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Second Report for Research and Modeling of Water Particles in Adverse Weather Simulation Facilities

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1.0 INTRODUCTION TO THE RESEARCH

This report describes a continuation of research into the modeling of water particle freezing for application to adverse weather simulation facilities. The research was initiated in FY1996 to investigate the physics of freezing of submillimeter supercooled water particles or droplets in both natural and artificial or simulated adverse weather environments. The first phase of the research was reported and discussed in a report [1] and a paper [2]. The work has continued into FY1997 and has been expanded to include work done to model three-dimensional ice accretions on surfaces, as well as modeling the near field of water spray clouds produced by air-atomized water spray nozzles. Because of the increased scope of the work, a single report cannot cover all of the work phases. Therefore, the present report covers only the continued research and development of water particulate freezing models and their application in a one-dimensional multiphase flow code to predict water spray freezing in ducted air flows.

The outline of the report is as follows:

Section 2 provides an overview of applications of classical homogeneous nucleation theory to predict supercooled water particle freezing. Specifically, it covers and discusses the *J(T)* and *I(T)* functions (which are identical except for nomenclature used by various authors) that predict the rate-of-formation of freezing centers or ice-germ nuclei that initiated the freezing process.

Section 3 describes how *J(T)* and/or *I(T)* were evaluated in the present study and compared to their evaluations in the literature.

Section 4 describes how *J(T)* and/or *I(T)* were modified to apply to the heterogeneous freezing of nominal purity supercooled water droplets.

Section 5 then provides calculated results from incorporating the modified heterogeneous droplet freezing model into the AEDC 1DMP code and evaluating some of the same flow cases as described in references [1,2] for a ten-droplet water spray. The results from a previously developed simple heterogeneous freezing model and the new modified homogeneous nucleation freezing function model are compared and evaluated.

Section 6 then summarizes the current status of research and development under this phase of the research task investigation, provides conclusions about accomplished and needed future research, and makes recommendations about how to pursue future development of adverse weather simulation test capabilities in ground test facilities.

2.0 OVERVIEW OF CLASSICAL HOMOGENEOUS NUCLEATION THEORY

2.1 Nucleation Probability Functions

This section very briefly reviews the homogeneous nucleation probability functions of the literature and describes the selection process used to select one of the functions for application to development of a heterogeneous freezing model for supercooled water droplets.

In this context, homogeneous nucleation refers to the creation of a condensed phase of a pure substance by the thermodynamically controlled formation of condensed phase precursors. These precursors are metastable clusters of molecules that potentially can serve to trigger the formation of the condensed phase, that is, act as condensation sites. Specifically, the precursors can be thought of as predroplets, or nandroplets, when a liquid condenses from a supersaturated vapor, or as ice germs when ice crystals form within a liquid. Heterogeneous nucleation follows the same thermodynamic process of molecular cluster formation as occurs in homogeneous nucleation, except that some foreign material, such as a particle or a surface, reduces the energy required to form the precursors. Thus, heterogeneous nucleation occurs at higher phase temperatures, in general, than homogeneous nucleation.

The literature on nucleation and condensation processes, that start with the formation of metastable molecular clusters in the non-condensed phase of a substance, is reasonably large in both papers [3-38], and books [39-43]. The "condensed" phase may be a liquid droplet condensing from a (non-condensed) supersaturated vapor, or it may represent a proto-crystal or ice germ, in the case where pure supercooled liquid water is beginning its spontaneous freezing process, at some temperature below 273.16 K. The freezing process that begins to occur in sprays of supercooled liquid metal droplets is essentially the same process as that in which pure supercooled water spray droplets freeze, except that liquid metals can be alloys and can freeze in different solid phases, depending on drop size, composition, and temperature at the time of solidification nucleation. However, pure liquid water droplets, supercooled and freezing, turn into ice I-type solid crystalline particles under normal "atmospheric" conditions.

As stated, the purpose of this section of the report is to briefly overview the probability functions, denoted in the literature as $J(T)$ or $I(T)$, which predict the production rate of nucleation sites per unit volume per unit time. In the present research effort, the theory for homogeneous nucleation of "pure" liquid water droplets, or homogeneous freezing, has been modified to account for heterogeneous (or mote-induced) freezing of water droplets. Heterogeneous freezing is the usual, typical, or most probable freezing process for liquid water of average purity, such as either unfiltered, or even filtered, and distilled drinking water. The modified homogeneous nucleation freezing theory can be applied in a straight-forward way to general numerical spray computation codes (numerical spray CFD codes) that track the position, lifetime, kinetic, and thermal states of particles or particle group packets that are injected and convected in gas flows. Moreover, the modified theory can incorporate probabilistic functions that extend the theory to stochastic processes of freezing. To explain the modified theory, it is necessary to review or overview classical homogeneous nucleation theory for particulate freezing. The theory begins in

Germany with the work of Volmer, et al. [3], Becker, et al. [4], and others with further development by Turnbull, and co-workers, e.g. [7,8]. Its exposition, however, is begun with Mason [14], for convenience.

2.2 Mason (1952)

In his paper, Mason [14] provides *J(T)* in the form

$$J(T)=\frac{nkT}{h}\exp\left\{-\frac{U}{kT}-\frac{W_c}{kT}\right\} \quad (1)$$

Mason then evaluates log J(T) [1] as

$$\log J(T)=32.84+\log T-\frac{U}{2.30kT}-\frac{760\sigma_{SL}^3}{(T_o-T)^2T} \quad (2)$$

In these expressions, the parameters are:

n ≡ number of molecules per cubic centimeter of the condensed phase,

k ≡ Boltzmann's constant,

h ≡ Planck's constant,

T ≡ the absolute temperature, Kelvins,

T_o ≡ the bulk water freezing temperature, Kelvins (273.16K)

U ≡ the "activation energy for self-diffusion of a molecule in the" non-condensed phase,

W_c ≡ "the work of nucleus formation".

Mason provides W_c as

$$W_c=\frac{1}{3}\sigma_{SL}A=\frac{1}{3}\sigma_{SL}\omega\, r_c^2 \quad (3)$$

attributing this to Frenkel [39]. These parameters are:

[1] Footnote: ln ( ) refers to the natural log, whereas log ( ) refers to log base 10.

$\sigma_{SL} \equiv$ the "specific surface energy of the crystal-liquid interface".

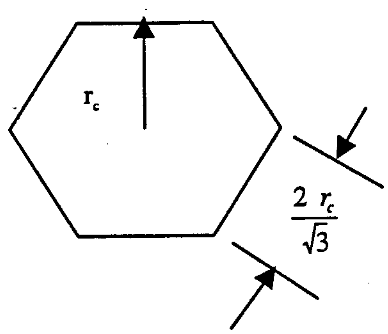
$A \equiv$ the surface area of the nucleus (the molecular cluster, or ice germ precursor).

$\omega \equiv$ shape factor for nucleus, relating the surface to volume ratio for the shape of the cluster (ω is approximately 21 – 23 in value).

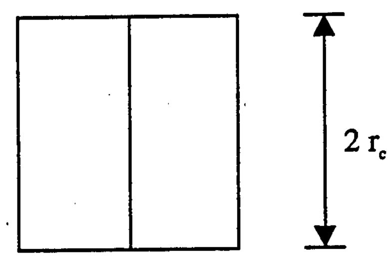
$r_c \equiv$ the radius of a sphere inscribed in a nucleus of critical size, i.e., that sized nucleus that can form a nucleation or crystallization site.

Mason evaluates ω by assuming that the nucleus forms a hexagonal prism with height equal to twice the radius to a prismatic side (see sketch below):

Schematic of Prismatic Ice Germ Nucleus



Top or Bottom View



Side View

The volume of this hexagonal prism is $V = 4\sqrt{3}\,r_c^3 = 6.9282 r_c^3$ (4)

The surface area is $A = 12\sqrt{3}\,r_c^2 = \omega r_c^2 = 20.785 r_c^2$ (5)

The surface to volume ratio is $\frac{A}{V} = \frac{12\sqrt{3}\,r_c^2}{4\sqrt{3}\,r_c^3} = \frac{3}{r_c}$ (6)

Note also that A can be written in terms of V as $A = 3^{7/6}\,4^{1/3}\,V^{2/3}$ (7)

So that the derivative dA/dV is

$$\frac{dA}{dV} = 3^{7/6}\, 4^{1/3}\left(\frac{2}{3}\right)V^{-1/3} = 2\cdot 3^{1/6}\cdot 4^{1/3}\, V^{-1/3} \tag{8}$$

Substituting for V

$$\frac{dA}{dV} = 2\cdot 3^{1/6}\cdot 4^{1/3} \Big/ \left(4\sqrt{3}\, r_c^3\right)^{1/3} \tag{9}$$

or

$$\frac{dA}{dV} = \frac{2\ 3^{1/6}}{3^{1/6}\ r_c} = \frac{2}{r_c} \tag{10}$$

This parameter, dA/dV, is important because Mason, in a later paper [25(1960)], shows that the change in Gibbs Free Energy for a collection containing g molecules that have passed from the liquid phase to form a cluster in the solid phase is

$$\Delta G = (\mu_S - \mu_L)g + A\sigma_{SL} \tag{11}$$

where

μ_L $\equiv$ Gibbs Free Energy of molecule in liquid phase,

μ_S $\equiv$ Gibbs Free Energy of molecule in an ice-like cluster,

g $\equiv$ number of molecules in the cluster.

Mason [25(1960)] defines the critical cluster of molecules as the metastable cluster reached when ΔG achieves a maximum, thus the two conditions

$$\frac{d\Delta G}{dg} = 0 \tag{12}$$

and

$$\Delta G = \Delta G_{\max} \tag{13}$$

define the cluster size when a metastable ice germ (cluster) has formed.

Therefore, for this condition,

$$\frac{d\Delta G}{dg} = 0 = (\mu_S - \mu_L) + \frac{dA}{dg}\sigma_{SL}. \qquad (14)$$

But,

$$\frac{dA}{dg} = \frac{dA}{dV}\,\frac{dV}{dg} \qquad (15)$$

and

$$V = \lambda g \qquad (16)$$

where $\lambda \equiv$ the effective volume, per molecule, in the cluster.

Thus,

$$\frac{dA}{dg} = \frac{dA}{dV}\lambda. \qquad (17)$$

An evaluation of λ gives

$$\lambda = \frac{W_{mol}}{N_A \rho_s} \qquad (18)$$

where

W_{mol} $\equiv$ the molecular weight of ice,

N_A $\equiv$ Avogadro's number,

ρ_s $\equiv$ the density of ice.

Thus,

$$\frac{dA}{dg} = \frac{dA}{dV}\frac{W_{mol}}{N_A \rho_s}. \qquad (19)$$

Consequently, the condition for metastability of the cluster is

$$(\mu_L - \mu_S) = \frac{dA}{dg}\sigma_{SL} = \frac{\sigma_{SL} W_{mol}}{N_A \rho_s}\frac{dA}{dV}. \qquad (20)$$

However, Mason, e.g. [1960], shows that

$$\frac{d}{dT}(\mu_L - \mu_S) = -(S_L - S_s) = \frac{L_F^*}{T} \tag{21}$$

where

L_F^* $\equiv$ the heat of fusion, per molecule (treated as a negative quantity),

S_L $\equiv$ the entropy of a molecule in the liquid phase,

S_S $\equiv$ the entropy of a molecule in the ice-like cluster or solid phase.

Thus, by integration

$$(\mu_L - \mu_S) = \int_{T_o}^{T} \frac{L_F^* dT}{T} \tag{22}$$

and, by substitution, therefore, based on equation (20),

$$(\mu_L - \mu_S) = \frac{\sigma_{SL} W_{mol}}{N_A \rho_s} \frac{dA}{dV} = \int_{T_o}^{T} \frac{L_F^* dT}{T}. \tag{23}$$

Substituting for *dA/dV*

$$\frac{\sigma_{SL} W_{mol}}{N_A \rho_s} \frac{2}{r_c} = \int_{T_o}^{T} \frac{L_F^* dT}{T}. \tag{24}$$

Solving for r_c, and rearranging terms gives r_c as

$$r_c = \left(\frac{2\sigma_{SL}}{\rho_s} \right) \Big/ \int_{T_o}^{T} \frac{N_A L_F^*}{W_{mol} T} dT. \tag{25}$$

But, the heat of fusion per unit mass of the liquid is

$$L_F = \frac{N_A}{W_{mol}} L_F^*. \tag{26}$$

Therefore, the equation for the critical radius of the metastable molecular cluster is

$$r_c = \frac{2\sigma_{SL}}{\rho_s \int_{T_o}^{T} \frac{L_F dT}{T}}. \tag{27}$$

The work of formation of the critical metastable cluster which was given by equation (3)

$$W_c = \frac{1}{3}\sigma_{SL} A = \frac{1}{3}\sigma_{SL}\omega r_c^2 \tag{28}$$

can now be written substituting for r_c, as

$$W_c = \frac{4}{3}\omega \frac{\sigma_{SL}^3}{\rho_s^2 \left[\int_{T_o}^{T} \frac{L_F dT}{T}\right]^2} \tag{29}$$

For the hexagonal prism defined by Mason, we had

$$A = 12\sqrt{3}\, r_c^2 = \omega r_c^2 \tag{5}$$

hence,

$$\omega = 12\sqrt{3}. \tag{30}$$

Therefore, W_c can be written as

$$W_c = \frac{16\sqrt{3}\,\sigma_{SL}^3}{\rho_s^2 \left[\int_{T_o}^{T} \frac{L_F dT}{T}\right]^2}. \tag{31}$$

However, in his 1952 paper [14], Mason simply introduces an equation for r_c that Mason calls "Thompson's equation," without reference, as

$$r_c = \frac{2\,\sigma_{SL}}{\rho_s L_F} \frac{T_o}{T_o - T}. \tag{32}$$

Mason later provides a derivation of this equation in his 1957 text, *The Physics of Clouds*, [44]. Clearly, equation (32) is also obtainable from equation (27) when L_F is treated as a constant, by expanding and linearizing the resulting log function. In the previous equation, ρ_s is the density of the condensed phase, here assumed to be Ice-I, normal ice. By using equations (3), (30), and (32) in equation (1), we can write the equation for $J(T)$ as

$$J(T)=\frac{nkT}{h}\exp\left\{-\frac{U}{kT}-\frac{\left(\frac{1}{3}\right)\sigma_{SL}\omega}{kT}\left(\frac{2\sigma_{SL}}{\rho_S L_F}\right)^2\left(\frac{T_o}{T_o-T}\right)^2\right\}. \tag{33}$$

By using $T_o = 273.16$ K, and simplifying, we get

$$J(T)=\frac{nkT}{h}\exp\left\{-\frac{U}{kT}-\frac{4}{3}\frac{\sigma_{SL}{}^3\omega}{kT\rho_S^2L_F^2}\left(\frac{273.16}{273.16-T}\right)^2\right\}. \tag{34}$$

Equation (2) is equation (34), after some of the parameters have been numerically evaluated. Mason provides values, in his 1952 paper, for the following parameters in J(T), as follows.

The interfacial surface tension, σ_{SL}, was evaluated by Mason as the difference between the surface tension of ice at -40°C and of liquid water at -40°C, that is,

$$\sigma_{SL}=\sigma_s-\sigma_L=102\frac{\text{erg}}{\text{cm}^2}-80\frac{\text{erg}}{\text{cm}^2}$$

or

$$\sigma_{SL}=22\frac{\text{erg}}{\text{cm}^2}=0.022\frac{\text{J}}{\text{m}^2}.$$

σ_s was estimated from breaking hydrogen bonds normal to a selected face of an ice crystal.

The value for U was estimated at $U = 3.3\,x\,10^{-13}\,\text{erg}$, or $3.3x10^{-20}\,J$, for $0 \le T \le -10^\circ\text{C}$, and this same value taken at T = -40°C. The density of ice and its latent heat of fusion were taken as

$$\rho_s = 0.92\ \text{gm/cm}^2 = 920\ \text{kg/m}^3$$

and

$$L_F = -3.33\,x\,10^9\,\frac{\text{erg}}{\text{gm}} = -3.33\,x\,10^5\,\frac{\text{J}}{\text{kg}}$$

The shape factor, ω, was taken by Mason to be $\omega = 23$. (However, it was computed in the present study as about 21 instead.)

The next parameter is the number n of molecules of liquid water per unit volume. This parameter is given by $n = \frac{\rho_L \cdot N_A}{W_{mol}}$ where ρ_L is the liquid density, N_A is Avogadro's number, and W_{mol} is the molecular weight of water. Thus, for

$$\rho_L = 1\frac{\text{gm}}{\text{cm}^3},$$

$$N_A = 6.022169\,x\,10^{23}\,\frac{\text{molecules}}{\text{gm}-\text{mole}},$$

$$W_{mol} = 18\ \text{gm/gm}-\text{mole},$$

n is computed as $n = 3.3456\,x\,10^{22}\,\frac{\text{molecules}}{\text{cm}^3} = 3.3456\,x\,10^{28}\,\frac{\text{molecules}}{\text{m}^3}$.

The remaining parameters are Boltzmann's constant, k, and Planck's constant, h, given by

$$k = 1.380622\,x\,10^{-16}\,\frac{\text{erg}}{\text{K}} = 1.380622\,x\,10^{-23}\,\frac{\text{J}}{\text{K}}$$

and

$$h = 6.626196\,x\,10^{-27}\,erg \cdot s = 6.626196\,x\,10^{-34}\,J \cdot s\,.$$

Evaluation of log $J(T)$

Using these values for the parameters in the $J(T)$ equation Mason evaluated log $J(T)$ as

$$\log J(T) = \log(3.3456\,x\,10^{22}) + \log(1.380622\,x\,10^{-16}) + \log T - \log(6.626196\,x\,10^{-27})$$
$$-\frac{U}{2.303\,kT} - \frac{4}{3}\cdot\frac{1}{2.303}\cdot\frac{\sigma_{SL}^3\,(23)(273.16)^2}{(1.380622\,x\,10^{-16})\,T\,(0.92)^2(3.33\,x\,10^9)^2}\cdot\frac{1}{(T_o - T)^2}. \tag{35}$$

Evaluating this, we get

$$\log J(T) = 32.843 + \log T - \frac{U}{2.303kT} - \frac{766.8\sigma_{SL}^3}{T(T_o - T)^2} \tag{36}$$

where σ_{SL} is in erg/cm^2 units and *J(T)* would be in units of nuclei per cubic centimeter per second. With minor numerical differences, this is Mason's equation, equation (2).

In the present study, using the values of the parameters as given in SI units, and using natural logarithms, this equation has been put into the form

$$\ln J(T) = 89.440 + \ln T - \frac{2390.2}{T} - \frac{252}{T}\left(\frac{273.16}{273.16 - T}\right)^2. \tag{37}$$

Alternately, this equation gives *J(T)* as

$$J(T) = 6.9708\,x\,10^{38}\,T\exp\left\{-\frac{2390.2}{T} - \frac{252}{T}\left(\frac{273.16}{273.16 - T}\right)^2\right\} \tag{38}$$

with units of nuclei per meter cubed per second.

In the following subsections of the report, alternate forms for *J(T)* are described which are given in the literature. *J(T)* has been also given the symbol *I(T)*. In this report, *J(T)* and *I(T)* are exactly the same functions.

2.3 McDonald (1953)

In this paper, McDonald [18] provides a critical review of homogeneous nucleation theory. In particular, with reference to the application of the theory to predict the spontaneous freezing of supercooled submillimeter water droplets by homogeneous nucleation, McDonald reviews and assesses the values of the physical parameters in the argument of the function, *J(T)*. McDonald writes the *J(T)* function as (with a sign correction).

$$J(T) \approx \frac{nkT}{h} \exp\left\{-\left(\frac{A+Fc}{kT}\right)\right\} \tag{39}$$

A is the activation energy for self-diffusion of liquid molecules near the water-ice germ interface. F_c is the work of formation of the ice germ or molecular cluster. n is the number of molecules per unit volume in the liquid phase, k is Boltzmann's constant, and h is Planck's constant.

McDonald gives F_c as

$$F_c = \sigma_s \, g \, r_c^2 / 3 \tag{40}$$

where r_c is the critical radius of the molecular cluster, given by

$$r_c = \frac{2\sigma_s T_o}{(\rho_s L_F (T_o - T))}. \tag{41}$$

In these equations, σ_s is the specific surface free energy of the water-ice germ interface, g is a geometric factor such that $g \, r_c^2$ is the total surface area of the ice germ or critical embryo, ρ_s is the density of ice, L_F is the latent heat of fusion of ice, and T_o is the melting temperature of ice, 273.16 K. Thus, the expression for *J(T)* is essentially the same as that presented earlier by Mason and co-workers.

The main thrust of McDonald's investigation is an examination of the parameters A, σ_S, and L_F. McDonald reviews the work of others, including Mason [14], in an attempt to obtain thermodynamically correct values of these parameters, in terms of the best theoretical model of an ice germ structure. McDonald notes that L_F, the heat of fusion of ice is not constant, but decreases with decreasing temperature. (This was discussed by the present author in previous work [1, 2].) McDonald also finds both A and σ_S to vary with temperature.

McDonald's rigorous analysis is well worth examination by those with expertise in molecular physics because the levels of uncertainty in the estimations or calculations of A, σ_S, and L_F, that McDonald demonstrates, implies that serious further theoretical and experimental research is required to put homogeneous nucleation theory on a rigorous basis. This is one of McDonald's main conclusions in 1953 and it appears to be valid even at present. In actual practice, therefore, the application of the freezing function *J(T)*, by Mason and others, is a correlative theory, rather than a predictive theory, due to the uncertainties in the physical parameters of the theory.

2.4 Day (1958)

J. A. Day [21] presented a functional form for J(T) that he attributed to J. B. McDonald [18]. This equation is

$$J(T) = \frac{nkT}{h} \exp\left\{ -\frac{A}{kT} - \frac{30.7\sigma_{SL}^3}{k\,\rho_S^2\,L_F^2\,T\left(\ln\frac{T_o}{T}\right)^2} \right\} \tag{42}$$

where T_o and the other parameters have been defined in the previous section. Obviously, this equation can be developed from equation (1) with W_c evaluated from equation (31) and with L_F treated as constant.

2.5 Mason (1958)

Mason presented another version of the *J(T)* equation in this 1958 paper [22]. In this paper, Mason uses *I(T)* to represent the nuclei density rate equation. The equation provided was

$$\log I(T) = 32.84 + \log T - \frac{U}{2.303kT} - \frac{1.11\,x\,10^{17}\sigma_{SL}^3}{L_F^2\,T\left(\ln\frac{T_o}{T}\right)^2}. \tag{43}$$

The same comments apply here to this equation as for the equation Day presented.

2.6 Langham and Mason (1958)

In 1958, Langham and Mason reviewed the heterogeneous and homogeneous nucleation of supercooled water [23] and presented a functional equation for $I(T)$ that is the same as that of Mason (1958) [22].

2.7 Mason (1960)

In a 1960 paper, Mason [25] applied nucleation theory to predict both the formation of water aerosol droplets from supersaturated water vapor, and also, homogeneous nucleation or freezing of supercooled water droplets. Mason also reviews the formation of water droplets by condensation of vapor on foreign nuclei such as ions, hygroscopic and non-hygroscopic motes, and on "mixed" nuclei.

Mason attributes the theoretical development of condensation theory to Becker and Doring [4], Zeldovich [45], and Turnbull and Fisher [7]. Mason discusses the validity of the theory, as well as the validity of the experiments that provided data on droplet condensation and freezing.

Mason discusses the freezing of submillimeter supercooled droplets by both heterogeneous and homogeneous nucleation processes and the applicable theories for both. Mason also reviews the effectiveness or activity of various mineral substances to act as ice nucleating motes. The most active substance Mason found was silver iodide which Mason says produces one ice crystal per 10000 AgI particles. This statement has relevant implications, therefore, in the interpretation of $J(T)$. It implies that the population number densities for nucleation, as correlated by $J(T)$ (or $I(T)$) must reflect only the active or effective nuclei, or the active/effective motes, and not the actual or physical nuclei/mote population number densities or their rates of creation. Especially this will be true if $J(T)$ is used to predict heterogeneous freezing by correlating the $J(T)$ function (actually σ_{SL}) to a given set of experimental data.

A derivation of $I(T)$ was provided by Mason in this paper [25] that leads to the equation

$$\log I(T) = 32.84 + \log T - \frac{U}{2.303kT} - \frac{16\sqrt{3}\,\sigma_{SL}^3}{2.303\rho_S^2\, kT\left[\int_T^{T_o} \frac{L_F}{T}\,dT\right]^2}. \tag{44}$$

It is clear that this equation can be derived from the approach described in section 2.2 of the present study. In discussing this equation, Mason notes that σ_{SL} probably cannot be calculated with sufficient accuracy to permit using $I(T)$ to predict freezing nucleation rates. However, he also notes, that by using experimental data for the freezing of pure supercooled water droplets, σ_{SL} values can be obtained by correlating $I(T)$ with appropriate sized drops freezing at measured temperatures. If the presence of motes in ordinary water acts to change the σ_{SL} values, then it should also be possible to correlate $I(T)$ to the heterogeneous freezing of supercooled droplets and obtain σ_{SL} versus drop size for each set of experimental data. This has been done in the present research investigation to obtain a $J(T)$ function applicable to heterogeneous nucleation freezing of supercooled water droplets and will be presented in section 4.

2.8 Fletcher (1960)

In this paper [24], Fletcher writes the nucleation site population density function as

$$J(T) = K\exp\{-\Delta G^* / kT\} \tag{45}$$

where "K is a kinetic constant typically of order 10^{25} cm^{-3} sec^{-1} for the cases which we shall consider," k is Boltzmann's constant, and T is absolute temperature, as utilized previously. Fletcher discusses the extension or application of nucleation/condensation theory to account for the effect of foreign surfaces or particles in modifying (reducing) the value of the work of formation of the molecular cluster or embryo nuclei, denoted ΔG^*. Thus, if a theoretical model can be developed of how substances, either as motes or surfaces, can change the value of ΔG^*, then this model can be incorporated into $J(T)$ to create a heterogeneous nucleation site population rate equation. Theoretically, therefore, as Becker, Turnbull, Mason, and others have also discussed, heterogeneous nucleation freezing of supercooled water droplets can be predicted with the same theoretical tools used to predict homogeneous freezing of submillimeter supercooled water droplets.

Fletcher discusses the effects of foreign surface geometry and size on ΔG* for heterogeneous nucleation or the formation of the ice germ or embryo. He presents a function, *f(m,x)*, that modifies the free energy of formation for homogeneous nucleation, i.e., Fletcher gives

$$\Delta G^{*} = \Delta G_{o}^{*}\ f(m,x) \tag{46}$$

where ΔG_o^* is the free energy of formation of a nucleus of critical radius under homogeneous nucleation conditions, such as given by equation (31) and where

$$m = \cos\theta\,. \tag{47}$$

Cosine θ is the cosine of the contact angle between ice germ (embryo) and the foreign particle and x is defined as

$$x = R/r^{*}. \tag{48}$$

R is the radius of a spherical foreign particle and r^* is the radius of curvature of the surface of the critical embryo.

Fletcher [24] provides distributions of *f(m,x)* in a figure (Fig. 1 of [24]) obtained from solving the "nucleation equations for a spherical cap embryo nucleating upon a perfect spherical particle." Details of this model are provided by Fletcher in another paper.

Fletcher shows that this theoretical model for accounting for the effects of foreign particles on the freezing of supercooled water predicts the correct trends when applied to silver iodide particles inducing higher spontaneous freezing temperatures in supercooled droplets of water. Thus, the use of modified homogeneous freezing theory to predict heterogeneous freezing can be justified by more than one theoretical approach.

2.9 Kuhns and Mason (1968)

This paper [29] continues the work of Mason on the assessment and theoretical evaluation of the freezing of submillimeter supercooled droplets of pure water. Kuhns and Mason review and describe the work of Mason (1957, 1958, 1960) and others who have studied the freezing of small water droplets. Kuhns and Mason report experimental data they obtained on freezing of freely falling water drops, noting that much of the existing data to 1968 consisted of freezing droplets that were supported or in contact with surfaces, wires, hypodermic needles, etc. Much of this paper describes the apparatus used by Kuhns and Mason to perform their experiments and to analyze the freely falling droplets to estimate their temperature time history, as well as, size. They also investigated the effect of different ambient gases surrounding the particles on the particle freezing process.

These authors review, and apparently expand, the heterogeneous freezing theory of Bigg [16], as well as, the homogeneous theory developed by Mason (1952, 1958, 1960) from the Turnbull-Fisher work [7]. They report the same $J(T)$ function that Mason presented in his 1960 paper (see section 2.7 of the present report). Based on the probability theory of Bigg [16], and using the concept of a "median" freezing temperature for a group of drops all of the same size, but freezing stochastically about this median temperature, the authors define the "median" freezing event as occurring when the product of $J(T_F)$, particle volume, V, and time, t, reach a critical value. That is, when the freezing probability, P_F, reaches $P_F = \frac{1}{2}$, half of the drops are assumed frozen, [16]. To illustrate this theory, let the probability of a drop remaining liquid be given by

$$P_L = 1 - e^{-J(T)Vt}$$

Then, the probability of freezing is

$$P_F = 1 - P_L = e^{-J(T)Vt}$$

Taking the logs of both sides

$$\ln P_F = \ln(1 - P_L) = -J(T)Vt$$

If the probability of freezing of half of the droplets in a given size group is set at ½, then by definition, the drop size group has reached its "median freezing temperature, T_F. Hence,

$$-\ln P_F = J(T_F)Vt = -\ln(1 - P_L) = -\ln\left(\frac{1}{2}\right) \approx 0.7 . \qquad (49)$$

The present author utilizes equation (49) differently. Equation (49) can be interpreted or utilized in several ways. With σ_{SL} determined, equation (49) can be used to predict the freezing temperature, T_F, of different sized droplets. Alternately, if the "median" freezing temperature, T_F, of a given sample of drops of all the same size is known, then equation (49) can be used to evaluate a "median" value for σ_{SL}. However, the present author interprets equation (49) somewhat differently.

There are two reasons for the present author using a different interpretation to the product, JVt. From a physical interpretation, the number, N_c, of (active) freezing nuclei present in a single sample or droplet of supercooled water at time, t, must be given by the following integral

$$N_c(t) = \int_{t_o}^{t_F} J(T, D, t)\, V(D, t)\, dt \qquad (50)$$

where t_F is the time at which the particle begins to freeze, and t_o is the time at which the particle first began to supercool (the time when its temperature reached 273.16K). In this integral, the function, J, which gives the population net rate-of-creation, has been generalized to be a function not only of particle temperature, T, but also of particle size, given by its diameter, D, and time, t. Thus, equation (50) can apply equally well to heterogeneous nucleation events in supercooled water.

With this interpretation, the minimum or critical value for N_c is unity, that is, for a single drop undergoing freezing,

$$N_{c,critical} \equiv 1.0 \tag{51}$$

Hence, by the present author's interpretation at least one active freezing site must come into existence in each sample to initiate freezing.

The second reason for this interpretation is that the freezing model must be implemented, in the present study, into a code wherein all droplets of the same size freeze at the same time. At present, the limitations of the code preclude modeling wherein half of the droplets of a given size freeze at the median freezing temperature and half remain liquid. Hence, when a defined measure of the product *JVt* reaches a critical value for the droplets of that size class, assumed in this study to be unity, all of these droplets begin to freeze. The measure of *JVt* used in the present study is an integral of the product *JV dt*, as defined below.

In the present study, a criterion or a measure of JVt for both homogeneous and heterogeneous nucleation freezing was adopted, given by the integral equality

$$\int_{t_0}^{t_F} J(T,D,t)\,V(D,t)\,dt = 1.0 \tag{52}$$

When this integral reaches unity, all drops of size D are assumed to begin freezing. This criterion (equation (52)) was adopted and has been applied in the present research study to predict heterogeneous nucleation freezing of water spray droplets in ducted air flow, by being incorporated into a numerical model for one-dimensional, multiphase flow described in a previous report [1], and paper [2]. Details of this model are presented later in the present report.

Returning to a discussion of the Kuhns and Mason paper, Kuhns and Mason determine the value of σ_{SL} required in $J(T)$ by requiring 20-micron drops to freeze at a median freezing temperature of -37C after a period of 1 second. This resulted in a σ_{SL} value of

$$\sigma_{SL} = 19.7 \frac{\text{erg}}{\text{cm}^2} = 0.0197 \, \text{J}/\text{m}^2 \tag{53}$$

where σ_{SL} is the same free energy of the ice-water interface or surface as described previously. With this set of conditions, with σ_{SL} of 19.7 erg/cm^2, the other freezing temperatures of droplets of different sizes can be determined when

$$J(T_{F_i})\, V_i (1\,\text{sec}) = 0.7 \tag{54}$$

where

$T_{F_i} \equiv$ spontaneous (median) freezing temperature of droplets of diameter, d_i

$V_i \equiv \frac{\pi}{6} d_i^3$, the droplet volume for a drop of diameter, d_i.

They presented the resulting T_{F_i} vs d_i curve and compared experimental data from various sources against it, including their own data. The results of the comparison were good.

Kuhns and Mason also estimate the size of the critical embryo, or nucleus or ice germ that reaches a metestable equilibrium, and thus has an opportunity to nucleate the freezing process. The critical radius of the cluster was given by the same equation as equation (27), namely

$$r_c = \frac{2\sigma_{SL}}{\rho_s \int_T^{T_0} \frac{L_f \, dT}{T}} \tag{55}$$

where, as before,

$\rho_s \equiv$ the density of ice,

$L_f \equiv$ the heat of fusion (or melting) of ice, (now, however, treated as positive).

If L_f is constant, r_c is given by

$$r_c = \frac{2\sigma_{SL}}{\rho_s L_f \ln\left\{\frac{T_o}{T}\right\}} \tag{56}$$

By assuming different values of σ_{SL}, the corresponding values of the critical radius r_c were computed, and the number of water molecules that form the ice precursor or embryos were estimated. The authors obtained 150-300 water molecules depending on σ_{SL} in the temperature range investigated. The authors also showed, albeit with some approximation, that the results of a statistical thermodynamics model of water molecule aggregates, termed the "flickering cluster" model, explored by Nemethy and Scheraga [46], can be interpreted to predict the same number of molecules required for a meta-molecular cluster and for a σ_{SL} value of about 20 erg/cm^2. Thus, it is implied that the methods of statistical thermodynamics, applied to a special model of molecular aggregates, could be used to predict the spontaneous freezing of pure supercooled water.

2.10 Anderson, Miller, Kassner, Jr., and Hagen (1980)

This paper [33] reviews condensation-freezing nucleation of small water droplets in an expansion cloud chamber. The authors report on their experimental cloud chamber test results where submillimeter liquid droplets first nucleate from a supersaturated vapor phase then undergo spontaneous homogeneous (nucleation) freezing. The freezing process is reported to occur where chamber temperature is "near -40°C." The authors also note minor effects of an electric field applied to the cloud chamber which reduces the presence of ions on which droplets can nucleate and thus freeze.

The authors investigate whether the occurrence of frozen nuclei in cold supersaturated vapors is due to the direct formation of ice germs or ice nuclei by vapor to solid nucleation processes or whether it occurs due to a two-step process of nucleation of vapor first to form liquid droplets, then, second, for the liquid droplets to freeze by liquid to solid nucleation. An understanding of which of these processes can account for the presence of atmospheric ice particles would improve our general knowledge about the mechanisms of formation of arctic precipitation clouds.

The authors discuss the literature on water nucleation, including vapor to liquid, vapor to solid, and liquid to solid nucleation. They provide expressions for two nucleation site creation rate functions, $J_{VL}(T)$ and $J_{VS}(T)$. $J_{VL}(T)$ is the homogeneous nucleation site creation rate of liquid water droplets forming by nucleation from supersaturated water vapor. $J_{VS}(T)$ is the homogeneous nucleation site creation rate, per unit volume, for the creation of solid ice particles directly from supersaturated water vapor by homogeneous nucleation. These functions are not presented herein, since it is the $J(T)$ function for nucleation of ice from liquid water (i.e. $J_{LS}(T)$) that is of interest herein. This function was reported in a following paper.

This important paper presents experimental data on nucleation rates of droplets condensing from supersaturated cloud chamber environments, and also, confirms that small submicron and micron sized liquid droplets spontaneously freeze, in about 0.01 seconds, when suddenly formed and environmentally exposed to temperatures at or below -41°C. Other aspects, results, and observations of this paper will not be reviewed herein.

2.11 <u>Hagen, Anderson, and Kassner, Jr. (1981)</u>

This paper [34] is a continuation of the work presented in Anderson, et al., (1980), described in 2.10. In their 1981 paper, Hagen, et al., continue to analyze experimental data on ice nucleation to gain a better understanding of ice nucleation rates, as well as, better estimates of the free energy of formation of ice germ embryos, under conditions of homogeneous nucleation, i.e., the nucleation of ice from pure supercooled water.

The authors discuss the important role of homogeneous nucleation in the ultimate objective of understanding heterogeneous nucleation. The authors present the *J(T)* function for the nucleation rate of ice germs, or ice precursors, or ice embryos, from pure supercooled liquid as $J_{LS}(T)$, in the form

$$J_{LS}(T) = n'v\left(\frac{4\sigma_{LS}}{kT}\right)^{\frac{1}{2}}\left(\frac{n_L\, kT}{h}\right)\exp\left\{-\frac{\Delta g}{kT} - \frac{\Delta G^*_{LS}}{kT}\right\}. \tag{57}$$

The parameters of this equation are defined as:

$n' \equiv$ the number of molecules of water in contact with a unit area of the ice germ surface,

$v \equiv$ the volume of a water molecule in ice,

$\sigma_{LS} \equiv$ the interfacial free surface energy of an ice and water interface,

$n_L \equiv$ the number of liquid water molecules per unit volume,

$\Delta g \equiv$ the activation energy for the transfer of a water molecule across the water-ice boundary,

$\Delta G^*_{LS} \equiv$ the increase in free energy of the system (of molecules) of a critical-sized embryo, i.e. an embryo that is metastable enough to become an ice germ or ice precursor.

The parameters k and h are the Boltzmann constant and the Planck constant, respectively. The expression for ΔG^*_{LS} was given as

$$\Delta G_{LS}^{*} = \frac{16\pi\sigma_{LS}^{3}}{\left[3\left(n_s kT \ln\left\{\frac{P_L}{P_S}\right\}\right)^2\right]} \tag{58}$$

where

$n_S \equiv$ the number of ice molecules per unit volume,

$P_L \equiv$ the saturated vapor pressure of water over a plane surface of liquid water,

$P_S \equiv$ the saturated vapor pressure of water over a plane surface of ice

This form for $J_{LS}(T)$ was ascribed to the theoretical developments of Turnbull and Fisher [7], Dufour and Defay [47], and Hobbs [48].

The authors note that small, 1-20 μm diameter drops, were found to freeze in time scales of order 0.01 seconds, when exposed to ambient temperatures at or below about -40°C.

By applying nucleation theory to fit the freezing populations in their cloud/expansion chamber experiments, Hagen, et al., determine the "energy barrier for freezing" as a set of empirical fits for $\Delta g + \Delta G_{LS}^{*}$, based on the minimum temperature achieved in each experiment. Then, an averaged fit for $\Delta g + \Delta G_{LS}^{*}$ was obtained by least squares, over all the experiments, as

$$\Delta g + \Delta G_{LS}^{*} = -1.739234 \, x \, 10^{-8} + 8.1157 \, x \, 10^{-21} T \quad \text{J} \tag{59}$$

in units of joules, for temperature in Kelvins. The authors present a figure (Fig. 6, [34]) wherein Δg has been separately estimated as a function of T, given by

$$\Delta g = -71.8 \, x \, 10^{-20} + 0.3400 \, x \, 10^{-20} \, T \quad \text{J} \tag{60}$$

where Δg has units of joules, and T is in Kelvin.

Note the Δg is the same as the parameter U in the equations for $J(T)$ or $I(T)$ that Mason and co-workers have published, or the parameter A of McDonald [18]. Values for Δg, U or A range from 3.3 x 10^{-20} J (Mason [14]), to about 9.4 x 10^{-20} J (Hagen, et al., [34]). Note that

McDonald also discussed a range of values for Δg (or, A) that he estimated [18] as being from about 2.35×10^{-20} to about 5.5×10^{-20} J. Hagen, et al., discussed the differences in the various values of Δg and the differences of interpretation of Δg. The authors note that Δg, determined from experiments in homogeneous nucleation, can be used without modification for application to predicting heterogeneous nucleation events.

The authors incorporate their empirical fit of $\Delta g + \Delta G^*_{LS}$ into the expression for $J_{LS}(T)$, the homogeneous nucleation freezing nuclei rate equation, to get

$$J_{LS}(T) = J(T) = 5.92 \times 10^{32}\, T \exp\left\{\frac{1.260 \times 10^5}{T} - 588.1\right\} \tag{61}$$

which has units of nuclei per cubic centimeter per second. The authors show a plot [their Fig. 7] of $\log_{10} J_{LS}(T)$ versus ambient temperature, covering the range of their experiments, and even extrapolating the curve to greater ambient temperatures. Also plotted was a $J(T)$ function attributed to McDonald [18], which does fall within part of their data in the lower temperature range. However, it is not clear to the present author that Hagen, et al., have interpreted the experimental data appropriately. The interpretation, and the evaluation of the $J(T)$ function in the present authors opinion, should be based on the product $J(T)Vt$, or its integral, which reflects not only the thermodynamic requirements of nucleation, but also reflects the size of the droplet through its volume, as well as the time spent before nucleation, t. Furthermore, in the present author's opinion, when fit to experimental data, the product, J(T)Vt, must reflect the active or effective nucleation sites, i.e., those that lead to actual droplet freezing, not to just theoretical population rates. That is, the nucleation population-rate density function when correlated to experiment, must subsequently predict actual, effective freezing site population rates, not theoretical population rates.

In summary of this paper, it's importance includes the fact that the authors analyze the energy requirements for homogeneous nucleation freezing of small (generally less than 1 micron) water droplets formed by condensation from a supersaturated vapor cloud produced in a cloud/expansion chamber. Their analysis shows that homogeneous as well as heterogeneous nucleation freezing of water droplets can be fit by empirical functions for Δg (or U or A) and ΔG^{*}_{LS} (or W_c). Thus, the present author's opinion is that when such correlations fit the product $J(T)Vt$ to actual freezing data, the fit must reflect the production rate of effective or active freezing nuclei, not just the total population rate of production.

2.12 Jensen, Toon, and Hamill (1991)

This paper [35] represents another instance wherein homogeneous nucleation freezing theory is modified to predict the reduction in the freezing temperature of atmospheric icing clouds by dissolved sulfuric and nitric acids and/or their hydrates in the supercooled droplets. The work also relates directly to understanding polar atmospheric cloud formation.

The authors review classic homogeneous nucleation theory, presenting a form of $J(T)$ derived in Pruppacher and Klett's classic text Microphysics of Clouds and Precipitation [49], namely

$$J(T) = 2\,N_c\left(\frac{\rho_w}{\rho_i h}\right)(\sigma_{iw}kT)^{1/2}\exp\left\{-\frac{\Delta F^{+}}{kT}-\frac{\Delta F_g}{kT}\right\} \tag{62}$$

in units of nuclei per cubic centimeter per second. The variables are:

N_c ≡ number of water molecules in contact with a unit surface area of the ice germ, embryo, or ice precursor molecular cluster.

ρ_w ≡ density of liquid water.

ρ_i ≡ density of (normal) ice.

σ_{iw} ≡ the surface energy of the ice-water interface.

ΔF^{+} $\equiv$ the energy that must be overcome for the free water molecules to become bound to the ice crystal precursor;

ΔF^{+} is equal to the difference between the equilibrium energy of the water molecule in the liquid state, and the energy of the water molecule in the ice phase. This quantity has been called the phase change activation energy or just the activation energy, and has been approximated by the energy of activation for the displacement of water molecules in bulk water. ΔF^{+} has been given the symbol Δg by Hagen, et al.. [34], U by Mason [14], and A by McDonald [18].

ΔFg $\equiv$ the work against surface forces required to form a critical ice germ of a meta-stable size, that can become an ice crystal or ice germ, or embryo.

Jensen, et al., give ΔFg as

$$\Delta Fg = \frac{4}{3}\pi\, \sigma_{iw} a_g^2 \tag{63}$$

where

$a_g \equiv$ the radius of the critical nucleus or ice germ. (the same as r_c, before).

The expression for a_g given was

$$a_g = \frac{2M_\omega\, \sigma_{i\omega}}{L_m \rho_i \ln\left\{\dfrac{T_o}{T_e}\right\}} \tag{64}$$

where

M_ω $\equiv$ the molecular weight of water

L_m $\equiv$ the latent heat of fusion of water (treated as positive)

T_o $\equiv$ the melting temperature of ice (273.16 K)

T_e $\equiv$ the ambient (supercooled) temperature

These two expressions for ΔFg and a_g are the same as that provided by, for example, Mason [14] (1960), for W_c and r_c, respectively.

Jensen, et al., report that a_g is modified by acids or acid hydrates present or in solution with the water, so that, based on the theory of Pruppacher and Klett [49], for this case

$$a_g = \frac{2\ M_\omega\ \sigma_{i/s}}{L_m \rho_i \ln\left\{\dfrac{T_o}{T_e}\right\} + \rho_i RT \ln\ a_\omega} \tag{65}$$

where

$\sigma_{i/s}$ $\equiv$ the "ice-solute surface energy,"

a_ω $\equiv$ the activity of water in the solution of water and acid.

Because a_ω was reported, experimentally, over a fairly wide temperature range, Jensen, et al., could determine the variation of $J(T)$ over the range of polar cloud temperatures for typical droplet sizes. The spontaneous freezing temperature of droplets now varies with the concentration of acid (such as H_2SO_4) present in solution. Freezing temperatures for solution droplets are predicted as low as 195K or –78C.

While this paper has other important results and conclusions concerning the applicability of modified classical homogeneous nucleation theory to predict the freezing of the atmospheric aerosol, these will not be reviewed here. The main point of the present review is merely to document the form for $J(T)$ used by the authors and the method used to modify the function to account for the effects of dissolved material in water to modify the spontaneous freezing temperature of very small, ~1 micron, aerosol droplets.

2.13 <u>Stoyanova, Kashchiev, and Kupenova (1994)</u>

This paper [36] develops and tests a method for analyzing and predicting the kinetics of supercooled droplet freezing that encompasses both homogeneous and heterogeneous (seeded) nucleation freezing. Classical homogeneous nucleation theory is the starting point for the kinetic freezing model. The aim of the paper is "to propose a method for experimental determination of the nucleation rate in freezing droplets, to employ the method for obtaining the ice nucleation rate, to characterize quantitatively the nucleation activity of the aerosols, and to verify the theoretically expected linear dependence of the nucleation rate on the aerosol concentration."

The theoretical considerations begin with the assumption that for each resulting frozen drop, one ice germ or embryo was formed that lead to the frozen drop. Under this hypothesis, if the population of a sample of initially N_o identical drops is studied while being uniformly supercooled at a rate, q, then the time rate of increase in frozen droplets should be functionally related to $J(T)$ (for both homogeneous as well as heterogeneous freezing processes). Stoyanova, et al., show that time can be eliminated as a variable of the problem as follows. If $dN(t)/dt$ is the time-rate-of-change of the number of frozen droplets, then, from the definition of $J(t)$,

$$\frac{dN(t)}{dt} = v[N_o - N(t)]J(t) \qquad (66)$$

where v is the volume of each identical droplet. For a constant cooling rate q, by definition

$$\frac{dT}{dt} = -q\,. \qquad (67)$$

Next, the time-rate-of-change of the number of drops freezing can be written

$$\frac{dN(t)}{dt} = \frac{dN(t)}{dT}\,\frac{dT}{dt} = v[N_o - N(t)]J(t) \qquad (68)$$

or, substituting for dT/dt and rearranging

$$\frac{dN(T)}{dT} = -\frac{v}{q}[N_o - N(T)]J(T)\,. \qquad (69)$$

Integrating this expression from the initial temperature, T_o = 273.16K, to some supercooled temperature, T, gives

$$N(T) = N_o \left\{ 1 - \exp\left\{ -\frac{v}{q} \int_T^{T_o} J(T^*) dT^* \right\} \right\}. \tag{70}$$

Note that $N(T_o) \equiv 0$, i.e. there were no frozen droplets at $T_o = 273.16$ K.

Stoyanova, et al., then solve this equation for $J(T)$ by first rearranging the terms, and then differentiating with respect to T to get

$$J(T) = \frac{q}{v} \frac{d}{dT} \ln\left\{ 1 - \frac{N(T)}{N_o} \right\} \tag{71}$$

This equation "shows that the experimental determination of the temperature dependence of the nucleation rate J at known droplet volume and constant cooling rate q reduces to finding the temperature derivative of the experimentally obtainable quantity $ln(1 - N(T)/N_o)$." Also, this procedure applies whether the droplets contain motes or foreign particles or not. Thus, $J(T)$ for heterogeneous nucleation/droplet freezing events can also be experimentally determined. The authors also remark that this method of determining $J(T)$ can also be applied to non-steady-state nucleation processes.

The authors next review classical nucleation theory and present $J(T)$ in the form

$$J(T) = A(T) \exp\{-W^* / kT\} \tag{72}$$

where

W^* $\equiv$ "the nucleation work,"

$A(T)$ $\equiv$ "a kinetic factor whose temperature dependence is usually weaker than that of the exponential term."

k is the Boltzmann constant as defined in a previous subsection. The authors note that $J(T)$ is really $J(T(t))$ or $J(t)$, since the phase temperature usually depends on time. Application of the classical theory is valid for relatively slow temperature transients ("...sufficiently small cooling rate, q"...), so that $J(T)$ represents an approximation valid for slow cooling rates. That is, in other words, $J(T)$ in the form due to Volmer [3], and others, was derived for steady-state isothermal processes. This does raise questions about whether this theory can be used directly to predict supercooled droplet freezing in rapidly accelerating and cooling ducted spray flow fields. Clearly, future research on the freezing of very rapidly cooled water droplets is needed.

Stoyanova, et al., present $A(T)$ as

$$A(T) = Z\ f\ N_a \tag{73}$$

where

Z ≡ the Zeldovich factor

f ≡ the frequency of attachment of water molecules to the molecular cluster or ice germ

N_a ≡ "the concentration of active centers on which nuclei can be formed"

The Zeldovich factor, Z, was then given as

$$Z = \left(W^*/3\pi\, kT\, n^{*2}\right)^{1/2} \tag{74}$$

where

n^* ≡ "the number of molecules in the nucleus"

Stoyanova, et al., give f as

$$f = n_s^*\, \beta\, kT / \eta\, v_m \tag{75}$$

where

n_s^* ≡ "the number of attachment sites of molecules on the nucleus surface,"

η ≡ "the viscosity of the liquid around the nucleus,"

v_m ≡ "the molecular volume," i.e. the volume of a single molecule,

β $\equiv$ is a factor that accounts for the change in liquid viscosity near the surface of the molecular cluster ($\beta \leq 1$).

The expression for *A(T)* that then results is

$$A(T) = \left(\frac{Z n_s^* \beta k T}{\eta v_m} \right) N_a . \tag{76}$$

Stoyanova, et al., report that classical nucleation theory gives

$$W^* = \alpha \sigma_{ef}^3 v_m^2 / \Delta\mu^2 \tag{77}$$

and

$$n^* = 2W^* / \Delta\mu \tag{78}$$

where

α $\equiv$ "a numerical shape factor for the molecular cluster, e.g., $\alpha = 16\pi/3$ for spherical nuclei,"

σ_{ef} $\equiv$ the specific (effective) surface free energy of the liquid/nucleus interface (equivalent to σ_{SL} or σ_{LS} used in other *J(T)* or *I(T)* expressions presented herein).

$\Delta\mu$ $\equiv$ the difference between the chemical potentials of the molecules in the liquid and in the ice germ or molecular cluster.

The authors note that, for heterogeneous nucleation, the value of σ_{ef} is less than that for homogeneous nucleation. So that, in general, one can write

$$\sigma_{ef}^3 = \Phi \sigma^3 \tag{79}$$

where

σ $\equiv$ the specific surface free energy for homogeneous nucleation (same as σ_{LS}).

Φ $\equiv$ $0 \leq \Phi \leq 1$; a parameter used for quantitative characterization of the nucleation activity of aerosol particles or "active centers."

Stoyanova, et al., note that "different theoretical models give different expressions for Φ." Thus, theoretical models such as that discussed by, for example, Fletcher [24] can be used to estimate Φ for the application of $J(T)$ to predict heterogeneous nucleation freezing of supercooled water drops. Stoyanova, et al., report a functional form for Φ in the case where a hemispherical cap shaped nucleus, or ice germ, begins to form on a flat surface:

$$\Phi(\theta)=\frac{(2+\cos\theta)(1-\cos\theta)^2}{4}. \tag{80}$$

This expression is attributed to Volmer [50]. In this expression for Φ, θ is the angle of "wetting" of the surface by the nucleus. Values of $\Phi(\theta)$ would be

$\Phi(180) = 1$

for either non-wetting or homogeneous nucleation;

$\Phi(90) = 0.5$

for "half-wetting" and;

$\Phi(0) = 0$

at "full wetting." Full wetting would seem to imply particle freezing at the bulk water freezing temperature, $T = 273.16$K.

Stoyanova, et al., also provide thermodynamic expressions for the evaluation of $\Delta\mu$. For the freezing of water, they provide

$$\Delta\mu=\frac{\Delta S_m\, T\,\Delta T}{T_m} \tag{81}$$

where

ΔS_m $\equiv$ the entropy change of melting (see equation (21), for example),

ΔT $\equiv$ $T_m - T$, the degree of supercooling experienced by the water sample,

T_m ≡ the melting temperature of ice, $T_m = 273.16$K.

By combining the various expressions given so far, Stoyanova, et al., write *J(T)* as

$$J(T) = Z\, n_s^* \beta \left(\frac{kT}{\eta\, v_m} \right) N_a \exp\left\{ \frac{-\alpha\, \sigma_{ef}^3\, v_m^2\, T_m^2}{\Delta S_m^2\, kT^3 \Delta T^2} \right\} \tag{82}$$

where, with $\sigma_{ef}^3 = \Phi\sigma^3$, *J(T)* will apply to both heterogeneous and homogeneous nucleation freezing events. For values of some of the parameters in the equation for *J(T)*, the authors provide:

α = $16\pi/3$

σ = 0.02 J/m^2 (or 20 erg/cm^2)

ΔS_m = 2.65 k (k is Boltzmann's constant)

v_m = 3 x 10^{-23} cm^3

An expression for the viscosity of liquid water was reported as

$$\eta(T) = 0.139 \left(\frac{T}{225} - 1 \right)^{-1.64} \text{ poise} \tag{83}$$

but, in the temperature range of their experiments, the authors used

$$\eta = 0.005 \text{ poise (constant } \eta).$$

The authors note that analysis of the heterogeneous water sample freezing data that they had obtained then required a value of β of about 10^{-6}. Recall that, for Stoyanova, et al., β is the factor that accounts for "the change in liquid viscosity very near to the nucleus or ice germ surface." The small value for β may "actually reflect the commonly observed failure of the classical nucleation theory to give absolute magnitudes correctly." These aspects of the formulation of *J(T)*, due to Volmer [50], Walton [51], and others, as presented by Stoyanova, et al., [36], as well as the extension of the theory to higher cooling rates of particles, need further review and clarification.

An application of the nucleation theory was made by Stoyanova, et al., to both seeded and unseed supercooled water freezing. The purpose was to evaluate key parameters of the theory, such as σ_{ef}, Φ, θ, $\Delta\mu$, and W^* for both "seeded" and "unseeded" water samples. The "unseeded" water was not pure enough to reflect homogeneous nucleation, being referred to as "distilled water." Stoyanova, et al., provided tabulated values for the various parameters listed above that resulted from analysis of supercooled water sample freezing due to different types and amounts or concentrations of "atmospheric aerosol particles." As expected, σ_{ef}, Φ, θ, $\Delta\mu$, and W^* all decrease as the concentrations of seed particles in the water samples increased. There were also changes in these variables for different types of seed particles or "active centers" as they were denoted.

In summary, Stoyanova, et al., like Fletcher [24], describe a general approach for the application of homogeneous nucleation theory to heterogeneous nucleation freezing processes. It is clear that atmospheric samples of water collected from flight through icing conditions will be needed in the future to begin the process of modeling freezing of atmospheric supercooled water, as well as for the simulation of icing tests in ground test facilities. The particle concentrations in these samples, as well as classification of particulate types will be needed for future computer-based modeling studies of the freezing of supercooled water. Water droplets that impinge on aircraft surfaces can form thin run off sheets whose small thickness may permit the use of modified homogeneous nucleation theory, or heterogeneous nucleation theory, to identify where in the run back process freezing begins. Other effects on the heterogeneous nucleation freezing process in supercooled water, such as the effect of different types of seed/mote particles simultaneously present in the water samples, as well as their concentrations, were also discussed

Stoyanova, et al., which makes their paper an excellent starting point for future researchers to review the theory.

2.14 Summary of the Overview

This section of the report was intended to provide a brief overview of some aspects of homogeneous nucleation theory applied to predict the nucleation or crystallization of supercooled liquid water droplets. This overview was not intended to be an inclusive survey of nucleation theory and it is not. It was also the purpose of this section to indicate how homogeneous nucleation theory has been extended to apply to heterogeneous nucleation events, that is, to instances where supercooled liquid water droplets, of ordinary purity, freeze due to contact with solid surfaces or to the presence of entrained foreign particles ("motes") in the water.

Because heterogeneous nucleation is the predominate mechanism by which supercooled water drops freeze in natural and artificial icing environments, the use of modified homogeneous nucleation theory to predict droplet freezing represents a physics-based freezing theory, compared to probability-based freezing theories developed earlier by Levine [11], Bigg [16,17], and applied by the present author to predict spray cloud freezing in ground test simulations of icing conditions [1,2]. The first-generation freezing model was based on the Levine-Bigg probability arguments for activities of the "freezing nuclei" in mote-induced freezing. The second-generation freezing model is based on modified homogeneous nucleation theory (MHNT) which can, in principle, account for the effects of mote-types on water particle freezing by accounting for the "wetting" characteristics of the mote-types, as well as for chemical additives that change either vapor pressures or interfacial surface free energies, and for surface geometries.

In the following sections, the development of a water particle crystallization model for heterogeneous freezing is described. The incorporation of this model into a numerical, one-dimensional, multiphase flow code is discussed and results are presented which were obtained from predictions made of water particle freezing in ducted flows using this code. Comparisons of these predictions are made to the same cases and similar results obtained with the first-generation water particle freezing model (the Levine-Bigg Model) [1,2].

Conclusions are drawn from the comparison of results and recommendations are made for further research and development of water droplet crystallization models for multi-dimensional numerical flow codes. The other implications of modified homogeneous nucleation theory are discussed, which include other aspects of adverse weather phenomena, as well as for weather simulation in ground test facilities.

3.0 BEHAVIOR OF THE FREEZING NUCLEI RATE OF CREATION FUNCTION, *J(T)*

3.1 *J(T)* Utilized in Present Study

The first step taken by the present author to understand the behavior of the function J(T) in predicting the onset of freezing of submillimeter, pure, supercooled water droplets was to reproduce the freezing temperature versus droplet diameter curve shown in Figure 54, page 496, of the paper of Langham and Mason [23]. This curve was based on their equation (4) of their paper which is provided as equation (43) of the present report (which corrects the typographical error in their equation (4)). The author presented the freezing temperature curve thus obtained, in Figure 1, of a previous report [1], as described in [1].

In the present study, the author found it convenient to use a simplified version of equation (43), which is the form first provided by Mason [14], shown in the present report as equation (36), page 11. The reason for using the simpler format for the equation is that by numerical experimentation, it is obvious that the parameters having the greatest effect on the value of *J(T)* are σ_{SL}, L_f, and *T*. For given values of L_f and *T*, the function *J(T)* is very sensitive to values of σ_{SL}, because its cube enters the exponential term of *J(T)*. Therefore, adopting a constant value for L_f, the heat of melting of ice as

$$L_f = 3.33 \, x \, 10^5 \ \mathrm{J/kg},$$

and a shape factor ω evaluated at

$$\omega = 23$$

the form of the *J(T)* equation used in the present study is given by

$$J(T) = 6.9708 \, x \, 10^{38} T \exp\left\{ -\frac{2390.2}{T} - \frac{2.367 \, x \, 10^7}{T} \sigma_{SL}^3 \left(\frac{273.16}{273.16 - T} \right)^2 \right\}. \qquad (84)$$

<u>3.2 Properties and Behavior of *J(T)*</u>

The form of *J(T)* given in equation (84) explicitly includes σ_{SL} as a free parameter meaning that σ_{SL} must be determined for both homogeneous as well as heterogeneous (mote-induced) freezing processes which are to be modeled in the present study. In the form given by equation (84), assuming, as did Langham and Mason [23], that 1 micron diameter pure water drops freeze in 0.6 seconds at -41°C, the value for σ_{SL} was found to be required at

$$\sigma_{SL}^* = 0.0212 \ \mathrm{J/M^2} \qquad (85)$$

Figure 1 shows a plot based on *J(T)* of the calculated number of critical-sized active freezing nuclei for a one-micron diameter droplet of pure water as a function of the droplet temperature (in degrees centigrade). It was assumed, in the present study, that as a minimum, at least one freezing nuclei had to be present in the drop to initiate freezing at -41°C. The number of critical-sized nuclei present was evaluated from equation (51) and (52) of the present study, using *J(T)* given by equation (84), under the assumption that each value of N_c obtained was obtained for a fixed particle size (1 μ) and at each fixed temperature, T. Thus, under these conditions, equation (52) reduced to

$$N_c = J(T) * \frac{\pi}{6} D^3 * t \tag{86}$$

where $D = 1$ micron, and $t = 0.6$ seconds. Note, that, the actual production rate term for nuclei generation, that is, $J(T)$, has a distribution with temperature as shown in Figure 2. Thus, the use of the thermodynamic theory of spontaneous nucleation to predict particle freezing cannot be simply based on values taken by $J(T)$, but rather, must be obtained with $J(T)$ using some criteria such as that expressed by equations (51) and (52) in the present study. As a second point of interest, Figure 3 is provided to show the freezing nuclei production rate term $J(T)$ normalized by the number of molecules per cubic meter present in the water sample, N. Thus, Figure 3 shows a plot of $J(T)/N$ versus the temperature of the supercooled water. As this figure shows, the formation of molecular clusters containing between 20-300 molecules, that form the ice germs or ice precursors, is still a fairly rare molecular process in the water sample, even at -41°C.

3.3 Review of Dorsch and Hacker Data for Heterogeneous Freezing of Submillimeter Drops

In [1], the present author selected the data provided by Dorsch and Hacker [10] to obtain a Levine-Bigg type heterogeneous freezing function for use in a one-dimensional multiphase flow code. The Levine-Bigg freezing function fit to the Dorsch and Hacker data was

$$T_F = 422.2 + 5.592 \ln (D) \mathrm{R} \tag{87}$$

where T_F is assumed to be the median freezing temperature of drops of diameter, D, in microns. In degrees centigrade, this function was

$$T_F = -38.6 + 3.11 \ln (D) C. \tag{88}$$

The Dorsch and Hacker data set was also selected in the present study for consistency with the previous study [1] and for the reasons it was selected in the first study, as well as because this data set falls in the range typical of heterogeneous freezing experiments. The first step taken in the present study to develop a more physics-based particle freezing function for heterogeneous freezing, based on modified homogeneous nucleation theory, was to review the Dorsch-Hacker data set. Figure 4 shows a set of data plotted that came from Fig. 8 and part of Table I of the Dorsch-Hacker report [10]. The figure shows both the original, hemispherical "drop" sizes, as well as the equivalent spherical droplet sizes, D_{eq}, where

$$D_{eq} = 2^{-1/3} D \tag{89}$$

In the present study, additional data points were assembled from Table I, Fig. 8, Fig. 10, and Fig. 11 of the Dorsch-Hacker report which were then combined into a single figure, Fig. 5, of the present report. Also on Fig. 5 is a curve representing the data utilized in [1] to obtain the Levine-Bigg curve fit, equations (87) and (88). Thus, the previously used representation of the Dorsch-Hacker data in [1] was deemed adequate, for defining a Levine-Bigg freezing function. Figure 6 shows the data of Fig. 5 corrected to spherical diameters. In the present study, using all of the data of Fig. 6 to obtain a new representation of a Levine-Bigg freezing function, a new curvefit equation was obtained for particle heterogeneous freezing temperature, given by

$$T_F = -38.3 + 3.19 \ln (D) \text{ in degrees C} \tag{90}$$

This function is plotted in Fig. 7, and is essentially the same as that obtained previously [1], i.e., it compares favorably to equation (88).

Therefore, either of the Levine-Bigg type representations of the Dorsch-Hacker data are assumed accurate enough for expressing freezing behavior of the Dorsch-Hacker experiments on heterogeneous particle freezing.

The Levine-Bigg type of freezing function for heterogeneous freezing of water particles is considered to be a first-order or lowest-level freezing model from the standpoint of the physics of the process.

3.4 Freezing Function Based on Modified Homogeneous Nucleation Theory (MHNT)

A second order, or higher-level freezing model, was developed next in the present study based on the following criterion and equations:

(1) Criterion for initiation of freezing of a water particle;

with the number of active freezing nuclei being given by

$$N_c(T,D,t) = \int_{t_o}^{t} J(T,D,t)\,V(D,t)\,dt \tag{91}$$

the freezing criterion is

$$N_c(T,D,t_F) = 1.0 \tag{92}$$

That is, in the present study, it is assumed that at least one active freezing nuclei must be created in the drop of volume, V, in the time period τ, where $\tau = t_F - t_o$, to initiate freezing. The times are defined herein as

> t_o = the time when the droplet temperature first reaches the bulk water freezing temperature, i.e. 273.16 K
>
> t_F = the time when the drop begins to freeze, i.e., by definition, when N_c = 1.0

(2) It is assumed that the homogeneous nucleation rate function, $J(T)$, can be used, as modified, for heterogeneous freezing predictions. That is, the freezing nuclei rate equation,

$J(T,D,t)$, is the same function as the homogeneous nucleation rate equations given by equation (84), except, that σ_{SL} is now a function of drop diameter; that is, $\sigma_{SL} = \sigma_{SL}(D)$. Thus, $J(T,D,t)$ for heterogeneous freezing is assumed given by

$$J(T,D,t) = 6.9708 \times 10^{38}\, T \exp\left\{-\frac{2390.2}{T} - \frac{2.367x10^{7}}{T}[\sigma_{SL}(D)]^{3}\left(\frac{273.16}{273.16-T}\right)^{2}\right\} \tag{93}$$

(3) It is assumed that the specific surface free energy for heterogeneous freezing is a function of drop volume, hence a function of the number and type of active freezing nuclei present in the droplet volume. For simplicity, at present, therefore, it was assumed that σ_{SL} could be represented by a smooth function of the droplet diameter, D, or,

$$\sigma_{SL} = \sigma_{SL}(D) \qquad \text{(heterogeneous freezing)}$$

From a practical standpoint, therefore, the specific surface free energy, $\sigma_{SL}(D)$, for the heterogeneous nuclei (water plus mote) responsible for the initiation of droplet freezing in the Dorsch-Hacker experiments can be determined for representative drop sizes by matching the criterion given by equation (92) for each drop size, at its median freezing temperature. To implement this process, and to develop a smoothly varying σ_{SL} function of D, the median freezing temperature of each size drop was assumed to be given by equation (90). Thus, $\sigma_{SL}(D)$ was determined by requiring $N_c(T_{Fi}, D_i, t_{Fi})$ to be unity for a selected set of freezing temperatures predicted by equation (90). Thus, if T_{Fi} is the median freezing temperature of droplet with diameter, D_i, then

$$N_c(T_{Fi}, D_i, t_{Fi}) = 1.0 = \int_{t_{oi}}^{t_{Fi}} J(T_{Fi}, D_i, t)\, V(D_i, t)\, dt \tag{94}$$

T_{Fi} and $V(D_i, t)$ were assumed constant during an assumed freezing interval given by

$$\tau_i = t_{Fi} - t_{oi} = 1.0 \text{ second.}$$

Then $N_c(D_i, T_{Fi})$ could be approximated by

$$N_c(T_{Fi}, D_i) = 1.0 = J(T_{Fi}, D_i)\, V(D_i)(1.0) \tag{95}$$

With

$$V(D_i) = \frac{\pi}{6} D_i^3 \tag{96}$$

the freezing criterion actually applied to determine $\sigma_{SL}(D_i)$ was

$$N_c(T_{Fi}, D_i) = 1.0 = J(T_{Fi}, D_i) \frac{\pi}{6} D_i^3 \tag{97}$$

Figure 8 shows $N_c(T_{Fi}, D_i)$ plotted as a function of T for drop sizes ranging from 1-10000 microns. The line N_c = 1.0 cuts each N_c curve at the median freezing temperature of that respective droplet size. For example, for the 5 micron droplet, the line N_c = 1.0 cuts the 5 micron N_c curve where T = -33°C. By inspection of Fig. 7, it can be seen that this corresponds to the point on the curve fit for the heterogeneous, spontaneous (median) freezing temperature where 5 micron droplets freeze at T_F = -33°C (the ordinate value of T_F for ln (5) = 1.609).

Each curve plotted on Fig. 8 was obtained by trial and error evaluation of σ_{SL}, changing the value of σ_{SL} for each drop size, until the N_c curve generated for that drop size passed through the appropriate freezing temperature when N_c = 1.0.

With the determination of each successful value of σ_{SL}, for each a'priori chosen drop size, the data in Fig. 9 was constructed. Shown in Fig. 9 are two curve fits for σ_{SL} that were obtained by the same method to deduce the variation of σ_{SL} for heterogeneous freezing. The first attempt produced the distribution denoted $\sigma_{SL1}(D)$. A second attempt to create a σ_{SL} distribution in the present study corresponds, in Fig. 8, to the curve $\sigma_{SL2}(D)$. The differences between σ_{SL1} and σ_{SL2} result from a later, more thorough reconstruction and analysis of the Dorsch-Hacker data by the author. The forms of the curvefit equations for σ_{SL1} and σ_{SL2} are

$$\sigma_{SL1}(D) = 0.02045 - 0.00044528\ x\ (\ln(D)) - 7.2527\ x\ 10^{-5} (\ln(D))^2 \qquad (98)$$

and

$$\sigma_{SL2} = 0.020228 - 0.00044755\ x\ (\ln(D)) - 7.9081\ x\ 10^{-5}\ x\ (\ln(D))^2 \qquad (99)$$

These two representations for σ_{SL} were kept in the present study to investigate the sensitivity of the predicted freezing behavior to variations in the values of σ_{SL}, for the same water sample data set. σ_{SL2} is the recommended curvefit because it is believed more accurate.

The differences in predicted submillimeter water particle freezing behavior in ducted flow when computed using the Levine-Bigg theory, σ_{SL1}, and σ_{SL2}, will be shown in the next section.

4.0 ANALYSIS AND EVALUATION OF THE WATER PARTICLE FREEZING MODEL BASED ON MODIFIED HOMOGENEOUS NUCLEATION THEORY

4.1 Introduction to the Approach

Because of a lack of detailed data on the freezing of convected, submillimeter, supercooled water droplets in ducted flows, the analysis and evaluation of the new model for heterogeneous freezing must be based on comparing model results with model results. Therefore, the predicted results of a calculation of water particle freezing in a ducted flow, made based on the Levine-Bigg freezing model [1], will be compared to the corresponding results obtained based on the modified homogeneous nucleation theory (MHNT) presented in the last section. The results obtained with the Levine-Bigg model were made with a one-dimensional, multiphase flow code described in references 52, 53 and modified and updated in the study reported in [1]. The flow code solves the fully-coupled mass, energy, and momentum conservation equations for a dilute, multiphase flow of water particles entrained in a ducted airflow [52, 53]. The solution procedure is a Runge-Kutta fifth-order numerical integration scheme [54, 55] that requires a set of input duct flow initial conditions as well as the duct geometry.

The code was denoted, in the author's first report on water particle modeling [1], as the "AEDC1DMP" code (pg. 34, [1]). This code designation will be retained in the present study, meaning AEDC one-dimensional, multiphase flow code. It will be made clear when the results of this code refer to predictions made based on the Levine-Bigg (LB) type freezing model or the modified homogenous nucleation theory (MHNT) model for particulate freezing.

4.2 Implementation of the Particle Freezing Model

4.2.1 Freezing Criterion

In implementing the MHNT model in AEDC1DMP, the transformation of the calculation of the time integral for $N_c(T, D, t)$ to an integral along the flow with respect to the axial flow coordinate, was done as follows. The time integral was rewritten as

$$N_c(T,D,x) = \int_{x_o}^{x} \frac{J(T,D,x)\,V(D,x)\,dx}{U(x)} \tag{100}$$

where

$$dx = U(x)\,dt \tag{101}$$

and $U(x)$ is the particle velocity at x. The lower limit on the integral, x_o, is the axial location in the flow where the given sized droplet first reaches (or cools down to) a temperature of 32°F (0 C or 273.16 K). Thus, droplet temperatures are monitored and when a given size drop temperature reaches 32°F, the evaluation of the integral is begun. However, the integral was actually implemented in the code by a running, finite summation

$$N_c(T,D,x_k) = \sum_{i}^{k} \frac{J^*\,V^* dx_i}{U^*} \tag{102}$$

where J^*, V^*, and U^* are mean or representative values of J, V, and U over the spatial integration step interval, dx_i, at the axial location, x_k, given by

$$x = x_k = x_o + \sum_{i}^{k} dx_i \tag{103}$$

The integration step intervals, dx_i, are controlled by the numerical integration scheme to control numerical (truncation) errors. Note, that when x reaches a limiting, input preset value, x_{max}, then the AEDC1DMP code terminates the calculation (integration) process for the entire flow.

The implementation of the Levine-Bigg type freezing function in AEDC1DMP was discussed previously [1,2]. However, to review the process, the implementation was as follows. In the course of computing the flow, the temperatures of the liquid drops are monitored. When a drop of diameter D cools to a temperature at or below the corresponding median freezing temperature T_{L_F}, for that drop size, the droplet is considered to have begun the freezing process, that is, the freezing procedure is initiated.

4.2.2 Model of the Freezing Process

Whether the initiation of freezing is triggered by a criterion given by the Levine-Bigg model or by the modified homogeneous nucleation theory (MHNT) model, once freezing has been initiated, the computation of the drop freezing is the same. The steps are

(1) the supercooled liquid drop is assumed to become, instantaneously, a slushball or mixture particle containing both liquid water and ice at the normal melting temperature of ice (492°R, 32°F, or 0°C).

(2) The amount of the mixture particle that is ice is determined from an energy balance for the particle based on conditions just before freezing was initiated and just after freezing was initiated. Since the mixture temperature is assumed at 492°R, the only

free variable that can be determined from the energy balance is the fraction of liquid that remains after freezing is triggered, given by

$$\alpha_F = 1 - \frac{C_L}{H_F}\left(492 - T_{L_F}\right) \tag{104}$$

where

$\alpha_F \equiv$ mass fraction of drop or mixture particle that remains liquid at 492°R. (hence, $(1 - \alpha_F)$ of the particle has become ice at 492°R).

$C_L \equiv$ specific heat of liquid water

$H_F \equiv$ heat of fusion of liquid water

$T_{L_F} \equiv$ freezing temperature of the supercooled liquid water droplet.

Details of the energy balance are provided in [1].

(3) The density of the mixture particle is now the mean density of a two-phase system wherein the phases cannot occupy the same volume. Hence, the mean density of the mixture particle is given by

$$\overline{\rho} = \frac{\rho_L \rho_I}{\alpha_F \rho_I + (1 - \alpha_F)\rho_L} \tag{105}$$

where

$\rho_L \equiv$ density of liquid water

$\rho_I \equiv$ density of ice

The specific heat of the particle is also redefined as a mass-average specific heat given by

$$\overline{C}_P = \alpha_F\, C_{P_L} + (1 - \alpha_F)\, C_{P_I} \tag{106}$$

where

C_{P_L} = specific heat of liquid water

C_{P_I} = specific heat of ice

(4) The size of the mixture particle is then given by requiring that the total mass of the particle remains constant during the (assumed instantaneous) transition of the particle from supercooled liquid drop to a mixture particle of water and ice at 492°R. Thus,

$$\overline{\rho}\,\frac{\pi}{6}\,\overline{D}^3 = \rho_L\,\frac{\pi}{6}\,D_{l_F}^3 \tag{107}$$

or

$$\overline{D} = \left(\frac{\rho_L}{\overline{\rho}}\right)^{1/3} D_{l_F} \tag{108}$$

where

$\overline{D} \equiv$ the new diameter of the mixture particle

$D_{L_F} \equiv$ the diameter of the supercooled liquid drop just before freezing is initiated.

(5) Thereafter, the mixture "drop" is treated as any other droplet in the flow. Heat, mass, and momentum exchanges with the air flow are computed in the same way as that for the all droplets. However, as each amount of heat is extracted from the particle, the amount of liquid remaining in the droplet is reduced (α_F is reduced), and a new mean density, and particle diameter are re-calculated. In the recalculation, the mass loss or gain of the particle by mass transfer is taken into account, as well as energy lost or gained by the mass transfer process. The amount of new ice formed is also calculated. The details of the mass and energy balance during freezing of the evaporating, two-phase particle are given in Appendix B.

When the entire particle has become ice, α_F reaches zero, and the particle is now completely frozen.

During the freezeout process for the mixture particle, the particle temperature is held constant at 492°R.

(6) Once the particle completely freezes, its density becomes that of ice, as well as its specific heat. From this instant or location in the duct flow, the particle undergoes mass, energy, and momentum exchanges with the air flow as an ice particle. It can gain or loose mass by sublimation based on the partial pressure of ice and the air flow specific humidity.

5.0 EVALUATION OF AEDC1DMP CODE ON REPRESENTATIVE DUCT FLOW CASES

5.1 Baseline Case of Ducted, Two-Phase Flow

The base case computed for a comparison purpose was a ducted flow with a "single" water spray station at its inlet.

In the code AEDC1DMP, the water is assumed to enter the airflow at up to ten different injection stations that are separated, axially in the duct. Each injection station is capable of putting in a given amount of water, in a given sized water particle with its specified velocity and temperature. When all of the injection stations are bunched close together, axially, in the duct, they can be used to model a single spray station with a spray droplet size distribution characterized by ten discrete drop sizes. This was the approach taken in the previous study [1] to examine the freezing of two-phase, ducted flows representative of both full-scale and research-scale icing test facilities. Note, that to illustrate and emphasize the ducted-flow freezing processes of supercooled, submillimeter water particles, the air flow inlet total temperature utilized was significantly lower, at 460°R, than is typical of many icing tests, where an airflow inlet total temperature of 486°R is more likely. In any case, for consistency with previously obtained results, the same airflow and water inlet conditions have been specified and are provided below.

Table 1. Duct Air Flow Inlet and Water Spray Conditions for Baseline Test Case 1

Air Inlet Conditions

Total Pressure, psfa	1123.48
Total Temperature, °R	460°R
Velocity, ft/s	20
Mach Number	0.0189
Inlet Relative Humidity, percent	15.78

Water (Particle) Input Conditions

Injection Station No. (ft)	Particle Diameter (microns)	Particle Temperature (°R)	Particle Velocity (ft/s)	Load Factor (FL)
1, 0.0	5	530	46	6.85 E-05
2, 0.01	10	530	46	2.06 E-04
3, 0.02	15	530	46	4.80 E-04
4, 0.03	20	530	46	3.62 E-04
5, 0.04	30	530	46	2.06 E-04
6, 0.05	40	530	46	3.43 E-05
7, 0.06	50	530	46	1.37 E-05
8, 0.07	60	530	46	1.37 E-06
9, 0.08	80	530	46	1.37 E-07
10, 0.09	100	530	46	1.4 E-08
			Total FL =	1.37 E-03

FL = lbm of water/lbm of dry air injected at a given injection station

The duct geometry used for this reference or baseline case is shown in Fig. 10. As is clear from inspection of Fig. 10, and as discussed in [1], this duct geometry is not representative of full-scale icing test facilities. Rather, it was chosen in the earlier study [1] because it was related to a similar geometry of interest. For consistency in comparing results, therefore, this geometry was also retained in the present study.

5.2 Comparison of Predicted Results of Baseline Case for Three Particulate Freezing Models

Figure 11 shows predicted temperatures of 10 micron water droplets, as they vary with axial distance along the flow, for three heterogeneous freezing models. The models utilized were the Levine-Bigg model, given specifically by equation (87), and the modified homogeneous nucleation theory (MHNT) using σ_{SL1} and σ_{SL2} for the specific surface free energy specifications.

As can be seen, the comparison is extremely good. The results obtained with the σ_{SL} function σ_{SL2} gives a closer agreement with the Levine-Bigg model than does σ_{SL1}. Since it is thought that σ_{SL2} was obtained from a more thorough data analysis than σ_{SL1}, the better agreement of the predicted results with σ_{SL2} is expected, although such good agreement in both quality and quantity displayed in Fig. 11 is remarkable.

On the basis of the results shown in Fig. 11, and found to be consistently the same for all droplet sizes, it was decided to utilize the function $\sigma_{SL2}(D)$ for the heterogeneous freezing model for all further calculations made in the present study.

Figure 12 shows a comparison of predicted droplet temperatures made with two versions of AEDC1DMP, one version with the Levine-Bigg (LB) freezing model implemented, and the other version with the modified homogeneous nucleation theory (MHNT) model implemented, based on σ_{SL2}. The agreement between the first (LB) and second order (MHNT) models is good. An interesting difference in the predicted results occurs for the 5 micron droplets. The Levine-Bigg model results in the 5 micron droplets freezing at the location in the duct flow where their temperature has reached about 427°R. (The freezing occurs so rapidly, it occurred between print step sizes in the program and is not shown, therefore, in the plot, Fig. 12.) The drops have shrunken, by evaporation, to about 2 micron in diameter at this location. On the other hand, the modified homogeneous nucleation theory model predicts that the 5 micron drops, shrunken to 2 micron, do not freeze within the domain of the calculation, because, even though the drops have reached a freezing temperature, their volume is too small to generate at least one active freezing nuclei. In other words, the criterion

$$N_c = \int JV\, dt = 1 \qquad (109)$$

was not satisfied for these small drops throughout the calculated length of flow. Thus, significant potential differences could arise in predicted freezing behaviors made with a Levine-Bigg model and with a modified homogeneous nucleation theory model, for certain circumstances.

The predicted temperature distributions for all of the other drop sizes appear similar or comparable, based on the two different freezing models.

(The calculated temperature distributions shown in Fig. 12 also indicate that the particles took longer (more distance) to freeze for the MHNT model predictions, than in the Levine-Bigg model predictions, than in the Levine-Bigg model predictions. This was not due to any differences caused by the freezing models, but due to improvements made in AEDC1DMP to integrate the heat and mass transfer processes of the freezing particles in a more recent version of AEDC1DMP in which the MHNT model was implemented.)

Figure 13 shows a comparison of the predicted droplet sizes from AEDC1DMP with the MHNT model implemented, for the ten different drop sizes as they move along the flow. Drop freezing shows up in these curves by sudden small increases in drop size (a kink) in the curves. Clearly, the 5 micron particle curve does not show a sudden increase, indicating that the drop stays liquid along the entire flow.

5.3 Calculations of Flow in a Representative Icing Test Facility

5.3.1 Introduction

The duct geometry of baseline case calculated, with results shown in Figures 10-13 was not representative of full scale icing test facility duct geometries. Therefore, a second test case was prepared and calculated wherein the duct or wind tunnel geometry and scale represents typical icing research or icing test wind tunnel geometry.

The results from computations of test case 2 are shown below.

5.3.2 Nominal Test Conditions in a Full-Scale Icing Facility

The duct or wind tunnel geometry assumed for test case 2 is shown in Figure 14. This wind tunnel like configuration has a large inlet and a steep contraction section, to minimize flow disturbances. Icing spray nozzles are assumed to be put in the plane of the large inlet. The test section is located at x = 46 ft, so that the state of the water particles injected at the inlet of the wind tunnel should be in kinetic and thermal equilibrium with the air flow by the time they reach the test section. The tunnel has a large contraction ratio (inlet flow area divided by test section flow area), hence, the range of permissible inlet air flow velocities is small, ranging from near 0 to about 45 ft per second. At the higher inlet air velocities, the test section has reached near-choking, or sonic flow conditions. Generally, icing tests are conducted at air flow or flight-simulating speeds in the range of a few hundred miles per hour. Therefore, a nominal set of inlet test conditions was defined for the representative calculation made with AEDC1DMP. The nominal test conditions are listed below.

Table 2. Nominal Tunnel Inlet Test Conditions for Icing Wind Tunnel-Test Case 2

Air Inlet Conditions

Total Pressure, psfa	2074
Total Temperature, °R	500
Velocity, ft/s	20.8
Mach Number	0.0188
Relative Humidity, %	54.7

Water (Particle) Input Conditions

Injection Station No. (ft)	Particle Dia. (microns)	Particle Temperature (°R)	Particle Velocity (ft/s)	Load Factor (FL)
(a) 1 (0.0)	50	634	15.6	0.00018
(b) 1 (0.0)	500	634	15.6	0.00018

Note: The case was computed first (case 2a) with a single particle size of 50 microns to represent the spray cloud, then computed (case 2b) with a single particle size of 500 microns. In each computation, the 50 or 500 micron particle represented the mean volumetric diameter of the spray cloud particle size distribution at the inlet.

Some selected results from computing these flow cases are shown in Figures 15-17. Figure 15 shows the gas velocity together with the velocities of a 50 micron particle and a 500 micron particle. The calculation shows that the larger particle did not reach velocity (kinetic) equilibrium with the air flow at the test section. On the other hand, the 50 micron particle did achieve a velocity equal to the gas velocity at the test section location.

Figure 16 shows similar results for the gas temperature and the temperatures of the two different sized particles. In the case of the 500 micron particle, its temperature is above the gas temperature by about 10 degrees, R, at the test section location due to thermal lag, however, the 50 micron particle temperature has fallen quickly, through evaporation and cooling, to its wet-bulb temperature about 5 degrees, R, below the gas temperature. The effects of air flow inlet humidity on droplet cooling and thermal non-equilibrium have been well-documented elsewhere, for example [53], and will not be discussed herein. However, it is possible to increase the inlet air flow humidity to increase the drop wet bulb temperature at the test section, to be equal to the gas temperature. Large droplet thermal lag effects could also be reduced, by reducing inlet humidity. Thus, opposite humidity modifications are required for large and small drops to account for thermal non-equilibrium effects at the test section.

Finally, Figure 17 shows the changes in the droplet diameters as the water particles pass down the duct. The changes in droplet diameter are greatest where the rate of evaporation is greatest, in the duct inlet throat region. (Note that kinks or slope discontinuities in the plotted curves are due to the data output frequency or axial spacing, not to discontinuities in computed results.)

Test Case 2, therefore, provided some nominal results which show how AEDC1DMP can be used for assessment of flow variations and flow quality typical of full-scale icing test or research wind tunnels. In this test case, neither the 50 micron drop nor the 500 micron drop were near their spontaneous (median) droplet freezing temperatures. The next test case computed will be one that represents a full-scale icing test with supercooled droplet freezing.

5.3.3 Test Conditions in a Full-Scale Icing Facility with Supercooled Droplet Freezing

By trial, computation, and output analysis, a set of wind tunnel inlet conditions was found that produced supercooled droplets, slushball or mixture particles, and ice particles in the test section located of the flow. The set of inlet conditions found is listed below in Table 3.

Table 3. Tunnel Inlet Test Conditions for Icing Wind Tunnel Flow with Water Particle Freezeout – Test Case 3

Air Inlet Conditions

Total Pressure, psfa	2076
Total Temperature, °R	475
Velocity, ft/s	40
Mach Number	0.037
Relative Humidity, %	26

Water (Particle) Input Conditions

Injection Station No. (ft)	Particle Dia. (microns)	Particle Temperature (°R)	Particle Velocity (ft/s)	Load Factor (FL)
1 (0.0)	5	495	16	9.06 E-06
2 (0.02)	10	495	16	2.73 E-05
3 (0.04)	15	495	16	6.35 E-05
4 (0.06)	20	495	16	4.79 E-05
5 (0.08)	30	495	16	2.73 E-05
6 (0.10)	40	495	16	4.54 E-06
7 (0.12)	50	495	16	1.31 E-06
8 (0.14)	60	495	16	1.81 E-07
9 (0.16)	80	495	16	1.8 E-08
10 (0.18)	100	495	16	2.0 E-09
			Total FL =	1.82 E-04

As the input data in Table 3 indicate, an inlet spray cloud with a 10 drop size distribution was input at the wind tunnel entrance station. The inlet air temperature and the water spray temperatures are rather low, the water being only slightly above freezing and the air at below freezing temperature (15°F). This combination of inlet conditions lead to predicted freezeout of some of the drop sizes in the wind tunnel flow at the test section station.

Figures 18 show some of the calculated results obtained with AEDC1DMP utilizing the modified homogeneous nucleation freezing model for predicting the freezing of supercooled water particles. Figure 18 shows the air flow Mach number distribution from duct entrance to the test section. Note that this case's inlet conditions lead to rather high test section Mach number, about 0.69. This is about twice the nominal or typical value for icing tests in full-scale facilities. The higher value of air flow Mach number ensured that air flow static temperatures would be low enough to induce particle freezeout, with a freezing model calibrated to the Dorsch-Hacker data set [10].

Figure 19 shows the predicted variations in drop or particle sizes from entrance to test section. Note that the initially 5 micron particle has disappeared, by evaporation, by about 4.5-5.0 feet from the duct entrance. This indicates that, for similar inlet conditions, a real water spray cloud with similar drop size distributions would experience all of the drops smaller than, say, 10 microns evaporating quickly in the inlet. The smallest surviving droplet at the test section would probably be in the range from 6-8 microns. These results, of course, depend on the inlet conditions, especially water injection temperature and inlet air flow humidity.

Figure 19 also shows size-jumps in the 15 to 80 micron particles which indicates that these water particles have begun to freezeout in the air flow where the size-jumps occur. The 10 and 100 micron droplets remain completely liquid at the test section.

Figure 20, which shows the predicted water particle or droplet temperatures, confirms that the 15-80 micron particles have begun to freeze in the flow. The (initially) 10 micron particle does not experience freezing, nor does the (initially) 100 micron particle, up to their arrival at the test section and, they have very different temperatures. The other particles have either become ice particles (15, 20, 30 micron particles) or are slushball or mixture particles (40, 50, 60, 80 micron particles) at the test section. The results of the calculation made with the MHNT freezing model indicate the potentially complex results that could be obtained in actual icing or adverse weather test simulations when either inlet flow, water spray nozzle, or duct geometry result in thermal and kinetic non-equilibrium flow conditions at the test station or test article.

Concluding the results of test case 3, Figure 21 shows the predicted water particle velocities. As Figure 21 shows, for this case, all of the particles, even the 100 micron droplet, are in, or very near to, kinetic or velocity equilibrium with the air flow at the test section (x = 46 feet).

Briefly summarizing this section, the AEDC1DMP code is capable of predicting results of two-phase, dilute, air and entrained water droplet flows in research scale and full-scale icing and adverse weather test facilities. The incorporation of a second generation or second order (in the hierarchy of physics of freezing modeling) modified homogeneous nucleation theory (MHNT) for particle freezing in AEDC1DMP gives the code the capability of accounting for particulate freezing over a wide range of flow conditions. Appendices C-E describe the data input audits format in detail, for user convenience. Included are the input data for test case 3. Appendix F lists a sample output from AEDC1DMP for test case 3.

6.0 DISCUSSION OF RESULTS OF STUDY, SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

6.1 Summary of the Present Study

The study and the report had three parts. The first part was an examination of homogeneous nucleation theory and its modifications and applications to the prediction of the freezing of supercooled pure water particles and heterogeneous freezing of water particles containing motes or foreign substances. The second part addressed the behavior of the homogenous nucleation rate function, *J(T)*, as a function of water temperature. This function was then calibrated to a set of heterogeneous particle freezing data, provided by Dorsch and Hacker [10], by assuming that the surface specific free energy for an ice-water interface could be represented as a function of the volume or diameter of the particles containing the motes. With this functional form for the surface free energy in hand, the function *J(T)* became, in essence, calibrated to the Dorsch-Hacker data set.

The third part of the study comprised some numerical computations of two-phase, dilute, air and entrained water particle flows, using a new version of the AEDC one-dimensional, multiphase flow code, AEDC1DMP. The results of these calculations demonstrated that modified homogeneous nucleation theory [MHNT] could be satisfactorily used in numerical flow models to identify the initiation of heterogeneous freezing events in submillimeter, supercooled water particles in the computed flows. The freezing model described in the report accounts for the effects of time, particle size, and particle temperature on the initiation of freezing.

6.2 Conclusions

The conclusions of the research reported herein are as follows:

(a) Classical homogeneous nucleation theory can be easily modified to predict heterogeneous freezing of submillimeter, supercooled water particles.

(b) Both empirical and theoretical methods can be used to account for the effect of foreign particles, surface wetting and dissolved chemicals in the initiation and formation of freezing events.

(c) A particulate freezing model for heterogeneous freezing of submillimeter, supercooled water particles based on modified homogeneous nucleation theory has been incorporated in a one-dimensional, multiphase flow code (AEDC1DMP) with excellent results, and can easily be incorporated into multidimensional, multiphase flow codes.

6.3 Recommendations

The recommendations of the present study are as follows:

(d) A multidimensional, multiphase flow analysis of water spray nozzle discharge plumes should be pursued with the highest priority. The analysis should include water particle freezing in the spray plumes to investigate the possibility of creating ice crystals in the spray plumes. This topic has been raised in the first part of this research program [1,2], and it is also seen as an important continuation of the present study.

(e) The physics of water particle freezing should continue to be studied under heterogeneous freezing conditions. The further development of models for the specific surface free energy of the molecular clusters that trigger freezing events should be pursued. Models of σ_{SL}, such as that described by Volmer [50], Fletcher [24], Stoyanova [36], and others, should be developed so that the effects on particle freezing of different kinds of motes in the atmospheric water particles, as well as in ground test facility water supplies, can begin to be addressed.

(f) In view of the previous recommendation, it is further recommended that additional atmospheric data be obtained on the composition of water particles in nominal icing conditions. The data should include the chemical and physical composition of supercooled water particles or water samples. This includes dissolved and/or entrained chemicals, as well as the kinds, shapes, and numbers of solid particles in the atmospheric icing environment. Similar effort should be made to catalogue the same information for water used in ground test simulations of icing and adverse weather simulations for aircraft engines and/or their components.

(g) Consideration of the freezing process for supercooled water should be extended to thin films of water on aircraft surfaces, including those on ice accretions. In other words, it should be investigated whether there are water run-back modes wherein thin films of supercooled water can be formed in the ice accretion process. If so, then the initiation of freezeout of run back water, under such conditions, might be predicted by a modified homogeneous nucleation theory.

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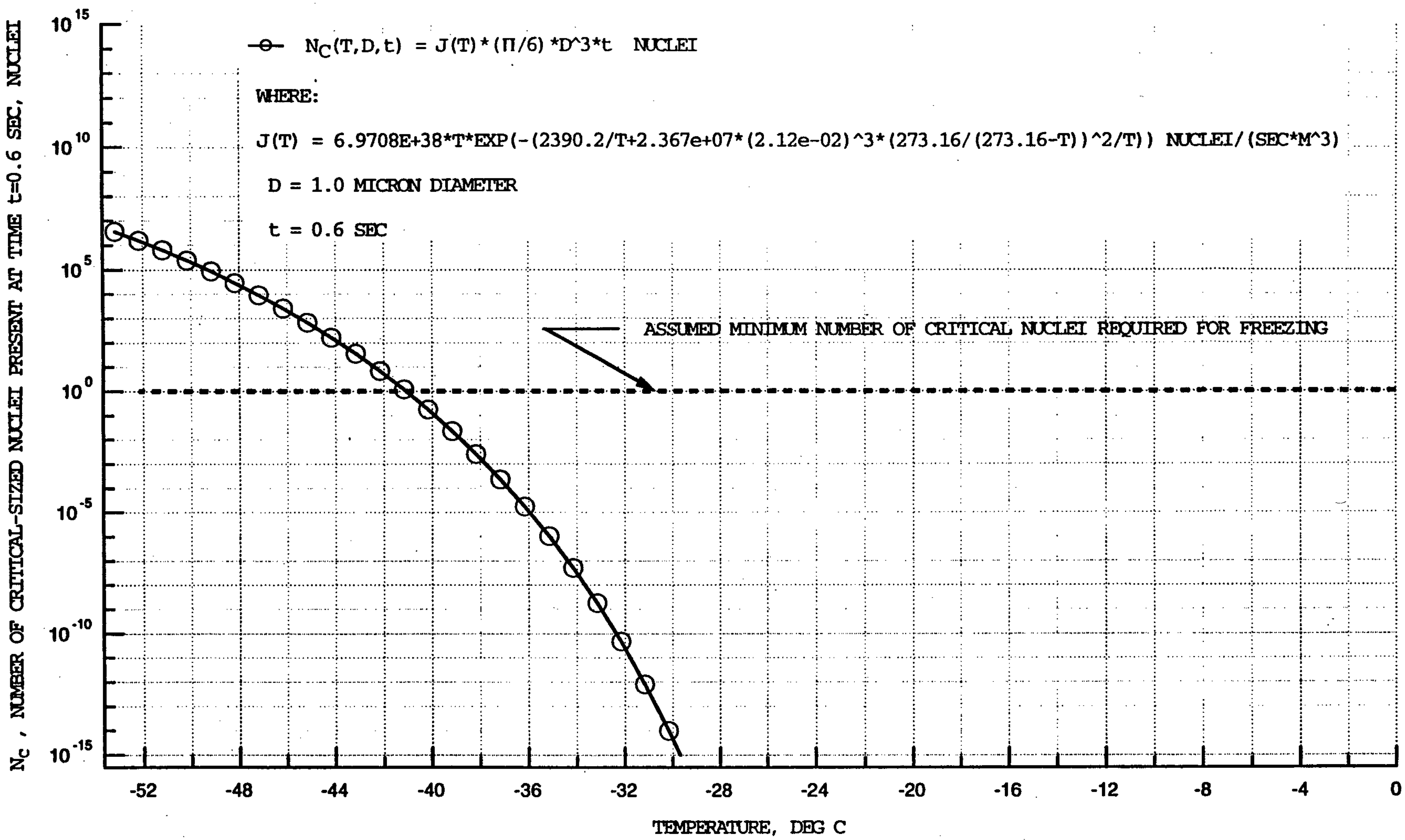

FIG.1 PLOT OF THE NUMBER OF CRITICAL-SIZED MOLECULAR CLUSTERS PRESENT IN A 1 MICRON DROP AFTER IT HAS EXISTED FOR t =0.6 SECONDS, AT TEMPERATURE, T , UNDERGOING HOMOGENEOUS FREEZING

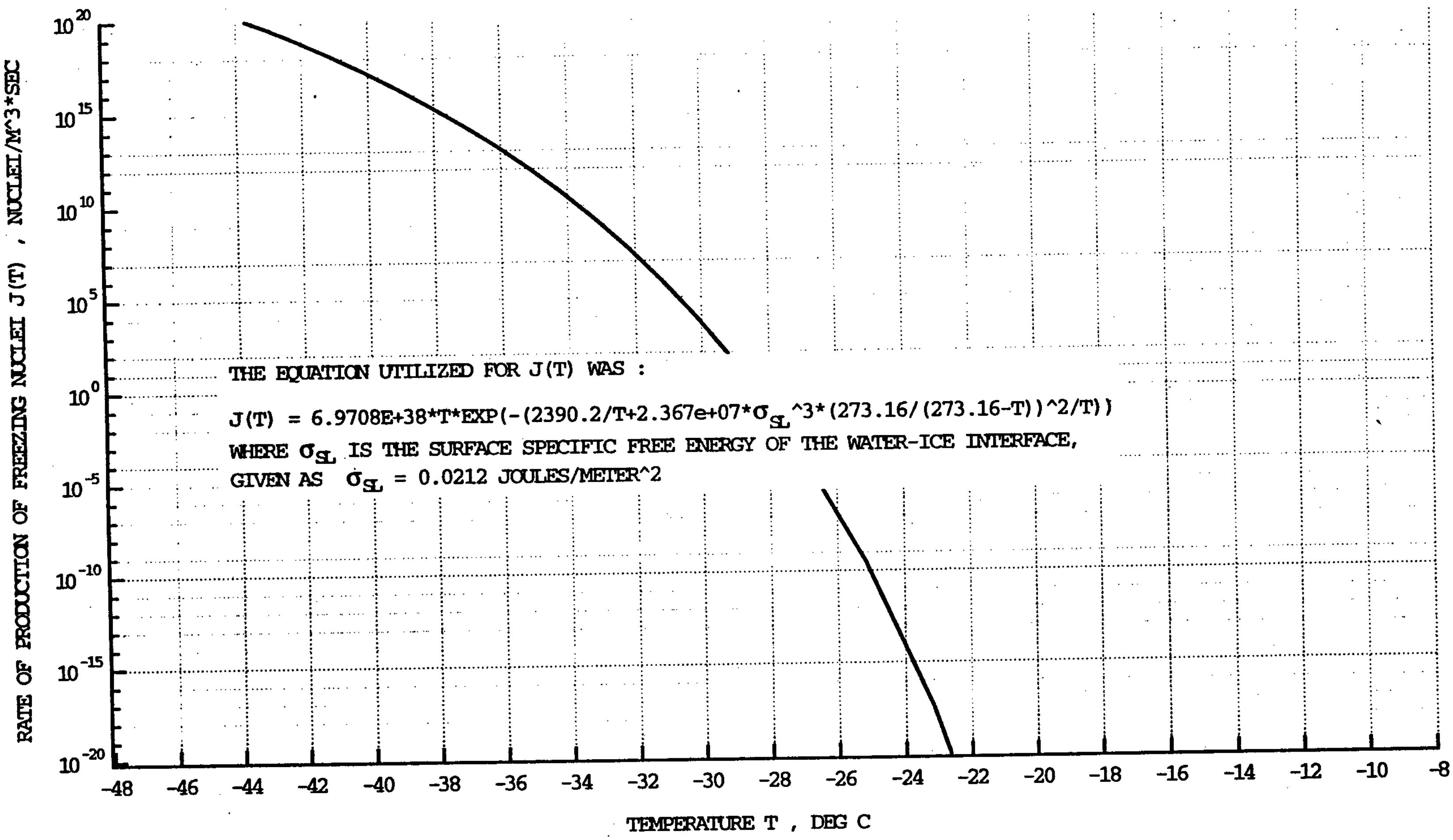

FIG.2 PLOT OF THE HOMOGENEOUS NUCLEATION RATE , J(T), AS A FUNCTION OF WATER PARTICLE TEMPERATURE

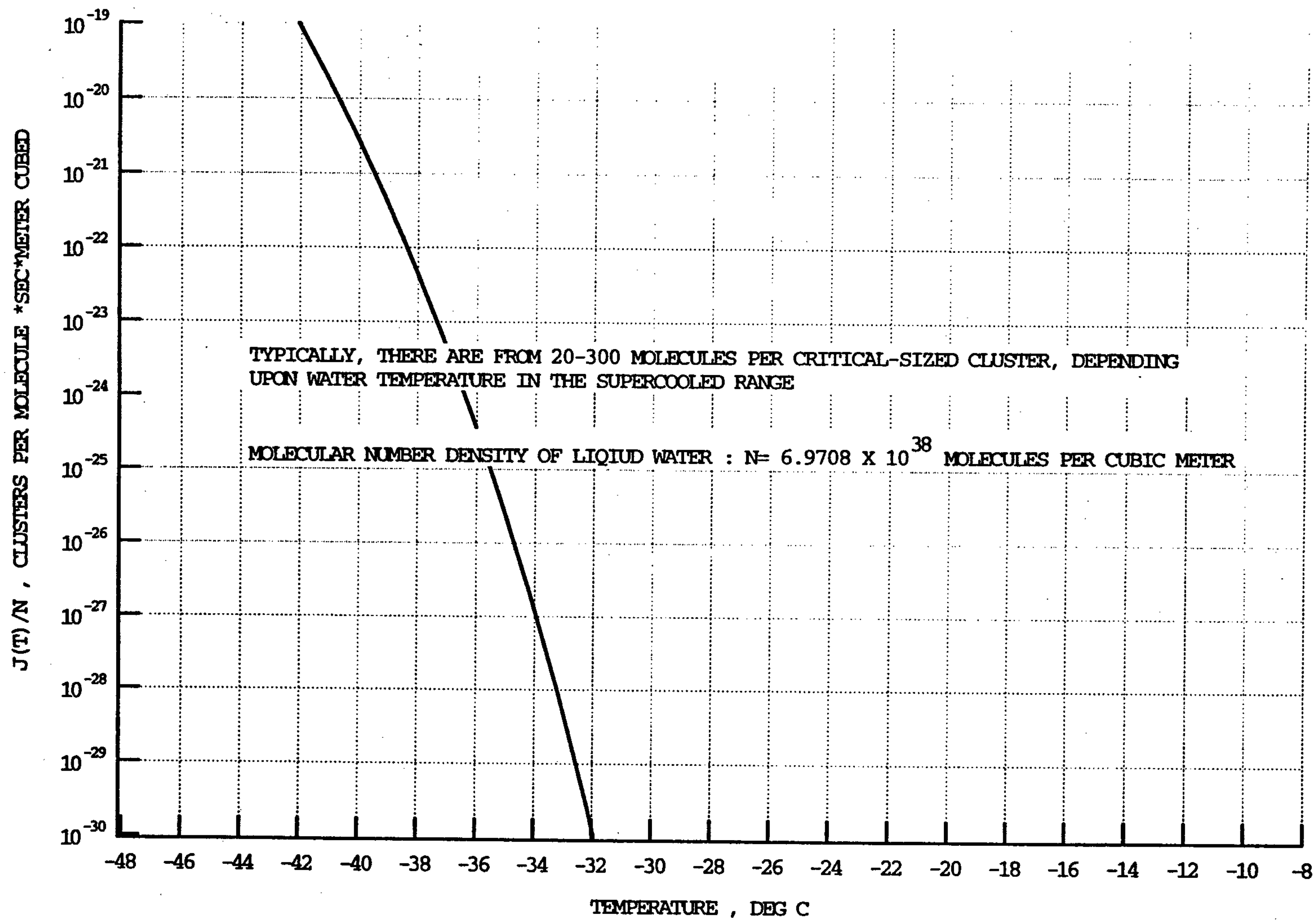

FIG. 3 PLOT OF THE NORMALIZED RATE OF CREATION OF CRITICAL-SIZED MOLECULAR CLUSTERS AS A FUNCTION OF THE WATER PARTICLE TEMPERATURE

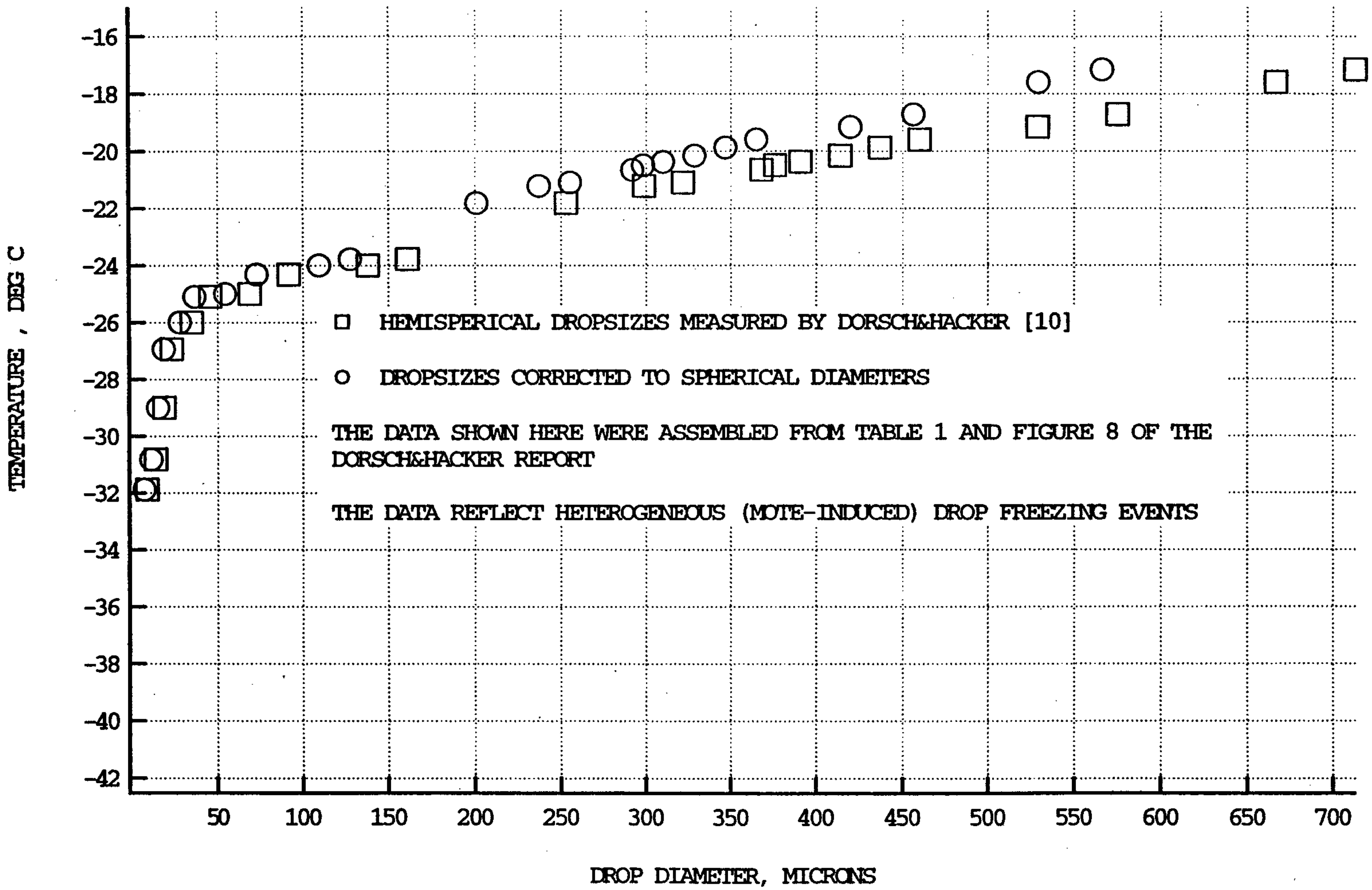

FIG. 4 PLOT OF "AVERAGE" OR MEDIAN, HEMISHERICAL, SUPERCOOLED DROP SPONTANEOUS FREEZING TEMPERATURE AS A FUNCTION OF DROP DIAMETER, FROM THE DORSCH AND HACKER REPORT

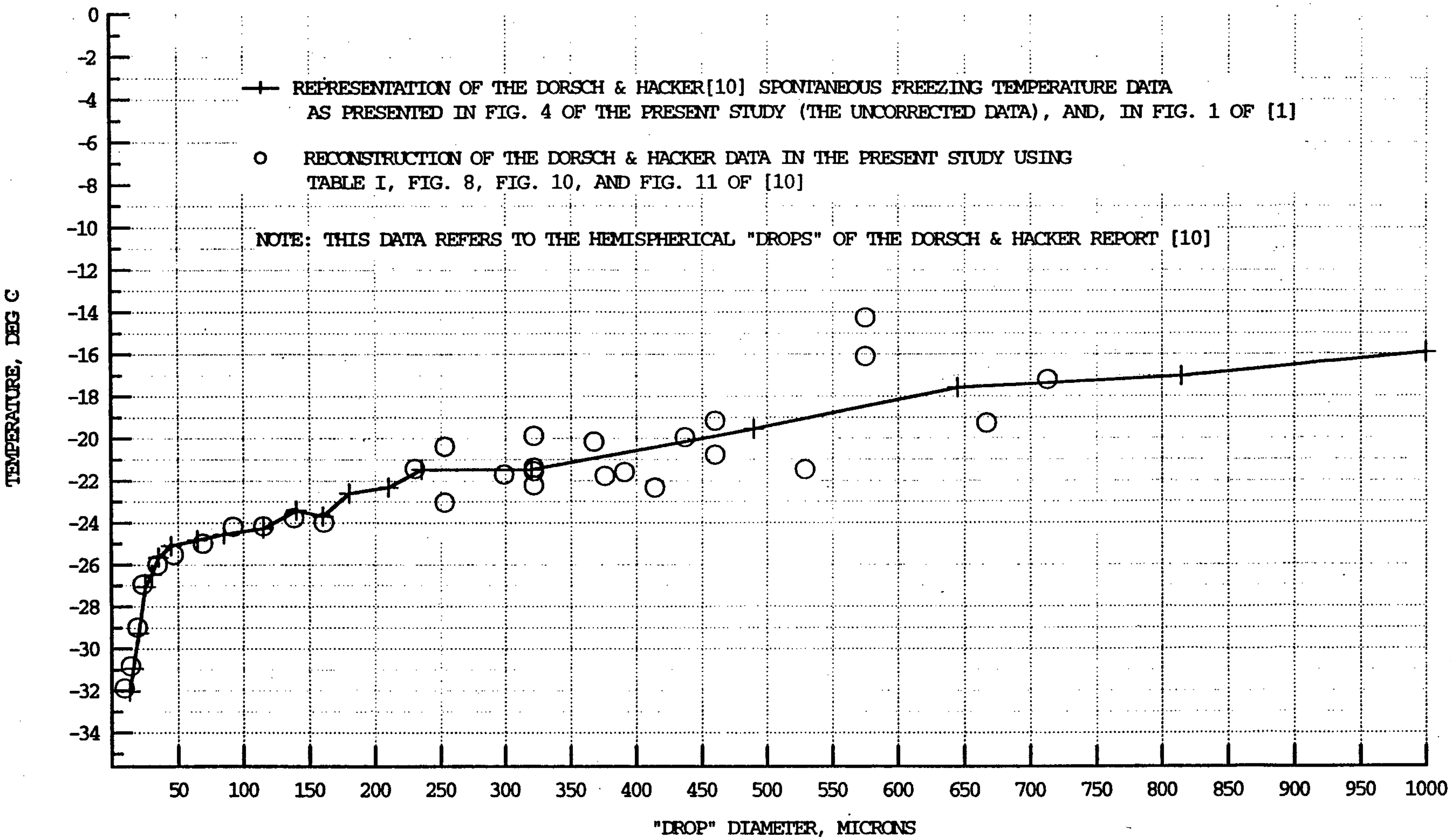

FIG. 5 REEXAMINATION OF THE DORSCH & HACKER "AVERAGE" SPONTANEOUS FREEZING TEMPERATURE DATA TO OBTAIN AN ACCEPTABLE LEVEL OF CONFIDENCE FOR MATCHING IT WITH MODIFIED HOMOGENEOUS FREEZING THEORY

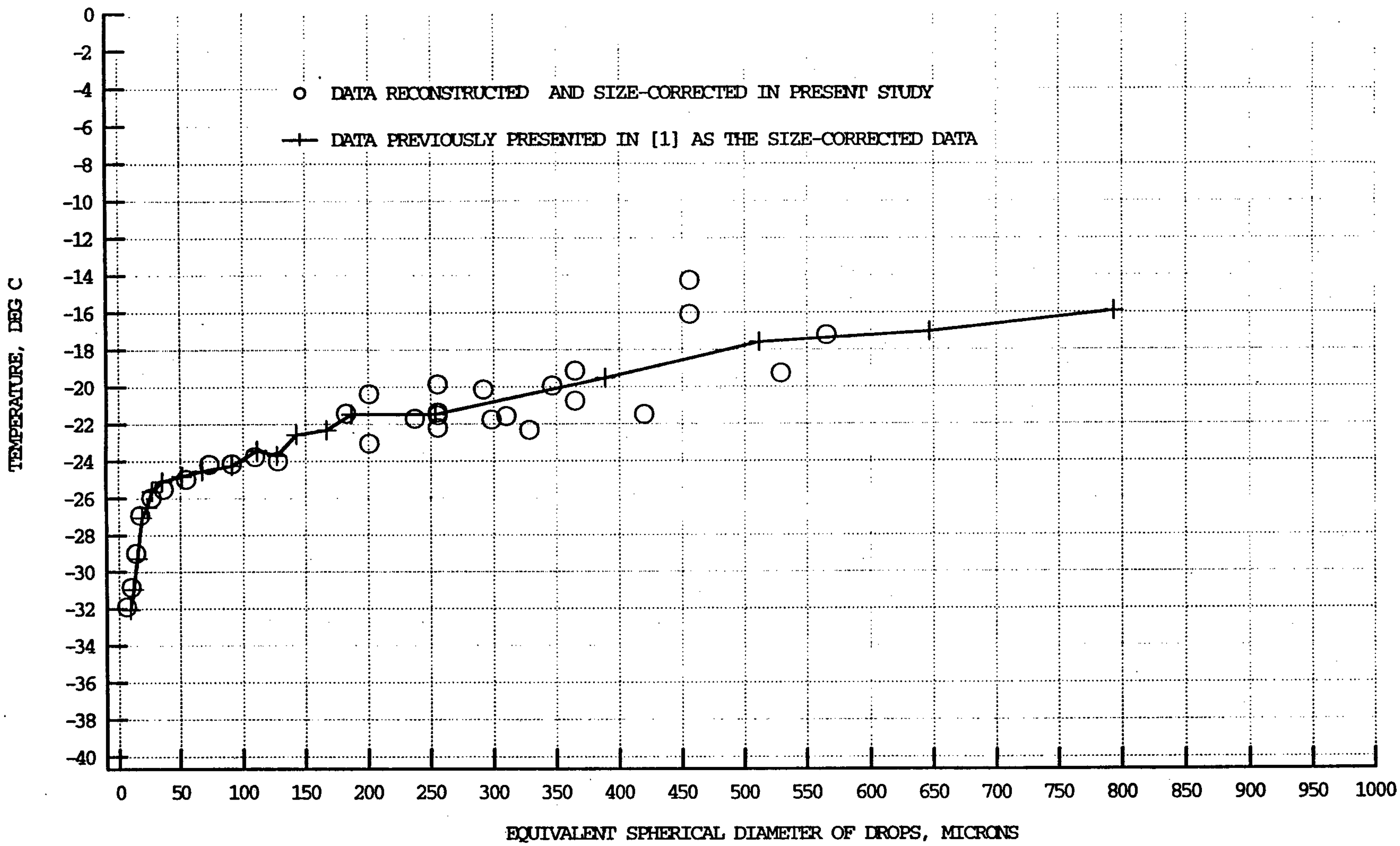

FIG. 6 DATA OF FIGURE 5 CORRECTED TO SPHERICAL SIZES

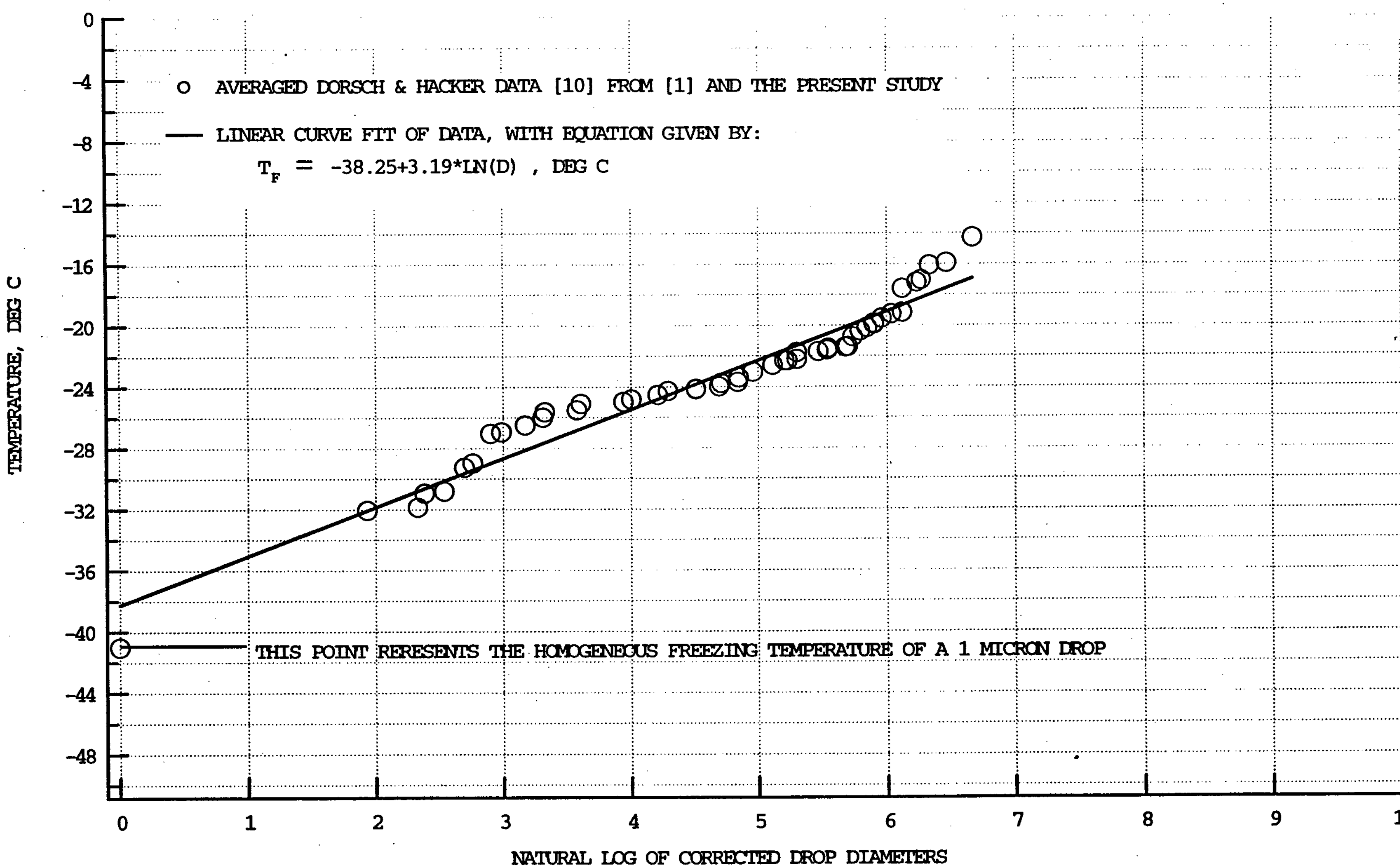

FIG. 7 PLOT SHOWING LINEAR FIT TO AVERAGED SPONTANEOUS FREEZING TEMPERATURES, T_F ,OF THE DORSCH AND HACKER DATA[10], BASED ON CORRECTED DROP DIAMETERS

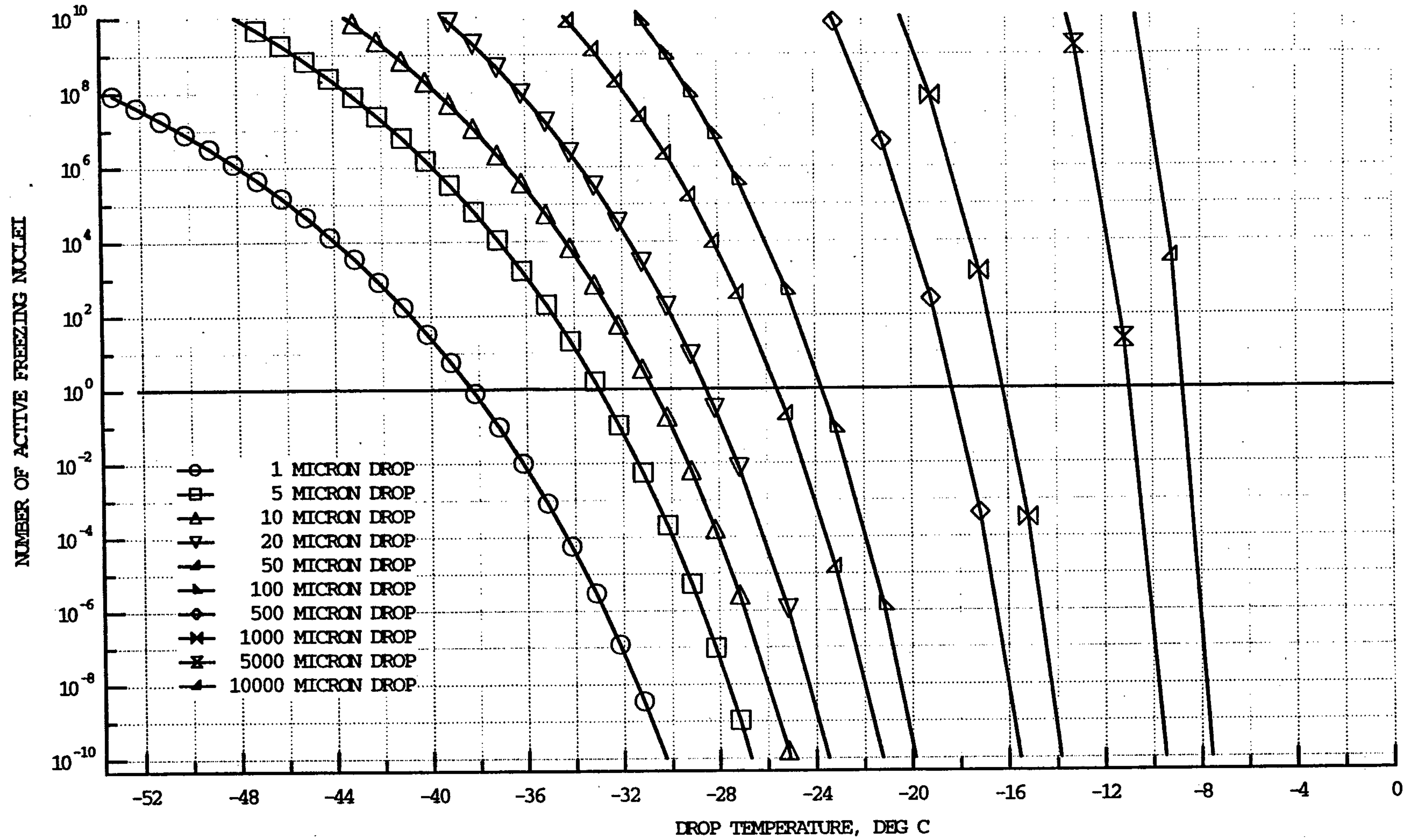

FIG. 8 PLOT OF THE PRODUCTS OF J(T)*DROP VOLUME*TIME, FOR DIFFERENT SIZED DROPS, USED TO MATCH THE DORSCH-HACKER MEDIAN FREEZING TEMPERATURES

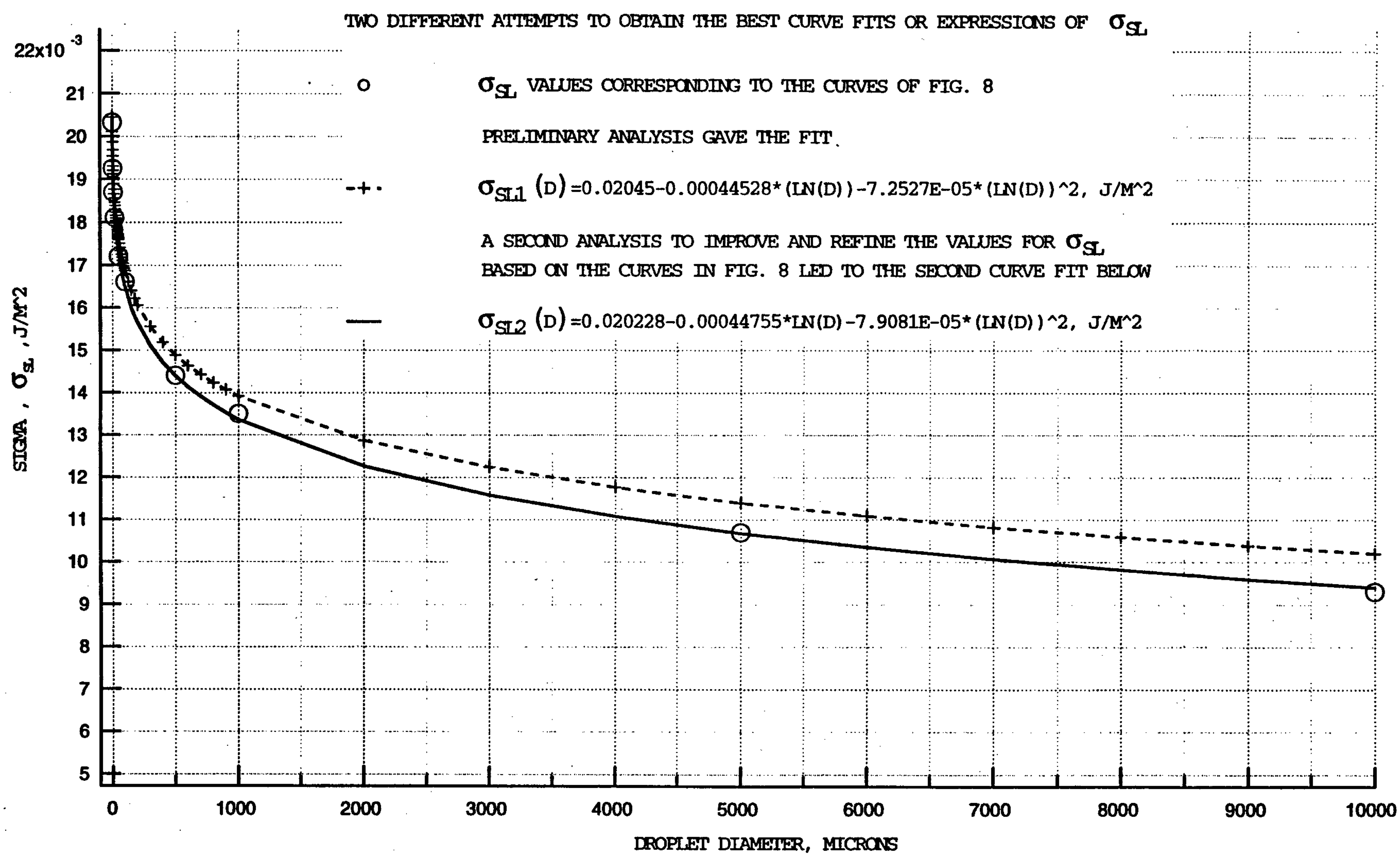

FIG. 9 CURVE FITS OF THE SPECIFIC SURFACE FREE ENERGY, σ_{SL}, OF AN ICE-WATER INTERFACE FOR HETEROGENEOUS NUCLEATION FREEZING, EVALUATED BASED ON THE DORSCH-HACKER DATA [10]

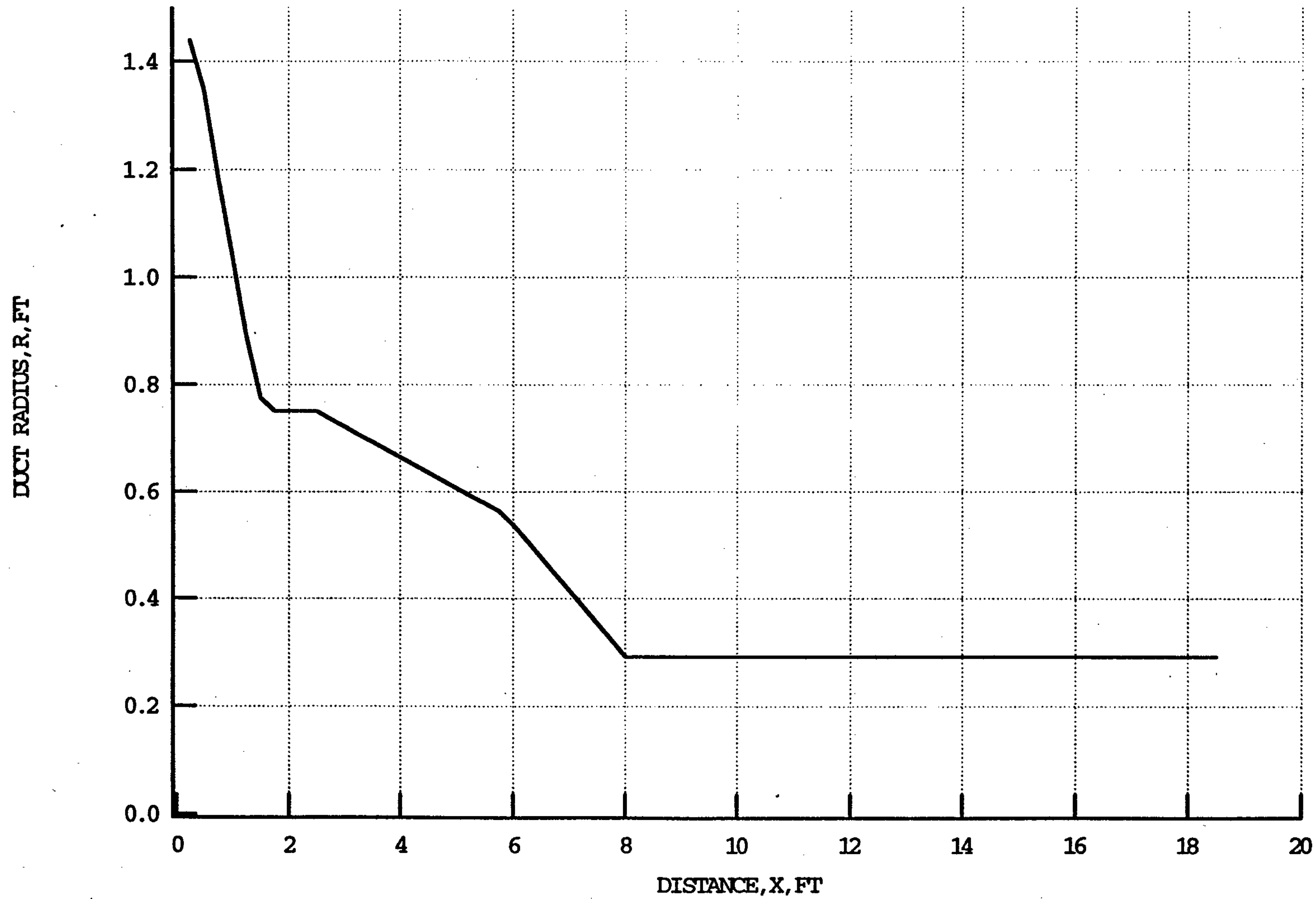

FIG. 10 DUCT GEOMETRY OF TEST CASE USED IN REFERENCE [1]

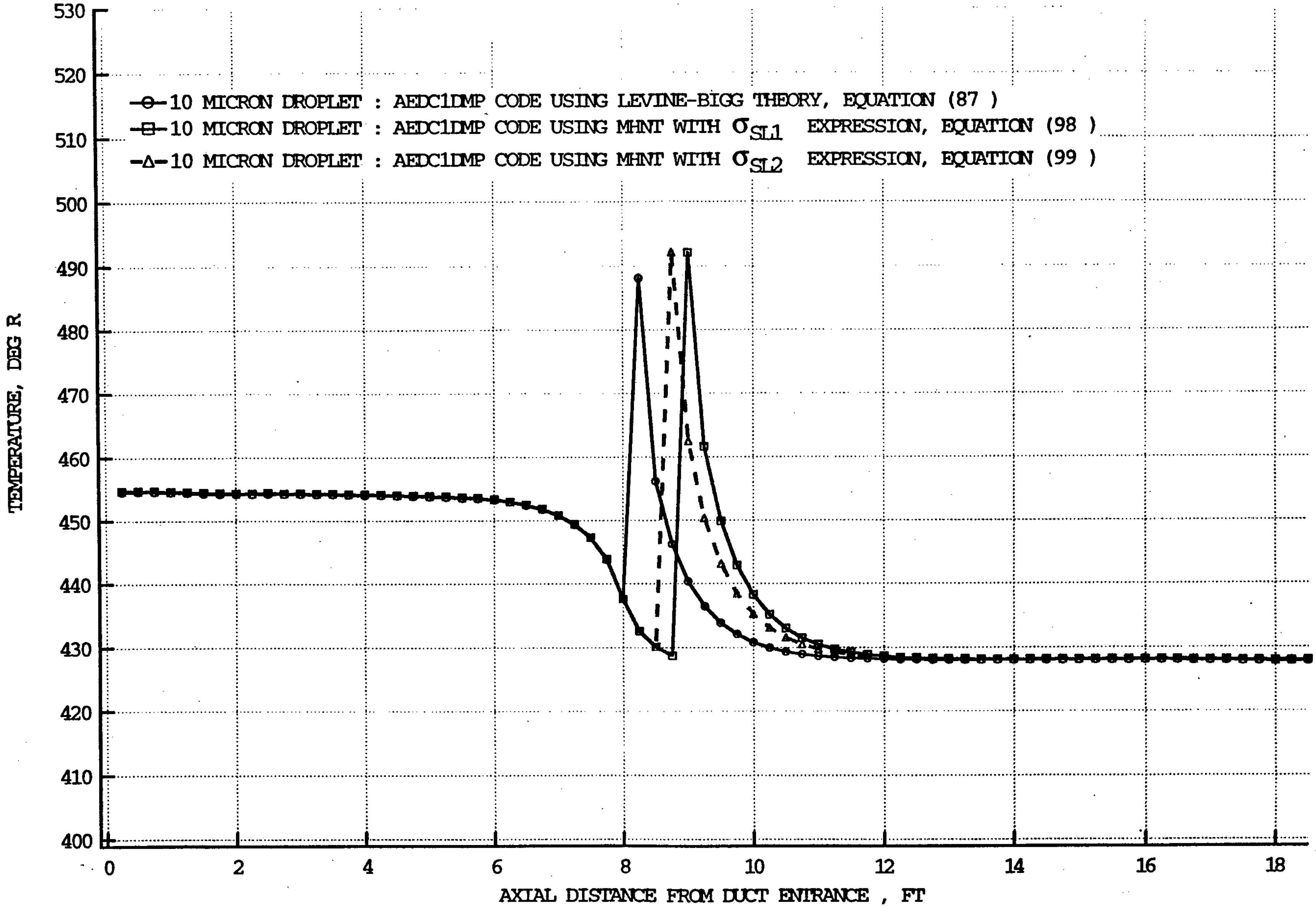

FIG. 11 COMPARISON OF CALCULATED DROPLET TEMPERATURE DISTRIBUTIONS IN DUCTED FLOW WITH FREEZING CONDITIONS PREDICTED

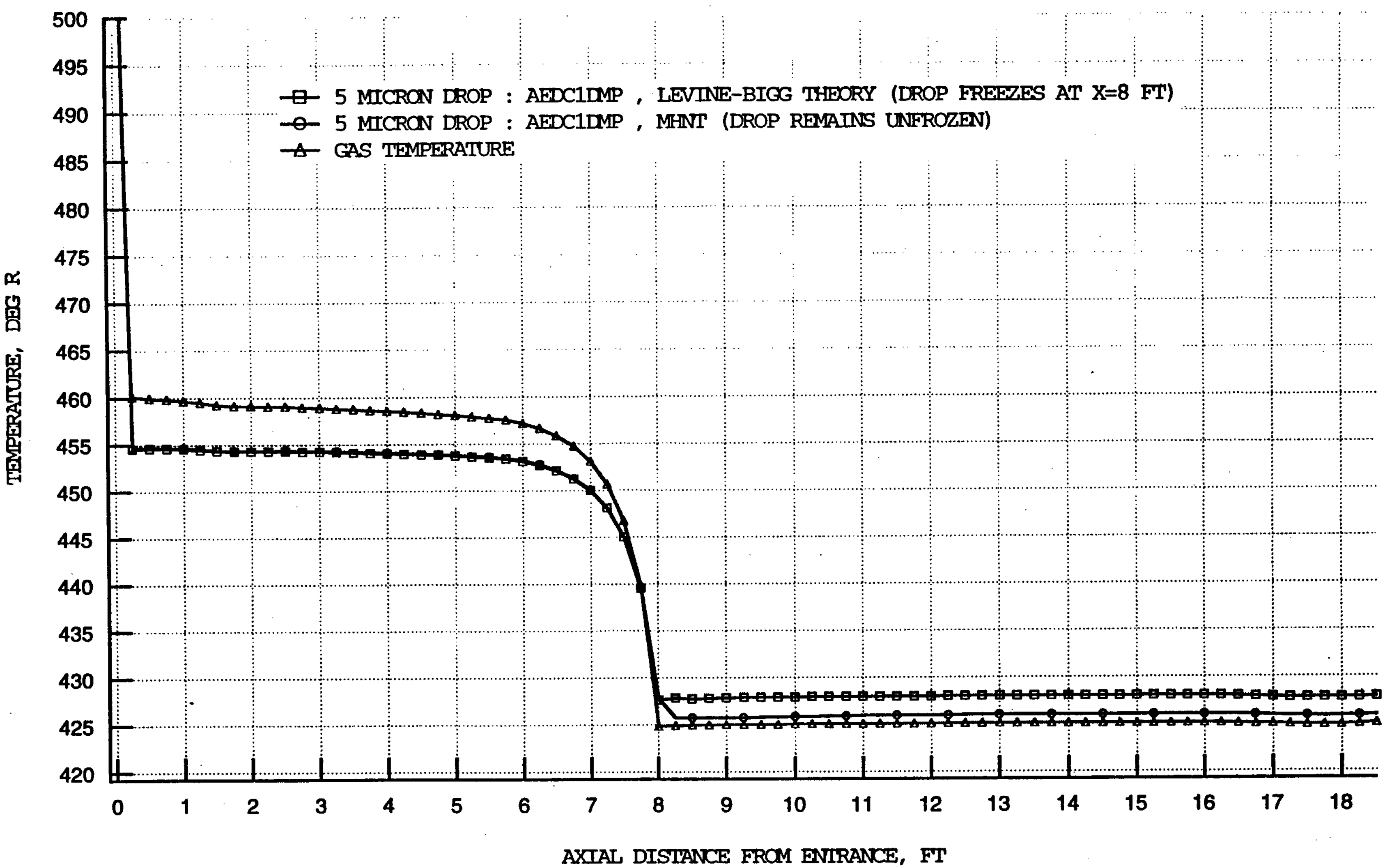

FIG. 12 COMPARISON OF PREDICTED PARTICLE TEMPERATURES DURING FREEZING: LEVINE-BIGG THEORY VS MODIFIED HOMOGENEOUS NUCLEATION THEORY (MHNT)

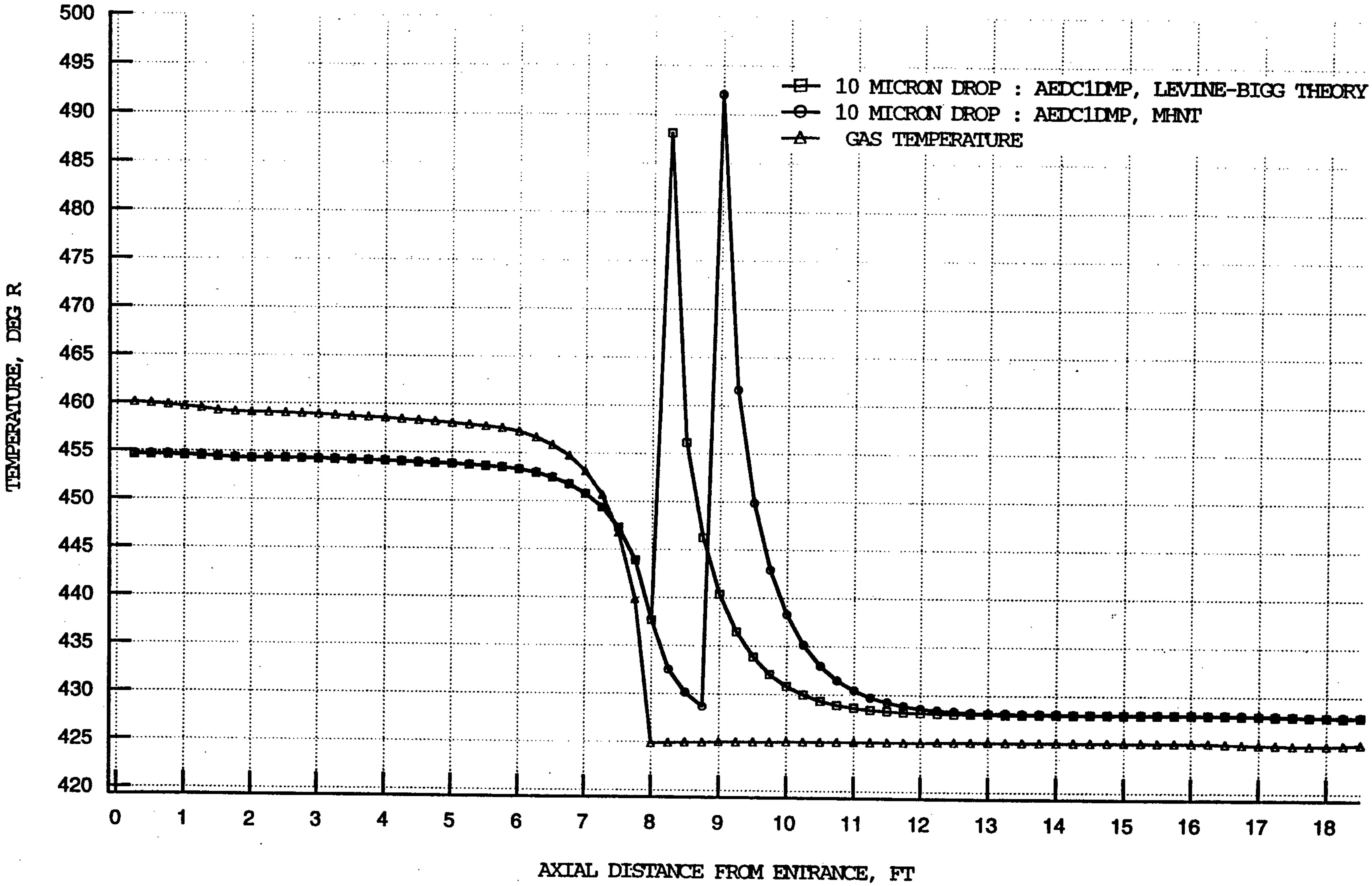

FIG. 12 (CONTINUED) COMPARISON OF PREDICTED PARTICLE TEMPERATURES DURING FREEZING: LEVINE-BIGG THEORY VS MODIFIED HOMOGENEOUS NUCLEATION THEORY (MHNT)

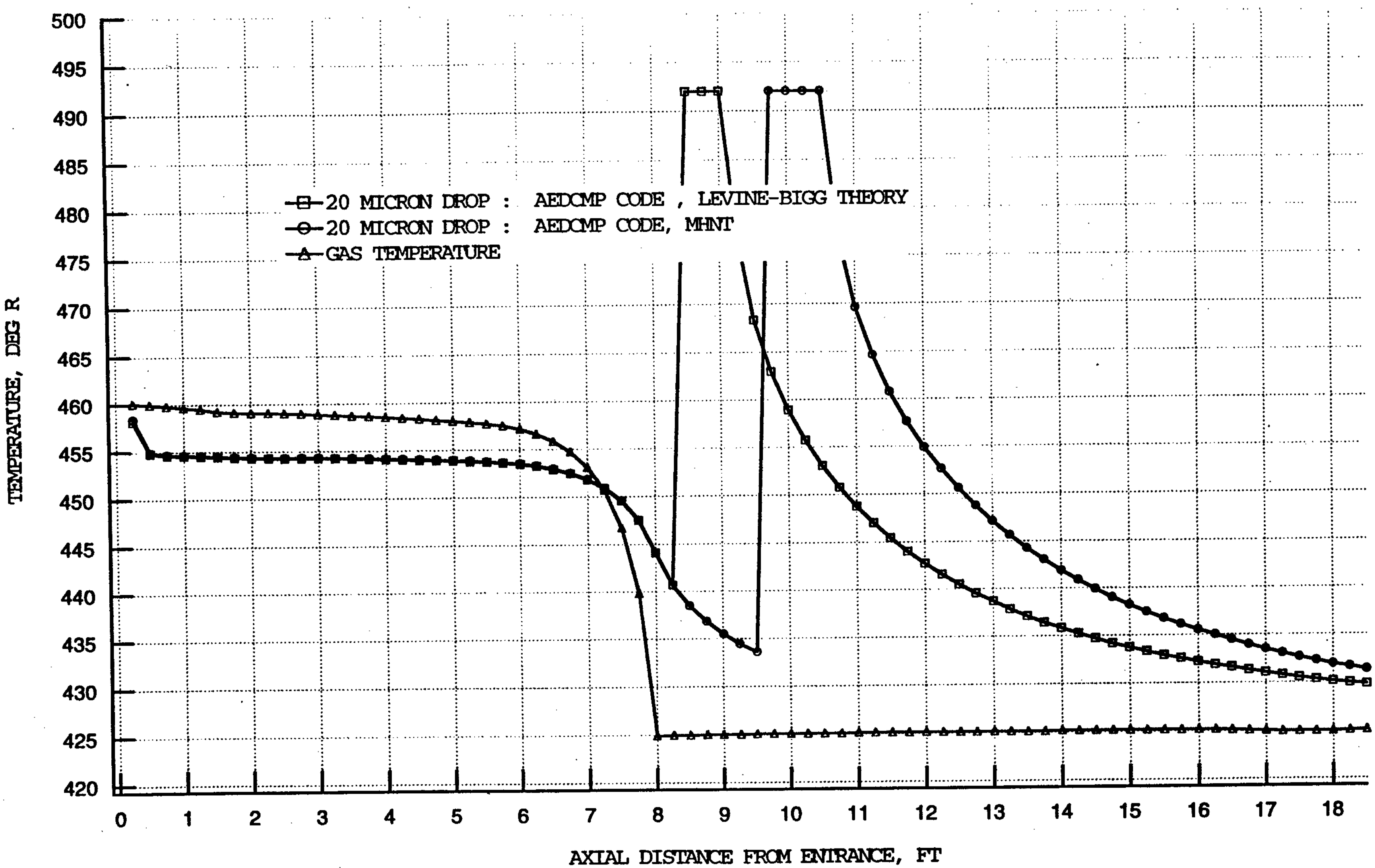

FIG. 12 (CONTINUED) COMPARISON OF PREDICTED PARTICLE TEMPERATURES DURING FREEZING: LEVINE-BIGG THEORY VS MODIFIED HOMOGENEOUS NUCLEATION THEORY (MHNT)

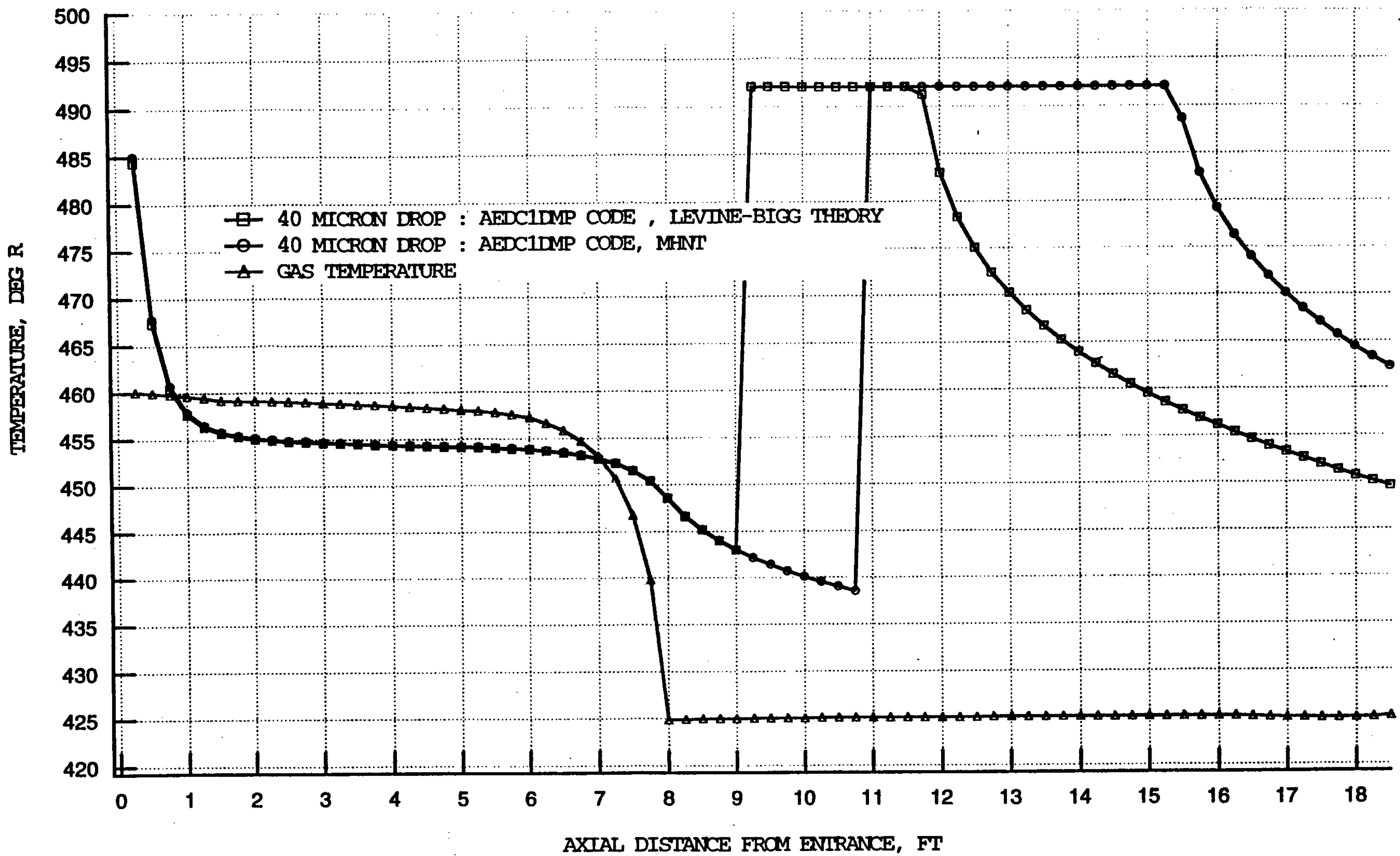

FIG. 12 (CONTINUED) COMPARISON OF PREDICTED PARTICLE TEMPERATURES DURING FREEZING: LEVINE-BIGG THEORY VS MODIFIED HOMOGENEOUS NUCLEATION THEORY (MHNT)

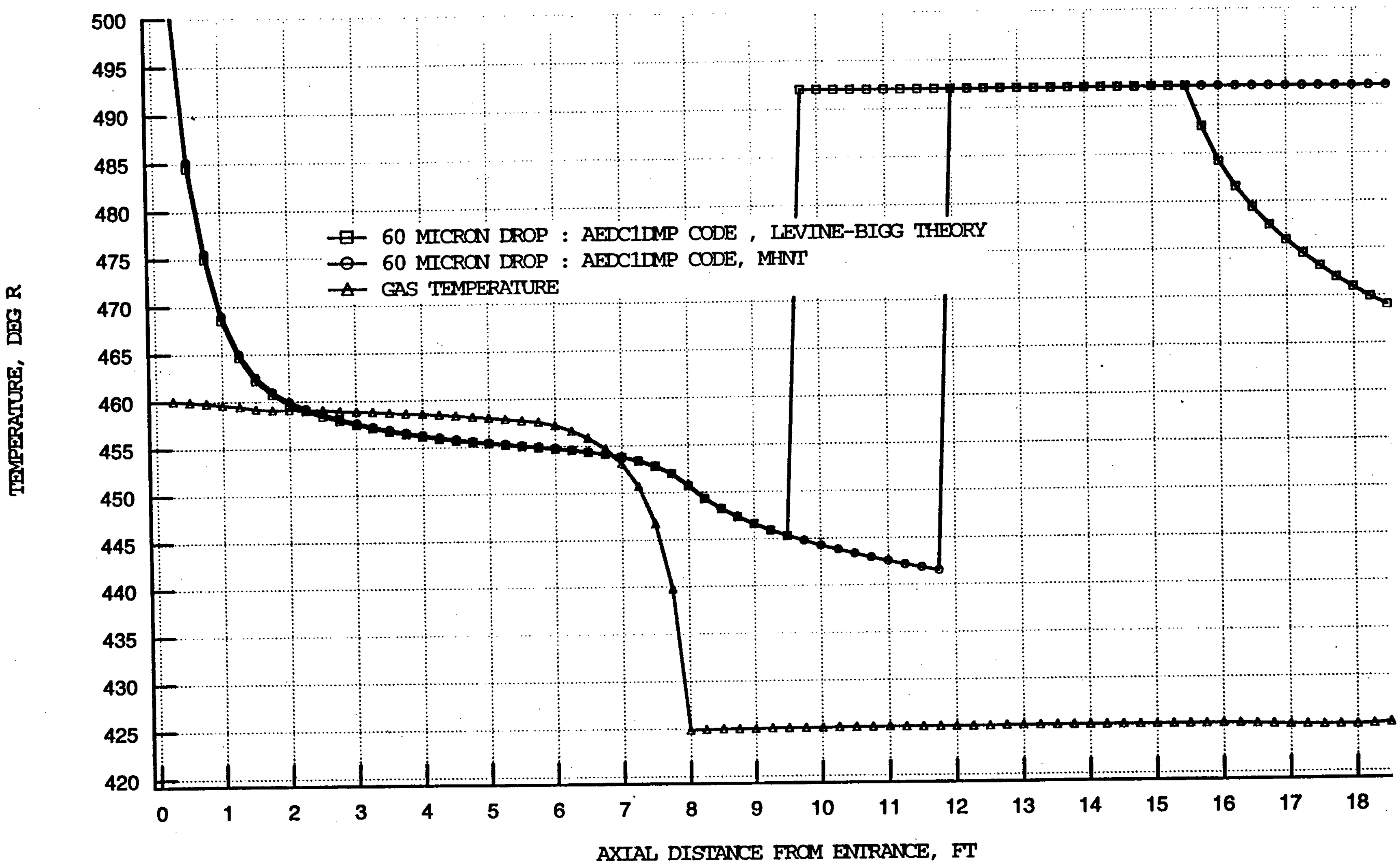

FIG. 12 (CONTINUED) COMPARISON OF PREDICTED PARTICLE TEMPERATURES DURING FREEZING: LEVINE-BIGG THEORY VS MODIFIED HOMOGENEOUS NUCLEATION THEORY (MHNT)

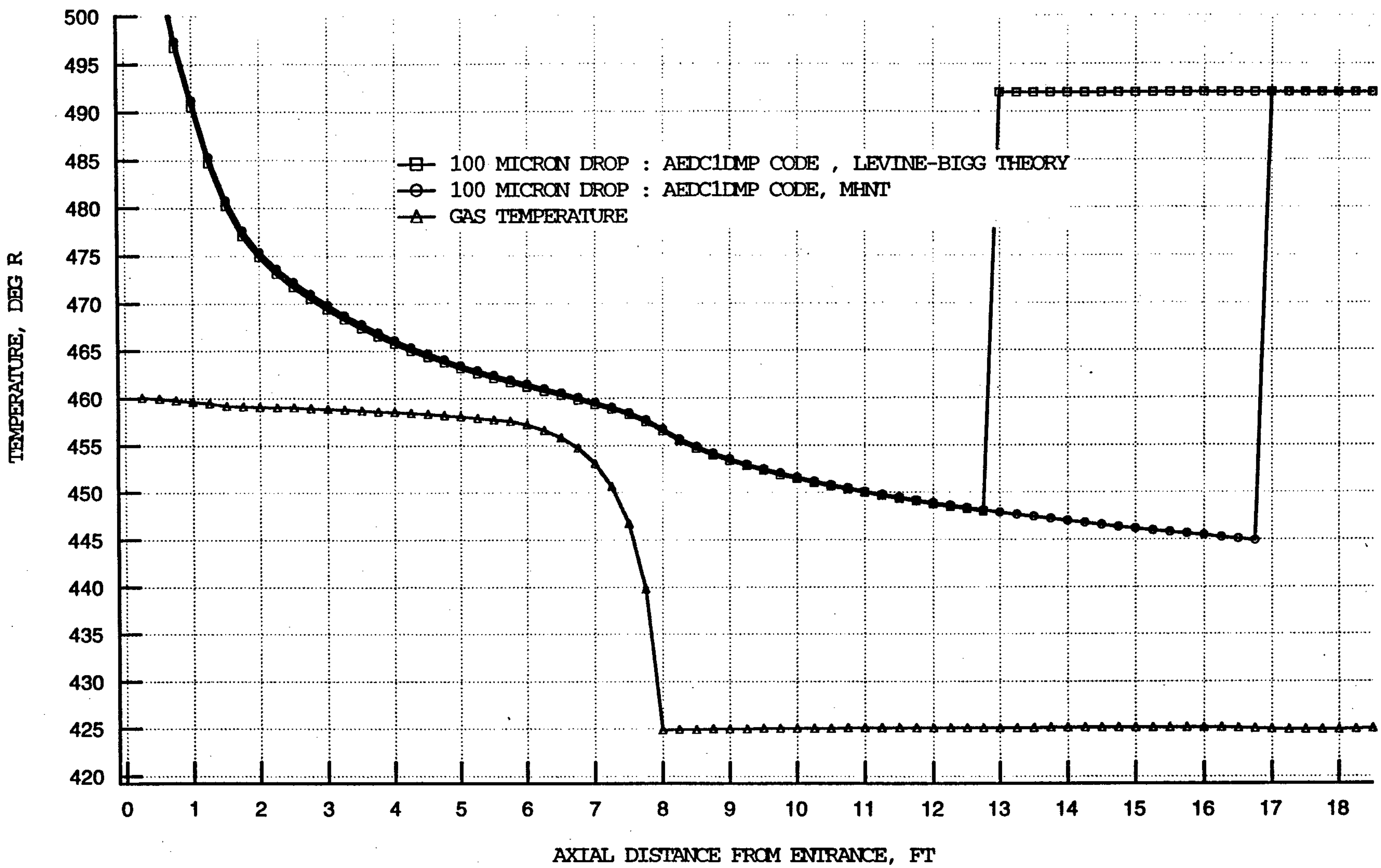

FIG. 12 (CONCLUDED) COMPARISON OF PREDICTED PARTICLE TEMPERATURES DURING FREEZING: LEVINE-BIGG THEORY VS MODIFIED HOMOGENEOUS NUCLEATION THEORY (MHNT)

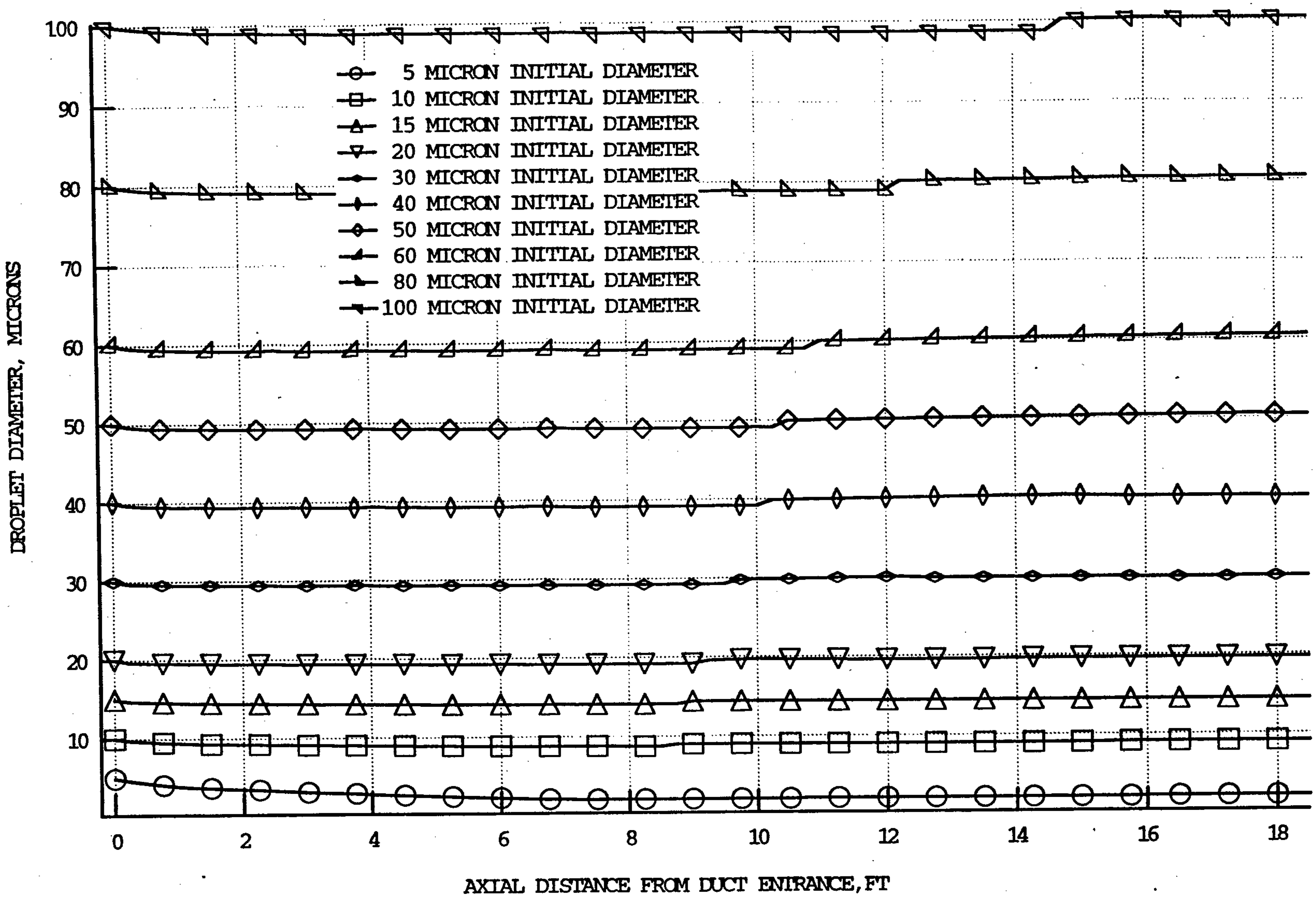

FIG. 13 PREDICTED VARIATIONS IN DROP SIZES ALONG THE DUCTED FLOW FREEZING PROCESS

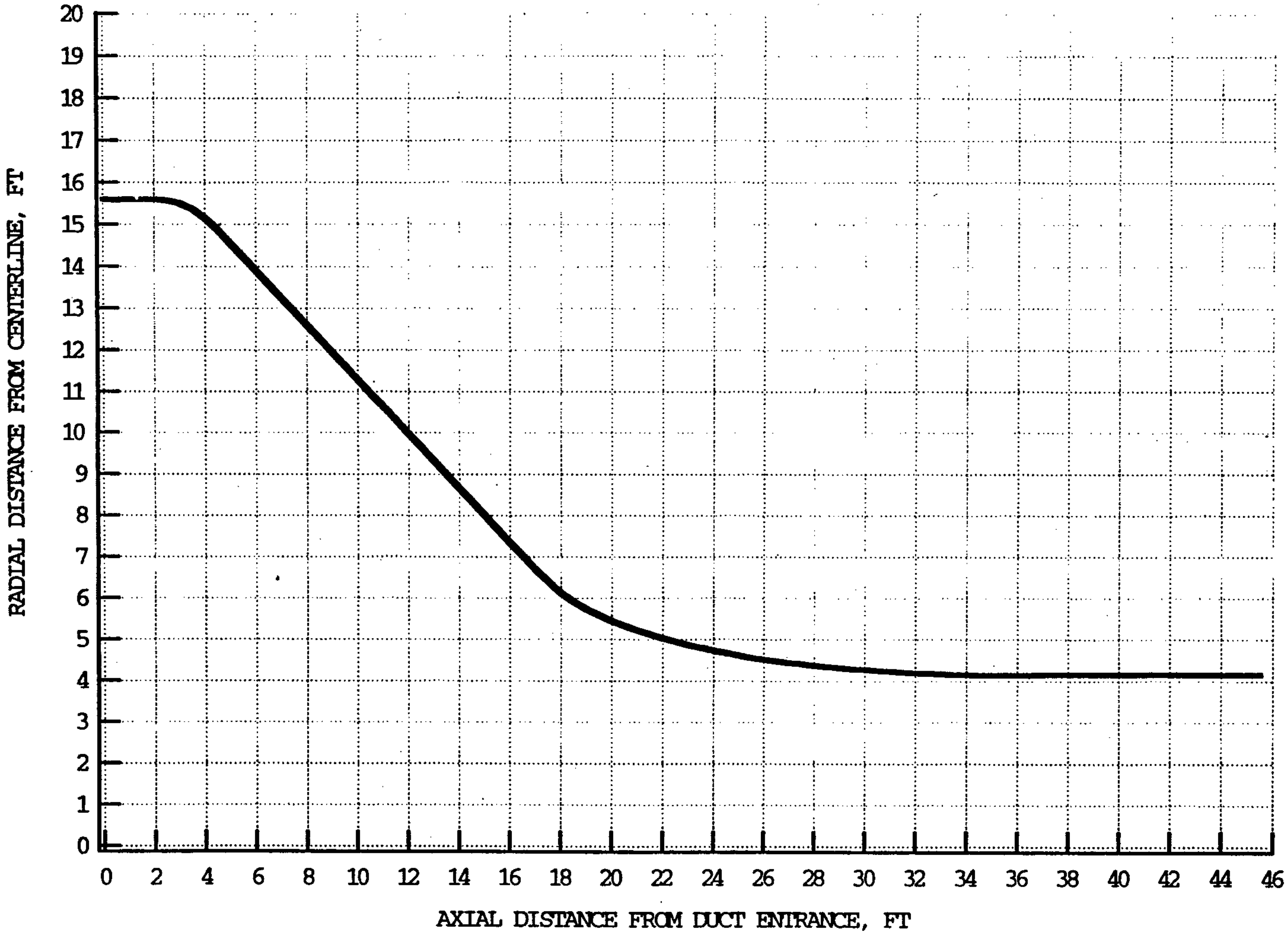

FIG. 14 DUCT WALL CONTOUR FOR REFERENCE CASE 2

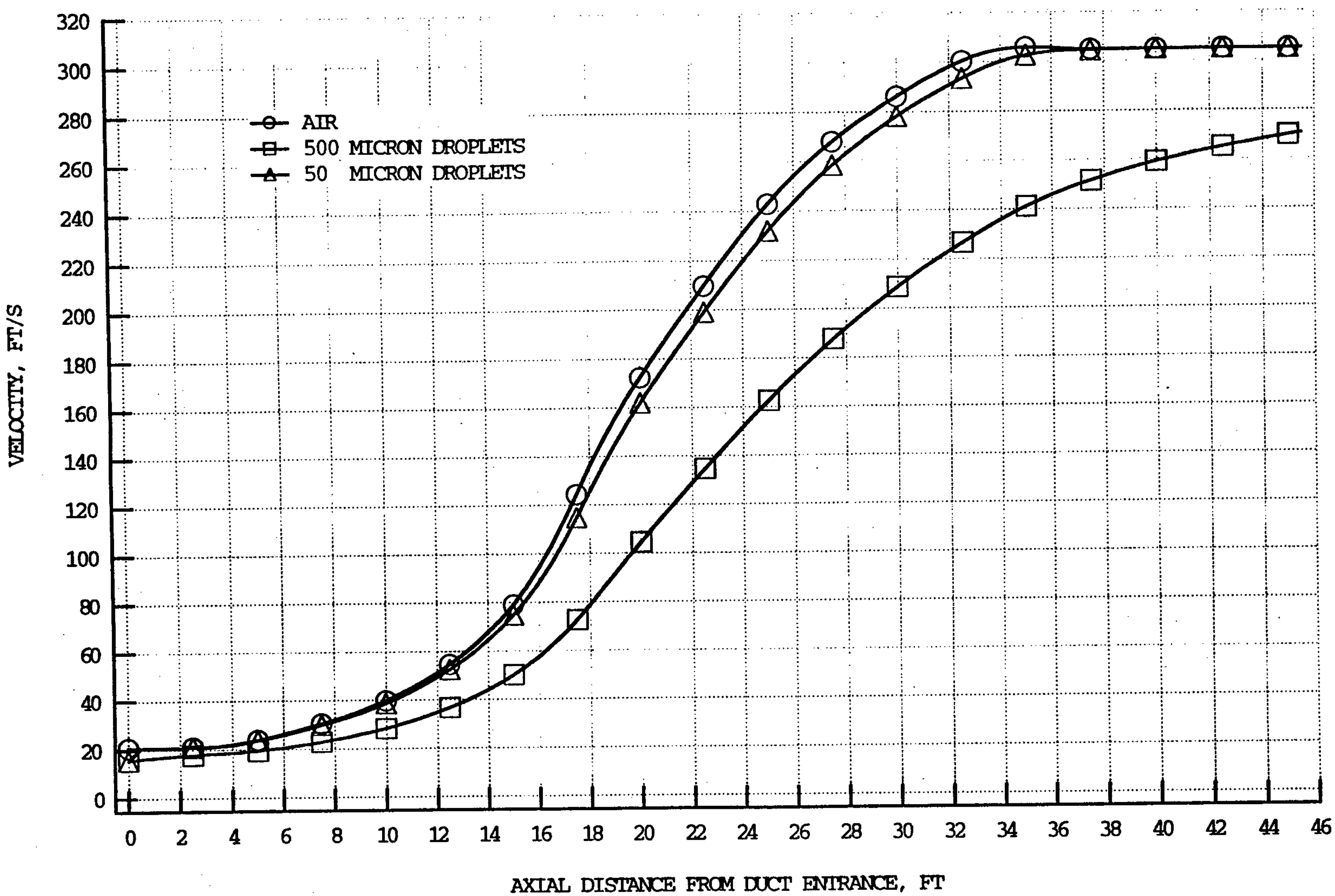

FIG. 15 PLOT OF AIR FLOW AND PARTICLE VELOCITIES FOR REFERENCE CASE 2

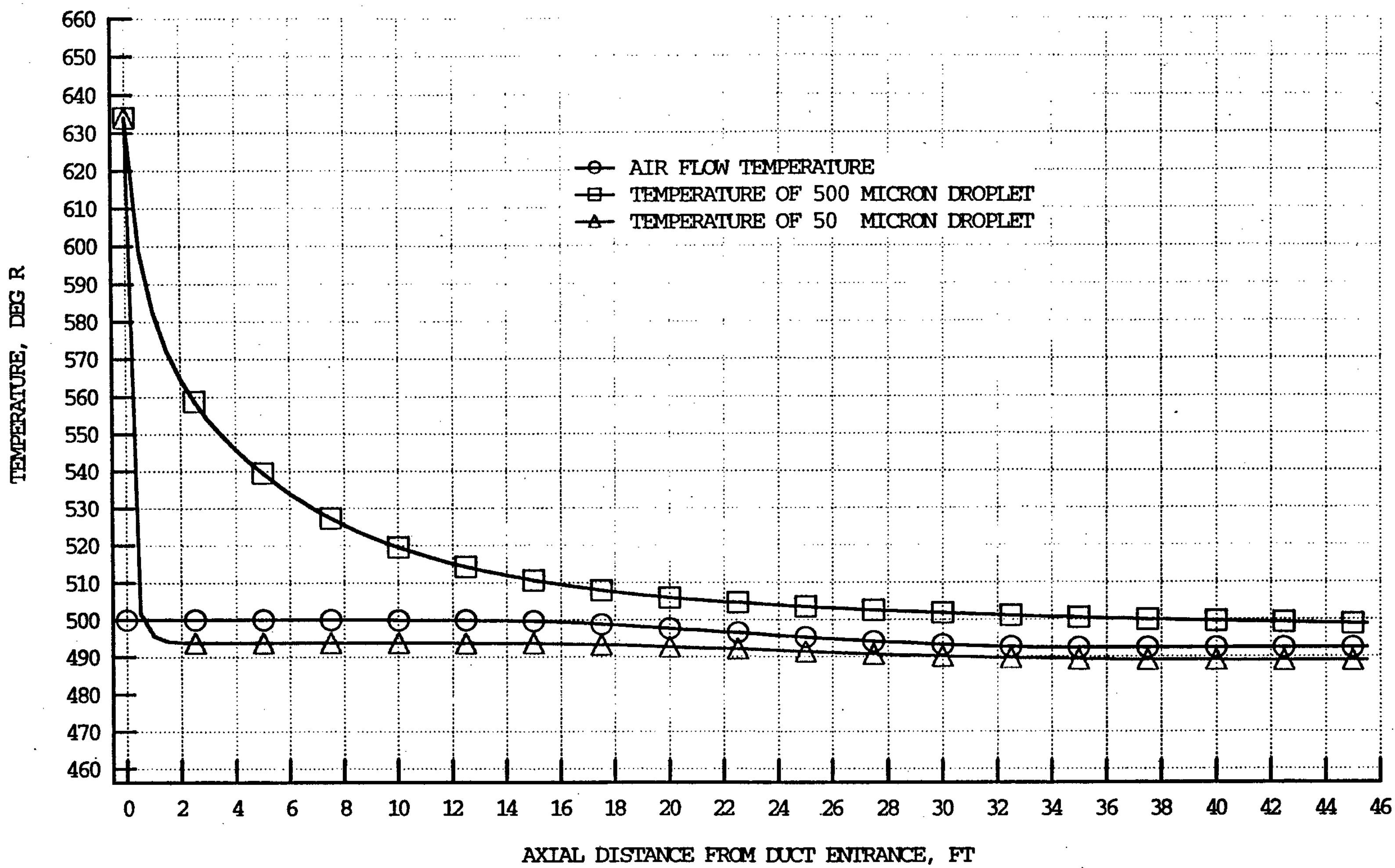

FIG. 16 PREDICTED AIR AND WATER PARTICLE TEMPERATURE VARIATIONS ALONG THE DUCTED FLOW, REFERENCE CASE 2

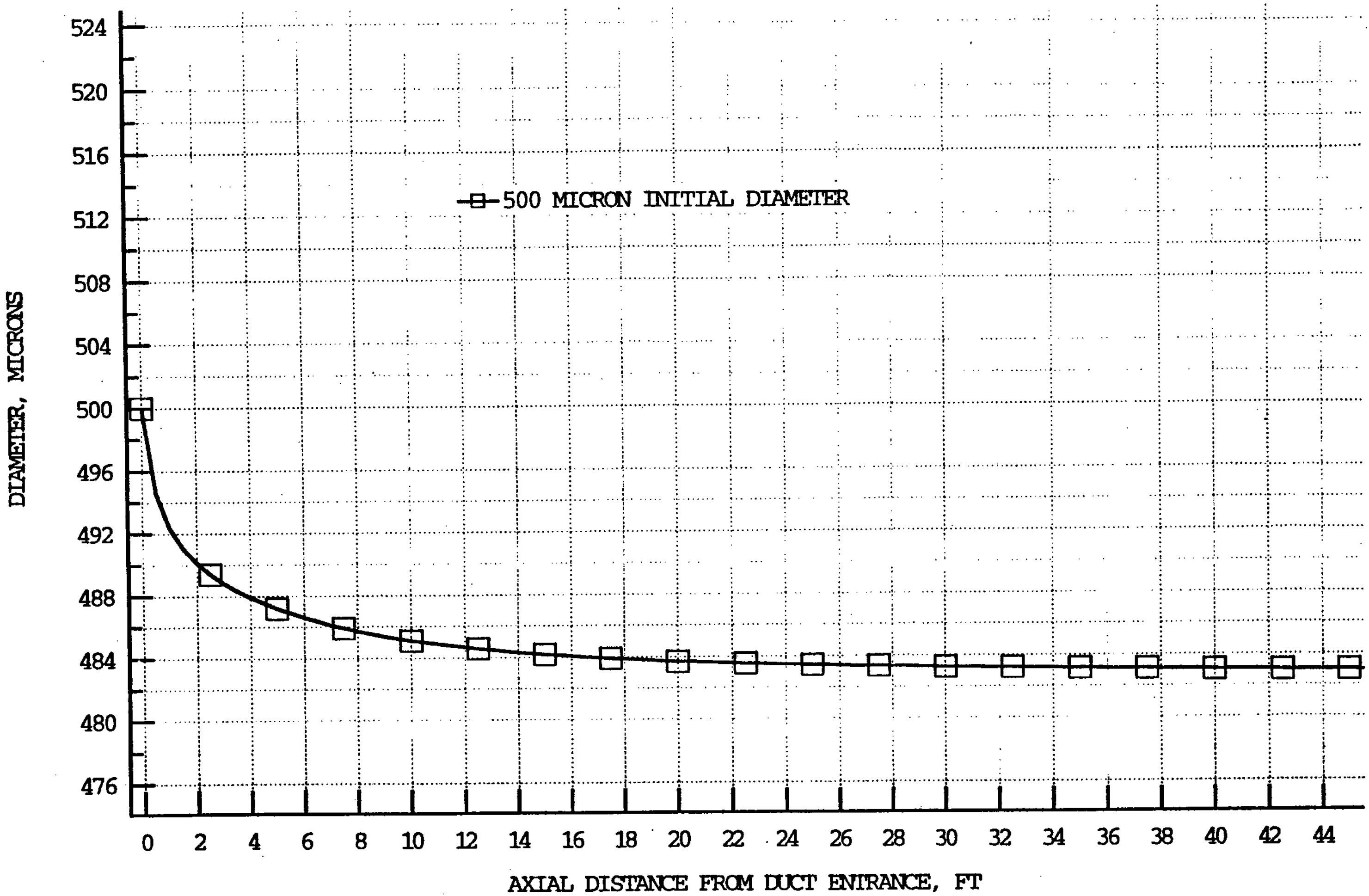

FIG. 17 PREDICTED VARIATIONS OF 50 AND 500 MICRON DROP SIZES ALONG THE DUCT FLOW, REFERENCE CASE 2

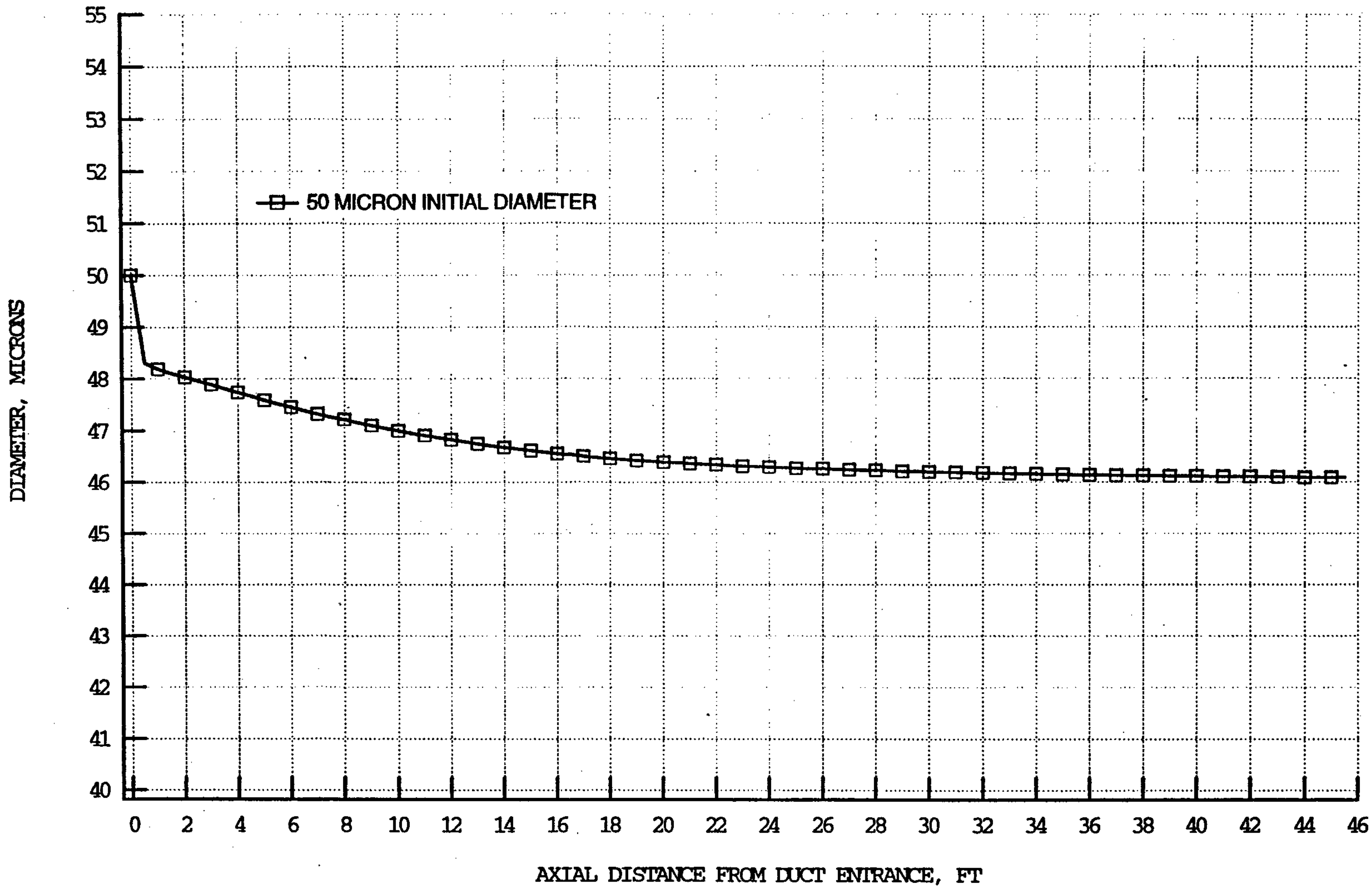

FIG. 17 (CONCLUDED) PREDICTED VARIATIONS OF 50 AND 500 MICRON DROP SIZES ALONG THE DUCT FLOW, REFERENCE CASE 2

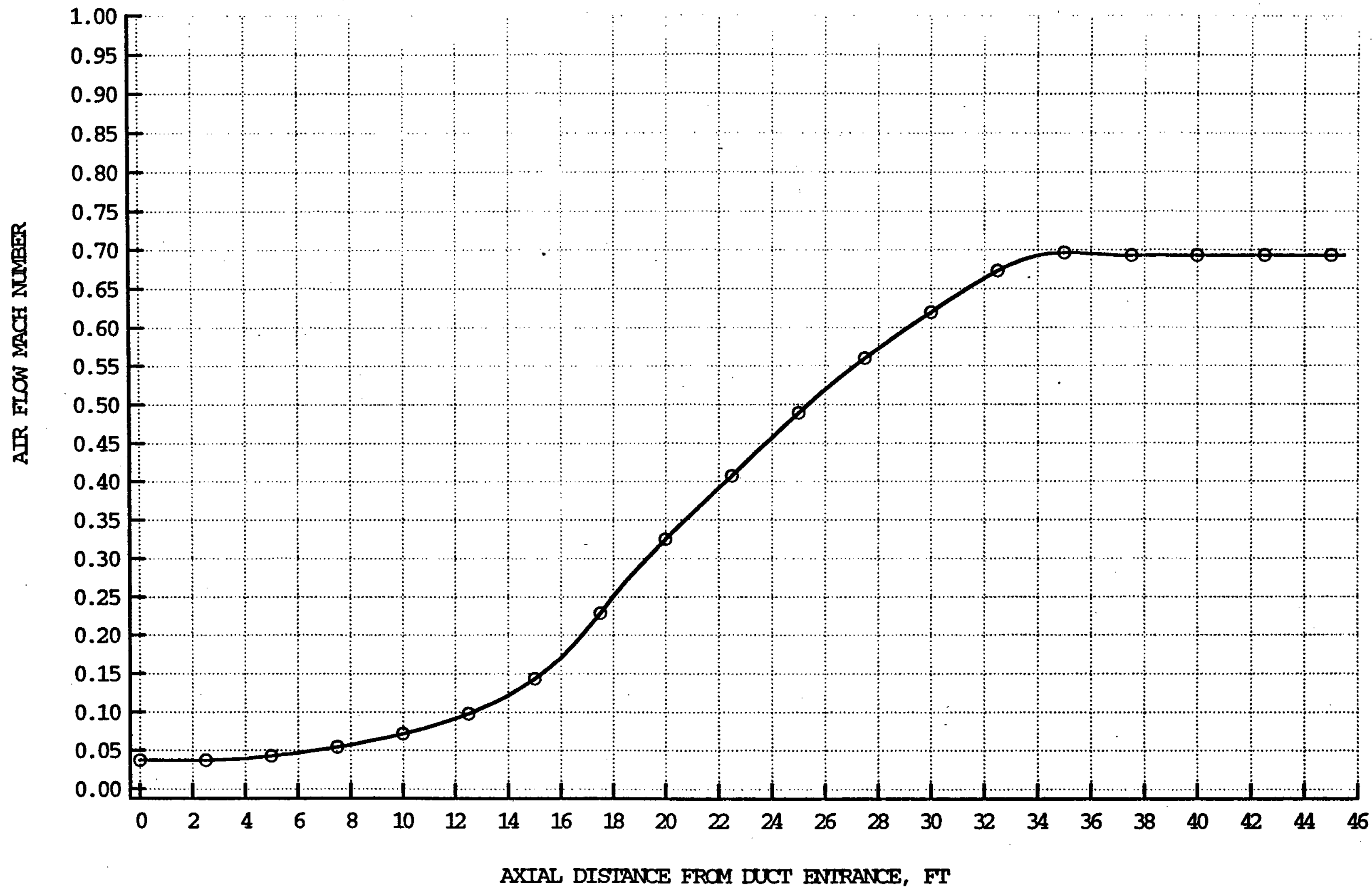

FIG. 18 PREDICTED AXIAL DISTRIBUTION OF AIR FLOW MACH NUMBER ALONG DUCTED FLOW

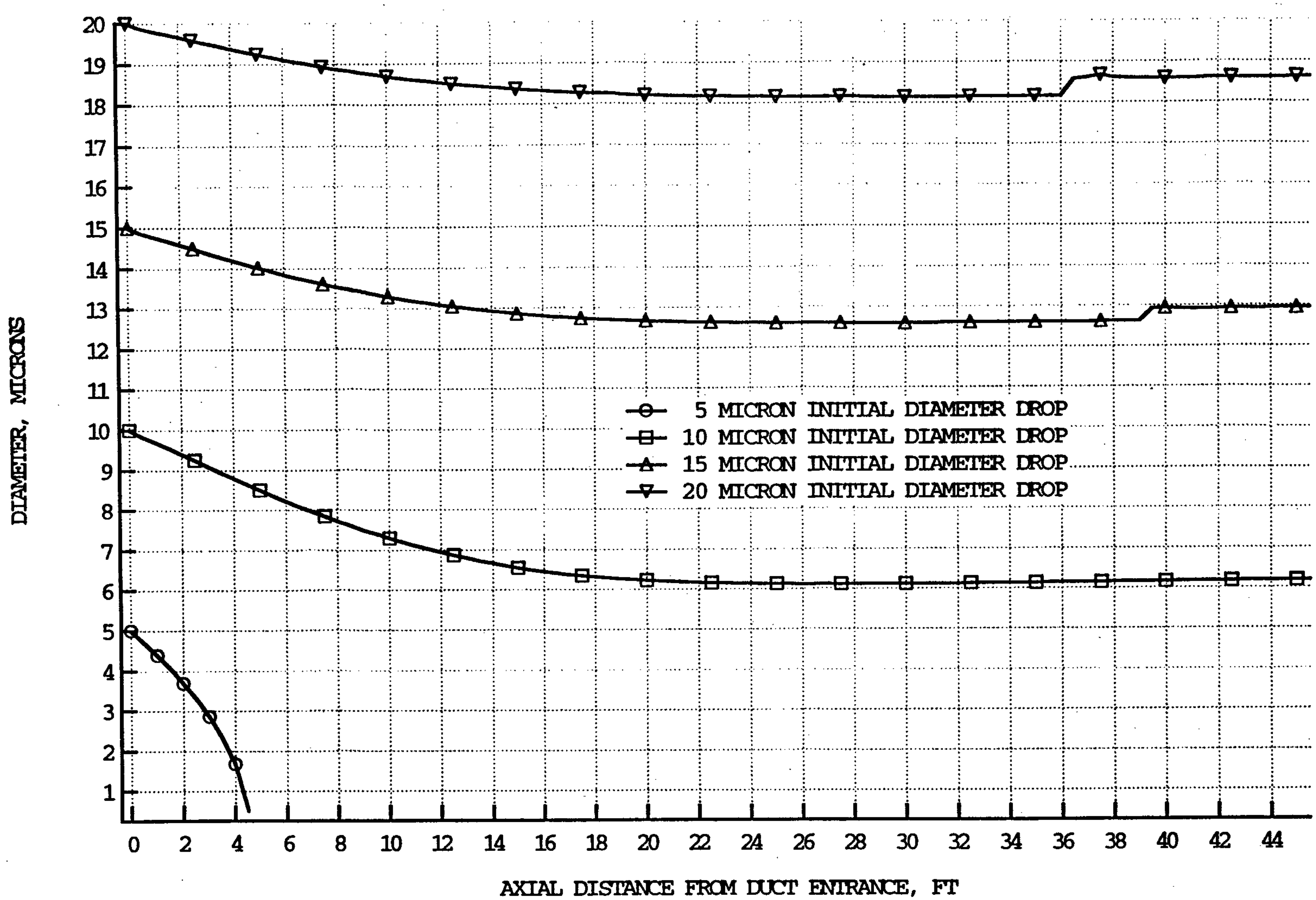

FIG. 19 PREDICTED AXIAL VARIATIONS OF WATER PARTICLE SIZES ALONG WIND TUNNEL FLOW

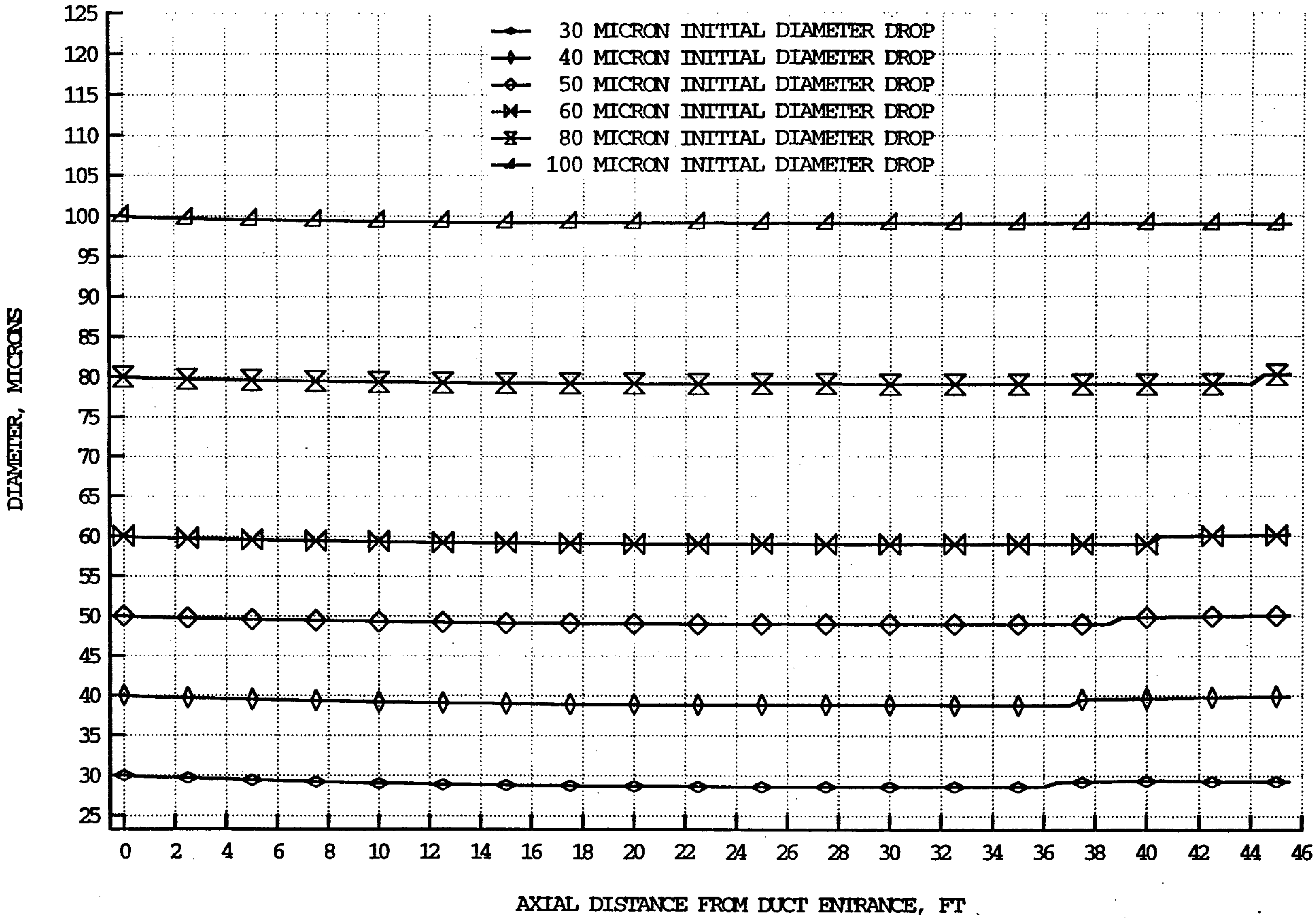

FIG. 19 (CONCLUDED) PREDICTED AXIAL VARIATIONS OF WATER PARTICLE SIZES ALONG WIND TUNNEL FLOW

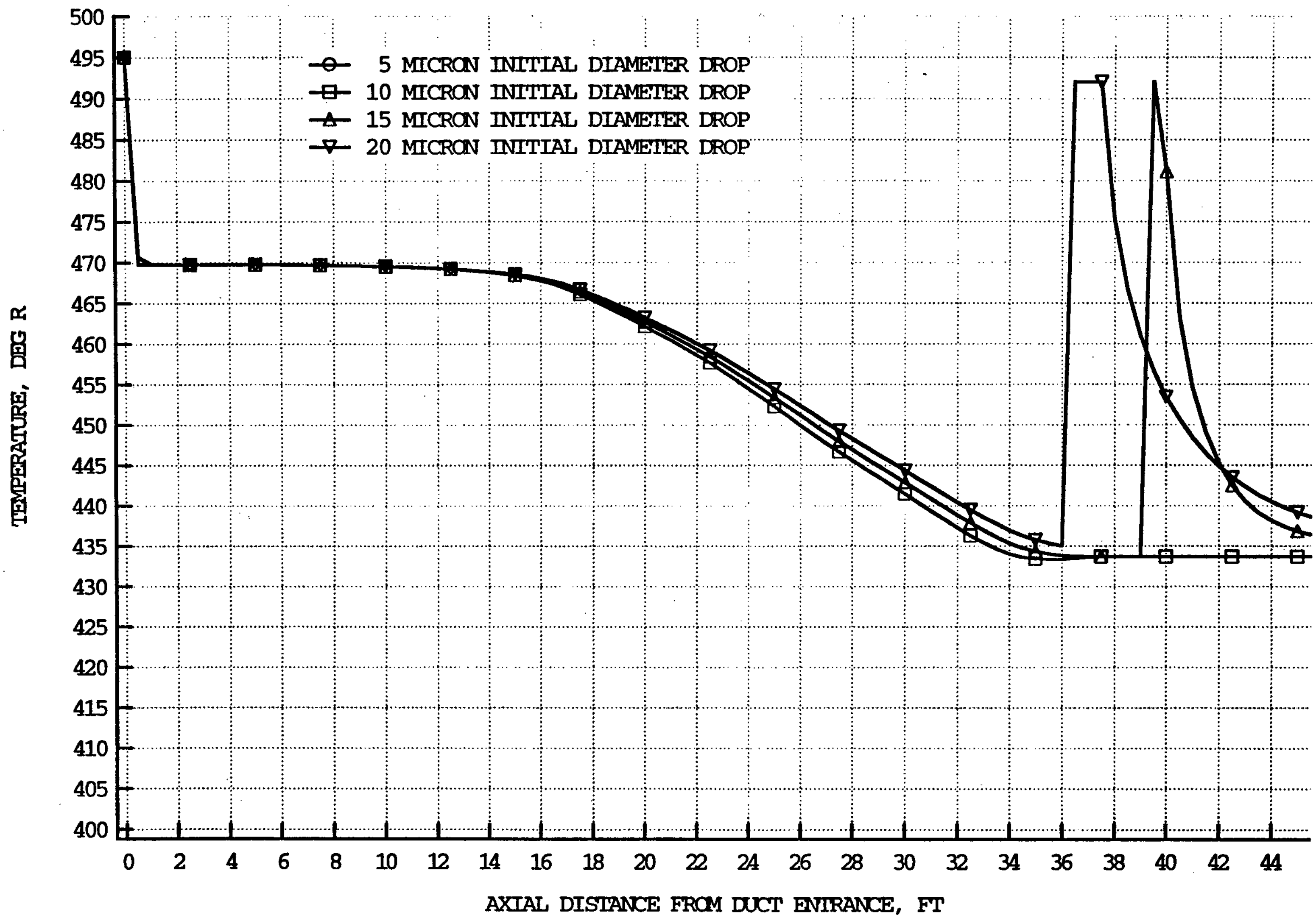

FIG. 20 PREDICTED AXIAL DISTRIBUTIONS OF WATER PARTICLE TEMPERATUIRES ALONG TUNNEL FLOW

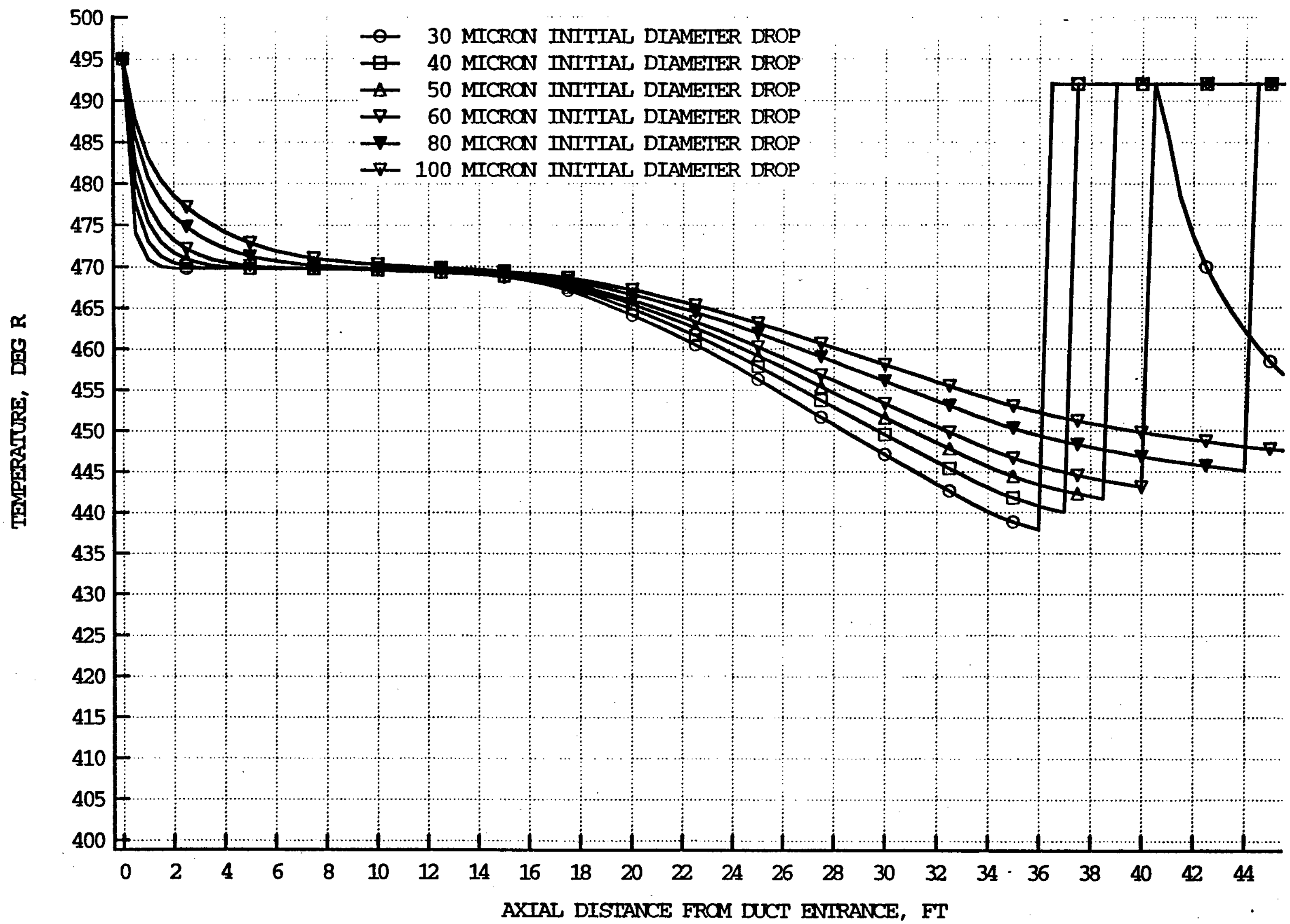

FIG. 20 (CONCLUDED) PREDICTED AXIAL DISTRIBUTIONS OF WATER PARTICLE TEMPERATUTRES ALONG TUNNEL FLOW

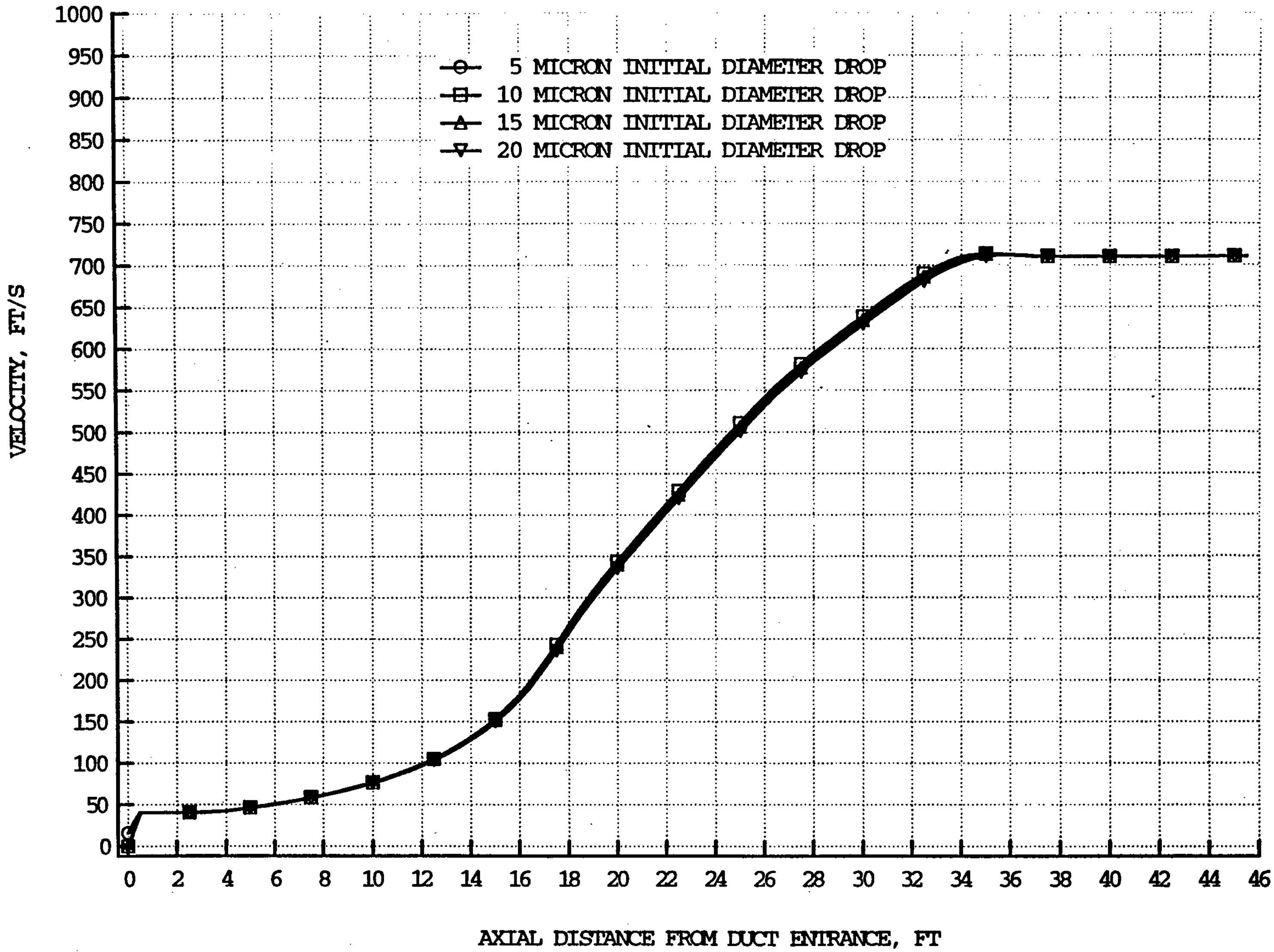

FIG. 21 PREDICTED VARIATIONS OF WATER PARTICLE VELOCITIES ALONG DUCT FLOW

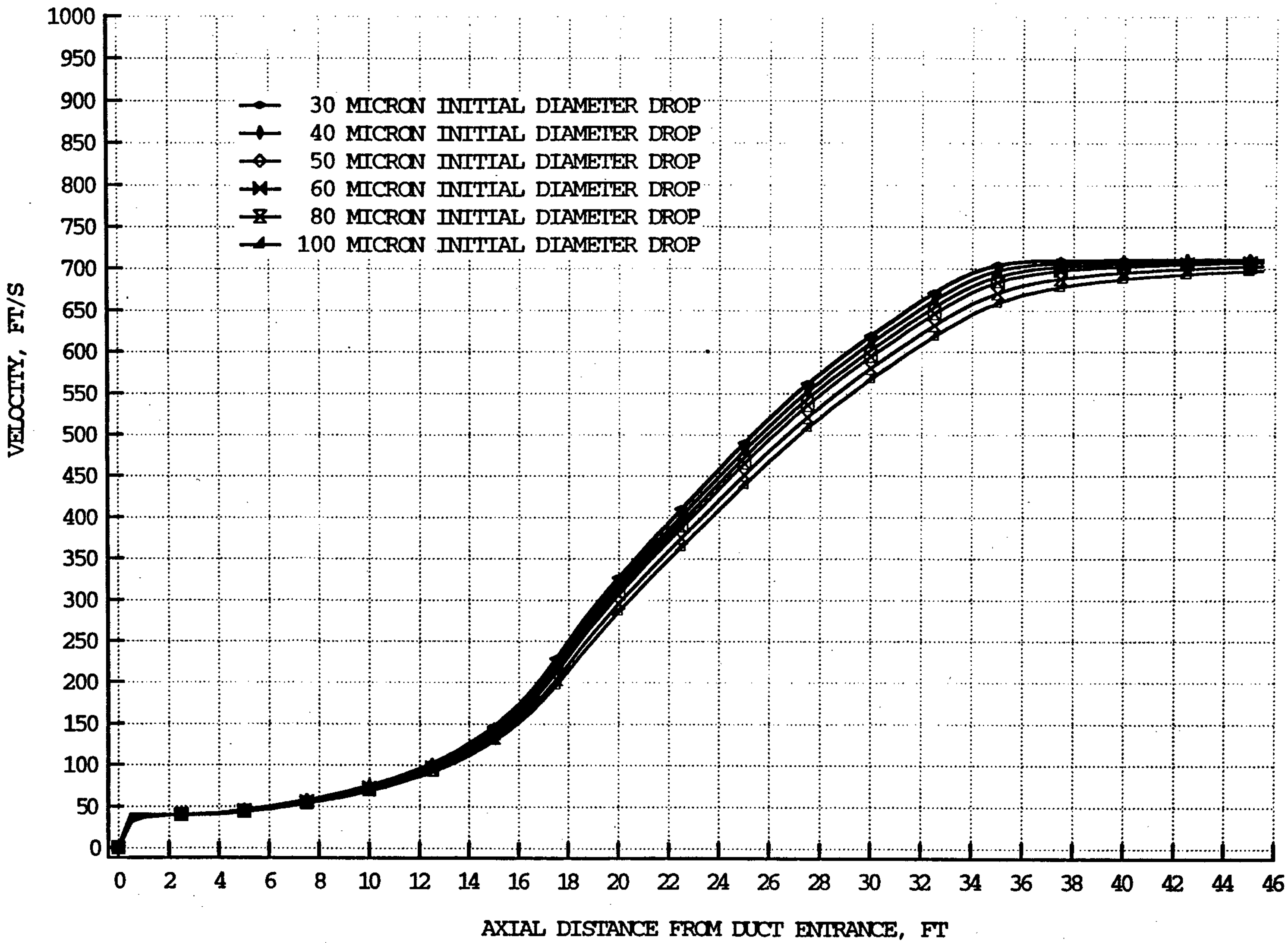

FIG. 21 (CONCLUDED) PREDICTED VARIATIONS OF WATER PARTICLE VELOCITIES ALONG DUCT FLOW

APPENDIX B

MASS AND ENERGY BALANCES FOR TWO-PHASE PARTICLE DURING FREEZING

B.1 The particle initially starts out as a two-phase mixture of water and ice in equilibrium. At the end of an integration step (or time, δt), the particle is still two-phase with a different ratio of ice mass to liquid mass because of freezing and evaporation that occurred during the period, δt. Heat transfer and mass transfer effects have changed the particle phase composition. Let the subscripts "I" refer to the solid or ice phase, and "L" refer to the liquid phase.

B.1.2 Particle Energy Change

The initial particle energy, E, at time t, is

$$E = M_I h_I + M_L h_L \tag{1}$$

The final particle energy at time $t + \delta t$ is

$$E' = M_I' h_I' + M_L' h_L' \tag{2}$$

The energy change is given by

$$\Delta E = E' - E = M_I' h_I' + M_L' h_L' - M_I h_I + M_L h_L \tag{3}$$

Because the process is isothermal,

$$h_I' = h_I \tag{4}$$

$$h_L' = h_L \tag{5}$$

Hence,

$$\Delta E = \left(M_I' - M_I\right) h_I + \left(M_L' - M_L\right) h_L \tag{6}$$

or

$$\Delta E = \Delta M_I h_I + \Delta M_L h_L \tag{7}$$

B.1.3 Liquid Mass Change by Evaporation

Evaporation of liquid mass occurs during the period, δt, in the amount

$$\delta M_{L_e} = \dot{M}_e'' A \delta t \tag{8}$$

where A is the surface area of the particle.

For a moving particle

$$\delta t = \frac{dx}{V} \tag{9}$$

where V is the particle velocity. Hence,

$$\delta M_{L_e} = \frac{\dot{M}_e'' A\, dx}{V} \tag{10}$$

The mass flux of evaporation is given by

$$\dot{M}_e'' = h_m \left(\frac{Y_s - Y_\infty}{1 - Y_s} \right) \tag{11}$$

where

$$h_m = \frac{h}{c_{p_f} L_e^m} \tag{12}$$

and

h = average convective heat transfer coefficient for the particle

L_e = the Lewis number for the particle "film" conditions

c_{p_f} = the specific heat of the "film" fluid

Y = mass fraction of vapor phase

Y_s = mass fraction at particle-gas "film" interface

Y_∞ = free stream mass fraction of vapor.

Thus,

$$\delta M_{L_e} = \frac{h\,A\,dx}{c_{p_f} L_e^m\, V}\left(\frac{Y_s - Y_\infty}{1 - Y_s}\right) \tag{13}$$

B.1.4 Total Liquid Mass Change

The total liquid mass change, ΔM_L, is thus in two parts: a part due to freezing of the liquid, with subscript L_F and a part due to evaporation, with subscript L_e. Hence,

$$-\Delta M_L = \delta M_{L_F} + \delta M_{L_e} \tag{14}$$

Clearly, however,

$$\delta M_{L_F} = \Delta M_I \tag{15}$$

Thus,

$$-\Delta M_L = \Delta M_I + \delta M_{L_e} \tag{16}$$

Solving,

$$\Delta M_L = -\Delta M_I - \delta M_{L_e} \tag{17}$$

B.1.5 Energy Balance Revisited

The energy balance can now be written

$$\Delta E = \Delta M_I h_I + \Delta M_L h_L \tag{18}$$

or, by substitution

$$\Delta E = \Delta M_I h_I + \left(-\Delta M_I - \delta M_{L_e}\right) h_L \tag{19}$$

$$\Delta E = \Delta M_I \left(h_I - h_L\right) - \delta M_{L_e} h_L \tag{20}$$

B.1.6 Heat Balance with Freestream

The energy balance for the particle must equal the energy lost or gained by the particle to the freestream. Thus,

$$\Delta E = -\dot{q}'' A \delta t - \dot{M}_e'' A\, h_v\, \delta t \tag{21}$$

where

$$\dot{q}'' = h(T_s - T_\infty) \tag{22}$$

and

h_v = the enthalpy of the vapor leaving the droplet.

Using previously defined parameters in equations (10), (11), (13) and (21), the energy flow from the particle is given by

$$\Delta E = -\frac{h\,A\,dx}{V}(T_s - T_\infty) - \frac{h\,A\,dx\,h_v}{c_{p_f} L_e^m V}\left(\frac{Y_s - Y_\infty}{1 - Y_s}\right) \tag{23}$$

B.1.7 Energy Equation Equality

The two energy equations for the particle can thus be combined by setting equation (20) equal to equation (21)

$$\Delta E = \Delta M_I (h_I - h_L) - \delta M_{L_e} h_L = -\dot{q}''\, A\, \delta t - \dot{M}_e''\, A\, h_v\, \delta t \tag{24}$$

Using equation (8) in equation (24)

$$\Delta E = \Delta M_I (h_I - h_L) - \delta M_{L_e} h_L = -\dot{q}'' A \delta t - \delta M_{L_e} h_v \tag{25}$$

Rearranging this equation

$$\Delta M_I (h_I - h_L) = -\dot{q}'' A \delta t - \delta M_{L_e} (h_v - h_L) \tag{26}$$

with

$$h_v - h_L = h_{fg} \tag{27}$$

where

h_{fg} = the enthalpy of evaporation of water

and

$$h_I - h_L = -H_F \tag{28}$$

where

H_F = the enthalpy of melting of ice

the energy balance becomes

$$\Delta M_I = \frac{\dot{q}'' A \delta t}{H_F} + \frac{\delta M_{L_e} h_{fg}}{H_F} \tag{29}$$

Using equations (9), (22) and (13) for δt, $\dot{q}''$, and δM_{L_e},

$$\Delta M_I = \frac{h A dx}{V H_F}(T_s - T_\infty) + \frac{h\ A\ h_{fg}\ dx}{V c_{p_f}\ L_e^m\ H_F}\left(\frac{Y_s - Y_\infty}{1 - Y_s}\right) \tag{30}$$

Thus, the amount of ice produced is given by this expression. In words, the amount of ice produced equals the heat lost by convection and evaporation, divided by the heat of fusion of water.

B.2 Method for Adjusting Phase Masses During Freezing Process

Define the initial amount of mass of the particle as M_ϕ, where

$$M_\phi = \frac{\pi}{6}\rho_\phi D_\phi^3 = M_L + M_I \tag{31}$$

and the subscript "ϕ" refers to the initial values of the parameters before the integration step. After computing ΔM_I and δM_{L_e} during the integration step, then determine the new values of the particle mass M_n as follows.

$$M_n = M_\phi - \delta M_{L_e} \tag{32}$$

But,

$$M_n = M_I' + M_L' \tag{33}$$

and

$$M_I' = M_I + \Delta M_I \tag{34}$$

thus,

$$M_L' = M_n - M_I' = M_L - \delta M_{L_e} - \Delta M_I \tag{35}$$

The mass fraction of the liquid phase is then given by

$$\alpha = M_L' / M_n \tag{36}$$

B.3 Particle Properties

The particle properties for the two-phase mixture particle of ice and liquid water are given in terms of α as follows:

average density

$$\bar{\rho} = \frac{\rho_L \rho_I}{\alpha \rho_I + (1-\alpha)\rho_L} \tag{37}$$

average specific heat

$$\bar{c}_p = \alpha c_{PL} + (1-\alpha) c_{PI} \tag{38}$$

average temperature

$$\bar{T} = T_L = T_I = 492^\circ R \text{ (isothermal assumption)} \tag{39}$$

APPENDIX C

FORTRAN DATA INPUT FORMATS ("CARD IMAGES")

The following data input statements identify the data parameters that are input, their input order, and the ("card image") format that is required for their input. The term LCR is an acronym from the "old days" meaning line card reader. It is taken care of in the code compiling process, and is of no concern to users of the code.

```
READ(LCR,7) NXY,NUNITS,NCASES
READ(LCR,707)NFREZ
READ(LCR,8) (XS(I),YS(I),I=1,NXY)
READ(LCR,9) NSTA,XPRINT,DX0
READ(LCR,10) (ALP(I),I=1,10)
NS1=NSTA+1
READ(LCR,12) (STA(I),I=1,NS1)
READ(LCR,11) CV,VG,TG,P
READ(LCR,12) (FL(I),I=1,NSTA)
READ(LCR,12) (VL(I),I=1,NSTA)
READ(LCR,12) (TS(I),I=1,NSTA)
READ(LCR,12) (DMICRON(I),I=1,NSTA)
```

The actual input formats for the data are given below. They are extremely important because the code AEDC1DMP expects to read in the data in the defined format. Future releases of AEDC1DMP will use user friendly data input formats, but at present, this set of input formats must be used.

```
7   FORMAT(3I2)
707 FORMAT(1I2)
8   FORMAT(2E12.0)
9   FORMAT(1I2,2E12.0)
10  FORMAT(10A7)
11  FORMAT(4E10.0)
12  FORMAT(8E10.0)
```

APPENDIX D

SAMPLE DATA INPUT CASE

The data below are for a single data input case. Multiple cases can be run on AEDC1DMP by starting each new data set with card NSTA,XPRINT,DX0 and those that follow, through (DMICRON(I), I=1, NSTA) ; no spaces between data input sets.

```
800001
01
.0000   1.5788
.0250   1.42511
.0500   1.29351
.0750   1.18135
.1000   1.08625
.1250   1.00599
.1500   0.938571
.1750   0.882179
.2000   0.835174
.2250   0.796079
.2500   0.763576
.2750   0.736492
.3000   0.713789
.3250   0.694557
.3500   0.678003
.3750   0.663443
.4000   0.650297
.4250   0.638074
.4500   0.62637
.4750   0.614858
.5000   0.603283
.5250   0.59145
.5500   0.579224
.5750   0.566517
.6000   0.55329
.6250   0.539538
.6500   0.525291
.6750   0.510605
.7000   0.495562
.7250   0.48026
.7500   0.46481
.7750   0.449333
.8000   0.433958
.8250   0.418814
.8500   0.40403
.8750   0.38973
```

.9000	0.376034
.9250	0.36305
.9500	0.350879
.9750	0.339605
1.0000	0.3293
1.0250	0.320021
1.0500	0.311807
1.0750	0.304681
1.1000	0.298648
1.1250	0.293696
1.1500	0.289796
1.1750	0.2869
1.2000	0.284946
1.2250	0.283857
1.2500	0.283541
1.2750	0.283541
1.3000	0.283541
1.3250	0.283541
1.3500	0.283541
1.3750	0.283541
1.4000	0.283541
1.4250	0.283541
1.4500	0.283541
1.4750	0.283541
1.5000	0.283541
1.5250	0.283541
1.5500	0.283541
1.5750	0.283541
1.6000	0.283541
1.6250	0.283541
1.6500	0.283541
1.6750	0.283541
1.7000	0.283541
1.7250	0.283541
1.7500	0.283541
1.7750	0.283541
1.8000	0.283541
1.8250	0.283541
1.8500	0.283541
2.0000	0.283541
2.2000	0.283541
2.4000	0.283541
2.6000	0.283541
2.8000	0.283541

10 0.025

GENERIC NOZZLE GEOMETRY FOR PARAMETRIC FREEZING STUDY

```
0.0      0.02     0.04     0.06     0.08     0.10     0.12     0.14
0.16     0.18     2.70
0.0002857 18.0    460.0    2116.0
6.85E-05 2.06E-04 4.80E-04 3.62E-04 2.06E-04 3.43E-05 1.37E-05 1.37E-06
1.37E-07 1.37E-08
46.      46.      46.      46.      46.      46.0     46.      46.
46.      46.
543.     543.     543.     543.     543.     543.     543.     543.
543.     543.
5.0      10.0     15.0     20.0     30.0     40.0     50.0     60.0
80.0     100.0
```

APPENDIX E

DEFINITIONS OF THE DATA INPUT PARAMETERS

The definitions of the data input parameters for AEDC1DMP are the same, for the most part, as those in the original version of the code reported in Reference 53. Their specific definitions, and units, where necessary, are provided below.

NXY= THE NUMBER OF DUCT WALL COORDINATES INPUT

NUNITS=0 OR1. IF NUNITS=0, ALL X AND Y COORDINATES, XPRINT, DX0, AND (STA(I), I=1,NS1) ARE INPUT IN UNITS OF FEET. IF NUNITS IS INPUT AS 1, THEN ALL SPACE COORDINATES ARE INPUT IN UNITS OF INCHES.

NCASES= THE NUMBER OF CASES INPUT TO BE COMPUTED.

NFREZ= 0 OR 1. IF NFREZ=0, THE WATER PARTICLE FREEZING MODEL IS NOT ACTIVATED; ALTERNATELY, FOR NFREZ=1, THE MODEL WILL BE UTILIZED IN THE DUCT FLOW COMPUTATIONS.

(XS(I), I=1,NXY)= THE AXIAL COORDINATES OF THE DUCT WALL CURVE.
(YS(I), I=1,NXY)=THE CORRESPONDING RADIAL COORDINATES OF THE DUCT WALL CURVE.

NSTA= THE NUMBER OF WATER INJECTION STATIONS, WITH A MAXIMUM OF TEN(10).

XPRINT= THE DISTANCE BETWEEN AXIAL LOCATIONS WHERE THE FLOW SOLUTION IS PRINTED OUT, AND, CONSEQUENTLY, STORED FOR INPUT TO DATA PLOTTING PROGRAMS SUCH AS WAVEMETRICS(R)' IGOR™ PRO(http://www.wavemetrics.com/).

DX0= THE INITIAL NUMERICAL INTEGRATION STEP SIZE THAT THE USER DESIRES. BY SETTING DX0=0 OR BLANK, THE CODE SELECTS A DEFAULT STEP SIZE BASED ON THE DUCT LENGTH.

ALP= AN 80 COLUMN ALPANUMERIC FILE IDENTIFIER.

(STA(I), I=1, NS1) = THE AXIAL LOCATIONS, OR STATIONS, WHERE WATER IS INJECTED INTO THE FLOW, PLUS, THE LAST VALUE, STA(NS1), WHICH INDICATES THE TERMINAL AXIAL LOCATION FOR FLOW SOLUTION. STA(NS1) USUALLY EQUALS XS(NXY) OR SLIGHTLY LESS.

CV= FLOW INITIAL SPECIFIC HUMIDITY, LBM OF WATER VAPOR/LBM OF DRY AIR.

VG= THE FLOW INITIAL VELOCITY, FT/SECOND.

TG= THE FLOW INITIAL STATIC TEMPERATURE, DEGREES RANKINE.

P= THE FLOW INITIAL STATIC PRESSURE, LBFORCE/SQUARE FOOT.

(FL(I), I=1, NSTA) = THE WATER LOADING INJECTED AT EACH STATION, LBM OF WATER/ LBM OF DRY AIR.

(VL(I), I=1,NSTA) = THE VELOCITIES OF THE WATER PARTICLES INJECTED AT THE WATER INJECTION STATIONS, FEET/SECOND.

(TS(I), I=1,NSTA) = THE TEMPERATURES OF THE WATER PARTICLES INJECTED AT EACH STATION, DEGREES RANKINE.

(DMICRONS(I), I=1,NSTA) = THE DIAMETERS OF THE WATER PARTICLES INJECTED AT EACH STATION, IN MICRONS (1 METER=1,000,000 MICRONS)

AS A POINT OF CLARIFICATION, FL(I),VL(I),TS(I), AND DMICRON(I) ALL CORRESPOND TO THE WATER PARTICLE CONDITIONS AT THE AXIAL INJECTION STATION LOCATED AT X=STA(I).

APPENDIX F

SAMPLE OUTPUT FROM CASE 3

```
A.E.D.C. ONE-DIMENSIONAL, MULTI-PHASE FLOW PROGRAM, AEDC1DMP
DEVELOPED FROM THE CODE OF C.E.WILLBANKS AND R.J.SCHULZ   (DESCRIBED IN AEDC TR 73-144)
UNDER AEDC-UTSI TASK ORDER 97-03; TOM TIBBALS SVERDRUP TECHNOLOGY,INC.,PROJECT MANAGER
THIS VERSION DEVELOPED BY R.J. SCHULZ, UTSI,TULLAHOMA, TN 37388: DECEMBER, 1997
THIS VERSION CONTAINS A DROPLET FREEZEOUT MODEL BASED ON MODIFIED HOMOGENEOUS NUCLEATION THEORY
CALIBRATED TO THE DATA OF DORSCH AND HACKER, NACA TN 2142

INITIAL FLOW CONDITIONS AND THEIR UNITS:
SPECIFIC HUMIDITY,CV, LBMS-WATER VAPOR/LBM-DRY AIR ; PRESSURE,P, PSFA ;  TEMPERATURE,TG AND TS, DEG R
VELOCITY,VG AND VL, FT/S ;  WATER LOAD FACTOR,FL, LBM- LIQUID WATER/LBM-DRY AIR ;
DROP DIA.,D,   MICRONS ; YDUCT=DUCT RADIUS,FT

IRT CASE 3 RADIAL: V=40 FT/SEC, T=15 DEG F, 10 DROP SIZES IN THE INLET

INLET SPECIFIC HUMIDITY=    .000500000  INLET STATIC PRESSURE=   2073.60  INLET STATIC TEMPERATURE=   475.00
AIR INLET VELOCITY=     40.000000   INLET RELATIVE HUMIDITY %=     25.997580  INITIAL FLtot=    .000181611

INITIAL X=      .000000   INITIAL INTEGRATION STEP SIZE,DX=    .000700000

SPRAY CONDITIONS AT EACH INJECTION STATION ARE:
INJECTION STATION 1  XINJ(I)=  .000000000  FL=     .000009060  VL=     16.000000  TS=    495.000000  D=   5.00000
INJECTION STATION 2  XINJ(I)=  .020000000  FL=     .000027300  VL=     16.000000  TS=    495.000000  D=  10.00000
INJECTION STATION 3  XINJ(I)=  .040000000  FL=     .000063500  VL=     16.000000  TS=    495.000000  D=  15.00000
INJECTION STATION 4  XINJ(I)=  .060000000  FL=     .000047900  VL=     16.000000  TS=    495.000000  D=  20.00000
INJECTION STATION 5  XINJ(I)=  .080000000  FL=     .000027300  VL=     16.000000  TS=    495.000000  D=  30.00000
INJECTION STATION 6  XINJ(I)=  .100000000  FL=     .000004540  VL=     16.000000  TS=    495.000000  D=  40.00000
INJECTION STATION 7  XINJ(I)=  .120000000  FL=     .000001810  VL=     16.000000  TS=    495.000000  D=  50.00000
INJECTION STATION 8  XINJ(I)=  .140000000  FL=     .000000181  VL=     16.000000  TS=    495.000000  D=  60.00000
INJECTION STATION 9  XINJ(I)=  .160000000  FL=     .000000018  VL=     16.000000  TS=    495.000000  D=  80.00000
INJECTION STATION10  XINJ(I)=  .180000000  FL=     .000000002  VL=     16.000000  TS=    495.000000  D= 100.00000

INITIAL AREA=  763.166377

X=       .000000  YDUCT=    15.586000    MG=      .037269    PO=   2075.6258    TO=    475.133999
DX=    .000700000 A(X)=     763.1664   A(X)/A0=   1.00000   REL HUM. %=     25.997580

CV=    .000500000   VG=     40.000000    TG=    475.000000   P=    2073.60   FLtot=    .000009060
FL=    .000009060   VL=     16.000000     TS=   495.000000   D=     5.00000  DMASS=  0.144222E-12

X=       .505403  YDUCT=    15.580455    MG=      .037296    PO=   2075.6254    TO=    475.125494
DX=    .007000000 A(X)=     762.6234   A(X)/A0=    .99929   REL HUM. %=     26.311553

CV=    .000505853   VG=     40.028167    TG=    474.991307   P=    2073.60   FLtot=    .000175752
FL=    .000007483   VL=     40.028233     TS=   469.748029   D=     4.69115  DMASS=  0.119113E-12
FL=    .000025949   VL=     40.028426     TS=   469.748086   D=     9.83222  DMASS=  0.109667E-11
FL=    .000061834   VL=     40.028634     TS=   469.853291   D=    14.86766  DMASS=  0.379184E-11
FL=    .000047021   VL=     40.027198     TS=   470.676583   D=    19.87691  DMASS=  0.906085E-11
FL=    .000026971   VL=     39.852714     TS=   474.090880   D=    29.87890  DMASS=  0.307763E-10
FL=    .000004499   VL=     39.094691     TS=   477.535286   D=    39.87783  DMASS=  0.731673E-10
FL=    .000001797   VL=     37.926089     TS=   480.267645   D=    49.87695  DMASS=  0.143160E-09
FL=    .000000180   VL=     36.500310     TS=   482.556906   D=    59.87860  DMASS=  0.247706E-09
FL=    .000000018   VL=     33.853338     TS=   485.638121   D=    79.88130  DMASS=  0.588109E-09
FL=    .000000002   VL=     31.467418     TS=   487.735676   D=    99.88631  DMASS=  0.114985E-08
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X=     1.002403     YDUCT=   15.586023    MG=        .037268      PO=   2075.6254    TO=      475.106282
DX=     .007000000  A(X)=   763.1686      A(X)/A0=   1.00000      REL HUM. %=        26.559700

CV=     .000510205    VG=     39.998143    TG=    474.972296    P=    2073.60     FLtot=     .000171396
FL=     .000006106    VL=     39.998347     TS=    469.750619   D=      4.38387   DMASS=   0.972066E-13
FL=     .000024832    VL=     39.999139     TS=    469.750927   D=      9.68905   DMASS=   0.104946E-11
FL=     .000060660    VL=     40.000448     TS=    469.751736   D=     14.77298   DMASS=   0.371986E-11
FL=     .000046510    VL=     40.002236     TS=    469.798763   D=     19.80466   DMASS=   0.896241E-11
FL=     .000026818    VL=     40.004206     TS=    470.859602   D=     29.82246   DMASS=   0.306022E-10
FL=     .000004480    VL=     39.935985     TS=    473.042335   D=     39.82218   DMASS=   0.728614E-10
FL=     .000001790    VL=     39.662687     TS=    475.331195   D=     49.81850   DMASS=   0.142657E-09
FL=     .000000179    VL=     39.157493     TS=    477.450015   D=     59.81580   DMASS=   0.246928E-09
FL=     .000000018    VL=     37.809281     TS=    480.746702   D=     79.81103   DMASS=   0.586558E-09
FL=     .000000002    VL=     36.306763     TS=    483.188061   D=     99.80941   DMASS=   0.114719E-08

X=     1.506403     YDUCT=   15.591582    MG=        .037241      PO=   2075.6255    TO=      475.087051
DX=     .007000000  A(X)=   763.7132      A(X)/A0=   1.00072      REL HUM. %=        26.802341

CV=     .000514443    VG=     39.968286    TG=    474.953266    P=    2073.60     FLtot=     .000167154
FL=     .000004814    VL=     39.968332     TS=    469.752553   D=      4.04968   DMASS=   0.766273E-13
FL=     .000023719    VL=     39.968567     TS=    469.752738   D=      9.54214   DMASS=   0.100244E-11
FL=     .000059483    VL=     39.969053     TS=    469.753021   D=     14.67676   DMASS=   0.364765E-11
FL=     .000046005    VL=     39.969910     TS=    469.755634   D=     19.73266   DMASS=   0.886501E-11
FL=     .000026683    VL=     39.973143     TS=    470.039948   D=     29.77234   DMASS=   0.304482E-10
FL=     .000004465    VL=     39.971780     TS=    471.271519   D=     39.77991   DMASS=   0.726296E-10
FL=     .000001786    VL=     39.913617     TS=    473.002160   D=     49.77707   DMASS=   0.142302E-09
FL=     .000000179    VL=     39.729700     TS=    474.821225   D=     59.77310   DMASS=   0.246399E-09
FL=     .000000018    VL=     39.013419     TS=    477.971382   D=     79.76444   DMASS=   0.585532E-09
FL=     .000000002    VL=     38.027579     TS=    480.471680   D=     99.75864   DMASS=   0.114544E-08

X=     2.003403     YDUCT=   15.585958    MG=        .037268      PO=   2075.6256    TO=      475.068699
DX=     .007000000  A(X)=   763.1623      A(X)/A0=    .99999      REL HUM. %=        27.033525

CV=     .000518466    VG=     39.995972    TG=    474.934728    P=    2073.60     FLtot=     .000163126
FL=     .000003648    VL=     39.995851     TS=    469.754228   D=      3.69212   DMASS=   0.580697E-13
FL=     .000022644    VL=     39.994442     TS=    469.754733   D=      9.39566   DMASS=   0.956984E-12
FL=     .000058335    VL=     39.992234     TS=    469.755127   D=     14.58171   DMASS=   0.357724E-11
FL=     .000045511    VL=     39.989520     TS=    469.755426   D=     19.66188   DMASS=   0.876996E-11
FL=     .000026555    VL=     39.983967     TS=    469.831073   D=     29.72471   DMASS=   0.303023E-10
FL=     .000004453    VL=     39.979770     TS=    470.471381   D=     39.74192   DMASS=   0.724218E-10
FL=     .000001782    VL=     39.964559     TS=    471.725164   D=     49.74249   DMASS=   0.142005E-09
FL=     .000000179    VL=     39.895277     TS=    473.242179   D=     59.73900   DMASS=   0.245978E-09
FL=     .000000018    VL=     39.501690     TS=    476.148065   D=     79.72861   DMASS=   0.584743E-09
FL=     .000000002    VL=     38.833277     TS=    478.604354   D=     99.72003   DMASS=   0.114412E-08

X=     2.501850     YDUCT=   15.563031    MG=        .037377      PO=   2075.6257    TO=      475.050919
DX=     .005638855  A(X)=   760.9187      A(X)/A0=    .99705      REL HUM. %=        27.258095

CV=     .000522358    VG=     40.113036    TG=    474.916164    P=    2073.59     FLtot=     .000159231
FL=     .000002597    VL=     40.112750     TS=    469.755338   D=      3.29683   DMASS=   0.413439E-13
FL=     .000021584    VL=     40.108290     TS=    469.756334   D=      9.24676   DMASS=   0.912201E-12
FL=     .000057189    VL=     40.101820     TS=    469.757301   D=     14.48567   DMASS=   0.350702E-11
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FL=   .000045016   VL=    40.093570    TS=   469.758098   D=  19.59031   DMASS=  0.867455E-11
FL=   .000026427   VL=    40.074340    TS=   469.778332   D=  29.67667   DMASS=  0.301556E-10
FL=   .000004440   VL=    40.055081    TS=   470.089864   D=  39.70441   DMASS=  0.722169E-10
FL=   .000001779   VL=    40.035744    TS=   470.949366   D=  49.70985   DMASS=  0.141726E-09
FL=   .000000178   VL=    39.998439    TS=   472.181726   D=  59.70830   DMASS=  0.245599E-09
FL=   .000000018   VL=    39.767285    TS=   474.816580   D=  79.69792   DMASS=  0.584068E-09
FL=   .000000002   VL=    39.301731    TS=   477.186334   D=  99.68758   DMASS=  0.114300E-08

X=    3.001806     YDUCT=  15.496723   MG=      .037698    PO=  2075.6257    TO=   475.033819
DX=   .004188597   A(X)=   754.4486    A(X)/A0=   .98858   REL HUM. %=     27.475854

CV=   .000526098   VG=    40.456645    TG=   474.896745   P=  2073.55    FLtot=   .000155486
FL=   .000001678   VL=    40.455718    TS=   469.755174   D=   2.84986   DMASS=  0.267050E-13
FL=   .000020543   VL=    40.445438    TS=   469.756869   D=   9.09569   DMASS=  0.868218E-12
FL=   .000056049   VL=    40.429719    TS=   469.758672   D=  14.38874   DMASS=  0.343709E-11
FL=   .000044519   VL=    40.409142    TS=   469.760386   D=  19.51795   DMASS=  0.857877E-11
FL=   .000026296   VL=    40.358204    TS=   469.767625   D=  29.62778   DMASS=  0.300068E-10
FL=   .000004427   VL=    40.302484    TS=   469.912620   D=  39.66646   DMASS=  0.720100E-10
FL=   .000001775   VL=    40.249274    TS=   470.469461   D=  49.67738   DMASS=  0.141449E-09
FL=   .000000178   VL=    40.195666    TS=   471.430484   D=  59.67853   DMASS=  0.245232E-09
FL=   .000000018   VL=    40.015843    TS=   473.777516   D=  79.66965   DMASS=  0.583447E-09
FL=   .000000002   VL=    39.667209    TS=   476.042268   D=  99.65853   DMASS=  0.114200E-08

X=    3.500972     YDUCT=  15.356598   MG=      .038390    PO=  2075.6258    TO=   475.017663
DX=   .002815455   A(X)=   740.8664    A(X)/A0=   .97078   REL HUM. %=     27.684746

CV=   .000529631   VG=    41.198292    TG=   474.875518   P=  2073.48    FLtot=   .000151949
FL=   .000000916   VL=    41.197230    TS=   469.752675   D=   2.32889   DMASS=  0.145737E-13
FL=   .000019534   VL=    41.178006    TS=   469.755233   D=   8.94416   DMASS=  0.825545E-12
FL=   .000054926   VL=    41.147575    TS=   469.758043   D=  14.29198   DMASS=  0.336821E-11
FL=   .000044025   VL=    41.107080    TS=   469.760899   D=  19.44551   DMASS=  0.848361E-11
FL=   .000026165   VL=    41.003412    TS=   469.766774   D=  29.57834   DMASS=  0.298568E-10
FL=   .000004414   VL=    40.884182    TS=   469.833668   D=  39.62792   DMASS=  0.718003E-10
FL=   .000001772   VL=    40.765148    TS=   470.178814   D=  49.64458   DMASS=  0.141169E-09
FL=   .000000178   VL=    40.653846    TS=   470.896491   D=  59.64872   DMASS=  0.244865E-09
FL=   .000000018   VL=    40.424227    TS=   472.930778   D=  79.64209   DMASS=  0.582842E-09
FL=   .000000002   VL=    40.107444    TS=   475.070452   D=  99.63098   DMASS=  0.114105E-08

X=    4.000846     YDUCT=  15.150661   MG=      .039442    PO=  2075.6258    TO=   475.002683
DX=   .001529440   A(X)=   721.1291    A(X)/A0=   .94492   REL HUM. %=     27.881960

CV=   .000532907   VG=    42.326375    TG=   474.852647   P=  2073.36    FLtot=   .000148669
FL=   .000000338   VL=    42.325566    TS=   469.747752   D=   1.67110   DMASS=  0.538430E-14
FL=   .000018562   VL=    42.297155    TS=   469.751070   D=   8.79328   DMASS=  0.784468E-12
FL=   .000053829   VL=    42.252030    TS=   469.754700   D=  14.19622   DMASS=  0.330096E-11
FL=   .000043540   VL=    42.191885    TS=   469.758514   D=  19.37371   DMASS=  0.838998E-11
FL=   .000026034   VL=    42.036678    TS=   469.765837   D=  29.52892   DMASS=  0.297074E-10
FL=   .000004402   VL=    41.852691    TS=   469.798869   D=  39.58911   DMASS=  0.715896E-10
FL=   .000001768   VL=    41.659692    TS=   470.007443   D=  49.61153   DMASS=  0.140887E-09
FL=   .000000178   VL=    41.472283    TS=   470.525547   D=  59.61879   DMASS=  0.244496E-09
FL=   .000000018   VL=    41.124067    TS=   472.238286   D=  79.61466   DMASS=  0.582240E-09
FL=   .000000002   VL=    40.761853    TS=   474.223169   D=  99.60392   DMASS=  0.114012E-08
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X=    4.500032   YDUCT=  14.863179   MG=        .040985   PO=   2075.6259   TO=     474.989305
DX=   .000145041 A(X)=   694.0221    A(X)/A0=    .90940   REL HUM. %=      28.063372

CV=   .000535833  VG=    43.980740   TG=     474.827312   P=    2073.18   FLtot=    .000145741
FL=   .000000010  VL=    43.980952    TS=    469.739348   D=     .51070   DMASS=  0.153680E-15
FL=   .000017638  VL=    43.940378    TS=    469.743671   D=    8.64490   DMASS=  0.745423E-12
FL=   .000052771  VL=    43.875367    TS=    469.748320   D=   14.10257   DMASS=  0.323607E-11
FL=   .000043067  VL=    43.788430    TS=    469.753263   D=   19.30336   DMASS=  0.829891E-11
FL=   .000025905  VL=    43.563088    TS=    469.762727   D=   29.48009   DMASS=  0.295603E-10
FL=   .000004389  VL=    43.295489    TS=    469.782241   D=   39.55046   DMASS=  0.713801E-10
FL=   .000001765  VL=    43.013052    TS=    469.907805   D=   49.57853   DMASS=  0.140606E-09
FL=   .000000177  VL=    42.734591    TS=    470.273892   D=   59.58897   DMASS=  0.244129E-09
FL=   .000000018  VL=    42.221708    TS=    471.682776   D=   79.58745   DMASS=  0.581643E-09
FL=   .000000002  VL=    41.750345    TS=    473.488318   D=   99.57717   DMASS=  0.113920E-08

X=    5.000321   YDUCT=  14.537372   MG=        .042850   PO=   2075.6259   TO=     474.977925
DX=   .007000000 A(X)=   663.9291    A(X)/A0=    .86997   REL HUM. %=      28.222983

CV=   .000538322  VG=    45.980515   TG=     474.800865   P=    2072.95   FLtot=    .000143248
FL=   .000016765  VL=    45.933460    TS=    469.733311   D=    8.49997   DMASS=  0.708557E-12
FL=   .000051758  VL=    45.854962    TS=    469.738670   D=   14.01176   DMASS=  0.317395E-11
FL=   .000042612  VL=    45.749683    TS=    469.744487   D=   19.23508   DMASS=  0.821116E-11
FL=   .000025780  VL=    45.474849    TS=    469.756118   D=   29.43240   DMASS=  0.294171E-10
FL=   .000004376  VL=    45.142701    TS=    469.771240   D=   39.51243   DMASS=  0.711744E-10
FL=   .000001761  VL=    44.784044    TS=    469.848686   D=   49.54594   DMASS=  0.140329E-09
FL=   .000000177  VL=    44.422190    TS=    470.105047   D=   59.55952   DMASS=  0.243768E-09
FL=   .000000018  VL=    43.740293    TS=    471.245687   D=   79.56065   DMASS=  0.581055E-09
FL=   .000000002  VL=    43.128640    TS=    472.860300   D=   99.55085   DMASS=  0.113830E-08

X=    5.504321   YDUCT=  14.210681   MG=        .044847   PO=   2075.6259   TO=     474.967115
DX=   .007000000 A(X)=   634.4241    A(X)/A0=    .83131   REL HUM. %=      28.377526

CV=   .000540687  VG=    48.122271   TG=     474.773176   P=    2072.69   FLtot=    .000140881
FL=   .000015941  VL=    48.072574    TS=    469.721217   D=    8.35837   DMASS=  0.673733E-12
FL=   .000050790  VL=    47.986845    TS=    469.726982   D=   13.92382   DMASS=  0.311456E-11
FL=   .000042174  VL=    47.871860    TS=    469.733323   D=   19.16903   DMASS=  0.812686E-11
FL=   .000025658  VL=    47.570706    TS=    469.746536   D=   29.38615   DMASS=  0.292786E-10
FL=   .000004364  VL=    47.202023    TS=    469.760852   D=   39.47537   DMASS=  0.709743E-10
FL=   .000001758  VL=    46.795862    TS=    469.811318   D=   49.51408   DMASS=  0.140058E-09
FL=   .000000177  VL=    46.376891    TS=    469.991531   D=   59.53075   DMASS=  0.243415E-09
FL=   .000000018  VL=    45.563690    TS=    470.907855   D=   79.53458   DMASS=  0.580484E-09
FL=   .000000002  VL=    44.822954    TS=    472.334399   D=   99.52528   DMASS=  0.113742E-08

X=    6.001321   YDUCT=  13.883709   MG=        .046989   PO=   2075.6259   TO=     474.957027
DX=   .007000000 A(X)=   605.5651    A(X)/A0=    .79349   REL HUM. %=      28.525340

CV=   .000542894  VG=    50.419719   TG=     474.744128   P=    2072.41   FLtot=    .000138672
FL=   .000015180  VL=    50.365361    TS=    469.707547   D=    8.22308   DMASS=  0.641544E-12
FL=   .000049883  VL=    50.268484    TS=    469.713869   D=   13.84049   DMASS=  0.305898E-11
FL=   .000041763  VL=    50.138800    TS=    469.720799   D=   19.10651   DMASS=  0.804760E-11
FL=   .000025544  VL=    49.800776    TS=    469.735280   D=   29.34229   DMASS=  0.291477E-10
FL=   .000004352  VL=    49.390626    TS=    469.749966   D=   39.44015   DMASS=  0.707845E-10
FL=   .000001755  VL=    48.940955    TS=    469.785733   D=   49.48376   DMASS=  0.139801E-09
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FL=   .000000177   VL=   48.475664   TS=   469.914980   D=  59.50338   DMASS=  0.243079E-09
FL=   .000000018   VL=   47.560113   TS=   470.653239   D=  79.50992   DMASS=  0.579945E-09
FL=   .000000002   VL=   46.712606   TS=   471.908075   D=  99.50119   DMASS=  0.113660E-08

X=    6.505321     YDUCT=  13.554534   MG=      .049306   PO=   2075.6260   TO=  474.947359
DX=   .007000000   A(X)=   577.1904    A(X)/A0=   .75631   REL HUM. %=   28.670749

CV=   .000545009   VG=   52.903465   TG=   474.712968   P=   2072.08    FLtot=   .000136554
FL=   .000014457   VL=   52.844621   TS=   469.691833   D=   8.09038   DMASS=  0.610983E-12
FL=   .000049012   VL=   52.736694   TS=   469.698715   D=  13.75946   DMASS=  0.300557E-11
FL=   .000041366   VL=   52.592599   TS=   469.706258   D=  19.04574   DMASS=  0.797106E-11
FL=   .000025432   VL=   52.218604   TS=   469.722060   D=  29.29958   DMASS=  0.290206E-10
FL=   .000004341   VL=   51.766881   TS=   469.737665   D=  39.40575   DMASS=  0.705995E-10
FL=   .000001751   VL=   51.273484   TS=   469.765347   D=  49.45409   DMASS=  0.139550E-09
FL=   .000000176   VL=   50.763666   TS=   469.859682   D=  59.47662   DMASS=  0.242751E-09
FL=   .000000018   VL=   49.756195   TS=   470.454574   D=  79.48594   DMASS=  0.579420E-09
FL=   .000000002   VL=   48.814411   TS=   471.553064   D=  99.47788   DMASS=  0.113580E-08

X=    7.002321     YDUCT=  13.230057   MG=      .051761   PO=   2075.6260   TO=  474.938351
DX=   .007000000   A(X)=   549.8868    A(X)/A0=   .72053   REL HUM. %=   28.810572

CV=   .000546980   VG=   55.536401   TG=   474.680049   P=   2071.72    FLtot=   .000134581
FL=   .000013789   VL=   55.472082   TS=   469.674223   D=   7.96394   DMASS=  0.582781E-12
FL=   .000048198   VL=   55.350648   TS=   469.681770   D=  13.68287   DMASS=  0.295566E-11
FL=   .000040993   VL=   55.189073   TS=   469.690014   D=  18.98836   DMASS=  0.789923E-11
FL=   .000025327   VL=   54.772454   TS=   469.707217   D=  29.25916   DMASS=  0.289007E-10
FL=   .000004330   VL=   54.273834   TS=   469.723995   D=  39.37311   DMASS=  0.704242E-10
FL=   .000001748   VL=   53.733357   TS=   469.747558   D=  49.42587   DMASS=  0.139311E-09
FL=   .000000176   VL=   53.177653   TS=   469.818719   D=  59.45117   DMASS=  0.242440E-09
FL=   .000000018   VL=   52.081514   TS=   470.302148   D=  79.46324   DMASS=  0.578924E-09
FL=   .000000002   VL=   51.053341   TS=   471.264691   D=  99.45594   DMASS=  0.113505E-08

X=    7.506321     YDUCT=  12.901450   MG=      .054441   PO=   2075.6260   TO=  474.929727
DX=   .007000000   A(X)=   522.9099    A(X)/A0=   .68518   REL HUM. %=   28.949491

CV=   .000548867   VG=   58.409065   TG=   474.644011   P=   2071.31    FLtot=   .000132692
FL=   .000013157   VL=   58.338447   TS=   469.653880   D=   7.84021   DMASS=  0.556040E-12
FL=   .000047417   VL=   58.201307   TS=   469.662199   D=  13.60853   DMASS=  0.290774E-11
FL=   .000040633   VL=   58.019540   TS=   469.671261   D=  18.93267   DMASS=  0.782993E-11
FL=   .000025225   VL=   57.554110   TS=   469.690087   D=  29.21984   DMASS=  0.287843E-10
FL=   .000004319   VL=   57.002091   TS=   469.708286   D=  39.34126   DMASS=  0.702534E-10
FL=   .000001745   VL=   56.408501   TS=   469.729982   D=  49.39828   DMASS=  0.139078E-09
FL=   .000000176   VL=   55.801943   TS=   469.785399   D=  59.42626   DMASS=  0.242135E-09
FL=   .000000018   VL=   54.611424   TS=   470.179977   D=  79.44110   DMASS=  0.578440E-09
FL=   .000000002   VL=   53.495855   TS=   471.022242   D=  99.43464   DMASS=  0.113432E-08

X=    8.003321     YDUCT=  12.577403   MG=      .057293   PO=   2075.6260   TO=  474.921703
DX=   .007000000   A(X)=   496.9719    A(X)/A0=   .65120   REL HUM. %=   29.084525

CV=   .000550624   VG=   61.466625   TG=   474.605291   P=   2070.84    FLtot=   .000130934
FL=   .000012574   VL=   61.388770   TS=   469.630963   D=   7.72267   DMASS=  0.531404E-12
FL=   .000046688   VL=   61.233472   TS=   469.640173   D=  13.53844   DMASS=  0.286304E-11
FL=   .000040296   VL=   61.028521   TS=   469.650173   D=  18.88016   DMASS=  0.776497E-11
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FL=   .000025129  VL=    60.507740   TS=   469.670840  D=  29.18265  DMASS=  0.286746E-10
FL=   .000004309  VL=    59.896116   TS=   469.690675  D=  39.31105  DMASS=  0.700917E-10
FL=   .000001743  VL=    59.243963   TS=   469.711943  D=  49.37205  DMASS=  0.138856E-09
FL=   .000000176  VL=    58.581957   TS=   469.757095  D=  59.40254  DMASS=  0.241845E-09
FL=   .000000018  VL=    57.290776   TS=   470.082954  D=  79.42007  DMASS=  0.577981E-09
FL=   .000000002  VL=    56.085222   TS=   470.822451  D=  99.41451  DMASS=  0.113363E-08

X=    8.500321    YDUCT=  12.252924  MG=    .060380    PO=  2075.6260   TO=   474.914136
DX=   .007000000  A(X)=  471.6604    A(X)/A0=  .61803  REL HUM. %=   29.218605

CV=   .000552280  VG=    64.776279  TG=   474.562732  P=   2070.31   FLtot=   .000129276
FL=   .000012029  VL=    64.690031   TS=   469.604705  D=   7.60957  DMASS=  0.508398E-12
FL=   .000045999  VL=    64.513432   TS=   469.614963  D=  13.47148  DMASS=  0.282077E-11
FL=   .000039976  VL=    64.281456   TS=   469.626065  D=  18.83000  DMASS=  0.770324E-11
FL=   .000025037  VL=    63.696868   TS=   469.648875  D=  29.14702  DMASS=  0.285696E-10
FL=   .000004300  VL=    63.017484   TS=   469.670610  D=  39.28200  DMASS=  0.699364E-10
FL=   .000001740  VL=    62.299511   TS=   469.692388  D=  49.34675  DMASS=  0.138643E-09
FL=   .000000175  VL=    61.575751   TS=   469.730914  D=  59.37964  DMASS=  0.241566E-09
FL=   .000000018  VL=    60.173987   TS=   470.002904  D=  79.39977  DMASS=  0.577538E-09
FL=   .000000002  VL=    58.871783   TS=   470.653685  D=  99.39516  DMASS=  0.113297E-08

X=    9.004321    YDUCT=  11.923750  MG=    .063776    PO=  2075.6260   TO=   474.906909
DX=   .007000000  A(X)=  446.6585    A(X)/A0=  .58527  REL HUM. %=   29.354661

CV=   .000553863  VG=    68.415869  TG=   474.514906  P=   2069.70   FLtot=   .000127691
FL=   .000011515  VL=    68.319864   TS=   469.574101  D=   7.49946  DMASS=  0.486646E-12
FL=   .000045339  VL=    68.118231   TS=   469.585604  D=  13.40673  DMASS=  0.278030E-11
FL=   .000039667  VL=    67.854735   TS=   469.598013  D=  18.78146  DMASS=  0.764383E-11
FL=   .000024948  VL=    67.196563   TS=   469.623362  D=  29.11241  DMASS=  0.284680E-10
FL=   .000004291  VL=    66.439895   TS=   469.647344  D=  39.25370  DMASS=  0.697853E-10
FL=   .000001737  VL=    65.647418   TS=   469.670345  D=  49.32203  DMASS=  0.138435E-09
FL=   .000000175  VL=    64.854147   TS=   469.704798  D=  59.35721  DMASS=  0.241292E-09
FL=   .000000018  VL=    63.328825   TS=   469.934194  D=  79.37990  DMASS=  0.577104E-09
FL=   .000000002  VL=    61.919974   TS=   470.507689  D=  99.37627  DMASS=  0.113232E-08

X=    9.501321    YDUCT=  11.599271  MG=    .067413    PO=  2075.6260   TO=   474.900205
DX=   .007000000  A(X)=  422.6796    A(X)/A0=  .55385  REL HUM. %=   29.490125

CV=   .000555331  VG=    72.313731  TG=   474.462261  P=   2069.01   FLtot=   .000126221
FL=   .000011042  VL=    72.206573   TS=   469.539345  D=   7.39541  DMASS=  0.466669E-12
FL=   .000044725  VL=    71.976138   TS=   469.552296  D=  13.34594  DMASS=  0.274265E-11
FL=   .000039379  VL=    71.676709   TS=   469.566219  D=  18.73585  DMASS=  0.758827E-11
FL=   .000024864  VL=    70.935815   TS=   469.594495  D=  29.07977  DMASS=  0.283723E-10
FL=   .000004282  VL=    70.093559   TS=   469.621061  D=  39.22689  DMASS=  0.696425E-10
FL=   .000001735  VL=    69.219370   TS=   469.645841  D=  49.29855  DMASS=  0.138237E-09
FL=   .000000175  VL=    68.350304   TS=   469.678190  D=  59.33587  DMASS=  0.241032E-09
FL=   .000000018  VL=    66.690963   TS=   469.875054  D=  79.36098  DMASS=  0.576691E-09
FL=   .000000002  VL=    65.167229   TS=   470.383313  D=  99.35832  DMASS=  0.113171E-08

X=   10.005321    YDUCT=  11.270093  MG=    .071433    PO=  2075.6260   TO=   474.893815
DX=   .007000000  A(X)=  399.0294    A(X)/A0=  .52286  REL HUM. %=   29.630342

CV=   .000556731  VG=    76.620454  TG=   474.402152  P=   2068.20   FLtot=   .000124819
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FL=   .000010596   VL=   76.499938   TS=   469.498594   D=    7.29449   DMASS=  0.447825E-12
FL=   .000044138   VL=   76.234897   TS=   469.513305   D=   13.28733   DMASS=  0.270667E-11
FL=   .000039102   VL=   75.892717   TS=   469.529057   D=   18.69183   DMASS=  0.753491E-11
FL=   .000024783   VL=   75.054942   TS=   469.560828   D=   29.04812   DMASS=  0.282798E-10
FL=   .000004273   VL=   74.114243   TS=   469.590462   D=   39.20080   DMASS=  0.695036E-10
FL=   .000001732   VL=   73.147254   TS=   469.617583   D=   49.27562   DMASS=  0.138044E-09
FL=   .000000175   VL=   72.192784   TS=   469.649278   D=   59.31499   DMASS=  0.240777E-09
FL=   .000000018   VL=   70.383401   TS=   469.820869   D=   79.34243   DMASS=  0.576287E-09
FL=   .000000002   VL=   68.731778   TS=   470.272708   D=   99.34077   DMASS=  0.113111E-08

X=   10.502321   YDUCT=  10.945054   MG=        .075767   PO=   2075.6260   TO=   474.887900
DX=   .007000000 A(X)=  376.3446    A(X)/A0=    .49314   REL HUM. %=   29.773230

CV=   .000558028   VG=   81.264172   TG=   474.334833   P=   2067.27   FLtot=    .000123521
FL=   .000010188   VL=   81.128130   TS=   469.451911   D=    7.19953   DMASS=  0.430562E-12
FL=   .000043594   VL=   80.822498   TS=   469.468726   D=   13.23246   DMASS=  0.267328E-11
FL=   .000038844   VL=   80.430656   TS=   469.486647   D=   18.65055   DMASS=  0.748510E-11
FL=   .000024707   VL=   79.482034   TS=   469.522519   D=   29.01830   DMASS=  0.281928E-10
FL=   .000004265   VL=   78.430577   TS=   469.555719   D=   39.17612   DMASS=  0.693724E-10
FL=   .000001730   VL=   77.360421   TS=   469.585697   D=   49.25387   DMASS=  0.137862E-09
FL=   .000000175   VL=   76.311758   TS=   469.617924   D=   59.29512   DMASS=  0.240536E-09
FL=   .000000018   VL=   74.338012   TS=   469.770792   D=   79.32476   DMASS=  0.575902E-09
FL=   .000000002   VL=   72.547057   TS=   470.175393   D=   99.32407   DMASS=  0.113054E-08

X=   11.006321   YDUCT=  10.615443   MG=        .080582   PO=   2075.6259   TO=   474.882279
DX=   .007000000 A(X)=  354.0186    A(X)/A0=    .46388   REL HUM. %=   29.924874

CV=   .000559262   VG=   86.420950   TG=   474.256790   P=   2066.18   FLtot=    .000122286
FL=   .000009803   VL=   86.266514   TS=   469.396746   D=    7.10786   DMASS=  0.414324E-12
FL=   .000043075   VL=   85.912471   TS=   469.416136   D=   13.17974   DMASS=  0.264146E-11
FL=   .000038596   VL=   85.462050   TS=   469.436702   D=   18.61082   DMASS=  0.743736E-11
FL=   .000024633   VL=   84.384600   TS=   469.477544   D=   28.98945   DMASS=  0.281088E-10
FL=   .000004257   VL=   83.206129   TS=   469.515030   D=   39.15213   DMASS=  0.692451E-10
FL=   .000001728   VL=   82.018637   TS=   469.548520   D=   49.23266   DMASS=  0.137684E-09
FL=   .000000175   VL=   80.863395   TS=   469.582319   D=   59.27570   DMASS=  0.240299E-09
FL=   .000000018   VL=   78.704480   TS=   469.721410   D=   79.30745   DMASS=  0.575525E-09
FL=   .000000002   VL=   76.757092   TS=   470.085576   D=   99.30771   DMASS=  0.112998E-08

X=   11.503321   YDUCT=  10.290903   MG=        .085789   PO=   2075.6259   TO=   474.877091
DX=   .007000000 A(X)=  332.7031    A(X)/A0=    .43595   REL HUM. %=   30.083472

CV=   .000560401   VG=   91.997002   TG=   474.168279   P=   2064.92   FLtot=    .000121146
FL=   .000009453   VL=   91.821077   TS=   469.333190   D=    7.02203   DMASS=  0.399494E-12
FL=   .000042594   VL=   91.410615   TS=   469.355663   D=   13.13058   DMASS=  0.261201E-11
FL=   .000038365   VL=   90.892863   TS=   469.379371   D=   18.57368   DMASS=  0.739292E-11
FL=   .000024564   VL=   89.669969   TS=   469.426077   D=   28.96233   DMASS=  0.280300E-10
FL=   .000004250   VL=   88.350422   TS=   469.468585   D=   39.12948   DMASS=  0.691249E-10
FL=   .000001726   VL=   87.033757   TS=   469.506233   D=   49.21255   DMASS=  0.137515E-09
FL=   .000000174   VL=   85.761720   TS=   469.542525   D=   59.25726   DMASS=  0.240075E-09
FL=   .000000018   VL=   83.400509   TS=   469.672389   D=   79.29096   DMASS=  0.575166E-09
FL=   .000000002   VL=   81.282528   TS=   470.003185   D=   99.29213   DMASS=  0.112945E-08

X=   12.000321   YDUCT=   9.966362   MG=        .091523   PO=   2075.6258   TO=   474.872242
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DX=   .007000000  A(X)=   312.0493    A(X)/A0=    .40889    REL HUM. %=    30.254311

CV=   .000561467  VG=     98.135393   TG=   474.065679   P=  2063.45   FLtot=    .000120079
FL=   .000009128  VL=     97.933485   TS=   469.258586   D=   6.94071  DMASS=  0.385775E-12
FL=   .000042144  VL=     97.454776   TS=   469.284888   D=  13.08415  DMASS=  0.258440E-11
FL=   .000038148  VL=     96.856745   TS=   469.312441   D=  18.53851  DMASS=  0.735101E-11
FL=   .000024498  VL=     95.464082   TS=   469.366212   D=  28.93650  DMASS=  0.279551E-10
FL=   .000004243  VL=     93.983409   TS=   469.414714   D=  39.10780  DMASS=  0.690101E-10
FL=   .000001724  VL=     92.521148   TS=   469.457336   D=  49.19324  DMASS=  0.137353E-09
FL=   .000000174  VL=     91.118424   TS=   469.497059   D=  59.23949  DMASS=  0.239859E-09
FL=   .000000018  VL=     88.532009   TS=   469.621473   D=  79.27503  DMASS=  0.574820E-09
FL=   .000000002  VL=     86.224699   TS=   469.924649   D=  99.27708  DMASS=  0.112894E-08

X=   12.504321    YDUCT=   9.636871   MG=    .097960     PO=  2075.6258   TO=  474.867657
DX=   .007000000  A(X)=   291.7575    A(X)/A0=    .38230    REL HUM. %=    30.444221

CV=   .000562477  VG=    105.024232   TG=   473.943876   P=  2061.68   FLtot=    .000119068
FL=   .000008824  VL=    104.790253   TS=   469.169100   D=   6.86286  DMASS=  0.372938E-12
FL=   .000041717  VL=    104.227513   TS=   469.200274   D=  13.03980  DMASS=  0.255821E-11
FL=   .000037940  VL=    103.532143   TS=   469.232663   D=  18.50480  DMASS=  0.731098E-11
FL=   .000024435  VL=    101.937660   TS=   469.295183   D=  28.91157  DMASS=  0.278829E-10
FL=   .000004236  VL=    100.268955   TS=   469.351011   D=  39.08678  DMASS=  0.688989E-10
FL=   .000001722  VL=     98.638723   TS=   469.399694   D=  49.17445  DMASS=  0.137196E-09
FL=   .000000174  VL=     97.086275   TS=   469.443921   D=  59.22215  DMASS=  0.239649E-09
FL=   .000000018  VL=     94.243285   TS=   469.566316   D=  79.25944  DMASS=  0.574481E-09
FL=   .000000002  VL=     91.721116   TS=   469.846773   D=  99.26235  DMASS=  0.112843E-08

X=   13.001321    YDUCT=   9.311708   MG=    .105011     PO=  2075.6256   TO=  474.863452
DX=   .007000000  A(X)=   272.4009    A(X)/A0=    .35694    REL HUM. %=    30.652955

CV=   .000563405  VG=    112.567177   TG=   473.802201   P=  2059.61   FLtot=    .000118139
FL=   .000008548  VL=    112.294775   TS=   469.064146   D=   6.79061  DMASS=  0.361285E-12
FL=   .000041324  VL=    111.631739   TS=   469.101375   D=  12.99871  DMASS=  0.253409E-11
FL=   .000037748  VL=    110.822154   TS=   469.139704   D=  18.47344  DMASS=  0.727388E-11
FL=   .000024376  VL=    108.995527   TS=   469.212831   D=  28.88821  DMASS=  0.278154E-10
FL=   .000004230  VL=    107.114033   TS=   469.277429   D=  39.06698  DMASS=  0.687942E-10
FL=   .000001720  VL=    105.295364   TS=   469.333324   D=  49.15668  DMASS=  0.137047E-09
FL=   .000000174  VL=    103.575766   TS=   469.383134   D=  59.20571  DMASS=  0.239449E-09
FL=   .000000018  VL=    100.447451   TS=   469.506822   D=  79.24460  DMASS=  0.574158E-09
FL=   .000000002  VL=     97.687045   TS=   469.769666   D=  99.24831  DMASS=  0.112796E-08

X=   13.505321    YDUCT=   8.981587   MG=    .112990     PO=  2075.6255   TO=  474.859497
DX=   .007000000  A(X)=   253.4289    A(X)/A0=    .33208    REL HUM. %=    30.893134

CV=   .000564280  VG=    121.098865   TG=   473.631267   P=  2057.10   FLtot=    .000117262
FL=   .000008292  VL=    120.778548   TS=   468.936708   D=   6.72194  DMASS=  0.350433E-12
FL=   .000040952  VL=    119.991115   TS=   468.981780   D=  12.95964  DMASS=  0.251132E-11
FL=   .000037564  VL=    119.042499   TS=   469.027682   D=  18.44351  DMASS=  0.723858E-11
FL=   .000024319  VL=    116.939564   TS=   469.114129   D=  28.86574  DMASS=  0.277505E-10
FL=   .000004223  VL=    114.809509   TS=   469.189596   D=  39.04782  DMASS=  0.686931E-10
FL=   .000001718  VL=    112.772781   TS=   469.254366   D=  49.13943  DMASS=  0.136903E-09
FL=   .000000174  VL=    110.860668   TS=   469.311194   D=  59.18970  DMASS=  0.239255E-09
FL=   .000000018  VL=    107.404828   TS=   469.439512   D=  79.23009  DMASS=  0.573843E-09
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FL=   .000000002   VL=   104.371604   TS=   469.689052   D=  99.23457   DMASS=  0.112749E-08

X=    14.002321    YDUCT=  8.656054   MG=   .121799   PO=  2075.6253   TO=   474.855893
DX=   .007000000   A(X)=  235.3910    A(X)/A0=  .30844   REL HUM. %=   31.166416

CV=   .000565081   VG=   130.512927   TG=   473.429259   P=  2054.12    FLtot=  .000116460
FL=   .000008060   VL=   130.134563   TS=   468.785363   D=   6.65871   DMASS=  0.340638E-12
FL=   .000040612   VL=   129.197538   TS=   468.840361   D=  12.92364   DMASS=  0.249045E-11
FL=   .000037395   VL=   128.085122   TS=   468.895703   D=  18.41579   DMASS=  0.720598E-11
FL=   .000024266   VL=   125.663654   TS=   468.998511   D=  28.84475   DMASS=  0.276900E-10
FL=   .000004218   VL=   123.251695   TS=   469.087155   D=  39.02982   DMASS=  0.685981E-10
FL=   .000001716   VL=   120.969544   TS=   469.162594   D=  49.12314   DMASS=  0.136767E-09
FL=   .000000174   VL=   118.841540   TS=   469.227947   D=  59.17454   DMASS=  0.239071E-09
FL=   .000000018   VL=   115.019278   TS=   469.364253   D=  79.21631   DMASS=  0.573544E-09
FL=   .000000002   VL=   111.681330   TS=   469.605009   D=  99.22149   DMASS=  0.112704E-08

X=    14.506321    YDUCT=  8.326501   MG=   .131832   PO=  2075.6251   TO=   474.852532
DX=   .007000000   A(X)=  217.8086    A(X)/A0=  .28540   REL HUM. %=   31.491470

CV=   .000565833   VG=   141.227373   TG=   473.182016   P=  2050.46    FLtot=  .000115708
FL=   .000007846   VL=   140.775951   TS=   468.599483   D=   6.59912   DMASS=  0.331575E-12
FL=   .000040292   VL=   139.653201   TS=   468.667495   D=  12.88964   DMASS=  0.247084E-11
FL=   .000037235   VL=   138.342204   TS=   468.735001   D=  18.38945   DMASS=  0.717511E-11
FL=   .000024215   VL=   135.543628   TS=   468.858572   D=  28.82463   DMASS=  0.276321E-10
FL=   .000004212   VL=   132.803421   TS=   468.963721   D=  39.01246   DMASS=  0.685066E-10
FL=   .000001715   VL=   130.237467   TS=   469.052408   D=  49.10737   DMASS=  0.136635E-09
FL=   .000000174   VL=   127.860529   TS=   469.128387   D=  59.15981   DMASS=  0.238893E-09
FL=   .000000018   VL=   123.616413   TS=   469.276570   D=  79.20286   DMASS=  0.573251E-09
FL=   .000000002   VL=   119.927944   TS=   469.512788   D=  99.20870   DMASS=  0.112661E-08

X=    15.003321    YDUCT=  8.001397   MG=   .143026   PO=  2075.6247   TO=   474.849502
DX=   .007000000   A(X)=  201.1322    A(X)/A0=  .26355   REL HUM. %=   31.874972

CV=   .000566517   VG=   153.171608   TG=   472.884430   P=  2046.04    FLtot=  .000115023
FL=   .000007653   VL=   152.627915   TS=   468.375367   D=   6.54480   DMASS=  0.323453E-12
FL=   .000040001   VL=   151.274671   TS=   468.460391   D=  12.85852   DMASS=  0.245299E-11
FL=   .000037088   VL=   149.723709   TS=   468.543389   D=  18.36519   DMASS=  0.714675E-11
FL=   .000024168   VL=   146.482162   TS=   468.692856   D=  28.80592   DMASS=  0.275783E-10
FL=   .000004207   VL=   143.364645   TS=   468.818269   D=  38.99621   DMASS=  0.684210E-10
FL=   .000001713   VL=   140.475721   TS=   468.923059   D=  49.09253   DMASS=  0.136511E-09
FL=   .000000173   VL=   137.816848   TS=   469.011941   D=  59.14591   DMASS=  0.238724E-09
FL=   .000000018   VL=   133.096509   TS=   469.176075   D=  79.19011   DMASS=  0.572975E-09
FL=   .000000002   VL=   129.013222   TS=   469.412258   D=  99.19655   DMASS=  0.112619E-08

X=    15.500321    YDUCT=  7.675488   MG=   .155785   PO=  2075.6243   TO=   474.846753
DX=   .007000000   A(X)=  185.0810    A(X)/A0=  .24252   REL HUM. %=   32.342914

CV=   .000567145   VG=   166.771847   TG=   472.517168   P=  2040.59    FLtot=  .000114394
FL=   .000007479   VL=   166.109239   TS=   468.098601   D=   6.49485   DMASS=  0.316103E-12
FL=   .000039733   VL=   164.464064   TS=   468.206515   D=  12.82973   DMASS=  0.243655E-11
FL=   .000036951   VL=   162.617366   TS=   468.309819   D=  18.34258   DMASS=  0.712039E-11
FL=   .000024124   VL=   158.843766   TS=   468.492449   D=  28.78829   DMASS=  0.275277E-10
FL=   .000004202   VL=   155.281352   TS=   468.643335   D=  38.98079   DMASS=  0.683399E-10
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FL=   .000001712   VL=   152.014994   TS=   468.768138   D=  49.07840   DMASS=  0.136393E-09
FL=   .000000173   VL=   149.028242   TS=   468.872985   D=  59.13261   DMASS=  0.238563E-09
FL=   .000000018   VL=   143.756302   TS=   469.058062   D=  79.17786   DMASS=  0.572709E-09
FL=   .000000002   VL=   139.217263   TS=   469.298945   D=  99.18485   DMASS=  0.112579E-08

X=   16.004321    YDUCT=   7.344689   MG=     .170628   PO=   2075.6238   TO=   474.844258
DX=   .007000000  A(X)=  169.4715     A(X)/A0=  .22206  REL HUM. %=   32.933757

CV=   .000567729   VG=   182.572581   TG=  472.052238   P=   2033.69    FLtot=   .000113809
FL=   .000007321   VL=   181.752410   TS=   467.748268   D=   6.44864   DMASS=  0.309404E-12
FL=   .000039484   VL=   179.735052   TS=   467.887591   D=  12.80290   DMASS=  0.242129E-11
FL=   .000036823   VL=   177.522391   TS=   468.018124   D=  18.32133   DMASS=  0.709567E-11
FL=   .000024082   VL=   173.105261   TS=   468.244297   D=  28.77152   DMASS=  0.274796E-10
FL=   .000004197   VL=   169.011614   TS=   468.428011   D=  38.96602   DMASS=  0.682622E-10
FL=   .000001710   VL=   165.296741   TS=   468.578289   D=  49.06477   DMASS=  0.136280E-09
FL=   .000000173   VL=   161.921286   TS=   468.703333   D=  59.11975   DMASS=  0.238408E-09
FL=   .000000018   VL=   155.996841   TS=   468.915857   D=  79.16593   DMASS=  0.572450E-09
FL=   .000000002   VL=   150.919927   TS=   469.166907   D=  99.17343   DMASS=  0.112540E-08

X=   16.501321    YDUCT=   7.013268   MG=     .187825   PO=   2075.6230   TO=   474.842102
DX=   .007000000  A(X)=  154.5222     A(X)/A0=  .20248  REL HUM. %=   33.687114

CV=   .000568253   VG=   200.850106   TG=  471.462934   P=   2024.95    FLtot=   .000113285
FL=   .000007182   VL=   199.820947   TS=   467.305311   D=   6.40744   DMASS=  0.303512E-12
FL=   .000039261   VL=   197.304943   TS=   467.489592   D=  12.77869   DMASS=  0.240759E-11
FL=   .000036706   VL=   194.613782   TS=   467.657278   D=  18.30196   DMASS=  0.707319E-11
FL=   .000024043   VL=   189.383626   TS=   467.940777   D=  28.75604   DMASS=  0.274353E-10
FL=   .000004193   VL=   184.638259   TS=   468.166585   D=  38.95226   DMASS=  0.681900E-10
FL=   .000001709   VL=   180.381404   TS=   468.349016   D=  49.05201   DMASS=  0.136174E-09
FL=   .000000173   VL=   176.540362   TS=   468.499311   D=  59.10765   DMASS=  0.238261E-09
FL=   .000000018   VL=   169.840584   TS=   468.746810   D=  79.15466   DMASS=  0.572205E-09
FL=   .000000002   VL=   164.129202   TS=   469.014199   D=  99.16259   DMASS=  0.112504E-08

X=   17.005321    YDUCT=   6.688209   MG=     .207484   PO=   2075.6220   TO=   474.840250
DX=   .007000000  A(X)=  140.5302     A(X)/A0=  .18414  REL HUM. %=   34.649761

CV=   .000568731   VG=   221.700256   TG=  470.722869   P=   2014.00    FLtot=   .000112806
FL=   .000007057   VL=   220.460186   TS=   466.745013   D=   6.37013   DMASS=  0.298241E-12
FL=   .000039057   VL=   217.443227   TS=   466.985496   D=  12.75650   DMASS=  0.239507E-11
FL=   .000036598   VL=   214.268247   TS=   467.201479   D=  18.28401   DMASS=  0.705240E-11
FL=   .000024006   VL=   208.183158   TS=   467.559911   D=  28.74146   DMASS=  0.273936E-10
FL=   .000004188   VL=   202.721692   TS=   467.840293   D=  38.93919   DMASS=  0.681213E-10
FL=   .000001708   VL=   197.853740   TS=   468.064036   D=  49.03981   DMASS=  0.136072E-09
FL=   .000000173   VL=   193.479612   TS=   468.246571   D=  59.09602   DMASS=  0.238121E-09
FL=   .000000018   VL=   185.880850   TS=   468.539233   D=  79.14375   DMASS=  0.571969E-09
FL=   .000000002   VL=   179.427240   TS=   468.830612   D=  99.15206   DMASS=  0.112468E-08

X=   17.502321    YDUCT=   6.389047   MG=     .228617   PO=   2075.6208   TO=   474.838774
DX=   .007000000  A(X)=  128.2396     A(X)/A0=  .16804  REL HUM. %=   35.817838

CV=   .000569152   VG=   244.057328   TG=  469.848785   P=   2001.11    FLtot=   .000112385
FL=   .000006949   VL=   242.623047   TS=   466.078372   D=   6.33759   DMASS=  0.293694E-12
FL=   .000038877   VL=   239.132672   TS=   466.383876   D=  12.73691   DMASS=  0.238405E-11
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FL=    .000036502   VL=    235.499305    TS=    466.656802   D=  18.26800   DMASS=  0.703388E-11
FL=    .000023973   VL=    228.600203    TS=    467.105287   D=  28.72827   DMASS=  0.273559E-10
FL=    .000004184   VL=    222.442613    TS=    467.451686   D=  38.92723   DMASS=  0.680586E-10
FL=    .000001707   VL=    216.966321    TS=    467.725345   D=  49.02856   DMASS=  0.135978E-09
FL=    .000000173   VL=    212.050872    TS=    467.946751   D=  59.08525   DMASS=  0.237991E-09
FL=    .000000018   VL=    203.519530    TS=    468.294334   D=  79.13355   DMASS=  0.571748E-09
FL=    .000000002   VL=    196.280650    TS=    468.617220   D=  99.14217   DMASS=  0.112434E-08

X=   18.006321    YDUCT=    6.119458    MG=      .250773    PO=  2075.6193    TO=   474.837634
DX=    .007000000 A(X)=   117.6456     A(X)/A0=    .15415   REL HUM. %=     37.206558

CV=    .000569530   VG=    267.428136    TG=   468.845780    P=  1986.38     FLtot=    .000112006
FL=    .000006854   VL=    265.883795    TS=    465.302396   D=   6.30862   DMASS=  0.289685E-12
FL=    .000038716   VL=    262.048391    TS=    465.676464   D=  12.71929   DMASS=  0.237416E-11
FL=    .000036415   VL=    258.053838    TS=    466.012931   D=  18.25344   DMASS=  0.701708E-11
FL=    .000023943   VL=    250.469750    TS=    466.565527   D=  28.71609   DMASS=  0.273211E-10
FL=    .000004181   VL=    243.693906    TS=    466.989802   D=  38.91609   DMASS=  0.680002E-10
FL=    .000001705   VL=    237.657281    TS=    467.322746   D=  49.01801   DMASS=  0.135891E-09
FL=    .000000173   VL=    232.229416    TS=    467.590441   D=  59.07508   DMASS=  0.237868E-09
FL=    .000000018   VL=    222.788904    TS=    468.003980   D=  79.12386   DMASS=  0.571538E-09
FL=    .000000002   VL=    214.762531    TS=    468.366641   D=  99.13271   DMASS=  0.112402E-08

X=   18.503321    YDUCT=    5.908304    MG=      .270671    PO=  2075.6178    TO=   474.836798
DX=    .007000000 A(X)=   109.6669     A(X)/A0=    .14370   REL HUM. %=     38.613365

CV=    .000569857   VG=    288.350870    TG=   467.870214    P=  1972.14     FLtot=    .000111679
FL=    .000006773   VL=    286.866538    TS=    464.523751   D=   6.28362   DMASS=  0.286254E-12
FL=    .000038577   VL=    283.120252    TS=    464.939485   D=  12.70402   DMASS=  0.236562E-11
FL=    .000036339   VL=    279.122789    TS=    465.329650   D=  18.24074   DMASS=  0.700245E-11
FL=    .000023916   VL=    271.340879    TS=    465.982514   D=  28.70534   DMASS=  0.272904E-10
FL=    .000004178   VL=    264.258092    TS=    466.486799   D=  38.90615   DMASS=  0.679481E-10
FL=    .000001704   VL=    257.880231    TS=    466.882280   D=  49.00852   DMASS=  0.135812E-09
FL=    .000000173   VL=    252.103812    TS=    467.199477   D=  59.06588   DMASS=  0.237757E-09
FL=    .000000018   VL=    241.983166    TS=    467.684611   D=  79.11500   DMASS=  0.571346E-09
FL=    .000000002   VL=    233.320455    TS=    468.092100   D=  99.12403   DMASS=  0.112372E-08

X=   19.000321    YDUCT=    5.732180    MG=      .289337    PO=  2075.6163    TO=   474.836211
DX=    .007000000 A(X)=   103.2261     A(X)/A0=    .13526   REL HUM. %=     40.082880

CV=    .000570147   VG=    307.917831    TG=   466.891512    P=  1957.91     FLtot=    .000111389
FL=    .000006702   VL=    306.440636    TS=    463.743707   D=   6.26146   DMASS=  0.283237E-12
FL=    .000038453   VL=    302.680767    TS=    464.194523   D=  12.69049   DMASS=  0.235807E-11
FL=    .000036272   VL=    298.667275    TS=    464.628757   D=  18.22945   DMASS=  0.698946E-11
FL=    .000023892   VL=    290.819140    TS=    465.373377   D=  28.69571   DMASS=  0.272630E-10
FL=    .000004175   VL=    283.605305    TS=    465.956066   D=  38.89718   DMASS=  0.679011E-10
FL=    .000001704   VL=    277.050106    TS=    466.414744   D=  48.99991   DMASS=  0.135740E-09
FL=    .000000173   VL=    271.068647    TS=    466.782811   D=  59.05748   DMASS=  0.237655E-09
FL=    .000000018   VL=    260.499297    TS=    467.342727   D=  79.10686   DMASS=  0.571169E-09
FL=    .000000002   VL=    251.374935    TS=    467.798430   D=  99.11599   DMASS=  0.112345E-08

X=   19.504321    YDUCT=    5.578275    MG=      .307476    PO=  2075.6147    TO=   474.835847
DX=    .007000000 A(X)=    97.7574     A(X)/A0=    .12809   REL HUM. %=     41.662366
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CV=   .000570409  VG=  326.872929  TG=    465.882261  P=  1943.32   FLtot=   .000111127
FL=   .000006638  VL=  325.375638  TS=    462.938409  D=     6.24143  DMASS= 0.280528E-12
FL=   .000038342  VL=  321.549204  TS=    463.427030  D=    12.67823  DMASS= 0.235125E-11
FL=   .000036210  VL=  317.477972  TS=    463.902375  D=    18.21920  DMASS= 0.697767E-11
FL=   .000023870  VL=  309.533645  TS=    464.734291  D=    28.68689  DMASS= 0.272378E-10
FL=   .000004172  VL=  302.215636  TS=    465.394954  D=    38.88891  DMASS= 0.678578E-10
FL=   .000001703  VL=  295.535379  TS=    465.918053  D=    48.99193  DMASS= 0.135674E-09
FL=   .000000173  VL=  289.409836  TS=    466.338709  D=    59.04968  DMASS= 0.237561E-09
FL=   .000000017  VL=  278.513863  TS=    466.976975  D=    79.09924  DMASS= 0.571004E-09
FL=   .000000002  VL=  269.036693  TS=    467.484343  D=    99.10844  DMASS= 0.112319E-08

X=    20.001321   YDUCT=   5.446888  MG=       .324540  PO=   2075.6131   TO=    474.835691
DX=    .007000000 A(X)=   93.2066    A(X)/A0=  .12213   REL HUM. %=  43.296958

CV=   .000570640  VG=  344.647004  TG=    464.881197  P=  1928.92   FLtot=   .000110895
FL=   .000006581  VL=  343.141669  TS=    462.133872  D=     6.22378  DMASS= 0.278153E-12
FL=   .000038244  VL=  339.282644  TS=    462.658555  D=    12.66740  DMASS= 0.234523E-11
FL=   .000036156  VL=  335.173637  TS=    463.172624  D=    18.21009  DMASS= 0.696721E-11
FL=   .000023850  VL=  327.145356  TS=    464.086415  D=    28.67900  DMASS= 0.272154E-10
FL=   .000004170  VL=  319.737493  TS=    464.822416  D=    38.88147  DMASS= 0.678189E-10
FL=   .000001702  VL=  312.957358  TS=    465.409092  D=    48.98471  DMASS= 0.135614E-09
FL=   .000000172  VL=  306.720605  TS=    465.882321  D=    59.04258  DMASS= 0.237475E-09
FL=   .000000017  VL=  295.573781  TS=    466.599871  D=    79.09227  DMASS= 0.570853E-09
FL=   .000000002  VL=  285.820963  TS=    467.160498  D=    99.10150  DMASS= 0.112296E-08

X=    20.505321   YDUCT=   5.327000  MG=       .341579  PO=   2075.6115   TO=    474.835746
DX=    .007000000 A(X)=   89.1487    A(X)/A0=  .11681   REL HUM. %=  45.085722

CV=   .000570851  VG=  362.337846  TG=    463.832264  P=  1913.92   FLtot=   .000110684
FL=   .000006531  VL=  360.783520  TS=    461.292844  D=     6.20772  DMASS= 0.276006E-12
FL=   .000038154  VL=  356.801219  TS=    461.860413  D=    12.65752  DMASS= 0.233974E-11
FL=   .000036106  VL=  352.594825  TS=    462.415129  D=    18.20175  DMASS= 0.695764E-11
FL=   .000023832  VL=  344.423632  TS=    463.410879  D=    28.67171  DMASS= 0.271946E-10
FL=   .000004167  VL=  336.900861  TS=    464.222691  D=    38.87456  DMASS= 0.677827E-10
FL=   .000001701  VL=  330.013094  TS=    464.874212  D=    48.97796  DMASS= 0.135558E-09
FL=   .000000172  VL=  323.668045  TS=    465.401590  D=    59.03592  DMASS= 0.237395E-09
FL=   .000000017  VL=  312.293751  TS=    466.201613  D=    79.08568  DMASS= 0.570711E-09
FL=   .000000002  VL=  302.299060  TS=    466.818481  D=    99.09492  DMASS= 0.112273E-08

X=    21.002321   YDUCT=   5.220702  MG=       .358035  PO=   2075.6097   TO=    474.836000
DX=    .007000000 A(X)=   85.6264    A(X)/A0=  .11220   REL HUM. %=  46.975415

CV=   .000571038  VG=  379.366509  TG=    462.773049  P=  1898.85   FLtot=   .000110497
FL=   .000006486  VL=  377.776564  TS=    460.437798  D=     6.19355  DMASS= 0.274120E-12
FL=   .000038075  VL=  373.700799  TS=    461.050166  D=    12.64874  DMASS= 0.233488E-11
FL=   .000036062  VL=  369.403044  TS=    461.647165  D=    18.19430  DMASS= 0.694910E-11
FL=   .000023816  VL=  361.071509  TS=    462.724613  D=    28.66514  DMASS= 0.271760E-10
FL=   .000004165  VL=  353.415183  TS=    463.611494  D=    38.86828  DMASS= 0.677498E-10
FL=   .000001701  VL=  346.408234  TS=    464.327729  D=    48.97180  DMASS= 0.135507E-09
FL=   .000000172  VL=  339.950290  TS=    464.909537  D=    59.02981  DMASS= 0.237321E-09
FL=   .000000017  VL=  328.354525  TS=    465.793127  D=    79.07961  DMASS= 0.570579E-09
FL=   .000000002  VL=  318.136100  TS=    466.467697  D=    99.08882  DMASS= 0.112253E-08
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X=    21.506321   YDUCT=  5.121473   MG=       .374708   PO=   2075.6078   TO=   474.836475
DX=    .007000000 A(X)=   82.4024    A(X)/A0=  .10797    REL HUM. %=       49.067156

CV=   .000571209  VG=  396.559489   TG=  461.654303   P=  1883.03    FLtot=  .000110326
FL=   .000006446  VL=  394.906419   TS=  459.534921   D=   6.18069   DMASS=  0.272417E-12
FL=   .000038003  VL=  390.676353   TS=  460.199223   D=  12.64072   DMASS=  0.233044E-11
FL=   .000036021  VL=  386.248386   TS=  460.842717   D=  18.18745   DMASS=  0.694126E-11
FL=   .000023800  VL=  377.711926   TS=  462.005941   D=  28.65905   DMASS=  0.271586E-10
FL=   .000004164  VL=  369.893140   TS=  462.970247   D=  38.86240   DMASS=  0.677191E-10
FL=   .000001700  VL=  362.746637   TS=  463.753349   D=  48.96600   DMASS=  0.135459E-09
FL=   .000000172  VL=  356.161830   TS=  464.391651   D=  59.02403   DMASS=  0.237252E-09
FL=   .000000017  VL=  344.330495   TS=  465.362501   D=  79.07382   DMASS=  0.570454E-09
FL=   .000000002  VL=  333.886206   TS=  466.097939   D=  99.08298   DMASS=  0.112233E-08

X=    22.003321   YDUCT=  5.031572   MG=       .391063   PO=   2075.6058   TO=   474.837157
DX=    .007000000 A(X)=   79.5348    A(X)/A0=  .10422    REL HUM. %=       51.308398

CV=   .000571360  VG=  413.362434   TG=  460.513047   P=  1866.98    FLtot=  .000110174
FL=   .000006411  VL=  411.656402   TS=  458.608176   D=   6.16941   DMASS=  0.270928E-12
FL=   .000037939  VL=  407.293095   TS=  459.327477   D=  12.63363   DMASS=  0.232652E-11
FL=   .000035985  VL=  402.738064   TS=  460.020540   D=  18.18134   DMASS=  0.693426E-11
FL=   .000023787  VL=  393.982919   TS=  461.272392   D=  28.65354   DMASS=  0.271430E-10
FL=   .000004162  VL=  385.984684   TS=  462.315114   D=  38.85705   DMASS=  0.676911E-10
FL=   .000001699  VL=  378.684031   TS=  463.165814   D=  48.96068   DMASS=  0.135414E-09
FL=   .000000172  VL=  371.961090   TS=  463.861357   D=  59.01871   DMASS=  0.237187E-09
FL=   .000000017  VL=  359.880976   TS=  464.921009   D=  79.06845   DMASS=  0.570338E-09
FL=   .000000002  VL=  349.207206   TS=  465.718910   D=  99.07754   DMASS=  0.112214E-08

X=    22.500321   YDUCT=  4.947965   MG=       .407486   PO=   2075.6036   TO=   474.838065
DX=    .007000000 A(X)=   76.9136    A(X)/A0=  .10078    REL HUM. %=       53.765953

CV=   .000571496  VG=  430.173288   TG=  459.323867   P=  1850.36    FLtot=  .000110038
FL=   .000006379  VL=  428.401364   TS=  457.640377   D=   6.15941   DMASS=  0.269613E-12
FL=   .000037882  VL=  423.875246   TS=  458.420101   D=  12.62727   DMASS=  0.232301E-11
FL=   .000035952  VL=  419.175853   TS=  459.166799   D=  18.17582   DMASS=  0.692795E-11
FL=   .000023774  VL=  410.181129   TS=  460.512217   D=  28.64850   DMASS=  0.271286E-10
FL=   .000004160  VL=  401.986896   TS=  461.636044   D=  38.85210   DMASS=  0.676653E-10
FL=   .000001699  VL=  394.517887   TS=  462.556339   D=  48.95572   DMASS=  0.135373E-09
FL=   .000000172  VL=  387.644931   TS=  463.310847   D=  59.01372   DMASS=  0.237127E-09
FL=   .000000017  VL=  375.298951   TS=  464.462244   D=  79.06337   DMASS=  0.570228E-09
FL=   .000000002  VL=  364.386013   TS=  465.325116   D=  99.07237   DMASS=  0.112197E-08

X=    23.004321   YDUCT=  4.869482   MG=       .424115   PO=   2075.6012   TO=   474.839217
DX=    .007000000 A(X)=   74.4930    A(X)/A0=  .09761    REL HUM. %=       56.486223

CV=   .000571619  VG=  447.128125   TG=  458.076477   P=  1833.05    FLtot=  .000109915
FL=   .000006352  VL=  445.300955   TS=  456.618367   D=   6.15050   DMASS=  0.268444E-12
FL=   .000037830  VL=  440.632784   TS=  457.462472   D=  12.62153   DMASS=  0.231984E-11
FL=   .000035923  VL=  435.795347   TS=  458.267260   D=  18.17079   DMASS=  0.692219E-11
FL=   .000023763  VL=  426.556897   TS=  459.712825   D=  28.64383   DMASS=  0.271154E-10
FL=   .000004159  VL=  418.156635   TS=  460.922019   D=  38.84746   DMASS=  0.676411E-10
FL=   .000001698  VL=  410.508220   TS=  461.915167   D=  48.95105   DMASS=  0.135334E-09
FL=   .000000172  VL=  403.474679   TS=  462.731370   D=  59.00898   DMASS=  0.237070E-09
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FL=   .000000017   VL=   390.845058    TS=   463.978953   D=  79.05852   DMASS=  0.570123E-09
FL=   .000000002   VL=   379.680091    TS=   464.910324   D=  99.06740   DMASS=  0.112180E-08

X=   23.501321    YDUCT=   4.797625   MG=      .440513   PO=   2075.5987    TO=   474.840588
DX=   .007000000  A(X)=   72.3107    A(X)/A0=   .09475   REL HUM. %=      59.419912

CV=   .000571726   VG=   463.778974   TG=   456.804494   P=   1815.51   FLtot=    .000109808
FL=   .000006328   VL=   461.897403    TS=   455.571195   D=   6.14283   DMASS=  0.267441E-12
FL=   .000037785   VL=   457.088044    TS=   456.481686   D=  12.61653   DMASS=  0.231708E-11
FL=   .000035896   VL=   452.117406    TS=   457.346909   D=  18.16634   DMASS=  0.691712E-11
FL=   .000023752   VL=   442.643536    TS=   458.896231   D=  28.63964   DMASS=  0.271035E-10
FL=   .000004157   VL=   434.040492    TS=   460.192779   D=  38.84325   DMASS=  0.676191E-10
FL=   .000001698   VL=   426.212874    TS=   461.260083   D=  48.94676   DMASS=  0.135299E-09
FL=   .000000172   VL=   419.017513    TS=   462.139025   D=  59.00461   DMASS=  0.237017E-09
FL=   .000000017   VL=   406.100810    TS=   463.484561   D=  79.05399   DMASS=  0.570025E-09
FL=   .000000002   VL=   394.681395    TS=   464.486024   D=  99.06274   DMASS=  0.112164E-08

X=   24.005321    YDUCT=   4.730433   MG=      .457001   PO=   2075.5960    TO=   474.842206
DX=   .007000000  A(X)=   70.2994    A(X)/A0=   .09212   REL HUM. %=      62.647015

CV=   .000571821   VG=   480.451022   TG=   455.484255   P=   1797.43   FLtot=    .000109712
FL=   .000006307   VL=   478.533401    TS=   454.475365   D=   6.13613   DMASS=  0.266566E-12
FL=   .000037745   VL=   473.617495    TS=   455.453259   D=  12.61207   DMASS=  0.231463E-11
FL=   .000035872   VL=   468.534033    TS=   456.381787   D=  18.16234   DMASS=  0.691254E-11
FL=   .000023742   VL=   458.845363    TS=   458.040510   D=  28.63578   DMASS=  0.270925E-10
FL=   .000004156   VL=   450.048515    TS=   459.428611   D=  38.83933   DMASS=  0.675986E-10
FL=   .000001698   VL=   442.045237    TS=   460.573336   D=  48.94272   DMASS=  0.135265E-09
FL=   .000000172   VL=   434.688749    TS=   461.517733   D=  59.00047   DMASS=  0.236968E-09
FL=   .000000017   VL=   421.482585    TS=   462.965591   D=  79.04965   DMASS=  0.569931E-09
FL=   .000000002   VL=   409.804932    TS=   464.040590   D=  99.05824   DMASS=  0.112149E-08

X=   24.502321    YDUCT=   4.669768   MG=      .472977   PO=   2075.5931    TO=   474.844009
DX=   .007000000  A(X)=   68.5079    A(X)/A0=   .08977   REL HUM. %=      66.066460

CV=   .000571904   VG=   496.536600   TG=   454.166208   P=   1779.52   FLtot=    .000109630
FL=   .000006290   VL=   494.600586    TS=   453.371847   D=   6.13049   DMASS=  0.265832E-12
FL=   .000037711   VL=   489.621723    TS=   454.412926   D=  12.60826   DMASS=  0.231253E-11
FL=   .000035852   VL=   484.461146    TS=   455.403942   D=  18.15885   DMASS=  0.690856E-11
FL=   .000023734   VL=   474.605914    TS=   457.172821   D=  28.63235   DMASS=  0.270828E-10
FL=   .000004155   VL=   465.645348    TS=   458.653320   D=  38.83578   DMASS=  0.675801E-10
FL=   .000001697   VL=   457.486774    TS=   459.876109   D=  48.93904   DMASS=  0.135235E-09
FL=   .000000172   VL=   449.983763    TS=   460.886526   D=  58.99665   DMASS=  0.236922E-09
FL=   .000000017   VL=   436.507724    TS=   462.437787   D=  79.04562   DMASS=  0.569844E-09
FL=   .000000002   VL=   424.584813    TS=   463.587420   D=  99.05403   DMASS=  0.112134E-08

X=   25.006321    YDUCT=   4.613415   MG=      .488871   PO=   2075.5901    TO=   474.846040
DX=   .007000000  A(X)=   66.8644    A(X)/A0=   .08761   REL HUM. %=      69.783386

CV=   .000571976   VG=   512.469992   TG=   452.817777   P=   1761.32   FLtot=    .000109558
FL=   .000006275   VL=   510.519128    TS=   452.235723   D=   6.12568   DMASS=  0.265208E-12
FL=   .000037681   VL=   505.491459    TS=   453.337700   D=  12.60493   DMASS=  0.231070E-11
FL=   .000035833   VL=   500.273626    TS=   454.391031   D=  18.15575   DMASS=  0.690502E-11
FL=   .000023726   VL=   490.289334    TS=   456.272441   D=  28.62922   DMASS=  0.270739E-10
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FL=   .000004154   VL=  481.193185   TS=  457.848018   D=  38.83249   DMASS=  0.675629E-10
FL=   .000001697   VL=  472.899942   TS=  459.151232   D=  48.93558   DMASS=  0.135206E-09
FL=   .000000172   VL=  465.265806   TS=  460.229748   D=  58.99304   DMASS=  0.236878E-09
FL=   .000000017   VL=  451.540799   TS=  461.887910   D=  79.04176   DMASS=  0.569760E-09
FL=   .000000002   VL=  439.385907   TS=  463.115041   D=  99.04997   DMASS=  0.112121E-08

X=   25.503321   YDUCT=   4.562385   MG=       .504256   PO=  2075.5869   TO=   474.848238
DX=   .007000000  A(X)=   65.3934    A(X)/A0=   .08569   REL HUM. %=    73.711062

CV=   .000572037   VG=  527.824901   TG=  451.477932   P=  1743.37    FLtot=   .000109497
FL=   .000006263   VL=  525.864809   TS=  451.100223   D=   6.12177   DMASS=  0.264699E-12
FL=   .000037656   VL=  520.794466   TS=  452.260668   D=  12.60214   DMASS=  0.230917E-11
FL=   .000035818   VL=  515.528131   TS=  453.374331   D=  18.15309   DMASS=  0.690199E-11
FL=   .000023719   VL=  505.438928   TS=  455.366898   D=  28.62646   DMASS=  0.270661E-10
FL=   .000004153   VL=  496.231318   TS=  457.037190   D=  38.82954   DMASS=  0.675475E-10
FL=   .000001697   VL=  487.824472   TS=  458.420685   D=  48.93244   DMASS=  0.135180E-09
FL=   .000000172   VL=  480.077145   TS=  459.567276   D=  58.98973   DMASS=  0.236838E-09
FL=   .000000017   VL=  466.131601   TS=  461.332551   D=  79.03817   DMASS=  0.569683E-09
FL=   .000000002   VL=  453.766310   TS=  462.637649   D=  99.04617   DMASS=  0.112108E-08

X=   26.000321   YDUCT=   4.516049   MG=       .519150   PO=  2075.5835   TO=   474.850590
DX=   .007000000  A(X)=   64.0718    A(X)/A0=   .08396   REL HUM. %=    77.854202

CV=   .000572088   VG=  542.625527   TG=  450.148939   P=  1725.69    FLtot=   .000109445
FL=   .000006253   VL=  540.688006   TS=  449.961114   D=   6.11860   DMASS=  0.264289E-12
FL=   .000037635   VL=  535.636028   TS=  451.174105   D=  12.59980   DMASS=  0.230788E-11
FL=   .000035804   VL=  530.357230   TS=  452.345548   D=  18.15081   DMASS=  0.689939E-11
FL=   .000023713   VL=  520.206058   TS=  454.447817   D=  28.62401   DMASS=  0.270591E-10
FL=   .000004152   VL=  510.916602   TS=  456.212917   D=  38.82686   DMASS=  0.675335E-10
FL=   .000001696   VL=  502.419527   TS=  457.677135   D=  48.92955   DMASS=  0.135156E-09
FL=   .000000172   VL=  494.578244   TS=  458.892349   D=  58.98666   DMASS=  0.236801E-09
FL=   .000000017   VL=  480.442148   TS=  460.765920   D=  79.03480   DMASS=  0.569610E-09
FL=   .000000002   VL=  467.888907   TS=  462.150181   D=  99.04257   DMASS=  0.112095E-08

X=   26.504321   YDUCT=   4.474166   MG=       .533468   PO=  2075.5801   TO=   474.853069
DX=   .007000000  A(X)=   62.8889    A(X)/A0=   .08241   REL HUM. %=    82.184253

CV=   .000572131   VG=  556.791448   TG=  448.842442   P=  1708.44    FLtot=   .000109402
FL=   .000006246   VL=  554.914564   TS=  448.824951   D=   6.11609   DMASS=  0.263963E-12
FL=   .000037618   VL=  549.971273   TS=  450.077484   D=  12.59786   DMASS=  0.230681E-11
FL=   .000035793   VL=  544.747911   TS=  451.301480   D=  18.14885   DMASS=  0.689716E-11
FL=   .000023708   VL=  534.619594   TS=  453.509958   D=  28.62182   DMASS=  0.270529E-10
FL=   .000004151   VL=  525.301257   TS=  455.369435   D=  38.82441   DMASS=  0.675207E-10
FL=   .000001696   VL=  516.752194   TS=  456.914818   D=  48.92687   DMASS=  0.135134E-09
FL=   .000000172   VL=  508.846682   TS=  458.199398   D=  58.98377   DMASS=  0.236766E-09
FL=   .000000017   VL=  494.564148   TS=  460.182976   D=  79.03159   DMASS=  0.569541E-09
FL=   .000000002   VL=  481.854610   TS=  461.648088   D=  99.03911   DMASS=  0.112084E-08

X=   27.001321   YDUCT=   4.436968   MG=       .546950   PO=  2075.5766   TO=   474.855602
DX=   .007000000  A(X)=   61.8475    A(X)/A0=   .08104   REL HUM. %=    86.602750

CV=   .000572166   VG=  570.074388   TG=  447.586719   P=  1691.98    FLtot=   .000109367
FL=   .000006240   VL=  568.239364   TS=  447.728893   D=   6.11422   DMASS=  0.263722E-12
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FL=   .000037604  VL=   563.390503   TS=   449.010571  D=  12.59632  DMASS=  0.230597E-11
FL=   .000035783  VL=   558.243454   TS=   450.279555  D=  18.14724  DMASS=  0.689532E-11
FL=   .000023703  VL=   548.195732   TS=   452.585983  D=  28.61993  DMASS=  0.270476E-10
FL=   .000004151  VL=   538.897920   TS=   454.535542  D=  38.82224  DMASS=  0.675094E-10
FL=   .000001696  VL=   530.337239   TS=   456.159422  D=  48.92445  DMASS=  0.135114E-09
FL=   .000000172  VL=   522.401193   TS=   457.511560  D=  58.98114  DMASS=  0.236735E-09
FL=   .000000017  VL=   508.025819   TS=   459.602939  D=  79.02862  DMASS=  0.569476E-09
FL=   .000000002  VL=   495.201273   TS=   461.147772  D=  99.03588  DMASS=  0.112073E-08

X=   27.505321   YDUCT=   4.402649   MG=    .560105   PO=   2075.5731   TO=   474.858263
DX=   .007000000 A(X)=    60.8945    A(X)/A0=   .07979  REL HUM. %=    91.262593

CV=   .000572194  VG=   582.981110   TG=   446.338130  P=   1675.73   FLtot=    .000109339
FL=   .000006236  VL=   581.177574   TS=   446.636168  D=   6.11288  DMASS=  0.263549E-12
FL=   .000037593  VL=   576.399914   TS=   447.943788  D=  12.59511  DMASS=  0.230531E-11
FL=   .000035775  VL=   571.319862   TS=   449.252991  D=  18.14590  DMASS=  0.689379E-11
FL=   .000023699  VL=   561.366018   TS=   451.652344  D=  28.61826  DMASS=  0.270428E-10
FL=   .000004150  VL=   552.113851   TS=   453.690119  D=  38.82027  DMASS=  0.674992E-10
FL=   .000001695  VL=   543.567117   TS=   455.391867  D=  48.92222  DMASS=  0.135096E-09
FL=   .000000172  VL=   535.624200   TS=   456.811481  D=  58.97868  DMASS=  0.236705E-09
FL=   .000000017  VL=   521.196562   TS=   459.011186  D=  79.02580  DMASS=  0.569415E-09
FL=   .000000002  VL=   508.289822   TS=   460.636604  D=  99.03278  DMASS=  0.112062E-08

X=   28.002321   YDUCT=   4.371915   MG=    .572538   PO=   2075.5695   TO=   474.860958
DX=   .007000000 A(X)=    60.0473    A(X)/A0=   .07868  REL HUM. %=    96.011516

CV=   .000572215  VG=   595.129444   TG=   445.137298  P=   1660.20   FLtot=    .000109318
FL=   .000006233  VL=   593.366224   TS=   445.577887  D=   6.11206  DMASS=  0.263442E-12
FL=   .000037585  VL=   588.673128   TS=   446.907613  D=  12.59423  DMASS=  0.230482E-11
FL=   .000035769  VL=   583.661353   TS=   448.251915  D=  18.14484  DMASS=  0.689258E-11
FL=   .000023695  VL=   573.806430   TS=   450.736791  D=  28.61684  DMASS=  0.270388E-10
FL=   .000004149  VL=   564.613154   TS=   452.858366  D=  38.81854  DMASS=  0.674901E-10
FL=   .000001695  VL=   556.096862   TS=   454.635066  D=  48.92022  DMASS=  0.135079E-09
FL=   .000000172  VL=   548.164286   TS=   456.120087  D=  58.97645  DMASS=  0.236678E-09
FL=   .000000017  VL=   533.717398   TS=   458.425435  D=  79.02320  DMASS=  0.569359E-09
FL=   .000000002  VL=   520.758031   TS=   460.129895  D=  99.02990  DMASS=  0.112052E-08

X=   28.506321   YDUCT=   4.343645   MG=    .584580   PO=   2075.5658   TO=   474.863738
DX=   .007000000 A(X)=    59.2732    A(X)/A0=   .07767  REL HUM. %=   100.958962

CV=   .000572230  VG=   606.849747   TG=   443.955236  P=   1645.01   FLtot=    .000109303
FL=   .000006232  VL=   605.129592   TS=   444.529184  D=   6.11167  DMASS=  0.263392E-12
FL=   .000037579  VL=   600.538437   TS=   445.876084  D=  12.59361  DMASS=  0.230448E-11
FL=   .000035764  VL=   595.609033   TS=   447.251251  D=  18.14400  DMASS=  0.689162E-11
FL=   .000023692  VL=   585.870973   TS=   449.816234  D=  28.61562  DMASS=  0.270353E-10
FL=   .000004149  VL=   576.752456   TS=   452.019154  D=  38.81698  DMASS=  0.674820E-10
FL=   .000001695  VL=   568.282470   TS=   453.869709  D=  48.91838  DMASS=  0.135064E-09
FL=   .000000172  VL=   560.375759   TS=   455.419690  D=  58.97437  DMASS=  0.236653E-09
FL=   .000000017  VL=   545.938513   TS=   457.830656  D=  79.02073  DMASS=  0.569306E-09
FL=   .000000002  VL=   532.951974   TS=   459.614614  D=  99.02714  DMASS=  0.112043E-08

X=   29.003321   YDUCT=   4.317875   MG=    .596120   PO=   2075.5621   TO=   474.866560
DX=   .007000000 A(X)=    58.5720    A(X)/A0=   .07675  REL HUM. %=   106.048075
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CV=   .000572240   VG=   618.037327   TG=    442.805327   P=   1630.34   FLtot=    .000109293
FL=   .000006232   VL=   616.326093    TS=   443.511788   D=    6.11169   DMASS=  0.263394E-12
FL=   .000037576   VL=   611.784429    TS=   444.875702   D=   12.59325   DMASS=  0.230429E-11
FL=   .000035760   VL=   606.917009    TS=   446.278216   D=   18.14339   DMASS=  0.689093E-11
FL=   .000023690   VL=   597.285049    TS=   448.916689   D=   28.61460   DMASS=  0.270325E-10
FL=   .000004149   VL=   588.242881    TS=   451.196478   D=   38.81563   DMASS=  0.674749E-10
FL=   .000001695   VL=   579.825593    TS=   453.117804   D=   48.91673   DMASS=  0.135050E-09
FL=   .000000172   VL=   571.953403    TS=   454.730505   D=   58.97248   DMASS=  0.236630E-09
FL=   .000000017   VL=   557.545646    TS=   457.244095   D=   79.01846   DMASS=  0.569257E-09
FL=   .000000002   VL=   544.552197    TS=   459.105738   D=   99.02456   DMASS=  0.112034E-08

X=   29.500321   YDUCT=   4.293277   MG=      .607690   PO=   2075.5582    TO=   474.869539
DX=   .007000000 A(X)=    57.9065    A(X)/A0=   .07588   REL HUM. %=   111.521491

CV=   .000572245   VG=   629.211406   TG=    441.635759   P=   1615.51   FLtot=    .000109288
FL=   .000006233   VL=   627.465450    TS=   442.486930   D=    6.11208   DMASS=  0.263444E-12
FL=   .000037575   VL=   622.867494    TS=   443.879251   D=   12.59313   DMASS=  0.230422E-11
FL=   .000035758   VL=   617.993595    TS=   445.310386   D=   18.14298   DMASS=  0.689046E-11
FL=   .000023688   VL=   608.400210    TS=   448.020541   D=   28.61375   DMASS=  0.270301E-10
FL=   .000004148   VL=   599.404810    TS=   450.375452   D=   38.81443   DMASS=  0.674687E-10
FL=   .000001695   VL=   591.026117    TS=   452.366379   D=   48.91524   DMASS=  0.135038E-09
FL=   .000000172   VL=   583.182120    TS=   454.041025   D=   58.97074   DMASS=  0.236610E-09
FL=   .000000017   VL=   568.802566    TS=   456.656373   D=   79.01632   DMASS=  0.569211E-09
FL=   .000000002   VL=   555.807795    TS=   458.595347   D=   99.02212   DMASS=  0.112026E-08

X=   30.004321   YDUCT=   4.269846   MG=      .619272   PO=   2075.5541    TO=   474.872680
DX=   .007000000 A(X)=    57.2762    A(X)/A0=   .07505   REL HUM. %=   117.402896

CV=   .000572246   VG=   640.352138   TG=    440.448742   P=   1600.56   FLtot=    .000109287
FL=   .000006236   VL=   638.604045    TS=   441.436963   D=    6.11282   DMASS=  0.263540E-12
FL=   .000037576   VL=   633.983458    TS=   442.865491   D=   12.59321   DMASS=  0.230426E-11
FL=   .000035756   VL=   629.084191    TS=   444.328375   D=   18.14274   DMASS=  0.689019E-11
FL=   .000023686   VL=   619.479423    TS=   447.111310   D=   28.61305   DMASS=  0.270281E-10
FL=   .000004148   VL=   610.497244    TS=   449.541649   D=   38.81337   DMASS=  0.674631E-10
FL=   .000001695   VL=   602.136128    TS=   451.602606   D=   48.91388   DMASS=  0.135026E-09
FL=   .000000172   VL=   594.307100    TS=   453.339719   D=   58.96912   DMASS=  0.236590E-09
FL=   .000000017   VL=   579.942498    TS=   456.057935   D=   79.01429   DMASS=  0.569167E-09
FL=   .000000002   VL=   566.942406    TS=   458.075298   D=   99.01978   DMASS=  0.112018E-08

X=   30.501321   YDUCT=   4.248294   MG=      .630462   PO=   2075.5500    TO=   474.875871
DX=   .007000000 A(X)=    56.6995    A(X)/A0=   .07430   REL HUM. %=   123.499791

CV=   .000572242   VG=   651.073370   TG=    439.286677   P=   1586.01   FLtot=    .000109291
FL=   .000006239   VL=   649.334689    TS=   440.400745   D=    6.11387   DMASS=  0.263676E-12
FL=   .000037578   VL=   644.725843    TS=   441.864720   D=   12.59349   DMASS=  0.230442E-11
FL=   .000035756   VL=   639.819815    TS=   443.360281   D=   18.14268   DMASS=  0.689012E-11
FL=   .000023685   VL=   630.200846    TS=   446.214554   D=   28.61251   DMASS=  0.270265E-10
FL=   .000004148   VL=   621.218058    TS=   448.718365   D=   38.81246   DMASS=  0.674584E-10
FL=   .000001694   VL=   612.862384    TS=   450.847762   D=   48.91267   DMASS=  0.135016E-09
FL=   .000000172   VL=   605.039315    TS=   452.646100   D=   58.96765   DMASS=  0.236572E-09
FL=   .000000017   VL=   590.679325    TS=   455.465426   D=   79.01241   DMASS=  0.569126E-09
FL=   .000000002   VL=   577.670307    TS=   457.560062   D=   99.01758   DMASS=  0.112011E-08
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X=   31.005321  YDUCT=  4.227821  MG=       .641624    PO=   2075.5456   TO=    474.879208
DX=  .007000000 A(X) =  56.1543   A(X)/A0=  .07358     REL HUM. %=     130.020404

CV=  .000572235  VG=  661.724706  TG=  438.113004  P=  1571.42   FLtot=  .000109299
FL=  .000006243  VL=  659.985981  TS=  439.351409  D=  6.11524   DMASS=  0.263853E-12
FL=  .000037583  VL=  655.385438  TS=  440.850182  D=  12.59396  DMASS=  0.230467E-11
FL=  .000035757  VL=  650.481290  TS=  442.379580  D=  18.14277  DMASS=  0.689022E-11
FL=  .000023684  VL=  640.854824  TS=  445.305570  D=  28.61210  DMASS=  0.270254E-10
FL=  .000004147  VL=  631.867891  TS=  447.882863  D=  38.81167  DMASS=  0.674543E-10
FL=  .000001694  VL=  623.512197  TS=  450.080953  D=  48.91157  DMASS=  0.135007E-09
FL=  .000000172  VL=  615.690225  TS=  451.940936  D=  58.96629  DMASS=  0.236556E-09
FL=  .000000017  VL=  601.328504  TS=  454.862390  D=  79.01063  DMASS=  0.569087E-09
FL=  .000000002  VL=  588.308004  TS=  457.035317  D=  99.01547  DMASS=  0.112004E-08

X=   31.502321  YDUCT=  4.208571  MG=       .652643    PO=   2075.5411   TO=    474.882650
DX=  .007000000 A(X) =  55.6441   A(X)/A0=  .07291     REL HUM. %=     136.924224

CV=  .000572224  VG=  672.198726  TG=  436.940215  P=  1556.94   FLtot=  .000109310
FL=  .000006248  VL=  670.444588  TS=  438.306391  D=  6.11686   DMASS=  0.264064E-12
FL=  .000037588  VL=  665.796525  TS=  439.844795  D=  12.59459  DMASS=  0.230502E-11
FL=  .000035758  VL=  660.865891  TS=  441.409751  D=  18.14301  DMASS=  0.689049E-11
FL=  .000023683  VL=  651.208704  TS=  444.407399  D=  28.61183  DMASS=  0.270246E-10
FL=  .000004147  VL=  642.204088  TS=  447.056858  D=  38.81102  DMASS=  0.674509E-10
FL=  .000001694  VL=  633.837988  TS=  449.322369  D=  48.91061  DMASS=  0.134999E-09
FL=  .000000172  VL=  626.009021  TS=  451.242943  D=  58.96506  DMASS=  0.236541E-09
FL=  .000000017  VL=  611.634749  TS=  454.264982  D=  79.00898  DMASS=  0.569052E-09
FL=  .000000002  VL=  598.597070  TS=  456.515201  D=  99.01349  DMASS=  0.111997E-08

X=   32.006321  YDUCT=  4.190821  MG=       .663305    PO=   2075.5365   TO=    474.886139
DX=  .007000000 A(X) =  55.1757   A(X)/A0=  .07230     REL HUM. %=     144.081356

CV=  .000572209  VG=  682.293765  TG=  435.792367  P=  1542.86   FLtot=  .000109324
FL=  .000006254  VL=  680.617356  TS=  437.256172  D=  6.11877   DMASS=  0.264311E-12
FL=  .000037595  VL=  676.062864  TS=  438.827004  D=  12.59540  DMASS=  0.230546E-11
FL=  .000035760  VL=  671.155089  TS=  440.427279  D=  18.14338  DMASS=  0.689092E-11
FL=  .000023683  VL=  661.497365  TS=  443.496781  D=  28.61168  DMASS=  0.270242E-10
FL=  .000004147  VL=  652.482517  TS=  446.218508  D=  38.81048  DMASS=  0.674481E-10
FL=  .000001694  VL=  644.107180  TS=  448.551732  D=  48.90974  DMASS=  0.134992E-09
FL=  .000000172  VL=  636.270395  TS=  450.533334  D=  58.96393  DMASS=  0.236528E-09
FL=  .000000017  VL=  621.880996  TS=  453.656993  D=  79.00741  DMASS=  0.569018E-09
FL=  .000000002  VL=  608.824469  TS=  455.985534  D=  99.01159  DMASS=  0.111990E-08

X=   32.503321  YDUCT=  4.175681  MG=       .672823    PO=   2075.5321   TO=    474.889406
DX=  .007000000 A(X) =  54.7778   A(X)/A0=  .07178     REL HUM. %=     150.896891

CV=  .000572192  VG=  691.271653  TG=  434.757133  P=  1530.24   FLtot=  .000109342
FL=  .000006260  VL=  689.751387  TS=  436.275209  D=  6.12088   DMASS=  0.264584E-12
FL=  .000037604  VL=  685.473163  TS=  437.849954  D=  12.59633  DMASS=  0.230597E-11
FL=  .000035763  VL=  680.713102  TS=  439.476698  D=  18.14388  DMASS=  0.689149E-11
FL=  .000023682  VL=  671.182255  TS=  442.609915  D=  28.61164  DMASS=  0.270241E-10
FL=  .000004147  VL=  662.218051  TS=  445.399106  D=  38.81005  DMASS=  0.674458E-10
FL=  .000001694  VL=  653.868448  TS=  447.796736  D=  48.90900  DMASS=  0.134986E-09
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FL=   .000000172  VL=   646.046505   TS=   449.836958  D=  58.96292  DMASS= 0.236515E-09
FL=   .000000017  VL=   631.670135   TS=   453.059011  D=  79.00597  DMASS= 0.568987E-09
FL=   .000000002  VL=   618.612563   TS=   455.463879  D=  99.00982  DMASS= 0.111984E-08

X=   33.000321   YDUCT=   4.163013   MG=   .681117   PO=  2075.5279   TO=  474.892388
DX=   .007000000 A(X)=   54.4459   A(X)/A0=   .07134  REL HUM. %=  157.187553

CV=   .000572172  VG=   699.069554   TG=  433.846968  P=  1519.20   FLtot=   .000109362
FL=   .000006267  VL=   697.748833   TS=   435.384559  D=   6.12317  DMASS= 0.264881E-12
FL=   .000037613  VL=   693.870302   TS=   436.926322  D=  12.59738  DMASS= 0.230655E-11
FL=   .000035767  VL=   689.382301   TS=   438.564549  D=  18.14448  DMASS= 0.689217E-11
FL=   .000023683  VL=   680.145158   TS=   441.747903  D=  28.61171  DMASS= 0.270243E-10
FL=   .000004147  VL=   671.328224   TS=   444.597494  D=  38.80974  DMASS= 0.674442E-10
FL=   .000001694  VL=   663.066592   TS=   447.055113  D=  48.90837  DMASS= 0.134981E-09
FL=   .000000172  VL=   655.303160   TS=   449.150976  D=  58.96202  DMASS= 0.236505E-09
FL=   .000000017  VL=   640.997971   TS=   452.467772  D=  79.00464  DMASS= 0.568958E-09
FL=   .000000002  VL=   627.977419   TS=   454.946926  D=  99.00815  DMASS= 0.111979E-08

X=   33.504321   YDUCT=   4.153004   MG=   .687901   PO=  2075.5242   TO=  474.894957
DX=   .007000000 A(X)=   54.1844   A(X)/A0=   .07100  REL HUM. %=  162.590335

CV=   .000572149  VG=   705.429941   TG=  433.097055  P=  1510.15   FLtot=   .000109384
FL=   .000006275  VL=   704.379989   TS=   434.609558  D=   6.12564  DMASS= 0.265202E-12
FL=   .000037624  VL=   701.067875   TS=   436.072761  D=  12.59855  DMASS= 0.230719E-11
FL=   .000035771  VL=   696.991854   TS=   437.701065  D=  18.14519  DMASS= 0.689298E-11
FL=   .000023683  VL=   688.245747   TS=   440.914812  D=  28.61187  DMASS= 0.270247E-10
FL=   .000004147  VL=   679.700571   TS=   443.814949  D=  38.80951  DMASS= 0.674430E-10
FL=   .000001694  VL=   671.612120   TS=   446.326649  D=  48.90784  DMASS= 0.134976E-09
FL=   .000000172  VL=   663.969670   TS=   448.474306  D=  58.96122  DMASS= 0.236495E-09
FL=   .000000017  VL=   649.822369   TS=   451.881348  D=  79.00340  DMASS= 0.568931E-09
FL=   .000000002  VL=   636.897424   TS=   454.432434  D=  99.00657  DMASS= 0.111973E-08

X=   34.001321   YDUCT=   4.145995   MG=   .692781   PO=  2075.5212   TO=  474.896927
DX=   .007000000 A(X)=   54.0017   A(X)/A0=   .07076  REL HUM. %=  166.625047

CV=   .000572125  VG=   709.994735   TG=  432.554726  P=  1503.63   FLtot=   .000109408
FL=   .000006283  VL=   709.254261   TS=   434.002968  D=   6.12818  DMASS= 0.265532E-12
FL=   .000037635  VL=   706.633266   TS=   435.340610  D=  12.59977  DMASS= 0.230787E-11
FL=   .000035775  VL=   703.097914   TS=   436.932803  D=  18.14595  DMASS= 0.689385E-11
FL=   .000023684  VL=   695.037561   TS=   440.150257  D=  28.61211  DMASS= 0.270254E-10
FL=   .000004147  VL=   686.894858   TS=   443.086242  D=  38.80939  DMASS= 0.674424E-10
FL=   .000001694  VL=   679.073259   TS=   445.642333  D=  48.90741  DMASS= 0.134973E-09
FL=   .000000172  VL=   671.622911   TS=   447.834860  D=  58.96053  DMASS= 0.236487E-09
FL=   .000000017  VL=   657.735914   TS=   451.322935  D=  79.00229  DMASS= 0.568907E-09
FL=   .000000002  VL=   644.978283   TS=   453.940185  D=  99.00513  DMASS= 0.111968E-08

X=   34.505321   YDUCT=   4.142291   MG=   .695406   PO=  2075.5191   TO=  474.898149
DX=   .007000000 A(X)=   53.9053   A(X)/A0=   .07063  REL HUM. %=  168.844664

CV=   .000572100  VG=   712.446682   TG=  432.262115  P=  1500.12   FLtot=   .000109433
FL=   .000006291  VL=   712.092135   TS=   433.589626  D=   6.13081  DMASS= 0.265874E-12
FL=   .000037646  VL=   710.400697   TS=   434.741555  D=  12.60105  DMASS= 0.230857E-11
FL=   .000035780  VL=   707.595902   TS=   436.264587  D=  18.14678  DMASS= 0.689479E-11
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FL=   .000023684   VL=   700.473695   TS=   439.452174   D=  28.61243   DMASS=  0.270263E-10
FL=   .000004147   VL=   692.894514   TS=   442.406292   D=  38.80934   DMASS=  0.674421E-10
FL=   .000001694   VL=   685.454715   TS=   444.995656   D=  48.90706   DMASS=  0.134970E-09
FL=   .000000172   VL=   678.284421   TS=   447.225460   D=  58.95993   DMASS=  0.236479E-09
FL=   .000000017   VL=   664.786181   TS=   450.785024   D=  79.00127   DMASS=  0.568885E-09
FL=   .000000002   VL=   652.287180   TS=   453.462865   D=  99.00378   DMASS=  0.111964E-08

X=    35.002321    YDUCT=  4.140999   MG=        .696329   PO=  2075.5179    TO=   474.898767
DX=   .007000000   A(X)=   53.8716    A(X)/A0=   .07059    REL HUM. %=   169.627466

CV=   .000572075   VG=   713.307912   TG=   432.159283   P=   1498.88   FLtot=   .000109458
FL=   .000006299   VL=   713.221453   TS=   433.374607   D=   6.13340   DMASS=  0.266211E-12
FL=   .000037657   VL=   712.365575   TS=   434.304917   D=  12.60232   DMASS=  0.230926E-11
FL=   .000035785   VL=   710.366129   TS=   435.729353   D=  18.14761   DMASS=  0.689574E-11
FL=   .000023685   VL=   704.350944   TS=   438.852854   D=  28.61279   DMASS=  0.270273E-10
FL=   .000004147   VL=   697.458916   TS=   441.805023   D=  38.80936   DMASS=  0.674423E-10
FL=   .000001694   VL=   690.494370   TS=   444.414086   D=  48.90681   DMASS=  0.134968E-09
FL=   .000000172   VL=   683.678649   TS=   446.671311   D=  58.95944   DMASS=  0.236474E-09
FL=   .000000017   VL=   670.682994   TS=   450.289048   D=  79.00038   DMASS=  0.568866E-09
FL=   .000000002   VL=   658.527330   TS=   453.019006   D=  99.00256   DMASS=  0.111960E-08

X=    35.506321    YDUCT=  4.141512   MG=        .695960   PO=  2075.5172    TO=   474.898919
DX=   .007000000   A(X)=   53.8850    A(X)/A0=   .07061    REL HUM. %=   169.300693

CV=   .000572050   VG=   712.964492   TG=   432.200702   P=   1499.37   FLtot=   .000109483
FL=   .000006307   VL=   713.081749   TS=   433.312997   D=   6.13600   DMASS=  0.266550E-12
FL=   .000037669   VL=   712.952415   TS=   434.009767   D=  12.60356   DMASS=  0.230995E-11
FL=   .000035790   VL=   711.758638   TS=   435.310196   D=  18.14845   DMASS=  0.689670E-11
FL=   .000023686   VL=   706.945811   TS=   438.337685   D=  28.61318   DMASS=  0.270284E-10
FL=   .000004147   VL=   700.829729   TS=   441.268716   D=  38.80944   DMASS=  0.674427E-10
FL=   .000001694   VL=   694.413515   TS=   443.884619   D=  48.90662   DMASS=  0.134966E-09
FL=   .000000172   VL=   688.013968   TS=   446.160096   D=  58.95902   DMASS=  0.236469E-09
FL=   .000000017   VL=   675.620436   TS=   449.823960   D=  78.99957   DMASS=  0.568849E-09
FL=   .000000002   VL=   663.886142   TS=   452.598647   D=  99.00144   DMASS=  0.111956E-08

X=    36.003321    YDUCT=  4.143008   MG=        .694893   PO=  2075.5171    TO=   474.898801
DX=   .007000000   A(X)=   53.9239    A(X)/A0=   .07066    REL HUM. %=   168.377039

CV=   .000572025   VG=   711.968545   TG=   432.320146   P=   1500.80   FLtot=   .000109508
FL=   .000006315   VL=   712.179722   TS=   433.360950   D=   6.13861   DMASS=  0.266890E-12
FL=   .000037680   VL=   712.552073   TS=   433.828129   D=  12.60480   DMASS=  0.231063E-11
FL=   .000035795   VL=   712.080574   TS=   435.011677   D=  18.14923   DMASS=  0.689759E-11
FL=   .000023687   VL=   708.437747   TS=   437.916704   D=  28.61358   DMASS=  0.270296E-10
FL=   .000004147   VL=   703.111101   TS=   440.810139   D=  38.80956   DMASS=  0.674433E-10
FL=   .000001694   VL=   697.264917   TS=   443.420926   D=  48.90650   DMASS=  0.134965E-09
FL=   .000000172   VL=   691.305403   TS=   445.705580   D=  58.95868   DMASS=  0.236464E-09
FL=   .000000017   VL=   679.561484   TS=   449.402813   D=  78.99887   DMASS=  0.568834E-09
FL=   .000000002   VL=   668.292353   TS=   452.213821   D=  99.00044   DMASS=  0.111953E-08

X=    36.500321    YDUCT=  4.144623   MG=        .693752   PO=  2075.5145    TO=   474.900330
DX=   .007000000   A(X)=   53.9660    A(X)/A0=   .07071    REL HUM. %=   167.432146

CV=   .000572169   VG=   710.903867   TG=   432.449312   P=   1502.33   FLtot=   .000109364
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  FL=   .000006323   VL=   711.105286   TS=   433.462180  D=   6.14122   DMASS=  0.267231E-12
  FL=   .000037691   VL=   711.663720   TS=   433.727839  D=  12.60611   DMASS=  0.231135E-11
 FLM=   .000035668  VLM=   711.720251  TSM=   492.000000 DM=  18.56372   DMASS=  0.689246E-11
 FLM=   .000023651  VLM=   709.247766  TSM=   492.000000 DM=  29.18043   DMASS=  0.270209E-10
  FL=   .000004147   VL=   704.618111   TS=   440.413440  D=  38.80971   DMASS=  0.674441E-10
  FL=   .000001694   VL=   699.335050   TS=   443.009400  D=  48.90643   DMASS=  0.134965E-09
  FL=   .000000172   VL=   693.818235   TS=   445.295824  D=  58.95841   DMASS=  0.236461E-09
  FL=   .000000017   VL=   682.741590   TS=   449.015989  D=  78.99825   DMASS=  0.568820E-09
  FL=   .000000002   VL=   671.961265   TS=   451.856450  D=  98.99953   DMASS=  0.111949E-08

  X=   37.004321    YDUCT=   4.146003    MG=       .692783   PO=  2075.5117    TO=   474.902081
 DX=    .007000000  A(X)=   54.0019    A(X)/A0=    .07076   REL HUM. %=   166.643317

  CV=   .000572329   VG=   710.000484   TG=   432.559215  P=   1503.62    FLtot=   .000109204
  FL=   .000006331   VL=   710.147072   TS=   433.572388  D=   6.14385   DMASS=  0.267574E-12
  FL=   .000037704   VL=   710.688986   TS=   433.689324  D=  12.60745   DMASS=  0.231209E-11
 FLM=   .000035526  VLM=   711.014084  TSM=   492.000000 DM=  18.61089   DMASS=  0.688670E-11
 FLM=   .000023612  VLM=   709.550546  TSM=   492.000000 DM=  29.21153   DMASS=  0.270115E-10
  FL=   .000004147   VL=   705.609773   TS=   440.063329  D=  38.80988   DMASS=  0.674450E-10
  FL=   .000001694   VL=   700.864203   TS=   442.636804  D=  48.90639   DMASS=  0.134964E-09
  FL=   .000000172   VL=   695.778449   TS=   444.919172  D=  58.95818   DMASS=  0.236458E-09
  FL=   .000000017   VL=   685.365647   TS=   448.654061  D=  78.99769   DMASS=  0.568808E-09
  FL=   .000000002   VL=   675.082785   TS=   451.518608  D=  98.99869   DMASS=  0.111947E-08

  X=   37.501321    YDUCT=   4.146187    MG=       .692660   PO=  2075.5087    TO=   474.904059
 DX=    .007000000  A(X)=   54.0067    A(X)/A0=    .07077   REL HUM. %=   166.568518

  CV=   .000572486   VG=   709.886670   TG=   432.574819  P=   1503.78    FLtot=   .000109047
  FL=   .000006339   VL=   709.888497   TS=   433.636318  D=   6.14637   DMASS=  0.267904E-12
  FL=   .000037715   VL=   710.123388   TS=   433.679486  D=  12.60875   DMASS=  0.231280E-11
 FLM=   .000035389  VLM=   710.443707  TSM=   492.000000 DM=  18.65670   DMASS=  0.688106E-11
 FLM=   .000023576  VLM=   709.639990  TSM=   492.000000 DM=  29.24004   DMASS=  0.270029E-10
 FLM=   .000004143  VLM=   706.352437  TSM=   492.000000 DM=  39.51378   DMASS=  0.674336E-10
  FL=   .000001694   VL=   702.032771   TS=   442.301697  D=  48.90638   DMASS=  0.134964E-09
  FL=   .000000172   VL=   697.338793   TS=   444.576628  D=  58.95800   DMASS=  0.236456E-09
  FL=   .000000017   VL=   687.543584   TS=   448.320475  D=  78.99719   DMASS=  0.568797E-09
  FL=   .000000002   VL=   677.734367   TS=   451.204719  D=  98.99792   DMASS=  0.111944E-08

  X=   38.005321    YDUCT=   4.146000    MG=       .692797   PO=  2075.5059    TO=   474.905894
 DX=    .007000000  A(X)=   54.0018    A(X)/A0=    .07076   REL HUM. %=   166.781018

  CV=   .000572871   VG=   710.016227   TG=   432.561175  P=   1503.60    FLtot=   .000108662
  FL=   .000006347   VL=   709.987269   TS=   433.651218  D=   6.14891   DMASS=  0.268235E-12
  FL=   .000037727   VL=   710.003625   TS=   433.673068  D=  12.61002   DMASS=  0.231350E-11
 FLI=   .000035025  VLI=   710.194488  TSI=   475.261419 DI=  18.60569   DMASS=  0.681442E-11
 FLM=   .000023540  VLM=   709.716611  TSM=   492.000000 DM=  29.26873   DMASS=  0.269942E-10
 FLM=   .000004139  VLM=   706.978261  TSM=   492.000000 DM=  39.54103   DMASS=  0.674185E-10
  FL=   .000001694   VL=   703.033115   TS=   441.984310  D=  48.90640   DMASS=  0.134965E-09
  FL=   .000000172   VL=   698.696002   TS=   444.250202  D=  58.95785   DMASS=  0.236454E-09
  FL=   .000000017   VL=   689.477453   TS=   447.999920  D=  78.99673   DMASS=  0.568787E-09
  FL=   .000000002   VL=   680.120811   TS=   450.901454  D=  98.99720   DMASS=  0.111942E-08

  X=   38.502321    YDUCT=   4.146000    MG=       .692801   PO=  2075.5038    TO=   474.907283
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 DX=   .007000000  A(X)=   54.0018   A(X)/A0=   .07076  REL HUM. %=  166.804816

 CV=   .000572981   VG=   710.020877   TG=  432.562016  P=  1503.59  FLtot=   .000108552
 FL=   .000006355   VL=   710.019874   TS=  433.652079  D=   6.15139  DMASS= 0.268561E-12
 FL=   .000037737   VL=   710.014585   TS=  433.667365  D=  12.61123  DMASS= 0.231417E-11
FLI=   .000034936  VLI=   710.108359  TSI=  466.635660 DI=  18.58992  DMASS= 0.679711E-11
FLM=   .000023504  VLM=   709.791484  TSM=  492.000000 DM=  29.29697  DMASS= 0.269856E-10
FLM=   .000004135  VLM=   707.490671  TSM=  492.000000 DM=  39.56726  DMASS= 0.674040E-10
 FL=   .000001694   VL=   703.879425   TS=  441.690457  D=  48.90644  DMASS= 0.134965E-09
 FL=   .000000172   VL=   699.858889   TS=  443.946339  D=  58.95772  DMASS= 0.236453E-09
 FL=   .000000017   VL=   691.163458   TS=  447.699286  D=  78.99632  DMASS= 0.568778E-09
 FL=   .000000002   VL=   682.225918   TS=  450.615642  D=  98.99654  DMASS= 0.111939E-08

 X=   39.006321  YDUCT=   4.146000   MG=   .692804   PO=  2075.5020   TO=  474.908515
 DX=   .007000000  A(X)=   54.0018   A(X)/A0=   .07076  REL HUM. %=  166.812549

 CV=   .000573033   VG=   710.024898   TG=  432.562773  P=  1503.58  FLtot=   .000108500
 FL=   .000006362   VL=   710.024158   TS=  433.653164  D=   6.15391  DMASS= 0.268890E-12
 FL=   .000037749   VL=   710.020825   TS=  433.663494  D=  12.61247  DMASS= 0.231485E-11
FLI=   .000034906  VLI=   710.066651  TSI=  460.929042 DI=  18.58459  DMASS= 0.679126E-11
FLM=   .000023468  VLM=   709.849308  TSM=  492.000000 DM=  29.32525  DMASS= 0.269770E-10
FLM=   .000004131  VLM=   707.914045  TSM=  492.000000 DM=  39.59319  DMASS= 0.673896E-10
FLM=   .000001693  VLM=   704.658976  TSM=  492.000000 DM=  49.74205  DMASS= 0.134950E-09
 FL=   .000000172   VL=   700.882051   TS=  443.655263  D=  58.95762  DMASS= 0.236452E-09
 FL=   .000000017   VL=   692.676548   TS=  447.409067  D=  78.99594  DMASS= 0.568770E-09
 FL=   .000000002   VL=   684.138603   TS=  450.338372  D=  98.99591  DMASS= 0.111937E-08

 X=   39.503321  YDUCT=   4.146000   MG=   .692813   PO=  2075.4970   TO=  474.911780
 DX=   .007000000  A(X)=   54.0018   A(X)/A0=   .07076  REL HUM. %=  166.863990

 CV=   .000573276   VG=   710.035790   TG=  432.564754  P=  1503.57  FLtot=   .000108256
 FL=   .000006370   VL=   710.033289   TS=  433.654795  D=   6.15639  DMASS= 0.269216E-12
FLM=   .000037547  VLM=   710.028366  TSM=  492.000000 DM=  12.92658  DMASS= 0.231237E-11
FLI=   .000034896  VLI=   710.049115  TSI=  456.725282 DI=  18.58287  DMASS= 0.678938E-11
FLM=   .000023433  VLM=   709.893695  TSM=  492.000000 DM=  29.35287  DMASS= 0.269686E-10
FLM=   .000004127  VLM=   708.256994  TSM=  492.000000 DM=  39.61819  DMASS= 0.673757E-10
FLM=   .000001692  VLM=   705.330263  TSM=  492.000000 DM=  49.76587  DMASS= 0.134929E-09
 FL=   .000000172   VL=   701.763142   TS=  443.383436  D=  58.95755  DMASS= 0.236451E-09
 FL=   .000000017   VL=   694.004302   TS=  447.136039  D=  78.99559  DMASS= 0.568763E-09
 FL=   .000000002   VL=   685.836604   TS=  450.076304  D=  98.99533  DMASS= 0.111935E-08

 X=   40.000321  YDUCT=   4.146000   MG=   .692824   PO=  2075.4912   TO=  474.915581
 DX=   .007000000  A(X)=   54.0018   A(X)/A0=   .07076  REL HUM. %=  166.987665

 CV=   .000573778   VG=   710.048966   TG=  432.567007  P=  1503.55  FLtot=   .000107754
 FL=   .000006378   VL=   710.046373   TS=  433.657924  D=   6.15887  DMASS= 0.269542E-12
FLI=   .000037078  VLI=   710.040018  TSI=  481.096710 DI=  12.94241  DMASS= 0.229370E-11
FLI=   .000034896  VLI=   710.046205  TSI=  453.412512 DI=  18.58273  DMASS= 0.678923E-11
FLM=   .000023399  VLM=   709.930259  TSM=  492.000000 DM=  29.38027  DMASS= 0.269602E-10
FLM=   .000004123  VLM=   708.541968  TSM=  492.000000 DM=  39.64268  DMASS= 0.673621E-10
FLM=   .000001690  VLM=   705.905220  TSM=  492.000000 DM=  49.78911  DMASS= 0.134908E-09
 FL=   .000000172   VL=   702.538347   TS=  443.125333  D=  58.95749  DMASS= 0.236450E-09
 FL=   .000000017   VL=   695.193171   TS=  446.874976  D=  78.99527  DMASS= 0.568756E-09
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  FL=   .000000002   VL=   687.373442   TS=   449.824616   D=  98.99478   DMASS=  0.111933E-08

  X=   40.504321   YDUCT=   4.146000   MG=   .692832   PO=  2075.4870   TO=   474.918309
 DX=    .007000000 A(X)=    54.0018   A(X)/A0=   .07076   REL HUM. %=   167.042370

  CV=   .000574021   VG=   710.058161   TG=   432.568653   P=   1503.54   FLtot=   .000107510
  FL=   .000006386   VL=   710.056619   TS=   433.661644   D=    6.16140  DMASS=  0.269873E-12
 FLI=   .000036862  VLI=   710.051209  TSI=   463.030942  DI=   12.91728  DMASS=  0.228037E-11
 FLI=   .000034899  VLI=   710.050128  TSI=   450.652106  DI=   18.58343  DMASS=  0.678999E-11
 FLM=   .000023364  VLM=   709.960999  TSM=   492.000000  DM=   29.40787  DMASS=  0.269518E-10
 FLM=   .000004119  VLM=   708.783055  TSM=   492.000000  DM=   39.66706  DMASS=  0.673485E-10
 FLM=   .000001689  VLM=   706.406871  TSM=   492.000000  DM=   49.81216  DMASS=  0.134888E-09
 FLM=   .000000172  VLM=   703.241922  TSM=   492.000000  DM=   59.90716  DMASS=  0.236445E-09
  FL=   .000000017   VL=   696.276525   TS=   446.621481   D=   78.99498  DMASS=  0.568749E-09
  FL=   .000000002   VL=   688.788427   TS=   449.579182   D=   98.99426  DMASS=  0.111932E-08

  X=   41.001321   YDUCT=   4.146000   MG=   .692837   PO=  2075.4840   TO=   474.920345
 DX=    .007000000 A(X)=    54.0018   A(X)/A0=   .07076   REL HUM. %=   167.066847

  CV=   .000574147   VG=   710.064893   TG=   432.569894   P=   1503.53   FLtot=   .000107384
  FL=   .000006393   VL=   710.063660   TS=   433.663970   D=    6.16388  DMASS=  0.270200E-12
 FLI=   .000036842  VLI=   710.059453  TSI=   454.556689  DI=   12.91487  DMASS=  0.227909E-11
 FLI=   .000034906  VLI=   710.055731  TSI=   448.382057  DI=   18.58461  DMASS=  0.679129E-11
 FLI=   .000023249  VLI=   709.985329  TSI=   485.917090  DI=   29.38161  DMASS=  0.268360E-10
 FLM=   .000004115  VLM=   708.981849  TSM=   492.000000  DM=   39.69067  DMASS=  0.673354E-10
 FLM=   .000001688  VLM=   706.834234  TSM=   492.000000  DM=   49.83441  DMASS=  0.134869E-09
 FLM=   .000000172  VLM=   703.901028  TSM=   492.000000  DM=   59.92873  DMASS=  0.236418E-09
  FL=   .000000017   VL=   697.240015   TS=   446.381715   D=   78.99471  DMASS=  0.568744E-09
  FL=   .000000002   VL=   690.059482   TS=   449.346094   D=   98.99378  DMASS=  0.111930E-08

  X=   41.505321   YDUCT=   4.146000   MG=   .692842   PO=  2075.4815   TO=   474.921968
 DX=    .007000000 A(X)=    54.0018   A(X)/A0=   .07076   REL HUM. %=   167.078832

  CV=   .000574222   VG=   710.070200   TG=   432.570889   P=   1503.52   FLtot=   .000107309
  FL=   .000006401   VL=   710.069262   TS=   433.665735   D=    6.16640  DMASS=  0.270532E-12
 FLI=   .000036851  VLI=   710.065951  TSI=   449.003101  DI=   12.91597  DMASS=  0.227967E-11
 FLI=   .000034915  VLI=   710.061545  TSI=   446.449778  DI=   18.58613  DMASS=  0.679295E-11
 FLI=   .000023154  VLI=   710.005269  TSI=   478.379477  DI=   29.34137  DMASS=  0.267259E-10
 FLM=   .000004111  VLM=   709.150976  TSM=   492.000000  DM=   39.71423  DMASS=  0.673222E-10
 FLM=   .000001687  VLM=   707.210226  TSM=   492.000000  DM=   49.85653  DMASS=  0.134849E-09
 FLM=   .000000172  VLM=   704.490881  TSM=   492.000000  DM=   59.95015  DMASS=  0.236391E-09
  FL=   .000000017   VL=   698.124376   TS=   446.148151   D=   78.99447  DMASS=  0.568738E-09
  FL=   .000000002   VL=   691.237420   TS=   449.118147   D=   98.99332  DMASS=  0.111928E-08

  X=   42.002321   YDUCT=   4.146000   MG=   .692845   PO=  2075.4796   TO=   474.923269
 DX=    .007000000 A(X)=    54.0018   A(X)/A0=   .07076   REL HUM. %=   167.075000

  CV=   .000574236   VG=   710.074350   TG=   432.571698   P=   1503.51   FLtot=   .000107295
  FL=   .000006409   VL=   710.073592   TS=   433.666898   D=    6.16889  DMASS=  0.270859E-12
 FLI=   .000036870  VLI=   710.070952  TSI=   445.218521  DI=   12.91816  DMASS=  0.228084E-11
 FLI=   .000034924  VLI=   710.066723  TSI=   444.842182  DI=   18.58782  DMASS=  0.679481E-11
 FLI=   .000023109  VLI=   710.021266  TSI=   473.598760  DI=   29.32233  DMASS=  0.266739E-10
 FLM=   .000004107  VLM=   709.291269  TSM=   492.000000  DM=   39.73711  DMASS=  0.673094E-10
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 FLM=  .000001686  VLM=  707.533085  TSM=  492.000000  DM=  49.87793  DMASS= 0.134830E-09
 FLM=  .000000171  VLM=  705.006203  TSM=  492.000000  DM=  59.97084  DMASS= 0.236364E-09
  FL=  .000000017   VL=  698.916283   TS=  445.926598   D=  78.99424  DMASS= 0.568734E-09
  FL=  .000000002   VL=  692.302069   TS=  448.901107   D=  98.99290  DMASS= 0.111927E-08

  X=  42.506321   YDUCT=  4.146000   MG=  .692848   PO=  2075.4780   TO=  474.924373
 DX=  .007000000  A(X)=  54.0018   A(X)/A0=  .07076   REL HUM. %=  167.065382

  CV=  .000574226   VG=  710.077821   TG=  432.572390   P=  1503.51  FLtot=  .000107305
  FL=  .000006417   VL=  710.077191   TS=  433.667703   D=   6.17140  DMASS= 0.271190E-12
 FLI=  .000036893  VLI=  710.075031  TSI=  442.494262  DI=  12.92086  DMASS= 0.228226E-11
 FLI=  .000034935  VLI=  710.071268  TSI=  443.460998  DI=  18.58968  DMASS= 0.679685E-11
 FLI=  .000023082  VLI=  710.034446  TSI=  469.918543  DI=  29.31111  DMASS= 0.266433E-10
 FLM=  .000004104  VLM=  709.411269  TSM=  492.000000  DM=  39.75999  DMASS= 0.672966E-10
 FLM=  .000001685  VLM=  707.819185  TSM=  492.000000  DM=  49.89926  DMASS= 0.134811E-09
 FLM=  .000000171  VLM=  705.470890  TSM=  492.000000  DM=  59.99142  DMASS= 0.236338E-09
  FL=  .000000017   VL=  699.647770   TS=  445.710199   D=  78.99404  DMASS= 0.568729E-09
  FL=  .000000002   VL=  693.294384   TS=  448.688343   D=  98.99249  DMASS= 0.111926E-08

  X=  43.003321   YDUCT=  4.146000   MG=  .692850   PO=  2075.4766   TO=  474.925305
 DX=  .007000000  A(X)=  54.0018   A(X)/A0=  .07076   REL HUM. %=  167.053266

  CV=  .000574204   VG=  710.080719   TG=  432.572977   P=  1503.50  FLtot=  .000107327
  FL=  .000006424   VL=  710.080180   TS=  433.668271   D=   6.17388  DMASS= 0.271517E-12
 FLI=  .000036918  VLI=  710.078362  TSI=  440.562893  DI=  12.92375  DMASS= 0.228380E-11
 FLI=  .000034946  VLI=  710.075099  TSI=  442.303454  DI=  18.59161  DMASS= 0.679896E-11
 FLI=  .000023066  VLI=  710.045036  TSI=  466.955664  DI=  29.30415  DMASS= 0.266244E-10
 FLM=  .000004100  VLM=  709.511318  TSM=  492.000000  DM=  39.78226  DMASS= 0.672842E-10
 FLM=  .000001684  VLM=  708.066488  TSM=  492.000000  DM=  49.91994  DMASS= 0.134793E-09
 FLM=  .000000171  VLM=  705.879711  TSM=  492.000000  DM=  60.01134  DMASS= 0.236313E-09
  FL=  .000000017   VL=  700.306667   TS=  445.504421   D=  78.99385  DMASS= 0.568725E-09
  FL=  .000000002   VL=  694.196074   TS=  448.485310   D=  98.99211  DMASS= 0.111924E-08

  X=  43.500321   YDUCT=  4.146000   MG=  .692852   PO=  2075.4754   TO=  474.926118
 DX=  .007000000  A(X)=  54.0018   A(X)/A0=  .07076   REL HUM. %=  167.039767

  CV=  .000574174   VG=  710.083226   TG=  432.573492   P=  1503.50  FLtot=  .000107357
  FL=  .000006432   VL=  710.082757   TS=  433.668693   D=   6.17636  DMASS= 0.271844E-12
 FLI=  .000036944  VLI=  710.081194  TSI=  439.160726  DI=  12.92676  DMASS= 0.228539E-11
 FLI=  .000034957  VLI=  710.078382  TSI=  441.316072  DI=  18.59361  DMASS= 0.680116E-11
 FLI=  .000023055  VLI=  710.053721  TSI=  464.433611  DI=  29.29957  DMASS= 0.266119E-10
 FLM=  .000004096  VLM=  709.596200  TSM=  492.000000  DM=  39.80427  DMASS= 0.672718E-10
 FLM=  .000001683  VLM=  708.284097  TSM=  492.000000  DM=  49.94030  DMASS= 0.134775E-09
 FLM=  .000000171  VLM=  706.245863  TSM=  492.000000  DM=  60.03092  DMASS= 0.236288E-09
  FL=  .000000017   VL=  700.910510   TS=  445.305721   D=  78.99368  DMASS= 0.568721E-09
  FL=  .000000002   VL=  695.029431   TS=  448.288597   D=  98.99174  DMASS= 0.111923E-08

  X=  44.004321   YDUCT=  4.146000   MG=  .692854   PO=  2075.4743   TO=  474.926850
 DX=  .007000000  A(X)=  54.0018   A(X)/A0=  .07076   REL HUM. %=  167.025267

  CV=  .000574140   VG=  710.085465   TG=  432.573957   P=  1503.50  FLtot=  .000107391
  FL=  .000006440   VL=  710.085049   TS=  433.669019   D=   6.17887  DMASS= 0.272176E-12
 FLI=  .000036970  VLI=  710.083683  TSI=  438.125888  DI=  12.92990  DMASS= 0.228706E-11
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FLI=  .000034969   VLI=  710.081255   TSI=  440.461213  DI=  18.59569  DMASS= 0.680344E-11
FLI=  .000023047   VLI=  710.060979   TSI=  462.203336  DI=  29.29648  DMASS= 0.266035E-10
FLM=  .000004093   VLM=  709.669300   TSM=  492.000000  DM=  39.82633  DMASS= 0.672594E-10
FLM=  .000001682   VLM=  708.478619   TSM=  492.000000  DM=  49.96063  DMASS= 0.134757E-09
FLM=  .000000171   VLM=  706.579112   TSM=  492.000000  DM=  60.05046  DMASS= 0.236263E-09
 FL=  .000000017    VL=  701.472745    TS=  445.111002   D=  78.99352  DMASS= 0.568718E-09
 FL=  .000000002    VL=  695.811821    TS=  448.095187   D=  98.99140  DMASS= 0.111922E-08

 X=  44.501321   YDUCT=  4.146000    MG=  .692856    PO=  2075.4734   TO=  474.927501
DX=  .007000000  A(X)=  54.0018  A(X)/A0=  .07076  REL HUM. %=  167.010482

 CV=  .000574103    VG=  710.087439    TG=  432.574373   P=  1503.49   FLtot=  .000107428
 FL=  .000006448    VL=  710.087066    TS=  433.669269   D=   6.18134  DMASS= 0.272503E-12
FLI=  .000036997   VLI=  710.085849   TSI=  437.381129  DI=  12.93304  DMASS= 0.228872E-11
FLI=  .000034980   VLI=  710.083729   TSI=  439.740404  DI=  18.59778  DMASS= 0.680574E-11
FLI=  .000023043   VLI=  710.066919   TSI=  460.252731  DI=  29.29448  DMASS= 0.265980E-10
FLM=  .000004089   VLM=  709.730633   TSM=  492.000000  DM=  39.84786  DMASS= 0.672473E-10
FLM=  .000001680   VLM=  708.648113   TSM=  492.000000  DM=  49.98041  DMASS= 0.134740E-09
FLM=  .000000171   VLM=  706.874816   TSM=  492.000000  DM=  60.06941  DMASS= 0.236239E-09
FLM=  .000000017   VLM=  701.990386   TSM=  492.000000  DM=  80.18404  DMASS= 0.568708E-09
 FL=  .000000002    VL=  696.527604    TS=  447.910110   D=  98.99107  DMASS= 0.111921E-08

 X=  45.005321   YDUCT=  4.146000    MG=  .692857    PO=  2075.4725   TO=  474.928105
DX=  .007000000  A(X)=  54.0018  A(X)/A0=  .07076  REL HUM. %=  166.995176

 CV=  .000574063    VG=  710.089257    TG=  432.574759   P=  1503.49   FLtot=  .000107468
 FL=  .000006456    VL=  710.088916    TS=  433.669468   D=   6.18385  DMASS= 0.272835E-12
FLI=  .000037025   VLI=  710.087819   TSI=  436.828635  DI=  12.93625  DMASS= 0.229043E-11
FLI=  .000034993   VLI=  710.085949   TSI=  439.114539  DI=  18.59993  DMASS= 0.680810E-11
FLI=  .000023040   VLI=  710.071960   TSI=  458.477023  DI=  29.29319  DMASS= 0.265945E-10
FLM=  .000004086   VLM=  709.783653   TSM=  492.000000  DM=  39.86948  DMASS= 0.672352E-10
FLM=  .000001679   VLM=  708.800338   TSM=  492.000000  DM=  50.00020  DMASS= 0.134722E-09
FLM=  .000000171   VLM=  707.145317   TSM=  492.000000  DM=  60.08834  DMASS= 0.236214E-09
FLM=  .000000017   VLM=  702.505136   TSM=  492.000000  DM=  80.20226  DMASS= 0.568666E-09
 FL=  .000000002    VL=  697.202389    TS=  447.727836   D=  98.99076  DMASS= 0.111920E-08

 X=  45.502321   YDUCT=  4.146000    MG=  .692859    PO=  2075.4717   TO=  474.928655
DX=  .007000000  A(X)=  54.0018  A(X)/A0=  .07076  REL HUM. %=  166.979880

 CV=  .000574022    VG=  710.090904    TG=  432.575112   P=  1503.49   FLtot=  .000107509
 FL=  .000006463    VL=  710.090589    TS=  433.669623   D=   6.18632  DMASS= 0.273162E-12
FLI=  .000037052   VLI=  710.089585   TSI=  436.429566  DI=  12.93944  DMASS= 0.229212E-11
FLI=  .000035005   VLI=  710.087912   TSI=  438.585577  DI=  18.60208  DMASS= 0.681045E-11
FLI=  .000023038   VLI=  710.076157   TSI=  456.891278  DI=  29.29246  DMASS= 0.265925E-10
FLM=  .000004082   VLM=  709.828297   TSM=  492.000000  DM=  39.89061  DMASS= 0.672233E-10
FLM=  .000001678   VLM=  708.933554   TSM=  492.000000  DM=  50.01946  DMASS= 0.134705E-09
FLM=  .000000171   VLM=  707.386474   TSM=  492.000000  DM=  60.10675  DMASS= 0.236191E-09
FLM=  .000000017   VLM=  702.971786   TSM=  492.000000  DM=  80.21994  DMASS= 0.568626E-09
 FL=  .000000002    VL=  697.822131    TS=  447.553142   D=  98.99047  DMASS= 0.111919E-08
```