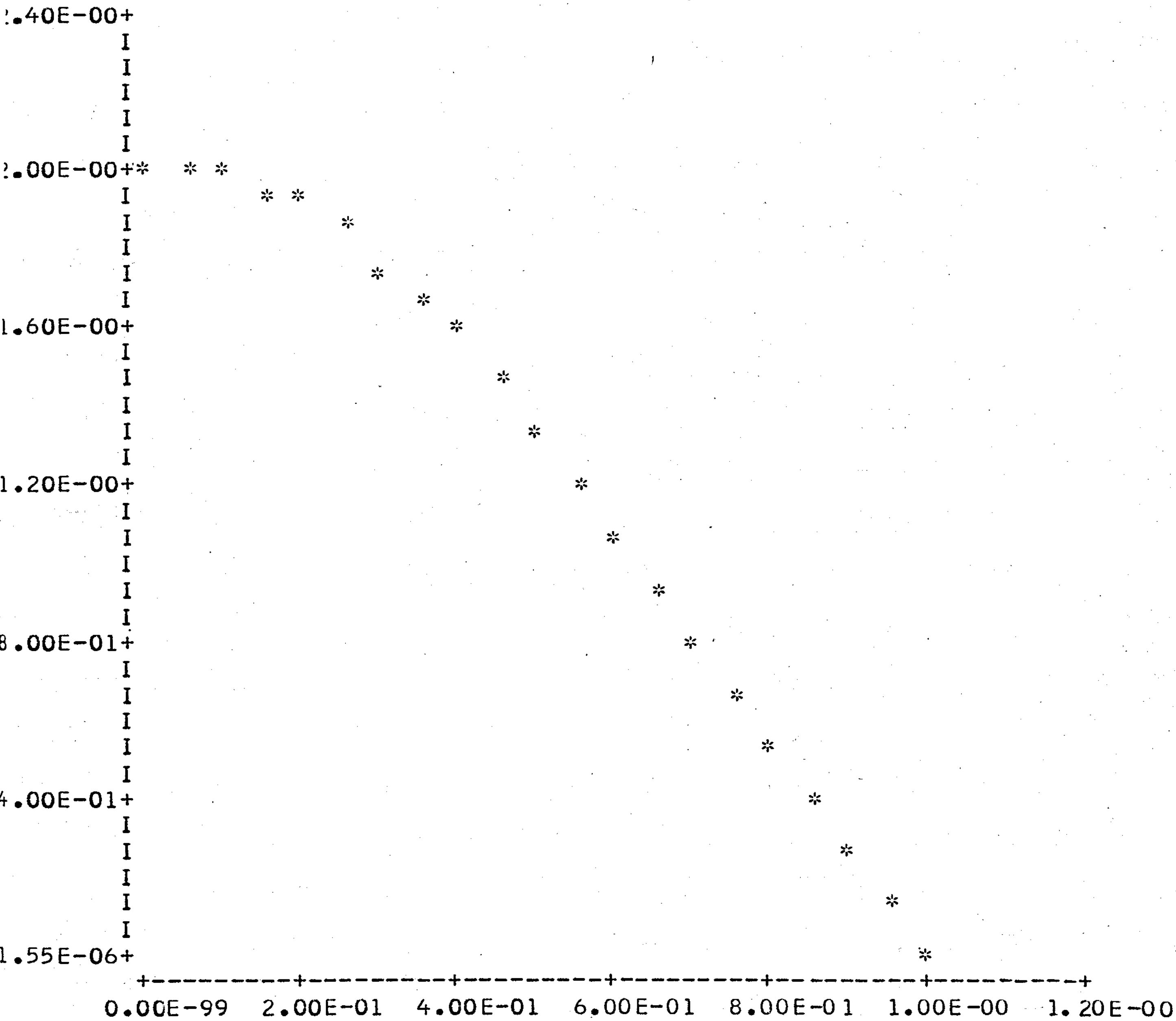

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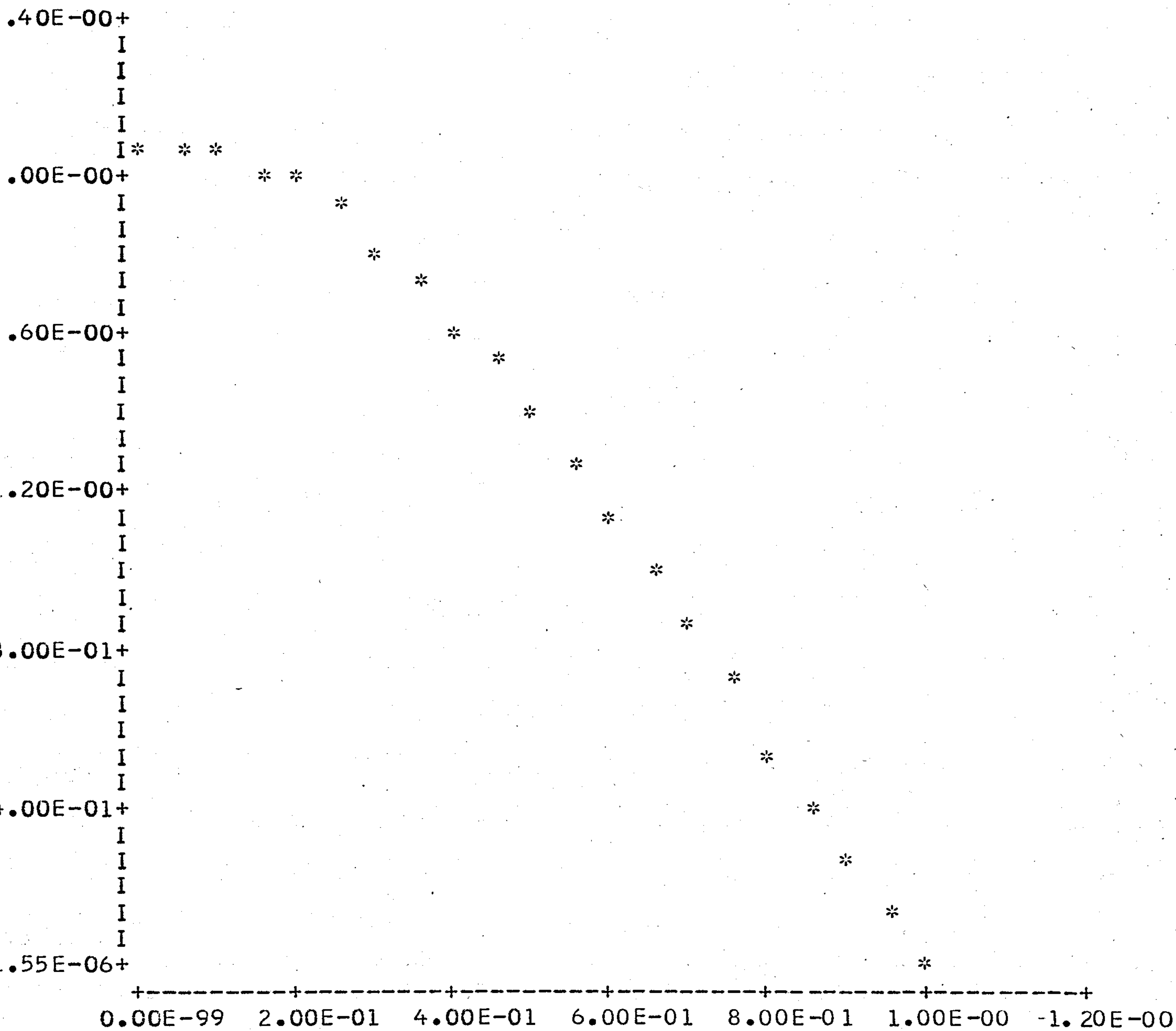

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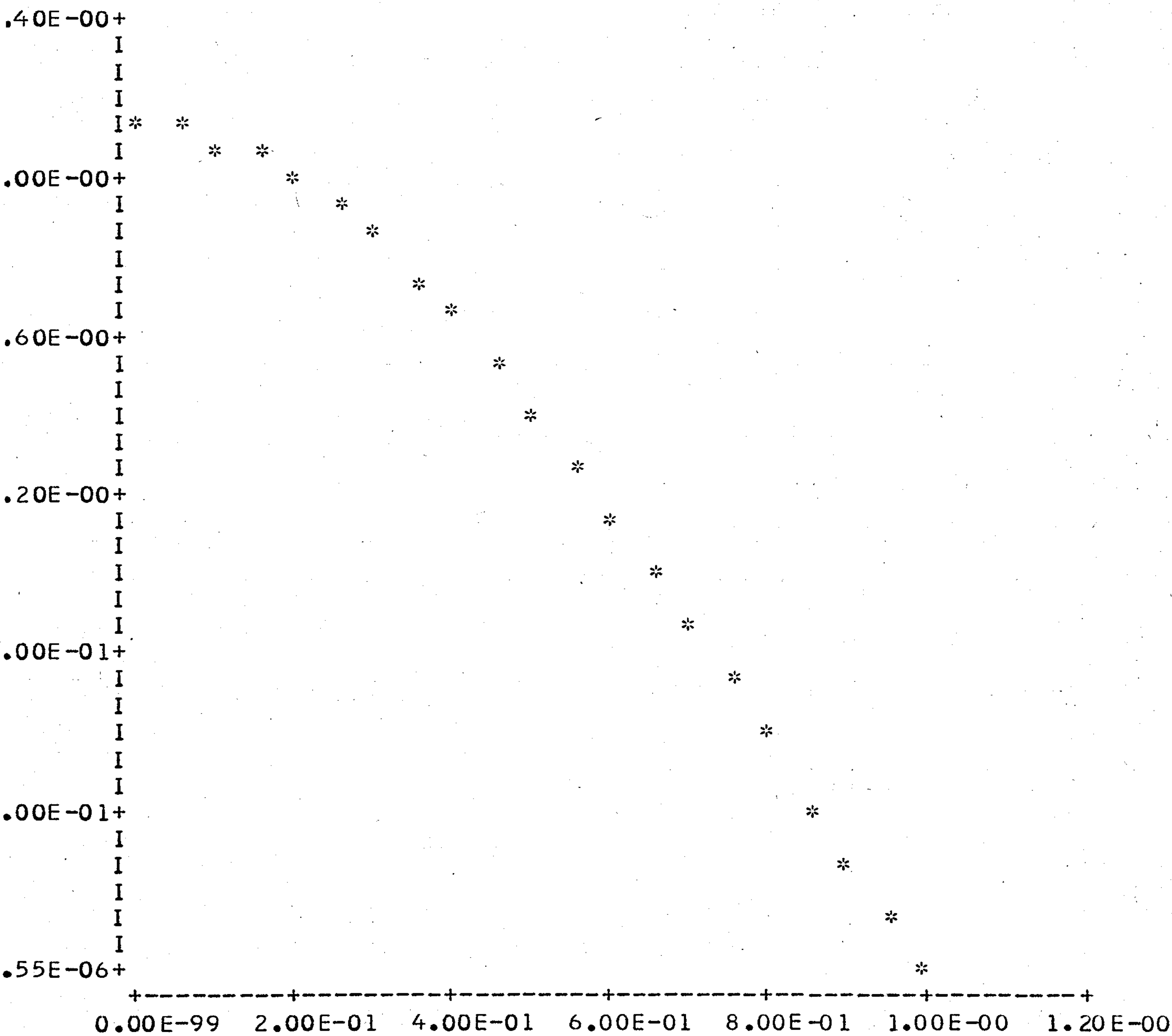

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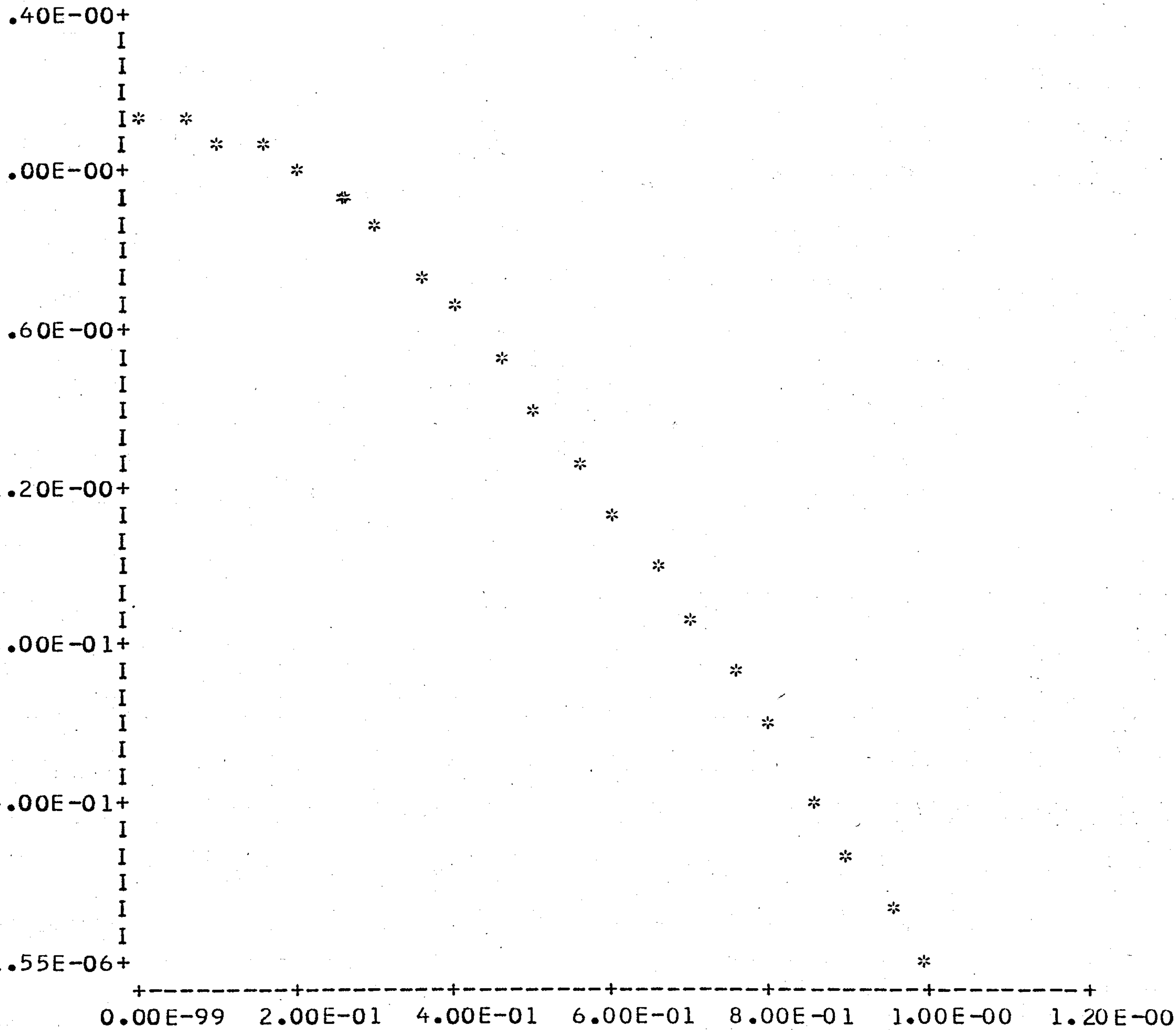

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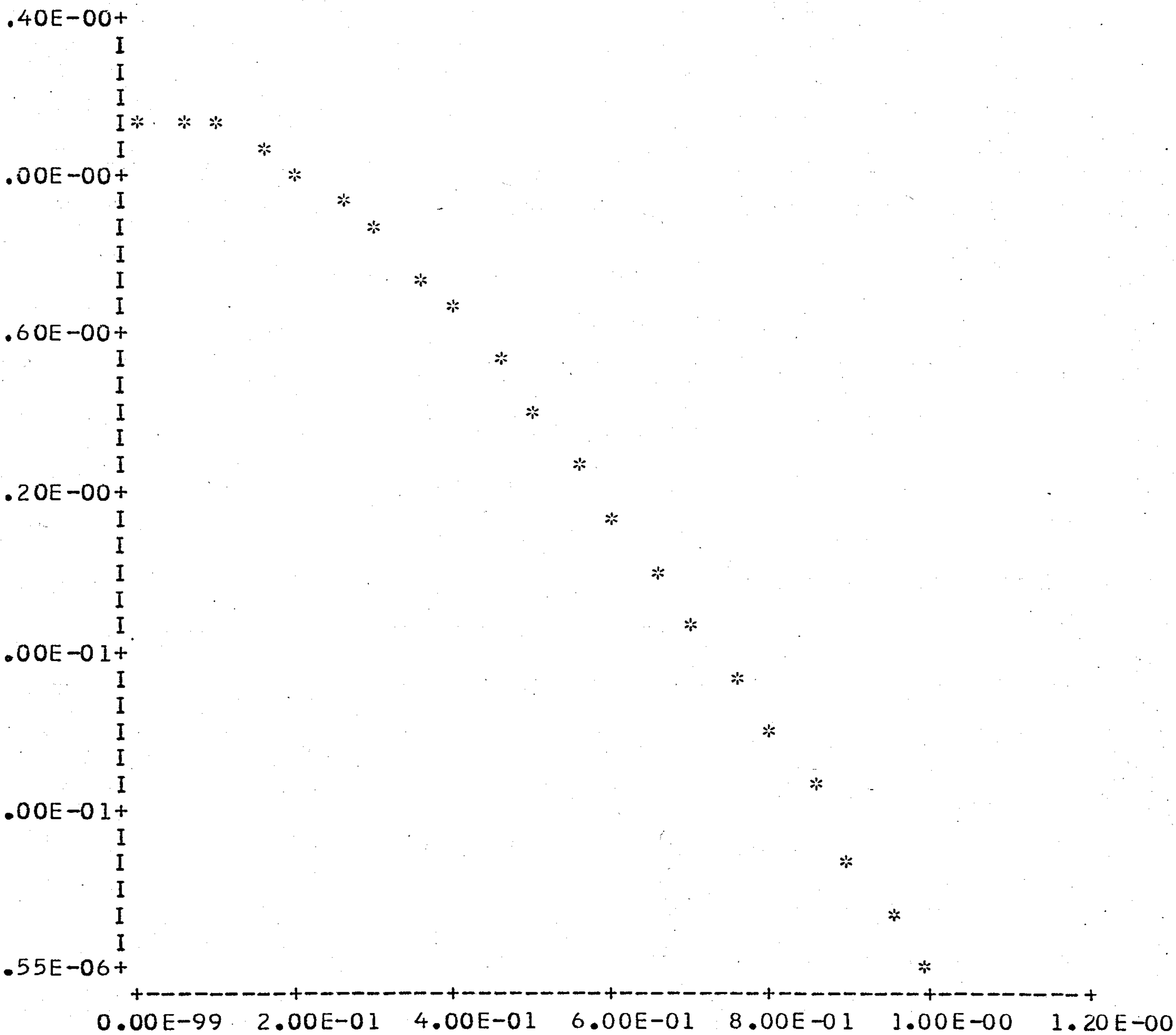

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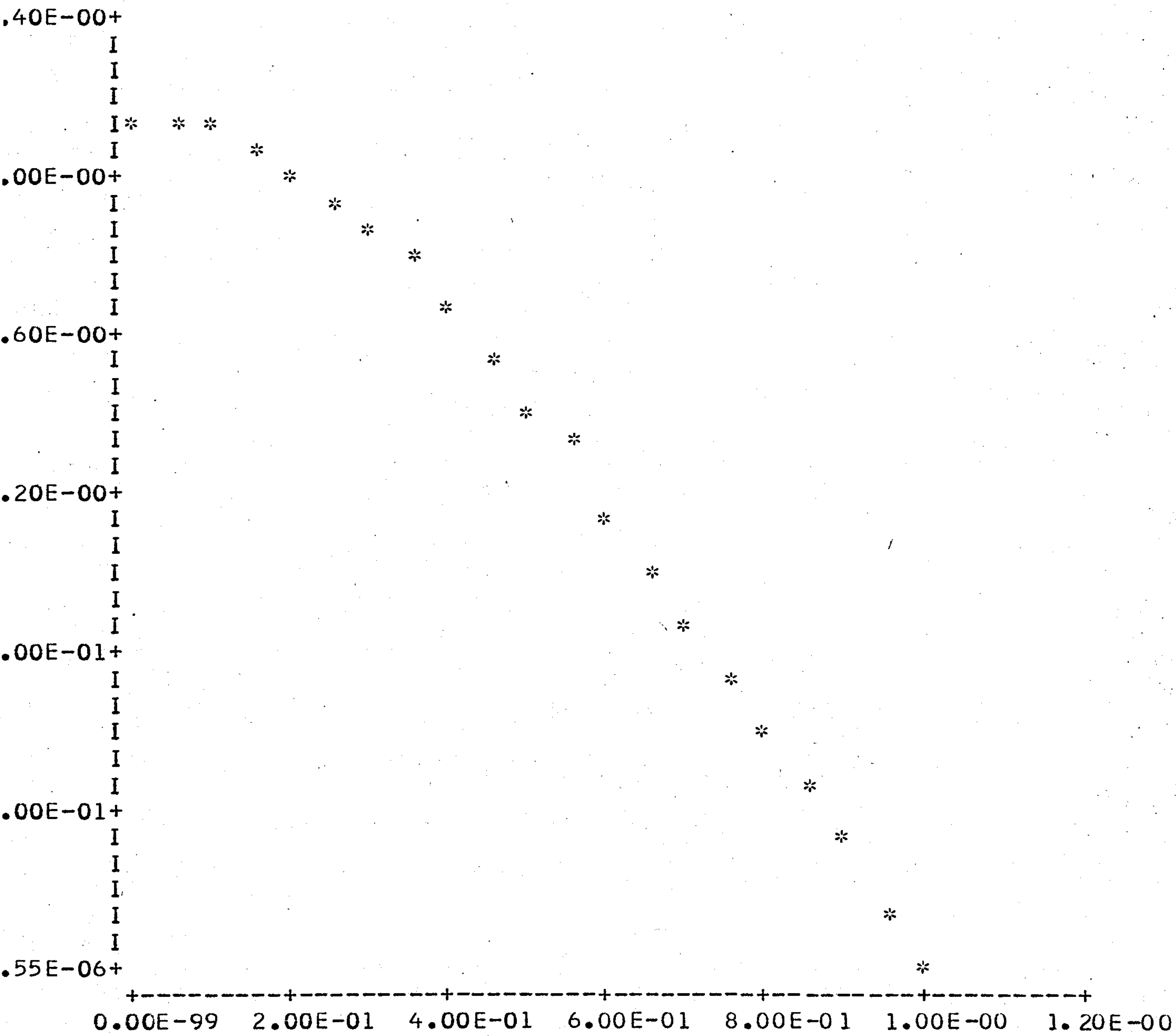
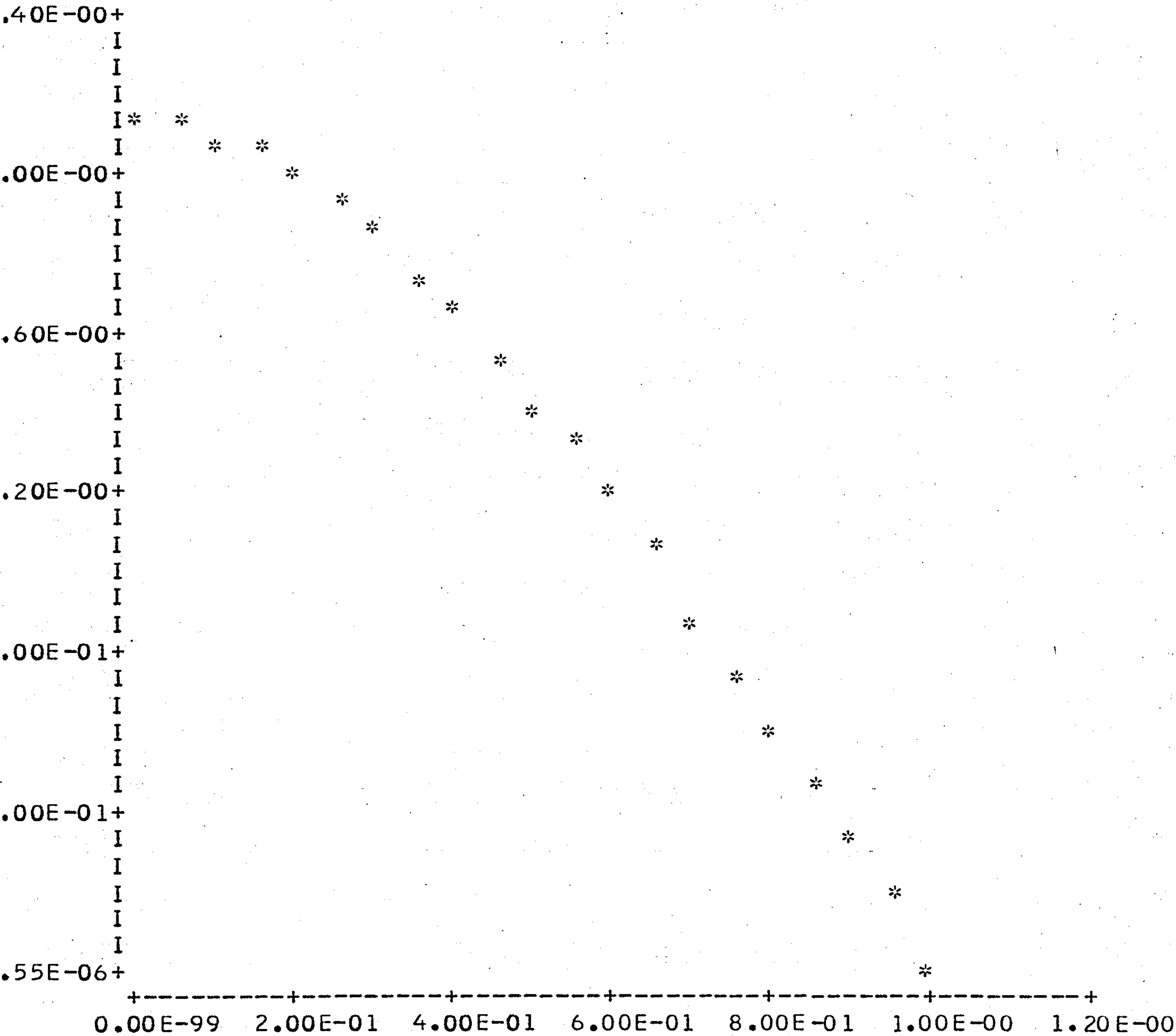
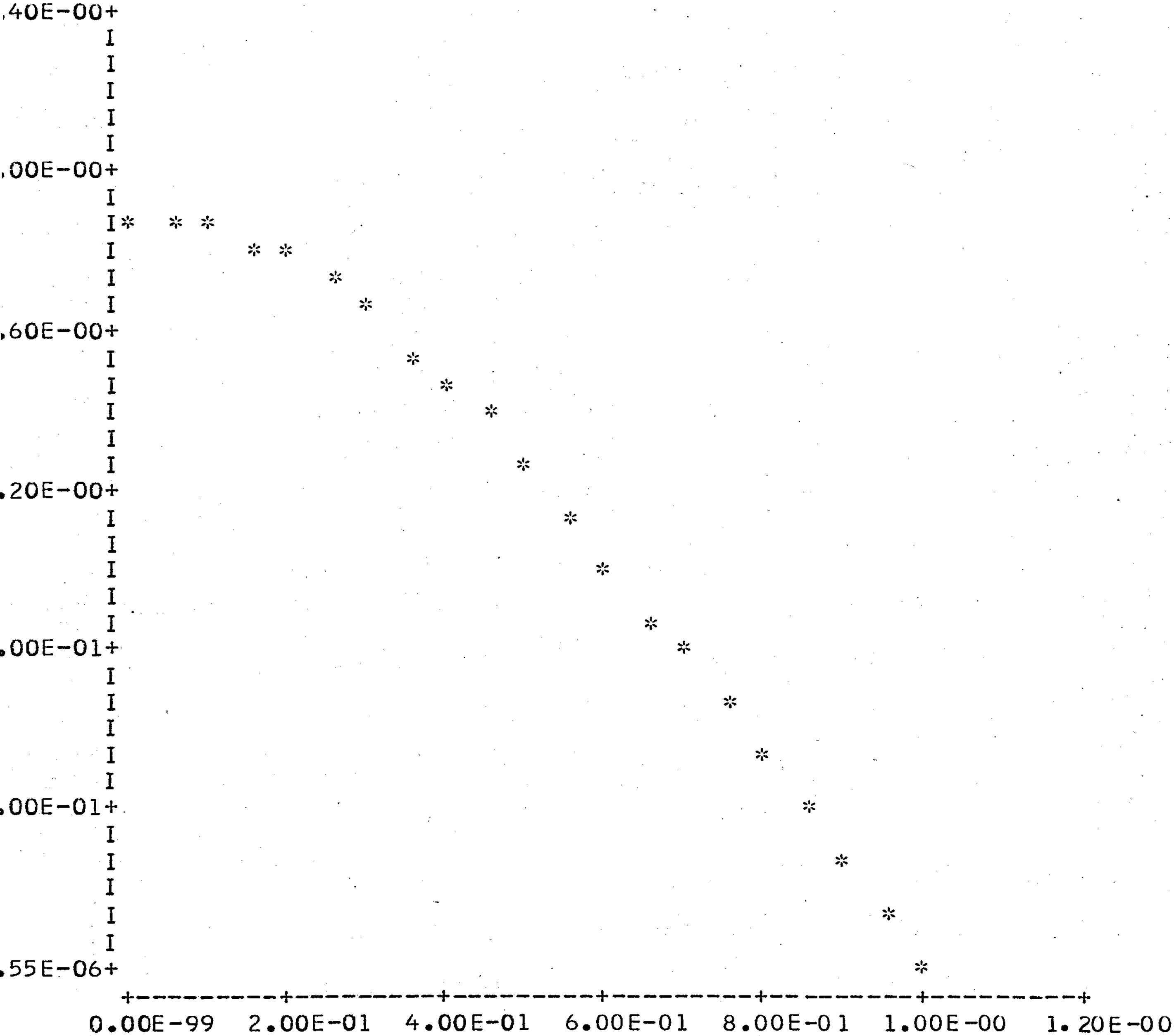
NOLDS NUMBER= 100000.0



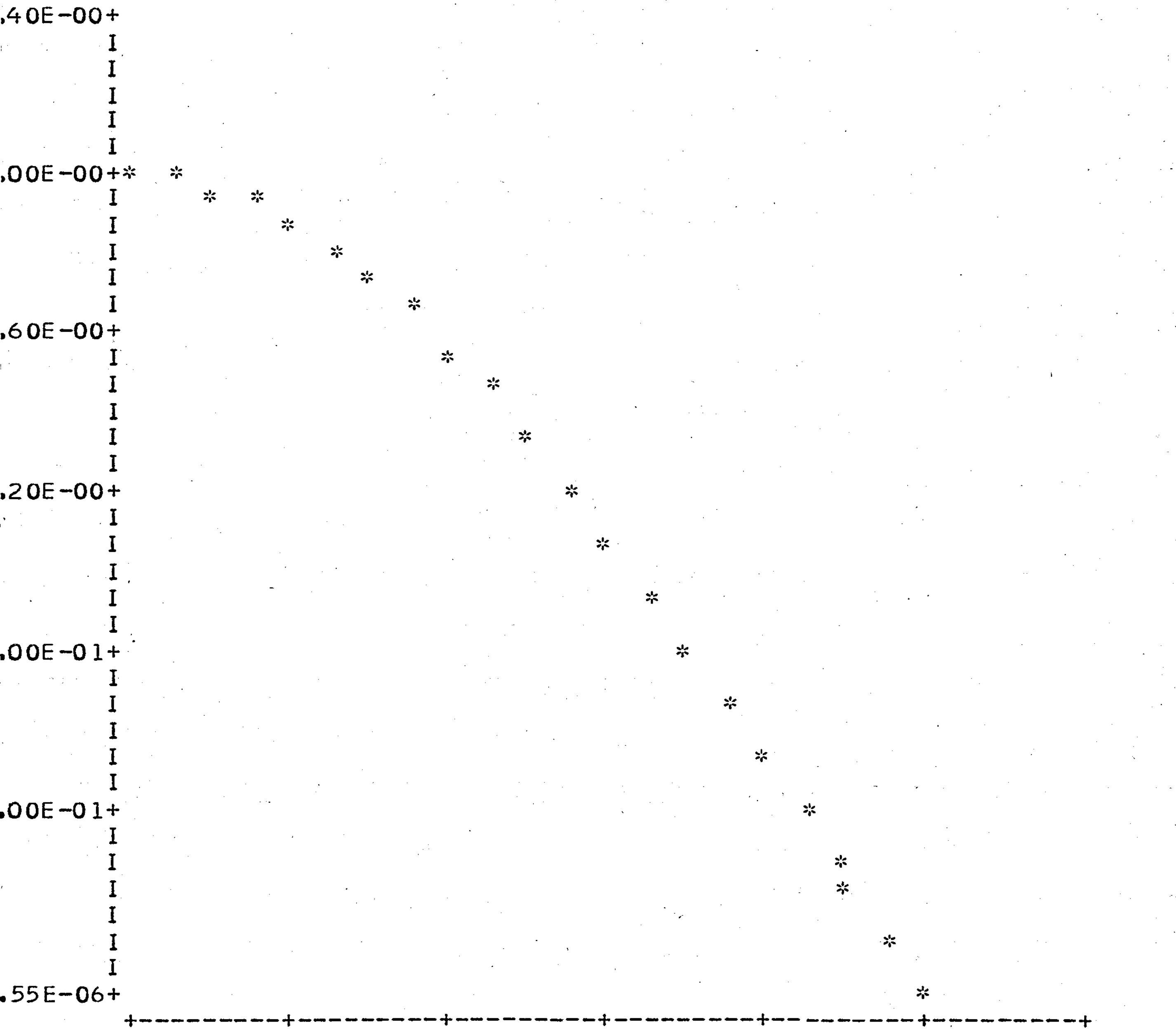
NDTL NUMBER= .005
NOLDS NUMBER= 300000.0



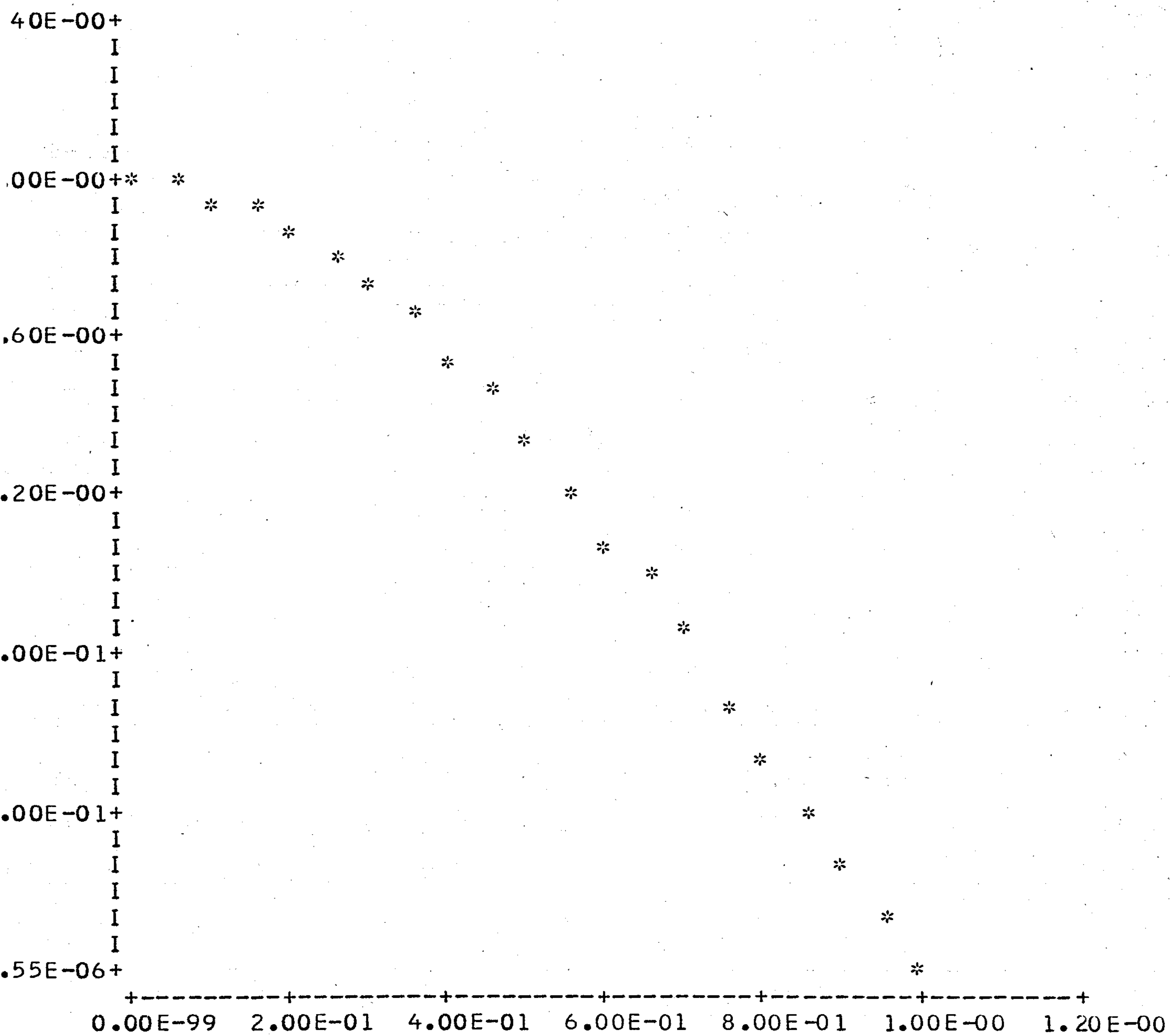
NDTL NUMBER = .005
NOLDS NUMBER = 500000.0



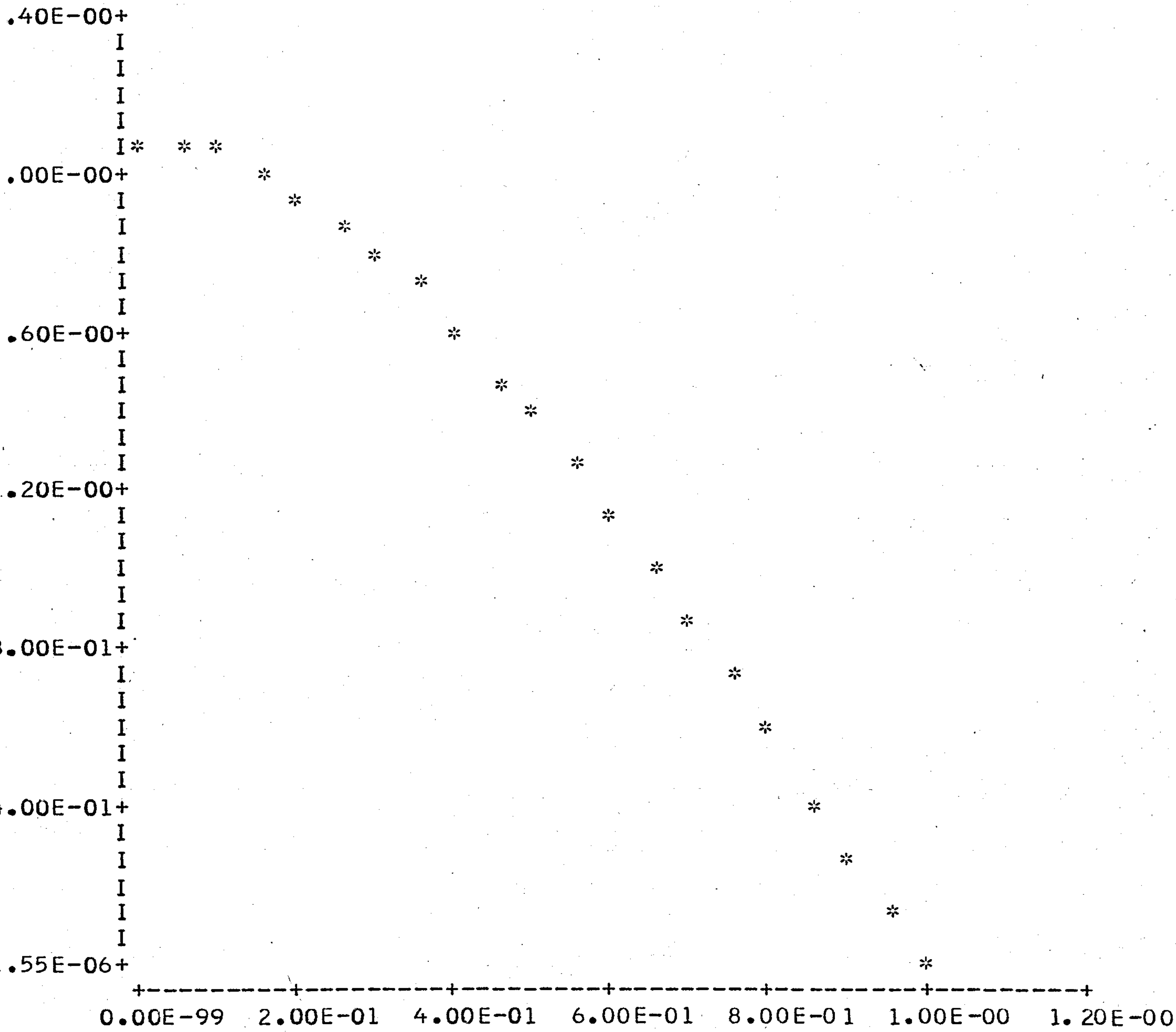
NDTL NUMBER= .010
NOLDS NUMBER= 3000.0



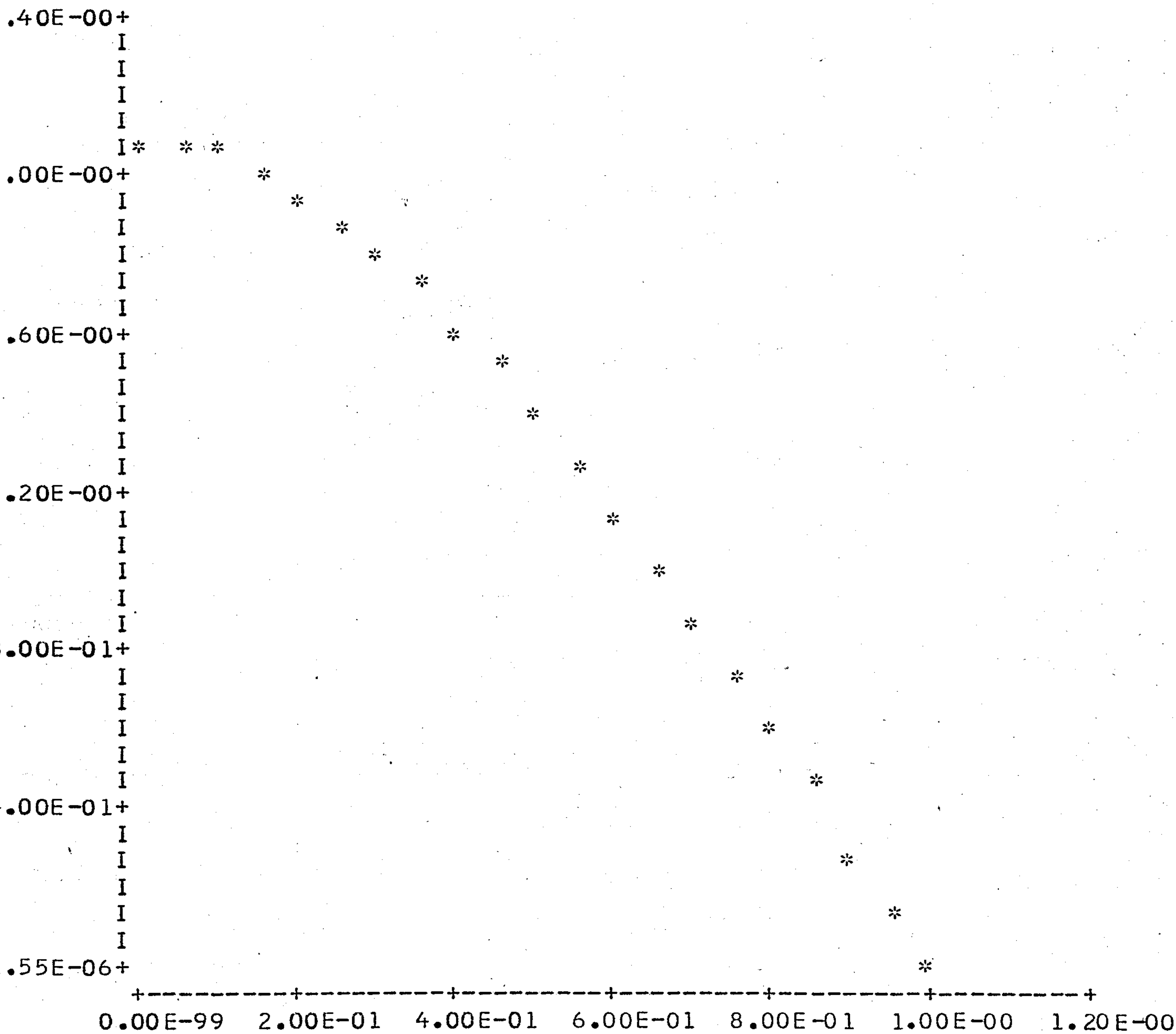
NDTL NUMBER = .010
NOLDS NUMBER = 8000.0



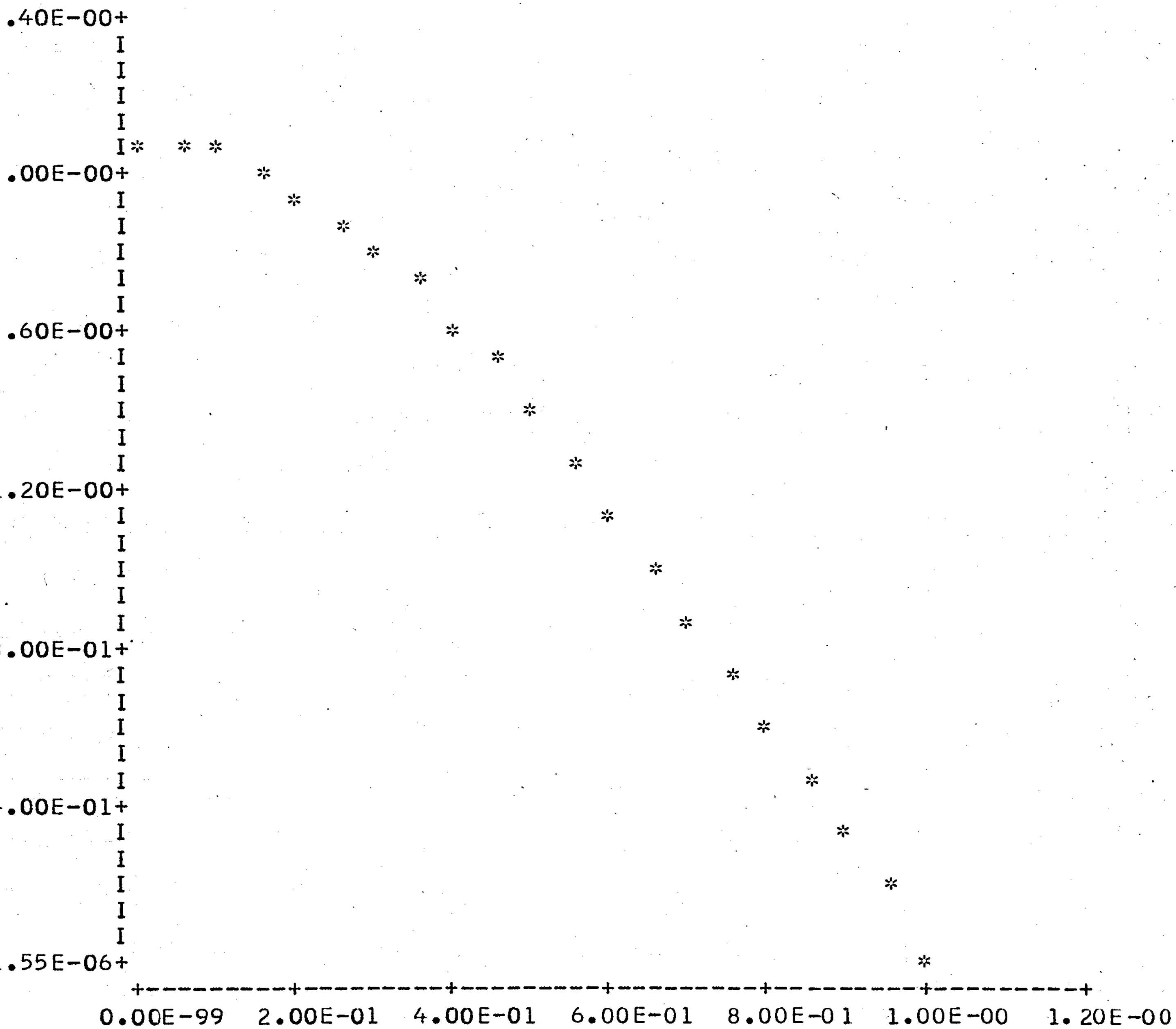
NDTL NUMBER= .010
NOLDS NUMBER= 10000.0



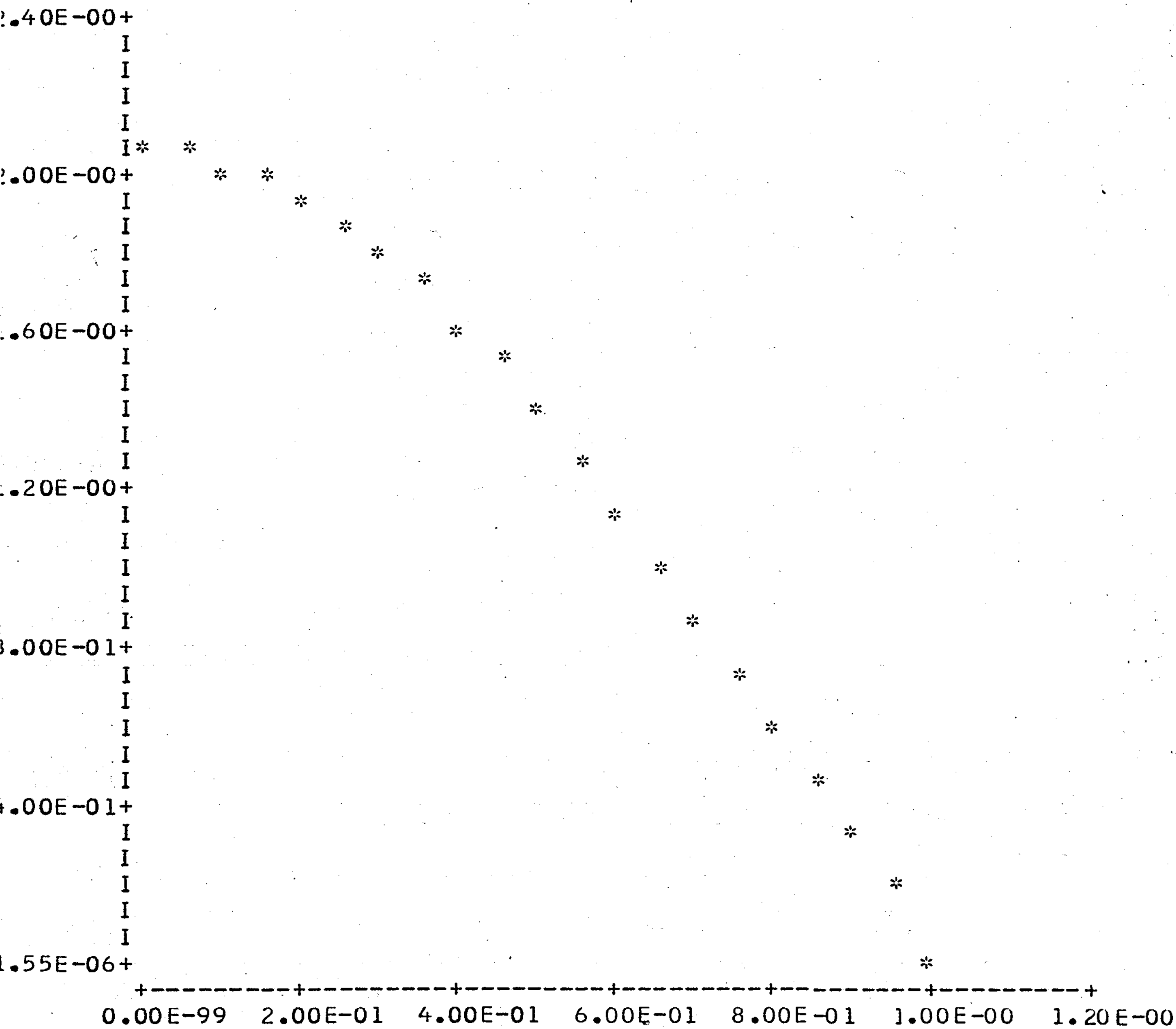
NDTL NUMBER = .010
NOLDS NUMBER = 30000.0



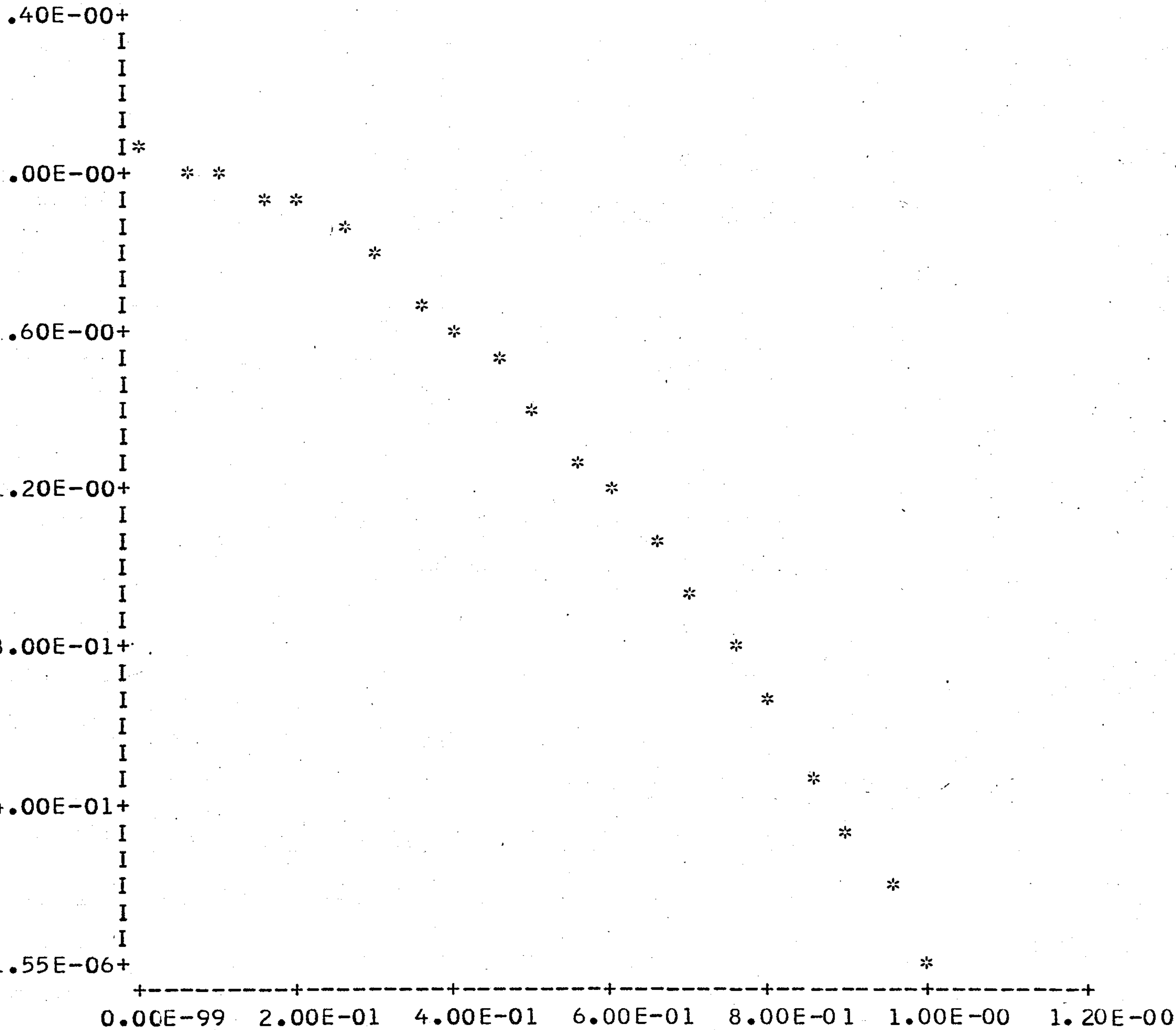
NDTL NUMBER= .010
NOLDS NUMBER= 50000.0



NDTL NUMBER = .010
NOLDS NUMBER = 70000.0



ANDTL NUMBER= .010
YNOLDS NUMBER= 100000.0



ANDTL NUMBER = .010
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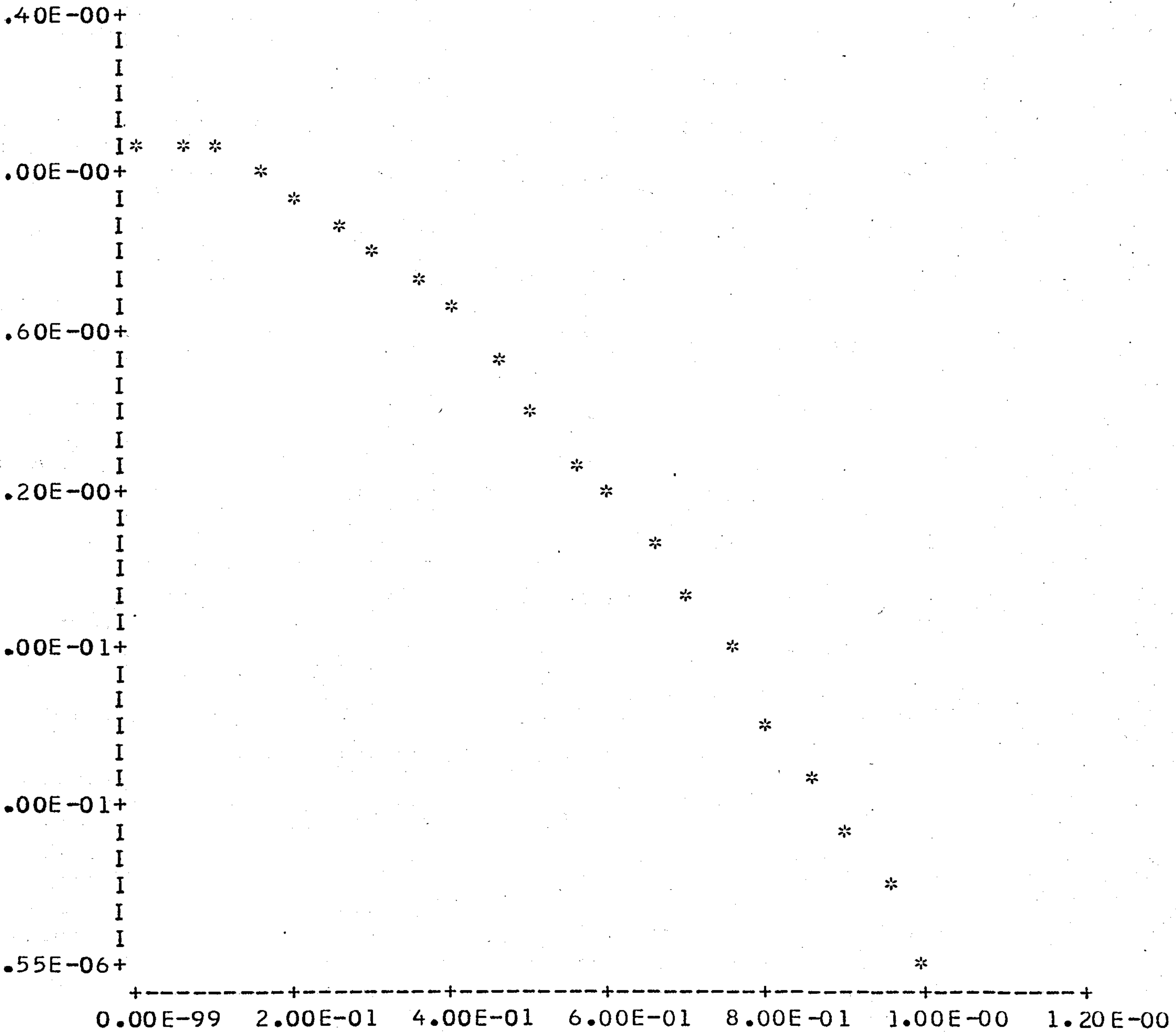
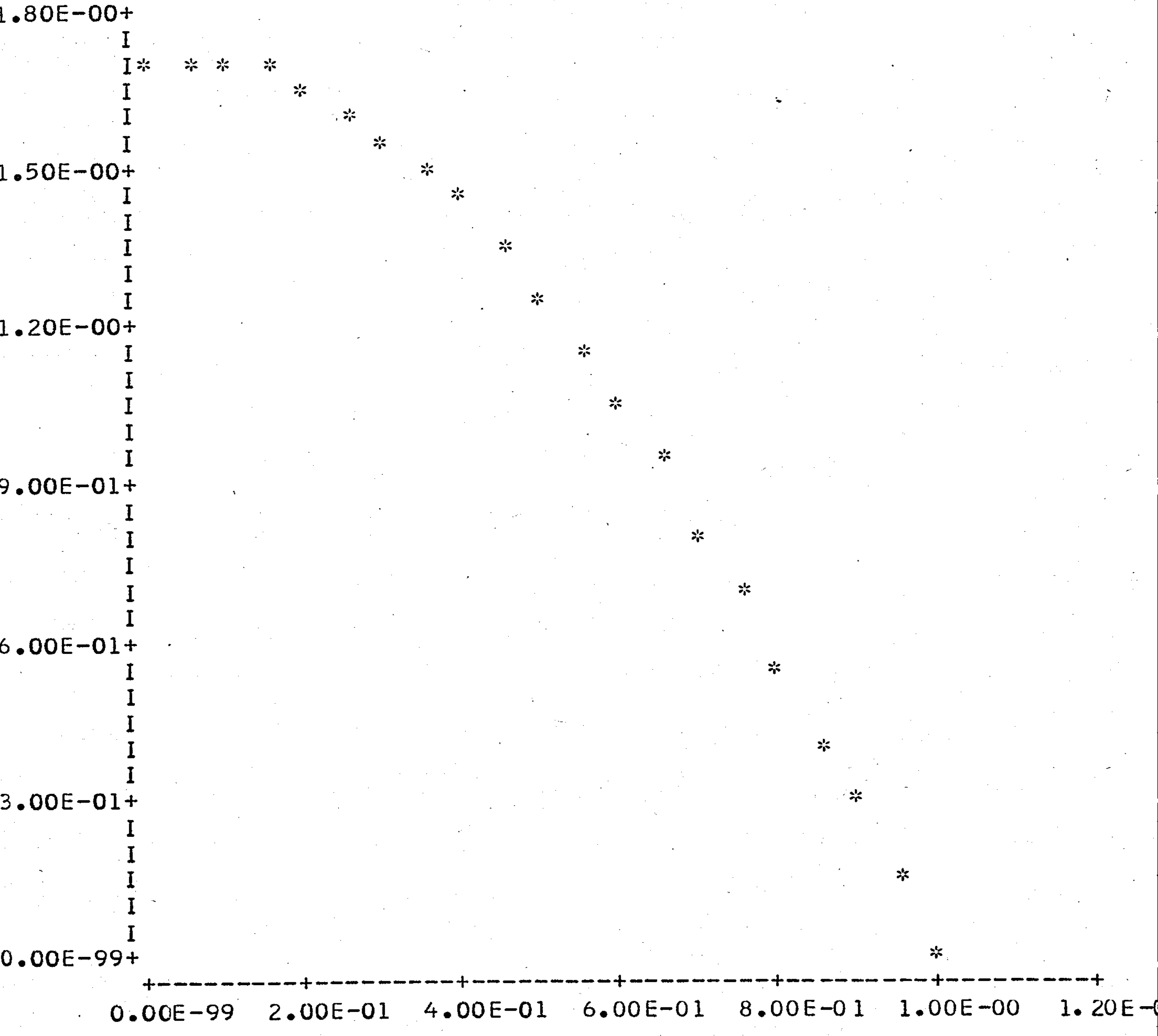
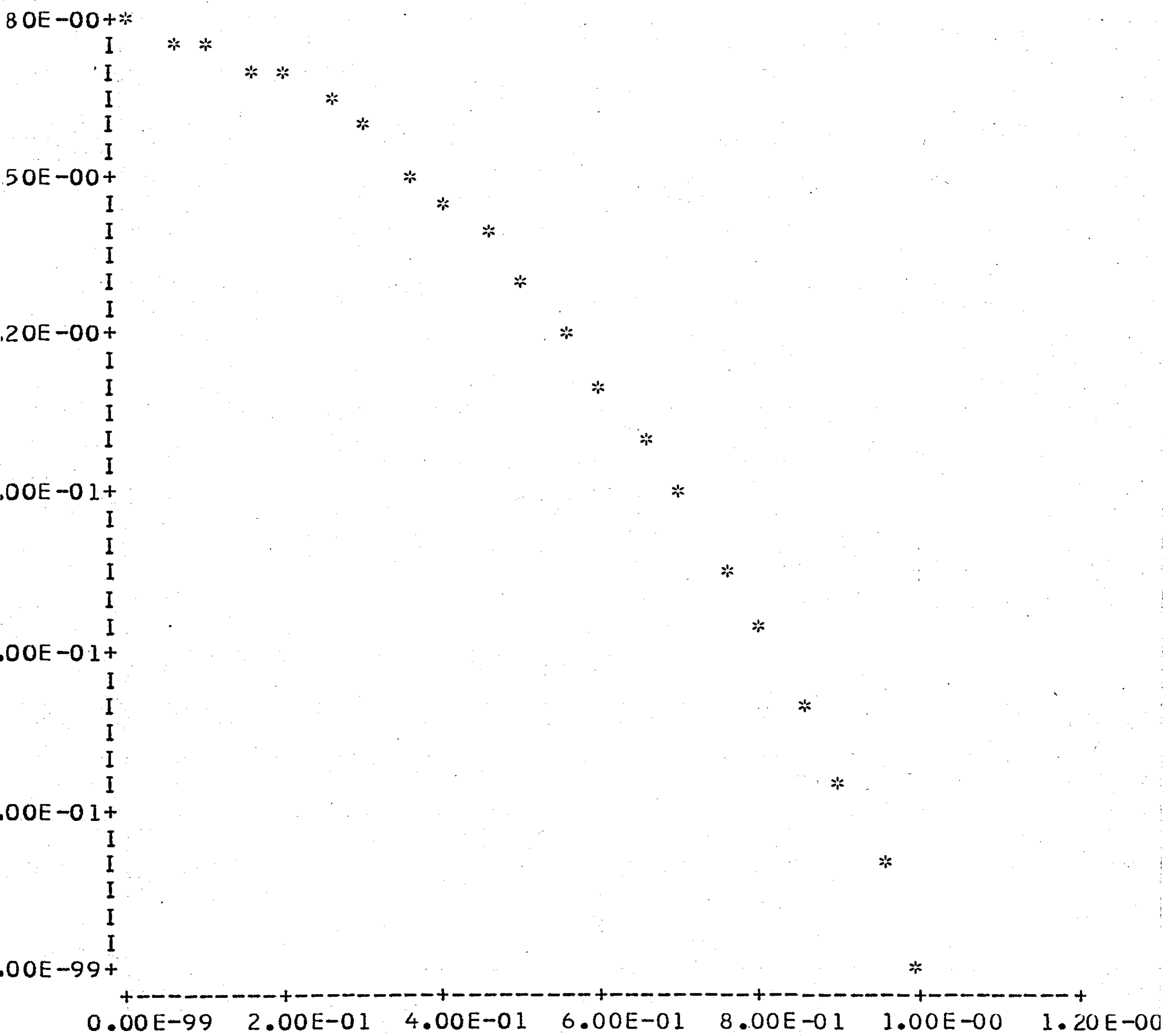


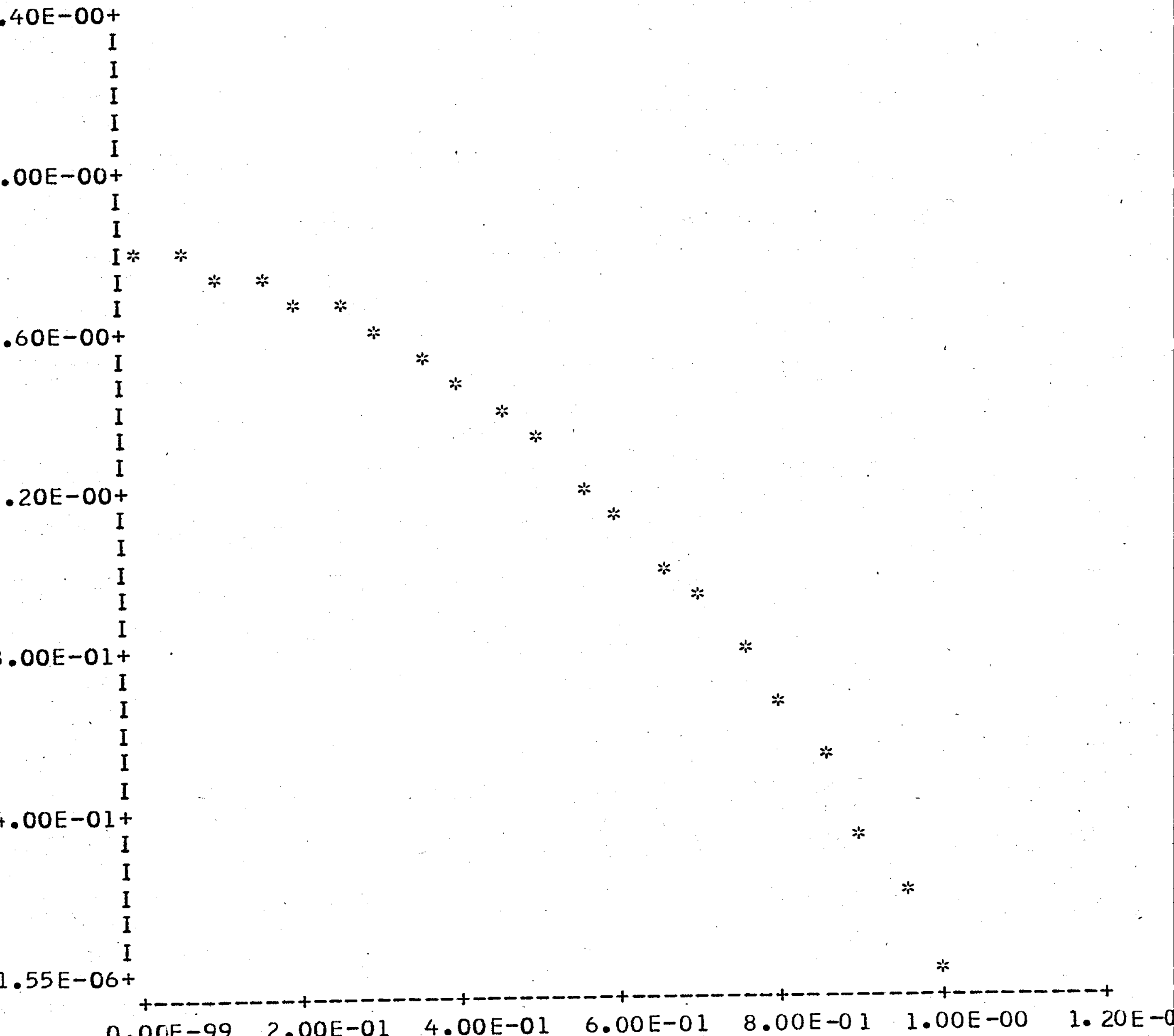
NDTL NUMBER= .010
NOLDS NUMBER= 500000.0



ANDTL NUMBER= .050
YNOLDS NUMBER= 3000.0



NDTL NUMBER= .050
NOLDS NUMBER= 8000.0



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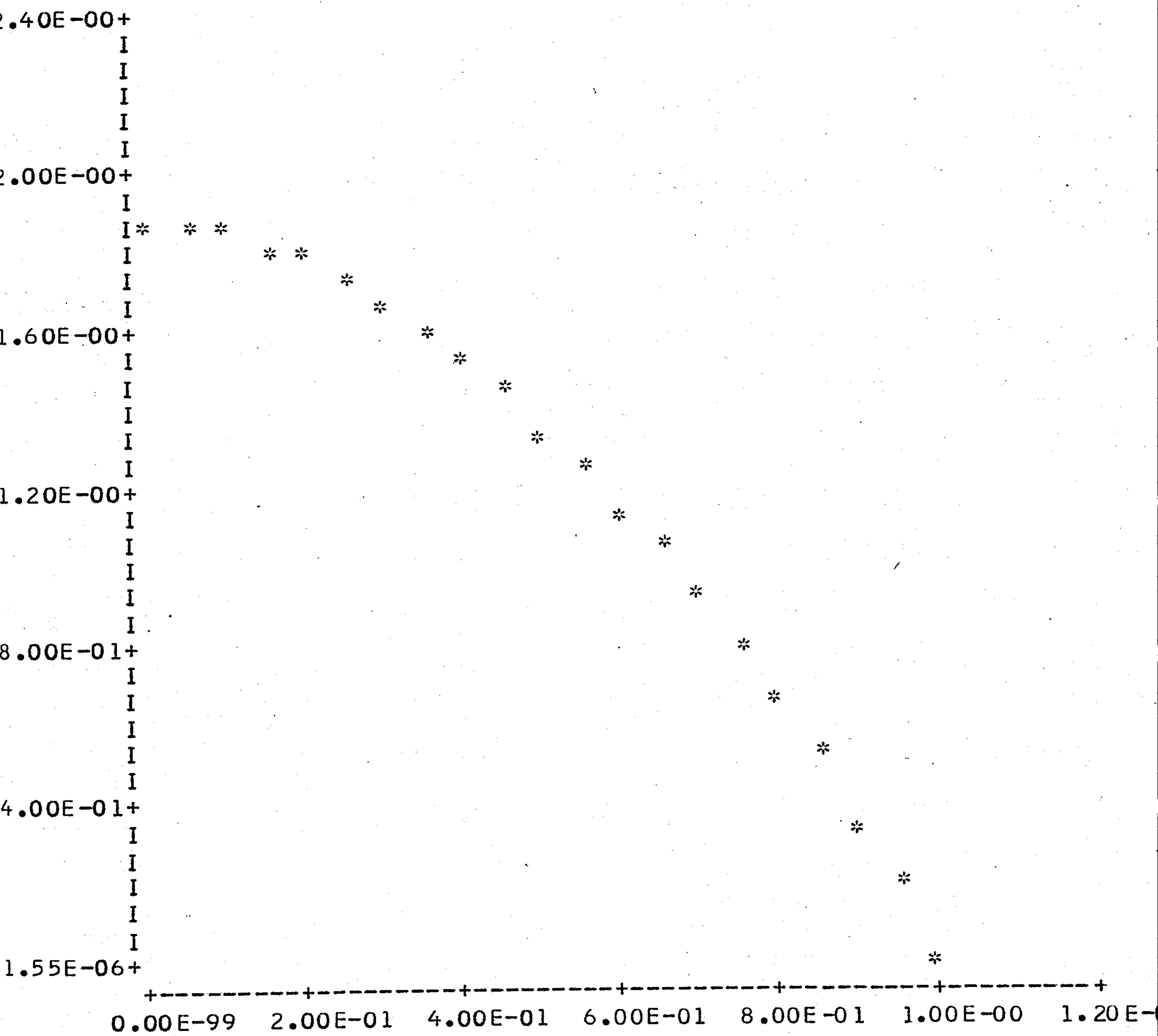
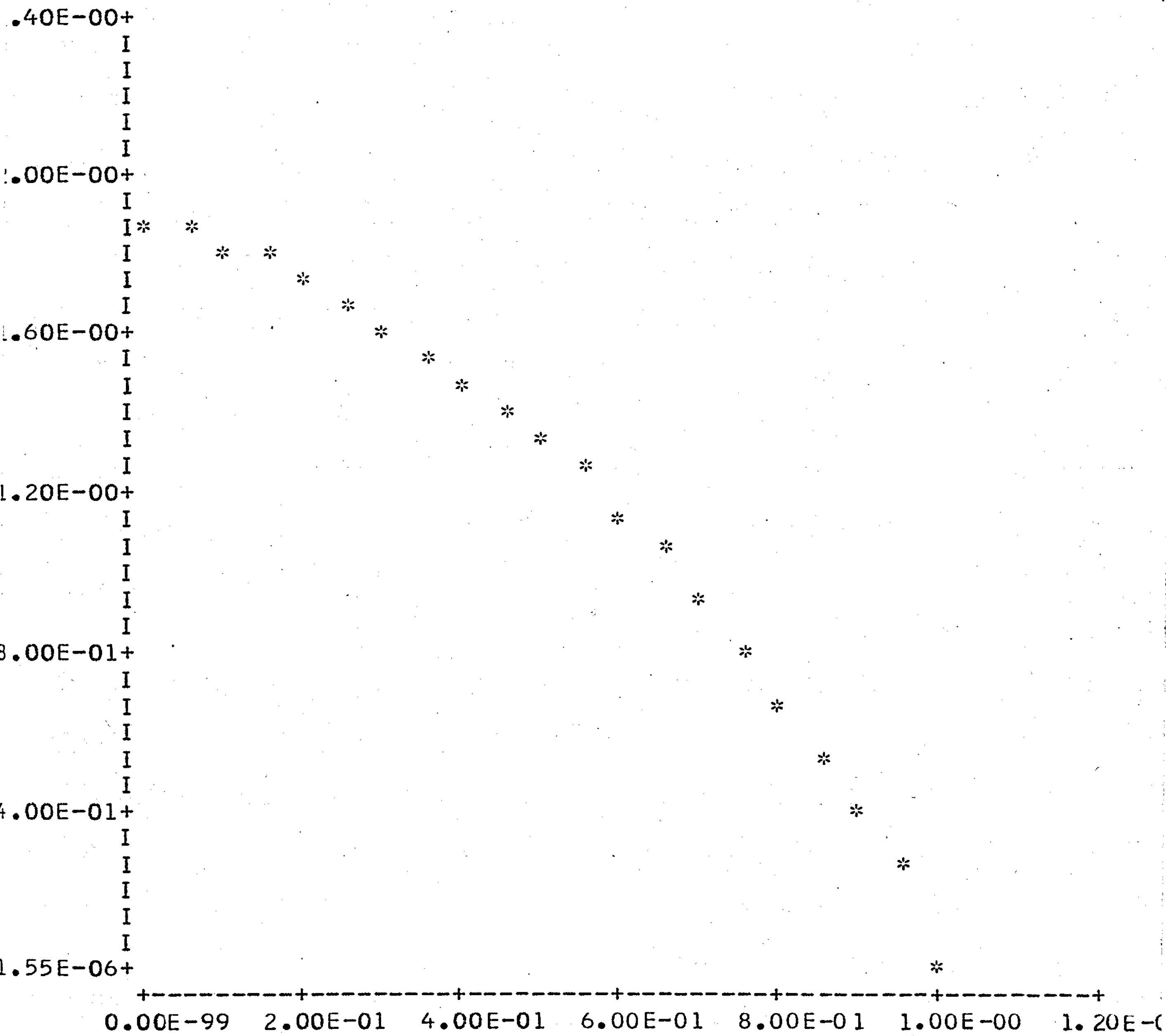
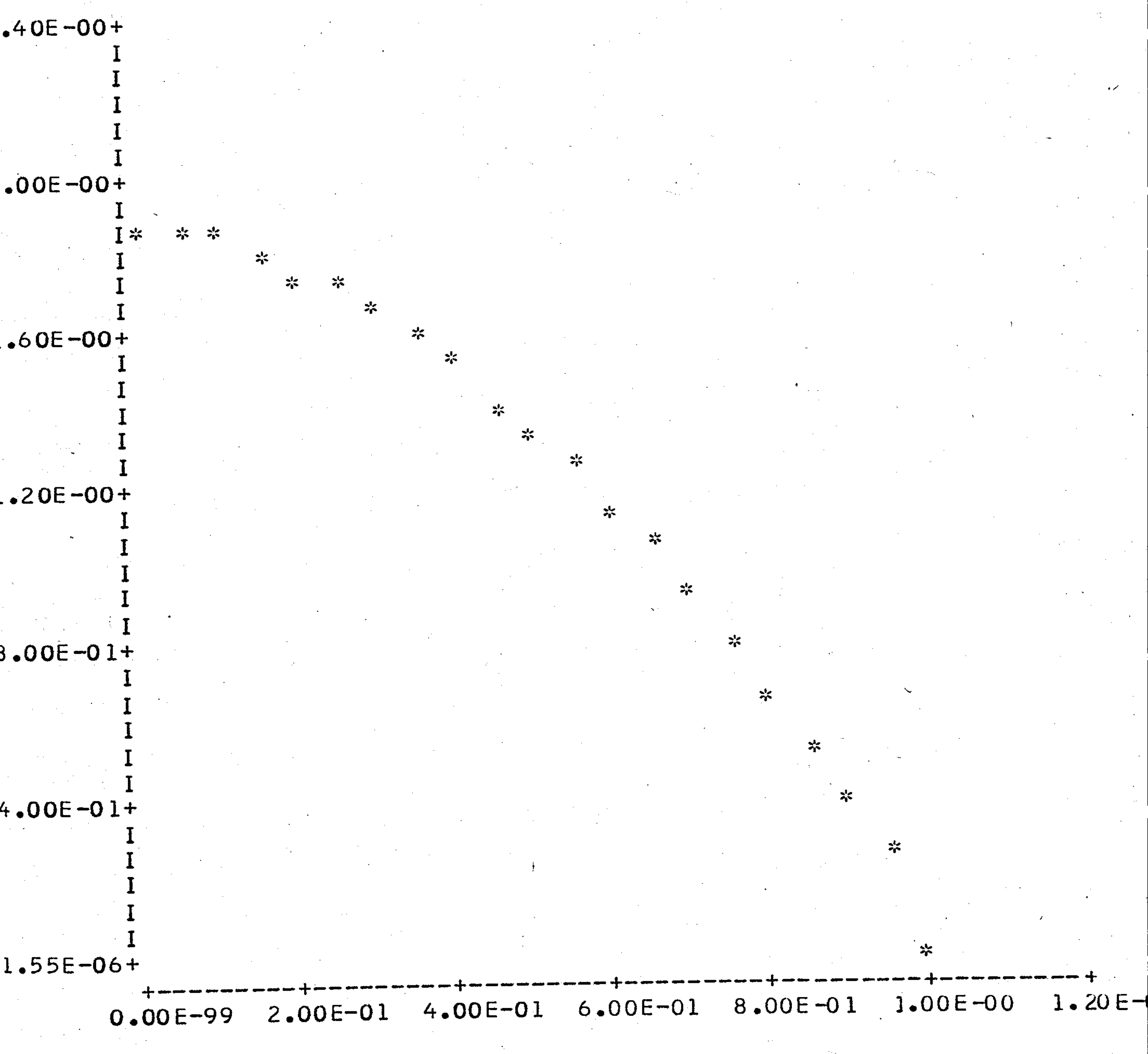
YNOLDS NUMBER= 10000.0



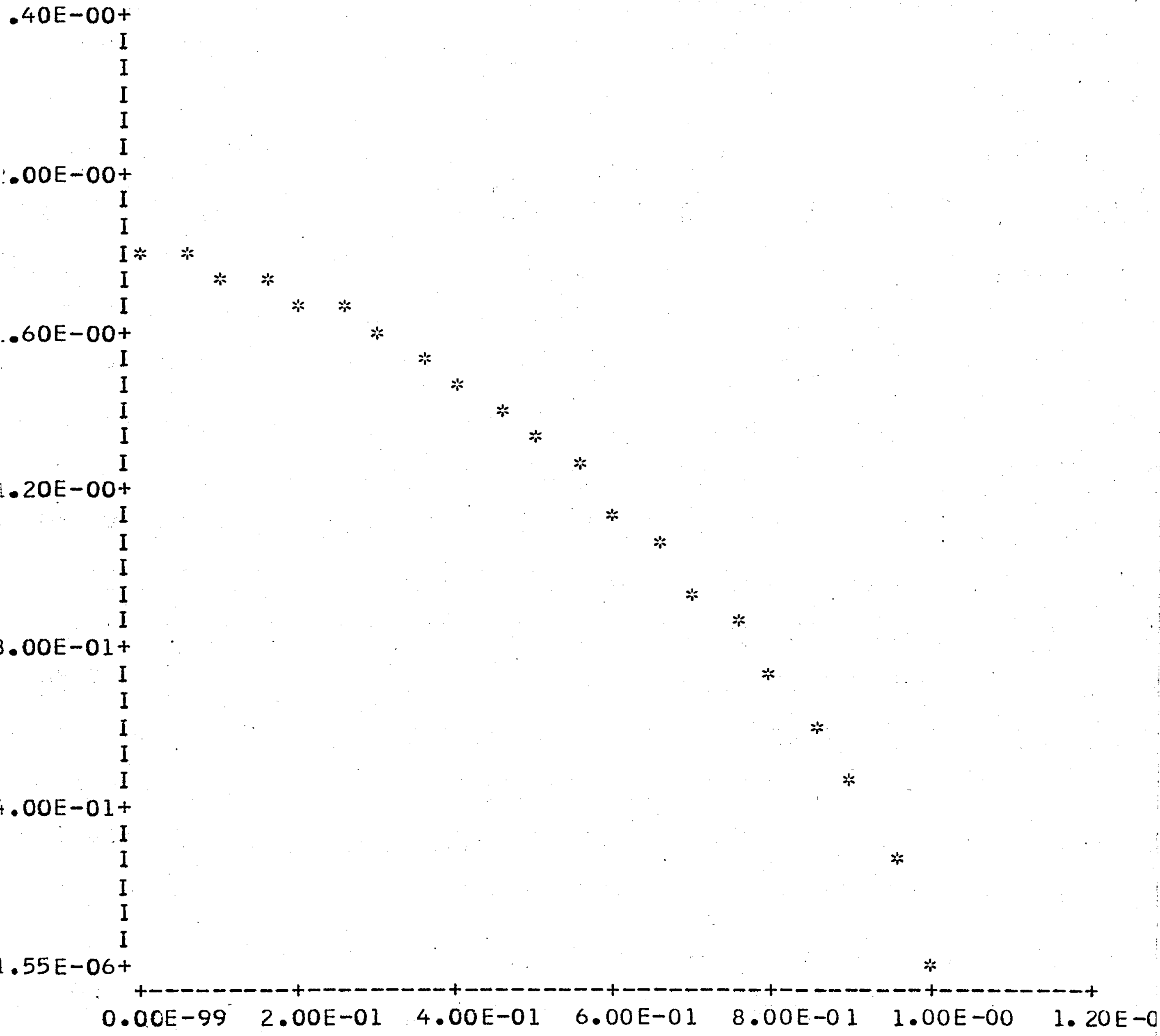
RANDTL NUMBER= .050
EYNOLDS NUMBER= 30000.0



ANDTL NUMBER = .050
YNOLDS NUMBER = 50000.



RANDTL NUMBER= .050
EYNOLDS NUMBER= 70000.0



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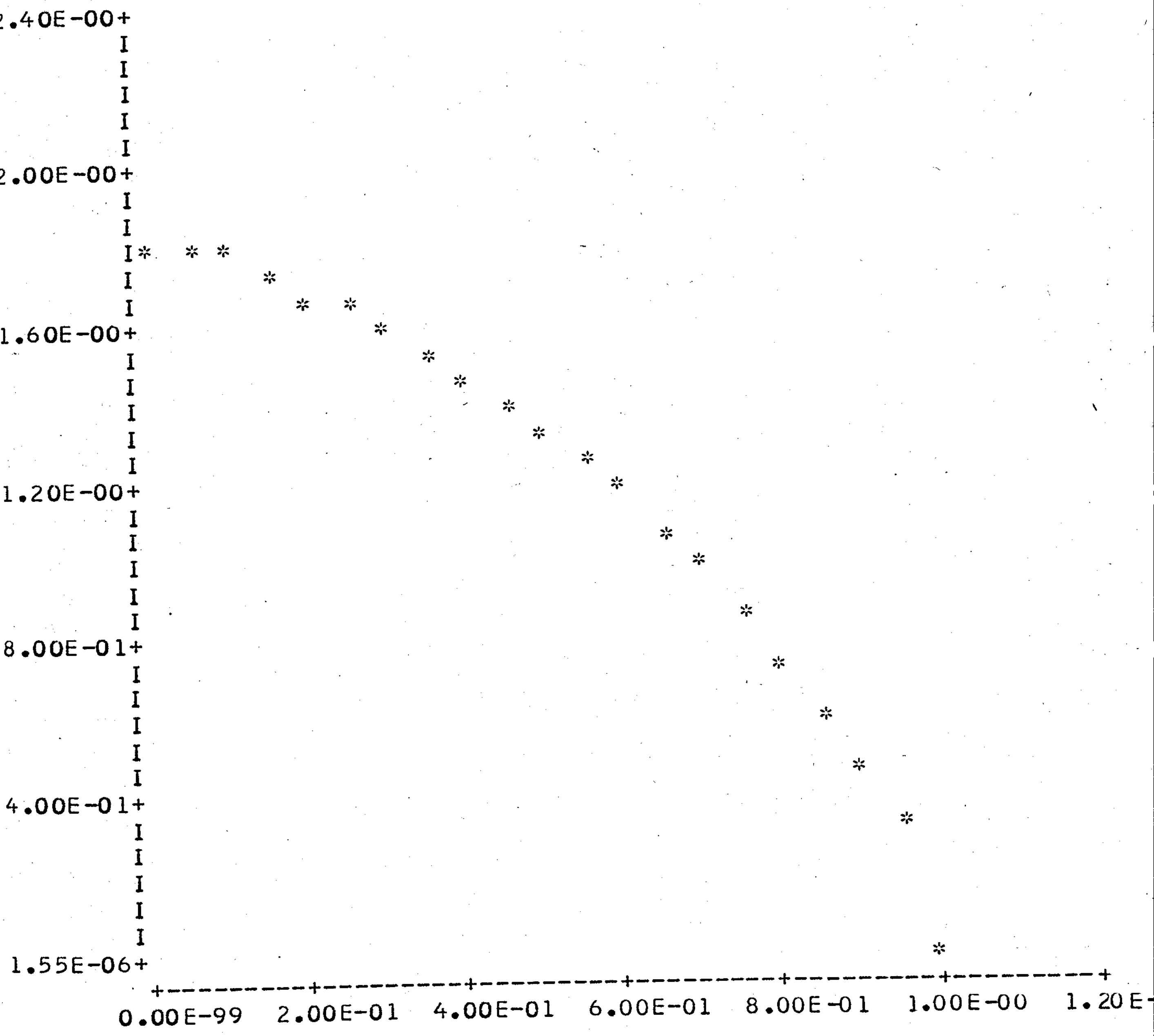
NOLDS NUMBER = 100000.0



RANDTL NUMBER= .050
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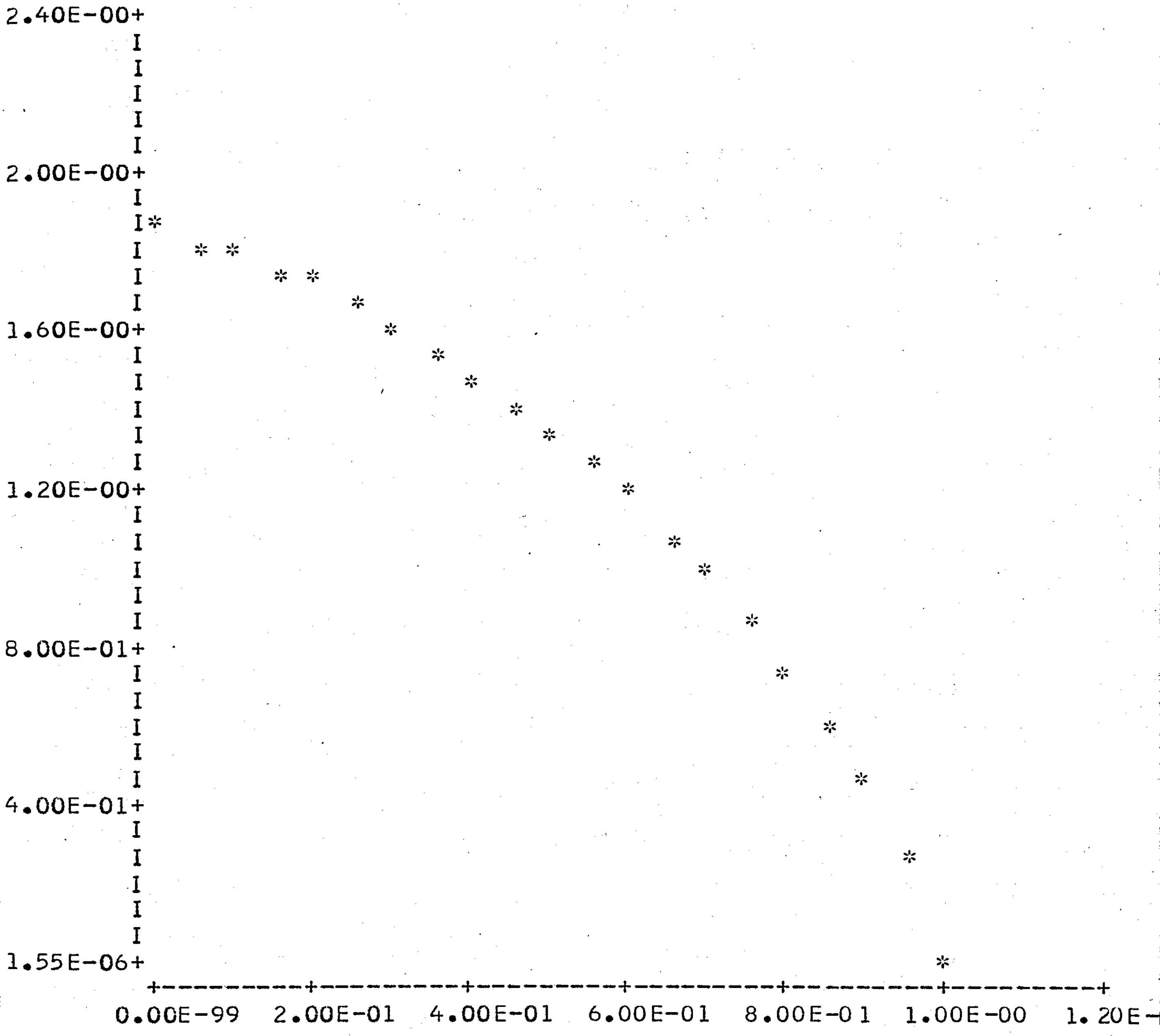

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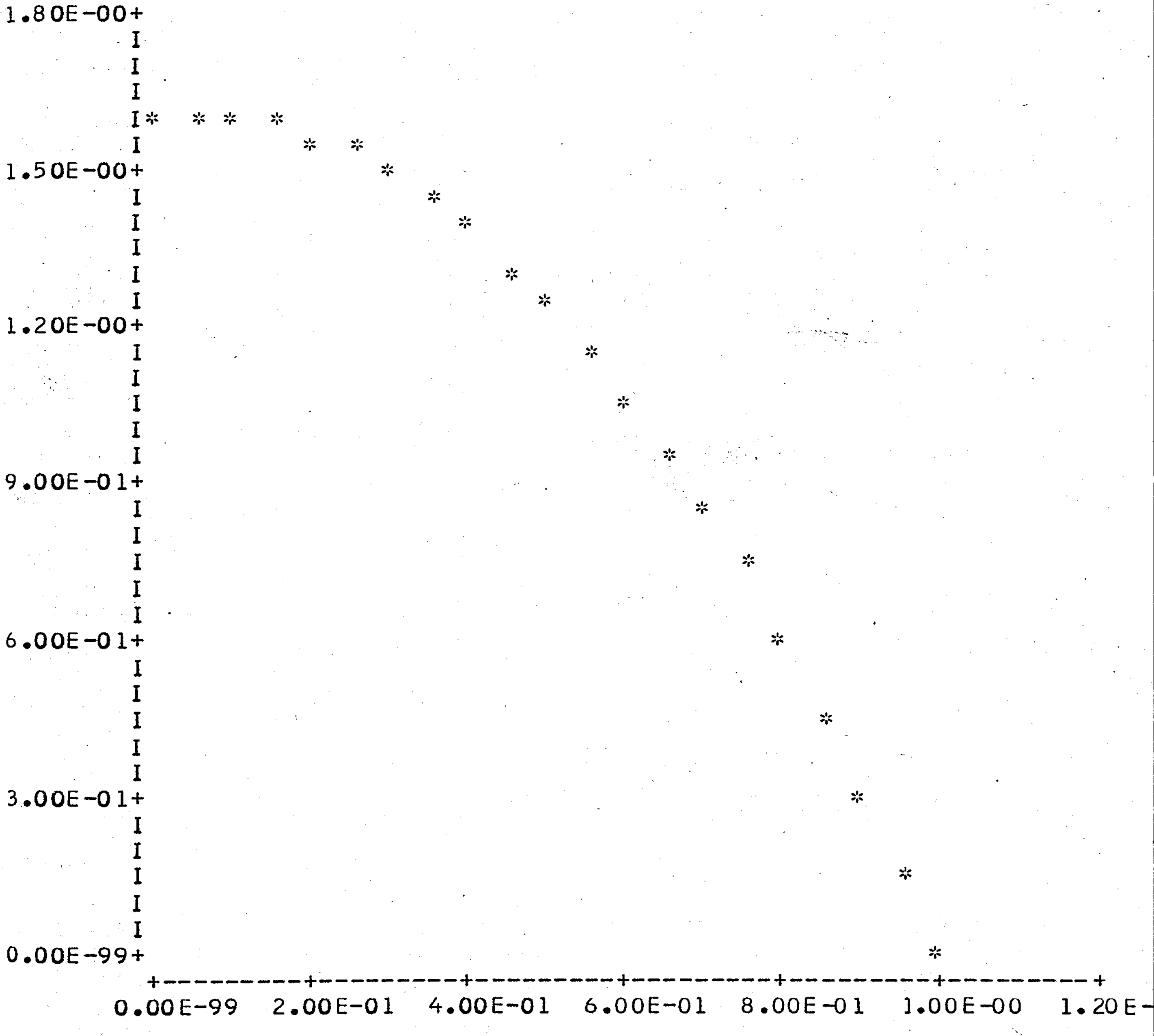

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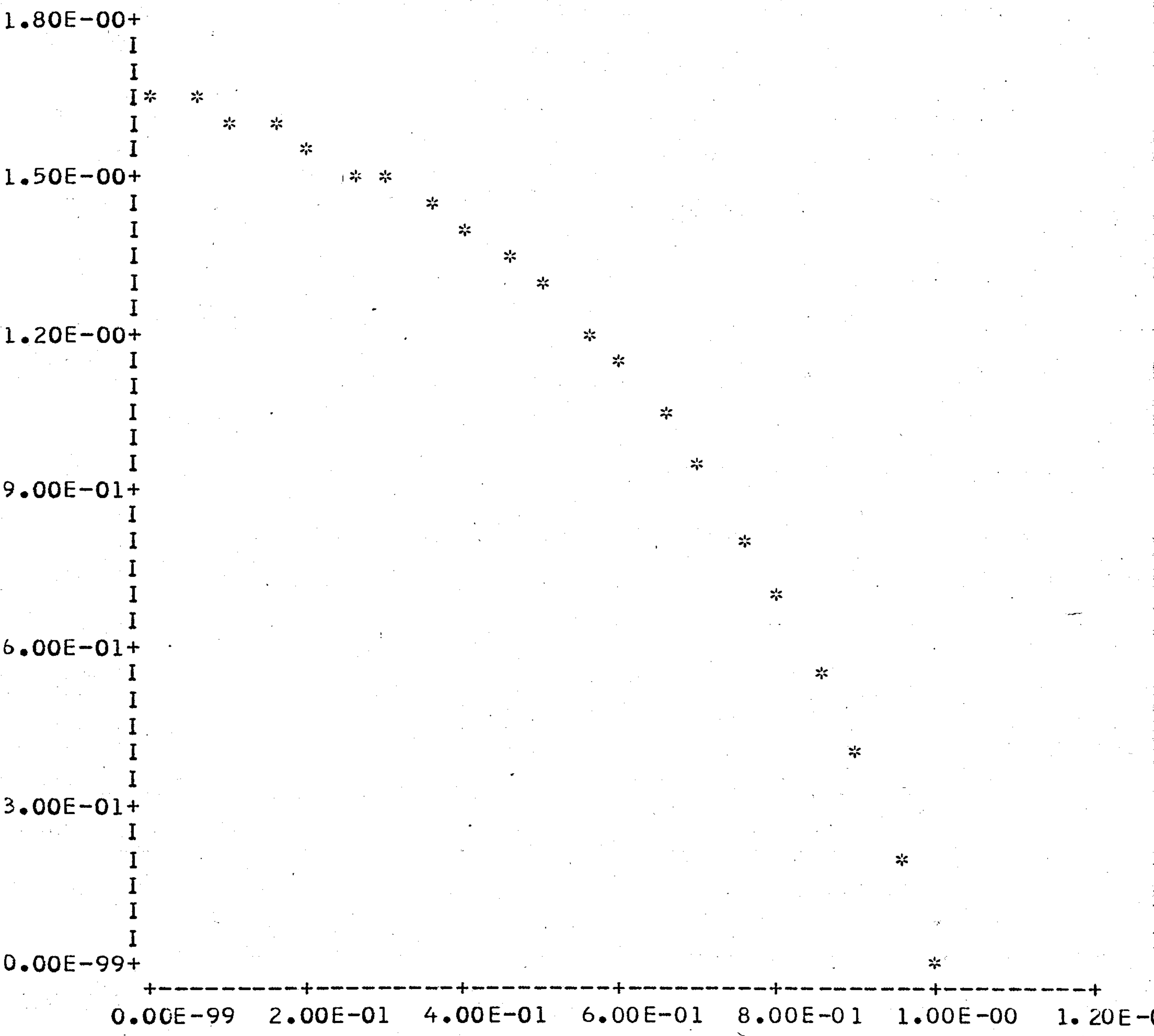

ANDTL NUMBER = .100
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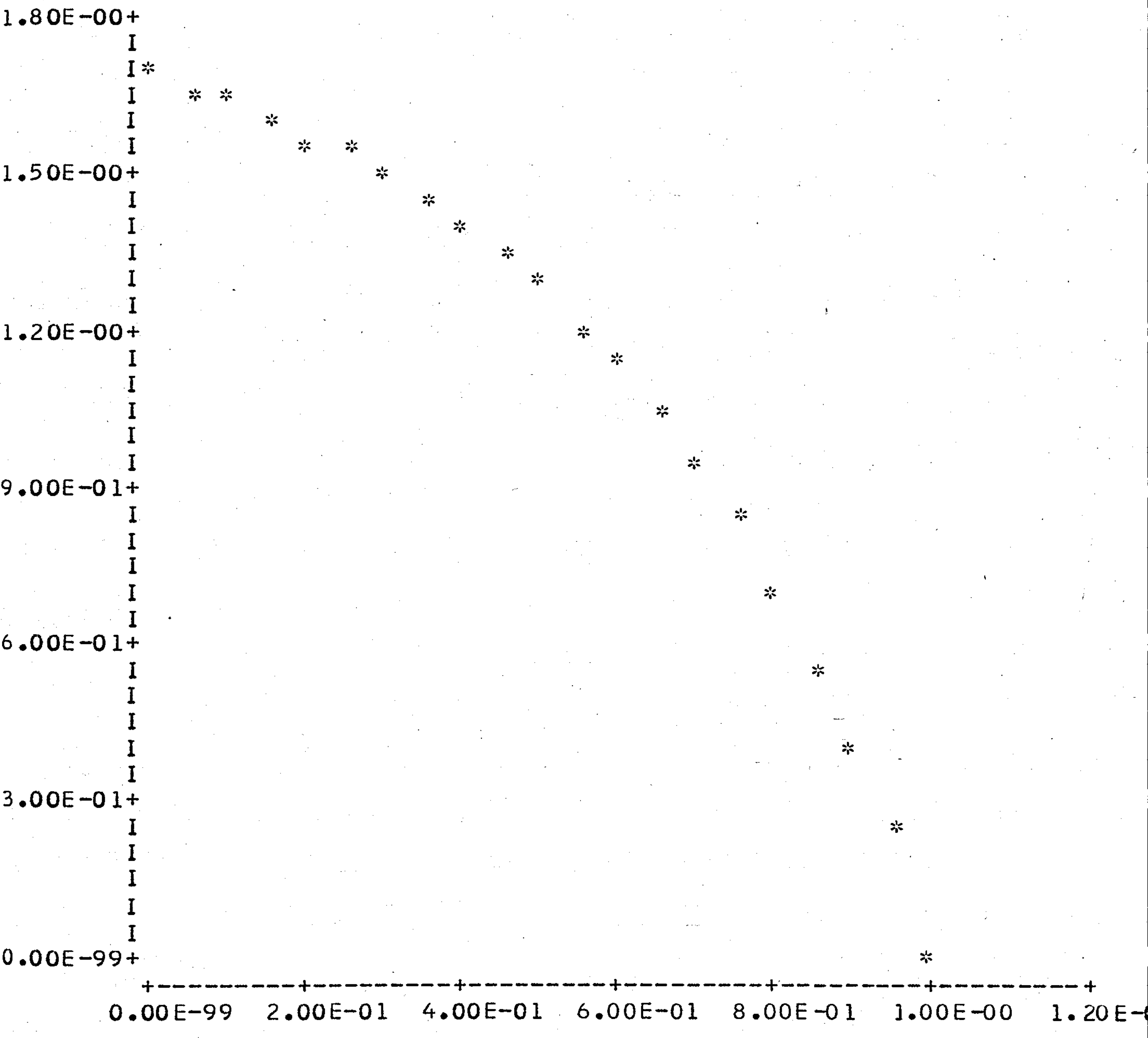
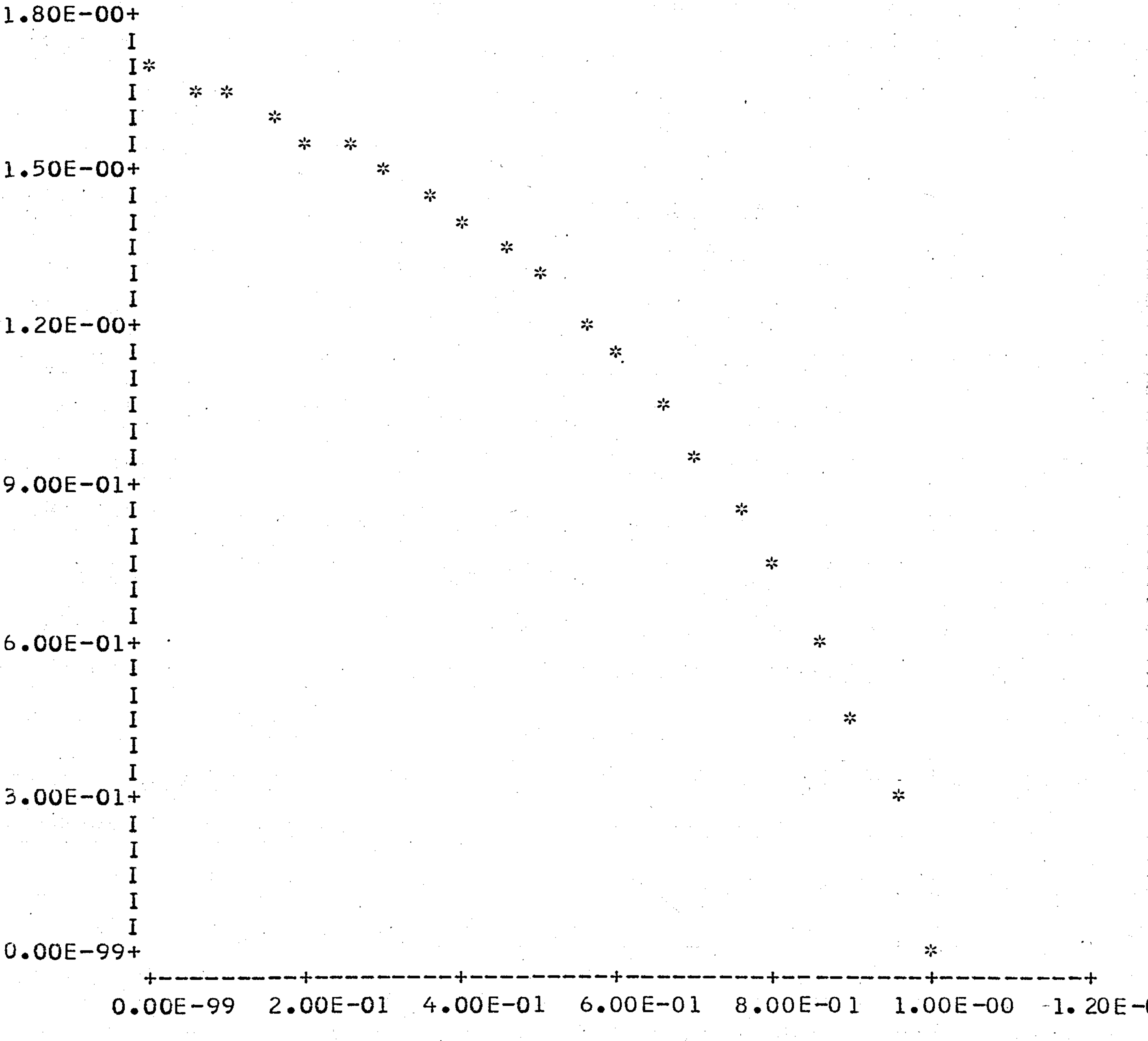
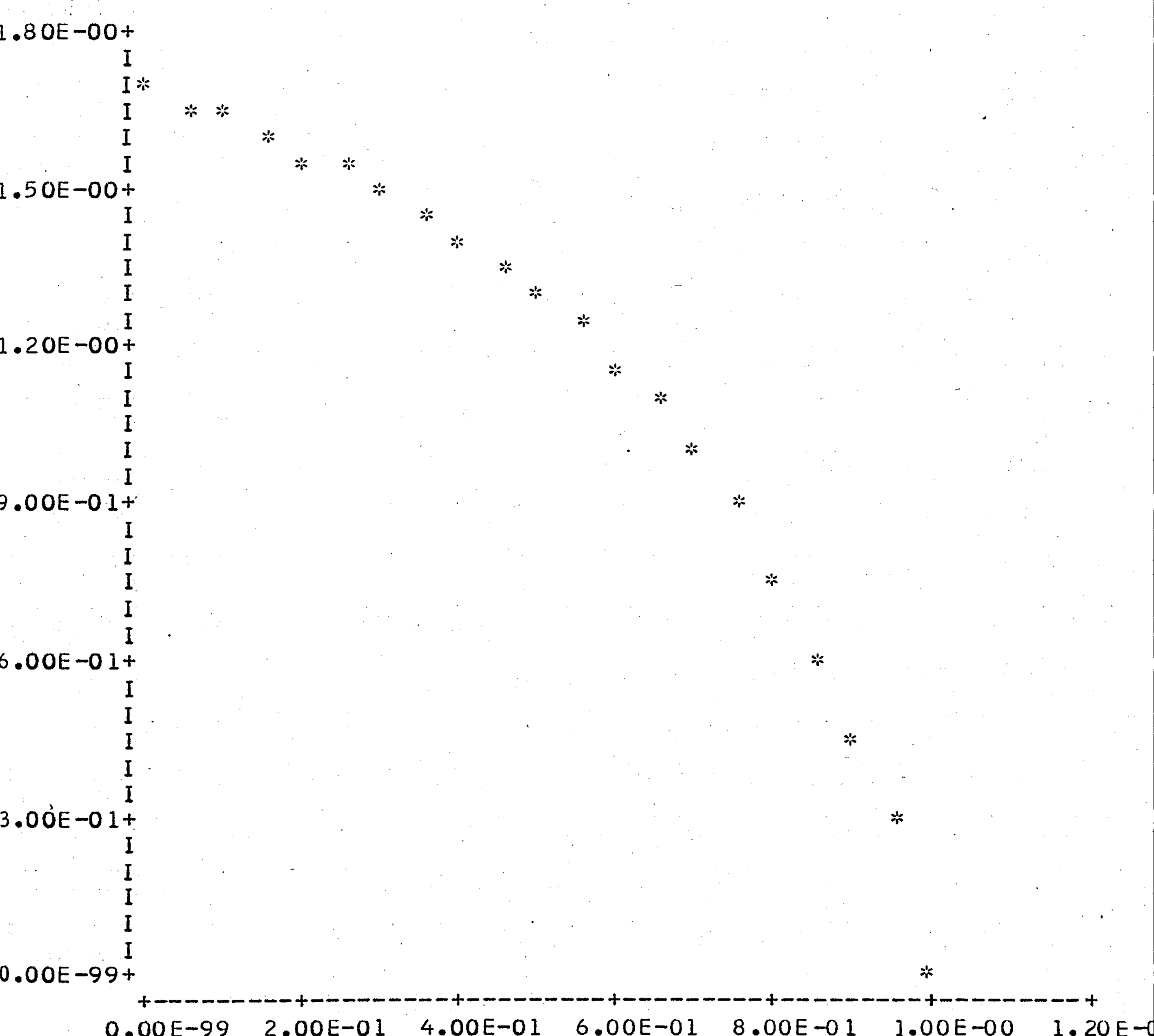


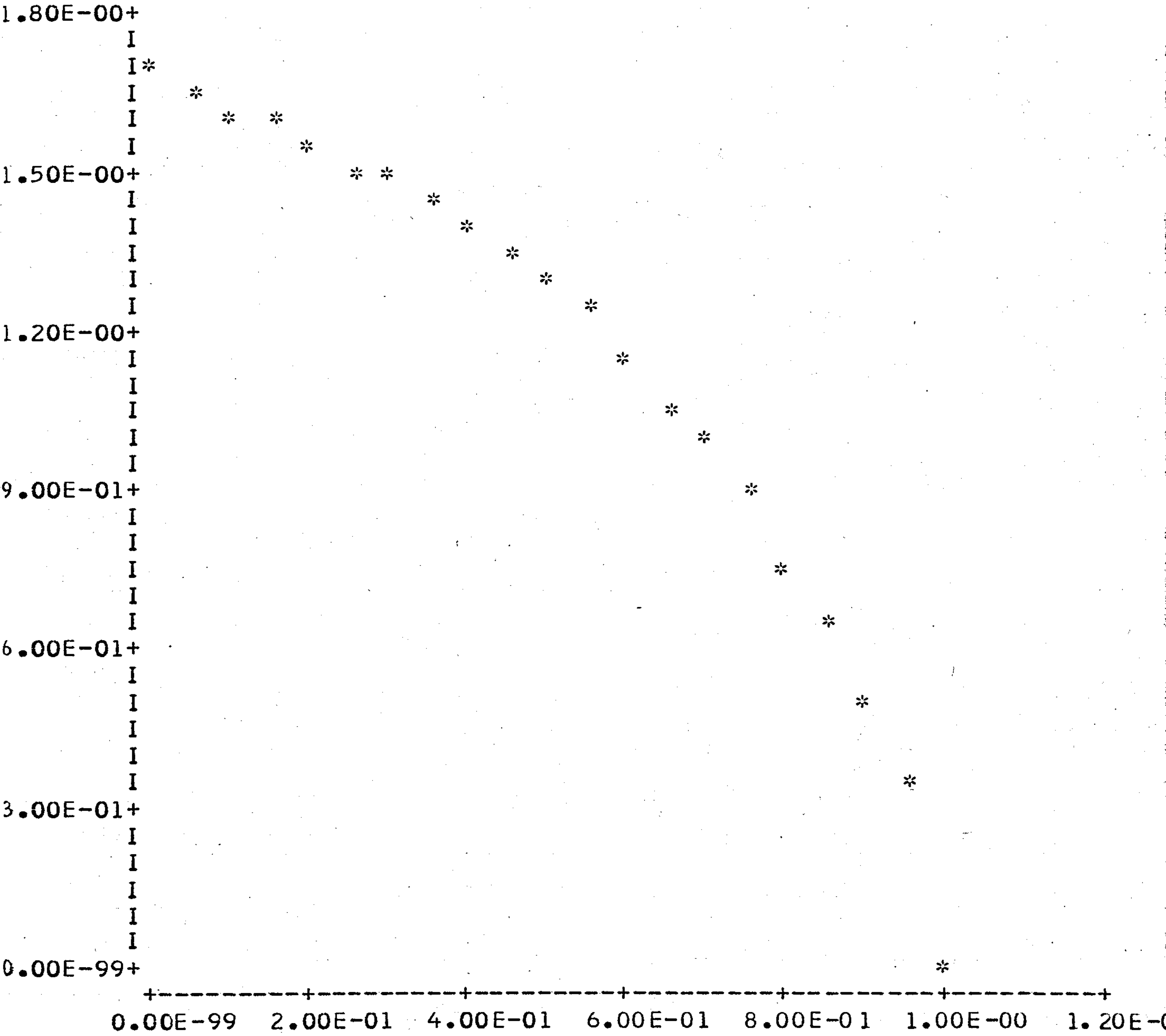
ANDTL NUMBER= .100
YNOLDS NUMBER= 10000.0



ANDTL NUMBER= .100
YNOLDS NUMBER= 30000.0



ANDTL NUMBER= .100
YNOLDS NUMBER= 50000.0



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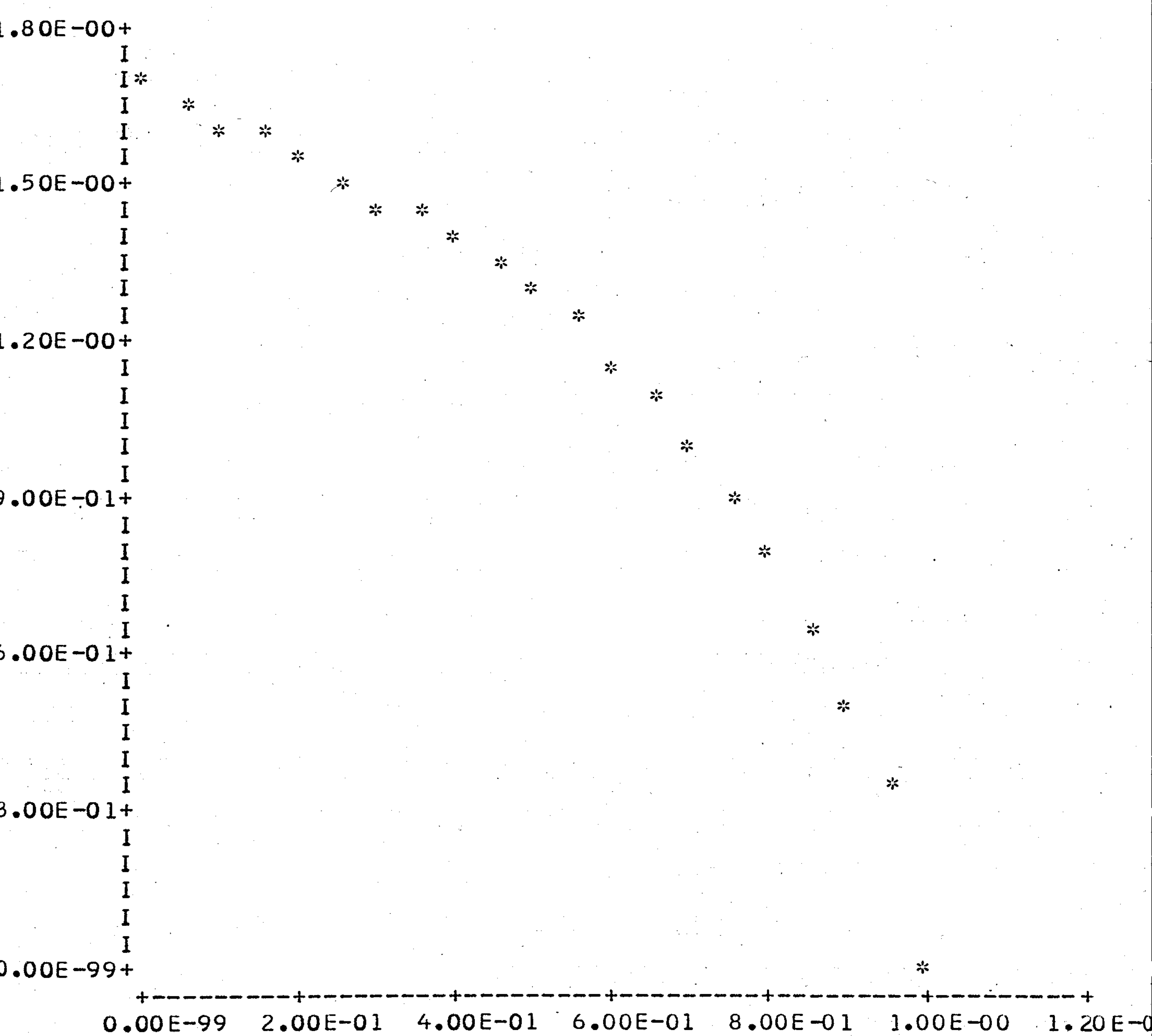
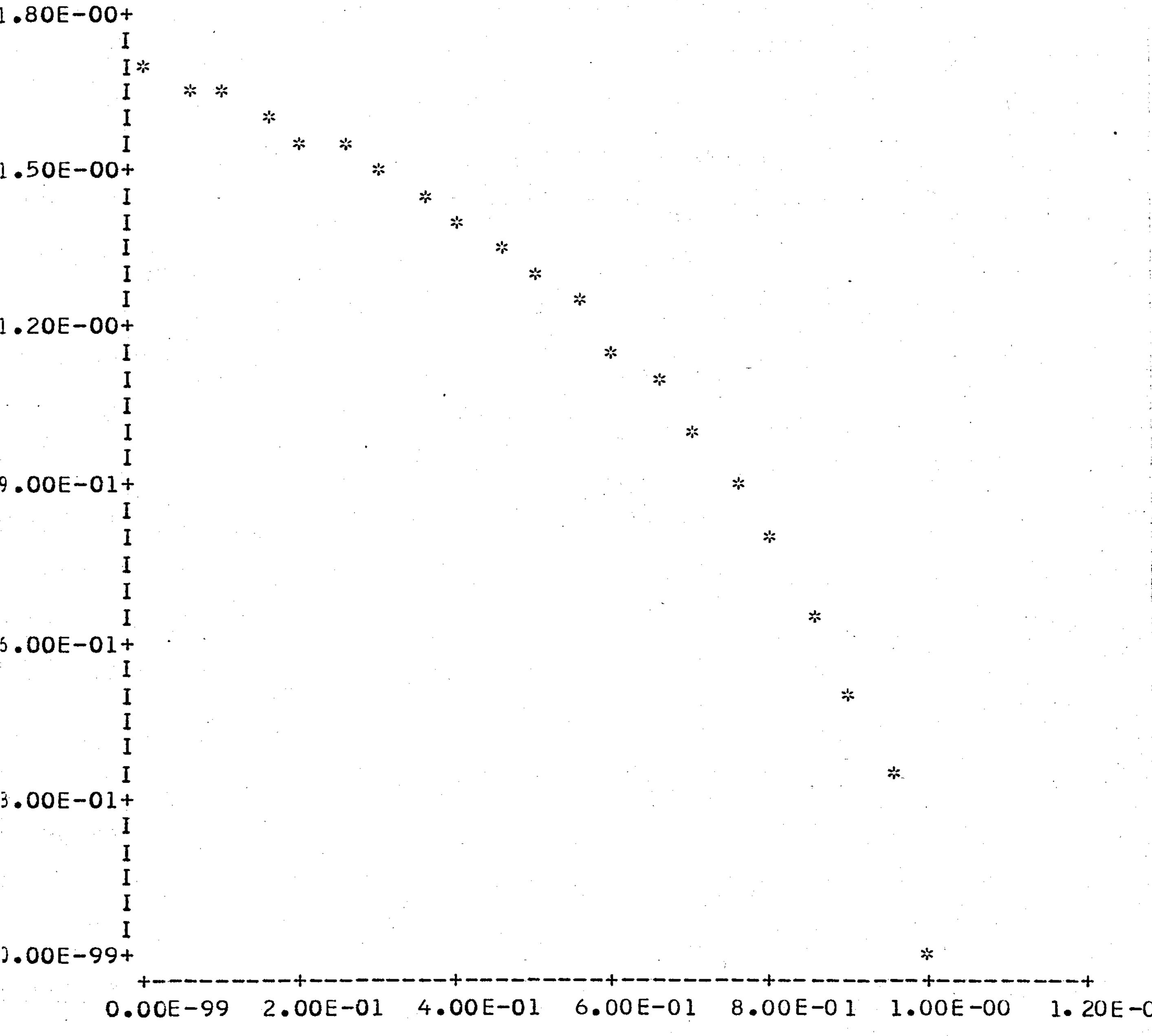
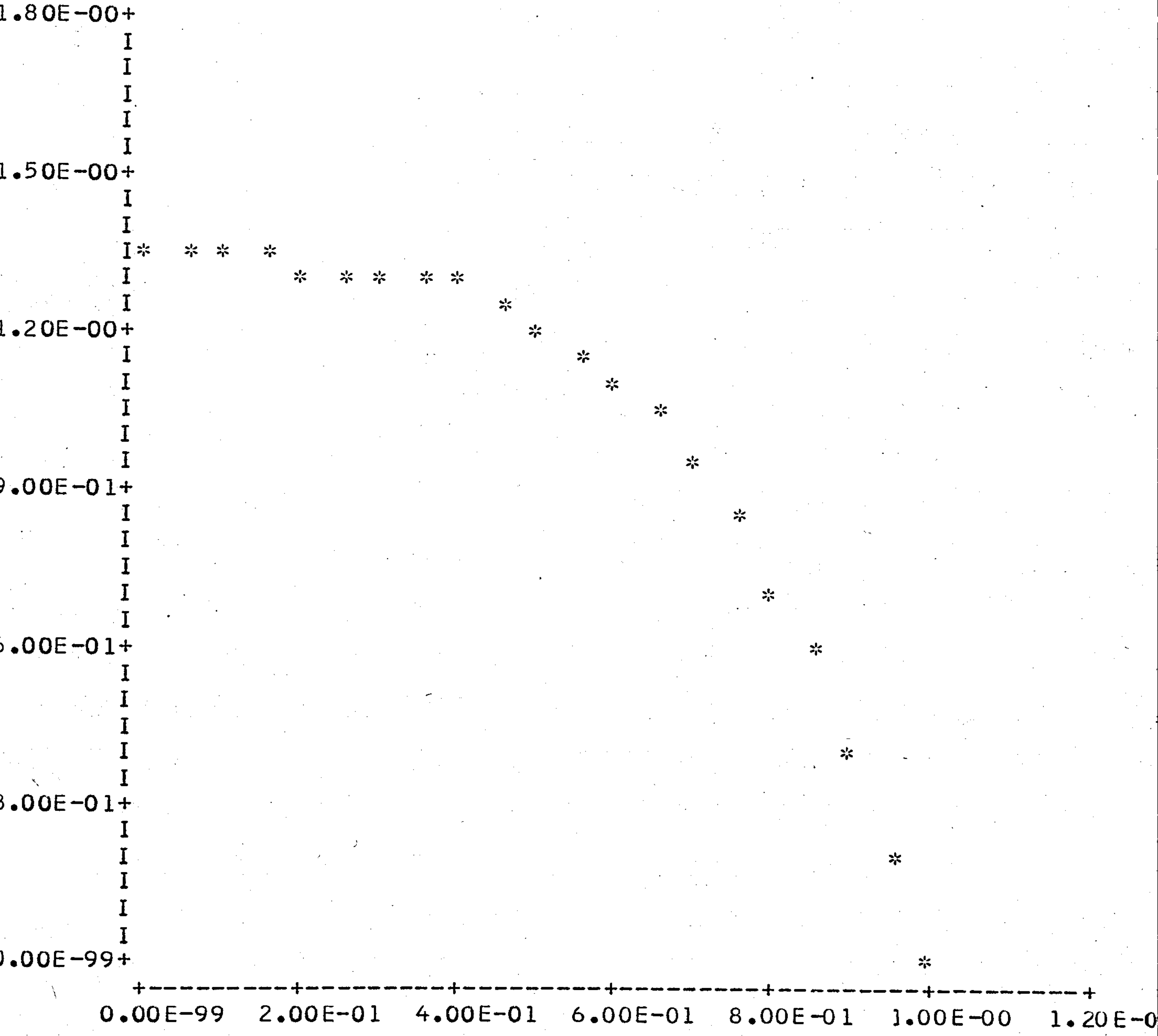
YNOLDS NUMBER= 70000.0



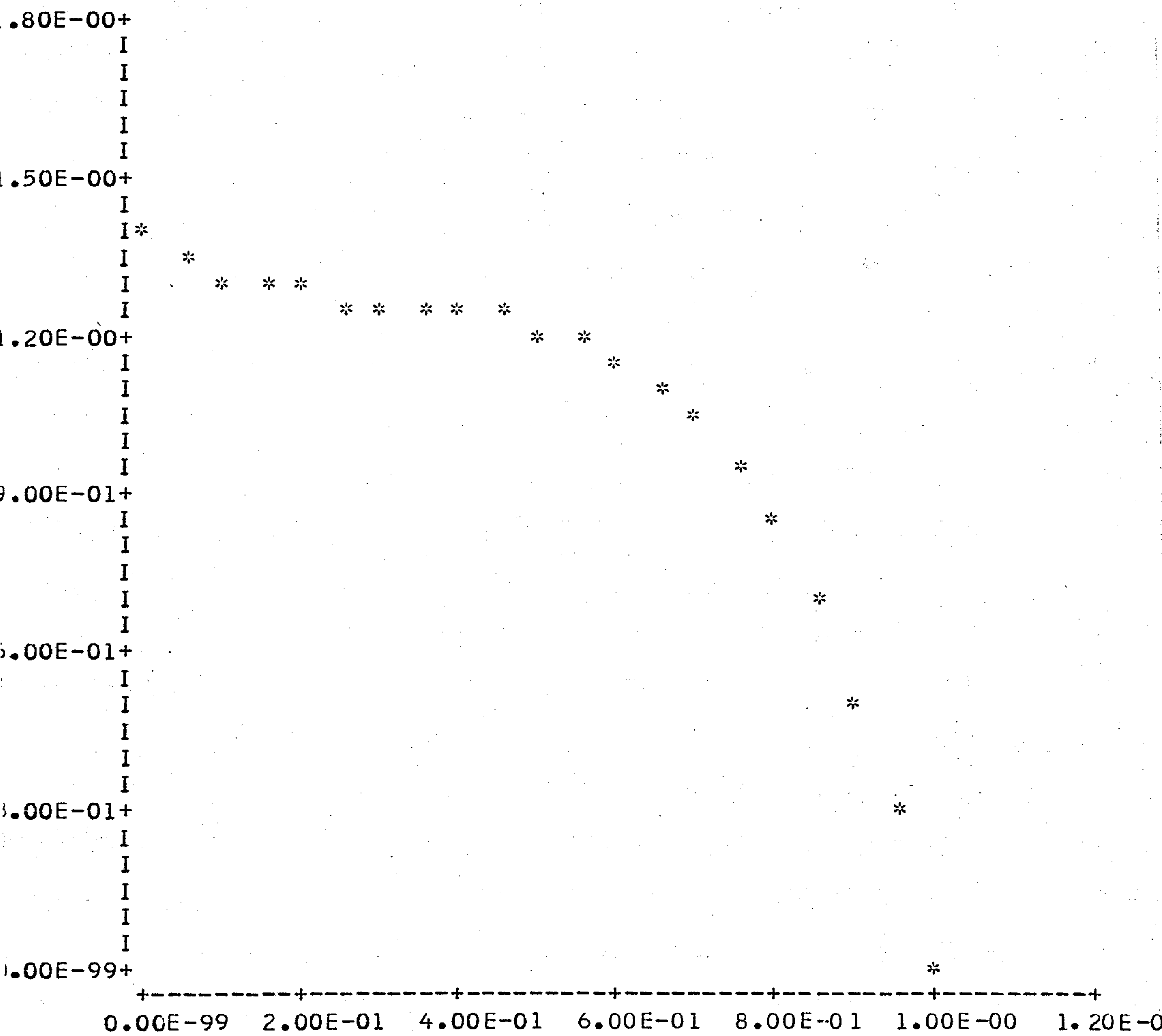
ANDTL NUMBER= .100
YNOLDS NUMBER= 100000.0



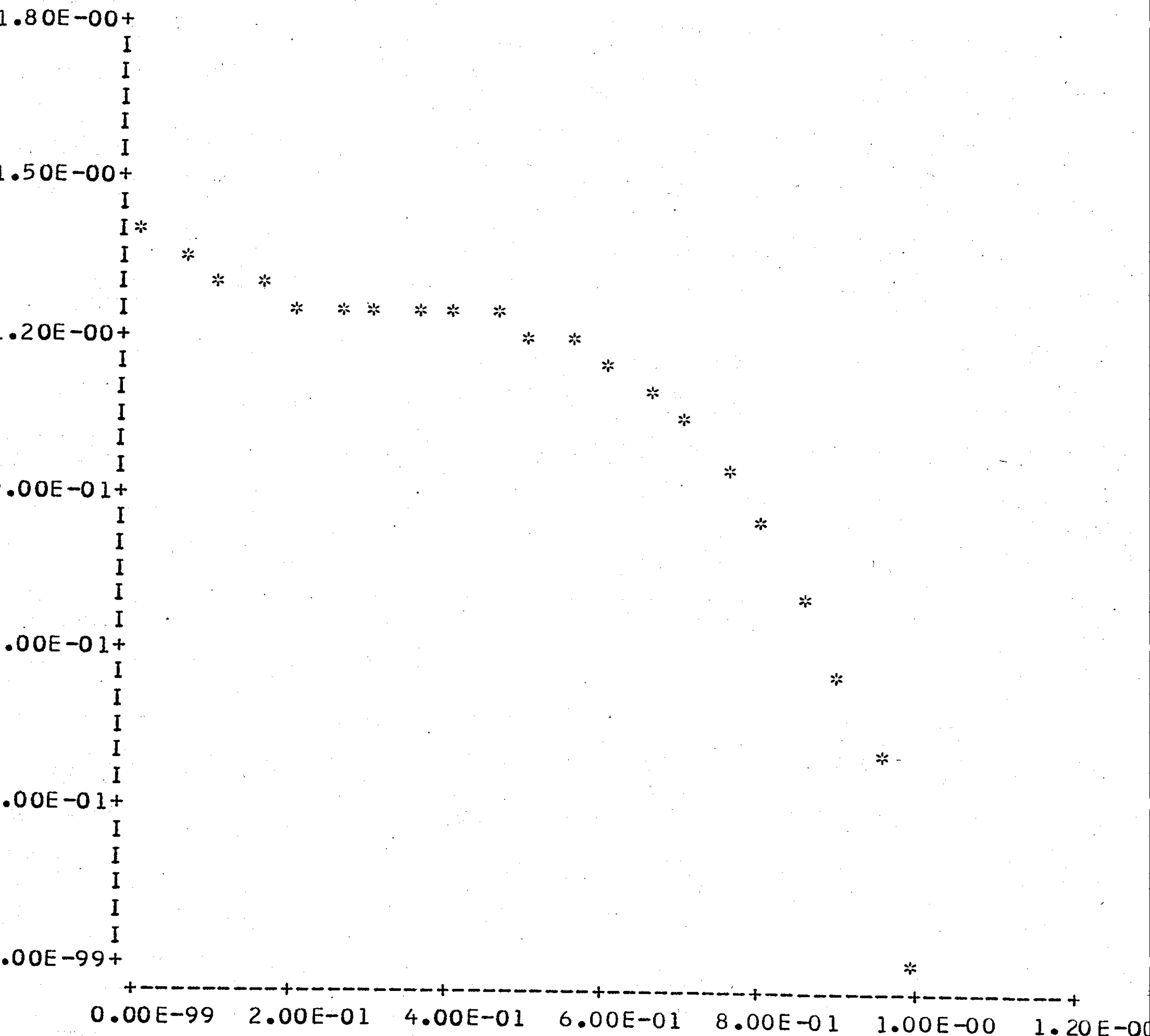
ANDTL NUMBER = .100
YNOLDS NUMBER = 300000.0



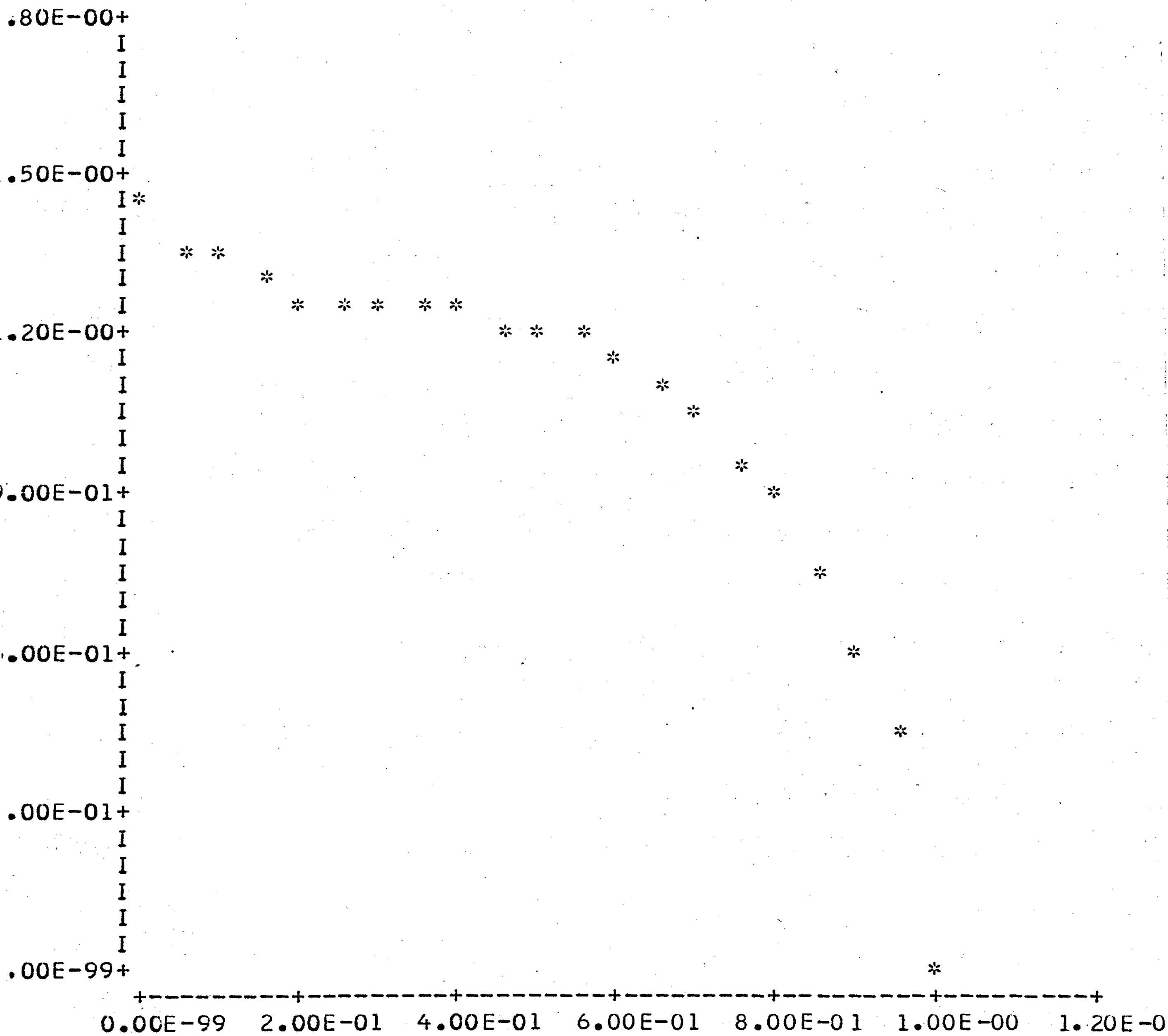
ANDTL NUMBER= .500
YNOLDS NUMBER= 3000.0



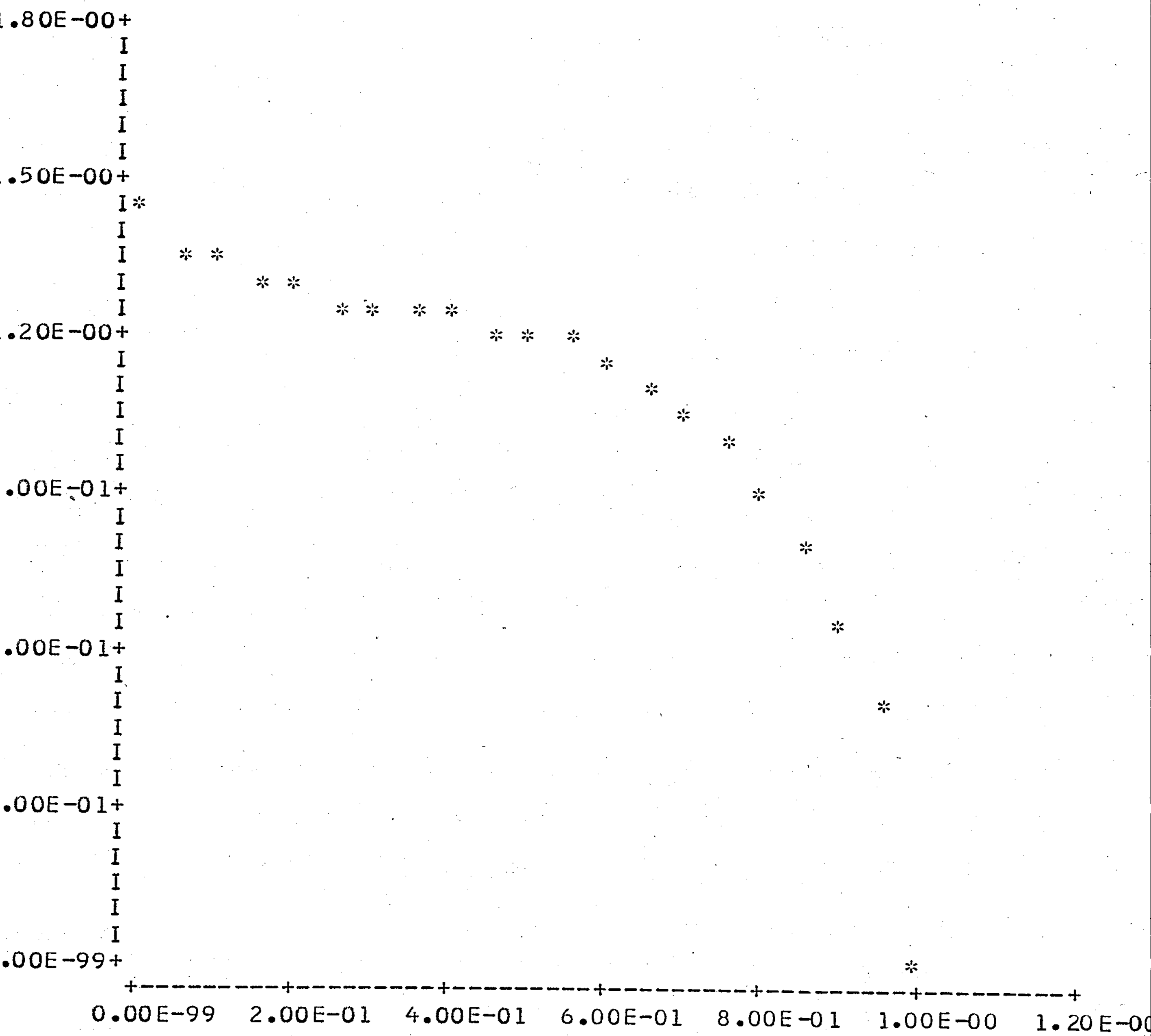
NDTL NUMBER = .500
NOLDS NUMBER = 8000.0



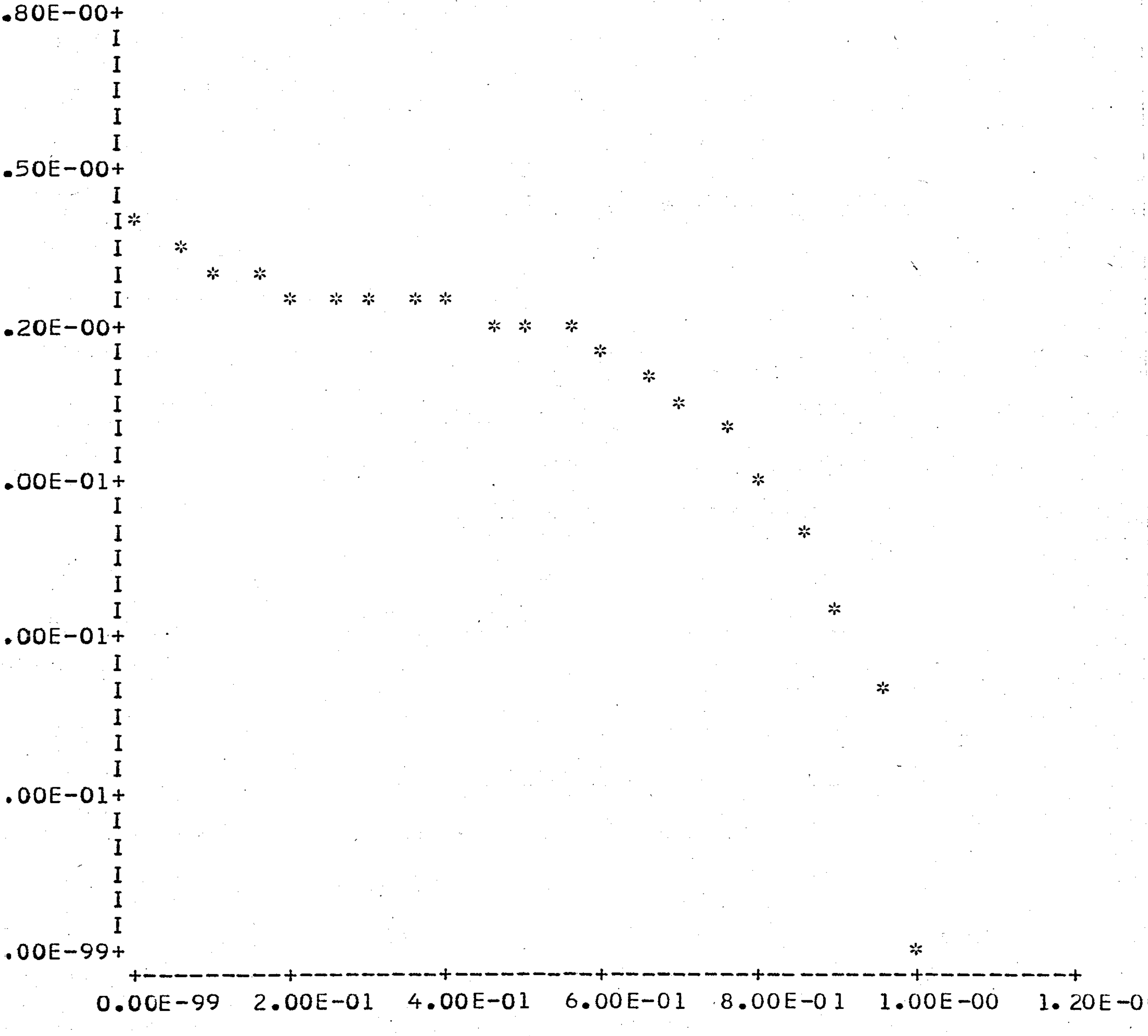
NDTL NUMBER= .500
NOLDS NUMBER= 10000.0



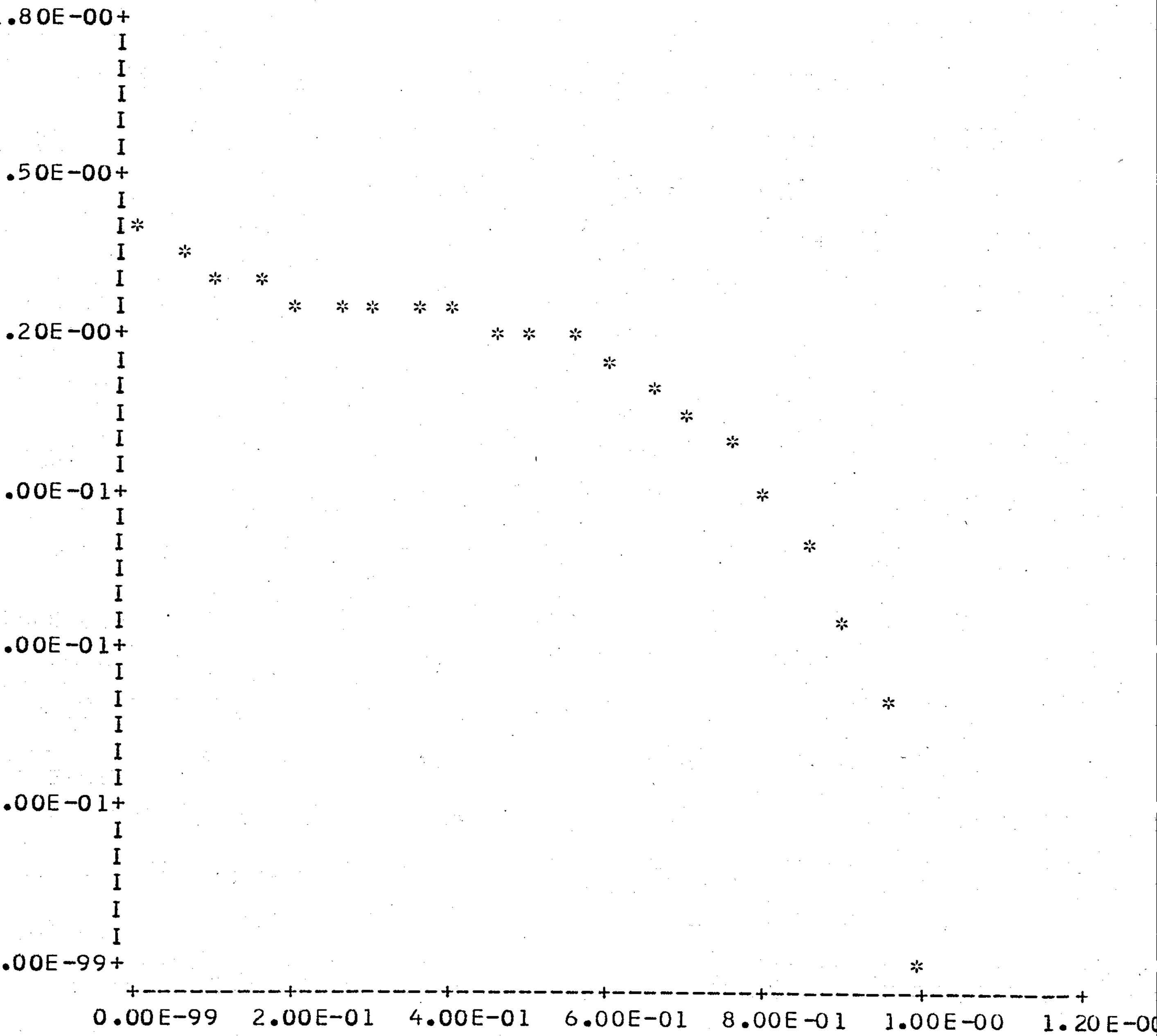
NDTL NUMBER = .500
NOLDS NUMBER = 30000.0



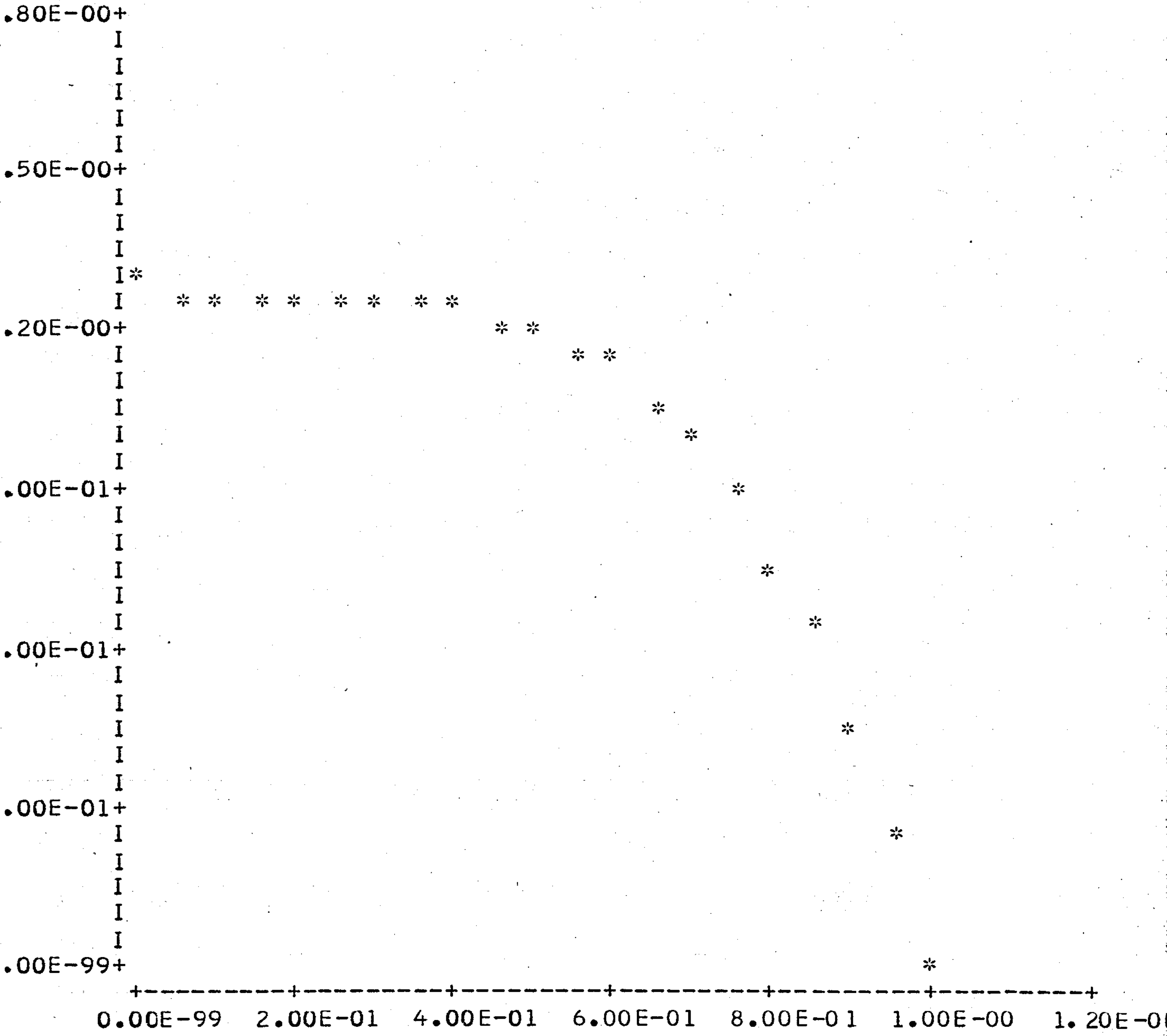
NDTL NUMBER= .500
NOLDS NUMBER= 50000.0



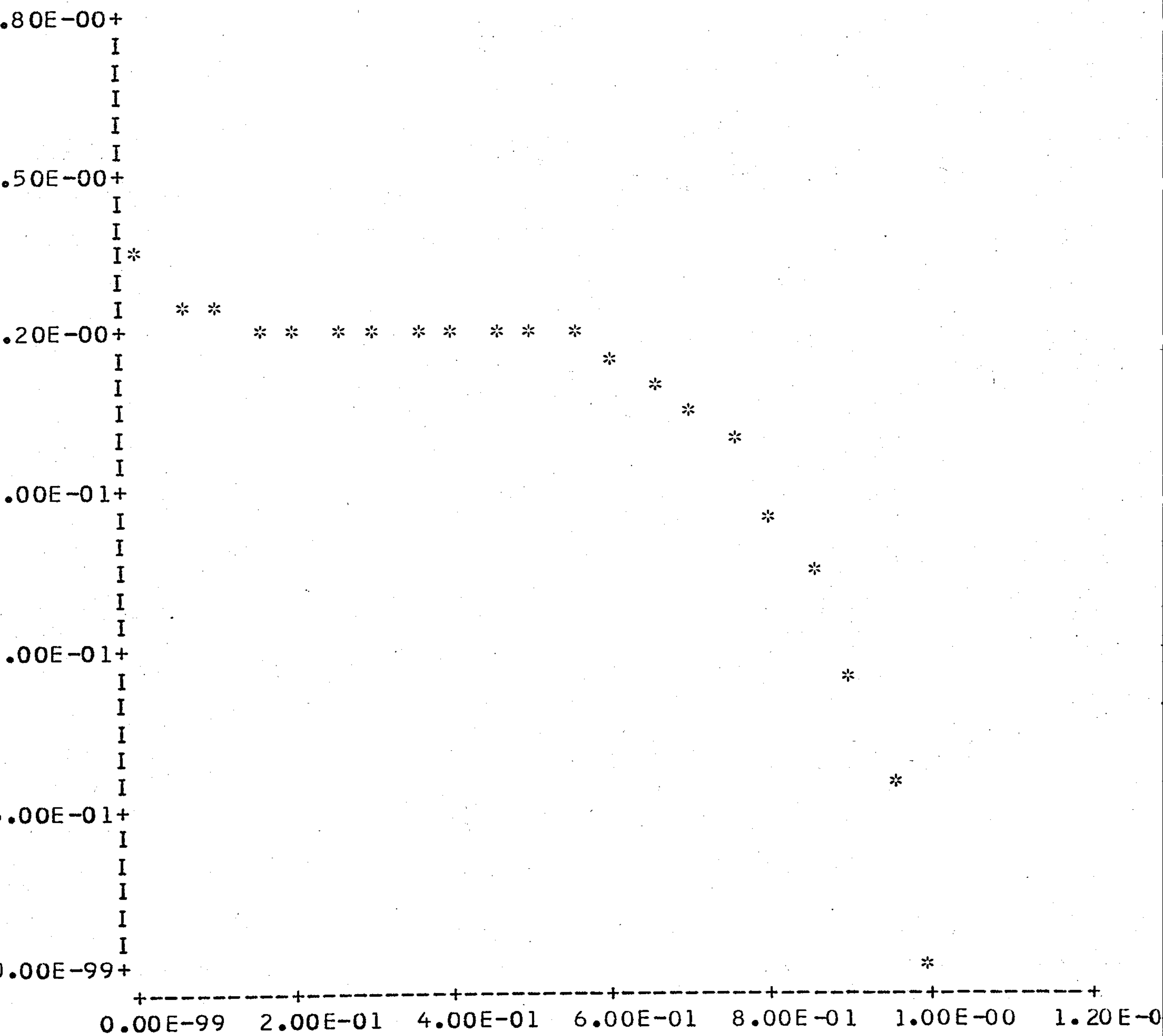
NDTL NUMBER= .500
NOLDS NUMBER= 70000.0



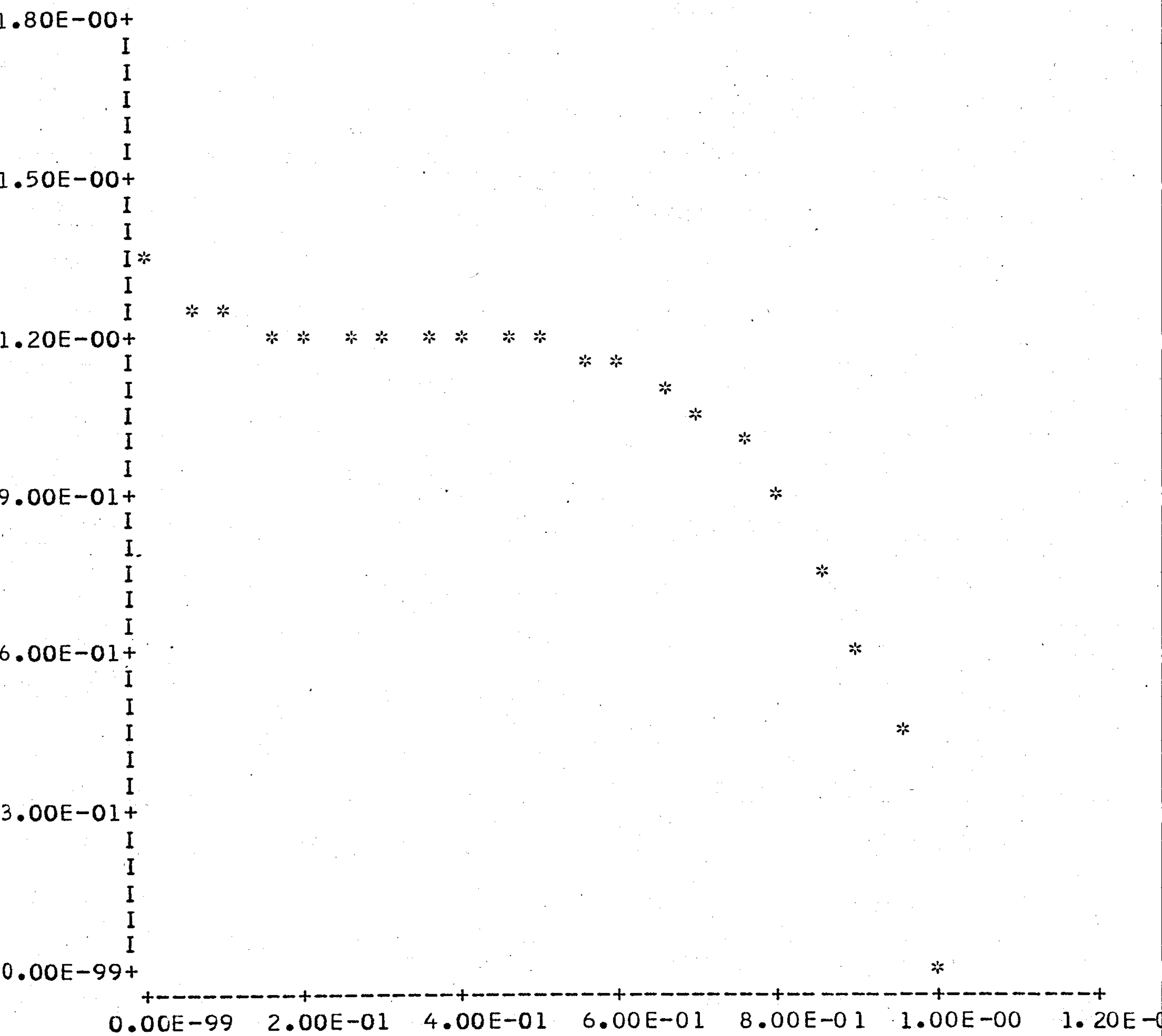
NDTL NUMBER= .500
NOLDS NUMBER= 100000.0



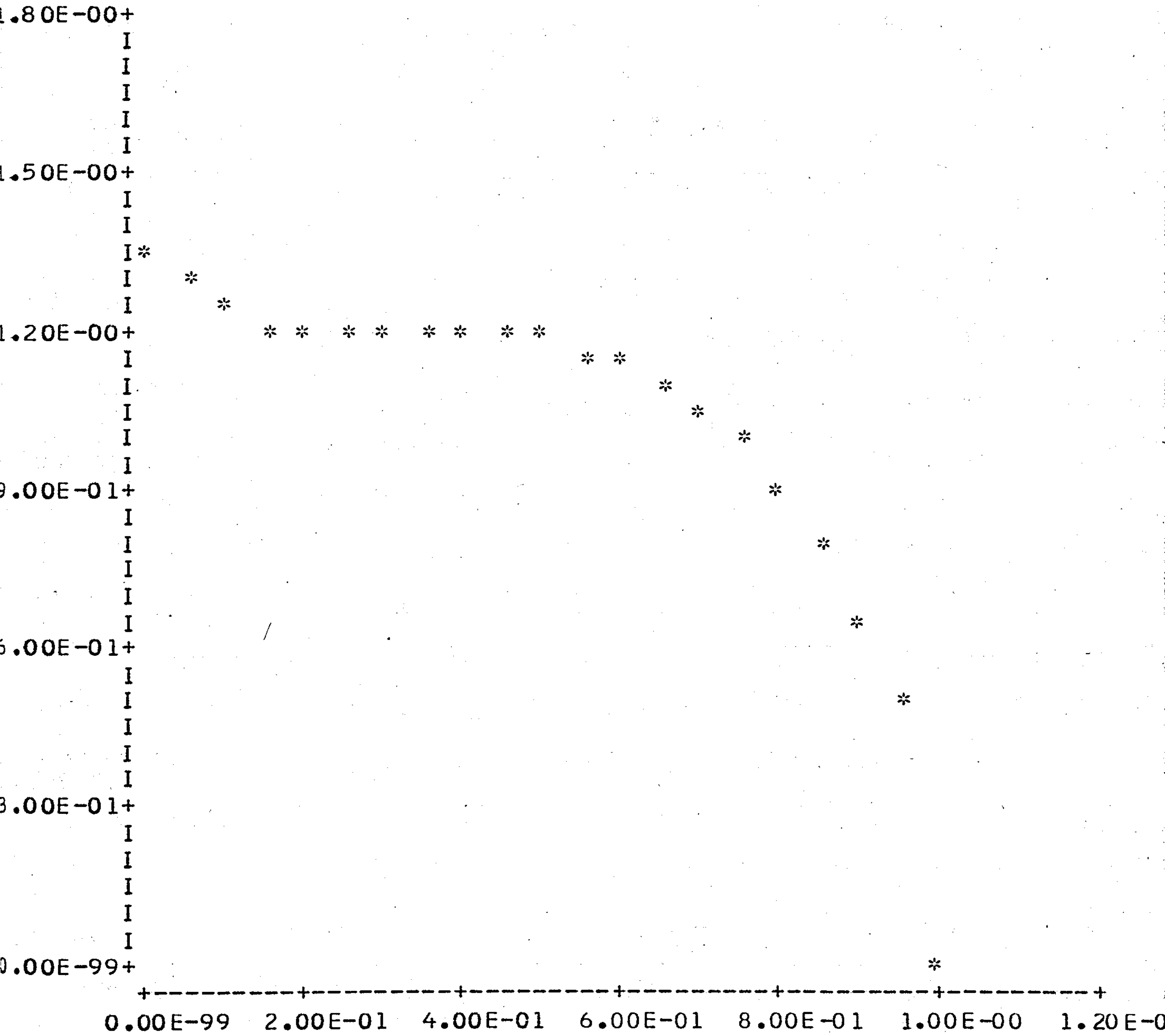
NDTL NUMBER = 1.000
NOLDS NUMBER = 3000.0



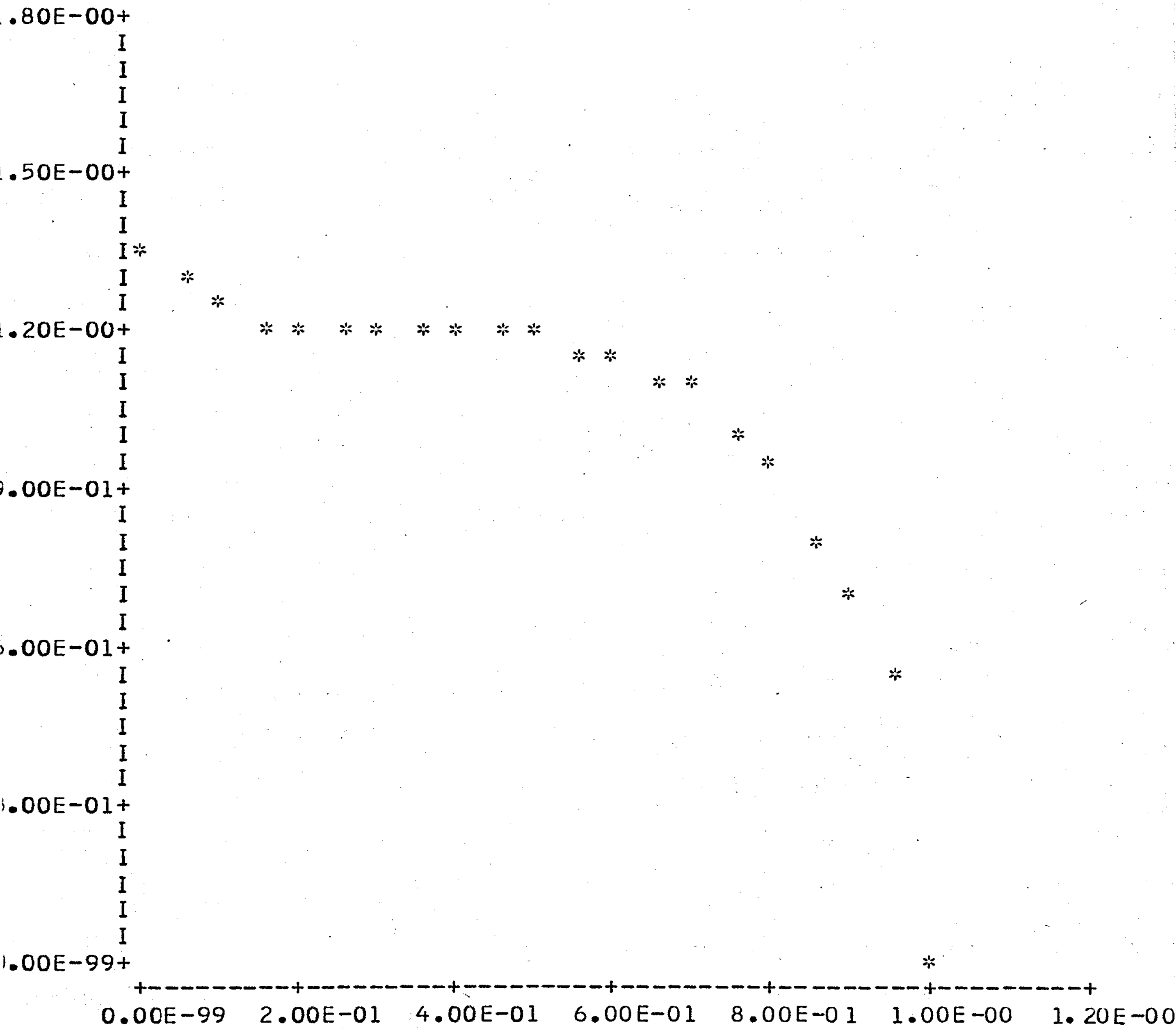
ANDTL NUMBER= 1.000
YNOLDS NUMBER= 8000.0



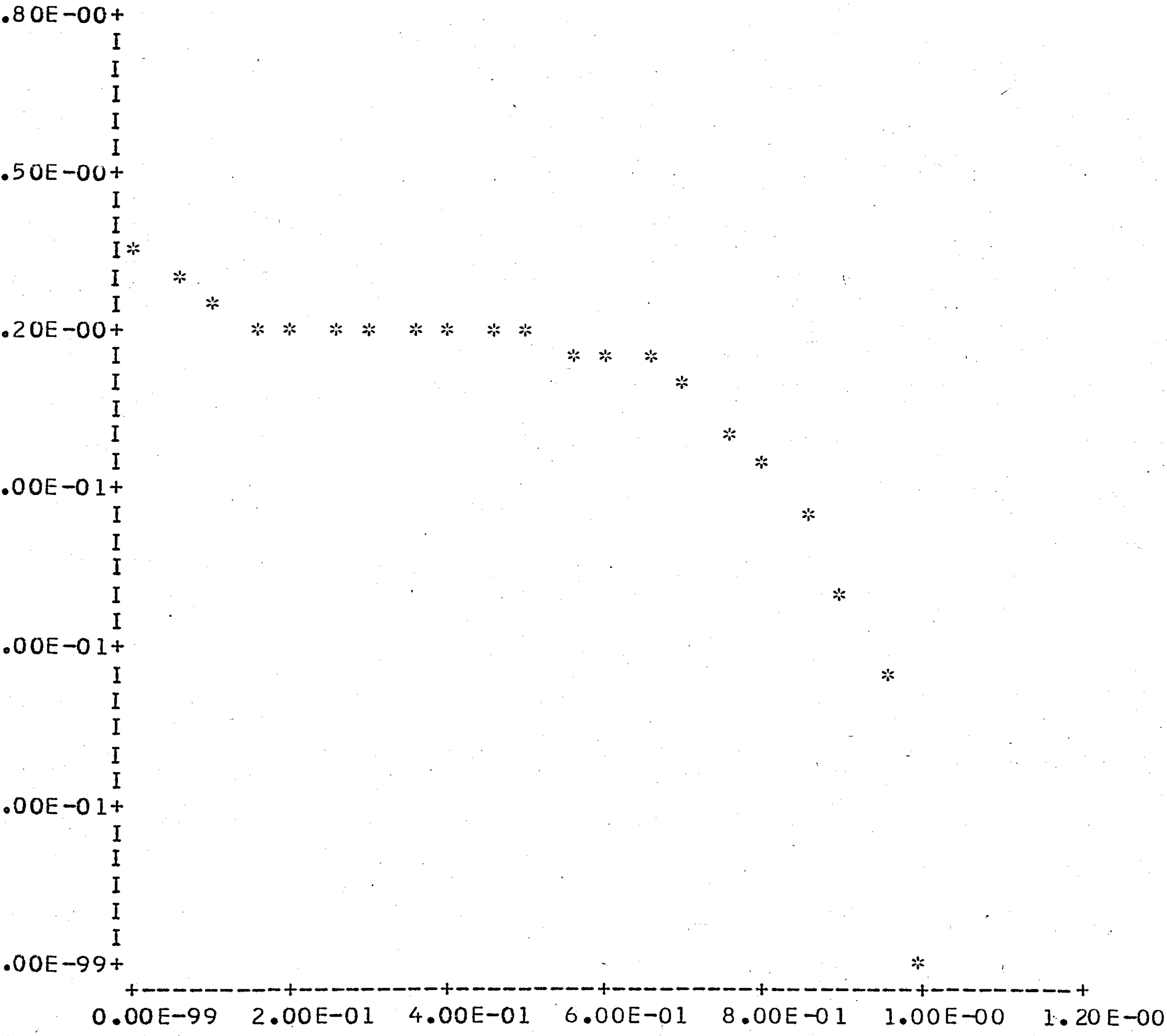
ANDTL NUMBER = 1.000
YNOLDS NUMBER = 10000.0



ANDTL NUMBER= 1.000
YNOLDS NUMBER= 30000.0



NDTL NUMBER = 1.000
NOLDS NUMBER = 50000.0



NDTL NUMBER= 1.000
NOLDS NUMBER= 70000.0

APPENDIX B

COMPUTER OUTPUTS

```
CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
************************************************************

PRANDTL NUMBER=      1.000
REYNOLDS NUMBER=  2000.000
PECLET NUMBER=       2000.0

************************************************************

S=      1.041
N=      9.250

************************************************************

ITERATION  1
A1=   1.33004 B1=  -1.42938 C1=   4.48148 D1=  -4.26217
COEFFICIENTS FROM CURVE FITTING
A2=    .41941 B2=    .03900 C2=   -.77654 D2=    .31698
NUSSELT NUMBER=  3.94706
COEFFICIENTS FROM  1. ITERATION
A3=   1.65546 B3=    .15395 C3=  -3.06506 D3=   1.25114
************************************************************

ITERATION  2
A1=   1.65546 B1=    .15395 C1=  -3.06506 D1=   1.25114
COEFFICIENTS FROM CURVE FITTING
A2=    .45782 B2=    .01508 C2=   -.95185 D2=    .47978
NUSSELT NUMBER=  3.87994
DIFFERENCE=    .06711
COEFFICIENTS FROM  2. ITERATION
A3=   1.77632 B3=    .05852 C3=  -3.69315 D3=   1.86153
************************************************************

ITERATION  3
A1=   1.77632 B1=    .05852 C1=  -3.69315 D1=   1.86153
COEFFICIENTS FROM CURVE FITTING
A2=    .46959 B2=    .00640 C2=   -.98042 D2=    .50561
NUSSELT NUMBER=  3.82776
DIFFERENCE=    .05218
COEFFICIENTS FROM  3. ITERATION
A3=   1.79749 B3=    .02450 C3=  -3.75283 D3=   1.93536
************************************************************

ITERATION  4
A1=   1.79749 B1=    .02450 C1=  -3.75283 D1=   1.93536
COEFFICIENTS FROM CURVE FITTING
A2=    .47140 B2=    .00482 C2=   -.98432 D2=    .50932
NUSSELT NUMBER=  3.82013
DIFFERENCE=    .00762
COEFFICIENTS FROM  4. ITERATION
A3=   1.80084 B3=    .01844 C3=  -3.76024 D3=   1.94569
************************************************************

ITERATION  5
A1=   1.80084 B1=    .01844 C1=  -3.76024 D1=   1.94569
COEFFICIENTS FROM CURVE FITTING
A2=    .47168 B2=    .00457 C2=   -.98489 D2=    .50988
NUSSELT NUMBER=  3.81898
DIFFERENCE=    .00115
```

```
COEFFICIENTS FROM  5. ITERATION
A3=   1.80135 B3=     .01748 C3=  -3.76130 D3=   1.94723
*************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*************************************************************

PRANDTL NUMBER=      1.000
REYNOLDS NUMBER=  3000.000
PECLET NUMBER=        3000.0

*************************************************************

S=      2.860
N=      3.310

*************************************************************

ITERATION  1
A1=   1.33004 B1=  -1.42938 C1=   4.48148 D1=  -4.26217
COEFFICIENTS FROM CURVE FITTING
A2=     .11681 B2=   -.06314 C2=     .24000 D2=    -.29158
NUSSELT NUMBER=  11.00555
COEFFICIENTS FROM 1. ITERATION
A3=   1.28565 B3=    -.69499 C3=   2.64137 D3=  -3.20903
*************************************************************

ITERATION  2
A1=   1.28565 B1=    -.69499 C1=   2.64137 D1=  -3.20903
COEFFICIENTS FROM CURVE FITTING
A2=     .11444 B2=    -.05926 C2=     .22457 D2=    -.27783
NUSSELT NUMBER=  11.28367
DIFFERENCE=      .27811
COEFFICIENTS FROM  2. ITERATION
A3=   1.29140 B3=    -.66872 C3=   2.53406 D3=  -3.13501
*************************************************************

ITERATION  3
A1=   1.29140 B1=    -.66872 C1=   2.53406 D1=  -3.13501
COEFFICIENTS FROM CURVE FITTING
A2=     .11456 B2=    -.05918 C2=     .22411 D2=    -.27757
NUSSELT NUMBER=  11.27649
COEFFICIENTS FROM 3. ITERATION
A3=   1.29191 B3=    -.66742 C3=   2.52724 D3=  -3.13006
*************************************************************

ITERATION 4
A1=   1.29191 B1=    -.66742 C1=   2.52724 D1=  -3.13006
COEFFICIENTS FROM CURVE FITTING
A2=     .11457 B2=    -.05918 C2=     .22408 D2=    -.27755
NUSSELT NUMBER=  11.27598
DIFFERENCE=      .00051
COEFFICIENTS FROM 4. ITERATION
A3=   1.29195 B3=    -.66734 C3=   2.52676 D3=  -3.12971
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
0.000 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
THETA VALUES
1.291 1.247 1.234 1.234 1.228 1.198 1.125 0.989 0.772 0.456 0.021
```

```
***********************************************************************

CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************

PRANDTL NUMBER=       1.000
REYNOLDS NUMBER=  8000.000
PECLET NUMBER=         8000.0

*****************************************************************

S=      6.430
N=      9.000

*****************************************************************

ITERATION  1
A1=   1.33004 B1=  -1.42938 C1=   4.48148 D1=  -4.26217
COEFFICIENTS FROM CURVE FITTING
A2=     .04855 B2=   -.05217 C2=    .16360 D2=   -.15559
NUSSELT NUMBER=  27.39338
COEFFICIENTS FROM 1. ITERATION
A3=   1.33002 B3=  -1.42938 C3=   4.48158 D3=  -4.26226
*****************************************************************

ITERATION  2
A1=   1.33002 B1=  -1.42938 C1=   4.48158 D1=  -4.26226
COEFFICIENTS FROM CURVE FITTING
A2=     .04855 B2=   -.05217 C2=    .16360 D2=   -.15559
NUSSELT NUMBER=  27.39356
COEFFICIENTS FROM  2. ITERATION
A3=   1.33002 B3=  -1.42938 C3=   4.48159 D3=  -4.26226
*********************************************************************

ITERATION 3
A1=   1.33002 B1=  -1.42938 C1=   4.48159 D1=  -4.26226
COEFFICIENTS FROM CURVE FITTING
A2=     .04855 B2=   -.05217 C2=    .16360 D2=   -.15559
NUSSELT NUMBER=  27.39339
DIFFERENCE=     .00016
COEFFICIENTS FROM  3. ITERATION
A3=   1.33002 B3=  -1.42938 C3=   4.48159 D3=  -4.26226
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.330 1.227 1.189 1.189 1.202 1.202 1.165 1.063  .872  .566  .119
*********************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*********************************************************************
PRANDTL NUMBER=       1.000
REYNOLDS NUMBER=         10000.0
PECLET NUMBER=       10000.0

*********************************************************************
```

```
***************************************************************
ITERATION  1
A1=   1.33951 B1=  -1.47226 C1=   4.29457 D1=  -3.94628
COEFFICIENTS FROM CURVE FITTING
A2=    .04061 B2=   -.04491 C2=    .13111 D2=   -.12023
NUSSELT NUMBER=  32.95465
COEFFICIENTS FROM  1. ITERATION
A3=   1.33836 B3=  -1.48029 C3=   4.32073 D3=  -3.96225
***************************************************************
ITERATION  2
A1=   1.33836 B1=  -1.48029 C1=   4.32073 D1=  -3.96225
COEFFICIENTS FROM CURVE FITTING
A2=    .04060 B2=   -.04492 C2=    .13114 D2=   -.12025
NUSSELT NUMBER=  32.95944
DIFFERENCE=     .00479
COEFFICIENTS FROM  2. ITERATION
A3=   1.33817 B3=  -1.48054 C3=   4.32258 D3=  -3.96362
***************************************************************
ITERATION  3
A1=   1.33817 B1=  -1.48054 C1=   4.32258 D1=  -3.96362
COEFFICIENTS FROM CURVE FITTING
A2=    .04059 B2=   -.04492 C2=    .13115 D2=   -.12025
NUSSELT NUMBER=  32.95981
DIFFERENCE=     .00037
COEFFICIENTS FROM  3. ITERATION
A3=   1.33815 B3=  -1.48055 C3=   4.32272 D3=  -3.96374
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.338 1.229 1.183 1.176 1.183 1.183 1.149 1.060  .890  .617  .216
***************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
***************************************************************
PRANDTL NUMBER=       1.000
REYNOLDS NUMBER=        30000.0
PECLET NUMBER=        30000.0

***************************************************************
S=     17.600
N=     26.510

***************************************************************
ITERATION  1
A1=   1.34910 B1=  -1.46043 C1=   4.06912 D1=  -3.64382
COEFFICIENTS FROM CURVE FITTING
A2=    .01692 B2=   -.01832 C2=    .05105 D2=   -.04571
NUSSELT NUMBER=  79.70018
COEFFICIENTS FROM  1. ITERATION
A3=   1.34912 B3=  -1.46042 C3=   4.06898 D3=  -3.64370
***************************************************************
ITERATION  2
A1=   1.34912 B1=  -1.46042 C1=   4.06898 D1=  -3.64370
COEFFICIENTS FROM CURVE FITTING
A2=    .01692 B2=   -.01832 C2=    .05105 D2=   -.04571
NUSSELT NUMBER=  79.69946
DIFFERENCE=     .00072
COEFFICIENTS FROM  2. ITERATION
```

```
A3=   1.34912 B3=  -1.46042 C3=   4.06897 D3=  -3.64369
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.349 1.240 1.190 1.178 1.182 1.180 1.150 1.070  .919  .674  .313
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=      1.000
REYNOLDS NUMBER=       50000.0
PECLET NUMBER=      50000.0

*****************************************************************
S=    26.620
N=    39.910

*****************************************************************
ITERATION  1
A1=   1.34884 B1=  -1.46133 C1=   4.06722 D1=  -3.62154
COEFFICIENTS FROM CURVE FITTING
A2=    .01101 B2=   -.01193 C2=    .03320 D2=   -.02956
NUSSELT NUMBER= 122.47466
COEFFICIENTS FROM  1. ITERATION
A3=   1.34894 B3=  -1.46128 C3=   4.06655 D3=  -3.62102
*****************************************************************
ITERATION  2
A1=   1.34894 B1=  -1.46128 C1=   4.06655 D1=  -3.62102
COEFFICIENTS FROM CURVE FITTING
A2=    .01101 B2=   -.01193 C2=    .03320 D2=   -.02956
NUSSELT NUMBER= 122.47337
DIFFERENCE=      .00129
COEFFICIENTS FROM  2. ITERATION
A3=   1.34895 B3=  -1.46128 C3=   4.06649 D3=  -3.62097
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.348 1.239 1.190 1.178 1.183 1.182 1.153 1.076  .928  .687 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=      1.000
REYNOLDS NUMBER=       70000.0
PECLET NUMBER=      70000.0

*****************************************************************
S=    35.040
N=    52.180

*****************************************************************
ITERATION  1
A1=   1.34573 B1=  -1.47664 C1=   4.13263 D1=  -3.66059
COEFFICIENTS FROM CURVE FITTING
```

```
A2=    .00835 B2=   -.00916 C2=    .02564 D2=   -.02271
NUSSELT NUMBER= 161.13857
COEFFICIENTS FROM  1. ITERATION
A3=   1.34579 B3=  -1.47663 C3=   4.13227 D3=  -3.66030
*****************************************************************
ITERATION  2
A1=   1.34579 B1=  -1.47663 C1=   4.13227 D1=  -3.66030
COEFFICIENTS FROM CURVE FITTING
A2=    .00835 B2=   -.00916 C2=    .02564 D2=   -.02271
NUSSELT NUMBER= 161.13696
DIFFERENCE=     .00161
COEFFICIENTS FROM  2. ITERATION
A3=   1.34579 B3=  -1.47663 C3=   4.13224 D3=  -3.66028
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.345 1.235 1.186 1.175 1.182 1.183 1.156 1.081  .935  .695 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*************************************************************

PRANDTL NUMBER=        .500
REYNOLDS NUMBER=         3000.0
PECLET NUMBER=         1500.0

*************************************************************

S=       2.860
N=       3.310

*************************************************************

ITERATION  1
A1=   1.29195 B1=   -.66734 C1=   2.52676 D1=  -3.12971
COEFFICIENTS FROM CURVE FITTING
A2=    .15457 B2=   -.04238 C2=    .15602 D2=   -.26813
NUSSELT NUMBER=   8.74694
COEFFICIENTS FROM  1. ITERATION
A3=   1.35201 B3=   -.37072 C3=   1.36470 D3=  -2.34531
*************************************************************

ITERATION  2
A1=   1.35201 B1=   -.37072 C1=   1.36470 D1=  -2.34531
COEFFICIENTS FROM CURVE FITTING
A2=    .15680 B2=   -.04091 C2=    .14684 D2=   -.26270
NUSSELT NUMBER=   8.66946
DIFFERENCE=     .07748
COEFFICIENTS FROM  2. ITERATION
A3=   1.35938 B3=   -.35468 C3=   1.27303 D3=  -2.27753
*************************************************************

ITERATION  3
A1=   1.35938 B1=   -.35468 C1=   1.27303 D1=  -2.27753
COEFFICIENTS FROM CURVE FITTING
A2=    .15699 B2=   -.04080 C2=    .14605 D2=   -.26222
NUSSELT NUMBER=   8.66332
DIFFERENCE=     .00613
```

```
COEFFICIENTS FROM  3. ITERATION
A3=   1.36008 B3=   -.35352 C3=   1.26534 D3=  -2.27172
*************************************************************

ITERATION  4
A1=   1.36008 B1=   -.35352 C1=   1.26534 D1=  -2.27172
COEFFICIENTS FROM CURVE FITTING
A2=    .15700 B2=   -.04079 C2=    .14598 D2=   -.26218
NUSSELT NUMBER=   8.66279
DIFFERENCE=     .00053
COEFFICIENTS FROM  4. ITERATION
A3=   1.36014 B3=   -.35343 C3=   1.26467 D3=  -2.27121
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
0.000 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
THETA VALUES
1.360 1.335 1.321 1.306 1.275 1.215 1.112 0.953 0.723 0.410 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************

PRANDTL NUMBER=         .500
REYNOLDS NUMBER=          8000.0
PECLET NUMBER=          4000.0

*****************************************************************

S=      6.430
N=      9.000

*****************************************************************

ITERATION  1
A1=   1.33002 B1=  -1.42938 C1=   4.48159 D1=  -4.26226
COEFFICIENTS FROM CURVE FITTING
A2=    .07129 B2=   -.06085 C2=    .17813 D2=   -.18390
NUSSELT NUMBER=  19.60097
COEFFICIENTS FROM  1. ITERATION
A3=   1.39743 B3=  -1.19273 C3=   3.49160 D3=  -3.60480
*****************************************************************

ITERATION  2
A1=   1.39743 B1=  -1.19273 C1=   3.49160 D1=  -3.60480
COEFFICIENTS FROM CURVE FITTING
A2=    .07236 B2=   -.06086 C2=    .17497 D2=   -.18179
NUSSELT NUMBER=  19.45348
DIFFERENCE=     .14748
COEFFICIENTS FROM  2. ITERATION
A3=   1.40774 B3=  -1.18411 C3=   3.40384 D3=  -3.53647
*****************************************************************

ITERATION  3
A1=   1.40774 B1=  -1.18411 C1=   3.40384 D1=  -3.53647
COEFFICIENTS FROM CURVE FITTING
A2=    .07247 B2=   -.06089 C2=    .17466 D2=   -.18156
NUSSELT NUMBER=  19.44082
DIFFERENCE=     .01266
COEFFICIENTS FROM  3. ITERATION
```

```
A3=   1.40891 B3=  -1.18379 C3=   3.39557 D3=  -3.52972
*****************************************************************

ITERATION  4
A1=   1.40891 B1=  -1.18379 C1=   3.39557 D1=  -3.52972
COEFFICIENTS FROM CURVE FITTING
A2=    .07248 B2=   -.06089 C2=    .17463 D2=   -.18153
NUSSELT NUMBER=  19.43952
DIFFERENCE=     .00129
COEFFICIENTS FROM  4. ITERATION
A3=   1.40904 B3=  -1.18378 C3=   3.39473 D3=  -3.52902
*****************************************************************
ITERATION  5
A1=   1.40904 B1=  -1.18378 C1=   3.39473 D1=  -3.52902
COEFFICIENTS FROM CURVE FITTING
A2=    .07248 B2=   -.06089 C2=    .17462 D2=   -.18153
NUSSELT NUMBER=  19.43939
DIFFERENCE=     .00013
COEFFICIENTS FROM  5. ITERATION
A3=   1.40905 B3=  -1.18377 C3=   3.39464 D3=  -3.52895
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.409 1.321 1.279 1.264 1.252 1.224 1.158 1.033  .827  .520  .090
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=        .500
REYNOLDS NUMBER=        10000.0
PECLET NUMBER=         5000.0

*****************************************************************
S=      7.560
N=     10.930

*****************************************************************
ITERATION  1
A1=   1.42852 B1=  -1.21152 C1=   3.36349 D1=  -3.47713
COEFFICIENTS FROM CURVE FITTING
A2=    .06312 B2=   -.05669 C2=    .15159 D2=   -.15076
NUSSELT NUMBER=  22.48643
COEFFICIENTS FROM  1. ITERATION
A3=   1.41949 B3=  -1.27481 C3=   3.40872 D3=  -3.39026
*****************************************************************
ITERATION  2
A1=   1.41949 B1=  -1.27481 C1=   3.40872 D1=  -3.39026
COEFFICIENTS FROM CURVE FITTING
A2=    .06272 B2=   -.05681 C2=    .15254 D2=   -.15119
NUSSELT NUMBER=  22.58911
DIFFERENCE=     .10268
COEFFICIENTS FROM  2. ITERATION
A3=   1.41691 B3=  -1.28336 C3=   3.44577 D3=  -3.41532
*****************************************************************
ITERATION  3
A1=   1.41691 B1=  -1.28336 C1=   3.44577 D1=  -3.41532
COEFFICIENTS FROM CURVE FITTING
A2=    .06269 B2=   -.05681 C2=    .15264 D2=   -.15126
```

```
NUSSELT NUMBER=  22.59501
DIFFERENCE=     .00590
COEFFICIENTS FROM  3. ITERATION
A3=   1.41651 B3=  -1.28366 C3=   3.44906 D3=  -3.41787
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.416 1.319 1.270 1.249 1.236 1.209 1.149 1.035  .847  .563 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=          .500
REYNOLDS NUMBER=          30000.0
PECLET NUMBER=          15000.0

*****************************************************************
S=     17.600
N=     26.510

*****************************************************************
ITERATION  1
A1=   1.42961 B1=  -1.27762 C1=   3.21529 D1=  -3.09880
COEFFICIENTS FROM CURVE FITTING
A2=    .02697 B2=   -.02412 C2=    .06078 D2=   -.05855
NUSSELT NUMBER=  52.98217
COEFFICIENTS FROM  1. ITERATION
A3=   1.42907 B3=  -1.27834 C3=   3.22028 D3=  -3.10243
*****************************************************************
ITERATION  2
A1=   1.42907 B1=  -1.27834 C1=   3.22028 D1=  -3.10243
COEFFICIENTS FROM CURVE FITTING
A2=    .02697 B2=   -.02412 C2=    .06078 D2=   -.05856
NUSSELT NUMBER=  52.98402
DIFFERENCE=     .00185
COEFFICIENTS FROM  2. ITERATION
A3=   1.42900 B3=  -1.27837 C3=   3.22081 D3=  -3.10284
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.426 1.327 1.274 1.249 1.231 1.204 1.148 1.045  .876  .622 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=          .500
REYNOLDS NUMBER=          50000.0
PECLET NUMBER=          25000.0

*****************************************************************
S=     26.620
N=     39.910

*****************************************************************
```

```
ITERATION  1
A1=   1.42692 B1=  -1.27683 C1=   3.21805 D1=  -3.07702
COEFFICIENTS FROM CURVE FITTING
A2=    .01759 B2=   -.01573 C2=    .03956 D2=   -.03783
NUSSELT NUMBER=  81.16468
COEFFICIENTS FROM  1. ITERATION
A3=   1.42818 B3=  -1.27701 C3=   3.21094 D3=  -3.07107
*************************************************************
ITERATION  2
A1=   1.42818 B1=  -1.27701 C1=   3.21094 D1=  -3.07107
COEFFICIENTS FROM CURVE FITTING
A2=    .01759 B2=   -.01573 C2=    .03955 D2=   -.03783
NUSSELT NUMBER=  81.15917
DIFFERENCE=     .00550
COEFFICIENTS FROM  2. ITERATION
A3=   1.42832 B3=  -1.27699 C3=   3.21005 D3=  -3.07035
*************************************************************
ITERATION  3
A1=   1.42832 B1=  -1.27699 C1=   3.21005 D1=  -3.07035
COEFFICIENTS FROM CURVE FITTING
A2=    .01759 B2=   -.01573 C2=    .03955 D2=   -.03783
NUSSELT NUMBER=  81.15857
DIFFERENCE=     .00059
COEFFICIENTS FROM  3. ITERATION
A3=   1.42833 B3=  -1.27699 C3=   3.20995 D3=  -3.07027
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.428 1.329 1.276 1.251 1.234 1.208 1.154 1.054  .889  .640  .291
*************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*************************************************************
PRANDTL NUMBER=         .500
REYNOLDS NUMBER=         70000.0
PECLET NUMBER=         35000.0

*************************************************************
S=    35.040
N=    52.180

*************************************************************
ITERATION  1
A1=   1.41093 B1=  -1.28748 C1=   3.34873 D1=  -3.17134
COEFFICIENTS FROM CURVE FITTING
A2=    .01335 B2=   -.01218 C2=    .03107 D2=   -.02940
NUSSELT NUMBER= 106.39691
COEFFICIENTS FROM  1. ITERATION
A3=   1.42116 B3=  -1.29651 C3=   3.30611 D3=  -3.12910
*************************************************************
ITERATION  2
A1=   1.42116 B1=  -1.29651 C1=   3.30611 D1=  -3.12910
COEFFICIENTS FROM CURVE FITTING
A2=    .01337 B2=   -.01219 C2=    .03103 D2=   -.02937
NUSSELT NUMBER= 106.36012
DIFFERENCE=     .03679
COEFFICIENTS FROM  2. ITERATION
A3=   1.42215 B3=  -1.29677 C3=   3.30076 D3=  -3.12456
```

```
*****************************************************************
ITERATION  3
A1=   1.42215 B1=  -1.29677 C1=   3.30076 D1=  -3.12456
COEFFICIENTS FROM CURVE FITTING
A2=    .01337 B2=   -.01219 C2=    .03102 D2=   -.02937
NUSSELT NUMBER= 106.35524
DIFFERENCE=    .00488
COEFFICIENTS FROM  3. ITERATION
A3=   1.42226 B3=  -1.29675 C3=   3.30009 D3=  -3.12401
*****************************************************************
ITERATION  4
A1=   1.42226 B1=  -1.29675 C1=   3.30009 D1=  -3.12401
COEFFICIENTS FROM CURVE FITTING
A2=    .01337 B2=   -.01219 C2=    .03102 D2=   -.02937
NUSSELT NUMBER= 106.35467
DIFFERENCE=    .00057
COEFFICIENTS FROM  4. ITERATION
A3=   1.42227 B3=  -1.29675 C3=   3.30001 D3=  -3.12395
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.422 1.322 1.269 1.245 1.231 1.208 1.157 1.060  .897  .650  .301
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=        .500
REYNOLDS NUMBER=     100000.0
PECLET NUMBER=       50000.0

*****************************************************************
S=     46.970
N=     69.270

*****************************************************************
ITERATION  1
A1=   1.42047 B1=  -1.31312 C1=   3.36792 D1=  -3.16811
COEFFICIENTS FROM CURVE FITTING
A2=    .00987 B2=   -.00913 C2=    .02347 D2=   -.02207
NUSSELT NUMBER= 143.80785
COEFFICIENTS FROM  1. ITERATION
A3=   1.41950 B3=  -1.31412 C3=   3.37610 D3=  -3.17417
*****************************************************************
ITERATION  2
A1=   1.41950 B1=  -1.31412 C1=   3.37610 D1=  -3.17417
COEFFICIENTS FROM CURVE FITTING
A2=    .00986 B2=   -.00913 C2=    .02348 D2=   -.02207
NUSSELT NUMBER= 143.81682
DIFFERENCE=    .00897
COEFFICIENTS FROM  2. ITERATION
A3=   1.41938 B3=  -1.31417 C3=   3.37696 D3=  -3.17484
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.419 1.318 1.266 1.243 1.230 1.209 1.160 1.065  .903  .657 0.000
*****************************************************************
```

```
CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************

PRANDTL NUMBER=        .100
REYNOLDS NUMBER=         3000.0
PECLET NUMBER=          300.0

*****************************************************************

S=      2.860
N=      3.310

*****************************************************************

ITERATION  1
A1=   1.36014 B1=    -.35343 C1=   1.26467 D1=  -2.27121
COEFFICIENTS FROM CURVE FITTING
A2=      .26410 B2=     .02652 C2=    -.23683 D2=    -.05676
NUSSELT NUMBER=   5.89547
COEFFICIENTS FROM  1. ITERATION
A3=   1.55703 B3=     .15635 C3=  -1.39626 D3=    -.33463
*****************************************************************

ITERATION  2
A1=   1.55703 B1=     .15635 C1=  -1.39626 D1=    -.33463
COEFFICIENTS FROM CURVE FITTING
A2=      .27789 B2=     .03089 C2=    -.29394 D2=    -.01776
NUSSELT NUMBER=   5.72806
DIFFERENCE=     .16741
COEFFICIENTS FROM  2. ITERATION
A3=   1.59180 B3=     .17695 C3=  -1.68375 D3=    -.10175
*****************************************************************

ITERATION  3
A1=   1.59180 B1=     .17695 C1=  -1.68375 D1=    -.10175
COEFFICIENTS FROM CURVE FITTING
A2=      .27974 B2=     .03117 C2=    -.30115 D2=    -.01267
NUSSELT NUMBER=   5.70763
DIFFERENCE=     .02043
COEFFICIENTS FROM  3. ITERATION
A3=   1.59668 B3=     .17791 C3=  -1.71886 D3=    -.07234
*****************************************************************

ITERATION  4
A1=   1.59668 B1=     .17791 C1=  -1.71886 D1=    -.07234
COEFFICIENTS FROM CURVE FITTING
A2=      .27999 B2=     .03119 C2=    -.30209 D2=    -.01200
NUSSELT NUMBER=   5.70496
DIFFERENCE=     .00266
COEFFICIENTS FROM  4. ITERATION
A3=   1.59734 B3=     .17798 C3=  -1.72342 D3=    -.06849
*****************************************************************

ITERATION  5
A1=   1.59734 B1=     .17798 C1=  -1.72342 D1=    -.06849
COEFFICIENTS FROM CURVE FITTING
A2=      .28002 B2=     .03120 C2=    -.30221 D2=    -.01191
NUSSELT NUMBER=   5.70461
DIFFERENCE=     .00035
```

```
COEFFICIENTS FROM  5. ITERATION
A3=   1.59743 B3=    .17799 C3=  -1.72402 D3=    -.06799
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.597 1.597 1.563 1.493 1.388 1.246 1.068  .853  .601  .311 -.016
****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
****************************************************************

PRANDTL NUMBER=        .100
REYNOLDS NUMBER=        8000.0
PECLET NUMBER=         800.0

****************************************************************

S=       6.430
N=       9.000

****************************************************************

ITERATION  1
A1=   1.40905 B1=  -1.18377 C1=   3.39464 D1=  -3.52895
COEFFICIENTS FROM CURVE FITTING
A2=    .16757 B2=   -.05820 C2=    .06005 D2=    -.16596
NUSSELT NUMBER=   9.61300
COEFFICIENTS FROM  1. ITERATION
A3=   1.61087 B3=   -.55949 C3=    .57732 D3=  -1.59544
****************************************************************

ITERATION  2
A1=   1.61087 B1=   -.55949 C1=    .57732 D1=  -1.59544
COEFFICIENTS FROM CURVE FITTING
A2=    .17775 B2=   -.05811 C2=    .02565 D2=    -.14173
NUSSELT NUMBER=   9.31805
DIFFERENCE=    .29494
COEFFICIENTS FROM  2. ITERATION
A3=   1.65629 B3=   -.54149 C3=    .23909 D3=  -1.32072
****************************************************************

ITERATION  3
A1=   1.65629 B1=   -.54149 C1=    .23909 D1=  -1.32072
COEFFICIENTS FROM CURVE FITTING
A2=    .17928 B2=   -.05848 C2=    .02092 D2=    -.13813
NUSSELT NUMBER=   9.28042
DIFFERENCE=    .03763
COEFFICIENTS FROM  3. ITERATION
A3=   1.66386 B3=   -.54279 C3=    .19415 D3=  -1.28195
****************************************************************

ITERATION  4
A1=   1.66386 B1=   -.54279 C1=    .19415 D1=  -1.28195
COEFFICIENTS FROM CURVE FITTING
A2=    .17952 B2=   -.05856 C2=    .02022 D2=    -.13759
NUSSELT NUMBER=   9.27483
DIFFERENCE=    .00558
COEFFICIENTS FROM  4. ITERATION
```

```
A3=   1.66504 B3=   -.54314 C3=    .18755 D3=  -1.27616
****************************************************************
ITERATION  5
A1=   1.66504 B1=   -.54314 C1=    .18755 D1=  -1.27616
COEFFICIENTS FROM CURVE FITTING
A2=    .17955 B2=   -.05857 C2=    .02011 D2=   -.13751
NUSSELT NUMBER=   9.27398
DIFFERENCE=     .00084
COEFFICIENTS FROM  5. ITERATION
A3=   1.66522 B3=   -.54320 C3=    .18655 D3=  -1.27528
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.665 1.611 1.553 1.484 1.396 1.280 1.131  .938  .697  .397  .033
****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
****************************************************************

PRANDTL NUMBER=        .100
REYNOLDS NUMBER=        10000.0
PECLET NUMBER =        1000.0

****************************************************************

S=     7.560
N=    10.930

****************************************************************

ITERATION  1
A1=   1.42854 B1=  -1.21151 C1=   3.36337 D1=  -3.47704
COEFFICIENTS FROM CURVE FITTING
A2=    .15203 B2=   -.05542 C2=    .05378 D2=   -.14631
NUSSELT NUMBER=  10.72525
COEFFICIENTS FROM  1. ITERATION
A3=   1.63059 B3=   -.59447 C3=    .57689 D3=  -1.56930
****************************************************************

ITERATION  2
A1=   1.63059 B1=   -.59447 C1=    .57689 D1=  -1.56930
COEFFICIENTS FROM CURVE FITTING
A2=    .16138 B2=   -.05542 C2=    .02219 D2=   -.12396
NUSSELT NUMBER=  10.39243
DIFFERENCE=     .33281
COEFFICIENTS FROM  2. ITERATION
A3=   1.67717 B3=   -.57598 C3=    .23066 D3=  -1.28832
****************************************************************

ITERATION  3
A1=   1.67717 B1=   -.57598 C1=    .23066 D1=  -1.28832
COEFFICIENTS FROM CURVE FITTING
A2=    .16283 B2=   -.05579 C2=    .01772 D2=   -.12055
NUSSELT NUMBER=  10.34903
DIFFERENCE=     .04340
COEFFICIENTS FROM  3. ITERATION
A3=   1.68514 B3=   -.57737 C3=    .18347 D3=  -1.24762
****************************************************************
```

```
ITERATION  4
A1=   1.68514 B1=   -.57737 C1=     .18347 D1=  -1.24762
COEFFICIENTS FROM CURVE FITTING
A2=    .16305 B2=   -.05586 C2=     .01705 D2=   -.12002
NUSSELT NUMBER=  10.34242
DIFFERENCE=     .00661
COEFFICIENTS FROM  4. ITERATION
A3=   1.68642 B3=   -.57775 C3=     .17636 D3=  -1.24139
******************************************************************

ITERATION  5
A1=   1.68642 B1=   -.57775 C1=     .17636 D1=  -1.24139
COEFFICIENTS FROM CURVE FITTING
A2=    .16309 B2=   -.05587 C2=     .01694 D2=   -.11994
NUSSELT NUMBER=  10.34139
DIFFERENCE=     .00103
COEFFICIENTS FROM  5. ITERATION
A3=   1.68662 B3=   -.57781 C3=     .17525 D3=  -1.24041
******************************************************************

ITERATION  6
A1=   1.68662 B1=   -.57781 C1=     .17525 D1=  -1.24041
COEFFICIENTS FROM CURVE FITTING
A2=    .16310 B2=   -.05587 C2=     .01693 D2=   -.11993
NUSSELT NUMBER=  10.34122
DIFFERENCE=     .00016
COEFFICIENTS FROM  6. ITERATION
A3=   1.68665 B3=   -.57783 C3=     .17508 D3=  -1.24026
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.686 1.629 1.568 1.495 1.404 1.286 1.135  .942  .701  .404  .043
******************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
******************************************************************
PRANDTL NUMBER=         .100
REYNOLDS NUMBER=       30000.0
PECLET NUMBER=         3000.0

******************************************************************
S=     17.600
N=     26.510

******************************************************************
ITERATION  1
A1=   1.70922 B1=   -.69410 C1=     .30331 D1=  -1.18216
COEFFICIENTS FROM CURVE FITTING
A2=    .08358 B2=   -.03399 C2=     .01545 D2=   -.05837
NUSSELT NUMBER=  20.42563
COEFFICIENTS FROM  1. ITERATION
A3=   1.70736 B3=   -.69438 C3=     .31561 D3=  -1.19225
******************************************************************
ITERATION  2
A1=   1.70736 B1=   -.69438 C1=     .31561 D1=  -1.19225
COEFFICIENTS FROM CURVE FITTING
```

```
A2=     .08356 B2=    -.03398 C2=      .01554 D2=    -.05843
NUSSELT NUMBER=  20.42874
DIFFERENCE=      .00311
COEFFICIENTS FROM  2. ITERATION
A3=   1.70704 B3=    -.69433 C3=      .31746 D3=  -1.19383
*****************************************************************
ITERATION  3
A1=   1.70704 B1=    -.69433 C1=      .31746 D1=  -1.19383
COEFFICIENTS FROM CURVE FITTING
A2=     .08355 B2=    -.03398 C2=      .01555 D2=    -.05844
NUSSELT NUMBER=  20.42926
DIFFERENCE=      .00051
COEFFICIENTS FROM  3. ITERATION
A3=   1.70699 B3=    -.69432 C3=      .31776 D3=  -1.19408
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.706 1.639 1.571 1.495 1.403 1.290 1.146  .967  .743  .469  .136
*****************************************************************


PRANDTL NUMBER=        .100
REYNOLDS NUMBER=        50000.0
PECLET NUMBER=         5000.0

*****************************************************************

S=     26.620
N=     39.910

*****************************************************************

ITERATION  1
A1=   1.68665 B1=    -.57783 C1=      .17508 D1=  -1.24026
COEFFICIENTS FROM CURVE FITTING
A2=     .05758 B2=    -.02626 C2=      .02642 D2=    -.05483
NUSSELT NUMBER=  29.70042
COEFFICIENTS FROM  1. ITERATION
A3=   1.71025 B3=    -.78007 C3=      .78491 D3=  -1.62857
*****************************************************************

ITERATION  2
A1=   1.71025 B1=    -.78007 C1=      .78491 D1=  -1.62857
COEFFICIENTS FROM CURVE FITTING
A2=     .05890 B2=    -.02748 C2=      .03064 D2=    -.05904
NUSSELT NUMBER=  28.85461
DIFFERENCE=      .84580
COEFFICIENTS FROM  2. ITERATION
A3=   1.69967 B3=    -.79293 C3=      .88423 D3=  -1.70380
*****************************************************************

ITERATION  3
A1=   1.69967 B1=    -.79293 C1=      .88423 D1=  -1.70380
COEFFICIENTS FROM CURVE FITTING
A2=     .05877 B2=    -.02746 C2=      .03107 D2=    -.05936
NUSSELT NUMBER=  28.88329
DIFFERENCE=      .02867
COEFFICIENTS FROM  3. ITERATION
A3=   1.69769 B3=    -.79325 C3=      .89751 D3=  -1.71474
*****************************************************************
```

```
ITERATION  4
A1=   1.69769 B1=   -.79325 C1=     .89751 D1=  -1.71474
COEFFICIENTS FROM CURVE FITTING
A2=    .05875 B2=   -.02745 C2=     .03113 D2=   -.05941
NUSSELT NUMBER=  28.88770
DIFFERENCE=     .00440
COEFFICIENTS FROM  4. ITERATION
A3=   1.69735 B3=   -.79322 C3=     .89953 D3=  -1.71645
******************************************************************
ITERATION  5
A1=   1.69735 B1=   -.79322 C1=     .89953 D1=  -1.71645
COEFFICIENTS FROM CURVE FITTING
A2=    .05875 B2=   -.02745 C2=     .03114 D2=   -.05942
NUSSELT NUMBER=  28.88841
DIFFERENCE=     .00070
COEFFICIENTS FROM  5. ITERATION
A3=   1.69730 B3=   -.79322 C3=     .89985 D3=  -1.71672
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.697 1.625 1.560 1.493 1.414 1.311 1.174  .994  .759  .460  .087
******************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
******************************************************************
PRANDTL NUMBER=        .100
REYNOLDS NUMBER=        70000.0
PECLET NUMBER=         7000.0

******************************************************************
S=     35.040
N=     52.180

******************************************************************
ITERATION  1
A1=   1.69357 B1=   -.72457 C1=     .47235 D1=  -1.26445
COEFFICIENTS FROM CURVE FITTING
A2=    .04393 B2=   -.01879 C2=     .01227 D2=   -.03282
NUSSELT NUMBER=  38.54191
COEFFICIENTS FROM  1. ITERATION
A3=   1.69348 B3=   -.72458 C3=     .47300 D3=  -1.26497
******************************************************************
ITERATION  2
A1=   1.69348 B1=   -.72458 C1=     .47300 D1=  -1.26497
COEFFICIENTS FROM CURVE FITTING
A2=    .04393 B2=   -.01880 C2=     .01227 D2=   -.03282
NUSSELT NUMBER=  38.54174
DIFFERENCE=     .00017
COEFFICIENTS FROM  2. ITERATION
A3=   1.69346 B3=   -.72458 C3=     .47313 D3=  -1.26508
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.693 1.624 1.557 1.484 1.398 1.291 1.155  .984  .768  .502  .176
******************************************************************
```

```
CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
******************************************************************
PRANDTL NUMBER=        .100
REYNOLDS NUMBER=     100000.0
PECLET NUMBER=       10000.0

******************************************************************
S=    46.970
N=    69.270

******************************************************************
ITERATION  1
A1=   1.68237 B1=   -.76146 C1=    .64393 D1=  -1.37660
COEFFICIENTS FROM CURVE FITTING
A2=    .03305 B2=   -.01499 C2=    .01299 D2=   -.02735
NUSSELT NUMBER=  50.82581
COEFFICIENTS FROM  1. ITERATION
   1.67988   -.76211    .66073  -1.39010
******************************************************************
ITERATION  2
A1=   1.67988 B1=   -.76211 C1=    .66073 D1=  -1.39010
COEFFICIENTS FROM CURVE FITTING
A2=    .03303 B2=   -.01499 C2=    .01304 D2=   -.02738
NUSSELT NUMBER=  50.83603
DIFFERENCE=    .01021
COEFFICIENTS FROM  2. ITERATION
   1.67946   -.76209    .66326  -1.39221
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.679 1.608 1.542 1.472 1.391 1.290 1.160  .993  .781  .515 0.000
******************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
******************************************************************
PRANDTL NUMBER=        .100
REYNOLDS NUMBER=     300000.0
PECLET NUMBER=       30000.0

******************************************************************
S=   116.400
N=   165.120

******************************************************************
ITERATION  1
A1=   1.71079 B1=   -.70027 C1=    .34591 D1=  -1.18143
COEFFICIENTS FROM CURVE FITTING
A2=    .01237 B2=   -.00544 C2=    .00412 D2=   -.00969
NUSSELT NUMBER= 137.90175
COEFFICIENTS FROM  1. ITERATION
   1.70611   -.75071    .56853  -1.33691
******************************************************************
ITERATION  2
A1=   1.70611 B1=   -.75071 C1=    .56853 D1=  -1.33691
COEFFICIENTS FROM CURVE FITTING
```

```
A2=    .01242 B2=    -.00550 C2=     .00441 D2=    -.00996
NUSSELT NUMBER= 136.91001
DIFFERENCE=    .99174
COEFFICIENTS FROM  2. ITERATION
   1.70142   -.75365    .60417  -1.36447
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.701 1.630 1.563 1.492 1.409 1.305 1.172 1.001  .786  .517 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************

PRANDTL NUMBER=         .050
REYNOLDS NUMBER=          3000.0
PECLET NUMBER=          150.0
*****************************************************************

S=      2.860
N=      3.310

*****************************************************************

ITERATION  1
A1=   1.59743 B1=    .17799 C1=  -1.72402 D1=    -.06799
COEFFICIENTS FROM CURVE FITTING
A2=    .32434 B2=    .04640 C2=   -.48174 D2=     .10823
NUSSELT NUMBER=   5.20776
COEFFICIENTS FROM  1. ITERATION
A3=   1.68911 B3=    .24168 C3=  -2.50879 D3=     .56366
*****************************************************************

ITERATION  2
A1=   1.68911 B1=    .24168 C1=  -2.50879 D1=     .56366
COEFFICIENTS FROM CURVE FITTING
A2=    .33074 B2=    .04648 C2=   -.50558 D2=     .12569
NUSSELT NUMBER=   5.15352
DIFFERENCE=    .05424
COEFFICIENTS FROM  2. ITERATION
A3=   1.70450 B3=    .23954 C3=  -2.60552 D3=     .64774
*****************************************************************

ITERATION  3
A1=   1.70450 B1=    .23954 C1=  -2.60552 D1=     .64774
COEFFICIENTS FROM CURVE FITTING
A2=    .33169 B2=    .04640 C2=   -.50896 D2=     .12821
NUSSELT NUMBER=   5.14579
DIFFERENCE=    .00773
COEFFICIENTS FROM  3. ITERATION
A3=   1.70684 B3=    .23879 C3=  -2.61903 D3=     .65976
*****************************************************************

ITERATION  4
A1=   1.70684 B1=    .23879 C1=  -2.61903 D1=     .65976
COEFFICIENTS FROM CURVE FITTING
A2=    .33183 B2=    .04639 C2=   -.50946 D2=     .12858
NUSSELT NUMBER=   5.14466
```

```
DIFFERENCE=     .00113
COEFFICIENTS FROM  4. ITERATION
A3=   1.70719 B3=    .23867 C3=  -2.62100 D3=     .66152
*****************************************************************

ITERATION  5
A1=   1.70719 B1=    .23867 C1=  -2.62100 D1=     .66152
COEFFICIENTS FROM CURVE FITTING
A2=    .33185 B2=    .04638 C2=   -.50953 D2=     .12863
NUSSELT NUMBER=   5.14449
DIFFERENCE=     .00016
COEFFICIENTS FROM  5. ITERATION
A3=   1.70724 B3=    .23865 C3=  -2.62129 D3=     .66178
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.707 1.705 1.655 1.560 1.425 1.253 1.049  .816  .559  .281 -.013
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************

PRANDTL NUMBER=       .050
REYNOLDS NUMBER=       8000.0
PECLET NUMBER=        400.0

*****************************************************************

S=      6.430
N=      9.000

*****************************************************************

ITERATION  1
A1=   1.80733 B1=   -.33245 C1=  -1.20645 D1=    -.24303
COEFFICIENTS FROM CURVE FITTING
A2=    .24588 B2=   -.04118 C2=   -.16804 D2=    -.03427
NUSSELT NUMBER=   7.27847
COEFFICIENTS FROM  1. ITERATION
A3=   1.78965 B3=   -.29977 C3=  -1.22310 D3=    -.24945
*****************************************************************

ITERATION  2
A1=   1.78965 B1=   -.29977 C1=  -1.22310 D1=    -.24945
COEFFICIENTS FROM CURVE FITTING
A2=    .24432 B2=   -.04059 C2=   -.16759 D2=    -.03378
NUSSELT NUMBER=   7.32333
DIFFERENCE=     .04486
COEFFICIENTS FROM  2. ITERATION
A3=   1.78928 B3=   -.29728 C3=  -1.22731 D3=    -.24743
*****************************************************************

ITERATION  3
A1=   1.78928 B1=   -.29728 C1=  -1.22731 D1=    -.24743
COEFFICIENTS FROM CURVE FITTING
A2=    .24432 B2=   -.04058 C2=   -.16761 D2=    -.03377
NUSSELT NUMBER=   7.32324
DIFFERENCE=     .00009
```

```
COEFFICIENTS FROM  3. ITERATION
A3=   1.78926 B3=   -.29717 C3=  -1.22750 D3=   -.24734
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.789 1.747 1.678 1.582 1.458 1.302 1.115  .894  .639  .347  .017
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************

PRANDTL NUMBER=       .050
REYNOLDS NUMBER=       10000.0
PECLET NUMBER=         500.0

*****************************************************************

S=     7.560
N=    10.930

*****************************************************************

ITERATION  1
A1=   1.68665 B1=   -.57783 C1=    .17508 D1=  -1.24026
COEFFICIENTS FROM CURVE FITTING
A2=    .22118 B2=   -.04150 C2=   -.12797 D2=   -.04859
NUSSELT NUMBER=   8.04985
COEFFICIENTS FROM  1. ITERATION
A3=   1.78052 B3=   -.33411 C3=  -1.03019 D3=   -.39120
*****************************************************************

ITERATION  2
A1=   1.78052 B1=   -.33411 C1=  -1.03019 D1=   -.39120
COEFFICIENTS FROM CURVE FITTING
A2=    .22723 B2=   -.04167 C2=   -.14883 D2=   -.03353
NUSSELT NUMBER=   7.93249
DIFFERENCE=    .11736
COEFFICIENTS FROM  2. ITERATION
A3=   1.80251 B3=   -.33058 C3=  -1.18059 D3=   -.26604
*****************************************************************

ITERATION  3
A1=   1.80251 B1=   -.33058 C1=  -1.18059 D1=   -.26604
COEFFICIENTS FROM CURVE FITTING
A2=    .22822 B2=   -.04194 C2=   -.15189 D2=   -.03116
NUSSELT NUMBER=   7.91572
DIFFERENCE=    .01676
COEFFICIENTS FROM  3. ITERATION
A3=   1.80652 B3=   -.33205 C3=  -1.20236 D3=   -.24673
*****************************************************************

ITERATION  4
A1=   1.80652 B1=   -.33205 C1=  -1.20236 D1=   -.24673
COEFFICIENTS FROM CURVE FITTING
A2=    .22838 B2=   -.04200 C2=   -.15239 D2=   -.03077
NUSSELT NUMBER=   7.91297
DIFFERENCE=    .00274
COEFFICIENTS FROM  4. ITERATION
```

```
A3=    1.80721 B3=    -.33239 C3=  -1.20586 D3=    -.24356
***************************************************************

ITERATION  5
A1=    1.80721 B1=    -.33239 C1=  -1.20586 D1=    -.24356
COEFFICIENTS FROM CURVE FITTING
A2=     .22841 B2=    -.04201 C2=   -.15247 D2=    -.03071
NUSSELT NUMBER=   7.91251
DIFFERENCE=     .00046
COEFFICIENTS FROM  5. ITERATION
A3=    1.80733 B3=    -.33245 C3=  -1.20645 D3=    -.24303
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.807 1.761 1.690 1.592 1.465 1.309 1.121  .900  .644  .353  .025
***************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
***************************************************************

PRANDTL NUMBER=         .050
REYNOLDS NUMBER=         30000.0
PECLET NUMBER=          1500.0

***************************************************************

S=     17.600
N=     26.510

***************************************************************

ITERATION  1
A1=    1.86553 B1=    -.43631 C1=  -1.01193 D1=    -.36458
COEFFICIENTS FROM CURVE FITTING
A2=     .13055 B2=    -.02303 C2=   -.10182 D2=    -.00291
NUSSELT NUMBER=  14.44027
COEFFICIENTS FROM  1. ITERATION
A3=    1.88521 B3=    -.33265 C3=  -1.47033 D3=    -.04210
***************************************************************

ITERATION  2
A1=    1.88521 B1=    -.33265 C1=  -1.47033 D1=    -.04210
COEFFICIENTS FROM CURVE FITTING
A2=     .13075 B2=    -.02276 C2=   -.10600 D2=     .00078
NUSSELT NUMBER=  14.48770
DIFFERENCE=     .04743
COEFFICIENTS FROM  2. ITERATION
A3=    1.89436 B3=    -.32981 C3=  -1.53581 D3=     .01137
***************************************************************

ITERATION  3
A1=    1.89436 B1=    -.32981 C1=  -1.53581 D1=     .01137
COEFFICIENTS FROM CURVE FITTING
A2=     .13099 B2=    -.02282 C2=   -.10678 D2=     .00137
NUSSELT NUMBER=  14.47439
DIFFERENCE=     .01330
COEFFICIENTS FROM  3. ITERATION
A3=    1.89613 B3=    -.33036 C3=  -1.54558 D3=     .01995
```

```
*****************************************************************

ITERATION  4
A1=   1.89613 B1=   -.33036 C1=  -1.54558 D1=     .01995
COEFFICIENTS FROM CURVE FITTING
A2=    .13104 B2=   -.02283 C2=   -.10691 D2=     .00148
NUSSELT NUMBER=  14.47213
DIFFERENCE=    .00225
COEFFICIENTS FROM  4. ITERATION
A3=   1.89645 B3=   -.33050 C3=  -1.54722 D3=     .02142
*****************************************************************

ITERATION  5
A1=   1.89645 B1=   -.33050 C1=  -1.54722 D1=     .02142
COEFFICIENTS FROM CURVE FITTING
A2=    .13104 B2=   -.02284 C2=   -.10693 D2=     .00149
NUSSELT NUMBER=  14.47173
DIFFERENCE=    .00040
COEFFICIENTS FROM  5. ITERATION
A3=   1.89651 B3=   -.33053 C3=  -1.54751 D3=     .02168
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.896 1.848 1.768 1.658 1.518 1.347 1.145  .914  .652  .361  .040
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=          .050
REYNOLDS NUMBER=          50000.0
PECLET NUMBER=           2500.0

*****************************************************************
S=     26.620
N=     39.910

*****************************************************************
ITERATION  1
A1=   1.86553 B1=   -.43631 C1=  -1.01193 D1=    -.36458
COEFFICIENTS FROM CURVE FITTING
A2=    .09486 B2=   -.02037 C2=   -.06299 D2=    -.00651
NUSSELT NUMBER=  19.61533
COEFFICIENTS FROM  1. ITERATION
A3=   1.86076 B3=   -.39973 C3=  -1.23557 D3=    -.12787
*****************************************************************
ITERATION  2
A1=   1.86076 B1=   -.39973 C1=  -1.23557 D1=    -.12787
COEFFICIENTS FROM CURVE FITTING
A2=    .09446 B2=   -.02070 C2=   -.06169 D2=    -.00707
NUSSELT NUMBER=  19.69719
DIFFERENCE=    .08185
COEFFICIENTS FROM  2. ITERATION
A3=   1.86063 B3=   -.40783 C3=  -1.21515 D3=    -.13935
*****************************************************************
```

```
ITERATION  3
A1=   1.86063 B1=   -.40783 C1=  -1.21515 D1=   -.13935
COEFFICIENTS FROM CURVE FITTING
A2=    .09443 B2=   -.02072 C2=   -.06156 D2=   -.00715
NUSSELT NUMBER=  19.70127
DIFFERENCE=    .00408
COEFFICIENTS FROM  3. ITERATION
A3=   1.86043 B3=   -.40822 C3=  -1.21293 D3=   -.14098
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.860 1.807 1.729 1.624 1.494 1.335 1.148  .931  .685  .407 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=        .050
REYNOLDS NUMBER=        70000.0
PECLET NUMBER=         3500.0

*****************************************************************
S=     35.040
N=     52.180

*****************************************************************
ITERATION  1
A1=   1.86553 B1=   -.43631 C1=  -1.01193 D1=   -.36458
COEFFICIENTS FROM CURVE FITTING
A2=    .07290 B2=   -.01390 C2=   -.05550 D2=    .00026
NUSSELT NUMBER=  25.82229
COEFFICIENTS FROM  1. ITERATION
A3=   1.88269 B3=   -.35907 C3=  -1.43317 D3=    .00680
*****************************************************************
ITERATION  2
A1=   1.88269 B1=   -.35907 C1=  -1.43317 D1=    .00680
COEFFICIENTS FROM CURVE FITTING
A2=    .07324 B2=   -.01425 C2=   -.05566 D2=    .00048
NUSSELT NUMBER=  25.74581
DIFFERENCE=    .07648
COEFFICIENTS FROM  2. ITERATION
A3=   1.88568 B3=   -.36694 C3=  -1.43315 D3=    .01240
*****************************************************************
ITERATION  3
A1=   1.88568 B1=   -.36694 C1=  -1.43315 D1=    .01240
COEFFICIENTS FROM CURVE FITTING
A2=    .07326 B2=   -.01427 C2=   -.05570 D2=    .00052
NUSSELT NUMBER=  25.74376
DIFFERENCE=    .00205
COEFFICIENTS FROM  3. ITERATION
A3=   1.88607 B3=   -.36756 C3=  -1.43399 D3=    .01348
*****************************************************************
ITERATION  4
A1=   1.88607 B1=   -.36756 C1=  -1.43399 D1=    .01348
COEFFICIENTS FROM CURVE FITTING
A2=    .07326 B2=   -.01428 C2=   -.05571 D2=    .00053
NUSSELT NUMBER=  25.74312
DIFFERENCE=    .00063
COEFFICIENTS FROM  4. ITERATION
```

```
A3=   1.88613 B3=   -.36761 C3=  -1.43423 D3=     .01371
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.886 1.835 1.755 1.647 1.510 1.345 1.152  .930  .681  .403  .098
******************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
******************************************************************
PRANDTL NUMBER=       .050
REYNOLDS NUMBER=      100000.0
PECLET NUMBER=        5000.0

******************************************************************
S=    46.970
N=    69.270

******************************************************************
ITERATION  1
A1=   1.83084 B1=   -.47589 C1=    -.84826 D1=    -.37968
COEFFICIENTS FROM CURVE FITTING
A2=    .05745 B2=   -.01586 C2=    -.02277 D2=    -.01461
NUSSELT NUMBER= 31.64911
COEFFICIENTS FROM  1. ITERATION
   1.81853   -.50200   -.72092   -.46267
******************************************************************
ITERATION  2
A1=   1.81853 B1=   -.50200 C1=    -.72092 D1=    -.46267
COEFFICIENTS FROM CURVE FITTING
A2=    .05725 B2=   -.01587 C2=    -.02207 D2=    -.01510
NUSSELT NUMBER= 31.71179
DIFFERENCE=      .06268
COEFFICIENTS FROM  2. ITERATION
   1.81573   -.50344   -.70008   -.47909
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.815 1.757 1.683 1.588 1.471 1.329 1.158  .955  .719  .446 0.000
******************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
******************************************************************
PRANDTL NUMBER=       .050
REYNOLDS NUMBER=      300000.0
PECLET NUMBER=       15000.0

******************************************************************
S=   116.400
N=   165.120

******************************************************************
ITERATION  1
A1=   1.82888 B1=   -.51325 C1=    -.65830 D1=    -.52106
COEFFICIENTS FROM CURVE FITTING
```

```
A2=    .02252 B2=   -.00637 C2=    -.00790 D2=    -.00657
NUSSELT NUMBER=  81.14624
COEFFICIENTS FROM  1. ITERATION
  1.82781   -.51691   -.64113   -.53367
*****************************************************************
ITERATION  2
A1=   1.82781 B1=   -.51691 C1=    -.64113 D1=    -.53367
COEFFICIENTS FROM CURVE FITTING
A2=    .02251 B2=   -.00632 C2=    -.00803 D2=    -.00648
NUSSELT NUMBER=  81.17696
DIFFERENCE=     .03072
COEFFICIENTS FROM  2. ITERATION
  1.82785   -.51318   -.65211   -.52625
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.827 1.769 1.694 1.600 1.484 1.342 1.171  .968  .730  .454 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=        .050
REYNOLDS NUMBER=     500000.0
PECLET NUMBER=      25000.0

*****************************************************************
S=   177.830
N=   247.000

*****************************************************************
ITERATION  1
A1=   1.83084 B1=   -.47589 C1=    -.84826 D1=    -.37968
COEFFICIENTS FROM CURVE FITTING
A2=    .01389 B2=   -.00367 C2=    -.00595 D2=    -.00327
NUSSELT NUMBER= 133.12128
COEFFICIENTS FROM  1. ITERATION
  1.84977   -.48960   -.79274   -.43606
*****************************************************************
ITERATION  2
A1=   1.84977 B1=   -.48960 C1=    -.79274 D1=    -.43606
COEFFICIENTS FROM CURVE FITTING
A2=    .01408 B2=   -.00373 C2=    -.00594 D2=    -.00339
NUSSELT NUMBER= 131.22029
DIFFERENCE=   1.90099
COEFFICIENTS FROM  2. ITERATION
  1.84786   -.48986   -.78043   -.44611
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.847 1.790 1.715 1.618 1.498 1.352 1.176  .969  .728  .449 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
```

```
****************************************************************

PRANDTL NUMBER=        .010
REYNOLDS NUMBER=        3000.0
PECLET NUMBER=          30.0

****************************************************************

S=      2.860
N=      3.310

****************************************************************

ITERATION  1
A1=   1.70724 B1=     .23865 C1=  -2.62129 D1=      .66178
COEFFICIENTS FROM CURVE FITTING
A2=     .39401 B2=     .04656 C2=    -.73947 D2=     .29740
NUSSELT NUMBER=   4.67045
COEFFICIENTS FROM  1. ITERATION
A3=   1.84025 B3=     .21748 C3=  -3.45366 D3=    1.38900
****************************************************************

ITERATION  2
A1=   1.84025 B1=     .21748 C1=  -3.45366 D1=    1.38900
COEFFICIENTS FROM CURVE FITTING
A2=     .40496 B2=     .04330 C2=    -.77474 D2=     .32522
NUSSELT NUMBER=   4.60463
DIFFERENCE=    .06582
COEFFICIENTS FROM  2. ITERATION
A3=   1.86473 B3=     .19940 C3=  -3.56740 D3=    1.49754
****************************************************************

ITERATION  3
A1=   1.86473 B1=     .19940 C1=  -3.56740 D1=    1.49754
COEFFICIENTS FROM CURVE FITTING
A2=     .40681 B2=     .04261 C2=    -.78041 D2=     .32978
NUSSELT NUMBER=   4.59396
DIFFERENCE=    .01067
COEFFICIENTS FROM  3. ITERATION
A3=   1.86889 B3=     .19577 C3=  -3.58518 D3=    1.51500
****************************************************************

ITERATION  4
A1=   1.86889 B1=     .19577 C1=  -3.58518 D1=    1.51500
COEFFICIENTS FROM CURVE FITTING
A2=     .40712 B2=     .04249 C2=    -.78134 D2=     .33053
NUSSELT NUMBER=   4.59220
DIFFERENCE=    .00175
COEFFICIENTS FROM  4. ITERATION
A3=   1.86958 B3=     .19514 C3=  -3.58808 D3=    1.51787
****************************************************************

ITERATION  5
A1=   1.86958 B1=     .19514 C1=  -3.58808 D1=    1.51787
COEFFICIENTS FROM CURVE FITTING
A2=     .40717 B2=     .04247 C2=    -.78149 D2=     .33065
NUSSELT NUMBER=   4.59191
DIFFERENCE=    .00029
COEFFICIENTS FROM  5. ITERATION
A3=   1.86970 B3=     .19504 C3=  -3.58856 D3=    1.51834
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
```

```
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.869 1.854 1.777 1.646 1.470 1.259 1.022  .768  .506  .245 -.005
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************

PRANDTL NUMBER=        .010
REYNOLDS NUMBER=        8000.0
PECLET NUMBER=          80.0

*****************************************************************

S=      6.430
N=      9.000

*****************************************************************

ITERATION  1
A1=   1.99591 B1=    -.00024 C1=  -3.24915 D1=   1.25874
COEFFICIENTS FROM CURVE FITTING
A2=    .37045 B2=     .00275 C2=   -.60744 D2=    .23466
NUSSELT NUMBER=   5.34287
COEFFICIENTS FROM  1. ITERATION
A3=   1.97932 B3=     .01470 C3=  -3.24549 D3=   1.25380
*****************************************************************

ITERATION  2
A1=   1.97932 B1=     .01470 C1=  -3.24549 D1=   1.25380
COEFFICIENTS FROM CURVE FITTING
A2=    .36783 B2=     .00294 C2=   -.60362 D2=    .23327
NUSSELT NUMBER=   5.38079
DIFFERENCE=    .03791
COEFFICIENTS FROM  2. ITERATION
A3=   1.97923 B3=     .01584 C3=  -3.24798 D3=   1.25521
*****************************************************************

ITERATION  3
A1=   1.97923 B1=     .01584 C1=  -3.24798 D1=   1.25521
COEFFICIENTS FROM CURVE FITTING
A2=    .36783 B2=     .00295 C2=   -.60366 D2=    .23330
NUSSELT NUMBER=   5.38071
DIFFERENCE=    .00007
COEFFICIENTS FROM  3. ITERATION
A3=   1.97924 B3=     .01589 C3=  -3.24815 D3=   1.25532
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.979 1.949 1.862 1.725 1.546 1.332 1.090  .829  .555  .277  .002
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
```

```
PRANDTL NUMBER=        .010
REYNOLDS NUMBER=       10000.0
PECLET NUMBER=         100.0

*******************************************************************

S=     7.560
N=    10.930

*******************************************************************

ITERATION  1
A1=   2.03178 B1=     .05649 C1=  -3.62480 D1=   1.53867
COEFFICIENTS FROM CURVE FITTING
A2=    .36364 B2=   -.00041 C2=    -.59809 D2=    .23583
NUSSELT NUMBER=   5.51022
COEFFICIENTS FROM  1. ITERATION
A3=   2.00374 B3=   -.00228 C3=  -3.29564 D3=   1.29948
*******************************************************************

ITERATION  2
A1=   2.00374 B1=   -.00228 C1=  -3.29564 D1=   1.29948
COEFFICIENTS FROM CURVE FITTING
A2=    .36084 B2=   -.00022 C2=    -.58828 D2=    .22858
NUSSELT NUMBER=   5.53478
DIFFERENCE=    .02456
COEFFICIENTS FROM  2. ITERATION
A3=   1.99717 B3=   -.00125 C3=  -3.25601 D3=   1.26518
*******************************************************************

ITERATION  3
A1=   1.99717 B1=   -.00125 C1=  -3.25601 D1=   1.26518
COEFFICIENTS FROM CURVE FITTING
A2=    .36036 B2=   -.00007 C2=    -.58682 D2=    .22744
NUSSELT NUMBER=   5.53853
DIFFERENCE=    .00374
COEFFICIENTS FROM  3. ITERATION
A3=   1.99591 B3=   -.00042 C3=  -3.25014 D3=   1.25968
*******************************************************************

ITERATION  4
A1=   1.99591 B1=   -.00042 C1=  -3.25014 D1=   1.25968
COEFFICIENTS FROM CURVE FITTING
A2=    .36028 B2=   -.00004 C2=    -.58657 D2=    .22724
NUSSELT NUMBER=   5.53918
DIFFERENCE=    .00064
COEFFICIENTS FROM  4. ITERATION
A3=   1.99569 B3=   -.00024 C3=  -3.24915 D3=   1.25874
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.995 1.964 1.875 1.737 1.556 1.340 1.097  .835  .560  .281  .005
*******************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*******************************************************************

PRANDTL NUMBER=        .010
```

```
REYNOLDS NUMBER=        30000.0
PECLET NUMBER=          300.0

***************************************************************

S=     17.600
N=     26.510

***************************************************************

ITERATION  1
A1=   2.08447 B1=   -.01529 C1=  -3.39742 D1=   1.34054
COEFFICIENTS FROM CURVE FITTING
A2=    .29211 B2=   -.00093 C2=   -.48096 D2=    .19124
NUSSELT NUMBER=   7.07422
COEFFICIENTS FROM  1. ITERATION
A3=   2.06645 B3=   -.00664 C3=  -3.40246 D3=   1.35289
***************************************************************

ITERATION  2
A1=   2.06645 B1=   -.00664 C1=  -3.40246 D1=   1.35289
COEFFICIENTS FROM CURVE FITTING
A2=    .28940 B2=   -.00090 C2=   -.47716 D2=    .19010
NUSSELT NUMBER=   7.14346
DIFFERENCE=     .06923
COEFFICIENTS FROM  2. ITERATION
A3=   2.06734 B3=   -.00645 C3=  -3.40862 D3=   1.35798
***************************************************************

ITERATION  3
A1=   2.06734 B1=   -.00645 C1=  -3.40862 D1=   1.35798
COEFFICIENTS FROM CURVE FITTING
A2=    .28945 B2=   -.00091 C2=   -.47733 D2=    .19023
NUSSELT NUMBER=   7.14275
DIFFERENCE=     .00070
COEFFICIENTS FROM  3. ITERATION
A3=   2.06751 B3=   -.00654 C3=  -3.40949 D3=   1.35878
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.067 2.034 1.940 1.795 1.606 1.381 1.129  .858  .575  .290  .010
***************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
***************************************************************

PRANDTL NUMBER=         .010
REYNOLDS NUMBER=        50000.0
PECLET NUMBER=          500.0

***************************************************************

S=     26.620
N=     39.910

***************************************************************

ITERATION  1
```

```
1=    1.99569 B1=    -.00024 C1=  -3.24915 D1=    1.25874
OEFFICIENTS FROM CURVE FITTING
2=     .23398 B2=    -.00145 C2=   -.38169 D2=     .15053
USSELT NUMBER=   8.90573
OEFFICIENTS FROM  1. ITERATION
3=    2.08379 B3=    -.01291 C3=  -3.39931 D3=    1.34064
**************************************************************

TERATION  2
1=    2.08379 B1=    -.01291 C1=  -3.39931 D1=    1.34064
OEFFICIENTS FROM CURVE FITTING
2=     .24380 B2=    -.00177 C2=   -.39737 D2=     .15678
USSELT NUMBER=   8.54947
IFFERENCE=     .35625
OEFFICIENTS FROM  2. ITERATION
3=    2.08439 B3=    -.01514 C3=  -3.39735 D3=    1.34039
**************************************************************

TERATION  3
1=    2.08439 B1=    -.01514 C1=  -3.39735 D1=    1.34039
OEFFICIENTS FROM CURVE FITTING
2=     .24381 B2=    -.00178 C2=   -.39738 D2=     .15680
USSELT NUMBER=   8.54935
IFFERENCE=     .00012
OEFFICIENTS FROM  3. ITERATION
A3=    2.08447 B3=    -.01529 C3=  -3.39742 D3=    1.34054
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.084 2.050 1.956 1.810 1.620 1.395 1.141  .868  .584  .296  .012
**************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
**************************************************************
PRANDTL NUMBER=         .010
REYNOLDS NUMBER=         70000.0
PECLET NUMBER=           700.0

**************************************************************
S=    35.040
N=    52.180

**************************************************************
ITERATION  1
A1=    2.07491 B1=    -.05293 C1=  -3.19178 D1=    1.18592
COEFFICIENTS FROM CURVE FITTING
A2=     .21187 B2=    -.00344 C2=   -.33645 D2=     .13107
NUSSELT NUMBER=   9.79611
COEFFICIENTS FROM  1. ITERATION
A3=    2.07553 B3=    -.03374 C3=  -3.29592 D3=    1.28407
**************************************************************
ITERATION  2
A1=    2.07553 B1=    -.03374 C1=  -3.29592 D1=    1.28407
COEFFICIENTS FROM CURVE FITTING
A2=     .21172 B2=    -.00370 C2=   -.33594 D2=     .13099
NUSSELT NUMBER=   9.80688
DIFFERENCE=     .01077
COEFFICIENTS FROM  2. ITERATION
```

```
A3=   2.07631 B3=   -.03633 C3=  -3.29452 D3=   1.28467
************************************************************
ITERATION  3
A1=   2.07631 B1=   -.03633 C1=  -3.29452 D1=   1.28467
COEFFICIENTS FROM CURVE FITTING
A2=    .21173 B2=   -.00372 C2=   -.33595 D2=    .13101
NUSSELT NUMBER=   9.80674
DIFFERENCE=    .00013
COEFFICIENTS FROM  3. ITERATION
A3=   2.07642 B3=   -.03654 C3=  -3.29461 D3=   1.28487
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.076 2.041 1.947 1.803 1.616 1.395 1.145  .877  .596  .311  .030
************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
************************************************************
PRANDTL NUMBER=        .010
REYNOLDS NUMBER=     100000.0
PECLET NUMBER=         1000.0

************************************************************
S=    46.970
N=    69.270

************************************************************
ITERATION  1
A1=   2.05079 B1=   -.09027 C1=  -2.98833 D1=   1.07294
COEFFICIENTS FROM CURVE FITTING
A2=    .17779 B2=   -.00698 C2=   -.26250 D2=    .09543
NUSSELT NUMBER=  11.55856
COEFFICIENTS FROM  1. ITERATION
   2.05500   -.08068  -3.03417   1.10312
************************************************************
ITERATION  2
A1=   2.05500 B1=   -.08068 C1=  -3.03417 D1=   1.10312
COEFFICIENTS FROM CURVE FITTING
A2=    .17802 B2=   -.00696 C2=   -.26331 D2=    .09600
NUSSELT NUMBER=  11.54908
DIFFERENCE=    .00948
COEFFICIENTS FROM  2. ITERATION
   2.05599   -.08043  -3.04108   1.10879
************************************************************
ITERATION  3
A1=   2.05599 B1=   -.08043 C1=  -3.04108 D1=   1.10879
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.055 2.018 1.927 1.788 1.608 1.394 1.152  .889  .613  .328 0.000
************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
************************************************************
```

```
PRANDTL NUMBER=          .010
REYNOLDS NUMBER=         300000.0
PECLET NUMBER=           3000.0

****************************************************************
S=   116.400
N=   165.120

****************************************************************
ITERATION  1
A1=   2.04518 B1=   -.13493 C1=  -2.74437 D1=     .89013
COEFFICIENTS FROM CURVE FITTING
A2=    .08888 B2=   -.00728 C2=   -.11323 D2=     .03438
NUSSELT NUMBER=  22.83165
COEFFICIENTS FROM  1. ITERATION
   2.02946   -.16644  -2.58536    .78511
****************************************************************
ITERATION  2
A1=   2.02946 B1=   -.16644 C1=  -2.58536 D1=     .78511
COEFFICIENTS FROM CURVE FITTING
A2=    .08748 B2=   -.00556 C2=   -.11741 D2=     .03784
NUSSELT NUMBER=  23.35807
DIFFERENCE=     .52641
COEFFICIENTS FROM  2. ITERATION
   2.04350   -.13008  -2.74257    .88392
****************************************************************
ITERATION  3
A1=   2.04350 B1=   -.13008 C1=  -2.74257 D1=     .88392
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.043 2.003 1.914 1.781 1.609 1.403 1.168  .911  .636  .348 0.000
****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
****************************************************************
PRANDTL NUMBER=          .010
REYNOLDS NUMBER=         500000.0
PECLET NUMBER=           5000.0

****************************************************************
S=   177.830
N=   247.000

****************************************************************
ITERATION  1
A1=   2.09569 B1=   -.05789 C1=  -3.15975 D1=    1.16183
COEFFICIENTS FROM CURVE FITTING
A2=    .05866 B2=   -.00210 C2=   -.08668 D2=     .03135
NUSSELT NUMBER=  35.61276
COEFFICIENTS FROM  1. ITERATION
   2.08924   -.07493  -3.08726   1.11661
****************************************************************
ITERATION  2
A1=   2.08924 B1=   -.07493 C1=  -3.08726 D1=    1.11661
COEFFICIENTS FROM CURVE FITTING
A2=    .05854 B2=   -.00212 C2=   -.08624 D2=     .03104
NUSSELT NUMBER=  35.66251
```

DIFFERENCE= .04974

COEFFICIENTS FROM 2. ITERATION
2.08768 -.07568 -3.07562 1.10730
****
ITERATION 3
A1= 2.08768 B1= -.07568 C1= -3.07562 D1= 1.10730
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
0.000 .100 .200 .300 .400 .500 .600 .700 .800 .900 1.000
THETA VALUES
2.087 2.050 1.958 1.818 1.636 1.419 1.174 .907 .625 .335 0.000
****

CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
****

PRANDTL NUMBER= .005
REYNOLDS NUMBER= 3000.0
PECLET NUMBER= 15.0

****

S= 2.860
N= 3.310

****

ITERATION 1
A1= 1.86970 B1= .19504 C1= -3.58856 D1= 1.51834
COEFFICIENTS FROM CURVE FITTING
A2= .41865 B2= .03936 C2= -.81937 D2= .36047
NUSSELT NUMBER= 4.52492
COEFFICIENTS FROM 1. ITERATION
A3= 1.89438 B3= .17811 C3= -3.70761 D3= 1.63112
****

ITERATION 2
A1= 1.89438 B1= .17811 C1= -3.70761 D1= 1.63112
COEFFICIENTS FROM CURVE FITTING
A2= .42061 B2= .03856 C2= -.82528 D2= .36526
NUSSELT NUMBER= 4.51417
DIFFERENCE= .01075
COEFFICIENTS FROM 2. ITERATION
A3= 1.89872 B3= .17407 C3= -3.72545 D3= 1.64888
****

ITERATION 3
A1= 1.89872 B1= .17407 C1= -3.72545 D1= 1.64888
COEFFICIENTS FROM CURVE FITTING
A2= .42094 B2= .03841 C2= -.82625 D2= .36607
NUSSELT NUMBER= 4.51236
DIFFERENCE= .00180
COEFFICIENTS FROM 3. ITERATION
A3= 1.89946 B3= .17334 C3= -3.72838 D3= 1.65184
****

ITERATION 4
A1= 1.89946 B1= .17334 C1= -3.72838 D1= 1.65184
COEFFICIENTS FROM CURVE FITTING

```
A2=     .42100 B2=     .03839 C2=    -.82642 D2=     .36620
NUSSELT NUMBER=   4.51206
DIFFERENCE=     .00030
COEFFICIENTS FROM  4. ITERATION
A3=   1.89958 B3=     .17322 C3=  -3.72887 D3=   1.65234
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.899 1.881 1.798 1.660 1.478 1.260 1.018  .760  .497  .239 -.003
********************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
********************************************************************

PRANDTL NUMBER=        .005
REYNOLDS NUMBER=         8000.0
PECLET NUMBER=           40.0

********************************************************************

S=      6.430
N=      9.000

********************************************************************

ITERATION  1
A1=   2.03158 B1=     .05666 C1=  -3.62394 D1=   1.53784
COEFFICIENTS FROM CURVE FITTING
A2=     .39812 B2=     .01302 C2=    -.71286 D2=     .30182
NUSSELT NUMBER=   5.06139
COEFFICIENTS FROM  1. ITERATION
A3=   2.01507 B3=     .06592 C3=  -3.60806 D3=   1.52767
********************************************************************

ITERATION  2
A1=   2.01507 B1=     .06592 C1=  -3.60806 D1=   1.52767
COEFFICIENTS FROM CURVE FITTING
A2=     .39526 B2=     .01308 C2=    -.70796 D2=     .29974
NUSSELT NUMBER=   5.09763
DIFFERENCE=     .03623
COEFFICIENTS FROM  2. ITERATION
A3=   2.01489 B3=     .06669 C3=  -3.60896 D3=   1.52797
********************************************************************

ITERATION  3
A1=   2.01489 B1=     .06669 C1=  -3.60896 D1=   1.52797
COEFFICIENTS FROM CURVE FITTING
A2=     .39525 B2=     .01309 C2=    -.70796 D2=     .29973
NUSSELT NUMBER=   5.09765
DIFFERENCE=     .00001
COEFFICIENTS FROM  3. ITERATION
A3=   2.01487 B3=     .06674 C3=  -3.60896 D3=   1.52794
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.014 1.986 1.896 1.751 1.561 1.336 1.085  .817  .540  .265 0.000
********************************************************************
```

```
CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
****************************************************************

PRANDTL NUMBER=        .005
REYNOLDS NUMBER=        10000.0
PECLET NUMBER=           50.0

****************************************************************

S=      7.560
N=     10.930

****************************************************************

ITERATION  1
A1=   2.06344 B1=    .10572 C1=  -3.95344 D1=   1.78410
COEFFICIENTS FROM CURVE FITTING
A2=    .39415 B2=    .01053 C2=   -.70844 D2=    .30421
NUSSELT NUMBER=   5.17237
COEFFICIENTS FROM  1. ITERATION
A3=   2.03872 B3=    .05450 C3=  -3.66432 D3=   1.57350
****************************************************************

ITERATION  2
A1=   2.03872 B1=    .05450 C1=  -3.66432 D1=   1.57350
COEFFICIENTS FROM CURVE FITTING
A2=    .39147 B2=    .01072 C2=   -.69899 D2=    .29722
NUSSELT NUMBER=   5.19299
DIFFERENCE=    .02061
COEFFICIENTS FROM  2. ITERATION
A3=   2.03290 B3=    .05569 C3=  -3.62987 D3=   1.54348
****************************************************************

ITERATION  3
A1=   2.03290 B1=    .05569 C1=  -3.62987 D1=   1.54348
COEFFICIENTS FROM CURVE FITTING
A2=    .39101 B2=    .01087 C2=   -.69759 D2=    .29611
NUSSELT NUMBER=   5.19614
DIFFERENCE=    .00315
COEFFICIENTS FROM  3. ITERATION
A3=   2.03178 B3=    .05649 C3=  -3.62480 D3=   1.53867
****************************************************************

ITERATION  4
A1=   2.03178 B1=    .05649 C1=  -3.62480 D1=   1.53867
COEFFICIENTS FROM CURVE FITTING
A2=    .39093 B2=    .01090 C2=   -.69735 D2=    .29592
NUSSELT NUMBER=   5.19669
DIFFERENCE=    .00054
COEFFICIENTS FROM  4. ITERATION
A3=   2.03158 B3=    .05666 C3=  -3.62394 D3=   1.53784
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.031 2.002 1.910 1.763 1.572 1.346 1.093  .822  .544  .268  .002
****************************************************************
```

```
CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
****************************************************************

PRANDTL NUMBER=        .005
REYNOLDS NUMBER=        30000.0
PECLET NUMBER=          150.0

****************************************************************

S=     17.600
N=     26.510

****************************************************************

ITERATION  1
A1=   2.09955 B1=     .05116 C1=  -3.75207 D1=    1.60656
COEFFICIENTS FROM CURVE FITTING
A2=     .34441 B2=     .00839 C2=    -.61582 D2=     .26380
NUSSELT NUMBER=    6.09567
COEFFICIENTS FROM  1. ITERATION
A3=   2.09982 B3=     .05119 C3=  -3.75384 D3=    1.60804
****************************************************************

ITERATION  2
A1=   2.09982 B1=     .05119 C1=  -3.75384 D1=    1.60804
COEFFICIENTS FROM CURVE FITTING
A2=     .34449 B2=     .00839 C2=    -.61588 D2=     .26384
NUSSELT NUMBER=    6.09544
DIFFERENCE=     .00022
COEFFICIENTS FROM  2. ITERATION
A3=   2.09987 B3=     .05116 C3=  -3.75408 D3=    1.60826
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.099 2.069 1.972 1.820 1.622 1.387 1.126  .847  .561  .277  .005
****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
****************************************************************

PRANDTL NUMBER=        .005
REYNOLDS NUMBER=        50000.0
PECLET NUMBER=          250.0

****************************************************************

S=     26.620
N=     39.910

****************************************************************

ITERATION  1
A1=   2.03158 B1=     .05666 C1=  -3.62394 D1=    1.53784
COEFFICIENTS FROM CURVE FITTING
A2=     .29677 B2=     .00723 C2=    -.52961 D2=     .22645
```

```
NUSSELT NUMBER=    7.14476
COEFFICIENTS FROM  1. ITERATION
A3=   2.12035 B3=    .05165 C3=  -3.78398 D3=    1.61797
*************************************************************

ITERATION  2
A1=   2.12035 B1=    .05165 C1=  -3.78398 D1=    1.61797
COEFFICIENTS FROM CURVE FITTING
A2=    .30939 B2=    .00735 C2=   -.55189 D2=     .23602
NUSSELT NUMBER=   6.85437
DIFFERENCE=     .29039
COEFFICIENTS FROM  2. ITERATION
A3=   2.12068 B3=    .05042 C3=  -3.78286 D3=    1.61780
*************************************************************

ITERATION  3
A1=   2.12068 B1=    .05042 C1=  -3.78286 D1=    1.61780
COEFFICIENTS FROM CURVE FITTING
A2=    .30939 B2=    .00734 C2=   -.55190 D2=     .23603
NUSSELT NUMBER=   6.85431
DIFFERENCE=     .00005
COEFFICIENTS FROM  3. ITERATION
A3=   2.12072 B3=    .05034 C3=  -3.78290 D3=    1.61788
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.120 2.089 1.992 1.839 1.639 1.402 1.138  .857  .568  .281  .006
*************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*************************************************************

PRANDTL NUMBER=          .005
REYNOLDS NUMBER=         70000.0
PECLET NUMBER=           350.0

*************************************************************

S=     35.040
N=     52.180

*************************************************************

ITERATION  1
A1=   2.12150 B1=    .03176 C1=  -3.68677 D1=    1.54150
COEFFICIENTS FROM CURVE FITTING
A2=    .28227 B2=    .00423 C2=   -.49050 D2=     .20506
NUSSELT NUMBER=   7.51556
COEFFICIENTS FROM  1. ITERATION
A3=   2.12142 B3=    .03182 C3=  -3.68645 D3=    1.54119
*************************************************************

ITERATION  2
A1=   2.12142 B1=    .03182 C1=  -3.68645 D1=    1.54119
COEFFICIENTS FROM CURVE FITTING
A2=    .28226 B2=    .00423 C2=   -.49049 D2=     .20505
NUSSELT NUMBER=   7.51557
DIFFERENCE=   0.00000
```

```
COEFFICIENTS FROM  2. ITERATION
A3=   2.12141 B3=     .03183 C3=  -3.68638 D3=    1.54112
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.121 2.089 1.992 1.840 1.642 1.408 1.146  .865  .576  .287  .007
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=         .005
REYNOLDS NUMBER=       100000.0
PECLET NUMBER=          500.0

*****************************************************************
S=    46.970
N=    69.270

*****************************************************************
ITERATION  1
A1=   2.12141 B1=     .03183 C1=  -3.68638 D1=    1.54112
COEFFICIENTS FROM CURVE FITTING
A2=     .24763 B2=    .00578 C2=   -.43950 D2=     .18785
NUSSELT NUMBER=   8.61848
COEFFICIENTS FROM  1. ITERATION
A3=   2.13425 B3=     .04983 C3=  -3.78784 D3=    1.61906
*****************************************************************
ITERATION  2
A1=   2.13425 B1=     .04983 C1=  -3.78784 D1=    1.61906
COEFFICIENTS FROM CURVE FITTING
A2=     .24900 B2=    .00566 C2=   -.44197 D2=     .18910
NUSSELT NUMBER=   8.57427
DIFFERENCE=     .04420
COEFFICIENTS FROM  2. ITERATION
A3=   2.13502 B3=     .04856 C3=  -3.78963 D3=    1.62147
*****************************************************************
ITERATION  3
A1=   2.13502 B1=     .04856 C1=  -3.78963 D1=    1.62147
COEFFICIENTS FROM CURVE FITTING
A2=     .24903 B2=    .00564 C2=   -.44204 D2=     .18916
NUSSELT NUMBER=   8.57387
DIFFERENCE=     .00039
COEFFICIENTS FROM  3. ITERATION
A3=   2.13515 B3=     .04839 C3=  -3.79001 D3=    1.62190
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.135 2.103 2.006 1.852 1.651 1.414 1.150  .868  .578  .291  .015
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=         .005
REYNOLDS NUMBER=       300000.0
```

```
PECLET NUMBER=          1500.0

*************************************************************
S=    116.400
N=    165.120

*************************************************************
ITERATION  1
A1=    2.14039 B1=      .03693 C1=  -3.67179 D1=    1.51367
COEFFICIENTS FROM CURVE FITTING
A2=      .14343 B2=      .00258 C2=    -.24857 D2=     .10384
NUSSELT NUMBER=  14.97215
COEFFICIENTS FROM  1. ITERATION
   2.14758      .03866  -3.72172    1.55478
*************************************************************
ITERATION  2
A1=    2.14758 B1=      .03866 C1=  -3.72172 D1=    1.55478
COEFFICIENTS FROM CURVE FITTING
A2=      .14364 B2=      .00252 C2=    -.24924 D2=     .10435
NUSSELT NUMBER=  14.96024
DIFFERENCE=      .01191
COEFFICIENTS FROM  2. ITERATION
   2.14903      .03780  -3.72871    1.56122
*************************************************************
ITERATION  3
A1=    2.14903 B1=      .03780 C1=  -3.72871 D1=    1.56122
COEFFICIENTS FROM CURVE FITTING
A2=      .14368 B2=      .00251 C2=    -.24935 D2=     .10444
NUSSELT NUMBER=  14.95825
DIFFERENCE=      .00198
COEFFICIENTS FROM  3. ITERATION
   2.14930      .03759  -3.72985    1.56233
*************************************************************
ITERATION  4
A1=    2.14930 B1=      .03759 C1=  -3.72985 D1=    1.56233
COEFFICIENTS FROM CURVE FITTING
A2=      .14369 B2=      .00251 C2=    -.24936 D2=     .10446
NUSSELT NUMBER=  14.95790
DIFFERENCE=      .00035
COEFFICIENTS FROM  4. ITERATION
   2.14935      .03754  -3.73004    1.56252
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.149 2.117 2.020 1.867 1.667 1.430 1.166  .883  .592  .300  .019
       .005       300000.0          1500.0
    14.95790      -5.29831      12.61153       7.31322
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.149 2.117 2.020 1.867 1.667 1.430 1.166  .883  .592  .300 0.000
*************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*************************************************************
PRANDTL NUMBER=          .005
REYNOLDS NUMBER=         500000.0
```

```
PECLET NUMBER=        2500.0

*****************************************************************
S=    177.830
N=    247.000

*****************************************************************
ITERATION  1
A1=    2.13515 B1=     .04839 C1=  -3.79001 D1=    1.62190
COEFFICIENTS FROM CURVE FITTING
A2=     .10137 B2=   -.00003 C2=    -.16858 D2=     .06855
NUSSELT NUMBER=  21.13531
COEFFICIENTS FROM  1. ITERATION
   2.14264   -.00073  -3.56306   1.44898
*****************************************************************
ITERATION  2
A1=    2.14264 B1=    -.00073 C1=  -3.56306 D1=    1.44898
COEFFICIENTS FROM CURVE FITTING
A2=     .10236 B2=   -.00006 C2=    -.16855 D2=     .06757
NUSSELT NUMBER=  20.85919
DIFFERENCE=     .27612
COEFFICIENTS FROM  2. ITERATION
   2.13535   -.00128  -3.51583   1.40951
*****************************************************************
ITERATION  3
A1=    2.13535 B1=    -.00128 C1=  -3.51583 D1=    1.40951
COEFFICIENTS FROM CURVE FITTING
A2=     .10222 B2=   -.00002 C2=    -.16808 D2=     .06721
NUSSELT NUMBER=  20.87522
DIFFERENCE=     .01602
COEFFICIENTS FROM  3. ITERATION
   2.13390   -.00045  -3.50889   1.40313
*****************************************************************
ITERATION  4
A1=    2.13390 B1=    -.00045 C1=  -3.50889 D1=    1.40313
COEFFICIENTS FROM CURVE FITTING
A2=     .10219 B2=   -.00001 C2=    -.16801 D2=     .06715
NUSSELT NUMBER=  20.87789
DIFFERENCE=     .00267
COEFFICIENTS FROM  4. ITERATION
   2.13363   -.00026  -3.50769   1.40201
*****************************************************************
ITERATION  5
A1=    2.13363 B1=    -.00026 C1=  -3.50769 D1=    1.40201
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.133 2.099 2.004 1.855 1.662 1.431 1.173  .895  .606  .314 0.000


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************

PRANDTL NUMBER=        .001
REYNOLDS NUMBER=         3000.0
PECLET NUMBER=            3.0

*****************************************************************
```

```
S=      2.860
N=      3.310

*************************************************************************

ITERATION  1
A1=   1.86970 B1=     .19504 C1=  -3.58856 D1=    1.51834
COEFFICIENTS FROM CURVE FITTING
A2=    .42864 B2=     .03602 C2=   -.85130 D2=     .38604
NUSSELT NUMBER=   4.46973
COEFFICIENTS FROM  1. ITERATION
A3=   1.91592 B3=     .16100 C3=  -3.80510 D3=    1.72550
*************************************************************************

ITERATION  2
A1=   1.91592 B1=     .16100 C1=  -3.80510 D1=    1.72550
COEFFICIENTS FROM CURVE FITTING
A2=    .43242 B2=     .03432 C2=   -.86244 D2=     .39518
NUSSELT NUMBER=   4.44982
DIFFERENCE=    .01991
COEFFICIENTS FROM  2. ITERATION
A3=   1.92422 B3=     .15273 C3=  -3.83770 D3=    1.75851
*************************************************************************

ITERATION  3
A1=   1.92422 B1=     .15273 C1=  -3.83770 D1=    1.75851
COEFFICIENTS FROM CURVE FITTING
A2=    .43307 B2=     .03400 C2=   -.86431 D2=     .39674
NUSSELT NUMBER=   4.44643
DIFFERENCE=    .00339
COEFFICIENTS FROM  3. ITERATION
A3=   1.92565 B3=     .15122 C3=  -3.84311 D3=    1.76408
*************************************************************************

ITERATION  4
A1=   1.92565 B1=     .15122 C1=  -3.84311 D1=    1.76408
COEFFICIENTS FROM CURVE FITTING
A2=    .43319 B2=     .03395 C2=   -.86463 D2=     .39700
NUSSELT NUMBER=   4.44585
DIFFERENCE=    .00057
COEFFICIENTS FROM  4. ITERATION
A3=   1.92590 B3=     .15095 C3=  -3.84403 D3=    1.76503
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.925 1.904 1.816 1.672 1.484 1.260 1.013  .753  .490  .234 -.002
*************************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*************************************************************************

PRANDTL NUMBER=         .001
REYNOLDS NUMBER=          8000.0
PECLET NUMBER=             8.0

*************************************************************************

S=      6.430
```

```
N=     9.000

************************************************************************

ITERATION  1
A1=   2.06344 B1=     .10572 C1=  -3.95344 D1=    1.78410
COEFFICIENTS FROM CURVE FITTING
A2=    .42406 B2=     .02265 C2=   -.81313 D2=     .36628
NUSSELT NUMBER=   4.82647
COEFFICIENTS FROM  1. ITERATION
A3=   2.04673 B3=     .10934 C3=  -3.92457 D3=    1.76784
************************************************************************

ITERATION  2
A1=   2.04673 B1=     .10934 C1=  -3.92457 D1=    1.76784
COEFFICIENTS FROM CURVE FITTING
A2=    .42089 B2=     .02257 C2=   -.80707 D2=     .36345
NUSSELT NUMBER=   4.86218
DIFFERENCE=      .03571
COEFFICIENTS FROM  2. ITERATION
A3=   2.04648 B3=     .10977 C3=  -3.92413 D3=    1.76720
************************************************************************

ITERATION  3
A1=   2.04648 B1=     .10977 C1=  -3.92413 D1=    1.76720
COEFFICIENTS FROM CURVE FITTING
A2=    .42088 B2=     .02258 C2=   -.80702 D2=     .36342
NUSSELT NUMBER=   4.86227
DIFFERENCE=      .00008
COEFFICIENTS FROM  3. ITERATION
A3=   2.04644 B3=     .10982 C3=  -3.92399 D3=    1.76706
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.046 2.019 1.925 1.773 1.575 1.341 1.081  .806  .527  .255 0.000
************************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
************************************************************************

PRANDTL NUMBER=          .001
REYNOLDS NUMBER=          10000.0
PECLET NUMBER=             10.0

************************************************************************

S=     7.560
N=    10.930

************************************************************************

ITERATION  1
A1=   2.06218 B1=     .10688 C1=  -3.94844 D1=    1.77914
COEFFICIENTS FROM CURVE FITTING
A2=    .41995 B2=     .02155 C2=   -.80453 D2=     .36298
NUSSELT NUMBER=   4.91303
COEFFICIENTS FROM  2. ITERATION
A3=   2.06225 B3=     .10590 C3=  -3.95269 D3=    1.78335
```

```
*****************************************************************

ITERATION  2
A1=   2.06325 B1=     .10590 C1=  -3.95269 D1=    1.78335
COEFFICIENTS FROM CURVE FITTING
A2=    .42003 B2=     .02152 C2=   -.80476 D2=     .36317
NUSSELT NUMBER=   4.91253
DIFFERENCE=     .00049
COEFFICIENTS FROM  2. ITERATION
A3=   2.06344 B3=     .10572 C3=  -3.95344 D3=    1.78410
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.063 2.036 1.940 1.787 1.587 1.350 1.089  .812  .531  .256 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************

PRANDTL NUMBER=         .001
REYNOLDS NUMBER=         30000.0
PECLET NUMBER=            30.0

*****************************************************************

S=     17.600
N=     26.510

*****************************************************************

ITERATION  1
A1=   2.06344 B1=     .10572 C1=  -3.95344 D1=    1.78410
COEFFICIENTS FROM CURVE FITTING
A2=    .39449 B2=     .01939 C2=   -.75482 D2=     .34104
NUSSELT NUMBER=   5.39952
COEFFICIENTS FROM  1. ITERATION
A3=   2.13011 B3=     .10473 C3=  -4.07567 D3=    1.84149
*****************************************************************

ITERATION  2
A1=   2.13011 B1=     .10473 C1=  -4.07567 D1=    1.84149
COEFFICIENTS FROM CURVE FITTING
A2=    .40707 B2=     .01993 C2=   -.77875 D2=     .35187
NUSSELT NUMBER=   5.23294
DIFFERENCE=     .16658
COEFFICIENTS FROM  2. ITERATION
A3=   2.13020 B3=     .10433 C3=  -4.07519 D3=    1.84133
*****************************************************************

ITERATION  3
A1=   2.13020 B1=     .10433 C1=  -4.07519 D1=    1.84133
COEFFICIENTS FROM CURVE FITTING
A2=    .40707 B2=     .01993 C2=   -.77875 D2=     .35187
NUSSELT NUMBER=   5.23293
DIFFERENCE=   0.00000
COEFFICIENTS FROM  3. ITERATION
A3=   2.13021 B3=     .10431 C3=  -4.07518 D3=    1.84134
VALUES FOR TEMPERATURE DISTRIBUTION
```

```
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.130 2.101 2.002 1.844 1.637 1.393 1.123  .837  .548  .265 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************

PRANDTL NUMBER=       .001
REYNOLDS NUMBER=     50000.0
PECLET NUMBER=         50.0

*****************************************************************

S=     26.620
N=     39.910

*****************************************************************

ITERATION  1
A1=   2.06344 B1=    .10572 C1=  -3.95344 D1=   1.78410
COEFFICIENTS FROM CURVE FITTING
A2=    .37947 B2=    .01878 C2=   -.72569 D2=    .32757
NUSSELT NUMBER=   5.67157
COEFFICIENTS FROM  1. ITERATION
A3=   2.15220 B3=    .10652 C3=  -4.11584 D3=   1.85789
*****************************************************************

ITERATION  2
A1=   2.15220 B1=    .10652 C1=  -4.11584 D1=   1.85789
COEFFICIENTS FROM CURVE FITTING
A2=    .39573 B2=    .01953 C2=   -.75658 D2=    .34146
NUSSELT NUMBER=   5.43831
DIFFERENCE=     .23325
COEFFICIENTS FROM  2. ITERATION
A3=   2.15212 B3=    .10624 C3=  -4.11457 D3=   1.85698
*****************************************************************

ITERATION  3
A1=   2.15212 B1=    .10624 C1=  -4.11457 D1=   1.85698
COEFFICIENTS FROM CURVE FITTING
A2=    .39572 B2=    .01953 C2=   -.75655 D2=    .34143
NUSSELT NUMBER=   5.43839
DIFFERENCE=     .00008
COEFFICIENTS FROM  3. ITERATION
A3=   2.15210 B3=    .10624 C3=  -4.11443 D3=   1.85687
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.152 2.123 2.023 1.863 1.655 1.408 1.135  .847  .554  .268 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
```

```
DTL NUMBER=        .001
OLDS NUMBER=        70000.0
ET NUMBER=           70.0

**************************************************************

  35.040
  52.180

**************************************************************

ATION  1
  2.15210 B1=     .10624 C1=  -4.11443 D1=    1.85687
FICIENTS FROM CURVE FITTING
   .38369 B2=     .01834 C2=   -.73003 D2=     .32819
ELT NUMBER=   5.63536
FICIENTS FROM  1. ITERATION
  2.16227 B3=     .10336 C3=  -4.11399 D3=    1.84950
**************************************************************

ATION  2
  2.16227 B1=     .10336 C1=  -4.11399 D1=    1.84950
FICIENTS FROM CURVE FITTING
   .38572 B2=     .01847 C2=   -.73349 D2=     .32949
ELT NUMBER=   5.60422
ERENCE=     .03114
FICIENTS FROM  2. ITERATION
  2.16169 B3=     .10352 C3=  -4.11066 D3=    1.84658
**************************************************************

ATION  3
  2.16169 B1=     .10352 C1=  -4.11066 D1=    1.84658
FICIENTS FROM CURVE FITTING
   .38568 B2=     .01848 C2=   -.73336 D2=     .32939
ELT NUMBER=   5.60455
ERENCE=     .00033
FICIENTS FROM  3. ITERATION
  2.16157 B3=     .10361 C3=  -4.11016 D3=    1.84611
ES FOR TEMPERATURE DISTRIBUTION
VALUES
00  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
A VALUES
61 2.132 2.032 1.872 1.663 1.416 1.142  .853  .559  .271  .001
**************************************************************


ULATION OF NUSSELT NUMBER
Y DEVELOPED TURBULENT FLOW IN PIPE
TANT WALL TEMPERATURE
**************************************************************
DTL NUMBER=        .001
OLDS NUMBER=       100000.0
ET NUMBER=          100.0

**************************************************************

  46.970
  69.270

**************************************************************
ATION  1
  2.16157 B1=     .10361 C1=  -4.11016 D1=    1.84611
```

```
COEFFICIENTS FROM CURVE FITTING
A2=     .36975 B2=     .01858 C2=    -.70569 D2=     .31790
NUSSELT NUMBER=   5.87549
COEFFICIENTS FROM  1. ITERATION
A3=   2.17247 B3=     .10920 C3=  -4.14633 D3=   1.86781
************************************************************
ITERATION  2
A1=   2.17247 B1=     .10920 C1=  -4.14633 D1=   1.86781
COEFFICIENTS FROM CURVE FITTING
A2=     .37171 B2=     .01866 C2=    -.70932 D2=     .31949
NUSSELT NUMBER=   5.84431
DIFFERENCE=     .03117
COEFFICIENTS FROM  2. ITERATION
A3=   2.17239 B3=     .10906 C3=  -4.14550 D3=   1.86723
************************************************************
ITERATION  3
A1=   2.17239 B1=     .10906 C1=  -4.14550 D1=   1.86723
COEFFICIENTS FROM CURVE FITTING
A2=     .37170 B2=     .01866 C2=    -.70929 D2=     .31947
NUSSELT NUMBER=   5.84439
DIFFERENCE=     .00007
COEFFICIENTS FROM  3. ITERATION
A3=   2.17238 B3=     .10906 C3=  -4.14540 D3=   1.86714
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.172 2.143 2.043 1.882 1.672 1.423 1.148  .857  .562  .273  .003
************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
************************************************************
PRANDTL NUMBER=         .001
REYNOLDS NUMBER=       300000.0
PECLET NUMBER=           300.0

************************************************************
S=   116.400
N=   165.120

************************************************************
ITERATION  1
A1=   2.17238 B1=     .10906 C1=  -4.14540 D1=   1.86714
COEFFICIENTS FROM CURVE FITTING
A2=     .30084 B2=     .01330 C2=    -.56321 D2=     .24999
NUSSELT NUMBER=   7.28018
COEFFICIENTS FROM  1. ITERATION
A3=   2.19021 B3=     .09684 C3=  -4.10033 D3=   1.82002
************************************************************
ITERATION  2
A1=   2.19021 B1=     .09684 C1=  -4.10033 D1=   1.82002
COEFFICIENTS FROM CURVE FITTING
A2=     .30406 B2=     .01352 C2=    -.56774 D2=     .25109
NUSSELT NUMBER=   7.19447
DIFFERENCE=     .08571
COEFFICIENTS FROM  2. ITERATION
A3=   2.18756 B3=     .09728 C3=  -4.08465 D3=   1.80646
************************************************************
ITERATION  3
```

```
A1=   2.18756 B1=     .09728 C1=  -4.08465 D1=    1.80646
COEFFICIENTS FROM CURVE FITTING
A2=    .30390 B2=     .01357 C2=   -.56727 D2=     .25072
NUSSELT NUMBER=   7.19643
DIFFERENCE=     .00195
COEFFICIENTS FROM  3. ITERATION
A3=   2.18705 B3=     .09766 C3=  -4.08237 D3=    1.80429
******************************************************************
ITERATION  4
A1=   2.18705 B1=     .09766 C1=  -4.08237 D1=    1.80429
COEFFICIENTS FROM CURVE FITTING
A2=    .30388 B2=     .01358 C2=   -.56719 D2=     .25065
NUSSELT NUMBER=   7.19676
DIFFERENCE=     .00032
COEFFICIENTS FROM  4. ITERATION
A3=   2.18695 B3=     .09775 C3=  -4.08199 D3=    1.80391
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.186 2.157 2.057 1.897 1.688 1.440 1.165  .873  .576  .283  .006
      .001        300000.0          300.0
     7.19676     -6.90775     12.61153     5.70378
******************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
******************************************************************
PRANDTL NUMBER=        .001
REYNOLDS NUMBER=      500000.0
PECLET NUMBER=          500.0

******************************************************************
S=   177.830
N=   247.000

******************************************************************
ITERATION  1
A1=   2.17238 B1=     .10906 C1=  -4.14540 D1=    1.86714
COEFFICIENTS FROM CURVE FITTING
A2=    .25408 B2=     .01208 C2=   -.47777 D2=     .21221
NUSSELT NUMBER=   8.67019
COEFFICIENTS FROM  1. ITERATION
   2.20296     .10480  -4.14240    1.83993
******************************************************************
ITERATION  2
A1=   2.20296 B1=     .10480 C1=  -4.14240 D1=    1.83993
COEFFICIENTS FROM CURVE FITTING
A2=    .25834 B2=     .01240 C2=   -.48478 D2=     .21464
NUSSELT NUMBER=   8.51803
DIFFERENCE=     .15216
COEFFICIENTS FROM  2. ITERATION
   2.20055     .10569  -4.12941    1.82837
******************************************************************
ITERATION  3
A1=   2.20055 B1=     .10569 C1=  -4.12941 D1=    1.82837
COEFFICIENTS FROM CURVE FITTING
A2=    .25822 B2=     .01244 C2=   -.48443 D2=     .21437
NUSSELT NUMBER=   8.52005
DIFFERENCE =0.00202
```

```
COEFFICIENTS FROM 3. ITERATION
   2.20009     .10605  -4.12744   1.82647
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.200 2.171 2.070 1.909 1.699 1.449 1.172  .878  .578  .283 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*************************************************************

PRANDTL NUMBER=      0.000
REYNOLDS NUMBER=         2000.0
PECLET NUMBER=            0.0

*************************************************************

S=     1.000
N=     0.000

*************************************************************

ITERATION  1
A1=   1.80621 B1=    .02564 C1=  -3.81924 D1=   1.99146
COEFFICIENTS FROM CURVE FITTING
A2=    .49418 B2=    .00692 C2=  -1.04551 D2=    .54552
NUSSELT NUMBER=   3.64870
COEFFICIENTS FROM  1. ITERATION
A3=   1.80315 B3=    .02527 C3=  -3.81477 D3=   1.99045
*************************************************************

ITERATION  2
A1=   1.80315 B1=    .02527 C1=  -3.81477 D1=   1.99045
COEFFICIENTS FROM CURVE FITTING
A2=    .49326 B2=    .00687 C2=  -1.04357 D2=    .54456
NUSSELT NUMBER=   3.65575
DIFFERENCE=    .00705
COEFFICIENTS FROM  2. ITERATION
A3=   1.80324 B3=    .02512 C3=  -3.81505 D3=   1.99079
*************************************************************

ITERATION  3
A1=   1.80324 B1=    .02512 C1=  -3.81505 D1=   1.99079
COEFFICIENTS FROM CURVE FITTING
A2=    .49327 B2=    .00686 C2=  -1.04359 D2=    .54458
NUSSELT NUMBER=   3.65572
DIFFERENCE=    .00003
COEFFICIENTS FROM  3. ITERATION
A3=   1.80326 B3=    .02509 C3=  -3.81508 D3=   1.99083
VALUES FOR TEMPERATURE DISTRIBUTION
ETA VALUES
0.000 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
THETA VALUES
1.803 1.769 1.671 1.521 1.330 1.110 0.874 0.634 0.400 0.186 0.004
*****************************************************************


CALCULATION OF NUSSELT NUMBER
```

```
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=      0.000
REYNOLDS NUMBER=        3000.0
PECLET NUMBER=           0.0

*****************************************************************
S=      2.860
N=      3.331

*****************************************************************
ITERATION  1
A1=   1.92590 B1=    .15095 C1=  -3.84403 D1=    1.76503
COEFFICIENTS FROM CURVE FITTING
A2=     .43602 B2=    .03405 C2=   -.87766 D2=     .40724
NUSSELT NUMBER=   4.43177
COEFFICIENTS FROM  1. ITERATION
   1.93237    .15091  -3.88959   1.80479
*****************************************************************
ITERATION  2
A1=   1.93237 B1=    .15091 C1=  -3.88959 D1=    1.80479
COEFFICIENTS FROM CURVE FITTING
A2=     .43657 B2=    .03378 C2=   -.87938 D2=     .40869
NUSSELT NUMBER=   4.42919
DIFFERENCE=     .00258
COEFFICIENTS FROM  2. ITERATION
   1.93368    .14965  -3.89495   1.81019
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 1.933 1.911 1.822 1.676 1.486 1.261 1.012  .750  .487  .233 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=      0.000
REYNOLDS NUMBER=        8000.0
PECLET NUMBER=           0.0

*****************************************************************
S=      6.430
N=      9.000

*****************************************************************
ITERATION  1
A1=   2.04644 B1=    .10982 C1=  -3.92399 D1=    1.76706
COEFFICIENTS FROM CURVE FITTING
A2=     .42690 B2=    .02607 C2=   -.83378 D2=     .38061
NUSSELT NUMBER=   4.80995
COEFFICIENTS FROM  1. ITERATION
   2.05341    .12543  -4.01046   1.83075
*****************************************************************
ITERATION  2
A1=   2.05341 B1=    .12543 C1=  -4.01046 D1=    1.83075
COEFFICIENTS FROM CURVE FITTING
A2=     .42774 B2=    .02598 C2=   -.83670 D2=     .38281
NUSSELT NUMBER=   4.80450
```

```
DIFFERENCE=     .00544
COEFFICIENTS FROM  2. ITERATION
   2.05510    .12485  -4.01994   1.83922
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.055 2.029 1.933 1.780 1.579 1.342 1.080  .803  .523  .252 0.000
****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
****************************************************************
PRANDTL NUMBER=       0.000
REYNOLDS NUMBER=        10000.0
PECLET NUMBER=             0.0

****************************************************************
S=      7.560
N=     10.930

****************************************************************
ITERATION  1
A1=   2.06344 B1=     .10572 C1=  -3.95344 D1=    1.78410
COEFFICIENTS FROM CURVE FITTING
A2=     .42709 B2=     .02527 C2=   -.83396 D2=     .38147
NUSSELT NUMBER=   4.84789
COEFFICIENTS FROM  1. ITERATION
   2.07049    .12252  -4.04295   1.84935
****************************************************************
ITERATION  2
A1=   2.07049 B1=     .12252 C1=  -4.04295 D1=    1.84935
COEFFICIENTS FROM CURVE FITTING
A2=     .42795 B2=     .02519 C2=   -.83699 D2=     .38374
NUSSELT NUMBER=   4.84215
DIFFERENCE=     .00574
COEFFICIENTS FROM  2. ITERATION
   2.07222    .12201  -4.05285   1.85813
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.072 2.045 1.949 1.794 1.591 1.352 1.087  .809  .527  .253 0.000
****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
****************************************************************
PRANDTL NUMBER=       0.000
REYNOLDS NUMBER=        30000.0
PECLET NUMBER=             0.0

****************************************************************
S=     17.600
N=     26.510

****************************************************************
ITERATION  1
```

```
A1=   2.13021 B1=     .10431 C1=  -4.07518 D1=    1.84134
COEFFICIENTS FROM CURVE FITTING
A2=     .42554 B2=     .02437 C2=   -.82928 D2=     .37932
NUSSELT NUMBER=   5.02200
COEFFICIENTS FROM  1. ITERATION
   2.13706     .12239  -4.16466    1.90498
*******************************************************************
ITERATION  2
A1=   2.13706 B1=     .12239 C1=  -4.16466 D1=    1.90498
COEFFICIENTS FROM CURVE FITTING
A2=     .42640 B2=     .02434 C2=   -.83234 D2=     .38156
NUSSELT NUMBER=   5.01579
DIFFERENCE=     .00620
COEFFICIENTS FROM  2. ITERATION
   2.13876     .12209  -4.17486    1.91386
*******************************************************************
ITERATION  3
A1=   2.13876 B1=     .12209 C1=  -4.17486 D1=    1.91386
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.138 2.111 2.011 1.851 1.642 1.395 1.122  .834  .544  .262 0.000
*******************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*******************************************************************
PRANDTL NUMBER=        0.000
REYNOLDS NUMBER=         50000.0
PECLET NUMBER=               0.0

*******************************************************************
S=     26.620
N=     39.910

*******************************************************************
ITERATION  1
A1=   2.15210 B1=     .10624 C1=  -4.11443 D1=    1.85687
COEFFICIENTS FROM CURVE FITTING
A2=     .42461 B2=     .02445 C2=   -.82653 D2=     .37742
NUSSELT NUMBER=   5.08418
COEFFICIENTS FROM  1. ITERATION
   2.15881     .12432  -4.20228    1.91888
*******************************************************************
ITERATION  2
A1=   2.15881 B1=     .12432 C1=  -4.20228 D1=    1.91888
COEFFICIENTS FROM CURVE FITTING
A2=     .42546 B2=     .02443 C2=   -.82955 D2=     .37961
NUSSELT NUMBER=   5.07792
DIFFERENCE=     .00626
COEFFICIENTS FROM  2. ITERATION
   2.16047     .12409  -4.21242    1.92767


VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
```

```
 2.160 2.132 2.032 1.870 1.659 1.410 1.134  .844  .550  .265 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=      0.000
REYNOLDS NUMBER=       70000.0
PECLET NUMBER=           0.0

*****************************************************************
S=     35.040
N=     52.180

*****************************************************************
ITERATION  1
A1=    2.16157 B1=     .10361 C1=  -4.11016 D1=    1.84611
COEFFICIENTS FROM CURVE FITTING
A2=     .42370 B2=     .02457 C2=   -.82366 D2=     .37531
NUSSELT NUMBER=   5.12150
COEFFICIENTS FROM  1. ITERATION
   2.16999    .12585  -4.21840   1.92219
*****************************************************************
ITERATION  2
A1=    2.16999 B1=     .12585 C1=  -4.21840 D1=    1.92219
COEFFICIENTS FROM CURVE FITTING
A2=     .42476 B2=     .02456 C2=   -.82743 D2=     .37805
NUSSELT NUMBER=   5.11352
DIFFERENCE=     .00798
COEFFICIENTS FROM  2. ITERATION
   2.17206    .12561  -4.23111   1.93317
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.172 2.144 2.043 1.881 1.669 1.418 1.141  .849  .554  .267 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=      0.000
REYNOLDS NUMBER=      100000.0
PECLET NUMBER=           0.0

*****************************************************************
S=     46.970
N=     69.270

*****************************************************************
ITERATION  1
A1=    2.17238 B1=     .10906 C1=  -4.14540 D1=    1.86714
COEFFICIENTS FROM CURVE FITTING
A2=     .42291 B2=     .02461 C2=   -.82117 D2=     .37356
NUSSELT NUMBER=   5.15671
COEFFICIENTS FROM  1. ITERATION
   2.18086    .12693  -4.23458   1.92638
*****************************************************************
```

```
ITERATION  2
A1=   2.18086 B1=    .12693 C1=  -4.23458 D1=   1.92638
COEFFICIENTS FROM CURVE FITTING
A2=    .42402 B2=    .02468 C2=   -.82505 D2=    .37628
NUSSELT NUMBER=   5.14782
DIFFERENCE=    .00888
COEFFICIENTS FROM  2. ITERATION
   2.18279    .12705  -4.24724   1.93707
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.182 2.154 2.053 1.890 1.678 1.426 1.148  .854  .557  .268 0.000
*****************************************************************


CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*****************************************************************
PRANDTL NUMBER=      0.000
REYNOLDS NUMBER=      300000.0
PECLET NUMBER=            0.0

*****************************************************************
S=   116.400
N=   165.120

*****************************************************************
ITERATION  1
A1=   2.18695 B1=    .09775 C1=  -4.08199 D1=   1.80391
COEFFICIENTS FROM CURVE FITTING
A2=    .41917 B2=    .02511 C2=   -.80896 D2=    .36452
NUSSELT NUMBER=   5.25739
COEFFICIENTS FROM  1. ITERATION
   2.20375    .13204  -4.25305   1.91647
*****************************************************************
ITERATION  2
A1=   2.20375 B1=    .13204 C1=  -4.25305 D1=   1.91647
COEFFICIENTS FROM CURVE FITTING
A2=    .42133 B2=    .02527 C2=   -.81655 D2=    .36981
NUSSELT NUMBER=   5.23933
DIFFERENCE=    .01806
COEFFICIENTS FROM  2. ITERATION
   2.20753    .13243  -4.27819   1.93757
*****************************************************************
ITERATION  3
A1=   2.20753 B1=    .13243 C1=  -4.27819 D1=   1.93757
COEFFICIENTS FROM CURVE FITTING
A2=    .42165 B2=    .02518 C2=   -.81754 D2=    .37058
NUSSELT NUMBER=   5.23717
DIFFERENCE=    .00215
COEFFICIENTS FROM  3. ITERATION
   2.20829    .13189  -4.28162   1.94082
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.208 2.180 2.078 1.914 1.700 1.446 1.165  .868  .567  .273 0.000
*****************************************************************
```

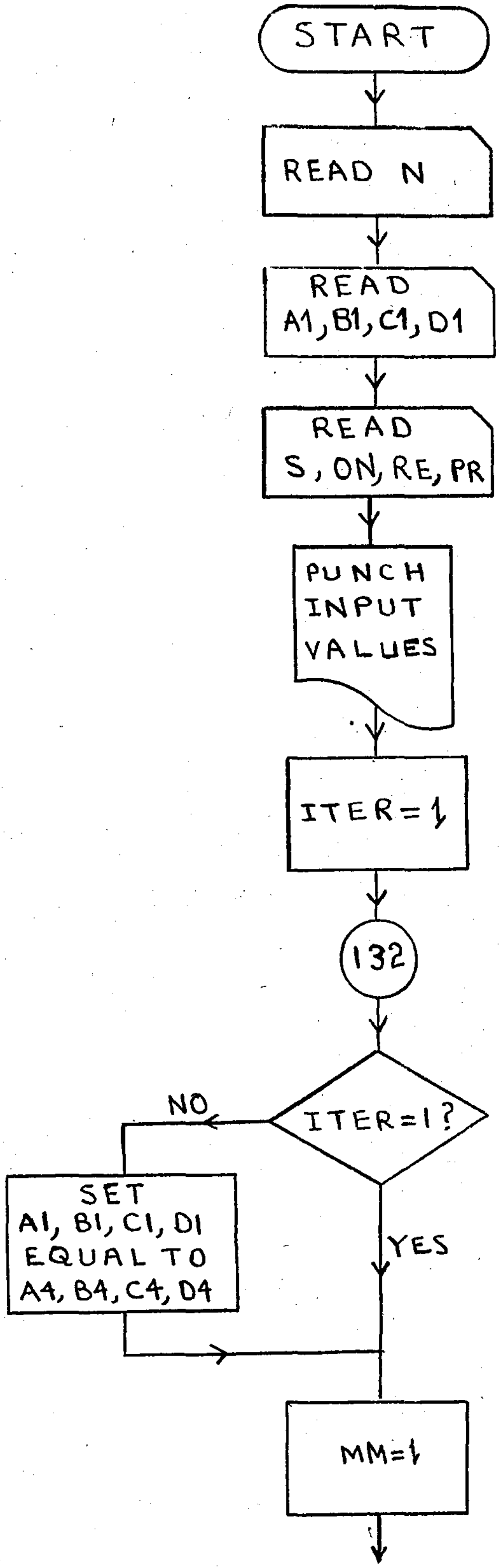
```
CALCULATION OF NUSSELT NUMBER
FULLY DEVELOPED TURBULENT FLOW IN PIPE
CONSTANT WALL TEMPERATURE
*************************************************************************
PRANDTL NUMBER=      0.000
REYNOLDS NUMBER=      500000.0
PECLET NUMBER=           0.0

*************************************************************************
S=   177.830
N=   247.000

*************************************************************************
ITERATION  1
A1=   2.20055 B1=     .10569 C1=  -4.12941 D1=    1.82837
COEFFICIENTS FROM CURVE FITTING
A2=     .41840 B2=     .02537 C2=   -.80659 D2=     .36264
NUSSELT NUMBER=   5.29143
COEFFICIENTS FROM  1. ITERATION
   2.21395    .13428  -4.26805   1.91892
*************************************************************************
ITERATION  2
A1=   2.21395 B1=     .13428 C1=  -4.26805 D1=    1.91892
COEFFICIENTS FROM CURVE FITTING
A2=     .42014 B2=     .02553 C2=   -.81272 D2=     .36689
NUSSELT NUMBER=   5.27669
DIFFERENCE=     .01474
COEFFICIENTS FROM  2. ITERATION
   2.21698    .13471  -4.28850   1.93599
*************************************************************************
ITERATION  3
A1=   2.21698 B1=     .13471 C1=  -4.28850 D1=    1.93599
COEFFICIENTS FROM CURVE FITTING
A2=     .42040 B2=     .02545 C2=   -.81352 D2=     .36751
NUSSELT NUMBER=   5.27494
DIFFERENCE=     .00174
COEFFICIENTS FROM  3. ITERATION
   2.21759    .13429  -4.29129   1.93863
VALUES  FOR TEMPERATURE DISTRIBUTION
ETA VALUES
 0.000  .100  .200  .300  .400  .500  .600  .700  .800  .900 1.000
THETA VALUES
 2.217 2.190 2.088 1.924 1.708 1.454 1.172  .873  .571  .275 0.000
*************************************************************************
```

APPENDIX C

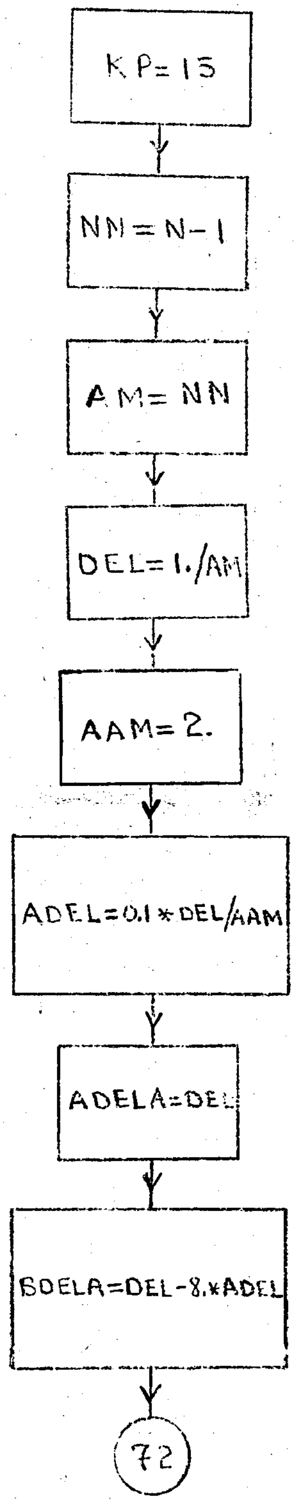
THE FLOW DIAGRAM AND THE COMPUTER PROGRAM

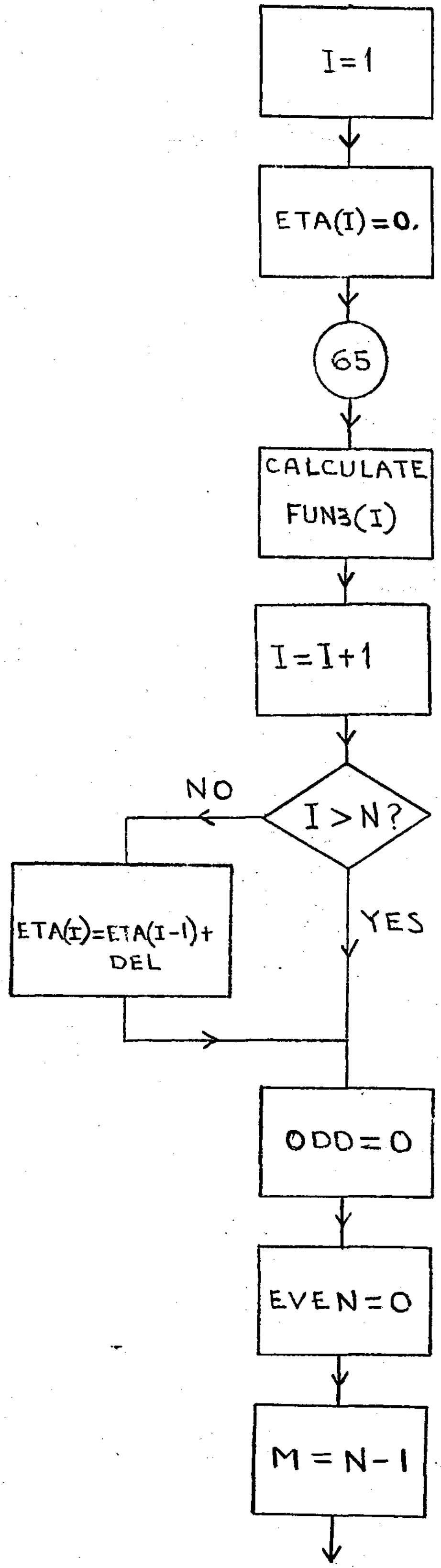
DEFINITIONS OF THE TERMS USED IN THE PROGRAM

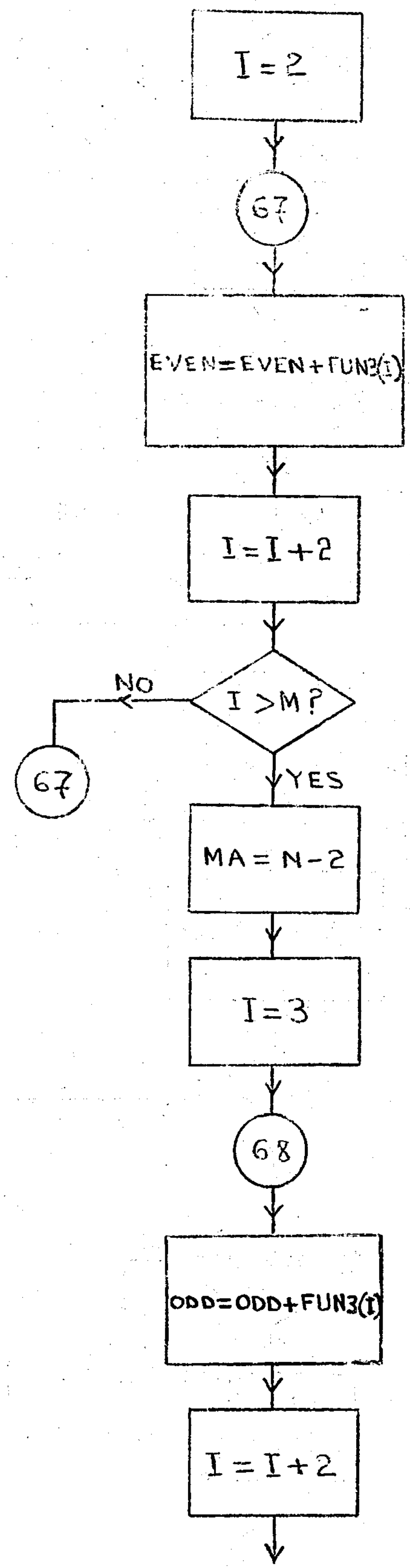
N	Number of integration increments
A1, B1, C1, D1	Coefficients of the approximate temperature profile (θ)
s	Flow parameter (s)
ON	Flow parameter (n)
PR	Prandtl number
RE	Reynolds number
A4, B4, C4, D4	Coeffients of the temperature profile calculated in the previous iteration
DEL	Integration interval
ADEL	Control term for integration when DEL = ADEL, integration is stopped
ADELA	Control term for integration when ADELA = DEL the lower limit of integral is equal to one
BDELA	Control term for integration when BDELA = DEL integration interval is increased
ETA(I)	η
FUN3(I)	$F(\eta)$
ONU	Nusselt number
AA, BB, CC, DD	Coefficients of the third degree polynomial fitted

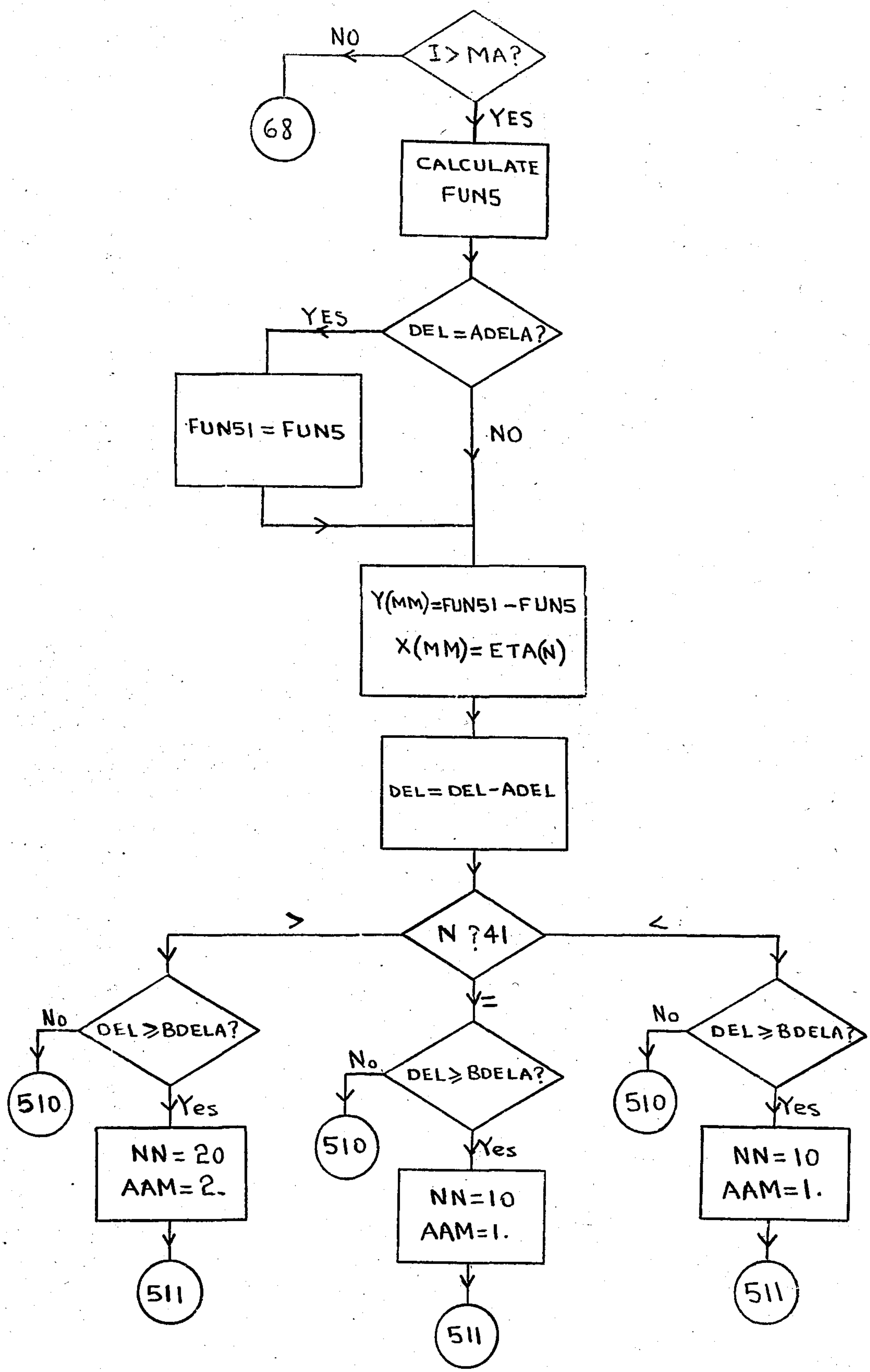


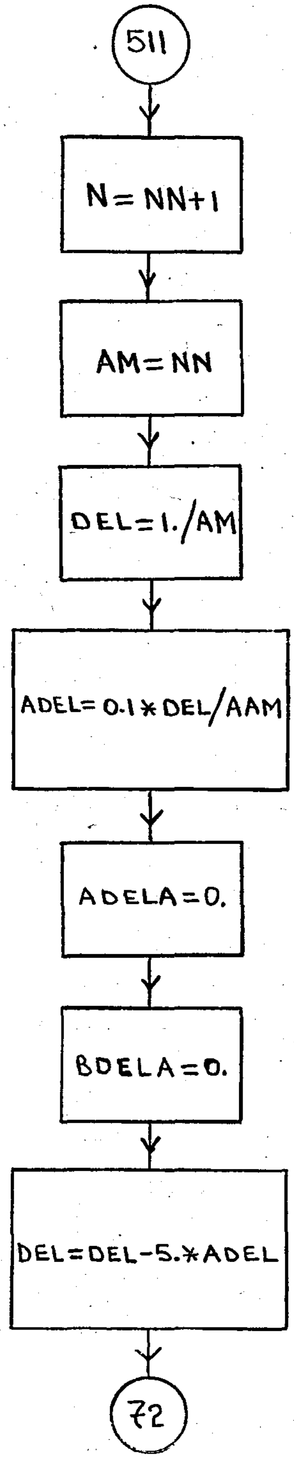
START
READ N
READ
A1, B1, C1, D1
READ
S, ON, RE, PR
PUNCH
INPUT
VALUES
ITER=1
132
ITER=1?
NO
YES
SET
A1, B1, C1, D1
EQUAL TO
A4, B4, C4, D4
MM=1

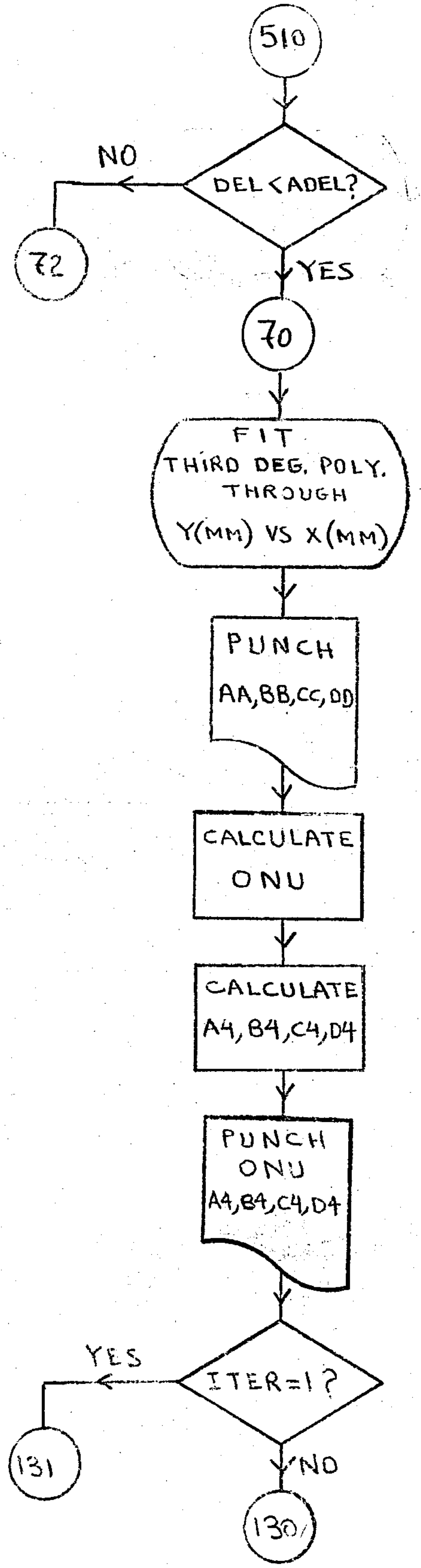

KP=15
NN=N-1
AM=NN
DEL=1./AM
AAM=2.
ADEL=0.1*DEL/AAM
ADELA=DEL
BDELA=DEL-8.*ADEL
72

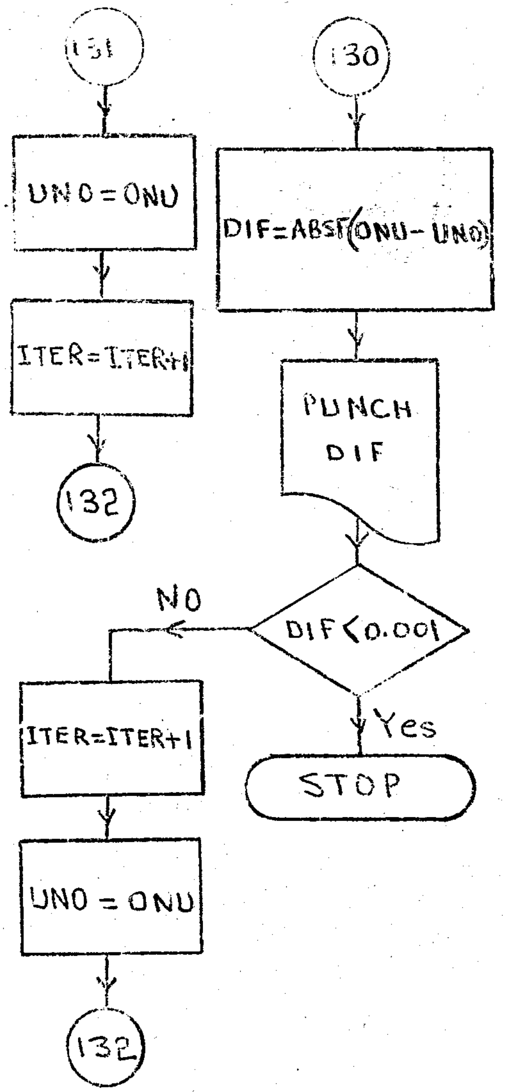

I=1
ETA(I)=0.
65
CALCULATE FUN3(I)
I=I+1
I > N?
NO
YES
ETA(I)=ETA(I-1)+ DEL
ODD=0
EVEN=0
M = N-1


I=2
67
EVEN=EVEN+FUN3(I)
I=I+2
I>M?
NO
67
YES
MA=N-2
I=3
68
ODD=ODD+FUN3(I)
I=I+2


I > MA?
NO
68
YES
CALCULATE FUN5
DEL = ADELA?
YES
FUN51 = FUN5
NO
Y(MM)=FUN51 − FUN5
X(MM)= ETA(N)
DEL = DEL−ADEL
N ?41
>
<
=
DEL ≥ BDELA?
No
510
Yes
NN = 20
AAM = 2.
511
DEL ≥ BDELA?
No
510
Yes
NN=10
AAM=1.
511
DEL ≥ BDELA?
No
510
Yes
NN=10
AAM=1.
511


511
N=NN+1
AM=NN
DEL=1./AM
ADEL=0.1*DEL/AAM
ADELA=0.
BDELA=0.
DEL=DEL-5.*ADEL
72


510
NO
DEL < ADEL?
72
YES
70
FIT
THIRD DEG. POLY.
THROUGH
Y(MM) VS X(MM)
PUNCH
AA,BB,CC,DD
CALCULATE
ONU
CALCULATE
A4,B4,C4,D4
PUNCH
ONU
A4,B4,C4,D4
YES
ITER=1?
131
NO
130



131
UNO=ONU
ITER=ITER+1
132
130
DIF=ABSF(ONU-UNO)
PUNCH DIF
DIF<0.001
NO
Yes
STOP
ITER=ITER+1
UNO = ONU
132

```
)ELETTULI1


LDISKTULI1

 INPUT PROGRAM

 N INTEGRATION INCREMENTS

 VALUES OF N 21 OR 41 OR 81

 A1,B1,C1,D1 ARE THE COEFFICIENTS OF THIRD DEGREE POLYNOMIAL

 S PARAMETER FOR THE PA1 PROFILE

 ON (N) PARAMETER FOR THE PAI PROFILE

 PR PRANDTL NUMBER

 RE REYNOLDS NUMBER

      DIMENSION ETA(161),X(161),Y(161),P1(161),P2(161),P3(161),FUN3(161)
     1,THETA(21),SM(2)
      COMMON IY,KY,A1,B1,C1,D1,S,ON,PR,RE,PE,A4,B4,C4,D4,A3,B3,C3,D3,C,
     1D,B,UU,ITER,X,Y,AAM,N,UNO,ETA,P1,P2,P3,FUN3,THETA,SM
      ITE2=1
      READ 3,N
  182 READ 51,A1,B1,C1,D1
      READ 61, S,ON,PR
      READ 170,RE
      PRINT 307
      PRINT 320
      PRINT 172
      PRINT 151,S,ON
      PRINT 316,PR
      PRINT 171, RE
      PRINT 320
      PE=RE*PR
      PUNCH 330
      PUNCH 331
      PUNCH 332,PR,RE,PE
      PUNCH 331
      PUNCH 333,S,ON
      ITER=1
    3 FORMAT(I4)
   51 FORMAT(4F10.5)
   61 FORMAT(3F10.3)
  151 FORMAT(2X,3F10.3)
  170 FORMAT(F20.1)
  171 FORMAT(2X,7HREYNOLD,1X,7HNUMBER=,F13.1,/)
  172 FORMAT(9X,1HS,9X,1HN)
  307 FORMAT(1H1,11HCALCULATION,1X,2HOF,1X,7HNUSSELT,1X,6HNUMBER,
     11X,9HTURBULENT,1X,13HFLOW*CONSTANT,1X,4HWALL,1X,12HTEMPERATURE*,
     21X,5HFULLY,1X,9HDEVELOPED,1X,4HCASE,/)
  316 FORMAT(2X,7HPRANDTL,1X,7HNUMBER=,F10.3)
  330 FORMAT(/,11HCALCULATION,1X,2HOF,1X,7HNUSSELT,1X,6HNUMBER,/,
     15HFULLY,1X,9HDEVELOPED,1X,9HTURBULENT,1X,4HFLOW,1X,2HIN,1X,4HPIPE,
     2/,8HCONSTANT,1X,4HWALL,1X,11HTEMPERATURE)
```

```
 332 FORMAT(7HPRANDTL,1X,7HNUMBER=,F10.3,/,
    18HREYNOLDS,1X,7HNUMBER=,F13.1,/,6HPECLET,1X,7HNUMBER=,F13.1,/)
 333 FORMAT(2HS=,F10.3,/,2HN=,F10.3,/)
 320 FORMAT(65(1H*))
     CALL LINK(TULI2)
     END


*DELETTULI2


*LDISKTULI2
C
C THIS PROGRAM INTEGRATES F(ETA) BY SIMPSON RULE
C
C UPPER LIMIT=1
C
C LOWER LIMIT=ETA
C
C DEL INTEGRATION INTERVAL
C
C KP NUMBER OF THE LOWER LIMIT OF THE INTEGRAL
C
C WHEN DEL=ADEL INTEGRATION STOPS
C
C WHEN DEL=ADELA THE LOWER LIMIT HAS A VALUE OF ONE
C
C WHEN DEL=BDELA NUMBER OF INTEGRATION INCREMENT IS CHANGED
C
C A4,B4,C4,D4 ARE THE COEFFICIENTS OF THE TEMPERATURE DISTRIBUTION
C
C CALCULATED IN THE PREVIOUS ITERATION
C
C FUN3=F(ETA)
C
C FUN5 INTEGRAL VALUE OF F(ETA)
C
C FUN51 INTEGRAL VALUE OF F(ETA) WHEN LOWER LIMIT=1
C
     DIMENSION ETA(161),X(161),Y(161),P1(161),P2(161),P3(161),FUN3(161)
    1,THETA(21),SM(2)

     COMMON IY,KY,A1,B1,C1,D1,S,ON,PR,RE,PE,A4,B4,C4,D4,A3,B3,C3,D3,C,
    1D,B,UU,ITER,X,Y,AAM,N,UNO,ETA,P1,P2,P3,FUN3,THETA,SM
 132 CONTINUE
     IF(ITER-1) 133,134,133
 133 A1=A4
     B1=B4
     C1=C4
     D1=D4
     PRINT 320
 134 CONTINUE
     PRINT 305,ITER
     PRINT 173,A1,B1,C1,D1
     PUNCH 331
     PUNCH 334,ITER
     PUNCH 335,A1,B1,C1,D1
     C=S-1.0
     D=ON-S
```

```
      A=ON+1.0
      F=ON+S
      UU=2.*A/F
      AS1=D/(4.*B)
      AS2=2.*ON+2.
      AS3=C/(B*AS2)
      AS4=D/(5.*B)
      AS5=2.*ON+3.
      AS6=C/(B*AS5)
      AS7=D/(6.*B)
      AS8=2.*ON+4.
      AS9=C/(B*AS8)
      AS10=D/(7.*B)
      AS11=2.*ON+5.
      AS12=C/(B*AS11)
      AS13=2.*ON-2.
      MM=1
      KP=15
      NN=N-1
      AM=NN
      DEL=1./AM
      AAM=2.
      ADEL=0.1*DEL/AAM
      ADELA=DEL
      BDELA=DEL-8.*ADEL
      GO TO 72
  511 N=NN+1
      AM=NN
      DEL=1./AM
      ADEL=0.1*DEL/AAM
      ADELA=0.
      BDELA=0.
      DEL=DEL-5.*ADEL
      GO TO 72
C
C INTEGRATES F(ETA) BY SIMPSON RULE
C
   72 CONTINUE
      ETA(1)=0.001
      ETA(2)=DEL
      DO 590 I=3,N
      K=I-1
  590 ETA(I)=ETA(K)+DEL
      DO 65 I=1,N
   65 FUN3(I)=(A1*((ETA(I)**2)/2.-AS1*ETA(I)**4-AS3*ETA(I)**AS2)+B1*
     1((1./3.)*ETA(I)**3-AS4*ETA(I)**5-AS6*ETA(I)**AS5)+C1*((ETA(I)**4)
     2/4.-AS7*ETA(I)**6-AS9*ETA(I)**AS8)+D1*(0.20*ETA(I)**5-AS10*ETA(I)*
     3*7-AS12*ETA(I)**AS11))/(ETA(I)+PR*((S*B)/(D+ON*C*ETA(I)**AS13)-1.)
     4*ETA(I))
      ODD=0.0
      EVEN=0.0
      M=N-1
      DO 67 I=2,M,2
   67 EVEN=EVEN+FUN3(I)
      MA=N-2
      DO 68 I=3,MA,2
   68 ODD=ODD+FUN3(I)
      FUN5=(DEL/3.)*(FUN3(1)+4.*EVEN+2.*ODD+FUN3(N))*UU
      IF(DEL-ADELA) 15,14,15
   14 FUN51=FUN5
   15 CONTINUE
```

```
      X(MM)=ETA(N)
      MM=MM+1
      DEL=DEL-ADEL
      IF(N-41) 508,507,601
  508 IF(DEL-BDELA) 509,510,510
  509 NN=10
      AAM=1.
      GO TO 511
  510 IF(DEL-ADEL) 70,72,72
  507 IF(DEL-BDELA) 548,510,510
  548 NN=10
      AAM=1.
      GO TO 511
  601 IF(DEL-BDELA) 602,510,510
  602 NN=20
      AAM=2.
      GO TO 511
   70 CONTINUE
      X(KP)=0.
      Y(KP)=FUN51
      AAM=KP
      N=KP
      PRINT 311
      PRINT 69,(X(I),I=1,N)
      PRINT 310,(Y(I),I=1,N)
   69 FORMAT(2X,1HX,1X,7HVALUES=,11F10.5,/)
  173 FORMAT(2X,3HA1=,F10.5,2X,3HB1=,F10.5,2X,3HC1=,F10.5,2X,3HD1=,F10.
     15,/)
  305 FORMAT(2X,9HITERATION,2X,I2,/)
  310 FORMAT(2X,1HY,1X,7HVALUES=,11F10.5,/)
  311 FORMAT(2X,1HX,1X,3HAND,1X,1HY,1X,6HVALUES,1X,3HFOR,1X,5HCURVE,1X,
     17HFITTING,/)
  320 FORMAT(65(1H*))
  331 FORMAT(65(1H*))
  334 FORMAT(9HITERATION,1X,I2)
  335 FORMAT(3HA1=,F10.5,1X,3HB1=,F10.5,1X,3HC1=,F10.5,1X,3HD1=,F10.5)
      CALL LINK(TULI3)
      END


*DELETTULI3


*LDISKTULI3
C
C FITS A THIRD DEGREE POLYNOMIAL BY THE METHOD OF LEAST SQUARE
C
C N AND AAM ARE THE NUMBER OF DATA POINTS
C
C Y=AA+BB*X+CC*X**2+DD*X**3
C
      DIMENSION ETA(161),X(161),Y(161),P1(161),P2(161),P3(161),FUN3(161)
     1,THETA(21),SM(2)
      COMMON IY,KY,A1,B1,C1,D1,S,ON,PR,RE,PE,A4,B4,C4,D4,A3,B3,C3,D3,C,
     1D,B,UU,ITER,X,Y,AAM,N,UNO,ETA,P1,P2,P3,FUN3,THETA,SM
  129 DO=AAM
      U1=0.
      DO 7 I=1,N
    7 U1=U1+X(I)
```

```
      DO 8 I=1,N
    8 P1(I)=X(I)-U1
      E1=0.
      DO 9 I=1,N
    9 E1=E1+P1(I)*P1(I)
      U2=0.
      DO 10 I=1,N
   10 U2=U2+X(I)*P1(I)*P1(I)
      U2=U2/E1
      V1=0.
      DO 11 I=1,N
   11 V1=V1+X(I)*P1(I)
      V1=V1/D0
      DO 12 I=1,N
   12 P2(I)=(X(I)-U2)*P1(I)-V1
      E2=0.
      DO 13 I=1,N
   13 E2=E2+P2(I)*P2(I)
      U3=0.
      DO 22 I=1,N
   22 U3=U3+X(I)*P2(I)*P2(I)
      U3=U3/E2
      V2=0.
      DO 23 I=1,N
   23 V2=V2+X(I)*P2(I)*P1(I)
      V2=V2/E1
      DO 50 I=1,N
   50 P3(I)=(X(I)-U3)*P2(I)-V2*P1(I)
      E3=0.
      DO 16 I=1,N
   16 E3=E3+P3(I)*P3(I)
      AS=0.
      DO 17 I=1,N
   17 AS=AS+Y(I)
      AS=AS/D0
      BS=0.
      DO 18 I=1,N
   18 BS=BS+Y(I)*P1(I)
      BS=BS/E1
      CS=0.
      DO 19 I=1,N
   19 CS=CS+Y(I)*P2(I)
      CS=CS/E2
      DS=0.
      DO 20 I=1,N
   20 DS=DS+Y(I)*P3(I)
      DS=DS/E3
      AA=AS+CS*U1*U2-CS*V1-BS*U1-DS*U1*U2*U3+U3*V1*DS+V2*U1*DS
      BB=BS-CS*U1-CS*U2+DS*U1*U2-DS*V1+DS*U1*U3+DS*U2*U3-DS*V2
      CC=CS-DS*U1-DS*U2-DS*U3
      DD=DS
      PRINT 314
      PRINT 21,AA,BB,CC,DD
      PUNCH 336
      PUNCH 337,AA,BB,CC,DD
    2 A3=AA
      B3=BB
      C3=CC
      D3=DD
   21 FORMAT(2X,3HA2=,F10.5,2X,3HB2=,F10.5,2X,3HC2=,F10.5,2X,3HD2=,F10.
     15,/)
```

```
 336 FORMAT(12HCOEFFICIENTS,1X,4HFROM,1X,5HCURVE,1X,7HFITTING)
 337 FORMAT (3HA2=,F10.5,1X,3HB2=,F10.5,1X,3HC2=,F10.5,1X,3HD2=,F10.5)
     CALL LINK(TULI4)
     END


*DELETTULI4


*LDISKTULI4
C
C OUTPUT PROGRAM
C
C CALCULATES NUSSELT NUMBER
C
C ONU NUSSELT NUMBER
C
C CALCULATES TEMPERATURE DISTRIBUTION
C
      DIMENSION ETA(161),X(161),Y(161),P1(161),P2(161),P3(161),FUN3(161)
     1,THETA(21),SM(2)
      COMMON IY,KY,A1,B1,C1,D1,S,ON,PR,RE,PE,A4,B4,C4,D4,A3,B3,C3,D3,C,
     1D,B,UU,ITER,X,Y,AAM,N,UNO,ETA,P1,P2,P3,FUN3,THETA,SM
    4 ETA(1)=1.
      T=2.*UU
      IN=1
      DO 304 I=1,IN
 304  SM(I)= T*(A3*((ETA(I)**2)/2.-D/(4.*B)*ETA(I)**4-(C/(B*(2.*ON+2.)))
     1*ETA(I)**(2.*ON+2.))+B3*((ETA(I)**3)/3.-(D/(5.*B))*ETA(I)**5-(C/(B
     2*(2.*ON+3.)))*ETA(I)**(2.*ON+3.))+C3*((ETA(I)**4)/4.-(D/(6.*B))*
     3ETA(I)**6-(C/(B*(2.*ON+4.)))*ETA(I)**(2.*ON+4.))+D3*((ETA(I)**5)/
     45.-(D/(7.*B))*ETA(I)**7-(C/(B*(2.*ON+5.)))*ETA(I)**(2.*ON+5.)))
      TM=SM(1)
      ONU=1./TM
      A4=A3*ONU
      B4=B3*ONU
      C4=C3*ONU
      D4=D3*ONU
      PRINT 92,ONU
      PUNCH 338,ONU
       IF(ITER-1) 130,131,130
 131  UNO=ONU
      PRINT 156,ITER
      PRINT 155,A4,B4,C4,D4
      PUNCH 340,ITER
      ITER=ITER+1
      PUNCH 341,A4,B4,C4,D4
      CALL LINK(TULI2)
 130  DIF=ABSF(ONU-UNO)
      PRINT 81,DIF
      PUNCH 339,DIF
      PRINT 156,ITER
      PRINT 155,A4,B4,C4,D4
      PUNCH 350,ITER
      PUNCH 351,A4,B4,C4,D4
      IF(DIF-0.001) 135,135,136
 136  ITER=ITER+1
      UNO=ONU
      CALL LINK(TULI2)
```

```
      ETA(1)=0.
      DO 82 I=2,21
      K=I-1
   82 ETA(I)=ETA(K)+.05
      DO 83 I=1,21
   83 THETA(I)=(A4+B4*ETA(I)+C4*(ETA(I)**2)+D4*ETA(I)**3)
      PRINT 308
      PRINT 309,(ETA(I),I=1,11)
      PRINT 87,(THETA(I),I=1,11)
      PRINT 309,(ETA(I),I=12,21)
      PRINT 87,(THETA(I),I=12,21)
      PUNCH 344
      PUNCH 342,(ETA(I),I=1,21,2)
      PUNCH 343,(THETA(I),I=1,21,2)
      ALPR=LOGF(PR)
      ALRE=LOGF(RE)
      ALPE=LOGF(PE)
      PUNCH 345,PR,RE,PE,ONU,ALPR,ALRE,ALPE
      PUNCH 331
  180 CONTINUE
      DO 600 I=1,20
      X(I)=ETA(I)
      Y(I)=THETA(I)
  600 CONTINUE
      X(21)=1.
      Y(21)=0.
      CALL GRAPH2(8.,8.,21,X,Y)
   81 FORMAT(2X,10HDIFFERENCE,1X,7HBETWEEN,1X,7HNUSSELT,1X,8HNUMBERS=,
     1F10.5,/)
   87 FORMAT(2X,6HTHETA=,11F10.5)
   92 FORMAT(2X,7HNUSSELT,1X,7HNUMBER=,F12.6,/)
  155 FORMAT(2X,2HA=,F10.5,2X,2HB=,F10.5,2X,2HC=,F10.5,2X,2HD=,F10.5)
  156 FORMAT(2X,12HCOEFFICIENTS,1X,4HFROM,1X,I2,1H.,1X,9HITERATION,/)
  308 FORMAT(2X,6HVALUES,1X,3HFOR,1X,11HTEMPERATURE,1X,12HDISTRIBUTION,
     1/)
  309 FORMAT(2X,4HETA=,2X,11F10.5)
  331 FORMAT(65(1H*))
  338 FORMAT(7HNUSSELT,1X,7HNUMBER=,F10.5)
  339 FORMAT(11HDIFFERENCE=,F10.5)
  340 FORMAT(12HCOEFFICIENTS,1X,4HFROM,1X,I2,1H.,1X,9HITERATION)
  341 FORMAT(4F10.5)
  342 FORMAT(3HETA,1X,6HVALUES,/,11F6.3)
  343 FORMAT(5HTHETA,1X,6HVALUES,/,11F6.3)
  344 FORMAT(6HVALUES,1X,3HFOR,1X,11HTEMPERATURE,1X,12HDISTRIBUTION)
  345 FORMAT(F10.3,F13.1,F13.1,/,4F12.5)
  350 FORMAT(12HCOEFFICIENTS,1X,4HFROM,1X,I2,1H.,1X,9HITERATION)
  351 FORMAT(4F10.5)
      CALL EXIT
      END
```

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