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THE TEMPERATURE OF THIN FOILS IN ION BEAMS

J. O. Liljenzin

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June 1973

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THE TEMPERATURE OF THIN FOILS IN ION BEAMS

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June 1973

ABSTRACT

The effect of beam-shape, pulsed operation and ion type on the temperature of thin foils in ion beams is discussed for cases where the cooling is by heat radiation, heat conduction, or convection in an external medium. Analytic solutions are given for various combinations of beam shape and cooling conditions. Nomographs are given for the estimation of the maximum temperature of thin circular foils when the cooling is either by radiation to the surroundings or by conduction to the edge of the foil. A program is described which can be used to calculate the temperature distribution at equilibrium conditions or as a function of time for arbitrarily shaped non-isotropic and non-homogeneous bodies heated internally and cooled by any combination of radiation, conduction, or convection of heat in an external gaseous medium. The heat conductivity, heat capacity, heat generation, and grayness can vary within the body; the heat conductivity and heat capacity can vary with temperature; and the heat-generation can be pulsed. Cooling by a liquid streaming on the backside of the foil is generally most effective. Radiative cooling is also dominant for very thin foils, and conduction cooling is dominant for thick foils. At a given diameter, this leads to a maximum temperature for foils with a thickness a little below the range of the ions.

THE TEMPERATURE OF THIN FOILS IN ION BEAMS

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Thin foils are used in ion beams for stripping of the ions, degradation of beam energy, as vacuum seals, and as beam-transparent targets. Homogenous foils, made from a single substance, are used for all of the mentioned purposes. Targets are, however, often made in two layers, a backing which gives mechanical strength and impermeability for gases and a layer of the target substance which can be much thinner than the backing and lack mechanical strength.

When the beam passes through the foil it loses part of its energy by interaction with the atoms in the foil. The major part of the energy transferred from the beam to the foil occurs as heat, which must be removed to prevent the target from melting or evaporating (see Fig. 12).

1. <u>CALCULATION OF THE TOTAL AMOUNT OF</u> BEAM ENERGY LOST IN A FOIL

For sufficiently thin foils the electronic stopping power, $^1 -dE/dl$, can be assumed constant. The energy transferred to the foil per unit time, P_{tot} , can then be calculated from the relation,

$$P_{tot} \approx \ell \left(-\frac{dE}{d\ell}\right) I / Z_{eff}, \qquad (1)$$

where l is the foil thickness, I the electric beam current and Z_{eff} the mean electric charge of the ions.

The electronic stopping power is no longer constant for thicker foils. The energy transferred to the foil must then be calculated from the range variation with energy.¹ Let E_0 and $R(E_0)$ be the energy and range in the foil material of the incident ions, E_0 and $R(E_0)$ the energy and range of the ions after passing a layer of foil material of thickness l. The residual range, $R(E_{d})$ is computed from

$$R(E_{\ell}) = R(E_{\ell}) - \ell, \qquad (2)$$

which gives E_{l} , and then P_{tot} can be calculated from

$$P_{tot} = (E_0 - E_{\ell}) \cdot I / Z_{eff}, \qquad (3)$$

where I/Z_{eff} is the "particle current."

Equation (2) is most conveniently solved in a graph of R vs E, where E_{ρ} then can be read off on the energy scale.

2. COOLING METHODS

The heat evolved in the target can be removed by many different mechanisms, some of which are probably without interest in practical applications, i.e., removal by vaporization of the foil material, or by melting of the foil. The most useful cooling methods are cooling by heat radiation, cooling by heat conduction, and cooling by convection in an external fluid medium.

2.1. Radiation Cooling

When the foil surface is at a temperature, T_{surf} , which is higher than the surroundings (which are at a temperature T_{sur}), the foil will radiate away heat with a rate per unit surface area, P_{rad} , given by Stefan's law.

$$p_{rad} = g \delta (T_{surf}^4 - T_{sur}^4),$$

(4)

where T_{surf} and T_{sur} are in degrees K, δ has the value $5.70 \times 10^{-12} (W \text{ cm}^{-2} \text{ degree}^{-4})$ and g is the grayness factor as compared to a black body ($0 < g \le 1$). The grayness factors for some common materials are listed in Table I.

2.2. Conduction Cooling

When an internal volume element of the foil is at a different temperature than its surroundings, heat will flow in a direction as to eliminate the temperature differences.

$$p_{cond} = \left\{ \frac{d(\lambda_{x} \quad \frac{dT}{dx})}{dx} + \frac{d(\lambda_{y} \quad \frac{dT}{dy})}{dy} + \frac{d(\lambda_{\ell} \quad \frac{dT}{d\ell})}{d\ell} \right\} dV,$$
(5)

where P_{cond} is the heat conduction rate; λ_x , λ_y and λ_l are the heat conductivities in the x, y, and l direction respectively; dV is the volume element dx dy dl. Constant values for the heat conductivities (λ) can only be used in a small temperature range. For larger temperature ranges an approximation with the following equation can be used:

$$\lambda_{i} = a_{i} - b_{i} \cdot T + c_{i} \cdot T^{-2}.$$
 (6)

Fortunately most materials are isotropic, i.e., $\lambda_x = \lambda_y = \lambda_l$. Values of a, b, and c in Eq. 6 are given in Table II for some common materials.

2.3. Convection Cooling

The effect of convection cooling is highly dependent on the heat transfer between the foil and the cooling medium. This is usually expressed as a film-transfer coefficient h defined by

$$P_{conv} = h (T_{surf} - T_{fluid}), \qquad (7)$$

where p_{conv} is the heat transfer rate per unit surface (wall area), h is the film transfer coefficient, T_{surf} is the foil surface temperature, and T_{fluid} is the fluid phase (gas or liquid) bulk temperature.

The calculation of the heat removed by convection cooling is now transformed to a problem to calculate the film-transfer coefficient (h). This is usually solved by the application of dimensional theory to relate the actual problem to another well-investigated case for which an empirical equation is available.

The dimensionless numbers of interest when scaling and comparing film-transfer coefficients are: Reynolds number (Re), Nusselts number (Nu), and Grashofs number (Gr).² For large streaming velocities (Re \geq 2100) with turbulent flow the value of Gr is no longer important for calculating the film-transfer coefficient.

The main problem is to find the comparable case. As a rough approximation, the foil can be thought of as a part of the wall in a circular tube. Then the following equation can be used² at low velocities and laminar flow

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(Re < 2100):

Nu =
$$1.62 \sqrt[3]{\mu/\mu_f} (1 + 0.015 \sqrt[3]{Gr}) \sqrt[3]{\frac{4 \text{ w C}_p}{\pi \lambda_{\text{fluid}} D}},$$

where Nu and Gr are

Nu =
$$h \cdot D/\lambda_{\text{fluid}}$$
, (8a)
Gr = $D^3 \rho^2 \beta g (T_{\text{surf}} - T_{\text{fluid}})$, (8b)

where μ is the viscosity of fluid at the bulk temperature, μ_f is the viscosity of the fluid at the film mean temperature, and w is the flow rate (mass per time). D is a characteristic length (the diameter), λ_{fluid} is the heat conductivity of the fluid, ρ is the density of the fluid, β is the volume expansion coefficient, g the gravity constant, and C_p is the heat capacity of the fluid. The Grashof number reflects the increased flow due to the heating of the fluid at the surface.

For water streaming upwards, the simpler equation

h =
$$(2.685 T_{water} + 51.62) \sqrt[3]{T_{surf} - T_{water}} \cdot 10^{-4}$$
 (9)

can be used instead of (8).² Here T is in degrees centrigrade and h is in $W/cm^2 \circ C$.

When the streaming velocity of the fluid is so high that turbulent flow occurs, $\text{Re} > 10\,000$, the following equation is valid for all fluids streaming upwards in a pipe:²

For liquids with $\mu \leq 2 \text{ cP}$ and for gases with $w \geq 600 \text{ p}^{2/3}$ (where p is in atm), Eq. (10) can be used almost down to Re = 2100; w should be calculated as kg/hour. In case of a downward flow, the corresponding empirical equation is²

where $\Pr = C_p \mu / \lambda$.

2.4. Combined Cooling

In practice, the cooling method used is some combination of radiation cooling, conduction cooling, and convection cooling. Sometimes, depending on geometry, surface area, gas pressure, and foil temperature, one of these processes may dominate over the others. To be able to treat realistic cases, all the mentioned cooling processes must be included in the final differential equation. Assuming that heat radiation is only lost in the l direction and that the eventual surrounding fluid passes by the foil in an x-y plane, the rate of heat loss by cooling, p_{cool} , can be written

$$P_{cool} = dV \left[\frac{ng\delta}{d\ell} \left(T^4 - T_{sur}^4 \right) + \frac{d(\lambda_x \frac{dT}{dx}}{dx} + \frac{d(\lambda_y \frac{dT}{dy}}{dy} + \frac{d(\lambda_\ell \frac{dT}{d\ell}}{d\ell} + \frac{nh}{d\ell} \left(T - T_{fluid} \right) \right].$$
(12)

Some of the "constants" (i.e., λ 's and h) are in turn functions of T and some (n and g) may be functions of x, y, and l.

3. BEAM SHAPE AND TIME FUNCTION

The shape of the beam, i.e., the variation in beam intensity with x and y on the foil, is of great importance for the temperature distribution over the foil and thus for the maximum temperature that will occur at a given total beam current. The variation of beam current with time is also important when the cooling time-constant is less than or comparable to the frequency of the beam-current variations. Of the many possible variations of beam current with time, only two will be discussed: continuous beam and pulsed beam with fixed frequency. All beams will be assumed to be circular symmetric.

3.1. Uniform Beam Shape

The beam is hitting the foil with the same intensity at all points of the surface. The power released on an area dA (= dxdy) is then

$$P_{beam} = P_{tot} dA/A,$$
 (13)

where A is the total exposed area of the foil.

When the beam is pulsed with a frequency f and a duty cycle of C percent,

$$t_{on} = 0.01 C/f,$$
 (14)

$$t_{\rm off} = (1-0.01 \,{\rm C})/{\rm f},$$
 (15)

where t_{on} is the ontime and t_{off} is the off time of each cycle.

The current during t_{on} must now be larger than in the stationary case to give the same mean current, I:

$$I_{on} = 100 I/C,$$
 (16a)
 $I_{off} = 0.0.$ (16b)

Thus in a pulsed beam,

$$P_{\text{beam, on}} = 100 P_{\text{tot}} dA/(AC), \qquad (17a)$$

 $p_{beam, off} = 0.0.$ (17a)

Tilting the foil against the beam will increase the total area A with a factor $1/\sin(\phi)$, where ϕ is the angle between the foil and the beam, and thus decrease P_{beam} .

3.2. Gaussian Beam Shape

The beam is hitting the foil with an intensity distribution (current distribution)

$$p(r) = k \cdot e^{-(r/s)^2},$$
 (18)

where r is the distance from the center of the beam, k is a proportionality constant and s is a shape factor: larger s, more diffuse beam; smaller s, more focused beam.

The total power dissipated within a radius R is P(R)

$$P(R) = 2\pi k \int_{r=0}^{R} r e^{-(r/s)^{2}} dr = \pi k s^{2} [1 - e^{-(R/s)^{2}}], \qquad (19)$$

where k is a proportionality constant between surface and power. The total power of the beam must be dissipated for $R = \infty$, thus

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$$P(\infty) = P_{tot} = \pi k s^{2}$$
(20)

and hence

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$$P(R) = P_{tot} [1 - e^{-(R/s)^2}].$$
 (21)

When a fraction, a, of the total beam is known to hit the foil within a certain radius, R_{a} , s² can be obtained from the equation

$$s^{2} = -\frac{R_{a}^{2}}{\ln(1-a)}.$$
 (22)

Thus the Gaussian beam is defined by its total energy, P_{tot}, and a fraction, a, of P_{tot} hitting within a radius R_a.

The proportionality constant k is then

$$k = - \frac{P_{tot} \ln (1 - a)}{\pi R_a^2} .$$
 (23)

The beam hitting a unit surface area is now

$$p_{\text{beam}}(\mathbf{r}) = -\frac{P_{\text{tot}} \ln (1-\alpha)}{\pi R_{\alpha}^{2}} e^{-\mathbf{r}^{2} \sqrt{-\ln (1-\alpha)} / R_{\alpha}^{2}}.$$
 (24)

In the case of a pulsed beam defined by Eqs. (16a) and (16b) we obtain

$$p(r)_{\text{beam, on}} = -\frac{100 P_{\text{tot}} \ln(1-\alpha)}{\pi C R_{\alpha}^2} e^{-r^2 \sqrt{-\ln(1-\alpha)}/R_{\alpha}^2},$$
 (25a)

$$p(r)$$
 beam, off = 0.0. (25b)

When the beam passing through the foil, P_{tr} , is used instead of P_{tot} , the term $-P_{tot} \ln (1-a)$ should be replaced by $-P_{tr} \ln (1-a)/a$ in all equations where it occurs.

3.3. Double-Gaussian Beam Shape

The beam is hitting the foil with an intensity distribution (current distribution)

$$p(\mathbf{r}) = \mathbf{k} \cdot \mathbf{e}$$
(26)

where k is a proportionality constant as before and \overline{R} is the radius at which the beam intensity is highest.

The total power dissipated within a radius R is P(R):

$$P(R) = 2\pi k \int_{0}^{R} re^{-\left(\frac{r-\overline{R}}{s}\right)^{2}} = \pi k s^{2} \left[e^{-\left(\frac{R}{s}\right)^{2}} - e^{-\left(\frac{R-\overline{R}}{s}\right)^{2}} \right] + \pi^{3/2} k s \overline{R} \left[erf\left(\frac{R}{s}\right) + erf\left(\frac{R-\overline{R}}{s}\right) \right], \quad (27)$$

where erf is the error function. As before, the total power of the beam must be dissipated for $R = \infty$, thus

$$P(\infty) = P_{tot} = \pi k s^{2} e^{-(\frac{R}{s})} + \pi^{3/2} k s \overline{R} \left[erf(\frac{R}{s}) + 1 \right]$$
(28)

and thus

$$P(R) = \frac{P_{tot}}{\left[e^{-\left(\frac{\overline{R}}{s}\right)^{2}} + \sqrt{\pi} \left[erf(\frac{\overline{R}}{s}) + 1\right]}} \left\{ s \left[e^{-\left(\frac{\overline{R}}{s}\right)^{2}} - e^{-\left(\frac{R-\overline{R}}{s}\right)^{2}}\right] + \sqrt{\pi} \overline{R} \left[erf(\frac{\overline{R}}{s}) - erf(\frac{R-\overline{R}}{s})\right] \right\}$$

$$(29)$$

is obtained with

$$k = \frac{P_{tot}}{\pi s^2 e^{-(\frac{\overline{R}}{s})^2} + \pi^{3/2} s \overline{R}[erf(\frac{\overline{R}}{s}) + 1]}$$
(30)

With this value for k the beam shape is

$$p(\mathbf{r})_{\text{beam}} = \frac{P_{\text{tot}}}{\pi s^2 e^{-\left(\frac{\overline{R}}{s}\right)^2} + \pi^{3/2} s \overline{R} \left[\text{erf}(\frac{\overline{R}}{s}) + 1 \right]} e^{-\left(\frac{\mathbf{r} - \overline{R}}{s}\right)^2}.$$
 (31)

To determine s and \overline{R} , two further values of P(R) must be given, but \overline{R} will probably be defined by other conditions and hence already be known. The spread s can then be obtained from any other known condition, e.g., P(0) known or $P(\overline{R})$ known. Transcendental equations are generally obtained of such a form that they must be solved by numerical methods.

As before, the beam at pulsed operation is given by the two states:

$$p(\mathbf{r})_{\text{beam; on}} = \frac{100 P_{\text{tot}}}{\left(\frac{\overline{R}}{s}\right)^2 + \sqrt{\pi} \overline{R} \left[\operatorname{erf} \left(\frac{\overline{R}}{s}\right) + 1 \right) \right]} e^{-\left(\frac{\mathbf{r} - \overline{R}}{s}\right)^2}, \quad (32a)$$

$$p(r)_{beam, off} = 0.0.$$

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4. THE FOIL TEMPERATURE

The foil temperature is given by the differential equation

$$p_{beam} - p_{cool} = \rho \cdot dV \cdot C_p \frac{dT}{dt}$$
, (33)

(32b)

where p_{beam} is given by any suitable beam shape and time function, and p_{cool} is given by Eq. (12).

No general solution to Eq. (33) is known, but for some combination of beam shape and cooling type special solutions can be obtained.

4.1. Radiation Cooling Dominates

Introducing polar coordinates, we obtain the equation

$$p_{\text{beam}} = n\delta g \left[T_{(r,t)}^{4} - T_{sur}^{4} \right] = d\ell \rho C_p \frac{dT_{(r,t)}}{dt} .$$
 (34)

4.1.1. Uniform beam shape

In this case Eqs. (34) and (13) give

$$\frac{P_{tot}}{\pi R^2} - n\delta g T(r,t)^4 + n\delta g T_{sur}^4 = d\ell \rho C_p \frac{dT(r,t)}{dt}.$$
(35)

The steady-state solution is obtained when dT(r, t)/dt = 0,

$$T(\mathbf{r},\infty) = \sqrt[4]{T_{sur}^4 + \frac{P_{tot}}{n \, \delta g \, \pi R^2}}$$
(36)

where n is the number of radiating surfaces. As can be seen, $T(r,\infty)$ in Eq. (36) is independent of r, so the surface will have the same temperature all over.³

When the beam is pulsed, however, the heat capacity of the foil will decrease the maximum temperature and increase the minimum temperature. The two differential equations valid during heating (t_{on}) and cooling (t_{off}) are

$$\frac{100 P_{tot}}{C \pi R^2} + n \delta g T_{sur}^4 - n \delta g T(r,t)^4 = d\ell \rho C_p \frac{dT(r,t)}{dt}$$
(37a)
for $\frac{m}{f} \le t \le \frac{m}{f} + t_{on}$ where $m = 0, 1, 2, 3, \text{ etc.}$

and

$$n \delta g T_{sur}^{4} - n \delta g T(r, t)^{4} = d \ell \rho C_{p} \frac{dT(r, t)}{dt}$$
(37b)

for
$$\frac{m}{f} + t_{on} \le t \le \frac{m+1}{f}$$
.

As C_p is a function of T very similar to Eq. (6),

$$C_{p} \approx a + bT + cT^{-2}.$$
 (38)

The exact solutions of Eqs. (37a) and (37b) are quite complicated functions of T. However, the third term in Eq. (38) is only important at very low temperatures where the radiation cooling is negligible in comparison with conduction and convection. Thus a linear dependence of C_p on T is sufficient. The solution is independent of r and can be written as follows:

$$t - t_{0} = \frac{1}{4B^{3}} \left\{ A \ln \frac{[B+T(t)][B-T(t_{0})]}{[B-T(t)][B+T(t_{0})]} + 2A \arctan \frac{B[T(t) - T(t_{0})]}{B^{2} + T(t)T(t_{0})} + D \ln \frac{[B^{2} + T(t)^{2}][B^{2} - T(t_{0})^{2}]}{[B^{2} - T(t)^{2}][B^{2} + T(t_{0})^{2}]} \right\},$$
(39)

where
$$B = \sqrt{\frac{100 P_{tot}}{C\pi R^2 n \delta g} + T_{sur}^4}$$
 with $P_{tot} = 0$ for
 $\frac{m}{f} + t_{on} \le t \le \frac{m+1}{f}$, $A = d\ell \rho a/(n \delta g)$, and

 $D = dl\rho b/(n\delta g)$. Figure 1 shows the temperature calculated for a frequency of 40 Hz and a typical foil. Similar results are given in Refs. 3 and 4, which however, consider C_p as a constant independent of T.

4.1.2. Gaussian beam shape

Equations (34) and (24) give

$$\frac{P_{\text{tot}}\ln(1-\alpha)}{\pi R_{\alpha}^{2}}e^{-\frac{r^{2}\sqrt{-\ln(1-\alpha)}}{R_{\alpha}^{2}}}-n\delta g T(r,t)^{4}+n\delta g T_{\text{sur}}^{4}=d\ell\rho C_{p}\frac{dT(r,t)}{dt}.$$
(40)

Obviously the temperature in the center of the beam will determine the behavior of the foil. A specialization of Eq. (40) to the hottest spot on the target gives for a continuous beam

$$\frac{P_{tot}\ln(1-\alpha)}{\pi R_{\alpha}^{2}} - n\delta g T_{max}^{4} + n\delta g T_{sur}^{4} = 0.$$
(41)

The solution of Eq. (41) can be written as follows:

$$T_{\max} = \sqrt[4]{-\frac{P_{tot}\ln(1-\alpha)}{\pi R_{\alpha}^2 n \delta g} + T_{sur}^4}.$$
 (42)

A comparison with Eq. (36), valid for uniform beam shape, shows that T_{max} for the Gaussian beam shape is higher. When T_{sur}^4 is negligible, $T_{max}/T(r,\infty) \approx \sqrt[4]{-\ln(1-\alpha)}$ is obtained. So, the smaller the utilized part of the Gaussian beam is, the cooler is the foil, approaching $T(r,\infty)$ as a goes to zero. Figure 2 shows the variation of $T_{max}/T(r,\infty)$ with a at equal transmitted beam intensities.

When a pulsed beam is used, the equation for the highest temperature T(0,t) is

$$-\frac{100 P_{tot} \ln(1-a)}{C\pi R_a^2} - n \, \delta g \, T(0,t)^4 + n \, \delta g \, T_{sur}^4 = d \, \ell \rho \, C_p \, \frac{d T(0,t)}{dt} \,. \tag{43}$$

Equation (39) is a solution to Eq. 43 with

$$B = \sqrt{\frac{4}{-\frac{100 P_{tot} \ln(1-\alpha)}{C_{\pi}R_{\alpha}^2 n \delta g} + T_{sur}^4} \text{ for } \frac{m}{f} \le t \le \frac{m}{f} + t_{on},$$

B = 0 for
$$\frac{m}{f} + t_{on} \le t \le \frac{m+1}{f}$$
, A = dlpa/(n \delta g) and

 $D = d\ell \rho b/n\delta g$. About the same shapes as shown in Fig. 1 are thus obtained. Some deviation occur at beam intensities where T_{sur}^4 is important in the calculation of B.

4.1.3. Double-Gaussian beam shape

The differential equation for radiation cooling at a double-Gaussian beam shape is obtained from Eqs. (34) and (31).

$$\frac{-\left(\frac{\mathbf{r}-\overline{\mathbf{R}}}{\mathbf{s}}\right)^{2}}{\frac{P_{\text{tot e}}}{\pi \mathbf{s}^{2} \mathbf{e}^{-\left(\frac{\overline{\mathbf{R}}}{\mathbf{s}}\right)^{2}} + \pi^{3/2} \mathbf{s} \,\overline{\mathbf{R}}[\operatorname{erf}(\frac{\overline{\mathbf{R}}}{\mathbf{s}}) + 1]} - n \,\delta g \left[\,\mathbf{T}(\mathbf{r},t)^{4} - \mathbf{T}_{sur}^{4} \right] = d \,\ell \,\rho \,C_{p} \,\frac{d \,\mathbf{T}(\mathbf{r},t)}{dt}.$$
 (44)

The steady-state solution to Eq. (44) is

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$$T(\mathbf{r},\infty) = \sqrt{T_{sur}^{4} + \frac{P_{tot} e^{-(\frac{\mathbf{r}-\overline{R}}{s})^{2}}}{n\delta g(\pi s^{2} e^{-(\frac{\overline{R}}{s})^{2}} + \pi^{3/2} s \overline{R} (erf(\frac{\overline{R}}{s}) + 1))}}.$$
(45)

In this case the highest temperature will occur at $r = \overline{R}$.

$$T(\overline{R},\infty) = \sqrt{\begin{array}{c} T_{sur}^{4} + \frac{P_{tot}}{n \delta g(\pi s^{2} e^{-\frac{(\overline{R}}{s})} + \pi^{3/2} s \overline{R}[erf(\frac{R}{s}) + 1)]} \end{array}}$$
(46)

Numerical calculations showed that $T_{\max} < T(\overline{R}, \infty) < T(0, \infty)$ holds for all investigated cases, as can intuitively be understood from the fact that the maximal intensity for a given beam is less for a double-Gaussian shape than for a Gaussian shape, but larger than for a uniform beam.

4.1.4. Calculation of the maximum temperature

Determination of the maximum temperature when radiation cooling dominated is a worst-case calculation, as there always will be some conduction cooling and often even some convection cooling. The result is presented as a nomogram, see Fig. 3, from which T_{max} can be estimated for various foilthicknesses, ions, foil materials, foil diameters, beam shapes, beam current, and duty-cycles, with the assumption of 7.5 MeV/amu initial beam energy and a 40-Hz repetition rate. It should be observed that the evaporation rate at reduced pressure, rather than the melting point, limits the highest temperature at which the foils can be operated in vacuum. As the variation of T_{max} with the duty cycle is moderate, only 0.63% and 100% duty-cycle is shown in Fig. 3, and all other values fall in between these limits.

4.2. Conduction Cooling Dominates

The equation for heat conduction in a thin circular disc is, expressed in polar coordinates with constant λ ,⁵

$$\frac{d^2 T(r,t)}{dr^2} + \frac{1}{r} \frac{dT(r,t)}{dr} - \frac{\rho C_p}{\lambda} \frac{dT(r,t)}{dt} + \frac{p_{beam}}{\lambda d\ell} = 0, \qquad (47)$$

where dl is the thickness of the foil and p_{beam} is any beam-shape function.

4.2.1. Uniform beam shape

The introduction of the uniform beam shape, as given by Eq. (13), into Eq. (47) gives

$$\frac{\mathrm{d}^{2}\mathrm{T}(\mathbf{r},t)}{\mathrm{d}r^{2}} + \frac{1}{r} \frac{\mathrm{d}\mathrm{T}(\mathbf{r},t)}{\mathrm{d}r} - \frac{\rho^{C}p}{\lambda} \frac{\mathrm{d}\mathrm{T}(\mathbf{r},t)}{\mathrm{d}t} + \frac{P_{\mathrm{tot}}}{\pi R^{2}\lambda \mathrm{d}\ell} = 0.$$
(48)

The steady-state solution, $T(r, \infty)$, is obtained by setting the time derivative to zero and solving the resulting differential equation with the boundary conditions $dT(0,\infty)/dr = 0$ and $T(a,\infty) = T_{sur}$. Assuming λ to be constant, the solution is then

$$T(r,\infty) = T_{sur} + \frac{P_{tot}}{4\pi\lambda d\ell} [1 - (\frac{r}{R})^2], \qquad (49)$$

where R is the radius of the foil and T_{sur} is the temperature at the cooled edge. It is evident from Eq. (49) that the temperature of a foil of given thickness is not dependent on the size of the foil. This is easily understood as the nearest distance from a point on the foil to the edge increases linearly with R and at the same time the cross section increases linearly with R. These two effects compensate each other, which makes the temperature independent of the absolute size.

As often high and low temperatures occur on the same foil, the heat conductivity cannot be assumed to be constant. The most common approximation for $\lambda(T)$ is Eq. (6), where a, b, and c are constants obtained by fitting Eq. (6) to experimental data.

When the heat conductivity varies it must be included in the second derivative of T. This gives Eq. (48) the following form:⁵

$$\frac{1}{r} \frac{\partial}{\partial r} \left\{ \lambda [T(r,t)] r \frac{\partial T(r,t)}{\partial t} \right\} \sim \rho C_{p} \frac{\partial T(r,t)}{\partial t} + \frac{P_{tot}}{\pi R^{2} d\ell} = 0.$$
(50)

Introduction of Eq. (6) into Eq. (50) and taking the partial derivatives as indicated yields

$$\frac{\partial^{2} T(\mathbf{r}, t)}{\partial \mathbf{r}^{2}} + \frac{1}{\mathbf{r}} \frac{\partial T(\mathbf{r}, t)}{\partial \mathbf{r}} - \frac{b + 2 c T(\mathbf{r}, t)^{-3}}{a - b T(\mathbf{r}, t) + c T(\mathbf{r}, t)^{2}} \left[\frac{\partial T(\mathbf{r}, t)}{\partial \mathbf{r}}\right]^{2} - \rho C_{p} \frac{\partial T(\mathbf{r}, t)}{\partial t} + \frac{P_{tot}}{\pi R_{d}^{2} \ell} = 0.$$
(51)

The solution at 100% duty cycle and long times is obtained by setting the time derivative to zero in Eq. (51). The resulting differential equation was solved with a fourth-order Runge-Kutta method. The result is shown in Fig. 4 as a nomograph for Al, Be, and C foils. As can be expected from Eq. (49), the temperature in the center of the foil is independent of the radius of the foil. This was tested by integrating Eq. (51) to various radii. The results showed that the temperature at the center was independent of R.

When a pulsed beam is used the solution to Eq. (48) during the first beam pulse is e^{2}

$$T(\mathbf{r},t) = T_{sur} + \frac{100 P_{tot}}{4\pi \lambda d\ell C} [1 - (\frac{r}{R})^{2}] - \frac{200 P_{tot}}{4\pi d\ell C} \sum_{n=1}^{\infty} e^{-\frac{P_{n}}{R^{2} \rho C_{p}} t} \cdot \frac{J_{0}(\frac{r}{R} \cdot \beta_{n})}{\beta_{n}^{3} J_{1}(\beta_{n})}$$
(52)

where J_0 and J_1 are Bessel functions and β_n are the roots of the equation $J_0(\beta_n) = 0$. The highest temperature will as usual occur at the center of the foil. Equation (52) can then be somewhat simplified as some r terms disappear:

$$T_{\max} = T_{sur} + \frac{100 P_{tot}}{4\pi\lambda d\ell C} - \frac{200 P_{tot}}{\pi\lambda d\ell C} \sum_{n=1}^{\infty} e^{-\frac{\beta_n^2 \lambda}{R^2 \rho C_p}} t_{on} \frac{1}{\beta_n^3 J_1(\beta_n)}.$$
 (53)

Equation (53) shows that the time constant for the heating cycle is determined by $\lambda/(R^2 \rho C_p)$. Thus a smaller foil tends to follow the variations in the beam to a larger extent than a bigger foil. Taking only the first term in the sum in Eq. (53) into account and using C/100 f for t_{on} , we obtain

$$T_{\max} \approx T_{sur} + \frac{100 P_{tot}}{4 \pi \lambda d \ell C} \begin{pmatrix} -\frac{5.783 \lambda C}{R^2 \rho C_p 100 f} \\ 1 - e \end{pmatrix}.$$
(54)

When 100 fR² $\rho C_p/\lambda$ is smaller than 1.25 times C, the foil will already reach its final maximum temperature during the first cycle. This condition has been used to obtain the worst-case temperatures for pulsed beam given in Fig. 4. For larger diameters the value of T_{max} will approach T_{max} for C = 100%. When the beam intensity varies with time only, the following solution to Eq. (47) is obtained, using Laplace transforms and the "faltung" theorem^{5, 6}

$$T(\mathbf{r},t) = T_{sur} + \frac{2\lambda}{\rho C_p R} \int_{0}^{t} Q(\tau) \sum_{n=1}^{\infty} e^{-\frac{\lambda \beta_n^2(t-\tau)}{\rho C_p}} \cdot \frac{J_0(\mathbf{r} \beta_n)}{a_n^{J_1}(R\beta_n)} d\tau, \quad (55)$$

where $Q(\tau)$ is the beam intensity as a function of time and β_n are the roots to the Eq. $J_0(\beta_n) = 0$.

When the beam is pulsed [Eqs. (17a) and (17b)] the integrand is zero during the "off" part of the beam cycle and $Q(\tau)$ is constant during the "on" part of the beam cycle. Thus the integral in Eq. (55) can be replaced by a sum giving the solution

$$T(\mathbf{r}, t) = T_{sur} + \frac{200 P_{tot}}{\pi C \lambda d \ell} \sum_{n=1}^{\infty} \frac{J_0(\frac{r}{R}\beta_n)}{\beta_n^3 J_1(\beta_n)} \left\{ e^{-\frac{\beta_n^2 \lambda t}{\rho C_p R^2}} \left(e^{-\frac{\beta_n^2 C \lambda}{100 \rho C_p f R^2}} -1 \right) \sum_{m=0}^{M} \frac{\beta_n^{-2} \lambda m}{\rho C_p f R^2} + \delta \left[1 - e^{-\frac{\beta_n^2 \lambda}{\rho C_p R^2}} (t - \frac{M+1}{f}) \right] \right\}, \quad (56)$$

where β_n is the solutions to the equation $J_0(\beta_n) = 0$, M is the integer number of complete beam cycles contained within t - (C/100 f), δ is a delta function which has the value 0 when t corresponds to the beam-off part and the value 1 when t corresponds to the beam-on part of the beam cycle. Equation (56) transforms to Eq. (53) for the first beam pulse (M = 0, δ = 0) and to Eq. (49) for C = 100.

It is seen from Eq. (56) that the cooling-off time constants are $\beta_n^2 \lambda / \rho C_p R^2$ and the same as the heating time constants. Figure 5 shows the central temperature as a function of time for some values of C when the time constant is comparable to the frequency. It is obvious that the large increase in λ obtained by cooling the edge to low temperatures will result in more rapid (and larger) temperature fluctuations. The increase in λ can to some degree be compensated by increasing the foil diameter, but this leads easily to such large diameters that the beam shape no longer is uniform. The increase in λ can also be compensated by using a higher frequency. The effect of foil diameter on the center temperature is shown in Fig. 6.

4.2.2. Gaussian beam shape

When the beam has any non-uniform shape, p_{beam} in Eq. (47) will be dependent on r. In the case of a Gaussian beam shape we obtain

$$\frac{\mathrm{d}^{2}\mathrm{T}(\mathbf{r},t)}{\mathrm{d}\mathbf{r}^{2}} + \frac{1}{\mathrm{r}} \frac{\mathrm{d}\mathrm{T}(\mathbf{r},t)}{\mathrm{d}\mathrm{r}} - \frac{\rho C_{\mathrm{p}}}{\lambda} \frac{\mathrm{d}\mathrm{T}(\mathbf{r},t)}{\mathrm{d}\mathrm{t}} - \frac{P_{\mathrm{tot}}\ln(1-\alpha)}{\pi R_{\alpha}^{2} \lambda \mathrm{d}\ell} e = 0. (57)$$

The steady-state solution, $T(r, \infty)$, is obtained by setting the time derivative to zero and solving the resulting differential equation with the boundary conditions $dT(0,\infty)/dr = 0$ and $T(R,\infty) = T_{sur}$. Assuming λ to be constant, the solution is

$$T(\mathbf{r},\infty) = T_{sur} + \frac{P_{tot}\sqrt{-\ln(1-a)}}{4\pi\lambda d\ell} \sum_{n=1}^{\infty} (-1)^{n-1} \frac{[-\ln(1-a)]^{n/2}[1-(\frac{\mathbf{r}}{R})]}{n \cdot n!}, \quad (58)$$

where α is the fraction of the total beam current hitting the foil and P_{tot} is the total power released by the beam. As usual, the highest temperature will occur at the center of the foil (r = 0). By introducing r = 0 in Eq. (58) we obtain the equation for T_{max},

$$T_{\max} = T_{\sup} + \frac{P_{tot}\sqrt{-\ln(1-\alpha)}}{4\pi\lambda d\ell} \sum_{n=1}^{\infty} (-1)^{n-1} \frac{[-\ln(1-\alpha)]^{n/2}}{n \cdot n!}, \quad (59)$$

which is very similar to Eq. (49) with r = 0. Figure 7 shows the shape factor $\psi(a)$ as a function of the transmission factor a.

$$\psi(a) = \sqrt{-\ln(1-a)} \sum_{n=1}^{\infty} (-1)^{n-1} \frac{[-\ln(1-a)]^{n/2}}{n \cdot n!} .$$
 (60)

Using ψ , equation (59) can be written as

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$$\Gamma_{\max} = T_{\sup} + \frac{P_{tot}}{4\pi \lambda d\ell} \cdot \psi(a) . \qquad (61)$$

If the transmitted beam power is used instead of the total beam power, Eq. (61) changes to

$$T_{\max} = T_{\sup} + \frac{P_{tr}}{4\pi\lambda d\ell} \cdot \frac{\psi(a)}{a}.$$
 (62)

The function $\psi(a)/a$ vs a is shown in Fig. 8. A comparison of Figs. 2 and 8 shows that the temperature rises more rapidly with a for conduction cooling than for radiation cooling.

The complete time-dependent solution of Eq. (57) was not obtained because of difficulties with the solution of the new differential equation obtained after Laplace transformation of Eq. (57). An analytical solution for a pulsed Gaussian beam was not obtained for the same reasons. A numerical solution is shown in Fig. 10.

4.2.3. Favorable beam shapes

The uniform beam can be regarded as one in a series of simple rdependent beam shapes of the general type

$$p_{\text{beam}} = \mathbf{k} \cdot \mathbf{r}^{\mathbf{n}}$$
, (63)

where the uniform beam corresponds to n = 0. The total beam power is then given by

$$P_{tot} = \int_{0}^{R} 2\pi k r^{n+1} dr, \qquad (64)$$

from which k can be determined:

$$k = \frac{(n+2) P_{tot}}{2\pi R^{n+2}}, \qquad (65)$$

The steady-state solution of the heat-conduction equation is then

$$T(r,\infty) = T_0 + \frac{P_{tot}}{2(n+2) \pi \lambda d\ell} \left[1 - \left(\frac{r}{R}\right)^{2+n}\right],$$
 (66)

where n = 0, 1, 2, 3 etc.

It can be seen from Eq. (66) that the maximum temperature decreases as n increases. When T_0 can be neglected, the following relations are obtained between the temperatures:

$$T_{\max}(n) = \frac{2}{2+n} T_{\max} \text{ (even-beam)}.$$
 (67)

And thus lower temperature can be obtained by choosing a beam shape which corresponds to a higher value of n in Eq. (63), i.e., by concentrating the beam to a small area near the rim.

4.3. Convection-Cooling Dominates

When convection cooling dominates over radiation cooling and conduction cooling, the amount of heat generated by the beam is equal to the amount of heat carried away by convection from any point on the foil. Thus we obtain the relation (one-sided cooling)

$$p_{\text{beam}} = h \left[T(\mathbf{r}, t) - T_{\text{fluid}} \right] + \rho C_p d\ell \frac{dT(\mathbf{r}, t)}{dt}, \qquad (68)$$

where h is a function of T(r, t), T_{fluid} , w, etc., as given by Eqs.(8),(9), (10), or (11). The resistance to heat flow through the thin foil is neglected. T_{fluid} can be calculated with sufficient accuracy from P_{tot} , w, $(C_p)_{fluid}$, and the entrance temperature of the fluid, T_{fluid}^0 :

$$T_{fluid} \approx T_{fluid}^{0} + \frac{P_{tot}}{w (C_p) fluid}$$
, (69)

where P_{tot} is the total beam power released in the foil and fluid. Analytic solutions to Eq. (68) can usually not be obtained because h is often given by a function containing fractional powers of T(r,t). The stationary state at constant beam can, however, be expressed analytically in some cases.

4.3.1. Water cooling

In the case of laminar flow of water, h is given by Eq. (9). For a uniform beam shape the temperature is almost constant on the foil and is given by the equation

$$T(\mathbf{r}, \infty) = \sqrt[3]{\left\{\frac{P_{tot} \cdot 10^4}{\pi R^2 (2.685 T_w + 51.62)}\right\}^4} + T_w,$$
(70)

where T_w is the water mean temperature. At sufficiently large flow rates $T_w \approx T_w^0$, where T_w^0 is the temperature of the incoming water. As can be seen from Eq. (70), the foil temperature is independent of r. The temperature increases roughly with the 1.33 power of P_{tot} and decreases roughly with the 2.66 power of R.

When the beam shape is Gaussian the temperature is given instead by

$$-\frac{r^{2}}{R_{a}^{2}} \cdot \frac{4}{3} \sqrt{-\ln(1-a)} = e \int_{-\frac{1}{R_{a}^{2}}}^{3} \sqrt{\frac{-\ln(1-a)}{\sqrt{\frac{1}{R_{a}^{2}(2.685 T_{w}^{2}+51.62)}}}} + T_{w}$$
(71)

and $T(r,\infty)$ varies with radius like $a \cdot e^{-br^2} + c$, i.e., in the same manner as the beam shape.

The water cooling is very effective in comparison with radiation cooling or conduction cooling. At a mean water temperature of 300°K, $P_{tot}/\pi R^2 \approx 3.8$ $(k W/cm^2)$ is needed to increase the foil temperature to 373°K. In comparison, a foil temperature of 373°K at pure radiation-cooling is reached for $P_{tot}/\pi R^2 \leq 0.13 (W/cm^2)$. Conduction cooling is more difficult to compare with, as it varies with P_{tot}/dl instead of $P_{tot}/\pi R^2$, but it is usually intermediate in efficiency. At a water temperature of 20°C and a surface temperature of 100°C the heat resistance at the metal-water interface corresponds to 84 cm copper.

4.3.2. Gas cooling

The heat-carrying capacity of gases is less than for water. Hence it is necessary to use large flow rates to obtain a good cooling with gases. When turbulent flow exists, Eq. (10) can be used to calculate the film coefficient, h. Then the foil temperature at uniform beam shape is given by

$$T(r,\infty) = T_{g}^{0} + \frac{P_{tot} + P_{g}}{w(C_{p})_{g}} + \frac{P_{tot}}{\pi R^{2}} \cdot \frac{D}{0.023 \lambda_{g}} \cdot \left(\frac{D V \rho_{g}}{\mu}\right)^{-0.8} \left(\frac{(C_{p})_{g} \mu}{\lambda_{g}}\right)^{-0.4}, \quad (72)$$

where subscript g refers to the gas, V is the linear gas velocity (cm/sec), D is the diameter of the gas channel, and w is the gas flow rate (g/sec). It can be seen that the foil temperature is very nearly inversely proportional to the gas flow rate. The term P_g accounts for the heat generated in the gas during passage of the cooling channel.

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5. NUMERICAL SOLUTION OF THE GENERAL CASE

In practice, the observed beam functions and foil arrangements often deviate from the simple shapes and forms discussed above. It is then necessary to solve Eq. (33) numerically for arbitrary beam shapes, foil geometries, and cooling arrangements. At the same time it is necessary to use temperature-dependent heat conductivities and heat capacities to make a realistic calculation.

A program was thus developed where the only assumptions are: beampower is independent of temperature, radiation can only escape in the ldirection, convection cooling is only possible in the x-y plane, the grayness factors are temperature-independent, and λ and C values can be expressed with sufficient accuracy as second-degree polynomials in T.

A mesh system is set up in the x-y plane which is then reproduced as layers in the l direction. At each mesh-point, the beam power, starting temperature, grayness factor, geometrical connection to adjacent points in the positive coordinate directions, type of polynomials for λ and C_p, and type of point-i.e., internal or boundary-is specified. The mesh width is prescribed for each coordinate separately.

Starting at a corner and proceeding through the whole mesh system, excluding boundary points, the temperature-heat conductivity product is interpolated from the surrounding mesh points by using a second-degree interpolation formula. This results in almost as many linear equations as there are mesh-points. The large number of mesh-points desirable makes normal solution by matrix-inversion impractical. Therefore the Gauss-Siedel iteration method was employed, as then only one equation had to be evaluated at a time. The coefficients were recalculated every time, thus avoiding the storage of large sparse matrices, of the size of about 250 000 elements. The Gauss-Siedel iteration is convergent, as the main diagonal elements are larger than the other elements in each row and the matrix is positive definite.⁶

The power lost by radiation and convection is calculated from the new set of temperatures in the mesh-points and subtracted from the power released from the beam. Then the whole iteration cycle is repeated until a new iteration changes all temperatures with less than a prescribed value.

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The calculation can be performed to obtain a steady-state solution by setting all C_p values to zero or to obtain snapshots at given time intervals with a continuous or pulsed beam.

Symmetry axes can be used freely to reduce the problem as long as the λ values, C values, and grayness factors for mesh-points at a symmetry cut are divided by the appropriate number of used symmetry axes passing through the mesh-point. Values beyond a symmetry axis will then be mirror images of the values before the axis.

For very thin foils, the heat conduction in the l direction is much larger than in the x and y directions. This may cause numerical difficulties which can give a premature halt in the calculations. The simplest cure is to treat such foils as 2-dimensional structures, which is equivalent to neglecting the resistance to heat flow in the l direction as compared to the resistances in the x-y plane. The heat conductivity and heat capacity are automatically multiplied by the actual thickness in a 2-dimensional treatment and by the product of thickness and length in a 1-dimensional case.

For cases where the beam power is small compared to the heat-capacity, it may be necessary to decrease the value of the allowed difference between two successive iterations. On the other hand, high values for the grayness factors seems to increase the convergence rate.

A complete listing of the program is given in Appendix 2. Appendix 3 gives a sample of input data and results. The organization and format of the input data is shown in Appendix 1. The algorithm is slightly modified, as the number of subscripts must be limited to three to be able to use the Fortran compilers available for the CDC-6600 and CDC-7600 computers. This is the reason for the split of the temperature array into two arrays (T and TG) and of the coupling-constant array into three arrays (CX, CY, and CZ) etc.

5.1. Combined Radiation and Conduction Cooling

The variation of temperature with radius and time can be obtained for any given foil, foil-material, ion, beam-shape, frequency, duty-cycle, and mean current with the aid of the program given in Appendix 2. To illustrate the effect of beam-pulsing and beam shape on foil temperature, a halfmil-thick gold foil of 1 cm diameter was chosen. The edge of the foil is clamped to 20°C and the surroundings are assumed to be at 20°C. The foil is surrounded on both sides by vacuum. The ion chosen was 40^{13+} of

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7.2 MeV/amu, which is typical for an Ar beam from the Berkeley SuperHILAC. These ions will release $10.9 \text{ W/}\mu\text{A}$ ($^{40}\text{Ar}^{13+}$) during their passage through a half-mil gold foil.

Figure 9 shows the variation of temperature with radius and time for an incident beam with a uniform shape. The steep increase of temperature near the edge of the foil is typical for the 'uniform beam shape. Figure 10 shows the variation of temperature with radius and time for a Gaussian beam shape. Here the temperature increases more rapidly towards the center, leading to higher maximum temperature. Figure 11 shows the effect of a double-Gaussian beam shape. Typical for this case is the delayed heating of the central part of the foil, leading to a lower maximum temperature than for a simple Gaussian beam shape.

When the foil thickness is decreased, the differential energy-loss $(dE/d\ell)$ of the beam becomes constant. For very thin foils the equilibrium temperature is determined by the radiation cooling, and the foil temperature falls approximately with the fourth root of the thickness, *l*, [see Eq. (36)], as P_{tot} is a linear function of l. For thicker foils, where dE/dl still is constant, the temperature becomes independent of the foil thickness, as the cooling is mainly by conduction. In this case both the beam power and the conduction area vary linearly with the thickness [see Eq. (47)]. When the foil thickness approaches the range of the ions in the foil material, $dE/d\ell$ increases, which leads to an increase in the foil temperature with thickness. When the foil is thicker than the range of the ions, the temperature drops again with increasing thickness-almost linearly at first, as long as the thickness is small compared to the diameter, and then the temperature levels off to a constant value, determined by conduction in the l direction. This temperature is mainly independent of the type of ion and depends almost only on the energy per charge unit, the beam current, and the foil diameter.

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Appendix 1.

Input data for HEAT v4m1 (Always punch the decimal point!)

1. HEADING-CARD (15A4)

Column 1 to 60: Alphanumeric text, which will be used as a heading on printout.

2. BEAM-CARD (8F10.0)

(A blank BEAM-CARD defines END-OF-DATA.)

- 2.1 Beam-Current in μA . Normally as mean particle current.
- 2.2 Beam-Energy-loss in MeV/Grid-unit. (See Grid-point cards!)
- 2.3 Beam-pulse on-time in seconds. (Only for pulsed beam, else 1.0)
- 2.4 Beam-pulse off-time in seconds. (Only for pulsed beam, else 0.0)
- 2.5 <u>Melting temperature</u> in °C. (Default is 10000 °C. Melted material is removed)
- 2.6 <u>Temperature offset</u> in °C. (The offset is <u>added</u> to all grid-pointtemperatures before calculation).
- 2.7 Surrounding radiation temperature in °C. (Default is -273.16 °C)
- 2.8 Grayness factor (Default is 1.0)
- 3. GRID-DIMENSION-CARD (8F10.0)
 - 3.1 Grid-spacing, X-direction, in cm.
 - 3.2 Grid-spacing, Y-direction, in cm.
 - 3.3 Grid-spacing, Z-direction, in cm. (Z is parallel to the beam)
 - 3.4 <u>Grid-spacing</u>, time-direction, in seconds. (Zero implies a steadystate condition)
 - 3.5 Time before full printout, in seconds. (Neglected for steady state)
 - 3.6 Time when calculation stops, in seconds. (Neglected for steady state)

4. COOLING-TYPE-CARD (I5)

4.1 COOLING TYPE

0=VACUUM ON BOTH SIDES IN x-y plane 1=GAS FLOWS ON ONE SIDE, PARALLEL TO THE x-y plane. (Only when cooling-type is 1)

5.1 Hydraulic diameter of cooling channel, in cm.

5.2 Heat conductivity of gas expressed as a Sutherland approximation $(\lambda_{gas} = a T \sqrt{T}/(b+T))$, with T in °K), in W/cm degree. 5.2.1 a.

5.2.2 b.

5.3 Viscosity of gas expressed as a Sutherland approximation

 $[\mu_{gas} = a T \sqrt{T}/(b+T)$, with T in °K], in poise.

5.3.1 a.

5.3.2 b.

5.4 Heat capacity of gas expressed as a polynominal

 $(C_{p_{gas}} = a + bT + c/T^2$, with T in °K), in J/g, degree. 5.4.1 a. 5.4.2 b

5.4.3 c.

5.5 Volume expansion coefficient of gas.

5.6 Flow-rate of gas, in g/sec.

5.7 Entering temperature of gas, in °C.

5.8 Gas pressure in atm.

5.9 Molecular weight of gas.

(The gas-cooling utilizes several similarity rules and rough approximations, hence the result should not be regarded as very accurate!)

6. λ_{x} -NUMBER CARD (15)

6.1 Number of heat-conductivities. (≤ 10 , ≥ 1)

7. λ_x -FUNCTION-CARDS (3F10.0)

One card for each heat-conductivity type. The heat conductivity is expressed as $\lambda_x = a + bT + c/T^2$, where T is in °K and λ_x in W/cm degree. 7.1 a.

7.2 b.

7.3 c.

The first card will be type 1, the 2nd type 2, etc. See 15.

8. λ_y -NUMBER CARD (I5)

8.1 Number of heat conductivities. $(\leq 10, \geq 1)$

For a one-dimensional case, only one dummy λ_v is needed.

9. $\frac{\lambda_y$ -FUNCTION CARDS (3F10.0)

Same as 7, but for conduction in y-direction.

10. λ_z -NUMBER CARD (I5)

10.1 Number of heat-conductivities. (≤ 10 , ≥ 1).

For a one- or two-dimensional case, only one dummy λ_z is needed.

11. λ_z -FUNCTION CARDS (3F10.0)

Same as 7, but for conduction in z direction.

12. <u>Cp-NUMBER CARD (I5)</u>

12.1 Number of C_p -types (≥ 1 , ≤ 10).

13. <u>Cp-FUNCTION CARD (3F10.0)</u>

One card for each C_p type. First card will be type 1, second type 2, etc. C_p is expressed as a polynomial $C_p = a + bT + c/T^2$, where T is in °K and C_p in J/ml degree. (OBS! not J/g degree) 13.1 a.

13.2 b.

.

13.3 c.

14. GRID-NUMBER CARD (315)

14.1 Number of grid lines crossing x coordinate (\geq 1, \leq 10)

14.2 Number of grid lines crossing y coordinate (≥ 1 , ≤ 10)

14.3 Number of grid lines crossing z coordinate (≥ 1 , ≤ 5)

15. GRID-POINT CARDS (613, 2X, 6F10.0)

Grid-point cards are needed to specify points deviating from the default assumption: outside beam area, clamped at 0°C and without connection to surrounding points. (A point is the crossing of three grid lines). One card per grid point.

15.1 Number of grid lines from origin along x axis. (>0. \leq 10)

15.2 Number of grid lines from origin along y axis. (> 0. \leq 10)

15.3 Number of grid lines from origin along z axis. (>0. \leq 5)

A card with 0 grid-lines from origin terminates the reading of grid-point cards. Normally grid-line no. 1 goes through origin.

15.4 C_p -function type for this point (>1, < 10)

15.5 λ -function type for this point (≥ 1 , ≤ 10)

The type selected is common for λ_x , λ_y , and λ_z . The λ_x is considered

to be for conduction between this point and the next along the x axis. The same holds for $\lambda_{\rm v}$ and $\lambda_{\rm z}$.

15.6 Gas contact. (0 = no gas contact, 1 = gas contact.)

- 15.7 Temperature in degrees centigrade. (Starting value includes temp. offset.)
- 15.8 Fraction of beam power released at the point. (Beam power-loss must be normalized to this value.)
- 15.9 Point type. 1.0 means that temperature is clamped to its initial value. 0.0 means that no radiation is lost from this point. When heat radiation can escape in the z direction, -G is specified, where G is the surface grayness factor 0< G< 1.0. For 2-dimensional foils G is the sum of the grayness factors for both surfaces.

15.10 Fractional area coupling to next point in x direction.

15.11 Fractional area coupling to next point in y direction.

15.12 Fractional area coupling to next point in z direction.

The fractional areas are especially useful when symmetry properties are used to reduce the size of a problem.

The test example supplied with the program is for 1 quadrant of an approximately circular foil with no radiation or gas cooling. It shows that the coupling areas (15.10 - 15.12) are not reduced along the symmetry axes, but how instead three different λ and C_p sets are used and the fractional beam (15.8) is used to adjust the conditions along the symmetry try lines. Thus functions and coupling areas can be traded against each other to simplify a problem.



Arrangement of data-deck for HEAT v4m1

XBL 736-3218

	APPENDIX 2. Program HEAT v4m1
НЕАТ	PRUGRAM HEAT(INPUT, UUTPUT, TAPE5=INPUT, TAPE6=OUTPUT)
C C	DEPENDENT FOR COLVENC OWNERS AND STATES 2 D. USAT TRANSFER VETU
<u> </u>	PROGRAM FUR SOLVING DINAMIC AND STATIC 3-D HEAT-TRANSFER WITH
C C	CASES, RADIATION SOURCES ARE TREATED AS BLACK RODLES, HEAT-TRANS
<u> </u>	FER COEFFICIENTS AND HEAT-CAPACITIES CAN BE LINERA DEPENDENT ON
č	TEMPERATURE. THE POWER SOURCES MAY BE IN TWO STATES FOR GIVEN
C	TIME INTERVALS.
<u> </u>	
C	J.O.LILJENZIN 29.9.1972
<u> </u>	
Ĺ	VERSION 4 USES PULYNUMIALS A+B*T+C/T**2 FOR HEAT-CONDUCTIVITIES
	TU ALLUW A LARGER TEMPERATURE RANGE TU BE CUVERED
C C	WHEN THIS IS NOT NECESSART, OSE VSHO WHICH IS PASTER.
<u> </u>	UA=BEAM CURRENT IN UA(DC)
č	PA=BEAM-POWER LOST IN MEV/POINT
C	TON=TIME INTERVAL WITH BEAM ON
	TOFF=TIME-INTERVAL WITH BEAM OFF
С	UA.LE.O. STOPS PROGRAM
<u> </u>	DX=CM/GRID-UNIT IN X-DIRECTION
C C	DY=CM/GRID-UNIT IN Y-DIRECTION
	DZ=CM/GRID-UNII IN Z-DIRECTION
Č	LE DT=0. THE STEADY-STATE IS CALCULATED
Č	TMAX=TIME-LIMIT IN SECONDS (STOPS THE PRESENT CASE)
Ċ	TMIN IS THE RUN-IN TIME BEFORE FIRST COMPLETE PRINT-OUT
C	MX=TOTAL NO. OF RX-FUNCTIONS
C	AX(I) AND BX(I) ARE THE COEFFICIENTS IN THE EXPRESSION
C	RX(I,J,K)=CX(I,J,K)*(AX(L)+BX(L)*T(I,J,K))*XM(WHERE L=NR(I,J,K))
	THE AX(I).S ARE IN W/CM DEG. AT U DEG.K (NUT DEG C)
C C	MY, AV(T) AND BY(T) ARE THE SAME FOR RY
Č	M7. A7(1) AND B7(1) ARE THE SAME FOR R7
č	MC, AC(I) AND BC(I) ARE THE CORRESPONDING DATA FOR THE HEAT-
C	CAPACITY. AC(I).S IN J/MLDEG AT O DEG. K
2	BC.S IN J/ML(DEG)**2
C	IM=NUMBER OF GRID-POINTS IN X-DIRECTION
<u> </u>	JM=NUMBER OF POINTS IN Y-DIRECTION
с г	IMENIMENSIONALITY OF ACTUAL CASE
C: -	I = NO. OF DX TO A POINT -1
Č godi	J=NO. OF DY TO A POINT -1
C	K=NO. OF DZ TO A PUINT-1
C	T(I,J,K)=TEMPERATURE IN DEG.C AT POINT I,J,K AND TIME
C	Q(I,J,K)=FRACTION OF POWER AT POINT I,J,K
C	F(I,J,K)=1. MEANS T(I,J,K)=CONSTANT (BORDER)
C	=U. MEANS I(1, J,K)=VARIABLE
	+-V. MEANS ILLIJJNJ=VAKLABLE AND KAULATION FRUM V SURFACES IN THE X-Y-DIANE (FACH ADEA IS DY+DV)
c C	$CX(I \cdot J \cdot K) = COUPLING+CONSTANT BETWEEN I AND I+1$
Č	CY(I, J, K)=DITO FOR J AND J+1
С	CZ(I,J,K)=DITO FOR K AND K+1
C	NR(I, J, K) SELECTS THE APPROPRIATE RX-, RY-, AND RZ-FUNCTIONS
C	NC(I, J, K) SELECTS THE APPROPRIATE C-FUNCTION
C	LIEK TO FORMER

.

T		· · · · · · · · · · · · · · · · · · ·
	С	SUM IS CONVERGENCE-TEST AGAINST RKT
	С	
	<u>C</u>	UBSERVE THE POSSIBILITY TO UTILIZE SYMMETRIES TO REDUCE A GIVEN
	C	PROBLEM.
	C	WHEN SYMMETRY IS USED THE Q, C AND V.S FOR A POINT MUST BE
	C	DIVIDED BY THE NUMBER OF USED SYMMETRY AXES PASSING THRU THIS
	C	POINT.
	C	UBSERVE ALSO THAT THE RZ-S OF A HIGHER LAYER (LARGER K) AFFECTS
	Ċ	THE RZ-S OF THE NEXT LOWER LAYER. THIS IS ALSO TRUE FOR MATERIAL
	С	CHANGES IN THE X- AND Z-DIRECTIONS.
	C	TSUR IS SURROUNDING TEMPERATURE TO BE USED FOR CALC OF RAD COOL
	C	
	Ċ	FOR CYCLIC PHENOMENA IT IS ADVISED TO START BY OBTAINING YOUR
·	Ċ	STEADY-STATE CONDITIONS AT THE MEAN-POWER USED AND THEN USE THIS
	č	AS THE STARTING POINT FOR THE T(X-Y-7-T) CALCULATIONS.
	č	TADD IS ADDED TO ALL POINT-TEMPERATURES
	č	
	c	VERSION 3 ALLOWS CAS-COOLING ON RADIATING SURFACES
	č	TERSTOR 5 REEDES ORS CODETING ON REPERTING SOM ACCS
,	<u>~</u>	
	ĉ	
	<u><u> </u></u>	I FUN GAS-COULING
	č	CO IS CHARACTERISTIC DIAMETER (CA)
N. 10107 W.L. 1711-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-	<u> </u>	CV - CAS UPAT CONDUCTIVITY (4/CH DEC)
	C C	CN-GAS HEAT CUMPOCITYITY (W/CM/DEG)
	<u><u> </u></u>	CKA AND CKB ARE CUNSTANTS IN CR=CKA+1+1.57(1+CKB)
	C	GNU IS GAS BULK VISCUSITY
	<u> </u>	GNUF IS GAS VISCUSITY IN BUUNDARY LAYER
	C C	CMA AND CMB ARE CUNSIANIS IN MU=CMA#I##I.57(I+CMB)
1	C	CP IS GAS HEAT CAPACITY (J/G DEG.)
	C	CPA, CPB AND CPC ARE CUEFFICIENTS IN CP=CPA+CPB*T+CPC/T**2
	C	CB IS VOLUME EXPANSION COEFFICIENT (/DEG.)
	C	CW IS GAS MASS FLOW (G/S)
	<u>C</u>	CTC IS GAS FEMPERATURE AT INLET (DEG. C)
	C	CPRES IS GAS PRESSURE AT TARGET SURFACE (ATA)
	C	CMV IS THE MOLECULAR WEIGHT OF THE GAS
	С	
	C	CR IS GAS DENSITY (G/ML) FROM THE GAS LAW
	С	CONA AND CONB ARE CUNSTANTS FOR GIVEN GAS, BULK TEMP AND PRESSUR
	C	GT IS CALCULATED MEAN TEMPERATURE OF GAS (DEG.K)
	C	NG(I, J, K) IS 1 IF GAS IS IN CONTACT WITH THIS POINT
	С	O IF NO GAS-CONTACT
	С	QTG IS TOTAL HEAT TRANSFERRED TO GAS-PHASE
	C	
		DIMENSION F(10,10,5),T(10,10,5),TG(10,10,5),O(10,10,5),AX(10).
		$13X(10) \cdot AY(10) \cdot BY(10) \cdot AZ(10) \cdot BZ(10) \cdot AC(10) \cdot BC(10) \cdot PR(10) \cdot PT(15)$.
		2CX(10,10,5),CY(10,10,5),CZ(10,10,5),DC(10),EX(10),EX(10),EZ(10),
		3NR(10.10.5).NC(10.10.5).NG(10.10.5)
	C	JIIII L 07 207 / 110 L A 07 207 / 110 L A 07 207 / 110 L A 07 207 / 1
	ř	STATEMENT FUNCTIONS
	ř	
	C C	SUDIA DICHLES SUITERLANDIEWN AND PUL PULTNUMIAL Sudia dichles suiterlandiewn and pul pultnumial
	c	YUL1 A 10 1 5 1 1 = A+ B # D+6/ D # # 2
	<u>ل</u>	
30		MUDIF=1
31	1000	TIME=0.

-32 -

ΗΕΔΤ		
32		[TFR=-]
33		BKT=0.
34	•	P(1 1 1 = 1 + 10)
35	******	DO 1 J=1.10
36		
50		
50		
<u> </u>		
51		
53		CY(1, J, K)=0.
53		CZ(1, J, K)=0-
54		NR(I, J, K) = 0
		NC(I,J,K)=0
55		NG(I,J,K)=0
55	1	Q(I,J,K)=0.
	C	
63		READ(5,4)(PT(1),I=1,15)
	4	FORMAT(15A4)
70	•	WRITE (6.5) (PT(I).I=1.15).IVERS.MODIE
	5	EORMAT(1H),1544,9HHEAT VERS, [3,5H MOD, [3]
	ŕ	
102	<u> </u>	DEAD 5 2114 DA TON THEE THET TAND TOUD COLCE
102	2	READ JJ2/04 JF AJ LONG TOFF JTMET JTADO JTSON JOSTOE
1.77	4	
126		IF (UALE + U-) SIOP
132		IF(IML1.LE.0.) IMLI=10000.
135		IF(ISUR - EQ.0.) $ISUR = -273.16$
137		READ(5,2)DX,DY,DZ,DT,TMAX,TMIN
157		IF(DT)200,200,201
	C	SET CONDITIONS FOR A STEADY-STATE CASE
161	200	TON=1.
162		TOFF=0.
163		TMAX=0.
164	201	CONTINUE
164		WRITE(6.3)UA.PA.TON.TOFF.TMLT
	3	FORMAT(6HOBEAM=, F10, 3, 10HUA, POWER=, F10, 3, 9HMEV/POINT, 5H TON=.
······		1E10-4-8HS. TOFF=-E10-4-14HS. MELTS AT T=-E10-2)
202		
, , , , , , , , , , , , , , , , , , ,	r	
204	C	HOITE (4 CONVINT DT THAY THIN
204		$\frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{10000} \frac{1}{10000} \frac{1}{10000000000000000000000000000000000$
	0	$FURMAT(4HOUA= FIU_0) f(HCM_1) DI= FIU_0 (HCM_1) DI= FIU_0) f(HCM_1) DI= f(HCM_1) $
		IF IU. 5, IUHSEC, IMAX=, FIU. 5, IUHSEC, IMIN=, FIU. 5, 3HSEC
224		IFTIMIN-GE-IMAX. AND. DI.NE.U.J GU TU 1000
234		WRITE (6,444)T SUR
	444	FORMAT(6HOTSUR=,F10.2,3HDEG)
241		TSUR=TSUR+273.16
	C	
243	•	SIG=5.70E-12*DX*DY
246		READ(5,300)ITYPE
-	300	FORMAT(15)
253		IF(ITYPE.LE.O) GO TO 301
223	C	OBS NEXT STATEMENT READS TWO CARDS
256	<u> </u>	READ 15.21CD.CKA.CKB.CMA.CMB.CDA.CDB.CDC.CB.CW.CTC.CDDEC.CMV
277		NEW CALL CALL TANGE
512		INTELOTO CUL CUL CUL CUL COL COL COL CUL CTC COLCO CUL
	302	FUKMAIT6HUITPE=,12,12H GAS-CUULING/
		16H UIAM=;9X;F10.2;2HCM/

* ****

2. --* *

HEAT				ana anto bana anaman at kanan a
		212H HEAT COND.=,8X,2E10.3,9HW/CM.DEG./		·
		311H VISCOSITY=,9X,2E10.3,4HPOIS/	*** ,*********	
		44H CP=,16X,3E10.3,8HJ/G.DEG./15H VOL.EXP.COEF.=,5X	,E10.3	37
		511H FLOW-RATE=,9X,E10.3,5HG/SEC/		
		615H ENTERING TEMP=,F10.2,5HDEG.C/		-
		710H PRESSURE=,7X,F10.4,3HATA/		-
		812H MOL.WEIGHT=,4X,F10.3)		
353		CTC=CTC+273.16		-
354		GT=CTC		<u>.</u>
355		GO TO 303		
356	301	WRITE(6,304)ITYPE		
	304	FORMAT(6HOTYPE=,12,7H VACUUM)		1
364	303	CONTINUE		
	C			3
364		READ(5,7)MX,(AX(I),BX(I),EX(I),I=1,MX)		
	7	FORMAT(15/(3F10.0))		
410		WRITE(6,8)(I,AX(I),BX(I),EX(I),I=1,MX)		
	8	FORMAT(8HORX-FUNC/(LX,I3,2F10.5,F11.2))		
	<u> </u>		, r	
434		READ(5,7)MY,(AY(I),BY(I),EY(I),I=1,MY)		
460		WRITE(6,9)([,AY(]),BY([),EY(]),[=1,MY)		har hand in the state of the
	9	FORMAT(8HORY-FUNC/(1X,13,2F10.5,F11.2))		
	<u> </u>			
504		READ(5,7)MZ,(AZ(I),BZ(I),EZ(I),I=1,MZ)		
530		WRITE(6,10)(I,AZ(I),BZ(I),EZ(I),I=1,MZ)		
	10	FORMAT(8HORZ-FUNC/(1X,I3,2F10.5,F11.2))		1
	<u> </u>			and a second
554		READ(5,70)MC, (AC(I), BC(I), DC(I), I=1, MC)		
	10	FURMAT(15/(3F10.0))		·····
600		WRITE(6,11)(1,AC(1),BC(1),DC(1),1=1,MC)		
	<u></u>	FURMA1(8H0 C-FUNC/(1X,13,2F10.5,F11.2))		•
() (L			
024	1 ')	KEAU(5)12JtM;JM;KM		
171	12	FUKMAI(31)	• •	
0.30				· ···
640	*	1 F (NM + EQ + 1) LM=LM=1	ń.	
642		$\frac{1}{1} \begin{bmatrix} 1 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ $		
040 450		LF\19+EQ+17 LM=14 UDITE/4 131TM 4M KM 14		
050	1.2	HALICIUILIIIIJIIIJANILII CADMATIINA 2012 20 41 12 20 - 12 120 DIMENSIONALI	:	
661	1.2	YM=DV=D7/DY		·· · · ·
440	•			
600 647				
670				۲ ز.
671		TE(DT_GT_0_) VM=DX+DV+07/0T		1.1
676		TIME=0.		
677				
700	14	READ (5.15) T. L.K. NCT IK, NRT IK, NCT IK, TT IK, AT IK, ET IK, C	(1.1K.C	VI IK . C 7
,	15	= FORMAT(613.2X.6F10.0)		
734	<u> </u>			and a state of the
736		IF(I_GT_IM) GO TO 14	•	
741		$\frac{1}{1} = \frac{1}{1} = \frac{1}$		
744		T IF(K2GT_KM) GO TO 14		,
752	-	POINTS=POINTS+OLIK		Λ.
755	$\mathcal{X} = \{x\}$			

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HEAT		and a supergram. The first is a black had been the supergram and		
757		TG(I,J,K) = TIJK		
760		Q(I, J, K) = QIJK		
761		F(I,J,K)=FIJK		
763		CX(I, J, K) = CXIJK		
764		CY(I,J,K)=CYIJK		
766		CZ(I,J,K)=CZIJK		
767		NC(I, J, K) = NCIJK		
771	***********************	NR(I,J,K)=NRIJK		
772		NG(I, J, K) = NGIJK		
774		60 TO 14		
	C			
775	16	WRITE(6.17)		
	17 :	EORMAT(5HODATA/2H T/2H 0/2H E/3H CT/3H RT/3H C	X/3H CY/	34 (7)
1001		$IE(ITYPE_E0.1) WRITE(6.170)$	<u></u>	<u>JII ULI</u>
1001	170	EORMAT(3H NG)		
1007	110		***	
1007	752		٠.,	
*****	<u></u>			
1016	L			
1015	********	UU 18 K=1,KM		
1017		WRITE(0,5)(PI(I),I=1,15),IVERS,MUUIF		
1030		WRITE 16, 19)K, TIME, TIER		
	19	FURMATIGHULAYER, 13, 8H AT TIME, F10.5, 3HSEC, 15, 4	HITER)	
1042		WRITE(6,20)(I,I=1,IM)		
	20	FORMAT(3HOX=,3X,10110)		
1055		DO 18 J=1, JM		
1057		WRITE($6,21$)J,(T(I,J,K),I=1,IM)		
	21	FURMAT(3HOY=, I3, 10F10.2)		
1073	_	WRITE(6,22)(Q(I,J,K),I=1,IM)		
	22	FORMAT(6X,10F10.2)		
1106		IF(GSIGE.EQ.0.0) GO TO 5433		
1107		DO 5432 I=1,IM	· 5	
1111		IF(F(I,J,K))5431,5432,5432		
1117	5431	F(I, J, K) = F(I, J, K) = GSIGE		- 19 20
1125	5432	CONTINUE		
1130	5433	CONTINUE		
1130		WRITE(6,22)(F(I,J,K),I=1,IM)		
1143		WRITE(6,23)(NC(I,J,K),I=1,IM)		
***************************************	23	FURMAT(4X,10110)	-	
1156		WRITE(6,23)(NR(1, J,K), I=1, IM)		
1171		WRITE $(6, 22)$ (CX(I, J, K), I=1, IM)		
1171 1204		WRITE $(6,22)(CX(I,J,K),I=1,IM)$ WRITE $(6,22)(CY(I,J,K),I=1,IM)$		
1171 1204 1217		WRITE(6,22)(CX(I,J,K),I=1,IM) WRITE(6,22)(CY(I,J,K),I=1,IM) WRITE(6,22)(CZ(I,J,K),I=1,IM)		
1171 1204 1217 1232	an a	WRITE(6,22)(CX(I,J,K),I=1,IM) WRITE(6,22)(CY(I,J,K),I=1,IM) WRITE(6,22)(CZ(I,J,K),I=1,IM) IE(ITYPE,EQ,I) WRITE(6,23)(NG(I,J,K),I=1,IM)		
1171 1204 1217 1232 1247		WRITE(6,22)(CX(I,J,K),I=1,IM) WRITE(6,22)(CY(I,J,K),I=1,IM) WRITE(6,22)(CZ(I,J,K),I=1,IM) IF(ITYPE.EQ.1) WRITE(6,23)(NG(I,J,K),I=1,IM) DO 120 I=1.IM		
1171 1204 1217 1232 1247 1251		WRITE(6,22)(CX(I,J,K),I=1,IM) WRITE(6,22)(CY(I,J,K),I=1,IM) WRITE(6,22)(CZ(I,J,K),I=1,IM) IF(ITYPE.EQ.1) WRITE(6,23)(NG(I,J,K),I=1,IM) DO 120 I=1,IM IF(E(I,J,K))121,121,120		
1171 1204 1217 1232 1247 1251 1257	121	WRITE(6,22)(CX(I,J,K),I=1,IM) WRITE(6,22)(CY(I,J,K),I=1,IM) WRITE(6,22)(CZ(I,J,K),I=1,IM) IF(ITYPE.EQ.1) WRITE(6,23)(NG(I,J,K),I=1,IM) DO 120 I=1,IM IF(F(I,J,K))121,121,120 IE(NC(I,J,K))121,121,120		
1171 1204 1217 1232 1247 1251 1257	121	WRITE(6,22)(CX(I,J,K),I=1,IM) WRITE(6,22)(CY(I,J,K),I=1,IM) WRITE(6,22)(CZ(I,J,K),I=1,IM) IF(ITYPE.EQ.1) WRITE(6,23)(NG(I,J,K),I=1,IM) DO 120 I=1,IM IF(F(I,J,K))121,121,120 IF(NC(I,J,K).LT.1) WRITE(6,150)I,J,K EDRMAT(3HONC.315//)		
1171 1204 1217 1232 1247 1251 1257	121 150	WRITE(6,22)(CX(I,J,K),I=1,IM) WRITE(6,22)(CY(I,J,K),I=1,IM) WRITE(6,22)(CZ(I,J,K),I=1,IM) IF(ITYPE.EQ.1) WRITE(6,23)(NG(I,J,K),I=1,IM) DO 120 I=1,IM IF(F(I,J,K))121,121,120 IF(NC(I,J,K).LT.1) WRITE(6,150)I,J,K FORMAT(3HONC,315//) IE(NP(I,J,K),IT.1) WPITE(2,151)I,IK		
1171 1204 1217 1232 1247 1251 1257 1277	121 150	WRITE(6,22)(CX(I,J,K),I=1,IM) WRITE(6,22)(CY(I,J,K),I=1,IM) WRITE(6,22)(CZ(I,J,K),I=1,IM) IF(ITYPE.EQ.1) WRITE(6,23)(NG(I,J,K),I=1,IM) DO 120 I=1,IM IF(F(I,J,K))121,121,120 IF(NC(I,J,K).LT.1) WRITE(6,150)I,J,K FORMAT(3HONC,315//) IF(NR(I,J,K).LT.1) WRITE(6,151)I,J,K FORMAT(3HONP,215//)		
1171 1204 1217 1232 1247 1251 1257 1277	121 150 151	<pre>WRITE(6,22)(CX(I,J,K),I=1,IM) WRITE(6,22)(CY(I,J,K),I=1,IM) WRITE(6,22)(CZ(I,J,K),I=1,IM) IF(ITYPE.EQ.1) WRITE(6,23)(NG(I,J,K),I=1,IM) DD 120 I=1,IM IF(F(I,J,K))121,121,120 IF(NC(I,J,K).LT.1) WRITE(6,150)I,J,K FORMAT(3HONC,315//) IF(NR(I,J,K).LT.1) WRITE(6,151)I,J,K FORMAT(3HONR,315//) RKT=PKT10 2001</pre>		
1171 1204 1217 1232 1247 1251 1257 1277 1317	121 150 151	<pre>WRITE(6,22)(CX(I,J,K),I=1,IM) WRITE(6,22)(CY(I,J,K),I=1,IM) WRITE(6,22)(CZ(I,J,K),I=1,IM) IF(ITYPE.EQ.1) WRITE(6,23)(NG(I,J,K),I=1,IM) DD 120 I=1,IM IF(F(I,J,K))121,121,120 IF(NC(I,J,K).LT.1) WRITE(6,150)I,J,K FORMAT(3HONC,315//) IF(NR(I,J,K).LT.1) WRITE(6,151)I,J,K FORMAT(3HONR,315//) RKT=RKT+0.0001 CONTINUE</pre>		
1171 1204 1217 1232 1247 1251 1257 1277 1317 1317 1321	121 150 151 120	<pre>WRITE(6,22)(CX(I,J,K),I=1,IM) WRITE(6,22)(CY(I,J,K),I=1,IM) WRITE(6,22)(CZ(I,J,K),I=1,IM) IF(ITYPE.EQ.1) WRITE(6,23)(NG(I,J,K),I=1,IM) DD 120 I=1,IM IF(F(I,J,K))121,121,120 IF(NC(I,J,K).LT.1) WRITE(6,150)I,J,K FORMAT(3HONC,315//) IF(NR(I,J,K).LT.1) WRITE(6,151)I,J,K FORMAT(3HONR,315//) RKT=RKT+0.0001 CONTINUE DD 20 I=1 IM</pre>		
1171 1204 1217 1232 1247 1251 1257 1277 1317 1321 1324	121 150 151 120	<pre>WRITE(6,22)(CX(I,J,K),I=1,IM) WRITE(6,22)(CY(I,J,K),I=1,IM) WRITE(6,22)(CZ(I,J,K),I=1,IM) IF(ITYPE.EQ.1) WRITE(6,23)(NG(I,J,K),I=1,IM) DO 120 I=1,IM IF(F(I,J,K))121,121,120 IF(NC(I,J,K).LT.1) WRITE(6,150)I,J,K FORMAT(3HONC,315//) IF(NR(I,J,K).LT.1) WRITE(6,151)I,J,K FORMAT(3HONR,315//) RKT=RKT+0.0001 CONTINUE DO 24 I=1,IM PS644644455 (MDD5445444545455445454545454545454545454</pre>		
1171 1204 1217 1232 1247 1251 1257 1277 1317 1321 1324	121 150 151 120 C	<pre>WRITE(6,22)(CX(I,J,K),I=1,IM) WRITE(6,22)(CY(I,J,K),I=1,IM) WRITE(6,22)(CZ(I,J,K),I=1,IM) IF(ITYPE.EQ.1) WRITE(6,23)(NG(I,J,K),I=1,IM) DD 120 I=1,IM IF(F(I,J,K))121,121,120 IF(NC(I,J,K).LT.1) WRITE(6,150)I,J,K FORMAT(3HONC,315//) IF(NR(I,J,K).LT.1) WRITE(6,151)I,J,K FORMAT(3HONR,315//) RKT=RKT+0.0001 CONTINUE DD 24 I=1,IM RECALCULATE CURRENT IN PULSE FROM PULSE-TIME AM </pre>	ND MEAN-	CURREN
1171 1204 1217 1232 1247 1251 1257 1277 1317 1321 1324 1340	121 150 151 120 C	<pre>WRITE(6,22)(CX(I,J,K),I=1,IM) WRITE(6,22)(CY(I,J,K),I=1,IM) WRITE(6,22)(CZ(I,J,K),I=1,IM) IF(ITYPE.EQ.1) WRITE(6,23)(NG(I,J,K),I=1,IM) DO 120 I=1,IM IF(F(I,J,K))121,121,120 IF(NC(I,J,K).LT.1) WRITE(6,150)I,J,K FORMAT(3HONC,315//) IF(NR(I,J,K).LT.1) WRITE(6,151)I,J,K FORMAT(3HONR,315//) RKT=RKT+0.0001 CONTINUE DO 24 I=1,IM RECALCULATE CURRENT IN PULSE FROM PULSE-TIME AN Q(I,J,K)=Q(I,J,K)*UA*PA*(TOFF+TON)/TON</pre>	ND MEAN-	CURREN

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HEA	T	*****	
	1350	18	CONTINUE
	1355		ION=1
	1355		TSW=TON
	1357	25	[TER=-1
	1360		TSUR4=TSUR**4
	1362	26	CONTINUE
		C.	GAUSS-SIEDEL ITERATION CYCLE STARTS
	1362		$IE(ITYPE_E,E)=0$ GO TO 3100
	1363		
	1364		$CK = SUD(CKA \cdot CKB \cdot GT)$
	1366		
	1371		CR = CMV + CPRES / (82 - 0.54 + GT)
	1276		$CP = DOI (CPA_CPB_CPC_CT)$
	1401		$CDNA=CK \pm DV \pm DV \pm 1 + C2 \pm (1 - 273 \pm C \pm \pm CD / (CK \pm CD)) \pm \pm A - 33333$
	1401		CONA-CRTDATD1 *1.02*(1.*2/3*CN*CF/(CRTCD)/************************************
-	1413	2100	
	1420	5100	
	1420		
	1422		
	1423		(A) 30 $I=1$, IM
	1424	·	
mpmananauronana ma	1425	an ya kanalakata kanala kanalar mata sa	DU 30 K=L,KM
	1426		DTA=0.
	1427		DNA=0.
	1427		IF(F(I,J,K))31,32,30
	1436	31	DTA=DTA+S[G*F(I,J,K)*(T(I,J,K)**4-TSUR4)
	1454		IF(ITYPE)32,32,306
	1456	306	IF(NG(I,J,K))32,32,307
	1464	307	GMUF = SUD(CMA, CMB, 0, 5*(GT+T(I, J, K)))
	1504		QCG=CONA*(GMU/GMUF)**0.3333
	1510		QCG=QCG*(1.+(CONB*(T(I,J,K)-GT)/GMU**2)**0.33333)
		С	LIMIT THE GAS-COOLING TO MAX 1 SURFACE
	1520		QCG=QCG*(T(1,J,K)-GT)*F(1,J,K)*0.5
	1524		QTG=QTG+QCG
	1526		DTA=DTA+QCG
	1527	32	L=NC(I,J,K)
	1534	antan ananan wasak ka asara at daarta talan ya goo	CC=VM*POL(AC(L),BC(L),DC(L),T(I,J,K))
	1544		IF(CC.LT.U.) CC=0.
	1547		DTA=DTA+TG(I,J,K)*CC
	1556		IF(ION, EQ.1) DTA=DTA+Q(I,J,K)
	1573		DNA=CC
	1574		L = NR(I, J, K)
*	1575		IF(LM.EQ.0) GO TO 74
	1577		GO TO(41.42.43).LM
		C	TREAT Z-COORDINATE
	1605	43	$CC = 7M + C7(1 \cdot 1 \cdot K) + POI(A7(1) \cdot B7(L) \cdot F7(L) \cdot T(1 \cdot 1 \cdot K))$
	1624		$\frac{1}{1} E(C + L_{2}) = 1 C = 0.$
	1627		DNA=DNA+CC
	1631		16(K.E0.1) GO TO 51
	1632	1	$M=NR\{I, I, K+1\}$
	1640		$\frac{1}{1} \frac{1}{1} \frac{1}$
	1641		
	1657		$\frac{1}{1} = 0 = 0 = 0$
	1667		
	1671		$\frac{1}{2} \frac{1}{2} \frac{1}$
	1473		りれる- UNA TUUM での TO 50
	10/3	2 •	
	17(11)	51	11 L A = 11 L A = 1 A = J = K J

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1703 DNA=DNA+CC 1706 DTA=DTA+CC 1706 DTA=DTA+CC=T[1,j,K+1] 1715 GU TO 42 1715 S3 DTA=DTA+CC=T[1,j,K] C TREAT Y-COGNOTATE 1724 42 CC=YM=CY(1,j,K)+PDL(AY(L),EY(L),FY(L),T[[,J,K]) 1746 DNA=DNA+CC 1750 IF(J=Gu,I) GO TO 61 1752 M=NR(1,J-1,K) 1753 IF(CG=V=YM=CY(1,J-1,K)+PDL(AY(M),BY(M),EY(M),T[1,J-1,K]) 1754 IF(CG=V=V=CY(1,J-1,K)+PDL(AY(M),BY(M),EY(M),T[1,J-1,K]) 1755 DTA=DTA+CC=T(1,J-1,K) 2007 DNA=DNA+CC 2016 61 DTA=DTA+CC=T(1,J,K) 2017 CD A=DTA+CC=T(1,J,K) 2018 61 DTA=DTA+CC=T(1,J,K) 2033 GO TO 41 2044 UTA=DTA+CC=T(1,J,K) 2056 IF(CG=V=V=CY(1,J+K,K) 2056 CT=REAT X-COGNOTATE 2044 CT=REAT X-COGNOTATE 2056 TF(1,EQ,I) GO TO 10 2056 TF(CG=V=V=CY(1,J,K) 2056 TF(1,EQ,I) GO TO 11 2056 TF(1,EQ,I) GO TO 12 2056 M=AR(1-1,J,K) 2072 CF(M=EQ,O) GO TO 11 2056 M=AR(1-1,J,K) 2072 CF(M=EQ,O) GO TO 11 2072 CF(M=EQ,O) GO TO 11 2074 CCM=XM=CCX[1,J,K] 2075 DTA=DTA+CC=T(1,J,K) 2072 CF(M=EQ,O) GO TO 71 2063 M=AR(1-1,J,K) 2072 CF(M=EQ,O) GO TO 71 2064 DTA=DTA+CC=T(1,J,K) 2110 TF(1,EQ,I) GO TO 71 2057 CF(1,EQ,I) GO TO 71 2120 DTA=DTA+CC=T(1,J,K) 2120 DTA=DTA+CC=T(1,J,K) 2120 DTA=DTA+CC=T(1,J,K) 2121 CF(1,EQ,I) GO TO 73 2137 DTA=DTA+CC=T(1,J,K) 2144 ONA=DTA+CC=T(1,J,K) 2157 74 SU=-TT(1,J,K) 2157 74 SU=-TT(1,J,K) 2159 74 SU=-TT(1,J,K) 2150 TF(1,EQ,I) GO TO 73 2131 71 DTA=DTA+CC=T(1,J,K) 2144 ONA=DTA+CC=T(1,J,K) 2155 74 SU=-TT(1,J,K) 2155 74 SU=-TT(1,J,K) 2255 TF(1)=TT(1,T,K) 2255 TF(1)=TT(1,T,K) GT=CTC=UEG/T(CM=CP) 2255 TF(1)=TT(1,T,K) GT=CTC=UEG/T(CM=CP) 2255 TF(1)=TT(T=TT) GO TO 26 C CALCULATE NEW GAS MEAN-TEMPERATURE C CALCULATE NEW GAS MEAN-TEMPERATURE C CALCULATE NEW GAS MEAN-TEMPERATURE C CALCULATE NEW GAS	HEAT	****	
1704 52 IF(K.EQ.KM) GO TO 53 1706 DTADTA+CCEVT(I,J,K+1) 1715 GU TO 42 1715 GU TO 42 1715 GU TO 42 1716 CTREAT Y-COORDINATE 1724 CCEVMCY(I,J,K)*POL(LY(L),EY(L),FY(L),T(I,J,K)) 1743 IF(CC,I,J,K)*POL(LY(L),BY(L),EY(L),T(I,J,K)) 1743 IF(CC,I,J,K)*POL(LY(L),BY(L),EY(L),T(I,J,K)) 1750 IF(L),EV,L) GO TO 61 1750 IF(M,EQ.O) GO TO 61 1750 IF(C,M,LI,J,K)*POL(LY(M),BY(M),EY(M),T(I,J-1,K)) 1775 IF(CC,I,I,J,K)*POL(LY(M),BY(M),EY(M),T(I,J-1,K)) 1775 IF(CC,I,I,J,K)*POL(LY(M),BY(M),EY(M),T(I,J,L,K)) 2007 DNA=DNA+CC 2016 GO TO 42 2016 GI DTA=DTA+CC+T(I,J,K) 2007 DNA=DNA+CC 2016 GI DTA=DTA+CC+T(I,J,K) 2017 CREATX+CCMPODINATE 2022 GZ IF(J,EQ,JM) GO TO 63 2024 OT A=DTA+CC+T(I,J,K) 2033 GO TO 41 2033 GO TO 41 2045 IF(CC,I,I,J,K) C FREATX+COORDINATE 2042 41 CC=XMEX(L,I,J,K)POL(LX(L),BX(L),EX(L),T(I,J,K)) 2056 IF(CC,I,I,J,K)POL(LX(L),BX(L),EX(L),T(I,J,K)) 2066 M=NR(I-1,J,J,K)POL(LX(M),BX(M),FX(M),T(I-1,J,K)) 2072 IF(M,EQ,D) GO TO 71 2065 M=NR(I-1,J,K) 2072 IF(M,EQ,D) GO TO 71 2074 CCM+AME(X(I,J,J,K)POL(LX(M),BX(M),FX(M),T(I-1,J,K)) 2110 IF(CC,M,I,I,J,K)POL(LX(M),BX(M),FX(M),T(I-1,J,K)) 2120 DTA=DTA+CC+T(I,J,K) 2131 71 DTA=DTA+CC+T(I,J,K) 2144 GU TO 72 2131 71 DTA=DTA+CC+T(I,J,K) 2145 73 DTA=DTA+CC+T(I,J,K) 2146 TO TO 74 2146 TO TO 74 2147 IF(I,GC,I,I,GC,I,J,K) 2148 TO TO TA+CC+T(I,J,K) 2148 TO TO TA+CC+T(I,J,K) 2149 DTA=DTA+CC+T(I,J,K) 2140 DTA=DTA+CC+T(I,J,K) 2141 TI TO TA+CC+T(I,J,K) 2142 DTA=DTA+CC+T(I,J,K) 2144 GU TO TA+CC+T(I,J,K) 2145 TA EDTA+CC+T(I,J,K) 2146 TO TO TA+CC+T(I,J,K) 2147 IF(I,GC,I,M, GU TO 73 2148 TO TO TA+CC+T(I,J,K) 2149 TA EDTA+CC+T(I,J,K) 2140 TF(C,G,I,I,GC,I,M,I) GU TO 73 2141 TI TA=DTA+CC+T(I,J,K) 2142 DTA=DTA+CC+T(I,J,K) 2144 CC TO TA+CC+T(I,J,K) 2145 TA EDTA+CC+T(I,J,K) 2146 TA EDTA+CC+T(I,J,K) 2147 IF(I,GC,I,C,T,M,I) TG TA+CC+T(I,J,K) 2148 TA EDTA+CC+T(I,GC TO 26 C CALCULATE NEW GAS MEAN-TEMPERATURE 2243 IF(I,TWFE,EQ,I,G GT TO 26 C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(I,TWFE,EQ,I,G GT TO 26 C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF	1703		DNA=DNA+CC
$ \begin{array}{c} 1706 & DTA=DTA+CC+T(I,J,K+1) \\ 1715 & GU TO 42 \\ 1715 & S3 & DTA=DTA+CC+T(I,J,K) \\ & C & TREAT Y-CORDNIATE \\ 1724 & 42 & CC=YM+CY(I,J,K)+PDL(AY(L), BY(L), EY(L),T(I,J,K)) \\ 1746 & DNA=DNA+CC \\ 1750 & TF(L,E,L) & GU TO 61 \\ 1752 & M=NR(I,J-L,K) \\ 1753 & TF(M,EQ,O) & GO TO 61 \\ 1754 & TF(M,EQ,O) & GO TO 61 \\ 1755 & TF(M,EQ,O) & GO TO 61 \\ 1756 & TF(CM,LT,O) & GC=O, \\ 2005 & DTA=DTA+CCM+T(I,J-L,K) + PDL(AY(M), BY(M), EY(M), T(I,J-L,K)) \\ 2007 & DTA=DTA+CCM+T(I,J-L,K) \\ 2007 & DTA=DTA+CCM+T(I,J-L,K) \\ 2011 & GO TD 42 \\ 2016 & G1 & DTA=DTA+CC+T(I,J,K) \\ 2021 & DTA=DTA+CC+T(I,J,K) \\ 2022 & 62 & TF(J,EQ,M) & GO TO 63 \\ 2022 & JTA=DTA+CC+T(I,J,K) \\ 2033 & G0 & TO 41 \\ 2033 & G0 & TO 41 \\ 2033 & G0 & TO 41 \\ 2044 & CC+M+CX(2,K) + PDL(AX(L), BX(L), EX(L), T(I,J,K)) \\ 2056 & TFREAT X-CJORDINATE \\ 2063 & DTA=DTA+CC+T(I,J,K) + PDL(AX(L), BX(M), EX(M), T(I-L,J,K)) \\ 2072 & TFREAT X-CJORDINATE \\ 2064 & DNA=DNA+CC \\ 2065 & M=NR(I-L), J, K) + PDL(AX(M), BX(M), EX(M), T(I-L,J,K)) \\ 2110 & TF(CCM,LT,O) & CCM=O, \\ 2120 & TTA=DTA+CC+T(I,J,K) + PDL(AX(M), BX(M), EX(M), T(I-L,J,K)) \\ 2122 & DTA=DTA+CC+T(I,J,K) \\ 2124 & GO TO 72 \\ 2133 & TD TA=DTA+CC+T(I,J,K) \\ 2144 & DNA=DNA+CC \\ 2135 & 72 & TF(T,EQ,M) & GO TO 73 \\ 2137 & DTA=DTA+CC+T(I,L), K) \\ 2144 & DNA=DNA+CC \\ 2145 & TA & DTA+CC+T(I,L), K) \\ 2145 & TA & DTA+CC+T(I,L), K) \\ 2145 & TA & DTA+CC+T(I,L), K) \\ 2146 & OU TO 74 \\ 2146 & TTA & DTA+CC+T(I,L), K) \\ 2155 & 74 & SU=-T(I,L), CA & TA & CC+T(L), CA & CC \\ 2235 & SU & CONTINUE \\ \hline C & CALCULATE NEW GAS MEAN-TEMPERATURE \\ \hline C & CALCULATE NE$	1704	52	IF(K.EQ.KM) GO TO 53
1715 GU TO 42 1715 GU TO 42 1715 GU TO 42 C TREAT Y-COORDINATE C TREAT Y-COORDINATE 1724 C CC+M+CY(1,J,K)+PUL(AY(L),BY(L),FY(L),T(I,J,K)) 1743 IF(CC.LT.0.) CC=0. 1750 FF(J.EQ.11 GO TO 61 1750 FF(M.EQ.0) GO TO 61 1750 FF(M.EQ.0) GO TO 61 1750 GCM+YMCCY(L,J-1,K)+POL(AY(M),BY(M),FY(M),T(I,J-1,K)) 1775 IF(CCALT.0.) CCM=0. 2005 DTA=DTA+CCM+T(I,J-1,K) 2007 DNA=DNA+CCM 2011 GO TO 62 2016 G1 DTA=DTA+CC+T(I,J,K) 2022 62 IF(J.EQ.4M) GO TO 63 2022 62 IF(J.EQ.4M) GO TO 63 2023 GO TO 4 2033 GO TO 4 2033 GO TO 4 2042 41 CC=XM+CX(2,4,K)+POL(AX(L),BX(L),FX(L),T(I,J,K)) 2055 FF(CC.LT.0.) CC=0. 2066 DNA=DNA+CC 2066 DNA=DNA+CC 2072 IF(M.EQ.01 GO TO TI 2065 FF(CC.LT.0.) CC=0. 2066 DNA=DNA+CC 2072 IF(M.EQ.01 GO TO TI 2074 CCM+XMCX(1-J,J,K)+POL(AX(M),BX(M),FX(M),T(I-1,J,K)) 2110 IF(CCM-LT.0.) CC=0. 2061 DTA=DTA+CC+T(I,J,K) 2122 DNA=DNA+CC 2124 GU TO 74 2124 GU TO 74 2124 GU TO 74 2125 TF(I.EQ.IM) GU TO 73 2135 TZ IF(I.EQ.IM) GU TO 73 2135 TZ IF(I.EQ.IM) GU TO 73 2135 T4 SU=-T(I,J,K) 2135 T4 SU=-T(I,J,K) 2245 SU F(ITI,J,K) SU F(I,J,K) 2255 T4	1706		DTA=DTA+CC*T(I,J,K+1)
1715 53 DTA=DTA+CC+T(1,J,K) C TREAT Y=COUNDINATE 1724 42 CC=YM=CY((J,J,K)+POL(AY(L), BY(L), EY(L),T(I,J,K)) 1736 IF(CC.t.T.o.) CC=0. 1750 IF(J.EQ.I) GO TO 61 1752 M=NR(I,J=1,K) 1750 CCM+M=CY(I,J=1,K)+POL(AY(M),BY(M),EY(M),T(I,J=1,K)) 1775 IF(CCM.LT.o.) CCM=0. 2007 DTA=DTA+CCMT(I,J=1,K) 2007 DTA=DTA+CCMT(I,J=1,K) 2016 61 DTA=DTA+CCKT(I,J,K) 2026 22 IF(J.EQ.M) GD TO 63 2022 62 IF(J.EQ.M) GD TO 63 2022 62 IF(J.EQ.M) GD TO 63 2023 GO TO 62 2033 GO TO 64 2040 CC = XM=CX(2,4,K)*POL(AX(L),BX(L),EX(L),T(I,J,K)) 2056 IF(CC,LT.o.) CC=0. 2063 IF(CC,LT.o.) CC=0. 2063 IF(CC,LT.o.) CC=0. 2063 IF(CC,LT.o.) CC=0. 2063 IF(CC,LT.o.) CC=0. 2063 IF(CC,LT.o.) CC=0. 2063 IF(CC,LT.o.) CC=0. 2064 UNA=DNA+CC 2077 IFA=DTA+CC*T(I,J,K) 2077 IFA=DTA+CC*T(I,J,K)*POL(AX(M),BX(M),EX(M),T(I=1,J,K)) 2078 IF(CCM.LT.o.) CC=0. 2063 IF(CCM.LT.o.) CCM=0. 2120 DTA=DTA+CCMT(I=1,J,K) 2110 IF(CCMLT.o.) CCM=0. 2122 DTA=DTA+CCMT(I=1,J,K) 2134 DTA=DTA+CC+T(I,J,K) 2135 T4 SU=-T(I,J,K) 2137 DTA=DTA+CC+T(I,J,K) 2134 DNA=DNA+CC 2135 T4 SU=-T(I,J,K) 2135 T4 SU=-T(I,J,K) 2136 DTA=DTA+CC+T(I,J,K) 2137 DTA=DTA+CC+T(I,J,K) 2138 DTA=DTA+CC+T(I,J,K) 2139 DTA=DTA+CC+T(I,J,K) 2134 DNA=DNA+CC 2135 T4 SU=-T(I,J,K) 2135 T4 SU=-T(I,J,K) 2136 DTA=DTA+CC+T(I,J,K) 2137 DTA=DTA+CC+T(I,J,K) 2138 DTA=DTA+CC+T(I,J,K) 2139 DTA=DTA+CC+T(I,J,K) 2130 DTA=DTA+CC+T(I,J,K) 2131 DTA=DTA+CC+T(I,J,K) 2134 DNA=DNA+CC 2245 IF(ITFF,EQ.L) GD TO T3 2357 DTA=DTA+CC+T(I,J,K) 2146 T3 DTA=DTA+CC+T(I,J,K) 2155 T4 SU=-T(I,J,K) 2252 IF(ITFF,EQ.L) GT=CTC-QTG/ICW*CP 2253 IF(ITFF,EQ.L) GD TO T4 2254 IF(ITFF,EQ.L) GD TO Z6 C CALCULATE NEW GAS MEAN-TEMPERATURE C CALCULATE NEW GAS MEAN-TEMPERATURE 2255 IF(ITFFE,EQ.L) GT=CTC-QTG/ICW*CP) 2256 IF(SUM-GF.AKCT) GD TO Z6 C CALCULATE NEW GAS MEAN-TEMPERATURE 2256 IF(SUM-GF.AKCT) GD TO Z6 C CALCULATE NEW GAS MEAN-TEMPERATURE 2250 IF(SUM-GF.AKCT) GD TO Z6 C CALCULATE NEW GAS MEAN-TEMPERATURE 2256 IF(SUM-GF.AKCT) GD TO Z6 C CALCULATE NEW GAS MEAN-TEMPERATURE 2256 IF(SUM-GF.AKCT) GD TO Z6 C CALCUL	1715		GU TO 42
C TREAT Y-COGNOINATE 1743 IF(CC.LT.0.) CC=0. 1743 IF(CC.LT.0.) CC=0. 1750 IF(J_E0.I) GU TO 61 1750 IF(J_E0.I) GU TO 61 1750 IF(M_E0.0) GO TO 61 1760 CCM+MSCY(I,JI,K)POL(AY(M),BY(M),EY(M),T(I,J-I,K)) 1765 IF(CCM.LT.0.) CCM+0. 2007 DNA=DNA+CC 2010 GU DA=DNA+CCM 2011 CO TO 62 2016 GI DIA=DTA+CC#T(I,J_K) 2022 C2 IF (I,EU.MH GO TO 63 2024 DIA=DTA+CC#T(I,J,K) 2033 GU TO 41 2033 GU TO 41 2042 C1 CC=XMSCX(2,4,K)*POL(AX(L),BX(L),EX(L),T(I,J,K)) 2065 IF(CC.LT.0.) CC=0. 2066 IF(CC.LT.0.) CC=0. 2067 DNA=DNA+CC 2072 IF(A.EQ.A) GU TO 71 2074 CCM+XMSCX(1-I,J,K)*POL(AX(M),BX(M),FX(M),T(I-I,J,K)) 2120 DIA=DTA+CC#T(I,J,K) 2120 DIA=DNA+CC 2122 IF(I.EQ.LT.0.) CC=0. 2131 TI DIA=DTA+CC#T(I,J,K) 2140 DIA=DNA+CC 2144 GU TO 72 2153 TZ IF(I.EQ.IM) GU TO 73 2135 T4 SU==T(I,J,K) 2146 GU TO 74 2146 GU TO 74 2146 T3 UTA=DTA+CC#T(I,J,K) 2155 T4 SU==T(I,J,K) 2155 T4 SU==T(I,J,K) 2255 IF(II,I,J,K)=T(S	1715	53	DTA=DTA+CC*T(I,J,K)
1724 42 CC-YM4CY([,J,K)PDL(Y(L),BY(L),FY(L),T([,J,K)) 1745 DNA=DNA+CC 1750 IF(J-Eu,I) GO TO 61 1752 M=RK(I,J-1,K) 1756 IF(M-EQ.O) GO TO 61 1760 CCM-YM4CY(I,J-1,K)*PDL(AY(M),BY(M),FY(M),T(I,J-1,K)) 1775 IF(CCM+LT+0.) CCM=0. 2005 DTA=DTA+CCM*T(I,J-1,K) 2007 DNA=DNA+CCM 2011 GO TO 62 2016 61 DTA=DTA+CC*T([,J,K) 2022 62 IF(J-E0.JM) GO TO 63 2024 OT A=DTA+CC*T([,J+L,K] 2033 GO TO 41 2033 GO TO 41 2044 CCA+MCCX(L),BX(L),BX(L),FX(L),T(I,J,K)) 2056 IF(CC,LT+O) CCE=0. 2064 DNA=DNA+CC 2052 1F(I-E0.JM) GO TO 71 2054 IF(I-E0.I)G GO TO 71 2055 M=RR(I-I,J,K) 2072 IF(I-E0.J) GO TO 71 2056 M=RR(I-I,J,K) 2074 CCM+XM4CX(I-I,J,K)+PDL(AX(M),BX(M),FX(M),T(I-I,J,K)) 2075 IF(I-E0.I) GO TO 71 2074 CCM+XM4CX(I-I,J,K) 2110 IF(CCM+LT+0.) CCM=0. 2120 DTA=DTA+CCM*T(I-I,J,K) 2137 IDA=DTA+CCM*T(I-I,J,K) 2136 GO TO 72 2131 TI DTA=DTA+CCM*T(I-I,J,K) 2137 DTA=DTA+CCM*T(I-I,J,K) 2136 GO TO 72 2131 TI DTA=DTA+CC*T(I,J,K) 2135 TA SU==T(I,J,K) 2137 DTA=DTA+CC*T(I,J,K) 2136 TA SU==T(I,J,K) 2137 CMA=DMA+CC M 2138 GO TO 74 2139 TA=DTA+CC*T(I,J,K) 2139 CMA=DMA+CC M 2140 CMA=DMA+CC M 2141 CA=TA+CC*T(I,J,K) 2152 DNA=DMA+CC M 2153 TA SU==T(I,J,K) 2154 CMA=DMA+CC M 2155 TA SU==T(I,J,K) 2155 TA SU==T(I,J,K) 2255 IF(T(I,J,K),-GT,TMTT) GO TO 400 2255 IF(T(I,J,K),-GT,TMTT) GO TO 26 C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITER,EE,IDOO) GO TO 1001 2255 IF(ITER,EE,IDOO) GO TO 26 C CALCULATE NEW GAS MEAN-TEMPERATURE 2240 IO01 TIME=TIME+DT		C	TREAT Y-COORDINATE
1743 IF ((C.(T.0.) CC=0. 1750 IF(J.EQ.1) GO TO 61 1750 IF(J.EQ.1) GO TO 61 1750 CC==YME(T,J=1,K) 1750 IF(M.EQ.0) GO TO 61 1760 CC==YME(T(J,J=1,K)*POL(AY(M),BY(M),EY(M),T(I,J=1,K)) 1775 IF(CM.IT.0.) CCM=0. 2005 DTA=DTA+CCM=T(I,J=K) 2007 DNA=DNA+CCM 2011 GO TO 62 2016 61 DTA=DTA+CC=T(I,J=K) 2022 OZ IF(J.EQ.JM) GO TO 63 2023 GO TO 41 2033 GO TO 41 2033 GO TO 41 2042 OTA=DTA+CC=T(I,J+1,K) 2042 OTA=DTA+CC=T(I,J+K) 2056 IF(CC,IT.0.) CC=0. 2061 DNA=DNA+CC 2063 IF(I:EQ.I) GO TO 71 2065 M=R(I-1,J,K) 2072 IF(M.EQ.I) GO TO 71 2072 CIF(M.EQ.I) GO TO 71 2074 CC=XMECX(Z:4,K)*POL(AX(M),BX(M),FX(M),T(I=1,J+K)) 2100 DTA=DTA+CC=T(I,J,K) 2120 DTA=DTA+CC=T(I,J,K) 2120 DTA=DTA+CC=T(I,J,K) 2121 OTF(CK,IT.0.) CC=0. 2131 71 DTA=DTA+CC=T(I,J,K) 2132 DTA=DTA+CC=T(I,J,K) 2144 GO TO 72 2131 71 DTA=DTA+CC=T(I,J,K) 2145 GO TO 74 2146 GO TO 74 2147 DTA=DTA+CC=T(I,J,K) 2157 74 SCU=T(I,G,I),GO TO 73 2137 DTA=DTA+CC=T(I,J,K) 2148 GO TO 74 2149 GO TO 74 2140 GO TO 74 2140 GO TO 74 2140 GO TO 74 2141 CIF(I:EQ.IM) GO TO 73 2137 DTA=DTA+CC=T(I,J,K) 2142 DNA=DNA+CC 2135 72 IF(I:EQ.IM) GO TO 73 2137 DTA=DTA+CC=T(I,J,K) 2140 GO TO 74 2140 GO TO 74 2141 CIF(I:EQ.IM) GO TO 73 2137 DTA=DTA+CC=T(I,J,K) 2142 DNA=DNA+CC 2157 IF(I:EQ.IM) GO TO 73 2137 DTA=DTA+CC=T(I,J,K) 2142 DNA=DNA+CC=T(I,J,K) 2152 IF(I:EQ.IM) GO TO 74 2162 IF(DMA:EQ.0.) GO, DTA:GT:I:E+100) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FORMAT(3HO@+,415,2E15.4) 2150 IF(I(I,J,K):EG.T,MET) GO TO 400 2255 IF(I(I,J,K):EG.T,MET) GO TO 400 2255 IF(I(TFK,GE:ED.00) GO TO 1001 2255 IF(I(TFK,GE:ED.00) GO TO 1001 2255 IF(I(TFK,GE:ED.00) GO TO 26 C CALCULATE NEW GAS MEAN-TEMPERATURE 2260 IO01 TIME=TIME+DT	1724	42	CC=YM*CY([,J,K)*POL(AY(L),BY(L),EY(L),T([,J,K))
1746 DNA=DNA+CC 1750 IF(J:Ey.) GO TO 61 1752 M=RK(I,J-1,K) 1751 IF(M:Eq.0) GO TO 61 1760 CCM=YM#CY(I,J-1,K)*POL(AY(M),BY(M),EY(M),T(I,J-1,K)) 1775 IF(CM.LT.0.) CCM=0. 2005 DTA=DTA+CCCM*T(I,J-1,K) 2016 G1 DTA=DTA+CC*T(I,J,K) 2017 DNA=DNA+CC 2022 G2 IF(J:EQ.JM) GO TO 63 2022 G2 IF(J.EQ.JM) GO TO 63 2023 GO TO 41 Componential (J,K) 2033 GO TO 41 Componential (J,K) 2044 CC=XMSCX(2,4;K)*POL(AX(L), BX(L), EX(L), FX(L), T(I,J,K)) 2055 DTA=DTA+CC*T((I,J,K) 2064 IF(I,EQ.I) GO TO 71 2065 M=RK(I-1,J,K) 2077 IF(M:EQ.0) GO TO 71 2064 IF(I,EQ.I) GO TO 71 2074 CCM=XM#CX(M*I(I-1,J,K) #POL(AX(M),BX(M),FX(M),T(I-1,J,K)) 2075 IF(I,GM,LT.0.), CCM=0. 2120 DNA=DNA+CC 2074 CCM=XM#CX(I-1,J,K) #POL(AX(M),BX(M),FX(M),T(I-1,J,K)) 2075 IF(I,GM,LT.0.), CCM=0. 2120 DT	1743		IF(CC.LT.0.) CC=0.
1750 IF(J.EQ.1) GO TO 61 1750 IF(J.EQ.1) GO TO 61 1750 IF(M.EQ.0) GO TO 61 1760 CCM=YMECY(I,J_I,K)*POL(AY(M),BY(M),EY(M),T(I,J-1,K)) 1775 IF(CCM.LT.0.) CCM=0. 2005 DITA=OIA+CCM=T(I,J_I,K) 2007 DNA=DNA+CCM 2011 GO TO 62 2016 61 DITA=DTA+CC*T(I,J,K) 2022 62 IF(J.EQ.JM) GO TO 63 2024 DITA=DTA+CC*T(I,J,K) 2033 GO TO 41 2033 GO TO 41 2033 GO TO 41 2042 41 CC=XMECX(2,4,K)*POL(AX(L),BX(L),EX(L),T(I,J,K)) 2056 IF(CC,IT.0.) CC=0. 2061 DNA=DNA+CC 2063 M=K(I-I,J,K) 2072 IF(M.EQ.0) GO TO 71 2072 CF(M.EQ.0) GO TO 71 2074 CCM=XM#CX(I-I,J,K) 2075 IF(CC,IT.0.) CC=0. 2100 DTA=DTA+CC*T(I,J,K) 2072 CF(M.EQ.0) GO TO 71 2075 CCM=XMECX(I-I,J,K)*POL(AX(M),BX(M),FX(M),T(I-I,J,K)) 2110 IF(CCM:TI-0,CCM=0. 2120 DTA=DTA+CC*T(I,J,K) 2122 DTA=DTA+CC*T(I,J,K) 2134 DNA=DNA+CC 2135 72 IF(T.EQ.IN) GO TO 73 2137 DTA=DTA+CC*T(I,J,K) 2146 GO TO 72 2131 71 DTA=DTA+CC*T(I,J,K) 2146 GO TO 74 2146 GO TO 74 2147 DIA=DTA+CC*T(I,J,K) 2157 74 SUM=TI(J,J,K) 2150 IF(T:EQ.IN) GO TO 73 2137 DTA=DTA+CC*T(I,J,K) 2148 DNA=DA+CC 2149 DNA=DA+CC 2140 DIA=DTA+CC*T(I,J,K) 2150 IF(T:EQ.IN) GO TO 73 2137 DTA=DTA+CC*T(I,J,K) 2140 CM TO 74 2140 GM TO 74 2140 GM TO 74 2140 GM TO 74 2141 DIA=DTA+CC*T(I,J,K) 2152 IF(TI:EQ.IN) GO TO 73 2157 CM=SUM=SUM=SUM 2253 IF(T(I,J,K),GT.TI=FID0) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FORMAT(3HO#,4I5,2EI5.4) 2251 IF(T(I,J,K),GT.TMET) GO TO 400 2252 IF(T(T,FQ.TM),GT.TMET) GO TO 400 2253 IF(T(I,J,K),GT.TMET) GO TO 400 2254 IF(TTE,G.TM TO GO TO 26 C CALCULATE NEW GAS MEAN-TEMPERATURE 2264 IF(ITEW,GS MEAN-TEMPERATURE 2265 IF(TTEW,GS MEAN-TEMPERATURE 2265 IF(TTEW,GS MEAN-TEMPERATURE 2265 IF(ITEW,GS MEAN-TEMPERATURE 2260 IO01 TIME=TIME+DT	1746		DNA=DNA+CC
1752 M=NR(1,J-1,K) 1750 IF(M=EQ.0) GO TO 61 1760 CCM=YMCY(1,J=1,K)*POL(AY(M),BY(M),EY(M),T(1,J=1,K)) 1775 IF(CCM_LT.0.) CCM=0. 2005 DTA=DTA+CC(M=T(1,J-1,K) 2016 61 DTA=DTA+CC(*T(1,J,K) 2021 62 IF(J=EQ.JM) GO TO 63 2022 62 IF(J=EQ.JM) GO TO 63 2023 63 OTA=DTA+CC*T(1,J,K) 2033 63 OTA=DTA+CC*T(1,J,K) 2033 63 OTA=DTA+CC*T(1,J,K) 2042 41 CC=XM*CX(2,4,K)*POL(AX(L),SX(L),EX(L),T(1,J,K)) 2056 IF(CC+LT.0.) CC=0. 2061 DNA=DNA+CC 2063 I+(T=EQ.L) GO TO 71 2065 M=NR(1=1,J,K) 2074 CCM=XM*CX(1=1,J,K)*POL(AX(M),BX(M),EX(M),T(1=1,J,K)) 2110 IF(CCM_LT.0.) CC=0. 2120 DTA=DTA+CC*T(1,J,K) 2122 DNA=DNA+CC 2131 71 DTA=DTA+CC*T(1,J,K) 2124 GU TO 72 2131 71 DTA=DTA+CC*T(1,J,K) 2135 72 IF(I=EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(1,J,K) 2136 TF(I=EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(1+1,J,K) 2146 GU TO 74 2146 GU TO 74 2146 GU TO 74 2146 GU TO 74 2146 GU TO A+CC*T(1+1,J,K) 2157 74 SU=T(1,J,K) 2157 74 SU=T(1,J,K) 2162 IF(I=EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(1+1,J,K) 2146 GU TO 74 2146 GU TO 74 2147 C(I=I,J,K) 2148 IF(I=I,J,K) 2149 DI A+CC*T(1+1,J,K) 2140 CU TO TA+DTA+CC*T(1+1,J,K) 2140 CU TO TA+DTA+CC*T(1+1,J,K) 2141 CI A=DTA+CC*T(1+1,J,K) 2142 CU TO TA+DTA+CC*T(1+1,J,K) 2143 DTA=DTA+CC*T(1+1,J,K) 2144 CU TO TA+DTA+CC*T(1+1,J,K) 2157 2 IF(I=EQ.IM) GO TO 74 2144 CU TO TA+DTA+CC*T(1+1,J,K) 2150 IF(I=I,J,K) 2151 F(I=I,J,K)=II=I,J,K) 2152 IF(I=I,J,K)=II=I,J,K) 2152 IF(I=I,J,K)=II=I,J,K) 2153 CU F(I=I,J,K)=II=I,J,K) 2164 CU TO TA+DTA+CC*T(I+1,J,K) 2165 IF(I=I,J,K)=II=I,J,K) 2165 IF(I=I,J,K)=II=II=I,J,K) 2167 IF(I=I,J,K)=II=I,J,K) 2168 IF(I=I,J,K)=II=I,J,K) 217 IF(I=I,J,K)=II=I,J,K) 2180 IF(I=I,J,K)=II=I,J,K) 2251 IF(I=I,J,K)=II=I,J,K) 2253 IF(I=I,J,K)=II=I,J,K) 2253 IF(I=I,J,K)=II=I,J,K) 2254 IF(I=I,J,K)=II=I,J,K) 2255 IF(I=I,J,K)=II=I,J,K) 2256 IF(I=I,J,K)=II=I,J,K) 2257 IF(I=I,J,K)=II=I,J,K) 2250 IF(I=I,J,K)=II=I,J,K) 2250 IF(I=I,J,K)=II=I,J,K) 2250 IF(I=I,J,K)=II=I,J,K) 2250 IF(I=I,J,K)=II=I,J,K) 2250 IF(I=I,J,K)=II=I,J,K) 2251 IF(I=I,J,K)=II=I,J,K) 2251 IF(I=I,J,K)=II=I,J,K)	1750		IF(J.EQ.1) GO TO 61
1750 IF(M,EQ.0) G0 T0 G1 1760 CCM+YMCY(I,J-J,K)*D0L(AY(M),BY(M),EY(M),T(I,J-I,K)) 1775 IF(CCM_LI.0.) CCM=0. 2005 DTA=DTA+CCM+T(I,J-I,K) 2007 DNA=DNA+CCM 2011 G0 T0 G2 2016 G1 DTA=DTA+CCM+T(I,J,K) 2026 20 IF(J,EQ.JM) C0 T0 G3 2024 DTA=DTA+CC+T(I,J,K) 2033 G0 T0 41 2033 G0 T0 41 2033 G0 T0 41 2034 C1 TA=DTA+CC+T(I,J,K) C FREAT X=C00RDINATE 2044 1 CC=XMCX(Z,4,K)*PDL(AX(L),SX(L),EX(L),T(I,J,K)) 2056 IF(CC,IT.0.) CC=0. 2063 IF(I.EQ.IN) C0 T0 71 2056 M=NN(I-1,J,K) 2072 IF(M,EQ.0) G0 T0 71 2074 CCM=XMCX(I-1,J,K)*PDL(AX(M),BX(M),EX(M),T(I-1,J,K)) 2110 IF(CCM_LT.0.) CCM=0. 2120 DTA=DTA+CCM+T(I,J,K) 2122 DTA=DTA+CCM+T(I,J,K) 2131 71 DTA=DTA+CCM+T(I,J,K) 2135 72 IF(I.EQ.IM) G0 TO 73 2136 T4=DTA+CCM+T(I,J,K) 2136 T4=DTA+CCM+T(I,J,K) 2137 DTA=DTA+CCM+T(I,J,K) 2136 T4=DTA+CCM+T(I,J,K) 2137 DTA=DTA+CCM+T(I,J,K) 2146 G0 T0 74 2146 G0 T0 74 2146 G0 T0 74 2147 T(I,J,K)=T(I,J,K) 2155 74 SU==T(I,J,K) 2155 74 SU==T(I,J,K) 2155 74 SU==T(I,J,K) 2162 IF(INA,EQ.0. OR. DTA.GT.I.E+100) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FORMATT3H0**,415,2EI5.40 2223 SUM=SUM+ABS(SU) 2225 IF(I(I,J,K).GT.TMTT) G0 T0 400 2235 30 CONTINUE C CALCULATE NEW GAS MEAN=TEMPERATURE 2245 IF(ITPFE,E0.1) G1=CTC=QTG/CCMECP) 2255 IF(ITPFE,E0.1) G1=CTC=QTG/CCMECP) 2255 IF(ITPFE,E0.1) G1=CTC=QTG/CCMECP) 2255 IF(ITPFE,E0.1) G1=CTC=QTG/CCMECP) 2255 IF(ITPE,E0.1) G1=CTC=QTG/CCMECP) 255 IF(I	1752		M=NR(I,J-1,K)
1760 CCM=YMCY(1,J=1,K)*POL(AY(M),BY(M),EY(M),T(I,J=1,K)) 1775 IF(CCM_LT.0.) CCM=0. 2005 DTA=DTA+CCM*T(I,J=1,K) 2011 C0 TO 62 2011 C0 TO 60 C2 2012 DTA=DTA+CC*T(I,J,K) 2022 C2 IF(J,EQ,JM) GO TO 63 2022 62 IF(J,EQ,JM) GO TO 63 2023 00 TO 41 2033 C0 TO 41 2042 41 CC=XM*CXC1(J,JK) 2042 41 CC=XM*CXC2+4(K)*POL(AX(L),BX(L),EX(L),T(I,J,K)) 2056 IF(CC,LT.0.) CC=0. 2061 DNA=DNA+CC 2063 IF(I,EQ,I) GO TO 71 2074 CCM=XM*CXC1+J,K) 2110 IF(CCM_LT.0.) CC=0. 2120 DTA=DTA+CCM*T(I-J,K) 2122 DNA=DNA+CC 2131 T1 DTA=DTA+CCM*T(I-J,K) 2124 C0 TO 72 2131 T1 DTA=DTA+CCM*T(I-J,K) 2135 T2 IF(I,EQ,IM) GO TO 73 2135 T2 IF(I,EQ,IM) GO TO 73 2135 T4 STA+CCM*T(I-J,K) 2146 T3 DTA=DTA+CC*T(I,J,K) 2155 T4 SU=-T(I,J,K) 2162 IF(I,GM,EQ,0., GR, DTA,GT,LE+LOO) MRITE(6,75)I,J,K,ITER,DNA,UT 75 FDMATGM**,045 ZEL5.4) 2223 SUM=SUM+ABS(SU) 2225 IF(ITFK,EQ,IO) GT T0 26 C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITFK,EQ,IO) GT T0 26 C CALCULATE NEW GAS MEAN-TEMPERATURE 2246 IOOT TIME=TIME+DT	1750		IF(M.EQ.0) GO TO 61
1775 IF (CCM_LT.0.) CCM=0. 2007 DNA=DNA+CCM (I,J=1,K) 2011 GO TO 62 2016 61 DTA=DTA+CC*T(I,J,K) 2024 DTA=DTA+CC*T(I,J,K) 2033 GO TO 41 2033 GO TO 41 2033 GO TO 41 2033 GO TO 41 2033 CO TA=DTA+CC*T(I,J,K) C TREAT X=COURDINATE 2044 12 CC=XMCX(2,4,K)*PDL(AX(L),BX(L),EX(L),T(I,J,K)) 2056 IF (CC,LT.0.) CC=0. 2061 DNA=DNA+CC 2063 IF (I = 1, J, K) 2072 IF (M.=C0.1) GO TO 71 2065 M=NR(I=1,J,K) 2072 IF (M.=C0.0) GO TO 71 2074 CCM=XM#CX(I=1,J,K)*PDL(AX(M),BX(M),EX(M),T(I=1,J,K)) 2110 IF (CCM_LT.0.) CCM=0. 2120 DTA=DTA+CC*T(I,J,K) 2122 DTA=DTA+CC*T(I,J,K) 2131 71 DTA=DTA+CC*T(I,J,K) 2135 72 IF (I = EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(I,J,K) 2146 GO TO 72 2135 74 IF (I = EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(I,J,K) 2162 IF (DNA.EQ.0.0R. DTA.GT.1.E+100) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FDMAT(IMO*7,4I5,ZEL5.4) 2121 SU = SUM=AB(SU) 2223 SUM=SUM+ABS(SU) 2223 SUM=SUM+ABS(SU) 2224 IF (IT,J,K)=GT TO 73 2235 IF (IT,J,K)=GT MCA 2245 IF (IT,J,K)=GT MCA 2255 IF (IT,J,K)=GT MCA 2255 IF (IT,J,K)=GT MCA 2265 IF (IT,J,K)=GT MCA 2275 IF (IT,J,K)=GT MCA C CALCULATE NEW GAS MEAN-TEMPERATURE 2275 IF (IT,J,K)=GT MCA 2260 IOOI TIME=TIME+DT	1760		CCM=YM*CY(I,J-1,K)*POL(AY(M),BY(M),EY(M),T(I,J-1,K))
2005 DTA=DTA+CCM*T(I,J=1,K) 2007 DNA=DNA+CC 2016 61 DTA=DTA+CC*T(I,J,K) 2021 DNA=DNA+CC 2022 62 IF(J,E0,JM) GO TO 63 2024 OTA=DTA+CC*T(I,J,K) 2033 GO TO 41 2033 63 DTA=DTA+CC*T(I,J,K) C TRFAT X=CORDINATE 2042 41 CC=XM*CX(2,4,K)*POL(AX(L),BX(L),EX(L),T(I,J,K)) 2056 IF(C,LT,0,) CC=0. 2061 DNA=DNA+CC 2063 IF(I,EQ,I) GO TO 71 2065 M*R(I=1,J,K) 2072 IF(M,EQ,O) GO TO 71 2065 M*R(I=1,J,K) 2110 IF(CCM,LT,0,) CCM=0. 2120 DTA=DTA+CC#T(I,J,K) 2122 DNA=DNA+CC 2124 GO TO 72 2131 71 DTA=DTA+CC#T(I,J,K) 2134 DNA=DNA+CC 2135 72 IF(I,EQ,IM) GO TO 73 2137 DTA=DTA+CC#T(I,J,K) 2146 GO TO 74 2146 GO TO 74 2146 GO TO 74 2147 T(I,J,K) 2155 74 SU==T(I,J,K) 2167 T(I,J,K) 2168 T(I,I,J,K) 2170 DTA=DTA+CC#T(I,J,K) 2180 T(I,J,K)=DTA+DNA+CC 2133 T1 DTA=DTA+CC#T(I,J,K) 2146 GO TO 74 2147 SU==T(I,J,K) 2148 DNA=DNA+CC 2138 DTA=DTA+CC#T(I,J,K) 2149 CO TA=DTA+CC#T(I,J,K) 2140 TA=DTA+CC#T(I,J,K) 2140 CO TA=DTA+CC#T(I,J,K) 2155 74 SU==T(I,J,K) 2167 FORMAT(3HO*,415,2E15.4) 75 FORMAT(3HO*,415,2E15.4) 75 FORMAT(3HO*,415,2E15.4) 75 FORMAT(3HO*,415,2E15.4) 76 C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITTF,J,K)-CTTMTT) GO TO 400 2255 IF(SUM,GT,RKT) GO TO 26 C 2260 IOD1 TIME=TIME+DT	1775	************************	IF(CCM.LT.O.) CCM=0.
2007 DNA=DNA+CCM 2011 GO TO 62 2016 61 DTA=DTA+CC*T(I,J,K) 2021 DNA=DNA+CC 2022 62 IF(J,EQ.JM) GO TO 63 2024 OTA=DTA+CC*T(I,J+1,K) 2033 GO TO 41 2033 GO TO 41 2033 GO TO 41 2033 GO TO 41 2033 CO TO 41 2034 C FREAT X=COURDINATE 2042 41 CC=XM*CX(2,4,K)*PPOL(AX(L),BX(L),EX(L),T(I,J,K)) 2056 IF(CC,LT,O,) CC=O. 2061 DNA=DNA+CC 2063 IF(I,EQ,I) GO TO 71 2065 M=NR(I=1,J,K) 2074 CCM=XM*CX(I=1,J,K)*POL(AX(M),BX(M),EX(M),T(I=1,J,K)) 2110 IF(CCM,LT,O,) CCM=O. 2120 DTA=DTA+CCM*T(I=1,J,K) 2122 DNA=DNA+CC 2131 71 DTA=DTA+CC*T(I,J,K) 2134 DNA=DNA+CC 2135 72 IF(I=EQ,IM) GO TO 73 2137 DTA=DTA+CC*T(I,J,K) 2146 GO TO 74 2146 GO TO 74 2146 GO TO 74 2146 TO TO A=DTA+CC*T(I,J,K) 2155 74 SU==T(I,J,K) 2155 74 SU==T(I,J,K) 2156 T SU==T(I,J,K) 2157 T FORMAT(3HO*+,4I5,2EI5.4) 2151 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(IT(I,J,K),GO TO 70 2235 30 CONTINUE C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE:EQ.I) GT=CTC-QTG/(CMCP) 2255 IF(SUM+GT.HKT) GO TO 26 C 2260 I001 TIME=TIME+DT	2005		DTA=DTA+CCM*T(I, J-1, K)
2011 G0 T0 62 2016 61 DTA=DTA+CC*T(I,J,K) 2021 DNA=DNA+CC 2022 62 IF(J,EQ,JM) G0 T0 63 2024 DTA=DTA+CC*T(I,J+1,K) 2033 G0 T0 41 2033 G0 T0 41 2033 G0 T0 41 2033 G0 T0 41 2033 G0 T0 41 2042 41 CC=XM*CK2+,K)*POL(AX(L),BX(L),EX(L),T(I,J,K)) 2056 IF(CC,I:T.0.) CC=0. 2061 DNA=DNA+CC 2063 IF(I,EQ,I) G0 T0 T1 2065 M=NR(I-1,J,K) 2072 IF(M,EQ,0) G0 T0 T1 2072 IF(M,EQ,0) G0 T0 T1 2074 CCM=XM*CX(I-1,J,K)*POL(AX(M),BX(M),FX(M),T(I-1,J,K)) 2110 IF(CCM,LT.0.) CCM=0. 2120 DTA=DTA+CC*T(I,J,K) 2120 DTA=DTA+CC*T(I,J,K) 2122 DNA=DNA+CCM 2124 G0 T0 T2 2131 T1 DTA=DTA+CC*T(I,J,K) 2134 DNA=DNA+CC 2135 T2 IF(I,EQ,IM) G0 T0 T3 2137 DTA=DTA+CC*T(I+1,J,K) 2146 G0 T0 74 2146 T3 DTA=DTA+CC*T(I,J,K) 2155 T4 SU=-T(I,J,K) 2165 IF(I,G,IM) G0 T0 T3. 217 T(I,J,K) 2165 IF(I,G,IM) G0 T0 T3. 2187 DTA=DTA+CC*T(I,J,K) 2184 G0 T0 74 2195 IF(I,EQ,IM) G0 T0 T3 2137 DTA=DTA+CC*T(I,J,K) 2146 G0 T0 74 2146 T3 DTA=DTA+CC*T(I,J,K) 2155 T4 SU=-T(I,J,K) 2165 IF(INA,EQ,0., OR, DTA,GT,I,E+100) WRITE(6,T5)[,J,K,ITER,DNA,DT T5 FORMAT(3H0**,415,2E15.4) 75 FORMAT(3H0**,415,2E15.4) 75 FORMAT(3H0**,415,2E15.4) 76 C 77 CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE-EQ,I) CT=CTC-QTG/CCM*CP) 2255 IF(SUM,GT,RKT) G0 T0 26 C 2260 1001 TIME=TIME+DT	2007		DNA= DNA +CCM
2016 61 DTA=DTA+CC+T(I,J,K) 2021 DNA=DNA+CC 2022 62 IF(J,EQ,JM) CD TD 63 2024 DTA=DTA+CC+T(I,J+I,K) 2033 63 DTA=DTA+CC+T(I,J,K) C FREAT X-COORDIMATE 2042 41 CC=XM*CX(2,4,K)*PDL(AX(L),BX(L),EX(L),T(I,J,K)) 2056 IF(CC,IT,0,1) CC=0. 2061 DNA=DNA+CC 2063 IF(I,EQ,I) GO TO 71 2065 M=NR(I-1,J,K) 2072 IF(M,EQ,I) GO TO 71 2074 CCM*XM*CX(I-1,J,K)*PDL(AX(M),BX(M),FX(M),T(I-1,J,K)) 2110 IF(CCM,IT,0,1) CCM=0. 2120 DTA=DTA+CCM*T(I-1,J,K) 2122 DNA=DNA+CC 2131 71 DTA=DTA+CCM*T(I-1,J,K) 2135 72 IF(I,EQ,IM) GO TO 73 2137 DTA=DTA+CCM*T(I+1,J,K) 2146 GO TO 74 2135 74 SU=-T(I,J,K) 2155 74 SU=-T(I,J,K) 2155 74 SU=-T(I,J,K) 2155 74 SU=-T(I,J,K) 2150 TF(DRAT(3H0*K,415,2EI3.4) 75 FORMAT(3H0*K,415,2EI3.4) 75 FORMAT(3H0*K,415,2EI3.4) 217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2225 IF(TIYPE,EQ,I) GT=CT=QTG/CCM*CP) 2225 IF(TIYPE,EQ,I) GT=CT=QTG/CCM*CP) 2255 IF(SUM+GT+RKT) GO TO 26 C 2260 I001 TIME=TIME+DT	2011		GO TO 62
2021 DNA=DNA+CC 2022 62 IF(J.EQ.JM) CD TO 63 2024 DTA=DTA+CC*T(I,J+1,K) 2033 GD TO 41 2033 63 DTA=CTA+CC*T(I,J,K) C TREAT X-C0ORDINATE 2042 41 CC=XM*CX(2,4,K)*POL(AX(L),BX(L),EX(L),T(I,J,K)) 2056 IF(CC,I,T,O,) CC=O. 2061 DNA=DNA+CC 2063 IF(T.EQ.I) GD TO 71 2065 M=NR(I-1,J,K) 2072 IF(M.EQ.O) GD TO 71 2074 CCM*XM*CX(I-1,J,K)*POL(AX(M),BX(M),FX(M),T(I-1,J,K)) 2110 IF(CCM.IT.O.) CCM=O. 2120 DTA=DTA+CCM*T(I-1,J,K) 2122 DNA=DNA+CC 2131 71 DTA=DTA+CC*T(I,J,K) 2135 72 IF(T.EQ.IM) GD TO 73 2137 DTA=DTA+CC*T(I,J,K) 2146 GD TO 74 2146 GD TO 74 2146 73 DTA=DTA+CC*T(I,J,K) 2157 74 SU=-T(I,J,K) 2162 IF(DNA,EQ.J.GR, DTA.GT.I.E+100) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FORMAT(3HO**,4I5,2EI5.4) 217 T(I,J,K) 218 IF(T,J,K) 218 IF(T,J,K),CT.IMIT) GD TD 400 2235 30 CONTINUE C C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(TIYPE-EQ.I) GT=CTC-QTG/(CW*CP) 2255 IF(SUM.GT.KKT) GD TD 26 C 2260 IO01 TIME=TIME+DT	2016	61	DTA=DTA+CC*T(I,J,K)
2022 62 IF(J.EQ.JM) GO TO 63 2024 DTA=DTA+CC*T(I,J+I,K) 2033 GO TO 41 2033 63 DTA=DTA+CC*T(I,J,K) C TREAT X=COORDINATE 2042 41 CC=XM*CX(2,4,K)*POL(AX(L),EX(L),EX(L),T(I,J,K)) 2056 IF(CC.LT.O.) CC=O. 2061 DNA=DNA+CC 2063 IF(I.EQ.I) GO TO 71 2065 M=RR(I-I,J,K) 2072 IF(M.EQ.O) GO TO 71 2074 CCM=XM*CX(I-1,J,K)*POL(AX(M),BX(M),EX(M),T(I-1,J,K)) 2110 IF(CCM.LT.O.) CCM=O. 2120 DTA=DTA+CCM*T(I-1,J,K) 2122 DNA=DNA+CC 2124 GO TO 72 2131 71 DTA=DTA+CCM*T(I-1,J,K) 2135 72 IF(I.EQ.IM) GO TO 73 2137 DTA=DTA+CCK*T(I+1,J,K) 2146 GO TO 74 2146 T3 DTA=DTA+CC*T(I+1,J,K) 2157 FORMAT(3HO**,415,2E15.4) 2157 FORMAT(3HO**,415,2E15.4) 217 T(I,J,K)=DTA/DNA 2223 SUM=SUM+AB(SU) 2224 CAULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2250 IF(SUM+GT+RKT) GO TO 26 C 2260 IO01 TIME=TIME+DT	2021	-	DNA=DNA+CC
2024 DT A=DTA+CC*T([,J+1,K) 2033 GD TO 41 2033 GD TA 0 TA 4 C TREAT X=COORDINATE 2042 41 CC=XM*CX(2,4,K)*POL(AX(L),BX(L),EX(L),T(I,J,K)) 2056 IF(CC.tTo.).CC=0. 2061 DNA=DNA+CC 2063 IF(I,E0,1) GD TO 71 2065 M=NR(I-1,J,K) 2072 IF(M.EQ.O) GD TU 71 2074 CCM=XM*CX(1-1,J,K)*POL(AX(M),BX(M),EX(M),T(I-1,J,K)) 2110 IF(CCM.LT.0.) CCM=0. 2120 DTA=DTA+CCM*T(I-1,J,K) 2122 DNA=DNA+CC 2122 DTA=DTA+CCM*T(I-1,J,K) 2124 GO TO 72 2131 71 DTA=DTA+CCA*T(I,J,K) 2134 DNA=DNA+CC 2135 72 IF(I.EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(I,J,K) 2146 GU TO 74 2146 73 DTA=DTA+CC*T(I,J,K) 2155 74 SU=-T(I,J,K) 2155 74 SU=-T(I,J,K) 2152 IF(T(I,J,K)-CT.I.E+100) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FORMAT(3HO**,415,2E15.4) 2217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(T(I,J,K)-GT.TMIT) GO TO 400 2235 30 CONTINUE C C C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2255 IF(ISUM.GT.KKT) GO TO 26 C 2260 IO01 TIME=TIME+DT	2022	62	IF(J.EQ.JM) GO TO 63
2033 G0 T0 41 2033 63 DTA=DTA+CC+T(I,J,K) C TREAT X=COORDINATE 2042 41 CC=XM*CX(2,4,K)*POL(AX(L),BX(L),EX(L),T(I,J,K)) 2056 IF(CC.LT.0.) CC=0. 2061 DNA=DNA+CC 2063 IF(I.EQ.1) GO TO 71 2065 M=NR(I-1,J,K) 2072 IF(M.EQ.0) GO TO 71 2074 CCM=XM*CX(1-1,J,K)*POL(AX(M),BX(M),EX(M),T(I-1,J,K)) 2110 IF(CCM.LT.0.) CC=0. 2120 DTA=DTA+CCM*T(I-1,J,K) 2122 DNA=DNA+CC 2124 GO TO 72 2131 71 DTA=DTA+CCM*T(I-1,J,K) 2134 DNA=DNA+CC 2135 72 IF(I.EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(I,J,K) 2146 GU TO 74 2146 GU TO 74 2146 GU TO 74 2155 74 SU=-T(I,J,K) 2162 IF(ONA+EQ.0OR. DTA.GT.1.E+100) WRITE(6,75)I,J,K,ITER,DNA+DT 75 FORMAT(3H04*,415,2EL5.4) 217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(IT(I,J,K).GT.TMIT) GO TO 400 2235 30 CONTINUE C C CALCULATE NEW GAS MEAN-TEMPERATURE 2460 IOO1 TIME=TIME+DT	2024		DTA=DTA+CC*T(I,J+1,K)
2033 63 0TA=DTA+CC+T(I,J,K) C TREAT X=CUORDINATE 2042 41 CC=XM*CX(2,4,K)*POL(AX(L),BX(L),EX(L),T(I,J,K)) 2056 [F(CC,LT,0,) CC=0. 2061 0NA=DNA+CC 2063 IF(I,EQ,I] GO TO 71 2065 M=NR(I=1,J,K) 2072 IF(M,EQ,O] GO TU 71 2074 CCM=XM*CX(I=1,J,K)*POL(AX(M),BX(M),FX(M),T(I=1,J,K)) 2110 IF(CCM=LT.0.) CCM=0. 2120 DTA=DTA+CCM*T(I=1,J,K) 2122 DNA=DNA+CC 2122 0NA=DNA+CC 2135 72 IF(I,EQ,IM) GO TO 73 2137 DTA=DTA+CCM*T(I+1,J,K) 2146 GO TO 74 2146 GO TO 74 2146 GO TO 74 2147 DTA=DTA+CC*T(I+1,J,K) 2155 74 SU=-T(I,J,K) 2162 IF(IAEQ,IM) GO TO 73 2137 DTA=DTA+CC*T(I+1,J,K) 2162 IF(IAEQ,IM) GO TO 74 2164 GO TO 74 2165 74 SU=-T(I,J,K) 2162 IF(IAEQ,IM) GO TO ALGT+1.E+100) WRITE(6,75)I,J,K,ITER,DNA,JT 75 FORMAT(3HO*+AI5,2EI5.4) 2217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2225 IF(T(I,J,K).GT.TMIT) GO TO 400 2235 30 CONTINUE C C C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(IYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITER.DEALORS) GO TO 26 C 2260 IOD1 TIME=TIME+DT	2033		G0 T0 41
C FREAT X-COORDINATE 2042 41 CC=XM*CX(2,4,K)*POL(AX(L),BX(L),EX(L),T(I,J,K)) 2056 IF(CC,LT.0.) CC=0. 2061 DNA=DNA+CC 2063 IF(I.EQ.I] GO TO 71 2065 M=NR(I-1,J,K) 2072 IF(M.EQ.0) GO TO 71 2074 CCM=XM*CX(I-1,J,K)*POL(AX(M),BX(M),EX(M),T(I-1,J,K)) 2110 IF(CCM+LT.0.) CCM=0. 2120 DTA=DTA+CCM*T(I-1,J,K) 2122 DNA=DNA+CC 2131 71 DTA=DTA+CCM*T(I-1,J,K) 2134 DNA=DNA+CC 2135 72 IF(I.EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(I,J,K) 2146 GU TO 74 2146 GU TO 74 2146 GU TO 74 2146 T3 DTA=DTA+CC*T(I,J,K) 2155 74 SU=-T(I,J,K) 2162 IF(DNA=EQ.0.GR.DTA=GT=1=E+100) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FORMAT(3H0**,415,2E15.4) 72 IF(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(ITYPE.EQ.I) GT=CTC=OTG/CCM*CP) 2252 IF(ITYPE.EQ.I) GT=CTC=OTG/CCM*CP) 2252 IF(ITYPE.EQ.I) GT=CTC=OTG/CCM*CP) 2252 IF(ITYPE.EQ.I) GT=CTC=OTG/CCM*CP) 2253 IF(ITYPE.EQ.I) GT=CTC=OTG/CCM*CP) 2254 IF(ITKP.EQ.I) GT=CTC=OTG/CCM*CP) 2255 IF(ITYPE.EQ.I) GT=CTC=OTG/CCM*CP) 2256 IF(ITYPE.EQ.I) GT=CTC=OTG/CCM*CP) 2257 IF(ITYPE.EQ.I) GT=CTC=OTG/CCM*CP) 2258 IF(ITYPE.EQ.I) GT=CTC=OTG/CCM*CP) 2259 IF(ITFR.GE.I000) GO TO 1001 2559 IF(ITYPE.EQ.I) GT=CTC=OTG/CCM*CP) 2550 IF(ITM=TIME+DT	2033	63	DTA=DTA+CC*T(I,J,K)
2042 41 CC=XM*CX(2,4,K)*POL(AX(L), BX(L), EX(L), T(I,J,K)) 2056 IF(CC.LT.0.) CC=0. 2061 DNA=DNA+CC 2063 IF(I.Eq.1) GO TO 71 2065 M=NR(I=1,J,K) 2072 IF(M.Eq.0) GO TO 71 2074 CCM=XM*CX(I=1,J,K)*POL(AX(M), BX(M), EX(M),T(I=1,J,K)) 2110 IF(CCM.LT.0.) CCM=0. 2120 DTA=DTA+CCM*T(I=1,J,K) 2122 DNA=DNA+CC 2124 GO TO 72 2131 71 DTA=DTA+CC*T(I,J,K) 2135 72 IF(I.Eq.IM) GO TO 73 2137 DTA=DTA+CC*T(I+1,J,K) 2146 GO TO 74 2146 73 DTA=DTA+CC*T(I,J,K) 2155 74 SU=-T(I,J,K) 2162 IF(IONA.EQ.0. OR. DTA-GT.1.E+100) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FORMAT(3H0**,415,2E15.4) 217 T(I,J,K)=DTA/DNA 2217 C(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 223 SUM=SUM+ABS(SU) 2245 IF(IT,J,K).GT.TMTT) GO TO 400 2235 30 CONTINUE C C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITFR.GE.1000) GD TO 1001 2255 IF(ITFR.GE.1000) GD TO 26 C 2260 IOD1 TIME=TIME+DT	****************	<u> </u>	IREAT X-COORDINATE
2056 IF (CC.LT.0.) CC=0. 2061 DNA=DNA+CC 2063 IF (I.EQ.1) GO TO 71 2065 M=NR(I-1,J,K) 2072 IF (M.EQ.0) GO TO 71 2074 CCM=XM*CX(I-1,J,K)*POL(AX(M),BX(M),FX(M),T(I-1,J,K)) 2110 IF (CCM.LT.0.) CCM=0. 2120 DTA=DTA+CCM*T(I-1,J,K) 2122 DNA=DNA+CCM 2124 GO TO 72 2131 71 DTA=DTA+CC*T(I,J,K) 2134 DNA=DNA+CC 2135 72 IF (I.EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(I+1,J,K) 2146 GO TO 74 2146 73 DTA=DTA+CC*T(I,J,K) 2155 74 SU=-T(I,J,K) 2162 IF (DNA-EQ.0OR. DTA-GT.1.E+100) WR ITE(6,75)I,J,K,ITER,DNA,DT 75 FORMAT(3H0**,415,2E15.4) 217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 223 SUM=SUM+ABS(SU) 225 IF (IT(I,J,K),GT.TMTT) GO TO 400 2235 30 CONTINUE C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF (ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2255 IF (SUM.GT.RKT) GO TO 26 C 2260 IOD1 TIME=TIME+DT	2042	41	CC = XM * C X (2, 4, K) * POI (AX(1), BX(1), FX(1), T(1, J, K))
2061 DNA=DNA+CC 2063 IF(I-EQ.I) GO TO T1 2065 M=NR(I-1,J,K) 2072 IF(M.EQ.O) GO TO T1 2074 CCM=XM*CX(I-1,J,K)*PDL(AX(M),BX(M),FX(M),T(I-1,J,K)) 2110 IF(CCM.LT.O.) CCM=O. 2120 DTA=DTA+CCM*T(I-1,J,K) 2122 DNA=DNA+CCM 2124 GO TO 72 2131 T1 DTA=DTA+CC*T(I,J,K) 2135 T2 IF(I.EQ.IM) GO TO T3 2137 DTA=DTA+CC*T(I+1,J,K) 2146 GU TO 74 2146 GU TO 74 2146 GU TO 74 2146 J DTA=DTA+CC*T(I+J,K) 2155 T4 SU=-T(I,J,K) 2162 IF(DNA.EQ.OOR. DTA.GT.1.E+100) WRITE(6,75)I,J,K,ITER,DNA,UT T5 FORMAT(3HO**,415,2E15.4) 217 T(I,J,K)=DTA+DXA 221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(T(I,J,K).GT.TMTT) GO TO 400 2235 JO CONTINUE C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CM*CP) 2255 IF(SUM.GT.KKT) GO TO 26 C 2260 IO01 TIME=TIME+DT	2056		[E(C, I, T, 0, r), C(=0, r)]
2063 IF(I.EQ.I) GO TO 7I 2065 M=NR(I-I,J,K) 2072 IF(M.EQ.O) GO TO 7I 2074 CCM=XM*CX(I-1,J,K)*POL(AX(M),BX(M),FX(M),T(I-1,J,K)) 2110 IF(CCM.LT.O.) CCM=0. 2120 DTA=DTA+CCM*T(I-1,J,K) 2121 DNA=DNA+CCM 2122 DNA=DNA+CC 2131 T1 2134 DNA=DNA+CC 2135 T2 2136 GO TO 72 2137 DTA=DTA+CC*T(I+J,K) 2146 GU TO 74 2155 74 2162 IF(DNA.EQ.0OR. DTA.GT.1.E+100) WRITE(6,75)I,J,K,ITER,DNA.DT 75 FORMAT(3H0**,415,2E15.4) 71 T(I,J,K) 2217 T(I,J,K)=DTA/DNA 2221 SUM=SUH+ABS(SU) 22223 SUM=SUH+ABS(SU) 2224 SUM=SUH+ABS(SU) 2225 IF(IT(I,J,K).GT.TMITT) GO TO 400 2235 30 CONTINUE C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(SUM.GT.KKT) GO TO 26 C	2061		$\partial N \Delta = D N \Delta + C C$
2065 M=NR(I=1,J,K) 2072 IF(M.EQ.0) GO TO 71 2074 CCM=XM*CX(I=1,J,K)*POL(AX(M),BX(M),FX(M),T(I=1,J,K)) 2110 IF(CCM.IT.0.) CCM=0. 2120 DTA=DTA+CCM*T(I=1,J,K) 2122 DNA=DNA+CC 2131 71 DTA=DTA+CC*T(I=1,J,K) 2134 DNA=DNA+CC 2135 72 IF(I=EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(I=1,J,K) 2146 GU TO 74 2147 DTA=DTA+CC*T(I=1,J,K) 2146 GU TO 74 2147 DTA=DTA+CC*T(I=1,J,K) 2155 74 SU==T(I=1,J,K) 2162 IF(DNA.EQ.0OR. DTA.GT.1.E+100) WRITE(6,75)I,J,K,ITER,DNA.UT 75 FORMAT(3HO*,415,2E15.4) 71 T(I,J,K)=DT.A/DNA 2221 SU=SU+T(I=1,J,K) 2223 SUM=SUM+ABS(SU) 2224 SU=SU+T(I=1,J,K).GT.TMTT) GO TO 400 2235 30 2245 IF(ITYPE.EQ.I) GT=CTC=QTG/(CW*CP) 2252 IF(ITYPE.EQ.I) GT=CTC=QTG/(CW*CP) 2252 IF(SUM.GT.RKT) GO TO 26 C C <t< td=""><td>2063</td><td></td><td>$F(1 + E_0) = 0$</td></t<>	2063		$F(1 + E_0) = 0$
2072 IF(M.EQ.0) GO TO 71 2074 CCM=XM*CX(I=1,J,K)*POL(AX(M),BX(M),FX(M),T(I=1,J,K)) 2110 IF(CCM.LT.O.) CCM=0. 2120 DTA=DTA+CCM*T(I=1,J,K) 2122 DNA=DTA+CCM*T(I=1,J,K) 2124 GO TO 72 2131 71 2145 DNA=DNA+CC 2135 72 2136 DTA=DTA+CC*T(I+1,J,K) 2137 DTA=DTA+CC*T(I+1,J,K) 2146 GO TO 74 2137 DTA=DTA+CC*T(I+1,J,K) 2146 GO TO 74 2155 74 SU=-rt(1,J,K) 2162 IF(ONA-EQ.0OR. DTA-GT.1.E+100) WRITE(6,75)I,J,K,ITER,DNA,UT 75 FORMAT(3HO**,415,2E15.4) 217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(TT(I,J,K).GT.TMTT) GO TO 400 2235 30 CONTINUE C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(TTYPE.EQ.1) GT=CTC-QTG/(CW*CP) 2252 IF(ITYPE.EQ.1) GT=CTC-QTG/(CW*CP) 2255 IF(SUM.GT.RKT) GO TO 26 C <	2065		$M = NR \left(I - 1 \cdot I \cdot K \right)$
2074 CCM=XM*CX(I-1,J,K)*POL(AX(M),BX(M),FX(M),T(I-1,J,K)) 2110 IF(CCM.LT.O.) CCM=0. 2120 DTA=DTA+CCM*T(I-1,J,K) 2122 DNA=DNA+CCM 2124 GO TO 72 2131 71 DTA=DTA+CC*T(I,J,K) 2134 DNA=DNA+CC 2135 72 IF(I.EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(I+1,J,K) 2146 GU TO 74 2146 GU TO 74 2146 T3 UTA=DTA+CC*T(I+1,J,K) 2155 74 SU=-T(I,J,K) 2162 IF(DNA.EQ.OGR. DTA.GT.1.E+100) WRITE(6,75)I,J,K,ITER,DNA,UT 75 FORMAT(3HO**,415,2E15.4) 2217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(T(I,J,K).GT.TMTT) GO TO 400 2235 30 CONTINUE C C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(SUM.GT.RKT) GO TO 26 C 2260 IOD1 TIME=TIME+DT	2072	•••••••••••••••••••••••	IE(M,E0,0) GO TO 7)
2110 IF(CCM.LT.O.) CCM=0. 2120 DTA=DTA+CCM*T(I=1,J,K) 2122 DNA=DNA+CCM 2124 GO TO 72 2131 T1 2134 DNA=DTA+CC*T(I,J,K) 2135 72 2136 TF(I.EQ.IM) GO TO 73 2146 GO TO 74 2147 DTA=DTA+CC*T(I+1,J,K) 2148 GU TO 74 2149 GU TO 74 2140 TA=DTA+CC*T(I+1,J,K) 2141 FICONA.EQ.0OR. DTA.GT.1.E+100) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FORMAT(3HO**,415,2E15.4) 76 T(I,J,K)=DTA/DNA 221 SU=SU+T(I,J,K) 2221 SU=SU+T(I,J,K) 2223 SUM= SUM+ABS(SU) 2224 SU=SU+T(I,J,K).GT.TMTT) GO TO 400 2235 30 C CALCULATE NEW GAS MEAN-TEMPERATURE C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2255 IF(SUM.GT.RKT) GO TO 26 C C 2260 1001 </td <td>2074</td> <td></td> <td>$CCM = XM + CX(T-1, I, K) + P(I) (\Delta X(M), BX(M), FX(M), T(T-1, I, K))$</td>	2074		$CCM = XM + CX(T-1, I, K) + P(I) (\Delta X(M), BX(M), FX(M), T(T-1, I, K))$
2120 DTA=DTA+CCM*T(I-1,J,K) 2122 DNA=DNA+CCM 2124 GU TO 72 2131 71 DTA=DTA+CC*T(I,J,K) 2134 DNA=DNA+CC 2135 72 IF(I.EQ.IM) GU TO 73 2137 DTA=DTA+CC*T(I+J,K) 2146 GU TO 74 2145 GU TO 74 2146 T3 2155 74 2162 IF(DNA.EQ.OOR. DTA.GT.1.E+100) WRITE(6,75)I,J,K,ITER,DNA.DT 75 FORMAT(3H0**,415,2E15.4) 217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(T(I,J,K).GT.TMTT) GO TO 400 2235 30 C C C C C C C C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2255 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2255 IF(ISUM.GT.RKT) GO TO 26 C C 2260 1001 TIME=TIME+DT	2110		$IF(C(M_{1} T_{0})) \cap (M=0)$
2122 DNA=DNA+CCM 2124 GU TO 72 2131 71 DTA=DTA+CC*T(I,J,K) 2134 DNA=DNA+CC 2135 72 IF(I.EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(I+1,J,K) 2146 GU TO 74 2145 GU TO 74 2146 GU TO 74 2147 DTA=DTA+CC*T(I,J,K) 2162 IF(DNA.EQ.OOR. DTA.GT.1.E+100) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FORMAT(3HO**,415,2E15.4) 217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2224 SU=SU+T(I,J,K) 225 IF(T(I,J,K).GT.TMTT) GO TO 400 2255 IF(T(I,J,K).GT.TMTT) GO TO 400 2255 IF(TYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2255 IF(ITYPE.EQ.I) GT 0 26 C C 2260 1001 71ME=TIME+DT	2120		DTA=DTA+CCM*T(I-1, I, K)
2122 GNA=GNA+GCH 2131 71 DTA=DTA+CC*T(I,J,K) 2134 DNA=DNA+CC 2135 72 IF(I.EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(I+1,J,K) 2146 GU TO 74 2147 OTA=DTA+CC*T(I,J,K) 2162 IF(DNA.EQ.0OR.DTA.GT.I.E+100) WRITE(6,75)I,J,K,ITER,DNA,UT 75 FORMAT(3H0**,415,2E15.4) 2217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(T(I,J,K).GT.TMTT) GO TO 400 2235 30 C C C C C C C C 2252 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITER.GE.I000) GD TO 1001 2255 IF(SUM.GT.RKT) GO TO 26 C C 2260 1001 TIME=TIME+DT	2122	87.97 .77 - 10.07 - 10.07 - 10.07 - 10.07 - 10.07	$\partial NA = \partial NA + C M$
2124 00 10 12 2131 71 0TA=DTA+CC*T(I,J,K) 2134 0NA=DNA+CC 2135 72 IF(I.EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(I+1,J,K) 2146 GO TO 74 2145 74 2146 TA=DTA+CC*T(I,J,K) 2162 IF(DNA.EQ.OOR. DTA.GT.L.E+100) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FORMAT(3HO**,415,2E15.4) 217 T(I,J,K)=DTA/DNA 2211 SU=SU+T(I,J,K) 2221 SU=SU+T(I,J,K) 2222 SUM=SUH*ABS(SU) 2223 SUM=SU+ABS(SU) 2225 IF(T(I,J,K).GT.TMIT) GO TO 400 2235 30 CONTINUE C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(SUM.GT.RKT) GO TO 26 C C 2260 1001 TIME=TIME+DT	2124		
2131 11 00 A=DAACC 2135 72 IF(I.EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(I+1,J,K) 2146 GU TO 74 2146 73 DTA=DTA+CC*T(I,J,K) 2155 74 SU=-T(I,J,K) 2162 IF(DNA.EQ.0OR. DTA.GT.1.E+100) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FORMAT(3H0**,415,2E15.4) 2217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(T(I,J,K).GT.TMTT) GO TO 400 2235 30 CONTINUE C C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(SUM.GT.RKT) GO TO 26 C 2260 IOD1 TIME=TIME+DT	2127	71	$\frac{1}{10} \frac{1}{10} \frac$
2135 72 IF(I.EQ.IM) GO TO 73 2137 DTA=DTA+CC*T(I+1,J,K) 2146 GU TO 74 2145 GU TO 74 2146 TO TA=DTA+CC*T(I,J,K) 2155 74 2162 IF(DNA.EQ.O. OR. DTA.GT.L.E+100) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FORMAT(3H0**,415,2E15.4) 217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 22245 IF(T(I,J,K).GT.TMTT) GO TO 400 2235 30 C CALCULATE NEW GAS MEAN-TEMPERATURE C C 2245 IF(ITYPE.EQ.1) GT=CTC-QTG/(CW*CP) 2252 IF(ITYPE.EQ.1) GT=CTC-QTG/(CW*CP) 2255 IF(SUM.GT.RKT) GO TO 26 C C 2260 IO01 TIME=TIME+DT	2131	<i>*</i> L	
2137 DTA=DTA+CC*T(I+1,J,K) 2137 DTA=DTA+CC*T(I+1,J,K) 2146 GU TO 74 2146 73 DTA=DTA+CC*T(I,J,K) 2155 74 SU=-T(I,J,K) 2162 IF(DNA.EQ.OOR. DTA.GT.1.E+100) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FORMAT(3H0**,415,2E15.4) 2217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(T(I,J,K).GT.TMIT) GO TO 400 2235 30 CONTINUE C C C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITER.GE.1000) GO TO 1001 2255 IF(SUM.GT.RKT) GO TO 26 C 2260 I001 TIME=TIME+DT	2135	7 0	$\frac{1}{1} \frac{1}{1} \frac{1}$
2146 GU TO 74 2146 GU TO 74 2146 To TA = DTA + CC * T(I, J, K) 2155 74 2162 IF(DNA.EQ.OOR. DTA.GT.1.E+100) WRITE(6,75)I, J, K, ITER, DNA, DT 75 FORMAT(3H0**,415,2E15.4) 2217 T(I, J, K) = DTA/DNA 2221 SU=SU+T(I, J, K) 2223 SUM= SUM + ABS(SU) 2225 IF(T(I, J, K).GT.TMTT) GO TO 400 2235 30 C C C C ALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITTPE.EQ.IOO) GO TO 1001 2255 IF(SUM.GT.RKT) GO TO 26 C C 2260 1001 TIME=TIME+DT	2137	12	$DTA = DTA = C \times T (T+1) + L K $
2146 73 DTA=DTA+CC*T(I,J,K) 2155 74 SU=-T(I,J,K) 2162 IF(DNA.EQ.O. OR. DTA.GT.1.E+100) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FORMAT(3HO**,415,2E15.4) 2217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(T(I,J,K).GT.TMTT) GO TO 400 2235 30 CONTINUE C C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITER.GE.1000) GO TO 1001 2255 IF(SUM.GT.RKT) GO TO 26 C 2260 IO01 TIME=TIME+DT	2137		αι το 74
2155 74 SU=-T(1,J,K) 2162 IF(DNA.EQ.O. OR. DTA.GT.1.E+100) WRITE(6,75)I,J,K,ITER,DNA,DT 75 FORMAT(3H0**,415,2E15.4) 2217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(T(I,J,K).GT.TMTT) GO TO 400 2235 30 CONTINUE C C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE.EQ.1) GT=CTC-QTG/(CW*CP) 2252 IF(ITER.GE.1000) GO TO 1001 2255 IF(SUM.GT.RKT) GO TO 26 C 2260 IO01 TIME=TIME+DT	2146	73	00 +0 ++ 0TA=DTA+CC *T(T, +, K)
2162 IF(DNA.EQ.0OR. DTA.GT.1.E+100) WRITE(6,75)I, J,K,ITER,DNA,DT 75 FORMAT(3H0**,415,2E15.4) 2217 T(I, J,K)=DTA/DNA 2223 SUM=SUHT(I, J,K) 2225 IF(T(I, J, K).GT.TMTT) GO TO 400 2235 30 C C C 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITER.GE.1000) GO TO 1001 2255 IF(SUM.GT.RKT) GO TO 26 C C 2250 IF(SUM.GT.RKT) GO TO 26	2140	74	Sil=T(1, 1, K)
75 FORMAT(3H0**,4I5,2E15.4) 2217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(T(I,J,K).GT.TMTT) GO TO 400 2235 30 C C C C 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITER.GE.1000) GO TO 1001 2255 IF(SUM.GT.RKT) GO TO 26 C C 2250 IF(SUM.GT.RKT) GO TO 26 C C 2260 IO01 TIME=TIME+DT	2122	14	- JUH (TANJUNA) - Trinknuk en de - de - dek et 1 floge udtels.75tt.1.v.tted daa ot
2217 T(I,J,K)=DTA/DNA 2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(T(I,J,K).GT.TMTT) GO TO 400 2235 30 C C C C 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITYPE.EQ.IOO) GO TO 1001 2255 IF(SUM.GT.RKT) GO TO 26 C C 2260 1001 TIME=TIME+DT	2102	75	LIJUMALLAND AUNA DIAOUALALTIUUJ WKLICADJIJIJANJIICKJUNAJUU
2221 SU=SU+T(I,J,K) 2223 SUM=SUM+ABS(SU) 2225 IF(T(I,J,K).GT.TMTT) GO TO 400 2235 30 C C C C 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITER.GE.1000) GO TO 1001 2255 IF(SUM.GT.RKT) GO TO 26 C C 2260 1001 TIME=TIME+DT	2217	12	FUNIAILUNUTT\$41J\$201J\$4# T/I K_DTA/DNA
2221 SUFSUFF(1, J, K) 2223 SUM=SUM+ABS(SU) 2225 IF(T(1, J, K) • GT • TMTT) GO TO 400 2235 30 CONTINUE C C C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE•EQ•I) GT=CTC-QTG/(CW*CP) 2252 IF(ITER•GE•1000) GO TO 1001 2255 IF(SUM•GT•RKT) GO TO 26 C C 2260 1001 TIME=TIME+DT	2211		1117JTT - UTA/UNA
2225 IF(T(I,J,K).GT.TMTT) GO TO 400 2235 30 CONTINUE C C C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITER.GE.1000) GO TO 1001 2255 IF(SUM.GT.RKT) GO TO 26 C C 2260 1001 TIME=TIME+DT	2441		SU = SU + 1
2225 IFTTTT, 5, N, GT, MITT, GO TO 400 2235 30 CONTINUE C C C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IFTTYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IFTTTER.GE.1000) G0 TO 1001 2255 IFTSUM.GT.RKT) GO TO 26 C C 2260 1001 TIME=TIME+DT	2223		
2233 30 CONTINUE C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE.EQ.1) GT=CTC-QTG/(CW*CP) 2252 IF(ITER.GE.1000) G0 T0 1001 2255 IF(SUM.GT.RKT) G0 T0 26 C C 2260 1001	2220	~~	
C CALCULATE NEW GAS MEAN-TEMPERATURE 2245 IF(ITYPE.EQ.1) GT=CTC-QTG/(CW*CP) 2252 IF(ITER.GE.1000) G0 T0 1001 2255 IF(SUM.GT.RKT) G0 T0 26 C C 2260 1001 TIME=TIME+DT	22.35	<u> </u>	CUNTINUE
2245 IF(ITYPE.EQ.1) GT=CTC-QTG/(CW*CP) 2252 IF(ITER.GE.1000) G0 T0 1001 2255 IF(SUM.GT.RKT) G0 T0 26 C C 2260 1001 TIME=TIME+DT		ະບີ ມີ - ຕ	
2245 IF(ITYPE.EQ.I) GT=CTC-QTG/(CW*CP) 2252 IF(ITER.GE.1000) G0 T0 1001 2255 IF(SUM.GT.RKT) G0 T0 26 C C 2260 1001 TIME=TIME+DT		L	LALULATE NEW GAS MEAN-TEMPERATURE
2252 IF(ITER.GE-I000) G0 TO 1001 2255 IF(SUM.GT.RKT) G0 TO 26 C C 2260 1001 TIME=TIME+DT	2245		1F(11YPE+EQ+1) 61=010-Q16/(0W=CP)
2200 IF(SUM.GI.KKI) GU TU 26 C 2260 1001 TIME=TIME+DT	2232		17(1)EK.0E.10007 GU TU 1001
2260 1001 TIME=TIME+DT	2205	<i>c</i>	LF(SUM+61+KKT) 60 TU 26
2200 1001 11ME=11ME+01	11/2	L	TIME-TIME OT
	2260	1001	11MC=11MC+U1

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HE	AT		•
	2262		DO 80 K=1,KM
	2264		IF(TIME.LT.TMIN)GO TO 2000
	2266		WRITE(6,5)(PT(I),I=1,15),IVERS,MODIF
	2300		WRITE(6,3)UA, PA, TON, TOFF, TMLT
	2316		IF(DT.LE.O.) WRITE(6,90)K,ITER
**********	2330		IF(DT.GT.U.) WRITE(6,19)K, TIME, ITER
		90	FORMAT(6HOLAYER, 13, 12HSTEADY-STATE, 15, 4HITER)
	2343	2000	CONTINUE
	2343		WRITE(6,404)
		404	FORMAT(1H)
	2347		IF(ION) 101,101,102
	2351	101	WRITE(6,105)
		105	FORMAT(9H+BEAM OFF)
	2355		GU TO 103
	2356	102	WRITE(6,106)
1966-07	an a	106	FORMAT(8H+BEAM ON)
	2362	103	CONTINUE
	2362		IF(TIME.IT.TMIN)GD TO 2001
	2365		WRITE(6.404)
	2370		WRITE(6.20)(1.1=1.1M)
	2403	2001	CONTINUE
	2403		TMN = -1000
	2405		$DD = 80 J=1 \cdot 1M$
1 p.a.	2406		D(1 82 I = 1.1M)
	2407		$1 \in (E(1, 1, K), GT, 0, 1) \in (0, T0, 82)$
-	2416		$IF(T(I_{\bullet},I_{\bullet},K)) = I T_{\bullet}[MN] = G(T) = R2$
	2427		TMN = T(I + I + K)
-	2430	******	1H=1
	2430		18=1
	2431	890 M # 111 - 20 - 20 - 10 - 10 - 10 - 10 - 10	KH=K
	2433	82	$PR(I) = T(I \cdot J \cdot K) - 273 \cdot 16$
	2444		IE(TIME_IT_TMINIG) TO 2002
	2447		WRITE(6.21), J. (PR(1), I=1.IM)
-	2457	2002	CONTINUE
	2457		$DO 81 I=1 \cdot IM$
	2461		PR(I) = -SIG + F(I + J + K) + T(I + J + K) + + 4
	2474		$PR(I) = PR(I) \neq 1000$.
	2476		[F(F([.J.K))81.81.83
	2503	83	PR(I)=0.
	2505	81	TG(I,J,K)=T(I,J,K)
	2520		IF(TIME.LT.TMIN) GO TO 80
	2522		WRITE(6,22)(PR(I),I=1,IM)
	2531		IF(ITYPE) 80.80.315
	2533	315	DO 310 I=1,IM
	2535		IF(F(I,J,K))311,312,312
•	2543	311	IF(NG(I, J, K)) 312, 312, 313
	2551	313	$GMUF = SUD(CMA \cdot CMB \cdot 0 \cdot 5 * (GT + T(I \cdot J \cdot K)))$
-	2571		QCG=CONA*(GMU/GMUF)**0.33333
	2575		QCG=QCG*(1.+(CUNB*(T(I,J,K)-GT)/GMU**2)**0.3333)
	2605		QCG=QCG*(T(1, J, K)-GT)*F(1, J, K)*0.5
	2611		PR(I) = -QCG
-	2613		GO TU 310
	2614	312	PR(I)=0.
	2616	310	CONTINUE
	2621		WRITE(6,22)(PR(I),I=1,IM)
-	2627	80	CONTINUE
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HEAT	*****		• :
2634		IF(TIME.GE.TMIN) WRITE(6,404)	
2643		IF(ITYPE.EQ.0) GO TO 321	•
2644	· .	GTT=GT-273.16	
2646		WRITE (6, 320) GTT	La La Calculation de
	320	FORMAT(1H+,60X,15H GAS MEAN-TEMP=,F10.2,5HDEG.(:)
2654	321	CONTINUE	
2654		TMN=TMN-273.16	
2656		WRITE(6,2005)TIME,TMN,IH,JH,KH,ITER	
	2,005	FORMAT(11X,7H T-MAX=,F10.5,F10.2,413)	
2676		IF(DT.LE.O.) GO TO 1000	
2700		IF(TIME.LT.TSW) GO TO 100	
2702		IF(ION.EQ.1) TSW=TSW+TOFF	
2706		IF(ION.NE.1) TSW=TSW+TON	
2711		ION=-ION	
2712	100	CONTINUE	
2712		IF(TIME.LT.TMAX) GO TO 25	N WARDON OF
2715		GO TO 1000	
	C	AN ELEMENT IS SU HOT THAT IT MELTS AWAY	tion makes
2715	400	WRITE(6,401)I, J, K, ITER	
	401	FORMAT(13H **MELTING AT,413,2H**)	ANT IS
2736		F(I, J,K)=1.	
2737	n a folde 2 mars a gant og ski nærde søre og for en folde søre og for som forder for	T(I,J,K)=273.16	
2741		CX(I,J,K)=0.	
2741		CY(I,J,K)=0.	
2742		CZ(I,J,K)=0.	
2743		IF(I.GT.1)CX(I-1,J,K)=0.	
2752		IF(J.GT.1) CY(I, J-1, K) = 0.	
2761		$IF(K \cdot GT \cdot 1) CZ(I, J, K-1) = 0.$	
2770		GO TO 25	
2771		END	

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1/2NIL 1CH DIAN AU-FOIL	IN DOUBLE GAUSS	IAN AT 1W/UA	ł	HEAT VER	S 4 MC	D 1		
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ħ.,	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00		
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BEAN OFF	T-MAX=	.01200	70.45	9 3 1 11					·		
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BEAM OFF	T-MAX=	.01400	69.44	9 2 1 11	1		• /		11 - F		
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BEAM OFF	T-MAX=	.01700	68.14	9 1 1 11							
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BEAM=	4.000UA,	POWER= 2.	526E-03ME	V/POINT TO	N= .00!	50S, TOFF=	.0200	S, MELTS A	T T= 100	00.00
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BEA M	OFF						·			
		· ·							:	25
(=	1	2	3	4	5	6	7	8	. 9	
/= 1	20.00	29.60	41.95	55.33	68.07	78.95	87.17	92.24	93.96	T(°C)
	0.00	• 0 0	• 00	.01	• 01	•01	.01	• 01	.00	Pradiated (mW
Y= 2	20.00	27.67	40.18	53.68	66.42	77.28	85.47	90.54	92.25	
	0.00	.01	• 01	.01	.01	.01	.01	• 02	•01	
Y= 3	0.00	20.00	35.13	49.03	61.67	72.36	80.45	85.48	87.18	
	0.00	0.00	• 01	• 01	.01	•01	.01	• 01	.01	
1= 4	0.00	20.00	29.65	42.38	54.32	64.55	72.38	77.30	78.98	
	0.00	0.00	• 01	01	• 01	.01	.01	• 01	01	• • •
'= 5	0.00	0.00	20.00	34.00	44.86	54.32	61.68	66.45	68.10	
	0.00	0.00	0.00	• 01	•01	.01	•01	• 01	.01	
(= 6	0.00	0.00	20.00	27.21	34.01	42.38	49.04	53.69	55.34	
	0.00	0.00	0.00	•01	•01	•01	.01	• 01	.01	1. Antonio anti interna interna da anti interna 1
(= 7	0.00	0.00	0.00	20.00	20.00	29.64	35.14	40.18	41.95	
	0.00	0.00	0.00	0.00	0.00	• 01	.01	• 01	.00	
r= 8	0.00	0.00	0.00	0.00	0.00	20.00	20.00	27.65	29.58	• • • • • • • • • • • • • • • • • • •
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	. 01	.00	
Y= 9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.00	20.00	
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.00	0.00	-
	T- MA X =	. 20100	93.96	911	11					

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Material	Surface	25° C	100°C	200° C	500°C	600°C	1000° C	1200° C	1 500° C
Aluminum	U	0.022	0.028	<u> </u>	0.060				and a second of the second
	0			0.11		0.19			
Bismuth	\mathbf{U}	0.048	0.061						
Brass	υ	0.035	0.035						
	. 0			0.61		0.59			
Carbon	U	0.81	0.81		0.79				
Chromium	U		0.08						
Cobalt	U			· · · ·	0.13		0.23		
Niobium	U	1							0.19
Copper	U		0.02						
	0			0.6			0.6		
Gold	U		0.02		0.03				
Iron	U		0.05						
	0		0.74		0.84			0.89	
Lead	U		0.05					•	
	O			0.63			•		
Monel	0			0.43		0.43			
Mercury	U.	0.10	0.12						
Molybdenum	U						0.13		0.19
Nickel	U.	0.045	0.06		0.12		0.19	• • •	
	0	-		0.37				0.85	
Platinum	U	0.037	0.047		0.096		0.152	·	0.191
Silica	Amorph.						0.80	0.85	
Silver	U		0.02		0.035				
Steel	U		0.08						
	0	0.80		0.79		0.79			
Tantalum	U								0.21
Tin	U	0.043	0.05	. •					
Tungsten	U	0.024	0.032		0.071		0.15		0.23
Zinc	U	0.05				· ·		•	

Table I. Approximate grayness factors (g) for some common materials (data from Ref. 7). O = oxidized, U = unoxidized.

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Table II. Coefficients in the polynomial approximation of the heat conductivity, $\lambda = a + b T + c/T^2$, with T in °K and λ in W/cm degree.

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Material	a	, b	c	Range (°K)	Max. deviation (%)
Aluminum	2.501	$-4.184.10^{-4}$	1.114.104	15-920	+30/-15
Beryllium	1.893	$-9.897.10^{-4}$	1.316.104	20-1250	+72/-18
Bismuth	0.03162	$1.091.10^{-4}$	4.308.10 ²	70-1070	+22/-26
Cadmium	1.495	$-1.537.10^{-3}$	-2.368.10 ³	86-673	+16/-10
Chromium	1.116	$-4.421.10^{-4}$	2.192.10 ³	20-1200	+39/-14
Cobalt	2.098	-4.883.10 ⁻³	1.909.10 ³	25-293	+10.7/-6.1
Copper	4.416	$-9.729.10^{-4}$	9.236.10 ³	20-1280	+32/-9
Germanium, single cryst.	0.8568	-1.135.10 ⁻³	7.142.103	30-370	+4.1/-5.8
Gold	3.294	-5.697.10-4	4.183.10 ³	30-1300	+3.5/-3.5
Graphite	0.1405	4.557.10 ⁻⁵	2.163.10 ⁵	293-2273	+1.5/-1.6
Iridium	0.8179	1.232.10 ⁻³	9.477.10 ³	24-500	+13/-8
Iron	0.9106	-6.042.10-4	3.934.10 ³	20-1040	+32/-18
Lead	0.1079	5.539.10 ⁻⁵	2.025.104	293-1073	+28/-20
Magnesium	1.891	$-8.682.10^{-4}$	4.285.10 ³	19-1073	+28/-13
Manganese	-1.143	9.842.10 ³	1.975.10 ³	56-273	
Mercury	0.02104	1.221.10 ⁻⁴	3.360.10 ³	83-1070	+53/-21
Molybdenum	1.467	$-3.465.10^{-4}$	2.435.10 ³	33-1910	+5.8/-7.6
Nickel	0.5272	$4.078.10^{-5}$	2.401.10 ³	33-1620	+38/-24
Niobium	0.4277	$1.347.10^{-4}$	5.718.10 ²	30-1900	+10/-6
Palladium	0.1035	$1.837.10^{-3}$	2.390.10 ³	30-373	+9.9/-7.1
Platinum	0.6327	$1.307.10^{-4}$	1.347.10 ³	12-2000	+6.0/-4.0
Rhenium	0.4242	$5.748.10^{-5}$	2.347.10 ³	30-500	+12/-10
Rhodium	1.903	$-1.110.10^{-3}$	1.879.10 ²	10-500	+2.1/-3.4
Selenium, single cryst.	0.02174	-2.714.10 ⁻⁷	1.658.10 ²	25-400	+13/-14
Silicon, single cryst.	0.9443	$-5.277.10^{-4}$	8.166.103	23-1400	+72/-43
Silver	5.334	$-2.454.10^{-3}$	$6.717.10^3$	15-800	+14/-5.5
Tantalum	0.4709	6.250.10 ⁻⁵	1.878.102	30-2500	+18/-8
Thorium	0.2298	2.227.10 ⁻⁴	-3.261.10 ²	300-580	
Tin	0.2287	$3.867.10^{-5}$	3.478.10 ⁴	293-773	+22/-10
Titanium	0.2934	$-1.245.10^{-4}$	-2.398.10 ¹	10-800	+22/-17
Tungsten	1.453	$-1.801.10^{-4}$	7.139.10 ³	30-3500	+17/-9
Uranium	0.1884	$2.433.10^{-4}$	-3.047.10 ¹	20-1070	+7.5/-6.2
Vanadium	0.2870	9.620.10 ⁻⁵	-9.041.10 ¹	20-1173	+2.0/-1.3
Zinc	1.256	$-4.509.10^{-4}$	-2.037.10 ²	, 73-673	+0.5/-0.3
Zirconium	0.3256	-1.364.10-4	2.143.10 ²	36-600	+1.3/-1.9

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Material	a	b	c	Range (°K)
Aluminum	2.061	1.235.10 ⁻³		298-932
Antimony	1.266	4.0 00.10 ⁻⁴		298-903
Arsenic, metallic	1.67	7 .09.10⁻⁴		298-1100
Beryllium	2.902	2.475.10 ⁻³		298-1300
Bismuth	0.881	1.059.10 ⁻³		298-544
Cadmium	1.707	9 . 45.10 ⁻⁴		298-594
Calcium	0.8478	5.50.10 ⁻⁴	~ ~ ~	298-673
Chromium	0.3336	1.348.10 ⁻³	-5.026.10 ⁴	2 98-1823
Cobalt	2.949	2.686.10 ⁻³		298-718
Copper	3.181	8.82.10 ⁻⁴		298-1357
Germanium, cryst.	1.837	3.519.10 ⁻⁴		298-1213
Gold	2.318	$5.075.10^{-4}$	 _ '	298-1336
Graphite	3.219	8.007.10 ⁻⁴	-1.649.10 ⁵	298-2300
Iridium	2.702	6 . 905.10 ⁻⁴		298-1223
Iron	1.985	4.181.10 ⁻³	2.53.10 ⁴	298-1033
Lead	1.332	4.354.10 ⁻⁴		298-600
Magnesium	1.837	$4.49.10^{-4}$	-2.33.10 ⁴	298-923
Manganese	3.126	1.854.10 ⁻³	-2.03.10 ⁴	298-1000
Mercury	1.868			298-634
Molybdenum	2.438	5.78.10-4		298-1800
Nickel	2.576	$4.467.10^{-3}$		298-633
Niobium	2.183	3.703.10-4		298-1900
Palladium	2.604	$6.194.10^{-4}$		298 - 1828
Platinum	2.629	6.13.10 ⁻⁴		298-1800
Rhenium	2.833			298
Rhodium	2.768	1.039.10 ⁻³	_ ~ -	298-1900
Selenium, cryst.	1.55			298
Silicon, cryst.	2.071	$2.016.10^{-4}$	-3.912.104	298-1200
Silver	2.073	8.31.10 ⁻⁴	1.47.104	298-1234
Tantalum	2.234	$2.988.10^{-4}$		298-1900
Thorium	1.292	$6.182.10^{-4}$	7.05.10 ³	298-1500
Tin	1.139	1.624.10 ⁻³		298 - 505
Titanium	2.064	9.904.10 ⁻⁴		298-1150
Tungsten	2.52	3.34.10 ⁻⁴		298-2000
Uranium	1.115	$2.635.10^{-4}$	2.3.10 ⁴	298-935
Vanadium	2.598	9.622.10-4		298-1900
Zinc, metallic	2.445	1.097.10-3		298-692
Zirconium	1.276	1.240.10 ⁻³	1.678.104	298-900

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Table III. Coefficients in the polynomial approximation of the heat capacity, $C_p = a+bT+c/T^2$, with T in °K and C_p in J/ml degree. Values recalculated from Ref. 8.



Fig. 1. Pure radiation cooling at different duty cycles [Eq. (39)]; $\frac{1}{4}$ mil (~ 1.4 mg/cm²) carbon foil at 51 W/cm².



Fig. 2. The temperature ratio between Gaussian and uniform beams as a function of the fraction, α , of the beam which is focused on the foil.

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Fig. 3. Nomograph for evaluation of foil temperatures at 7.5 MeV/amu incident beam energy and pure radiation cooling. The nomograph is constructed for beryllium, aluminum, and carbon foils, and it consists of four quadrants. In the first quadrant the total dissipated power per current unit is evaluated from foil thickness, ion beam, and material. In the second quadrant the maximal power load per surface and current unit is evaluated from the total power, the foil diameter, and the fraction, α , of a Gaussian beam hitting the foil. The correction for α should be omitted for a uniform beam. In the third quadrant the maximal power per surface unit is evaluated from the total temperature is evaluated from the material and duty cycle (in percent).



Fig. 4. Nomograph for the evaluation of foil temperatures at 7.5 MeV/amu incident beam energy, uniform beam shape, and pure conduction cooling. A first-order correction for Gaussian beam shape can be made as follows. First obtain the correction factor ψ/α from Fig. 8, then read off the temperature for uniform beam shape, subtract T_{sur}, multiply the remainder by ψ/α and add T_{sur} again. The nomograph is constructed for beryllium, aluminum, and carbon foils and it consists of four quadrants. In the first quadrant the power per unit thickness and current is evaluated from the foil thickness, ion beam, and foil material. This is converted in the second quadrant to power per unit thickness by multiplication with the beam current. The third quadrant involves mainly a change of scale from logarithmic to linear but it also corrects for the duty cycle. The curves are to be used for foils where the foil diameter (cm) is smaller than $\sqrt{0.05 c \lambda / f \rho C_p}$, where c is the duty cycle (percent), λ is the heat conductivity (W/cm degree) f is the beam pulse frequency (Hz), ρ is the density (g/cm³) and C_p is the heat capacity (J/cm³ degree). In the fourth quadrant the maximum temperature is evaluated from the edge temperature and material.



Fig. 5. Pure conduction cooling at different duty cycles [Eq. (56)]; $\frac{1}{2}$ -mil, 0.71-mm diameter aluminum foil at 3.18 W/cm².



Fig. 6. Variation of the center temperature with time for $\frac{1}{2}$ -mil circular aluminum foils of 2, 1.4, 1.0, 0.71 and 0.5 cm diameter at a frequency of 50 Hz and a duty cycle of 10%.

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Fig. 7. The multiplier, ψ , for Gaussian beam shape and conduction-cooled foils as a function of the fraction, α , of the beam focused on the foil [see Eq. (61)].

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Fig. 8. The multiplier ψ/α for Gaussian beam shape and conduction-cooled foils as a function of the beam fraction, α, focused on the foil [see Eq. (62)].



Fig. 9. $\frac{1}{2}$ -mil, 1-cm-diameter gold foil in a pulsed uniform beam and a total dissipated power of 4W at a frequency of 40Hz and a duty cycle of 20%.

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Fig. 10. $\frac{1}{2}$ -mil, 1-cm-diameter gold foil in a pulsed Gaussian beam at a total dissipated power of 4W, a frequency of 40Hz and a duty cycle of 20%.



Fig. 11. $\frac{1}{2}$ -mil, 1-cm-diameter gold foil in a pulsed double-Gaussian beam at a total dissipated power of 4W, a frequency of 40Hz and a duty cycle of 20%.



Fig. 12. Temperature limits for material as a function of pressure. At high pressure the limit is set by the melting point and at low pressure by the vapor pressure.

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