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Lewis Research Center

Cleveland, Ohio

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COMPUTER CODE FOR CALCULATING TEMPERATURE PROFILES IN A PROPELLANT TANK

by Ronald L. Danilowicz
Lewis Research Center

SUMMARY

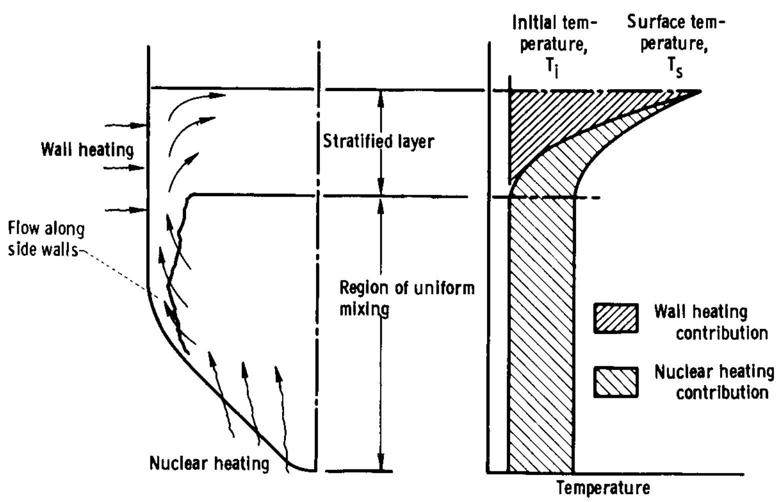
A FORTRAN IV computer code for determining temperature histories in a propellant tank due to wall and internal heating was written. The analysis, on which the code is based, is presented. The assumptions and approximations made are also discussed. Also included are instructions for use of the code, a sample problem, a flow chart and a complete listing of the code.

INTRODUCTION

In designing space vehicles using cryogenic liquid propellants, it is necessary to know how wall and internal heating affect the temperature distribution within the propellant. Many different analytical models have been developed to predict these effects on temperature profiles. Reference 1 is a review article which discusses the different approaches to this problem. An analytical model developed at Lewis Research Center is discussed in detail in reference 2. Computer calculations based on that analysis, and presented in references 2 to 4 agreed well with experimental data. Recently, renewed interest in the problem has led to modifications and expansion of the original code based on the model of reference 2. The process of developing the computer code from the theory of reference 2 is presented in this report. Because a thorough treatment of the theory exists in reference 2, only the detail necessary to show the development of the computer code is presented herein. Also presented are instructions for use of the resulting FORTRAN IV code, a sample problem, a flow chart, and a complete listing of the code.

THEORY

The theory presented in reference 2 was developed for determining the temperature profiles in an outflowing subcooled fluid subjected to both wall and internal heating.[1] The assumed analytical flow model was based on results from small-scale experiments performed at Lewis. These experiments are described in reference 5. The results showed that, when a subcooled fluid is subjected to both nonuniform internal heating and wall heating, two distinct temperature regions are developed. In the lower region the fluid is thoroughly mixed and maintains a uniform temperature profile. In the upper region or stratified layer a temperature gradient is formed from the accumulation of warm fluid from the boundary layer along the tank walls. This is illustrated in figure 1(a) for a typical propellant tank. It was further observed that the temperature profiles in the stratified layer exhibited similarity. As used herein similarity is the property that two temperature profiles $\theta(X,t)$ at different times t differ only by a scale factor in X and θ. The profile $\theta(X,t)$ is the temperature difference between $T(X,t)$ and the initial temperature T_i, and X is the axial position within the tank. (All symbols are defined in appendix A.) The analytical flow model thus assumed that the temperature profile consists



(a) Heating in typical propellant tank.

(b) Temperature profile for typical propellant tank.

Figure 1. - Schematic diagram of flow model.

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[1]The theory was developed primarily for internal heating caused by nuclear radiation. However, the theory and resulting computer code are applicable for any form of internal or bulk heating, for example, propellant heated by conduction from the tank bottom or other similar heat sources that contribute to the temperature profile in a manner indistinguishable from nuclear radiation heating.

of two parts: a lower region of constant temperature due to the internal heating and an upper region or stratified layer that has a temperature profile which exhibits the property of similarity and which is due primarily to the heat transfer from the walls. To simplify the analysis the following additional assumptions were made:

(1) The fluid is subjected to a constant ullage pressure with no heat or mass transfer across the gas-liquid surface.

(2) The liquid surface is at saturation temperature corresponding to the constant ullage pressure.

(3) The fluid flows out of the system at a constant rate.

(4) The heat input to the subcooled fluid originates from two sources: heat transfer from the tank walls and heat absorbed internally such as heat from nuclear radiation.

(5) The heat input does not vary in the radial or circumferential directions.

(6) The resulting temperature profiles do not vary in the radial or circumferential directions, except for the very thin boundary layer along the tank walls.

(7) The physical properties of the fluid do not vary appreciably over the temperature range involved. These assumptions lead to the following expression for the temperatures in the stratified layer

$$\theta(X,t) = \theta_s\left\{f(t)\left[1 - \psi(X,t)\right] + \psi(X,t)\right\} \tag{1}$$

where

$$f(t) \equiv \frac{\theta_b(t)}{\theta_s} \tag{2}$$

and

$$\psi(X,t) \equiv \frac{\theta(X,t) - \theta_b(t)}{\theta_s - \theta_b(t)} \tag{3}$$

where $\theta_b(t)$ is the temperature difference $(T_b(X,t) - T_i)$ in the uniform or bulk temperature region, θ_s is the saturation temperature difference $(T_s - T_i)$ corresponding to the ullage pressure, and $\psi(X,t)$ is a similarity parameter and may be thought of as being the contribution to $\theta(X,t)$ due to wall heating. The term $f(t)\left[1 - \psi(X,t)\right]$ is the necessary contribution of internal heating in the stratified layer to preserve the property of similarity. A typical profile illustrates the flow model in figure 1(b). Because $\psi(X,t)$ vanishes below the stratified layer, equation (1) can be used as the temperature profile in the entire fluid. The parameter $\psi(X,t)$ is assumed to have the following form

$$\psi(X, t) = \left(\frac{X - X_0(t)}{\delta(t)}\right)^n \qquad X > X_0(t)$$

$$\psi(X, t) = 0 \qquad X \leq X_0(t)$$

where $X_0(t)$ is the axial position of the bottom of the stratified layer, $\delta(t)$ is the thickness of the stratified layer, and n is a parameter which will be determined later.

The term $X_0(t)$ can also be written as $X_s(t) - \delta(t)$ where $X_s(t)$ is the position of the liquid surface. The period of growth of the stratified layer, called the initial period, is then defined by $0 \leq X_0 \leq X_s$. A later period is then defined by $0 \leq X_s \leq X_{s,l}$ where $X_{s,l}$ is the location of the liquid surface at $X_0(t) = 0$. In the later period equation (1) is replaced by

$$\theta(X, t) = \theta_s\left\{F(t)\left[1 - \left(1 - \frac{X_s(t) - X}{X_{s,l}}\right)^n\right] + \left(1 - \frac{X_s(t) - X}{X_{s,l}}\right)^n\right\} \tag{4}$$

where equations (1) and (4) are matched at t_0 corresponding to $X_0(t) = 0$ by the condition that $f(t_0) = F(t_0)$.

In order to solve for the unknowns, f(t), F(t), $X_{s,l}$, $\delta(t)$, and n, an equation for the energy balance for the system and an equation for the energy balance between the boundary layer and the wall heating are used.

For convenience, the variable X_s is introduced as the independent variable through the transformation.

$$X_s = L - \int_0^t \frac{\dot{W}_P}{\rho A(t)}\, dt \tag{5}$$

where L is the initial liquid level, $\dot{W}_P$ is the flow rate, ρ is the density of the propellant, and A(t) is the cross-sectional area of the propellant tank.

The equations which result from the theory and their numerical solution are discussed in the following section.

NUMERICAL SOLUTION OF EQUATIONS

Of the unknowns, f(t), F(t), $X_{s,l}$, $\delta(t)$, and n, the equation for n is the most straightforward and is given by

$$n = 4\,\frac{\theta_s}{\theta_w} - 1 \tag{6}$$

where θ_w is the temperature rise across the boundary layer.

Equation (6) was developed from the vertical-flat plate turbulent free-convection boundary-layer theory.

The solutions for $X_{x,l}$ and $\delta(X_s)$ both come from the same equation which is

$$\frac{d}{dX_s}\left\{\frac{\delta(X_s)A(X_s)}{(n+1)} - \frac{\delta^2(X_s)\dfrac{d}{dX_s}\left[A(X_s)\right]}{(n+1)(n+2)} + \frac{\delta^3(X_s)\dfrac{d^2}{dX_s^2}\left[A(X_s)\right]}{(n+1)(n+2)(n+3)} - \cdots\right\}$$

$$= -\frac{A(X_s)}{C_P\dot{W}_P\theta_s}\int_0^{X_s} q_w(X)\,\frac{d\sigma}{dX}\,dX \tag{7}$$

where C_P is the specific heat at constant pressure of the fluid, $q_w(X)$ is the wall heat flux, and σ is the surface area of the tank. Let

$$Q_w(X_s) = \int_0^{X_s} q_w(X)\,\frac{d\sigma}{dX}\,dX$$

As will be seen later $Q_w(X_s)$ is essential input information for the computer code.

To solve for $X_{s,l}$, integrate both sides of equation (7) with respect to X_s between the limits L and $X_{s,l}$. Noting that $\delta(L) = 0$ leads to the following equation:

$$\frac{\delta(X_{s,l})A(X_{s,l})}{(n+1)} - \frac{\delta^2(X_{s,l})\dfrac{d}{dX_{s,l}}\left[A(X_{s,l})\right]}{(n+1)(n+2)} + \frac{\delta^3(X_{s,l})\dfrac{d^2}{dX_{s,l}}\left[A(X_{s,l})\right]}{(n+1)(n+2)(n+3)} - \cdots$$

$$= -\int_L^{X_{s,l}} \frac{A(X_s)}{C_P\dot{W}_P\theta_s}\,Q_w(X_s)\,dX_s \tag{8}$$

Noting that $\delta(X_{s,l}) \equiv X_{s,l}$ gives the following equation

$$\frac{X_{s,l}A(X_{s,l})}{(n+1)} - \frac{X_{s,l}^2 \frac{d}{dX_{s,l}}\left[A(X_{s,l})\right]}{(n+1)(n+2)} + \frac{X_{s,l}^3 \frac{d^2}{dX_{s,l}^2}\left[A(X_{s,l})\right]}{(n+1)(n+2)(n+3)} - \ldots$$

$$= -\int_{L}^{X_{s,l}} \frac{A(X_s)}{C_P\dot{W}_P\theta_s} Q_w(X_s)dX_s = +\int_{X_{s,l}}^{L} \frac{A(X_s)Q_w(X_s)}{C_P\dot{W}_P\theta_s} dX_s \tag{9}$$

Equation (9) can now be put in a form suitable for solution in the computer code by letting the left side be $Z_L(X_{s,l})$ and the right side be $Z_R(X_{s,l})$, then

$$Z_L(X_{s,l}) - Z_R(X_{s,l}) = 0 \tag{10}$$

This equation is solved in the computer code by iteration, that is, by letting

$$Z_L(X_{s,l}) - Z_R(X_{s,l}) = R(X_{s,l}) \tag{11}$$

and continually readjusting $X_{s,l}$ until $R(X_{s,l})$ becomes sufficiently close to zero. The integration involved for determining $Z_R(X_{s,l})$ is performed within the code by using a straightforward Simpson's rule integration.

Equation (7) is also used, as mentioned previously, to calculate $\delta(X_s)$. Substituting $Q_w(X_s)$ on the right and taking the derivative on the left gives,

$$\delta'(X_s)\left[\frac{A(X_s)}{(n+1)} - \frac{2\delta(X_s)A'(X_s)}{(n+1)(n+2)} + \frac{3\delta^2(X_s)A''(X_s)}{(n+1)(n+2)(n+3)} - \ldots\right]$$

$$+\left[\frac{\delta(X_s)A'(X_s)}{(n+1)} - \frac{\delta^2(X_s)A''(X_s)}{(n+1)(n+2)} + \frac{\delta^3(X_s)A'''(X_s)}{(n+1)(n+2)(n+3)} - \ldots\right] = -\frac{A(X_s)}{C_P\dot{W}_P\theta_s} Q_w(X_s) \tag{12}$$

Solving for $\delta'(X_s)$ from equation (12) and using a Taylor series expansion for $\delta(X_s - \Delta X_s)$ about X_s, neglecting all but the first two terms, gives the expression for $\delta(X_s - \Delta X_s)$ used in the computer code

$$\delta(X_s - \Delta X_s) = \delta(X_s) - \delta'(X_s)\Delta X_s \tag{13}$$

The remaining unknowns are calculated by solving the following equations for $f(X_s)$ and $F(X_s)$

$$a(X_s)\frac{df(X_s)}{dX_s} - b(X_s)f(X_s) = -\frac{A(X_s)}{c_P\dot{W}_P\theta_s}Q_n(X_s) \tag{14}$$

and

$$-\alpha(X_s)\frac{dF(X_s)}{dX_s} - \gamma(X_s)\left[1 - F(X_s)\right] = \frac{A(X_s)}{c_P W_P\theta_s}\left[Q_w(X_s) + Q_n(X_s)\right] \tag{15}$$

where

$$Q_n(X_s) = \int_0^{X_s} q_{n}(X)A(X)dX \tag{16}$$

$$b(X_s) = -\frac{A(X_s)}{c_P\dot{W}_P\theta_s}Q_w(X_s) \tag{17}$$

$$a(X_s) = \int_0^{X_s} A(X)dX + \int_{X_s}^{L} b(X)dX \tag{18}$$

$$\alpha(X_s) = \int_0^{X_s} A(X)dX - \int_0^{X_s}\left(1 - \frac{X_s - X}{X_{s,l}}\right)^n A(X)dX \tag{19}$$

$$\gamma(X_s) = \frac{d}{dX_s}\int_0^{X_s}\left(1 - \frac{X_s - X}{X_{s,l}}\right)^n A(X)dX - \left(1 - \frac{X_s}{X_{s,l}}\right)^n A(X_s) \tag{20}$$

and $q_n(X_s)$ is the nuclear or internal heating rate per unit volume.

The second integral indicated in equation (18) for $a(X_s)$ is approximated by the following equation:

$$\int_{X_s}^{L} b(X)dX = \sum_{i=0}^{M} \left\{ \frac{b(L - i\Delta X_s) + b\left[L - (i + 1)\Delta X_s\right]}{2} \right\} \Delta X_s \qquad (21)$$

where

$$M = \frac{L - X_s}{\Delta X_s} - 1$$

Both quantities $f(X_s - \Delta X_s)$ and $F(X_s - \Delta X_s)$ may be expanded in a Taylor series about X_s. Neglecting all but the first two terms of each series and solving for df/dX_s and dF/dX_s from equations (14) and (15), respectively, give the following expressions which are used in the code:

$$f(X_s - \Delta X_s) = f(X_s) + \left[\frac{Q_n(X_s)A(X_s)}{a(X_s)C_P\dot{W}_P\theta_s} - \frac{b(X_s)}{a(X_s)} f(X_s)\right]\Delta X_s \qquad (22)$$

$$F(X_s - \Delta X_s) = F(X_s) + \left\{\frac{\left[Q_w(X_s) + Q_n(X_s)\right]A(X_s)}{\alpha(X_s)C_P\dot{W}_P\theta_s} + \frac{\gamma(X_s)}{\alpha(X_s)}\left[1 - F(X_s)\right]\right\}\Delta X_s \qquad (23)$$

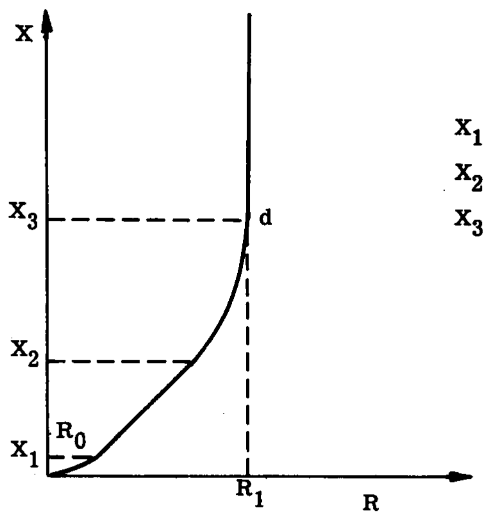
USING CODE

The quantities $Q_w(X_s)$ and $Q_n(X_s)$ that appear in the previous equations are essential input to the computer code. The values needed as a function of X_s are obtained from two subroutines WALL and NUC which are written by the code user for the heating configuration of concern.

The computer code was written specifically for a propellant tank with the geometry described in table I. The code may also be used for a cylindrical tank with a spherical bottom by letting $R_0 = R_1 = d = X_1 = X_2 = X_3$. However, the code may be rewritten for propellant tanks with other geometries. To do this, new solutions for variables which depend on $A(X_s)$ must be developed. This is a straightforward process especially in situations where there are only two or three different geometric regions.

The following lists contain the essential input information and a description of the output for the existing code.

TABLE I. - PROPELLANT TANK GEOMETRY



$X_1 = R_0(\sqrt{2} - 1)/\sqrt{2}$

$X_2 = d - R_1/\sqrt{2}$

$X_3 = d$

Region[a]	Equation of tank profile, R(X)	Cross-sectional area, A(X)	Geometry
$0 \leq X \leq X_1$	$\left[R_0^2 - (R_0 - X)^2\right]^{1/2}$	$\pi\left[-X^2 + 2R_0X\right]$	Sphere
$X_1 \leq X \leq X_2$	$X + R_0(\sqrt{2} - 1)$	$\pi\left[X^2 + 2R_0(\sqrt{2} - 1)X + R_0^2(\sqrt{2} - 1)^2\right]$	Cone
$X_2 \leq X \leq X_3$	$\left[R_1^2 - (d - X)^2\right]^{1/2}$	$\pi\left[-X^2 + 2dX + R_1^2 - d^2\right]$	Sphere
$X_3 \leq X \leq L$	R_1	πR_1^2	Cylinder

[a]Regions are defined by tangent point.

Input Instructions

The input data for the computer code is entered in the following manner:

Card 1

Card column	Variable	Format	Remarks
1-72	TITLE(I)	(12A6)	Any hollerith identification information

Cards 2, 5, 8, etc.

Card column	Variable	Format	Remarks
1-4	N	(8I4)	Number of intervals in Simpson's rule integration for determining $X_{s,l}$. Must be odd number. Use N = 11
5-8	NN		Number of time steps in later period. Use NN ≥ 50
9-12	NNN		Number of time steps in later period. Use NNN ≥ 50

Cards 3, 6, 9, etc.

Card column	Variable	Format	Remarks
1-8	R0	(10E8.4)	R_0 (see table I), ft
9-16	R1		R_1 (see table I), ft
17-24	D		d (see table I), ft
25-32	X1		X_1 (see table I), ft
33-40	X2		X_2 (see table I), ft
41-48	X3		X_3 (see table I), ft
49-56	WP		$\dot{W}_P$, flow rate, lb_{mass}/sec
57-64	AL		L, initial liquid level, ft
65-72	CONST		Constant sometimes used to vary heating rates. Use 1.0
73-80	QW1		Average wall heat flux, Btu/(sec)(ft^2)

Card 4, 7, 10, etc.

Card column	Variable	Format	Remarks
1-8	RHO	(10E8.4)	ρ, density of propellant, lb_{mass}/ft^3
9-16	BETA		Coefficient of thermal expansion of the propellant, $^{o}R^{-1}$
17-24	AMU		Viscosity of the propellant, $lb_{mass}/(ft)(sec)$
25-32	CP		C_p, specific heat at constant pressure of the propellant, $Btu/(^{o}R)(lb_{mass})$
33-40	AK		Thermal conductivity of propellant, $Btu/(sec)(^{o}R)(ft)$
41-48	TREF		θ_s, saturation temperature rise, ^{o}R
49-56	GLIL		g, acceleration due to gravity, ft/sec^2
57-64	Y		Axial point in tank at which temperature history is desired, ft
65-72	XAMB		Axial position of starting point of the boundary layer, ft
73-80	POWER		Constant sometimes used for varying heating rates. Use 1.0

As mentioned previously the integrated heating curves $Q_w(X_s)$ and $Q_n(X_s)$ are also necessary input. Ordinarily, these curves are described in the subroutines WALL and NUC with tables of values of Q_w or Q_n as a function of X_s. The heating values are then determined from these tabular arrays by interpolation. However, at the option of the user, an equation or any other means may be used to describe the curves Q_w and Q_n as a function of X_s. Communication with the main computer code is mainted through the two variables XXX and YYY which appear in common. The variable XXX corresponds to an axial coordinate, such as X_s, and YYY corresponds to a heating rate, such as Q_w in WALL or Q_n in NUC. The sample problem, presented in appendix B, gives one example of how these subroutines are used.

OUTPUT

Line	Variable	Format	Remarks
1	AL	(9E13.5)	Same as input
	R0		Same as input
	R1		Same as input
	D		Same as input
	X1		Same as input
	X2		Same as input
	X3		Same as input
	WP		Same as input
	GLIL		Same as input
2	RHO	(9E13.5)	Same as input
	BETA		Same as input
	AMU		Same as input
	CP		Same as input
	AK		Same as input
	TREF		Same as input
	CONST		Same as input
	QW1		Same as input
	XAMB		Same as input
3	V1	(8E13.5)	Volume in region of tank between $0 \leq X \leq X_1$, ft^3
	V2		Volume in region of tank between $X_1 \leq X \leq X_2$, ft^3

Line	Variable	Format	Remarks
	V3		Volume in region of tank between $X_2 \leq X \leq X_3$, ft^3
	V4		Volume in region of tank between $X_3 \leq X \leq AL$, ft^3
	T1		Time required to outflow V_4, sec
	T2		Time required to outflow V_3, sec
	T3		Time required to outflow V_2, sec
	T4		Time required to outflow V_1, sec
4	PR	(8E13.5)	Prandtl number, dimensionless
	GT		Grashof number divided by θ_w, ${}^oR^{-1}$
	TW		θ_w, ${}^oR$
	H		Heat transfer coefficient, Btu/(ft^2)(sec)(${}^oR$)
	ETA		n, dimensionless
	XSL		$X_{s,l}$, ft
	POWER		Same as input
	Y		Same as input
5, 6, 7, . . ., last line	TIME	(10E13.5)	t, sec
	TEMP		$\theta(X, X_s)$, ${}^oR$
	XS		X_s, ft
	F(XS)		$f(X_s)$ or $F(X_s)$ for the initial or later period, respectively, dimensionless
	ACAP		$b(X_s)/a(X_s)$ or $\gamma(X_s)/\alpha(X_s)$ for the initial or later period respectively, ft^{-1}

Line	Variable	Format	Remarks
	BCAP		$\frac{A(X_s)Q_w(X_s)}{C_p\dot{W}_p\theta_s a(X_s)}$ or $\frac{A(X_1)}{C_p\dot{W}_p\theta_s}\frac{\left[Q_w(X_s) + Q_n(X_s)\right]}{\alpha(X_s)}$ for the initial or later period respectively, ft^{-1}
	QWAL		$Q_w(X_s)$, Btu/sec
	QNVC		$Q_n(X_s)$, Btu/sec
	VOLUME		volume of fluid in the tank, ft^3
	DEL		$\delta(X_s)$, ft

SAMPLE CALCULATION

The sample problem described is for a 33-foot-diameter nuclear-rocket propellant tank of liquid hydrogen with a geometry as shown in table I. The pressure head corresponds to the pressure difference of 22.3 to 15.0 psia. This is equivalent to a temperature rise of 2.53° R or TREF = 2.53° R. The flow rate is 3000 pounds mass per second. The heating rates, QNVC and QWAL correspond to nuclear radiation heat deposition in the propellant, and nuclear radiation heat deposition and ambient heating of the tank walls, respectively.

The remaining input is presented in table II. The output for this calculation follows the computer listing in appendix B. A flow chart for the computer code is presented in figure 2. Note that the two subroutines, WALL and NUC, in the program listing are also input information. A plot of the resulting exit temperature history is presented in figure 3. Typical running times average around 0.04 minute per case on an IBM 7094II/7044 direct-couple system.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, December 20, 1967,
121-30-01-07-22.

TABLE II. - INPUT FOR SAMPLE PROBLEM

TITLE | PROJECT NUMBER | ANALYST | SHEET ____ OF ____

STATEMENT NUMBER | CONT | FORTRAN STATEMENT | IDENTIFICATION

```
                              SAMPLE PROBLEM
  11 400 100
  4.9792    16.5  21.269  1.4584   9.603  21.269    300.  71.604     1.0  .00075
    4.31     .01  .74-05    2.51   .35-05   2.53    32.2      0.0   14.0     1.0
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CD-7729

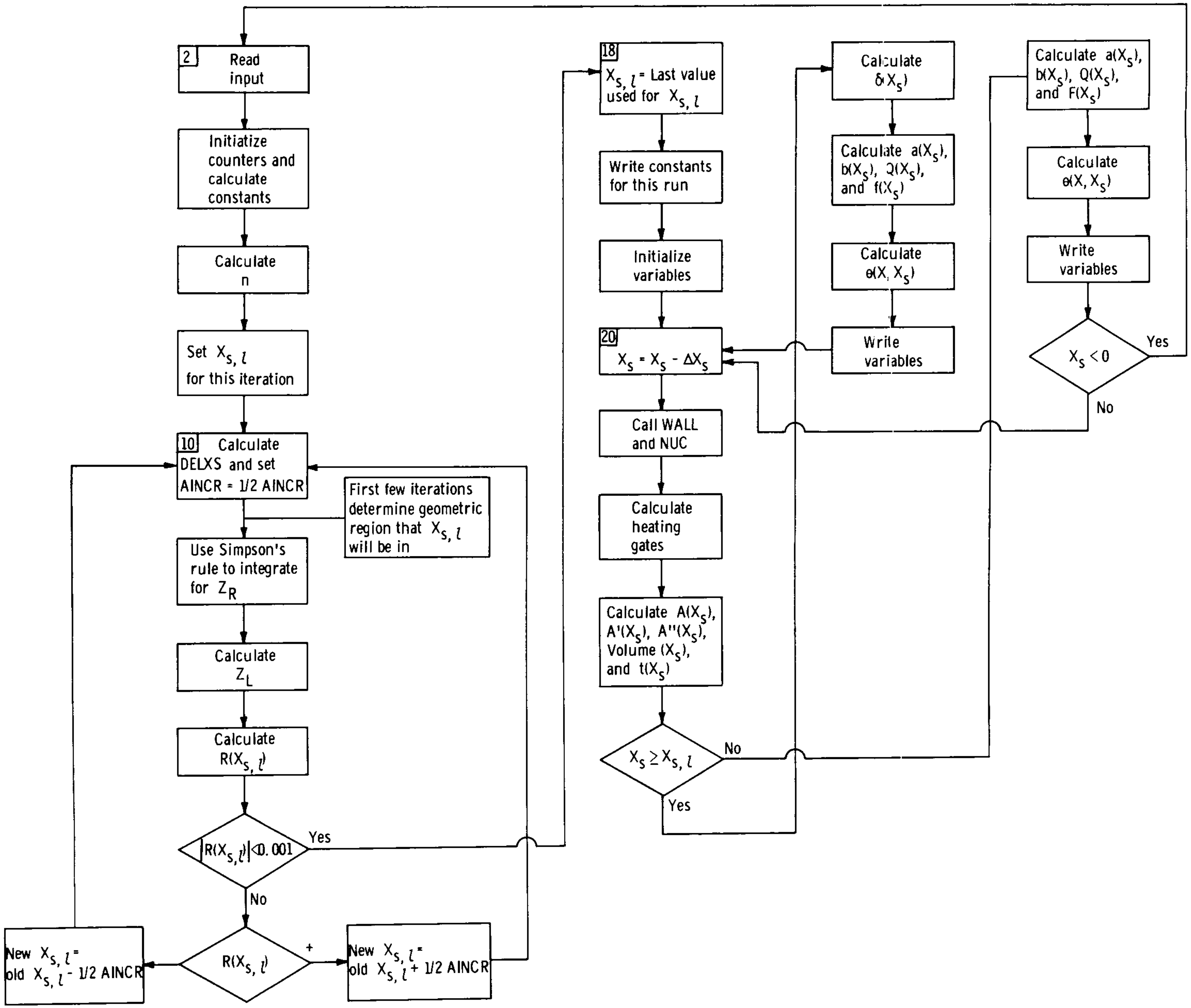

Figure 2. - Flow chart of computer code.

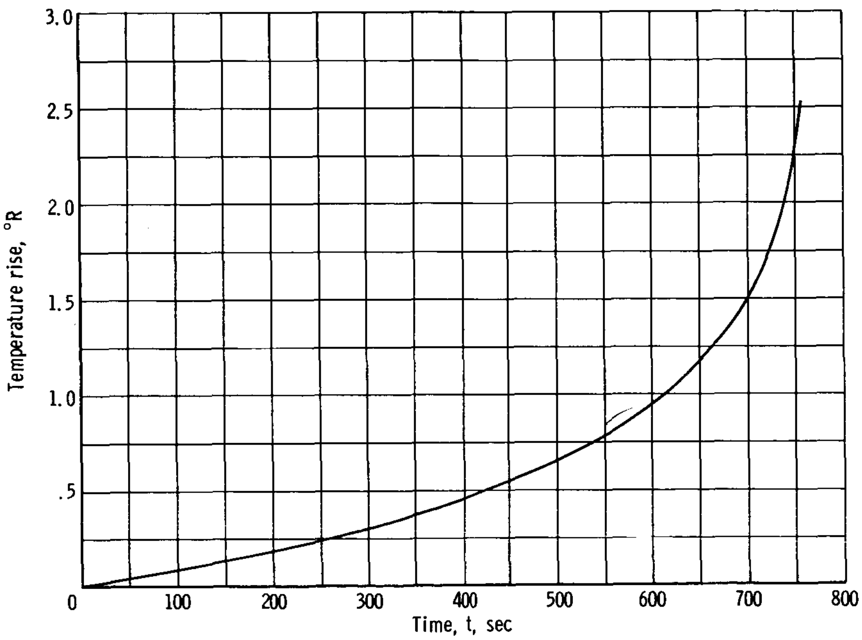

Figure 3. - Temperature history for sample problem. Axial position in propellant, 0.

APPENDIX A

SYMBOLS

Engineering symbol	FORTRAN symbol	Definition
a	A	variable defined by eq. (18)
A	AR, ARE, AREA	cross-sectional area of propellant tank, ft^2
A'	DAR, DARE, DAREA	first derivative of A with respect to X_s
A''	DDAR, DDARE	second derivative of A with respect to X_s
A'''		third derivative of A with respect to X_s
b	B	variable defined by eq. (17)
C_p	CP	specific heat at constant pressure, Btu/(^oR)(lb $_{mass}$)
d	D	see table I, ft
F	FXS	variable defined by eq. (15)
f	FXS	variable defined by eq. (2)
i		index used in summation in eq. (21)
L	AL	initial liquid level, ft
M		upper limit defined in eq. (21)
n	AN, ETA	parameter defined by eq. (6)
Q_n	QNVC	integrated nuclear heating, Btu/sec
Q_w	QWAL	integrated wall heating, Btu/sec
q_n		nuclear heating rate per unit volume, Btu/(sec)(ft^2)
q_w		wall heat flux, Btu/(sec)(ft^2)
R	TEST	remainder defined by eq. (11)
R_0	R0	see table I, ft
R_1	R1	see table I, ft
T		temperature, ^oR
T_b		bulk temperature, ^oR
T_i		initial temperature of fluid, ^oR

T_s		saturation temperature corresponding to ullage pressure, ^oR
t	TIME	time, sec
t_0		time when bottom of stratified layer first reaches $X = 0$, sec
$\dot{W}_P$	WP	flow rate, lb_{mass}/sec
X_0	XI	position of bottom of stratified layer, ft
X_1	X1	see table I, ft
X_2	X2	see table I, ft
X_3	X3	see table I, ft
X_s	XS	liquid level, ft
$X_{s,l}$	XSL	liquid level at $t = t_0$, ft
X	Y	axial position in propellant, ft
Z_L		equivalent to left side of eq. (9)
Z_R		equivalent to right side of eq. (9)
α	A	variable defined by eq. (19)
δ	DEL	stratified layer thickness, ft
δ'	DELPR	first derivative of δ with respect to X_s
ΔX_s	DELXS	change in liquid level in one time interval
γ	B	variable defined by eq. (20)
μ	AMU	viscosity, $lb_{mass}/(ft)(sec)$
ψ		defined by eq. (3)
ρ	RHO	density, lb_{mass}/ft^3
σ		surface area of tank, ft^2
θ	TEMP	temperature rise $(T - T_i)$, ^oR
θ_b		temperature rise of bulk fluid $(T - T_i)$, ^oR
θ_s	TREF	saturation temperature rise $(T_s - T_i)$, ^oR
θ_w	TW	temperature rise across boundary layer, ^oR

APPENDIX B

PROGRAM LISTING AND SAMPLE FOR TEMPERATURE PROFILES

Computer Listing

```
      DIMENSION XSPR(101),QW(100),TITLE(12),AR(101)
      COMMON XXX,YYY
  100 FORMAT(8I4)
  102 FORMAT(10E8.4)
  110 FORMAT(1H1,5X,2HAL,12X,2HR0,11X,2HR1,10X,1HD,12X,2HX1,11X,2HX2,11X
     1,2HX3,11X,2HWP,10X,4HGLIL/(9E13.5))
  112 FORMAT(1H0,4X,3HRHO,11X,4HBETA,9X,3HAMU,10X,2HCP,11X,2HAK,11X,4HTR
     1EF,7X,5HCONST,10X,3HQW1,9X,4HXAMB/(9E13.5))
  114 FORMAT(1H0,5X,2HV1,12X,2HV2,11X,2HV3,10X,2HV4,11X,2HT1,11X,2HT2,11
     1X,2HT3,11X,2HT4/(8E13.5))
  116 FORMAT(1H0,5X,2HPR,12X,2HGT,11X,2HTW,10X,1HH,12X,3HETA,10X,3HXSL,8
     1X,5HPOWER,11X,1HY/(8E13.5))
  118 FORMAT(1H0,4X,4HTIME,10X,4HTEMP,10X,2HXS,8X,5HF(XS),10X,4HACAP,9X,
     14HBCAP,9X,4HQWAL,9X,4HCNVC,8X,6HVOLUME,10X,3HDEL)
  120 FORMAT(10E13.5)
  122 FORMAT(12A6)
      READ (5,122) (TITLE(I),I=1,12)
      WRITE (6,122) (TITLE(I),I=1,12)
    2 READ (5,100) N,NN,NNN
      READ (5,102) R0,R1,D,X1,X2,X3,WP,AL,CONST,QW1
      READ (5,102) RHO,BETA,AMU,CP,AK,TREF,GLIL,Y,XAMB,POWER
C
C        CALCULATE CONSTANTS FOR THIS RUN
C
      KNN = 0
      PI = 3.14159
      A1 = -PI
      PI2 = 2.*PI
      B1 = PI2*R0
      A2 = PI
      SQ2 = SQRT(2.)
      SQ21 = SQ2-1.
      B2 = B1*SQ21
      C2 = PI*R0*R0*SQ21*SQ21
      A3 = A1
      B3 = PI2*D
      PIR = PI*R1*R1
      C3 = PIR-PI*D*D
      C4 = PIR
      PR = (CP*AMU)/AK
      GT = RHO*RHO*GLIL*BETA*AL*AL*AL/(AMU*AMU)
      TEM2 = 0.13*AK/AL
      TEM3 = (GT*PR)**0.33333
      TW = (QW1/(TEM2*TEM3))**0.75
      H = QW1/TW
      AN = 4.00*(TREF/TW)-1.0
      ETA = AN
      X12 = X1*X1
      X13 = X12*X1
```

```
      X22 = X2*X2
      X23 = X22*X2
      X32 = X3*X3
      X33 = X32*X3
      V1 = A1*X13/3.+B1*X12/2.
      V2 = A2/3.*(X23-X13)+B2/2.*(X22-X12)+C2*(X2-X1)
      V3 = A3/3.*(X33-X23)+B3/2.*(X32-X22)+C3*(X3-X2)
      V4 = C4*(AL-X3)
      RWP = RHO/WP
      T1 = V4*RWP
      T2 = V3*RWP
      T3 = V2*RWP
      T4 = V1*RWP
      A1N = AN+1.
      A2N = AN+2.
      A3N = AN+3.
      AN1 = 1./A1N
      AN2 = AN1/A2N
      AN3 = AN2/A3N
      BETAC = 1./(CP*WP*TREF*AN1)
      XXX = XAMB
      CALL WALL
      QWX = YYY
C
C         CALCULATE XSL
C
      NXSL = 0
      M = N-1
      MN = M-1
      AINCR = 2.*(AL-X3)
      XSPR(1) = X3
   10 DELXS = (AL-XSPR(1))/FLOAT(M)
      AINCR = AINCR*.5
      DO 11  I=1,M
   11 XSPR(I+1) = XSPR(I)+DELXS
      DO 12  I=1,N
      XXX = XSPR(I)
      IF(XXX.GT.XAMB) GO TO 212
      QW(I) = 0.0
      GO TO 12
  212 CALL WALL
      QW(I) = POWER*(YYY-QWX)
   12 CONTINUE
      IF(NXSL.GT.0) GO TO 80
   89 W1 = QW(1)+QW(N)
      W2 = 0.0
      DO 13 I=2,M,2
   13 W2 = W2+4.0*QW(I)
      W3 = 0.0
      DO 14  I=3,MN,2
   14 W3 = W3+2.0*QW(I)
      W = W1+W2+W3
      DEL = BETAC*(DELXS/3.0)*W
      IF(NXSL.GT.0) GO TO 899
      TEST = DEL-XSPR(1)
   76 IF (ABS(TEST)-.001) 18,18,15
```

```
15 KNN = KNN+1
   IF(KNN.GE.5C) GO TO 25
   IF(TEST)16,18,17
16 IF(KNN.EC.1) GO TO 81
   IF((NXSL.EC.1).AND.(KNN.EQ.2)) GC TC 82
   IF((NXSL.EC.2).AND.(KNN.EQ.3)) GC TC 83
   XSPR(1) = XSPR(1)-C.5*AINCR
   GC TO 10
17 XSPR(1) = XSPR(1)+C.5*AINCR
   GC TO 10
25 XSL = XSPR(1)
   GC TO 26
81 NXSL = 1
   XSPR(1) = X2
   AINCR = 2.*(X3-X2)
   GC TO 10
82 NXSL = 2
   XSPR(1) = X1
   AINCR = 2.*(X2-X1)
   GC TO 10
83 NXSL = 3
   XSPR(1) = C.0
   AINCR = 2.*X1
   GC TO 10
8C DC 84 I=1,N
   Z = XSPR(I)
   IF(Z.GE.X3)GO TO 85
   IF(Z.GE.X2)GO TO 86
   IF(Z.GE.X1)GO TO 87
   AR(I) = A1*Z*Z+B1*Z
   GC TO 88
87 AR(I) = A2*Z*Z+B2*Z+C2
   GC TO 88
86 AR(I) = A3*Z*Z+B3*Z+C3
   GO TO 88
85 AR(I) = C4
88 CCNTINUE
   QW(I) = CW(I)*AR(I)
84 CCNTINUE
   GC TO 89
899 IF(XSPR(1).GE.X3) GO TC 95
   IF(XSPR(1).GE.X2) GO TO 96
   IF(XSPR(1).GE.X1) GO TO 97
   DAR = PI2*(-XSPR(1)+RO)
   DDAR = -PI2
   GO TO 99
97 DAR = PI2*(XSPR(1)+RC*SQ21)
   DDAR = PI2
   GC TO 99
96 DAR = PI2*(-XSPR(1)+D)
   DDAR = -PI2
   GO TO 99
95 DAR = C.0
   DDAR = C.0
99 ZZ =(XSPR(1)*AR(1)*AN1-XSPR(1)*XSPR(1)*AN2*DAR+XSPR(1)*XSPR(1)*XSP
  1R(1)*DDAR*AN3)/AN1
```

```
      TEST = DEL-ZZ
      GO TO 76
   18 XSL = XSPR(1)
C
C         XSL CALCULATION FINISHED
C
   26 ZETA1 = AN1*XSL
      ZETA2=AN2 * XSL*XSL
      ZETA3 = AN3*XSL*XSL*XSL
      ALPHAN = PI2*ZETA3
      BETAN = PI2*ZETA2
      GAMMAN = PI2*RO*ZETA1
      ETAN = RO*BETAN
      DEL = 0.0
      DELXS = (AL-XSL)/FLOAT(NN)
      WRITE (6,110) AL,RO,R1,D,X1,X2,X3,WP,GLIL
      WRITE (6,112) RHO,BETA,AMU,CP,AK,TREF,CONST,QWI,XAMB
      WRITE (6,114) V1,V2,V3,V4,T1,T2,T3,T4
      WRITE (6,116) PR,GT,TW,H,ETA,XSL,POWER,Y
      WRITE (6,118)
      XS = AL
      GO TO 19
  201 DELPR = -BETAO*QWAL
      FXS = 0.0
      QOWAL = 0.0
      NZ = 0
      A = V1+V2+V3+V4
      BAN1 = BETAO*AN1
      B = -QWAL*C4*BAN1
      ACAP = B/A
      BCAP =C4*QNVC*BAN1/A
   20 XS = XS-DELXS
   19 XXX = XS
C
C         CALCULATE HEATING RATES
C
      CALL WALL
      IF (XS-XAMB) 71,71,72
   71 QNX = YYY
      QWX = 0.0
      GO TO 73
   72 QNX = 0.0
      QWAL = POWER*(YYY-QWX)
      GO TO 77
   73 QWAL = 0.0
   77 CALL NUC
      QNVC = POWER*(YYY*CONST+QNX+QWX)
      XS2 = XS*XS
      XS3 = XS2*XS
      IF(XS.GT.AL-DELXS/2.) GO TO 201
      IF(XS.GT.X3) GO TO 90
      IF(XS.GT.X2) GO TO 91
      IF(XS.GT.X1) GO TO 92
      ARE = A1*XS2+B1*XS
      DARE = PI2*(-XS+RO)
      DDARE = -PI2
```

```
      OMEGA = A1*XS3/3.+B1*XS2/2.
      TIME = T1+T2+T3+RWP*(V1-OMEGA)
      GO TO 94
   92 ARE = A2*XS2+B2*XS+C2
      DARE = PI2*(XS+RO*SQ21)
      DDARE = PI2
      OMEGA = V1+A2*(XS3-X13)/3.+B2*(XS2-X12)/2.+C2*(XS-X1)
      TIME = T1+T2+RWP*(V1+V2-OMEGA)
      GO TO 94
   91 ARE = A3*XS2+B3*XS+C3
      DARE = PI2*(-XS+D)
      DDARE = -PI2
      OMEGA = V1+V2+A3*(XS3-X23)/3.+B3*(XS2-X22)/2.+C3*(XS-X2)
      TIME = T1+RWP*(V1+V2+V3-OMEGA)
      GO TO 94
   90 ARE = C4
      DARE = 0.0
      DDARE = 0.0
      OMEGA = V1+V2+V3+C4*(XS-X3)
      TIME = C4*RHO*(AL-XS)/WP
   94 AREA = ARE
      DAREA = DARE
      IF (XSL-XS) 22,22,46
C
C        CALCULATE INITIAL PERIOD
C
   22 CONTINUE
      DEL = DEL-DELPR*DELXS
      DEL2 = DEL*DEL
      DELPR = -(ARE*BAN1*QWAL+DEL*DARE*AN1-DEL2*DDARE*AN2)/(ARE*AN1-2.*D
     1EL*DARE*AN2+3.*DEL2*DDARE*AN3)
      IF(DEL.GE.XS)DEL=XS
      XI = XS-DEL
      BP = B
      B = -AREA*QWAL*BAN1
      QQWAL = QQWAL-(B+BP)*DELXS/2.
      A = OMEGA-QQWAL
   38 Q = (AREA*CNVC)/(CP*WP*TREF)
      FXS = FXS+(BCAP-ACAP*FXS)*DELXS
      ACAP = B/A
      BCAP = Q/A
      IF (Y-XI) 40,40,42
   40 TEMP = TREF*FXS
      GO TO 44
   42 TEM1 = ((Y-XI)/DEL)**AN
      TEMP = TREF*(FXS*(1.0-TEM1)+(TEM1))
   44 IF(TEMP.GE.TREF)TEMP = TREF
      WRITE (6,120) TIME,TEMP,XS,FXS,ACAP,BCAP,QWAL,CNVC,OMEGA,DEL
      GO TO 20
C
C        INITIAL PERIOD FINISHED
C        CALCULATE FINAL PERIOD
C
   46 PHI = (1.-XS/XSL)**AN
      IF(XS.LE.X1) GO TO 48
      IF(XS.LE.X2) GO TO 50
```

```
      IF(XS.LE.X3) GO TO 52
      XS3X = (XS-X3)/XSL
      E33 = (1.-XS3X)**A3N
      E23 = (1.-XS3X)**A2N
   52 XS2X = (XS-X2)/XSL
      E32 = (1.-XS2X)**A3N
      E22 = (1.-XS2X)**A2N
   50 XS1X = (XS-X1)/XSL
      E31 = (1.-XS1X)**A3N
      E21 = (1.-XS1X)**A2N
   48 XSX = XS/XSL
      E30 = (1.-XSX)**A3N
      E20 = (1.-XSX)**A2N
      E10 = (1.-XSX)**A1N
      IF(XS.GT.X3) GO TO 54
      IF(XS.GT.X2) GO TO 56
      IF(XS.GT.X1) GO TO 58
      IF(XS.GT.O.) GO TO 60
      GO TO 2
   60 A = OMEGA-ZETA1*AREA+ZETA2*CAREA-ALPHAN*(-1.0+E30)-ETAN*E20
      B = ZETA1*CAREA+BETAN*(1.0-E20)-GAMMAN*E10-PHI*AREA
      GO TO 62
   58 A = OMEGA-ZETA1*AREA+ZETA2*CAREA-ALPHAN*(1.0-2.0*E31+E30)-ETAN*E20
      B = ZETA1*CAREA+BETAN*(-1.0+2.0*E21-E20)-GAMMAN*E10-PHI*AREA
      GO TO 62
   56 A = OMEGA-ZETA1*AREA+ZETA2*CAREA-ALPHAN*(-1.0+2.0*E32-2.0*E31 +
     1E30) - ETAN*E20
      B = ZETA1*CAREA + BETAN*(1.0-2.0*E22+2.0*E21-E20)-GAMMAN*E10-
     1PHI*AREA
      GO TO 62
   54 A = OMEGA-ZETA1*AREA-ALPHAN*(-E33+2.0*E32-2.0*E31+E30)-ETAN*E20
      B = BETAN*(E23-2.0*E22+2.0*E21-E20)-GAMMAN*E10-PHI*AREA
   62 Q = (AREA*(CNVC+QWAL     ))/(CP*WP*TREF)
      IF(NZ.GT.0)GO TO 200
      ACAP = B/A
      BCAP = Q/A
      NZ = 1
  200 FXS = FXS+(BCAP+ACAP*(1.0-FXS))*DELXS
      ACAP = B/A
      BCAP = Q/A
      IF (Y-XS) 64,64,66
   64 TEMP = TREF*(FXS*(1.0-(1.0-(XS-Y)/XSL)**AN)+(1.C-(XS-Y)/XSL) **AN)
      GO TO 68
   66 TEMP = TREF
   68 IF(TEMP.GE.TREF)TEMP = TREF
      WRITE (6,120) TIME,TEMP,XS,FXS,ACAP,BCAP,QWAL,CNVC,OMEGA
      DELXS = XSL/FLOAT(NNN)
      GO TO 20
      END
```

```
      SUBROUTINE WALL
      COMMON XXX,YYY
      YYY = 2.56589*(XXX/33.0-27.0/64.0)
      IF(XXX.LE.13.9219) YYY = 0.0
      RETURN
      END
```

```
      SUBROUTINE NUC
      DIMENSION X(13),Y(13)
      DATA X,Y/0.0,.66667,1.47,2.3,5.6,8.9,12.1,15.6,18.9,22.3,25.6,48.9
     1,100.0,0.0,42.683,73.415,102.440,215.123,312.441,384.149,428.539,4
     247.320,457.564,462.686,469.515,469.515/
      COMMON XXX,YYY
      DO 10 I=1,13
      IF(XXX.LE.X(I)) GO TO 20
   10 CONTINUE
   20 M = I-1
      IF(M)40,40,30
   30 YYY = Y(M)+(Y(M+1)-Y(M))*(XXX-X(M))/(X(M+1)-X(M))
      GO TO 50
   40 YYY = 0.0
   50 RETURN
      END
```

Sample

AL	RO	R1	D	X1
0.716C4E C2	C.49792E 01	C.1650CE C2	C.21269E 02	0.14584E 01

RHO	BETA	AMU	CP	AK
0.4310CE C1	C.10000E-C1	C.74000E-C5	C.25500E C1	0.35000E-05

V1	V2	V3	V4	T1
C.30022E C2	C.16167E C4	0.83153E C4	0.43C51E C5	C.61851E 03

PR	GT	TW	H	ETA
0.53914E 01	C.4C101E 17	C.29534E CC	0.25395E-C2	C.33266E C2

TIME	TEMP	XS	F(XS)	ACAP
0.19741E C1	0.15908E-02	C.71443E C2	0.62877E-03	-0.37329E-04
0.39481E C1	0.31857E-02	C.71283E C2	C.12592E-02	-0.37322E-04
0.59222E 01	C.47848E-C2	C.71122E C2	C.18912E-02	-C.37314E-04
C.78962E 01	C.63881E-C2	0.70961E C2	0.25249E-02	-0.373C7E-04
0.98703E 01	C.79956E-02	0.7C8C1E C2	C.316C3E-02	-C.37300E-04
0.11844E C2	C.96074E-C2	0.70640E C2	0.37974E-02	-0.37292E-04
C.13818E 02	0.11223E-C1	C.70479E C2	C.44361E-02	-0.37285E-04
C.15792E 02	C.12844E-01	0.70319E C2	0.50766E-02	-0.37278E-04
C.17767E 02	0.14468E-01	C.70158E C2	0.57187E-02	-0.37270E-04
0.19741E C2	C.16097E-C1	0.69997E C2	C.63626E-02	-0.37263E-04
0.21715E 02	0.17731E-C1	C.69837E C2	0.70081E-02	-0.37255E-04
C.23689E C2	0.19368E-C1	C.69676E C2	0.76554E-02	-0.37248E-04
C.25663E C2	0.21010E-C1	C.69516E C2	0.83045E-C2	-0.37240E-04
0.27637E C2	C.22657E-C1	0.69355E C2	C.89553E-02	-0.37232E-04
C.29611E 02	0.243C8E-C1	0.69194E C2	0.96078E-02	-0.37225E-04
0.31585E C2	0.25963E-01	C.69034E C2	0.10262E-01	-0.37217E-04
0.33559E C2	0.27623E-C1	C.68873E C2	0.10918E-01	-C.372C9E-04
C.35533E 02	C.29288E-C1	0.68712E C2	0.11576E-01	-0.37201E-04
0.37507E 02	0.30957E-01	0.68552E C2	0.12236E-01	-0.37193E-04
0.39481E C2	C.32630E-01	0.68391E C2	0.12897E-01	-0.37185E-C4
0.41455E C2	C.343C8E-01	0.68230E C2	C.13561E-01	-0.37177E-04
C.43429E C2	0.35991E-01	0.68C70E C2	0.14226E-01	-0.37169E-04
0.45403E 02	C.37678E-C1	C.67909E C2	0.14893E-01	-0.37161E-04
0.47377E 02	C.39371E-01	C.67748E C2	C.15561E-01	-0.37153E-04
0.49351E C2	C.41067E-01	0.67588E C2	0.16232E-01	-0.37145E-04
0.51326E C2	C.42769E-C1	0.67427E C2	C.169C5E-01	-0.37137E-04
0.5330CE 02	C.44475E-C1	0.67266E C2	C.17579E-01	-0.37129E-04
0.55274E C2	C.46186E-01	0.671C6E C2	0.18255E-01	-C.37120E-04
C.57248E 02	C.47902E-01	C.66945E C2	0.18934E-01	-C.37112E-04
0.59222E 02	C.49623E-01	C.66784E C2	0.19614E-01	-0.37104E-04
C.61196E C2	C.51348E-C1	C.66624E C2	C.20296E-01	-0.37C95E-04
0.6317CE C2	C.53079E-C1	C.66463E C2	0.20980E-01	-C.37C87E-04
0.65144E 02	C.54814E-C1	C.66302E C2	C.21666E-01	-0.37078E-04
0.67118E 02	C.56554E-C1	0.66142E C2	0.22353E-01	-0.37C70E-C4
C.69092E 02	C.58299E-01	0.65981E C2	C.23043E-01	-C.37061E-04
0.71066E 02	C.60050E-C1	C.65821E C2	0.23735E-01	-0.37052E-04
C.7304CE 02	0.61805E-01	0.65660E C2	0.24429E-01	-C.37043E-C4
0.75014E C2	C.63565E-01	C.65499E C2	0.25125E-01	-C.37035E-04
0.76988E C2	C.65331E-C1	0.65339E C2	C.25822E-01	-C.37026E-04
0.78962E 02	C.67101E-C1	C.65178E C2	0.26522E-01	-0.37017E-04
C.80936E C2	C.68877E-C1	C.65C17E C2	0.27224E-01	-C.370C8E-04
C.8291CE C2	C.70657E-C1	C.64857E C2	0.27928E-01	-0.36999E-04
0.84885E C2	C.72443E-C1	C.64696E C2	0.28634E-01	-0.36990E-04
0.86859E C2	C.74235E-C1	C.64535E C2	C.29342E-01	-0.36981E-04
0.88833E C2	C.76031E-01	C.64375E C2	C.30052E-01	-0.36972E-C4
0.908C7E 02	C.77833E-C1	0.64214E C2	0.30764E-01	-0.36963E-04
0.92781E 02	C.79640E-C1	C.64053E C2	0.31478E-01	-0.36953E-04
0.94755E C2	C.81453E-01	C.63893E C2	C.32195E-01	-0.36944E-C4
C.96729E 02	C.83270E-C1	C.63732E C2	0.32913E-01	-0.36935E-04
0.98703E 02	C.85094E-01	0.63571E C2	0.33634E-01	-0.36925E-04
C.10068E 03	C.86922E-01	0.63411E C2	0.34357E-01	-0.36916E-04
0.10265E 03	C.88757E-01	0.63250E C2	0.35082E-01	-0.36906E-04
0.10463E C3	C.90596E-01	C.63C89E C2	C.358C9E-01	-0.36897E-C4
0.10660E 03	C.92442E-C1	C.62929E C2	C.36538E-01	-0.36887E-C4

PRECEDING PAGE BLANK NOT FILMED.

Output

X2	X3	WP	GLIL
C.96C30E 01	0.21269E 02	C.3CCC0E C3	0.32200E 02

TREF	CONST	QW1	XAMB
0.25300E 01	0.1C0C0E C1	C.75CC0E-C3	C.140CCE 02

T2	T3	T4
0.11946E 03	0.23226E 02	C.43132E 00

XSL	POWER	Y
0.73434E 01	0.10000E 01	C.

BCAP	QWAL	QNVC	VOLUME	DEL
0.39241E-02	0.44665E 01	C.46952E C3	C.52876E C5	0.12739E-01
0.39343E-02	0.44540E 01	0.46952E C3	C.52739E 05	0.25443E-01
0.39446E-02	0.44415E 01	0.46952E C3	C.526C1E C5	0.38111E-01
0.39550E-02	0.44290E 01	C.46952E C3	0.52464E 05	0.50744E-01
0.39654E-02	0.44165E 01	C.46952E C3	C.52326E 05	0.63341E-C1
0.39758E-02	0.44040E 01	C.46952E 03	0.52189E 05	0.75902E-01
0.39863E-02	0.43915E 01	C.46952E C3	C.52052E 05	0.88428E-01
0.39969E-02	0.43790E 01	C.46952E 03	0.51914E 05	0.10092E 00
0.40076E-02	0.43665E 01	0.46952E C3	C.51777E 05	0.11337E 00
0.40182E-02	0.43540E 01	0.46952E C3	C.51639E 05	0.12579E 00
0.40290E-02	0.43416E 01	C.46952E C3	C.515C2E 05	0.13818E 00
0.40398E-02	0.43291E 01	0.46952E C3	C.51365E 05	0.15053E 00
0.40507E-02	0.43166E 01	0.46952E C3	C.51227E 05	0.16284E 00
0.40616E-02	0.43041E 01	C.46952E C3	C.5109CE 05	0.17512E 00
0.40725E-02	0.42916E 01	C.46952E C3	C.50952E 05	0.18736E 00
0.40836E-02	0.42791E 01	C.46952E 03	C.50815E 05	C.19956E 00
0.40947E-02	0.42666E 01	C.46952E C3	C.50678E 05	0.21173E 00
0.41058E-02	0.42541E 01	0.46952E C3	0.5C540E 05	0.22387E 00
0.41171E-02	0.42416E 01	C.46952E C3	0.50403E 05	0.23597E 00
0.41283E-02	0.42291E 01	0.46952E 03	0.50265E 05	0.24803E 00
0.41397E-02	0.42166E 01	C.46952E C3	0.50128E 05	C.26006E 00
0.41511E-02	0.42041E C1	C.46952E C3	C.4999CE 05	0.27206E 00
0.41626E-02	0.41917E C1	C.46952E C3	C.49853E 05	0.28401E 00
0.41741E-02	0.41792E 01	C.46952E C3	C.49716E 05	0.29593E 00
0.41857E-02	0.41667E 01	C.46952E C3	C.49578E 05	0.30782E 00
0.41973E-02	0.41542E 01	C.46952E C3	C.49441E 05	0.31967E 00
0.42091E-02	0.41417E 01	C.46952E 03	0.49303E 05	0.33149E 00
0.42209E-02	0.41292E 01	C.46952E C3	C.49166E 05	0.34327E 00
0.42327E-02	0.41167E 01	0.46952E C3	C.49C29E 05	0.35501E 00
0.42446E-02	0.41042E 01	C.46952E 03	C.48891E 05	0.36672E 00
0.42566E-02	0.4C917E C1	C.46952E C3	C.48754E 05	0.37839E 00
0.42687E-02	0.4C792E 01	C.46952E C3	C.48616E 05	0.39003E 00
0.42808E-02	0.4C667E C1	C.46952E C3	C.48479E 05	0.40163E 00
0.42930E-02	0.40542E 01	C.46952E C3	C.48342E 05	0.41320E 00
0.43053E-02	0.40418E C1	0.46952E C3	C.482C4E 05	0.42473E 00
0.43176E-02	0.40293E C1	0.46952E C3	C.48067E 05	0.43623E 00
0.43300E-02	0.40168E 01	C.46952E C3	C.47929E 05	0.44769E 00
0.43425E-02	C.40043E 01	C.46952E 03	C.47792E 05	0.45911E 00
0.43550E-02	0.39918E 01	C.46952E C3	C.47655E 05	0.47050E C0
0.43677E-02	0.39793E 01	0.46952E C3	C.47517E 05	0.48186E 00
0.43804E-02	0.39668E 01	0.46952E C3	C.47380E 05	0.49317E 00
0.43931E-02	0.39543E 01	C.46952E C3	C.47242E 05	0.50446E 00
C.44C60E-02	0.39418E 01	C.46952E 03	C.471C5E 05	0.51570E 00
0.44189E-02	0.39293E 01	C.46952E C3	C.46968E 05	0.52691E 00
0.44319E-02	0.39168E C1	0.46952E C3	0.46830E 05	0.53809E C0
0.44450E-02	0.39044E C1	C.46952E C3	C.46693E 05	0.54923E 00
0.44581E-02	0.38919E 01	C.46952E C3	C.46555E 05	0.56034E 00
0.44713E-02	C.38794E C1	C.46952E C3	C.46418E 05	0.57140E 00
0.44846E-02	0.38669E 01	0.46952E C3	C.46281E 05	0.58244E C0
0.44980E-02	0.38544E C1	0.46952E C3	0.46143E 05	0.59344E 00
0.45115E-02	0.38419E C1	0.46952E C3	C.46006E 05	0.60440E C0
0.45250E-02	0.38294E 01	0.46952E C3	0.45868E 05	0.61533E 00
0.45387E-02	0.38169E 01	C.46952E C3	C.45731E 05	0.62622E 00
0.45524E-02	0.38044E C1	C.46952E 03	C.45594E 05	0.63707E 00

AL	RO	R1	D	X1
0.71604E 02	0.49792E 01	0.16500E 02	0.21269E 02	0.14584E 01

RHO	BETA	AMU	CP	AK
0.43100E 01	0.10000E-01	0.74000E-05	0.25500E 01	0.35000E-05

V1	V2	V3	V4	T1
0.30022E 02	0.16167E 04	0.83153E 04	0.43051E 05	0.61851E 03

PR	GT	TW	H	ETA
0.53914E 01	0.40101E 17	0.29534E 00	0.25395E-02	0.33266E 02

TIME	TEMP	XS	F(XS)	ACAP
0.10857E 03	0.94292E-01	0.62768E 02	0.37270E-01	-0.36877E-04
0.11055E 03	0.96149E-01	0.62607E 02	0.38004E-01	-0.36867E-04
0.11252E 03	0.98011E-01	0.62447E 02	0.38740E-01	-0.36858E-04
0.11450E 03	0.99879E-01	0.62286E 02	0.39478E-01	-0.36848E-04
0.11647E 03	0.10175E 00	0.62126E 02	0.40218E-01	-0.36838E-04
0.11844E 03	0.10363E 00	0.61965E 02	0.40961E-01	-0.36828E-04
0.12042E 03	0.10552E 00	0.61804E 02	0.41706E-01	-0.36818E-04
0.12239E 03	0.10741E 00	0.61644E 02	0.42454E-01	-0.36807E-04
0.12437E 03	0.10930E 00	0.61483E 02	0.43203E-01	-0.36797E-04
0.12634E 03	0.11121E 00	0.61322E 02	0.43955E-01	-0.36787E-04
0.12831E 03	0.11312E 00	0.61162E 02	0.44710E-01	-0.36777E-04
0.13029E 03	0.11503E 00	0.61001E 02	0.45466E-01	-0.36766E-04
0.13226E 03	0.11695E 00	0.60840E 02	0.46226E-01	-0.36756E-04
0.13424E 03	0.11888E 00	0.60680E 02	0.46987E-01	-0.36745E-04
0.13621E 03	0.12081E 00	0.60519E 02	0.47751E-01	-0.36735E-04
0.13818E 03	0.12275E 00	0.60358E 02	0.48517E-01	-0.36724E-04
0.14016E 03	0.12469E 00	0.60198E 02	0.49286E-01	-0.36713E-04
0.14213E 03	0.12665E 00	0.60037E 02	0.50057E-01	-0.36702E-04
0.14411E 03	0.12860E 00	0.59876E 02	0.50831E-01	-0.36691E-04
0.14608E 03	0.13057E 00	0.59716E 02	0.51607E-01	-0.36680E-04
0.14805E 03	0.13254E 00	0.59555E 02	0.52386E-01	-0.36669E-04
0.15003E 03	0.13451E 00	0.59394E 02	0.53167E-01	-0.36658E-04
0.15200E 03	0.13650E 00	0.59234E 02	0.53951E-01	-0.36647E-04
0.15398E 03	0.13848E 00	0.59073E 02	0.54737E-01	-0.36636E-04
0.15595E 03	0.14048E 00	0.58912E 02	0.55526E-01	-0.36625E-04
0.15792E 03	0.14248E 00	0.58752E 02	0.56317E-01	-0.36613E-04
0.15990E 03	0.14449E 00	0.58591E 02	0.57111E-01	-0.36602E-04
0.16187E 03	0.14651E 00	0.58431E 02	0.57908E-01	-0.36590E-04
0.16385E 03	0.14853E 00	0.58270E 02	0.58707E-01	-0.36579E-04
0.16582E 03	0.15056E 00	0.58109E 02	0.59509E-01	-0.36567E-04
0.16779E 03	0.15259E 00	0.57949E 02	0.60314E-01	-0.36555E-04
0.16977E 03	0.15464E 00	0.57788E 02	0.61121E-01	-0.36543E-04
0.17174E 03	0.15669E 00	0.57627E 02	0.61931E-01	-0.36531E-04
0.17372E 03	0.15874E 00	0.57467E 02	0.62744E-01	-0.36519E-04
0.17569E 03	0.16080E 00	0.57306E 02	0.63559E-01	-0.36507E-04
0.17766E 03	0.16287E 00	0.57145E 02	0.64377E-01	-0.36495E-04
0.17964E 03	0.16495E 00	0.56985E 02	0.65198E-01	-0.36483E-04
0.18161E 03	0.16704E 00	0.56824E 02	0.66022E-01	-0.36470E-04
0.18359E 03	0.16913E 00	0.56663E 02	0.66848E-01	-0.36458E-04
0.18556E 03	0.17122E 00	0.56503E 02	0.67678E-01	-0.36445E-04
0.18754E 03	0.17333E 00	0.56342E 02	0.68510E-01	-0.36433E-04
0.18951E 03	0.17544E 00	0.56181E 02	0.69345E-01	-0.36420E-04
0.19148E 03	0.17756E 00	0.56021E 02	0.70183E-01	-0.36407E-04
0.19346E 03	0.17969E 00	0.55860E 02	0.71024E-01	-0.36394E-04
0.19543E 03	0.18183E 00	0.55699E 02	0.71868E-01	-0.36381E-04
0.19741E 03	0.18397E 00	0.55539E 02	0.72715E-01	-0.36368E-04
0.19938E 03	0.18612E 00	0.55378E 02	0.73564E-01	-0.36355E-04
0.20135E 03	0.18828E 00	0.55218E 02	0.74417E-01	-0.36342E-04
0.20333E 03	0.19044E 00	0.55057E 02	0.75273E-01	-0.36329E-04
0.20530E 03	0.19261E 00	0.54896E 02	0.76132E-01	-0.36315E-04
0.20728E 03	0.19479E 00	0.54736E 02	0.76994E-01	-0.36302E-04
0.20925E 03	0.19698E 00	0.54575E 02	0.77859E-01	-0.36288E-04
0.21122E 03	0.19918E 00	0.54414E 02	0.78727E-01	-0.36274E-04

X2	X3	WP	GLIL
0.96030E 01	0.21269E 02	0.30000E 03	0.32200E 02

TREF	CONST	QWI	XAMB
0.25300E 01	0.10000E 01	0.75000E-03	0.14000E 02

T2	T3	T4
0.11946E 03	0.23226E 02	0.43132E 00

XSL	POWER	Y
0.73434E 01	0.10000E 01	0.

BCAP	QWAL	CNVC	VOLUME	DEL
0.45662E-02	0.37919E 01	0.46952E 03	0.45456E 05	0.64790E 00
0.45801E-02	0.37794E 01	0.46952E 03	0.45319E 05	0.65868E 00
0.45940E-02	0.37669E 01	0.46952E 03	0.45181E 05	0.66943E 00
0.46081E-02	0.37545E 01	0.46952E 03	0.45044E 05	0.68014E 00
0.46222E-02	0.37420E 01	0.46952E 03	0.44906E 05	0.69082E 00
0.46364E-02	0.37295E 01	0.46952E 03	0.44769E 05	0.70147E 00
0.46507E-02	0.37170E 01	0.46952E 03	0.44632E 05	0.71207E 00
0.46651E-02	0.37045E 01	0.46952E 03	0.44494E 05	0.72265E 00
0.46796E-02	0.36920E 01	0.46952E 03	0.44357E 05	0.73318E 00
0.46942E-02	0.36795E 01	0.46952E 03	0.44219E 05	0.74368E 00
0.47088E-02	0.36670E 01	0.46952E 03	0.44082E 05	0.75415E 00
0.47236E-02	0.36545E 01	0.46952E 03	0.43945E 05	0.76458E 00
0.47384E-02	0.36420E 01	0.46952E 03	0.43807E 05	0.77497E 00
0.47534E-02	0.36295E 01	0.46952E 03	0.43670E 05	0.78533E 00
0.47684E-02	0.36171E 01	0.46952E 03	0.43532E 05	0.79565E 00
0.47836E-02	0.36046E 01	0.46952E 03	0.43395E 05	0.80594E 00
0.47988E-02	0.35921E 01	0.46952E 03	0.43258E 05	0.81619E 00
0.48141E-02	0.35796E 01	0.46952E 03	0.43120E 05	0.82641E 00
0.48295E-02	0.35671E 01	0.46952E 03	0.42983E 05	0.83659E 00
0.48451E-02	0.35546E 01	0.46952E 03	0.42845E 05	0.84674E 00
0.48607E-02	0.35421E 01	0.46952E 03	0.42708E 05	0.85685E 00
0.48764E-02	0.35296E 01	0.46952E 03	0.42571E 05	0.86692E 00
0.48922E-02	0.35171E 01	0.46952E 03	0.42433E 05	0.87696E 00
0.49082E-02	0.35046E 01	0.46952E 03	0.42296E 05	0.88696E 00
0.49242E-02	0.34921E 01	0.46952E 03	0.42158E 05	0.89693E 00
0.49404E-02	0.34796E 01	0.46952E 03	0.42021E 05	0.90687E 00
0.49566E-02	0.34672E 01	0.46952E 03	0.41884E 05	0.91676E 00
0.49730E-02	0.34547E 01	0.46952E 03	0.41746E 05	0.92662E 00
0.49894E-02	0.34422E 01	0.46952E 03	0.41609E 05	0.93645E 00
0.50060E-02	0.34297E 01	0.46952E 03	0.41471E 05	0.94624E 00
0.50227E-02	0.34172E 01	0.46952E 03	0.41334E 05	0.95599E 00
0.50395E-02	0.34047E 01	0.46952E 03	0.41197E 05	0.96571E 00
0.50564E-02	0.33922E 01	0.46952E 03	0.41059E 05	0.97540E 00
0.50734E-02	0.33797E 01	0.46952E 03	0.40922E 05	0.98505E 00
0.50905E-02	0.33672E 01	0.46952E 03	0.40784E 05	0.99466E 00
0.51078E-02	0.33547E 01	0.46952E 03	0.40647E 05	0.10042E 01
0.51251E-02	0.33422E 01	0.46952E 03	0.40510E 05	0.10138E 01
0.51426E-02	0.33297E 01	0.46952E 03	0.40372E 05	0.10233E 01
0.51602E-02	0.33173E 01	0.46952E 03	0.40235E 05	0.10328E 01
0.51779E-02	0.33048E 01	0.46952E 03	0.40097E 05	0.10422E 01
0.51958E-02	0.32923E 01	0.46952E 03	0.39960E 05	0.10516E 01
0.52138E-02	0.32798E 01	0.46952E 03	0.39823E 05	0.10610E 01
0.52318E-02	0.32673E 01	0.46952E 03	0.39685E 05	0.10703E 01
0.52501E-02	0.32548E 01	0.46952E 03	0.39548E 05	0.10796E 01
0.52684E-02	0.32423E 01	0.46952E 03	0.39410E 05	0.10888E 01
0.52869E-02	0.32298E 01	0.46952E 03	0.39273E 05	0.10981E 01
0.53055E-02	0.32173E 01	0.46952E 03	0.39135E 05	0.11072E 01
0.53242E-02	0.32048E 01	0.46952E 03	0.38998E 05	0.11164E 01
0.53431E-02	0.31923E 01	0.46952E 03	0.38861E 05	0.11255E 01
0.53621E-02	0.31799E 01	0.46952E 03	0.38723E 05	0.11346E 01
0.53813E-02	0.31674E 01	0.46952E 03	0.38586E 05	0.11436E 01
0.54005E-02	0.31549E 01	0.46952E 03	0.38448E 05	0.11526E 01
0.54199E-02	0.31424E 01	0.46952E 03	0.38311E 05	0.11616E 01

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