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EQUATIONS AND COMPUTER PROGRAM TO CALCULATE THE THERMAL HISTORY OF A DUAL-LAYERED PLATE SUBJECT TO THE THERMAL PULSE OF A NUCLEAR WEAPON

SF 011-05-11, Task 11292
Lab. Project 9400-105, Progress Report 3

28 DEC 1966

R. J. Heilferty
J. E. Koch
M. L. Cohen

TECHNICAL REPORT

U. S. NAVAL APPLIED SCIENCE LABORATORY

NAVAL BASE
BROOKLYN 1, NEW YORK

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DEPARTMENT OF THE NAVY
BUREAU OF SHIPS

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Lab. Project 9400-105
Progress Report 3

ABSTRACT

A generalized computational technique to be used in the calculation of the temperature profiles and histories in single and dual layered plates exposed to the thermal pulse of a nuclear weapon is presented. The program ~~has been~~ written to accommodate materials whose thermophysical properties are an arbitrary function of the local temperature. In addition, quite general boundary conditions are permitted. Sample calculations are presented in order to illustrate the nature of the output format.

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ADMINISTRATIVE INFORMATION

As outlined in the U. S. Naval Applied Science Laboratory Program Summary dated 1 November 1966, SF 011-05-11, Task (Work Unit) 11292, the Laboratory is engaged in a research and development program to study the effects of extreme thermal environments on advanced design naval vessels. This report covers the recent effort by North Eastern Research Associates, Queens Village, N. Y., in support of this task.

ACKNOWLEDGMENTS

The work reported herein was conducted by personnel of North Eastern Research Associates under contract to the U. S. Naval Applied Science Laboratory. R. Heilferty, NASL Principal Investigator for this task, served as project monitor. The overall NASL program is under the supervision of W. L. Derksen, Senior Task Leader, and under the general direction of T. I. Monahan, Head, Physics Branch. The Naval Ship Systems Command Program Manager is L. E. Sieffert, SHIPS 03541, and the Naval Ship Engineering Center Project Engineer is Y. Park, Code 6423H.

DISCUSSION

The objective of Task 11292 is to determine from theoretical, analytical and experimental studies the nature and extent of thermal radiation damage to shipboard structures and systems exposed to the thermal radiation and blast environment associated with a nuclear detonation. Studies will also be conducted where required, with the objective of preparing bases for material specifications for advanced designs and for hardening existing installations.

There is a requirement for the Navy to maintain the operational capabilities of combat and support vessels during nuclear attack. This involves the development of ships and critical structures which can sustain the effects of thermal radiation without functional degradation. Prerequisite to the development of the above, is the necessity to determine vulnerability to the thermal radiation damage and to develop means of hardening ships and critical structures to combined thermal and blast effects. Past work on thermal radiation effects is of limited application to the problem of vulnerability. Past experimental programs have been concerned mainly with direct effects such as ignition of susceptible materials or ablative effects on resistant materials. The work in this program will encompass both analytical and experimental approaches for determination of strength and failure of materials and structures under thermal loading.

The theory and analytical techniques needed for computer programs to calculate the temperature profile histories in solids with temperature dependent thermophysical properties which are exposed to time varying pulses of thermal radiation have been developed. In addition, a computer program has been developed for semi-infinite solids, and sample calculations have been conducted on several materials to establish the precision of the techniques used and the need for considering temperature dependent properties. The effort in this phase of the overall task is covered in Appendix A.

FUTURE WORK

Future effort is planned to proceed in the following steps which may be prosecuted consecutively or simultaneously:

a. Complete an analysis of the characteristics of the thermal radiation loads as a function of distance, overpressure, yield, height of burst and visibility.

b. Develop a computer program to determine the thermal stresses developed in Naval structural materials and shapes having temperature profiles as calculated using the methods and techniques described herein.

c. Develop experimental techniques for exposing materials to simulated weapons pulses to measure the calculated temperature profile histories and thermal stresses.

d. Initiate a comprehensive program which will evaluate the analytical and experimental data to determine the safe separation distances for the various vulnerable structures and components so that an estimate may be made of the operational capability of a ship at various ranges from a nuclear detonation.

e. Initiate a comprehensive program to develop protective measures and hardening procedures.

APPENDIX A

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"Equations and Computer Program to Calculate the Thermal History of a Dual-Layered Plate Subject to the Thermal Pulse of a Nuclear Weapon

by

J.E. Koch
M.L. Cohen

Research Report No. 1 15 September 1966

Prepared for: U.S. Naval Applied Science Laboratory, Code 9410
Brooklyn, New York

Contract Number: N00140-66-C-0482

N.E.R.A. No. RR-NA-1

List of Symbols

A	Material A
B	Material B
c	Specific heat
$\bar{h}$	Surface film coefficient
H	Thermal irradiance
k	Thermal conductivity
L	Distance
$p, q. s$	Thickness of a space increment
x, y, z	Distances
α	Absorptivity
β, ξ, Υ	Psuedo-temperatures (See eqns. 2.9,10)
ϵ	Emisivity
θ	Temperature
σ	Stefan-Boltzmann Constant
τ	Time

Super and Sub Scripts

k, t	Time increment
i, j	Space increment
A	Material A
B	Material B
N, M	Number of space increments
o	The starting conditions for the tabulation
1	Space increment number 1

Contents

Appendices

I. Introduction

The work described in this report was performed to satisfy the requirements of Task No. 1 of the scope of work of contract N00140-66-C-0482, "Thermal and Thermal Stress Analysis of Solids Subject to the Thermal Pulse of a Nuclear Weapon." The primary objective of the work phase covered by this report is to provide a generalized computational technique to facilitate the calculation of the temperature profiles and histories in dual layered plates exposed to the thermal pulse of a nuclear weapon.

Solutions to problems dealing with conduction heat transfer in solids have been classically accomplished by using analytical techniques. Unfortunately those problems which may be profitably handled by these techniques are usually limited to problems of relatively simple geometry, and those whose thermophysical properties vary, at most, linearly with temperature. Further, the class of boundary conditions which can be applied are also limited to well behaved functions. An alternate approach to the solution of this class of problem is to avoid the analytical solution of the boundary value problem as such, and treat the problem by a finite-difference technique, using a digital computer to perform the resultant numerical calculations. The advantage of this approach is obvious when one considers that any complexity of geometry and any variation in thermophysical properties may be handled. In addition, boundary conditions of the most general type may be applied to the problem.

II. Problem Statement

The specific problem to be treated in the analysis presented herein may be stated as follows: To determine the temperature profile and history in a dual-layered infinite slab of arbitrary thickness, when subject to a time varying radient flux. The thermal conductivity, specific heat, and density of both slab layers are temperature dependent. Both faces of the slab are considered to be radiating to fixed, but unequal, space environments. Further, both faces are in contact with a convective film whose heat transfer coefficient varies as a function of surface temperature. The front surface of the slab, or the surface receiving the radient flux is considered to be non-grey, and the rear surface is considered to be grey. Figure 1 indicates the physical model and its boundary conditions.

III. The Mathematical Model

A- General Solution

The general solution for the conduction of heat in an isotropic homogeneous solid whose thermal conductivity and specific heat are temperature dependent, is:

$$\frac{\partial}{\partial x}\left(k\frac{\partial\theta}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial\theta}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial\theta}{\partial z}\right)=\rho c\frac{\partial\theta}{\partial t} \qquad \ldots 1$$

Equation 1 may be simplified by introducing a pseudo-temperature, β, defined as:

$$\beta=\frac{1}{k_i}\int_{\theta_i}^{\theta}k(\theta)\,d\theta \qquad \ldots 2$$

where:

$$k_i=k(\theta_i) \qquad \ldots 3$$

Hence, equation 1 may be written as:

$$\nabla^2\beta=\frac{\rho c(\theta)}{k(\theta)}\frac{\partial\beta}{\partial t} \qquad \ldots 4$$

Equation 4, together with the appropriate boundary conditions, are sufficient to completely define the conduction heat transfer problem.

B. The General Solution in Open Form

In the one dimensional case, equation 4 reduces to:

$$\beta\frac{\partial^2\theta}{\partial x^2}=\frac{\rho c(\theta)}{k(\theta)}\frac{\partial\beta}{\partial t} \qquad \ldots 5$$

The temperature at any point in the interior of the solid may be formed by placing equation 5 in its finite difference form. That is, consider an infinite slab defined in the region $0<X<L$, subdivided into n intervals of

thickness s. The general recurrence relationship for the pseudo-temperature, ζ, at all interior points is:

$$\beta_j^{k+1} = \frac{k(\theta)\tau}{s^2\rho c(\theta)}\left\{\beta_{j+1}^{k} + \beta_{j-1}^{k} + \left[\frac{s^2\rho c(\theta)}{k(\theta)\tau} - 2\right]\beta_j^{k}\right\} \qquad \ldots 6$$

where:

$$2 \leq j \leq n$$

the values of the pseudo-temperature at the surface elements of the slab is found by taking energy balances about the surface element.

C. The Particular Open Form Equations

The model of the exposed plate, indicated in Figure 2, is composed of materials A and B, whose specific heat and thermal conductivity are functionally related to the local temperature. The plate receives energy at x = 0 via a time varying thermal irradiance $H(\tau)$. The plate is assumed to lose energy from either side via convection and radiation. The general recurrence relationships for all interior points of the model slab may be obtained by rewriting equation 6 for both materials A and B. Viz:

Material A

$$\zeta_i^{t+1} = \frac{k_A\tau}{\rho_A c_A p^2}\left[\zeta_{i+1}^{t} + \zeta_{i-1}^{t} + \zeta_i^{t}\left(\frac{\rho_A c_A p^2}{k_A\tau} - 2\right)\right] \qquad \ldots 7$$

Where:

$$2 \leq i \leq N$$

Material B

$$\zeta_i^{t+1} = \frac{k_B\tau}{\rho_B c_B g^2}\left[\zeta_{i+1}^{t} + \zeta_{i-1}^{t} + \zeta_i^{t}\left(\frac{\rho_B c_B g^2}{k_B\tau} - 2\right)\right] \qquad \ldots 8$$

Where:

$$N \leq i \leq M-1$$

The pseudo-temperature, ξ and ζ , are defined via equation 2 as:

$$\xi = \frac{1}{k_{A0}} \int_{\theta_0}^{\theta} k_A(\theta)\, d\theta \qquad \ldots 9$$

$$\zeta = \frac{1}{k_{B0}} \int_{\theta_0}^{\theta} k_B(\theta)\, d\theta \qquad \ldots 10$$

For stability to be insured in the utilization of equations 7 and 8, the space and time increments must be chosen in each of the two materials, such that the following are both satisfied:

$$\frac{p^2}{\tau} \geq \frac{2\, k_A(\theta)}{\rho_A\, c_A(\theta)} \qquad \ldots 11$$

$$\frac{q^2}{\tau} \geq \frac{2\, k_B(\theta)}{\rho_B\, c_B(\theta)} \qquad \ldots 12$$

The temperature at the interface, N, between material A and B is determined in terms of either ξ or ζ , by taking a heat balance about the half-nodes on either side of the interface. This will yield:

$$\xi_N^{t+1} = \xi_N^t + \frac{k_A}{k_{A0}} \left\{ \frac{2\tau}{\rho_A c_A p + \rho_B c_B q} \left[\frac{k_{A0}}{p} \left(\xi_{N-1}^t - \xi_N^t \right) + \frac{k_{B0}}{q} \left(\zeta_{N+1}^t - \zeta_N^t \right) \right] \right\} \qquad \ldots 13$$

$$\zeta_N^{t+1} = \zeta_N^t + \frac{k_B}{k_{B0}} \left\{ \frac{2\tau}{\rho_B c_B q + \rho_A c_A p} \left[\frac{k_{B0}}{q} \left(\zeta_{N-1}^t - \zeta_N^t \right) + \frac{k_{A0}}{p} \left(\xi_{N-1}^t - \xi_N^t \right) \right] \right\} \qquad \ldots 14$$

Stability of equations 13 and 14 will be insured by satisfying the greater of either equation 11 or 12.

D. Boundary Conditions

The boundary conditions to be used at the front and rear surfaces of the plate are derived by taking heat balances about those surfaces. For the front surface (the surface exposed to the thermal pulse). This yields:

$$\xi_1^{t+1} = \frac{2k_A\tau}{\rho_A c_A p^2}\left[\frac{p\alpha_A}{k_{A0}} H^t + \xi_2^t + \frac{p}{k_{A0}}\epsilon_A\sigma\left(\theta_{A\infty}^4 - \theta_1^{t^4}\right)\right.$$

$$\left. + \frac{p\bar{h}_A}{k_{A0}}\left(\theta'_{A\infty} - \theta_1^t\right) + \xi_1^t\left(\frac{\rho_A c_A p^2}{2k_A\tau} - 1\right)\right]$$

...15

Where $\theta_{A\infty}$ is taken to be the space temperature to which the surface is re-radiating, $\theta'_{A\infty}$ the temperature of the immediate surroundings, and $\bar{h}_A$ the average convective heat transfer coefficient at the plate surface. Hence, equation 15 takes into account the radiation received from the blast, the radient exchange between the plate surface and the space temperature, and the effects of a convective film. The stability equation to be satisfied in this case becomes:

$$\frac{p^2}{\tau} \geq \left\{1 + \frac{p\theta_1^t}{k_{A0}\xi_1^t}\left[\epsilon_A\sigma\theta_1^{t^3} + \bar{h}_A\right]\right\}\frac{2k_A}{\rho_A c_A}$$

...16

At the rear surface there exists the possibility of two different governing equations for the same set of boundary conditions. The first equation will result if, as has been discussed, the slab is dual-layered. In this instance the resulting boundary equation is:

$$\zeta_M^{t+1} = \frac{2k_B\tau}{\rho_B c_B \delta^2}\left[\zeta_{M-1}^t + \frac{\delta\epsilon_B\sigma}{k_{B0}}\left(\theta_{B\infty}^4 - \theta_M^{t^4}\right) + \frac{\delta\bar{h}_B}{k_{B0}}\left(\theta'_{B\infty} - \theta_M^t\right) + \zeta_M^t\left(\frac{\rho_B c_B \delta^2}{2k_B\tau} - 1\right)\right] \quad ...17$$

Stability is satisfied by insuring that:

$$\frac{\delta^2}{\tau} \geq \left\{1 + \frac{\delta\theta_M^t}{k_{B0}\zeta_M^t}\left[\epsilon_B\sigma\theta_M^{t^3} + \bar{h}_B\right]\right\}\frac{2k_B}{\rho_B c_B} \quad ...18$$

In the case of material A being indentical to material B, i.e., a single layered plate, the appropriate governing equation becomes:

$$\zeta_N^{t+1} = \frac{2k_A\tau}{\rho_A c_A p^2}\left[\zeta_{N-1}^t + \frac{p\epsilon_B\sigma}{k_{A0}}\left(\theta_{B\infty}^4 - \theta_N^{t^4}\right) + \frac{p\bar{h}_B}{k_{A0}}\left(\theta'_{B\infty} - \theta_N^t\right) + \zeta_N^t\left(\frac{\rho_A c_A p^2}{2k_A\tau} - 1\right)\right) \quad ...19$$

and the stability equation becomes:

$$\frac{p^2}{\tau} \geq \left\{1 + \frac{p\theta_N^t}{k_{A0}\zeta_N^t}\left[\epsilon_B\sigma\theta_N^{t^3} + \bar{h}_B\right]\right\}\frac{2k_A}{\rho_A c_A} \quad ...20$$

Equations 17 and 19 are similar to equation 15, but do not include the radient flux due to the nuclear event. It should be noted that the surface emissivity of the front surface of the plate is not necessarily equal to its absorptivity (non-grey condition). Further, the space temperatures for radient exchange, $\theta_{A\infty}$ and $\theta_{B\infty}$, are not necessarily the same, nor are the space temperatures for the convective condition, $\theta'_{A\infty}$ and $\theta'_{B\infty}$, equal.

IV. Computer Program

A. General Description

The preceding analysis has provided a set of equations with which the temperature profiles and histories in one- or two-layered plates may be calculated under quite general conditions. Therefore in writing the computer program the objective has been to devise a computational scheme which utilizes these equations effeciently while introducing no additional restrictions on their generality. The following brief comments about the input data requirements, computational scheme, and output record will serve to describe the program in a general way.

Input Data

The input data required for computation must be provided in punched card form. The precise sequence of these data cards as well as the exact format of each card is given in Appendix I. Generally speaking this input includes:

1. Space and time increment data and directions for terminating the calculation.
2. Directions for printing the results of the computation.
3. Thermophysical properties of the plate(s) versus temperature (in tabular form to allow perfectly arbitrary temperature dependence).
4. Convective heat transfer coefficient versus surface temperature (in tabular form)
5. Initial temperature versus position in plate (in tabular form).
6. Absorptance at front face versus surface temperature (in tabular form).

7. Irradiation data: Yield and Exposure if a standard weapon pulse (a standard pulse shape is generated automatically by subroutine "PULSE", Appendix III.) Intensity versus time if a non-standard pulse (in tabular form).

Computational Scheme

The computational scheme closely follows the finite difference equations developed in section III. Since certain of the terms in these equations are temperature dependent, they must be re-evaluated after every step of the computation. In order to do this, a two-storage indirect interpolation procedure has been developed which gives the same degree of accuracy as direct interpolation from the input tables, while using considerably less computational effort. The efficiency of the program is a direct result of this technique. This is described in greater detail in section IV-B. For details about the sequence of calculations refer to Appendix II.

Output Record

The program provides a printed record of the input data as well as the temperature distribution at selected times. Directions governing this selection are supplied in the input data. For details of the actual printed format refer to Appendix IV which gives the printed output of three sample calculations.

B. Detailed Description

The program has been written in "FORTRAN IV" for operation on an IBM 7040 computer having a 32,766 word (32K) memory capacity. Operation on a computer other than this one will in all probability require some degree of modification because of slight variations in "FORTRAN IV" between computers, and differences in their memory capacity. Appendix III lists the actual program deck. A flow chart of the program is given in Appendix II.

A detailed discussion of the program and its features may conveniently be sub-divided into the three sections which follow:

1. Arrangement and Choice of Input Data

The input data (refer to Appendix I for precise details) enters the program through a sequence of data cards. This sequence begins with three individual data cards which must be provided for every computation.

Card No. 1 contains an identifying label which is printed on each page of the printed output record for that particular computation in order to prevent accidental mixing of data.

Card No. 2 contains the space and time increment data. The number of nodal elements in each layer may be specified explicitly or, if desired, the total number in the entire plate may be given instead. In the latter case the program automatically subdivides the plate in such a way that:

a) There is at least one element in each layer.

b) The total number of elements is the number specified.

c) The critical time intervals in each layer are as nearly equal as possible. This calculation is based on equations 16 and 18 which are the most restrictive, and therefore the controlling stability conditions.

The time increment may be specified explicitly, together with the degree of computational stability desired. If the time increment is not specified, or if it does not give the desired degree of stability, the program will automatically compute a suitable time increment based on equations 16 and 18 (or equations 16 and 20 in the case of a single layered plate).

Card No. 3 provides termination data. The computation ends after a specified number of time steps have been taken or after real time equals a specified value, whichever occurs first. Since the actual time increment may not be known, the maximum number of time steps is specified in addition to the termination time. This is done in order to prevent excessively long computations being made inadvertantly.

These three data cards are followed by seven decks of data cards (six for a single layered plate) which contain directions for printing the results of the calculations; the thermal data required to make them; and a description of the incident thermal radiation pulse. With the exception of the absorptance deck each of these decks is quite independent of all the others. For example, the convective data is independent of the plate material properties. Thus a single property data deck for each particular material to be investigated would suffice for all computations made for that material, thereby avoiding a substantial amount of repetitive key-punching.

By arranging the data in tabular form where applicable, the temperature dependence of the material properties (for example) may be perfectly arbitrary. Thus no restriction is imposed on the generality of the finite-difference equations. For convenience the data points may be chosen quite arbitrarily, the only restriction being that the arguments appear in acending order in each deck.

If desired, any or all of these decks may be partially or completely omitted from all but the first of a series of computations. Thus the data stored in the computer is used until replaced by new data. Detailed instructions on this point are given in Appendix I.

2. Details of the Computation Scheme

As indicated earlier, the main feature of the computational scheme lies in the indirect method of evaluating the temperature-dependent terms of the finite-difference equations after each time step. Since these evaluations are made during the most frequently repeated parts of the program, it is highly desirable to develop an efficient method for making them. The technique developed requires the arrangement of the input tables into tables having the same starting point and increment (ξ_0 and $\Delta\xi$ for example). Subroutine "TABLE" accomplishes this.

The location of a data point, $Y(\xi)$, in any of these tables may be found by computing a "locater" number such as $i = 1 + \frac{\xi - \xi_0}{\Delta \xi}$. Thus, if $\xi = 13$, $\xi_0 = 1$, and $\Delta\xi = 1$ the desired data is Y_{13}, the thirteenth element of the table. If more precision is desired, an interpolation between the points of the table may be made. For example, if $\xi = 13.5$ the data desired is $Y(13.5) = Y_{13} + 0.5\,(Y_{14} - Y_{13})$. This refinement has been used in the program in which data is interpolated to within 1/10,000th of the increment $\Delta\xi$.

The appropriate "locater" number is computed by function "NODE". This "locater" number is then used by subroutines "FIND 1","FIND 2" and "FIND 4" to compute the interpolated data.

3. Output Record

The printed output of the program is composed of a record of the input data, the temperature distribution at selected time points, and the reasons for terminating the computation. Appendix IV illustrates many of the features of the program by showing a listing of the input data cards for three sample computations together with the resulting output record.

a) Input data record. The input data record always begins with a description of the actual plate (i.e., the thickness and composition of each layer), the incident thermal radiation; the space and time increments used; and the location of the remainder of the input data record. On subsequent pages the precise details (in tabular form where applicable) of the material properties, ambient temperature conditions, convection data, absorptance data, and incident thermal radiation history are presented. The second part of the input record is omitted if it is unchanged. Subroutine "PAGE" is used to print the identifying label and page number on each page. As an example consider a series of computations involving a plate subjected to several different weapons or exposures. The second part of the input record would be printed only for the first computation. Subsequent input records refer to the first computation for this data. Thus the input to any computation is recorded without the need for excessive amounts of printing.

b) Output data record. As may be seen in the sample output (Appendix IV), the temperature distribution is printed in columns, each column referring to a particular point in time. The choice of output data to be printed is governed by the printer control deck (see Appendix I). Thus the program prints the temperature distribution every N_1 time steps up to time τ_1, then every N_2 steps up to time τ_2 and so on. As a programming convenience this output data is stored in an output array large enough to accommodate ten time points (a full page). This array is then printed using subroutine "OUTPUT" whenever necessary (i.e., either when the array is full or upon termination).

c) Termination data. Subroutine "EXPUT" is used to print on the final page the reasons for terminating the computation. This is done whenever any of the following occurs: the number of time steps exceeds the specified limit; real time exceeds its limit; the temperature in either plate exceeds its limit.

V. Concluding Remarks

Appendix III is a listing of the computer program developed to fulfill the requirement of Task No. 1 of the scope of work of contract N00140-66-C-0482, "Thermal and Thermal Stress Analysis of Solids Subject to the Thermal Pulse of a Nuclear Weapon".

This program has the capability of computing the temperature distribution and history in one- and two-layered plates subjected to arbitrary thermal irradiation. The temperature dependence of the thermophysical data, the initial temperature distribution, and the ambient conditions may be perfectly arbitrary.

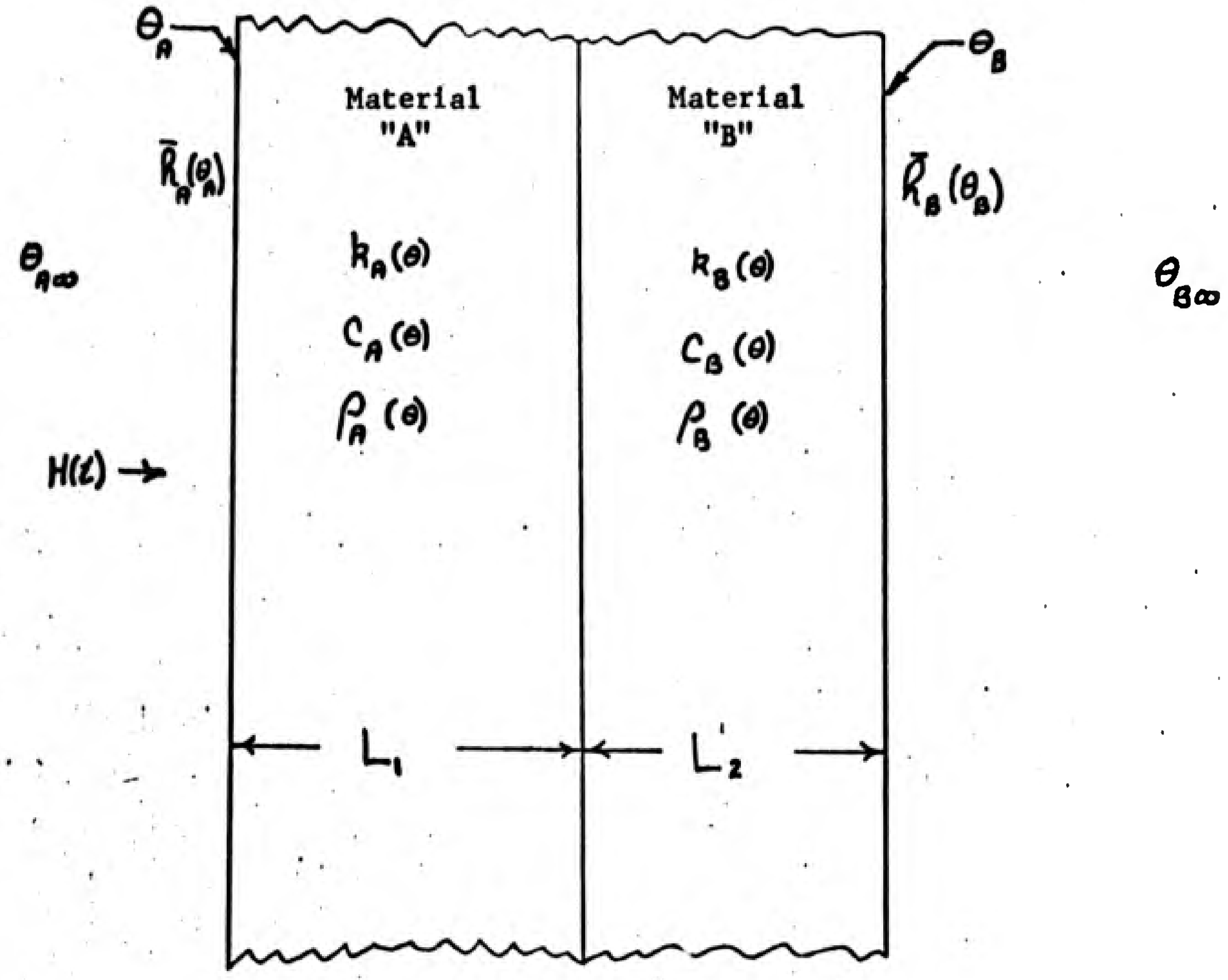


Figure 1 - Physical Model and Boundary Conditions

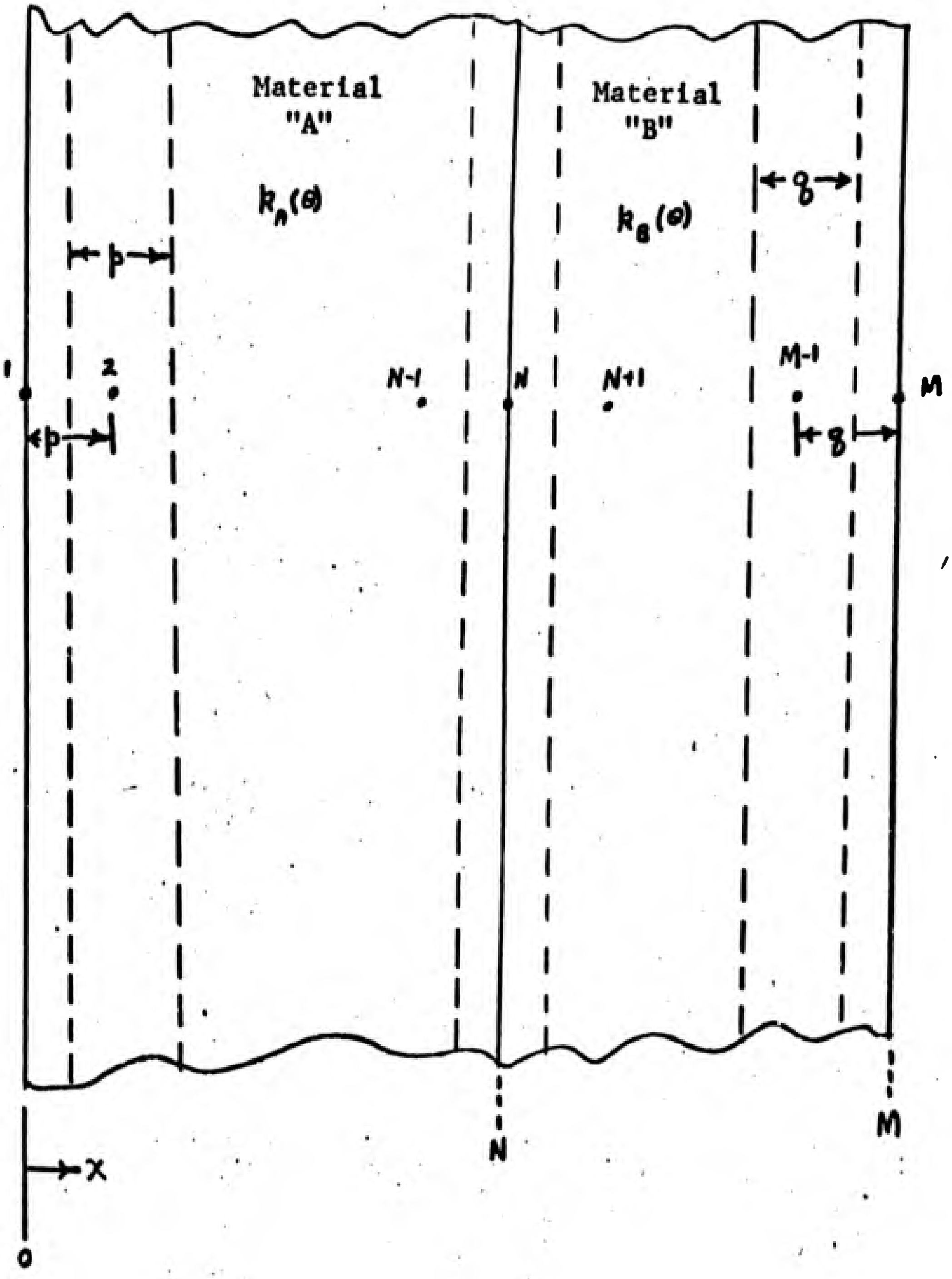


Figure 2- The Model Plate

Appendix Ia

Input Data

The following listing specifies the information required by the program both for control and for the performance of the computations. The sequence and format of the input data cards is shown together with a definition of the symbols used. Numbers in parentheses at the beginning of each line of input data refer to the detailed format of each data card given in Appendix Ib.

I. Identification

(1) IDENT	...An identifying label up to 24 characters in length printed on each page of the output record.

II. Space and Time Increment Data

(2) $N_a, N_b, N_{ab}, N_\tau, \Delta\tau, L_a, L_b$	...Layers "A" and "B" are L_a and L_b cm. thick and are subdivided into N_a and N_b nodal elements, respectively. The entire plate is subdivided into N_{ab} elements. Make computations using a time increment $\Delta\tau$ or at N_τ percent of the critical time, whichever is smaller.

NOTE: $N_a, N_b, N_{ab} \leq 200$; $0 < N_\tau \leq 100$. For a single layered plate N_b is ignored and L_b must be set equal to zero. If N_a and N_b are both given, N_{ab} is ignored. Otherwise the program selects the best choice of N_a and N_b based on equations 16 and 18. The specified value $\Delta\tau$ is used as the time increment if it is smaller than N_τ percent of the computed critical time but not equal to zero. Otherwise an appropriate value is substituted by the program.

III. Program Termination Condition

(3) N_s, τ_s	...Stop computation after N_s time steps or after real time equals τ_s, whichever is smaller.

IV. Printer Control Data Deck

(4)	m	...Number of cards in list to follow.
(3)	N_1, τ_1	...Print results every N_1 time steps up to time τ_1 then every N_2 time steps up to τ_2, etc.
	⋮	
(3)	N_m, τ_m	

NOTE: $0 \leq m \leq 10$. If m = 0, data from previous computation is re-used.

Cards in deck to be arranged in ascending values of τ_i.

V. Material "A" Properties Deck

(4)	m	...Number of cards in list to follow.
(5)	θ_{max}	...Maximum allowable temperature in material.
(6)	CAPTION	...Description of material up to 66 characters in length.
(7)	$\epsilon_{A_1}, \epsilon_{B_1}, \rho_1, C_1, K_1, \theta_1$	...Front emissivity, rear emissivity, density, specific heat, thermal conductivity, at temperature θ_1, etc.
	⋮	
(7)	$\epsilon_{A_{m-2}}, \epsilon_{B_{m-2}}, \rho_{m-2}, C_{m-2}, K_{m-2}, \theta_{m-2}$	

NOTE: $0 \leq m \leq 52$; $m \neq 2$. If a two layered plate, ϵ_{B_i} is not used in the computations. Whenever $\theta \geq \theta_{max}$, computation is terminated. Deck is to be arranged in ascending values of θ_i.

VI. Material "B" Properties Deck

Same format as material "A" above.

NOTE: ϵ_{A_i} is not used in the computation. If a single layered plate the entire deck, including m, is omitted.

VII. Convection Data Deck

(4)	m	...Number of cards in list to follow.
(8)	$\theta'_{A\infty}, \theta'_{B\infty}$	...Ambient temperatures for convection at front and rear faces, respectively.

(9) $\bar{h}_{A_1}$, $\bar{h}_{B_1}$, θ_1	...Film coefficient on front surface, film coefficient on rear sruface, at temperature θ_1, etc.
⋮	
(9) $\bar{h}_{A_{m-1}}$, $\bar{h}_{B_{m-1}}$, θ_{m-1}	

NOTE: $0 \leq m \leq 51$. Deck arranged in ascending values of θ_i.

VIII. Initial Temperature Data Deck

(4) m	...Number of cards in list to follow.
(8) θ_1, X_1	...Initial temperature is θ_1 at location X_1, etc.
⋮	
(8) θ_m, X_m	

NOTE: $0 \leq m \leq 50$. Deck arranged in ascending values of X_i.

IX. Absorptance Data Deck

(4) m	... Number of cards in list to follow.
(8) α_1, θ_1	...Absorptance of blast irradiation at front surface is α_1 at surface temperature θ_1, etc.
⋮	
(8) α_m, θ_m	

NOTE: $\theta \leq m \leq 50$. Absorptance applies to front surface only. Deck arranged in ascending values of θ_i.

X. Irradiation Data Deck

A. Standard Dimensionless Weapon Pulse

(4) m	...Number of cards in list to follow.
(8) W, Q	...W= weapon yield in Kilotons Q= exposure in cal/cm^2
(8) $\theta_{A\infty}$, $\theta_{B\infty}$	...Ambient temperatures for radiation at front and rear faces, respectively.

B. Arbitrary Irradiation

(4)	m	...Number of cards in list to follow.
(8)	$\theta_{A\infty}, \theta_{B\infty}$	...Ambient temperatures for radiation at front and rear faces, respectively.
(6)	CAPTION	...Description of incident irradiation up to 66 characters in length.
(8)	H_i, τ_i	...Thermal irradiation at front face is H_1 at time τ_1, etc.
	$\vdots$	
(8)	H_{m-2}, τ_{m-2}	

NOTE: Either deck A or deck B (but not both) is used.

For case A: $m=2$ for the first computation of a series. $0 \le m \le 2$ for subsequent computations of the series. The dimensionless weapon pulse and the scale factors H_{max} and τ_{max} are generated by subroutines "PULSE" and "BLAST".

For case B: $3 \le m \le 122$ for the first computation of a series. $0 \le m \le 122$ and $m \ne 2$ for subsequent computations of the series. The deck is arranged in ascending values of τ_i. $H_i^{\bullet}$ and τ_i are not dimensionless in contrast to case A.

Appendix Ib

Input Card Formats

Following is a detailed description of the format of each input card as indicated in parentheses in Appendix Ia.

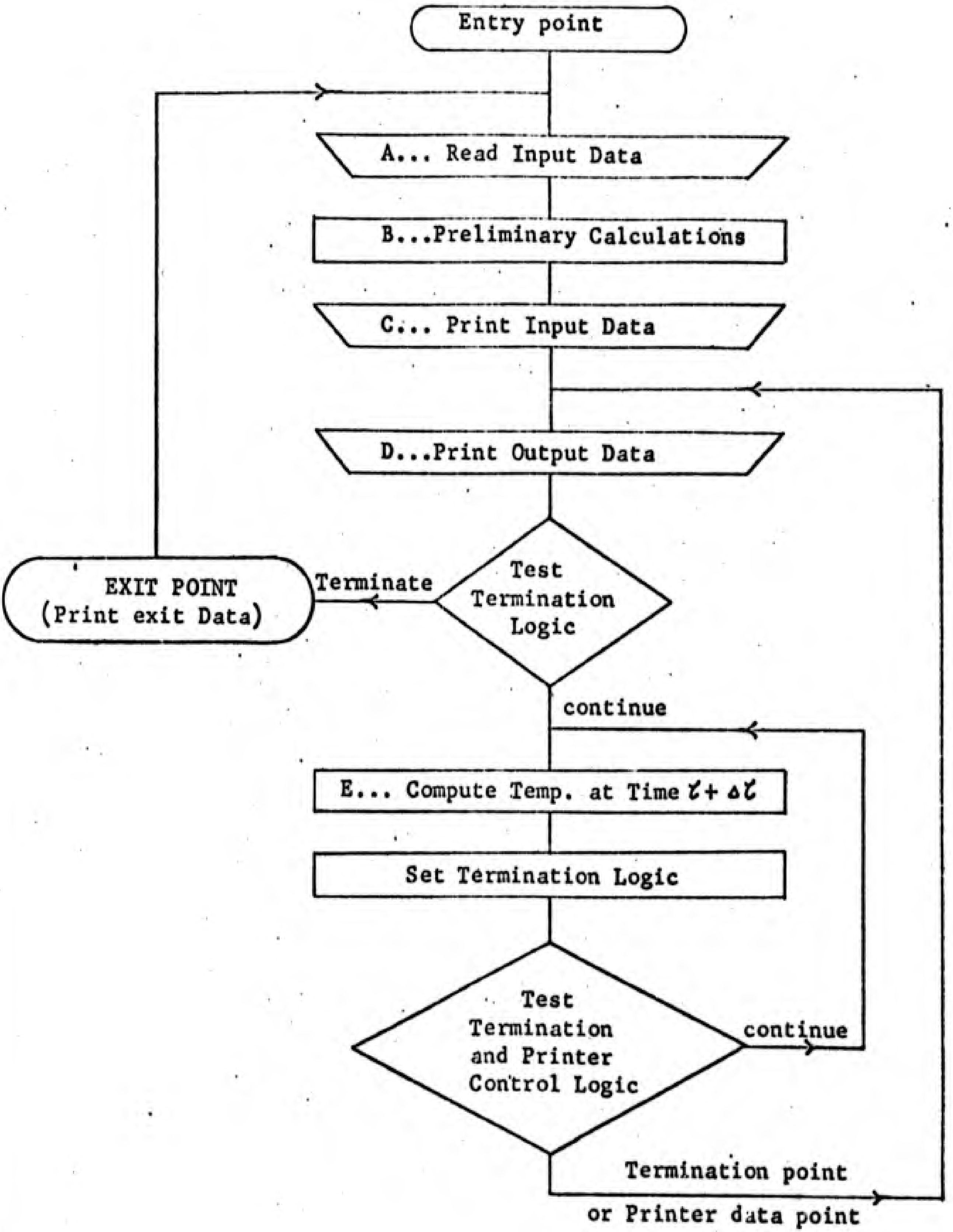
TYPE	FORMAT
1	Up to 24 alphanumeric characters beginning in column 1.
2	I, I, I, I, F, F, F
3	I, F
4	I
5	F
6	Up to 66 alphanumeric characters beginning in column 1.
7	F, F, F, F, F, F
8	F, F
9	F, F, F

NOTE: All numerical fields (I and F) are ten columns wide. "I" indicates integer data (I10). "F" indicates single precision floating point decimal data without exponent (F10.4).

Appendix II

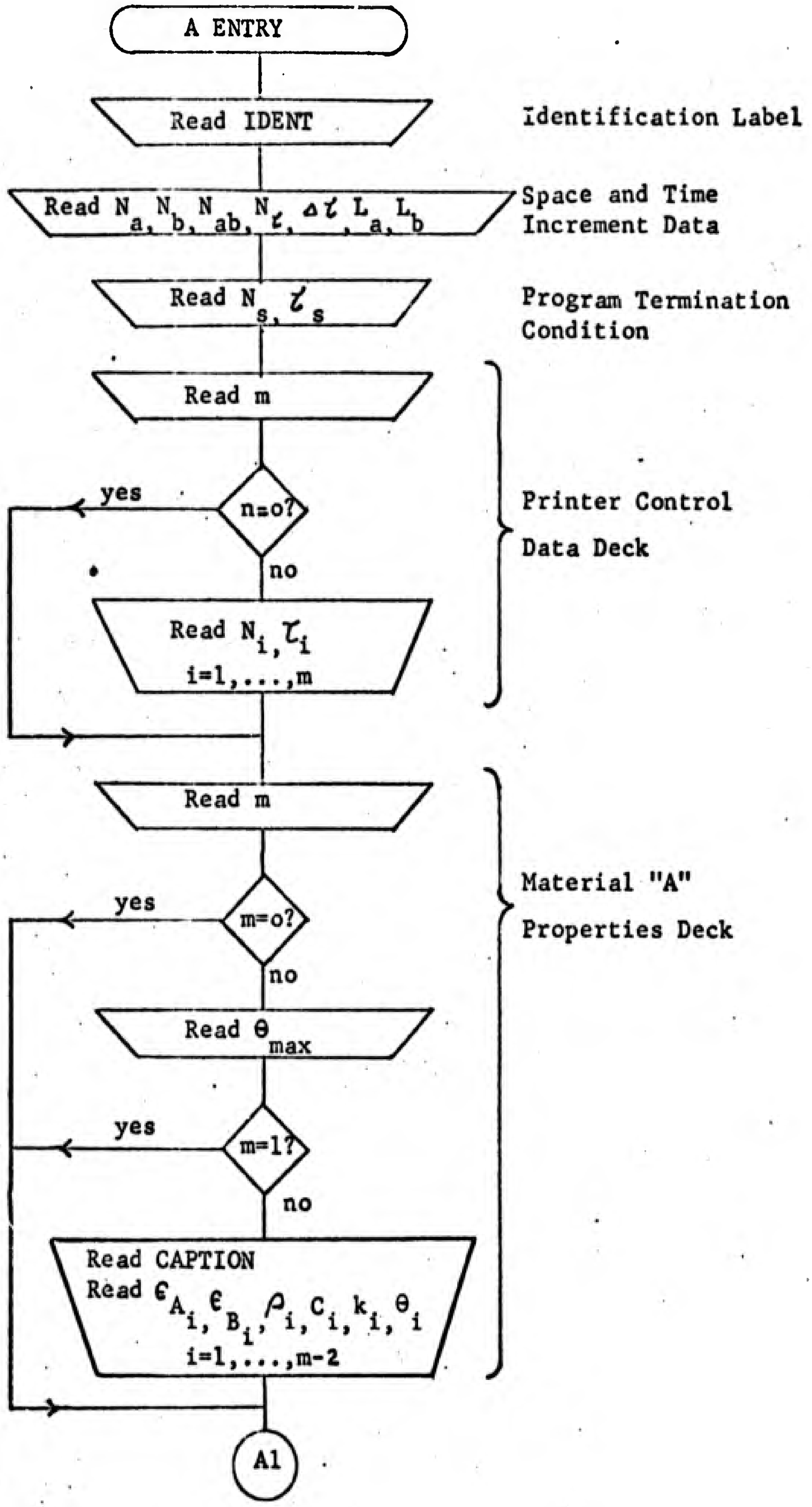
Flow Charts

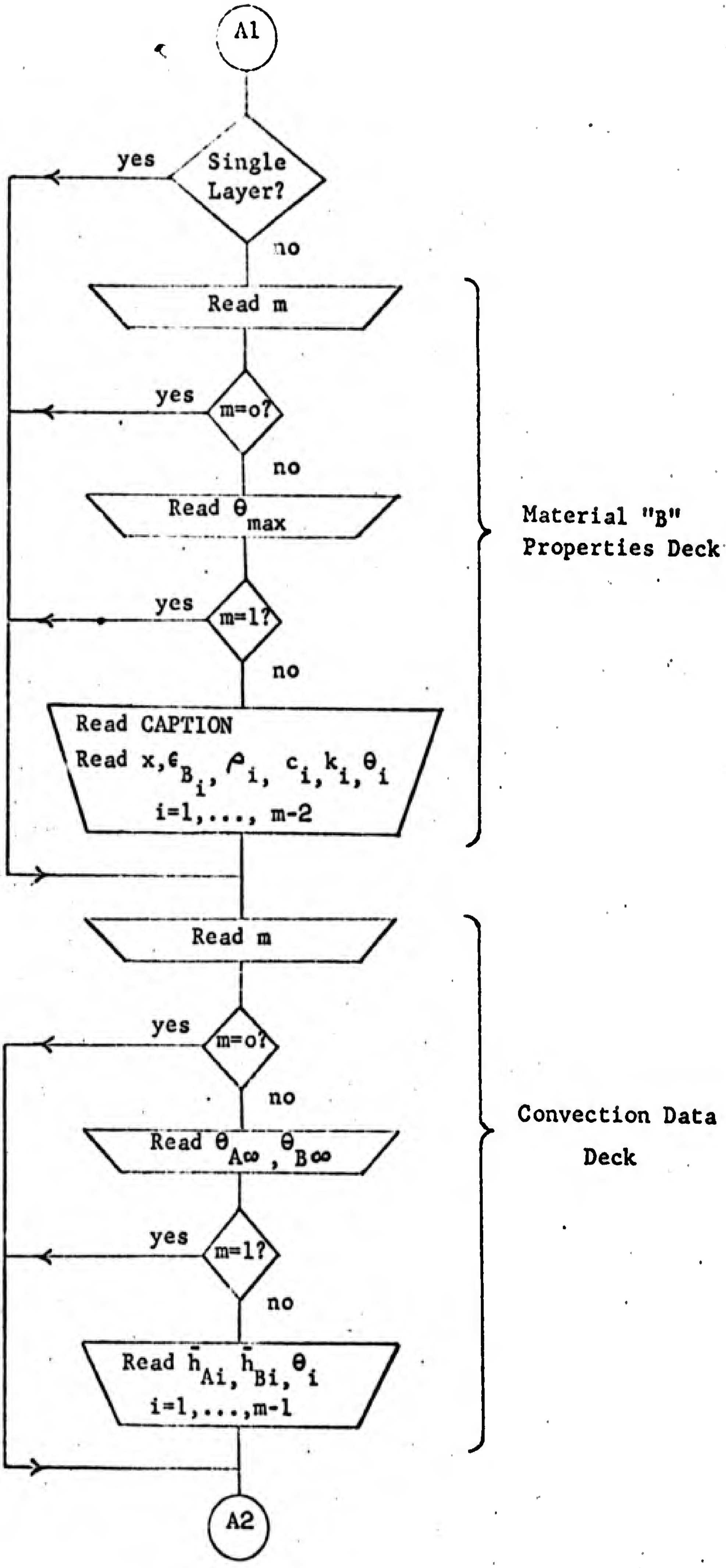
A flow diagram outlining the basic sequence of program operations is shown below. More detailed flow diagrams of blacks A,B,C,D, and E are presented in Appendices IIa, b, c, d and e which follow.

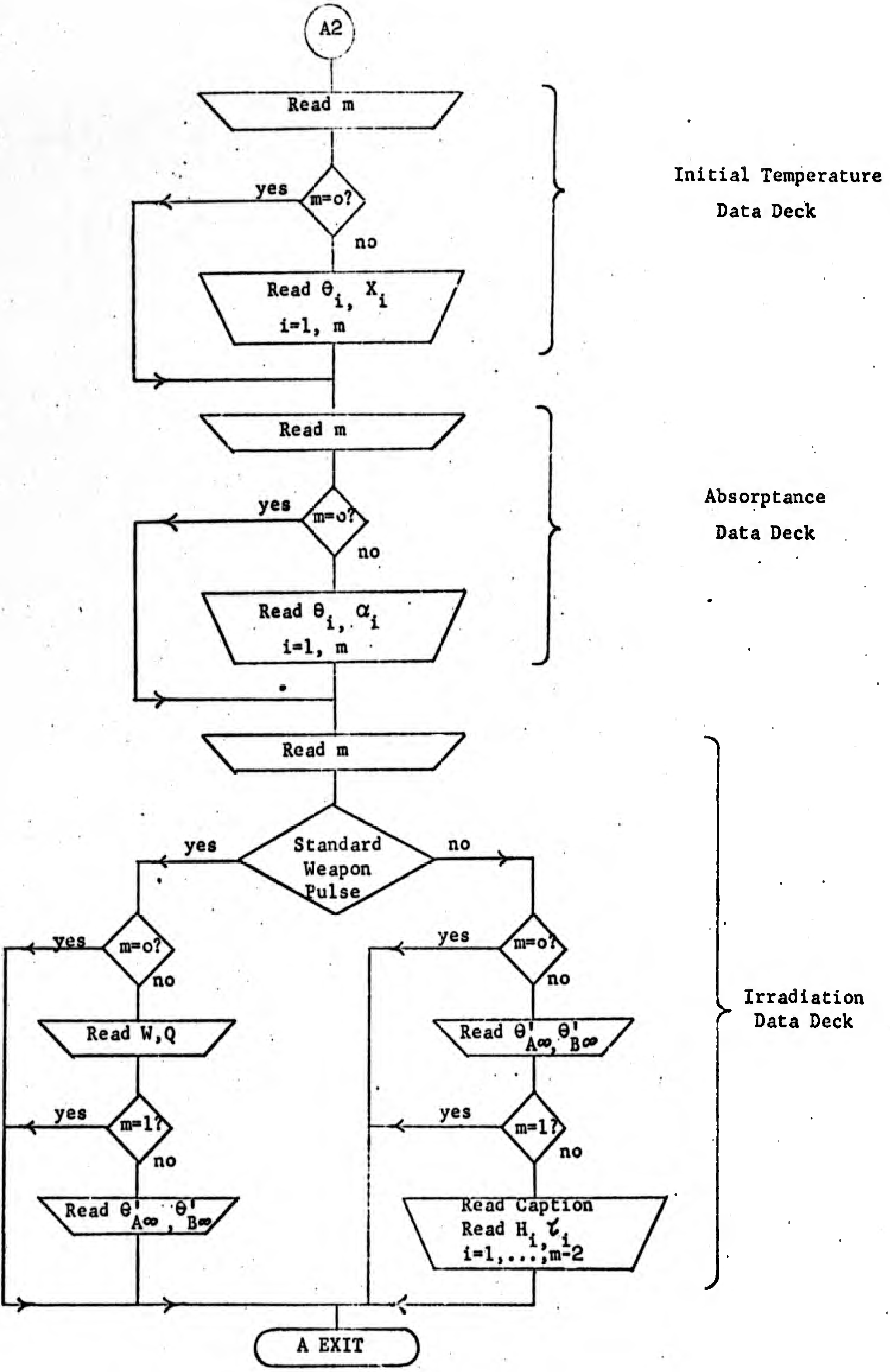


Appendix IIa

Input Data Sequence (Block A)

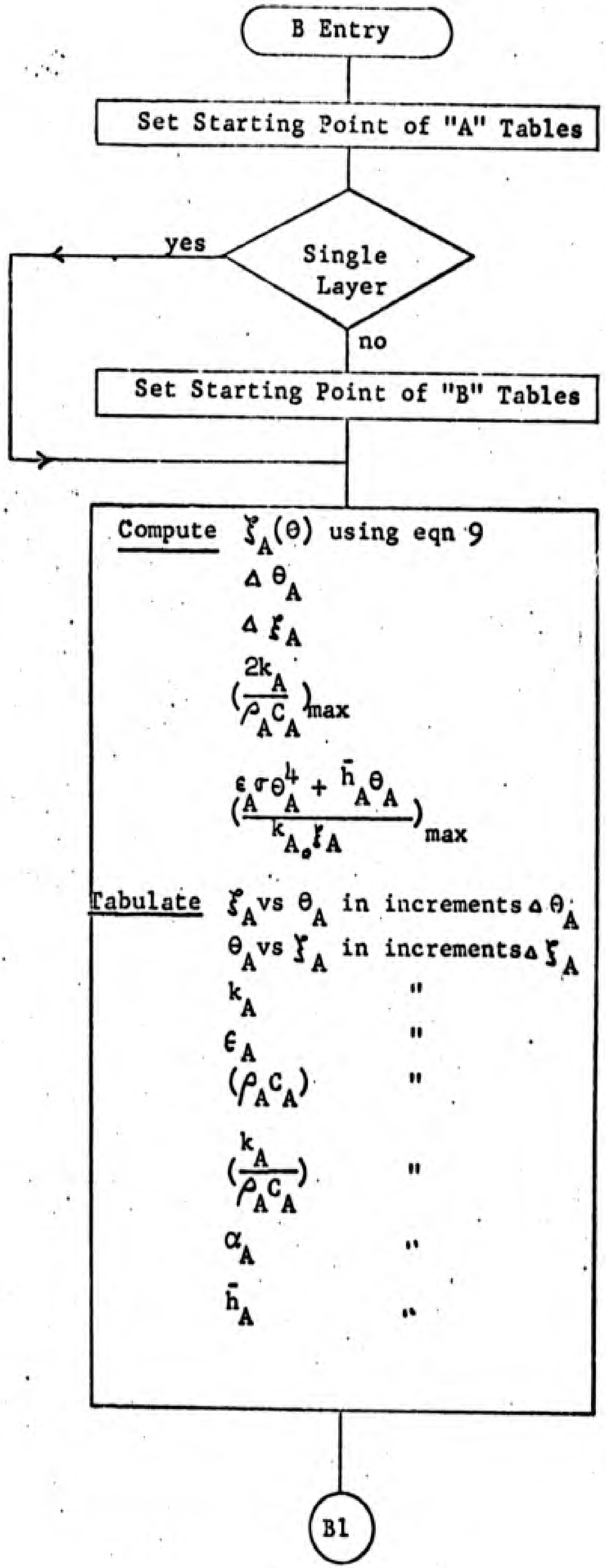


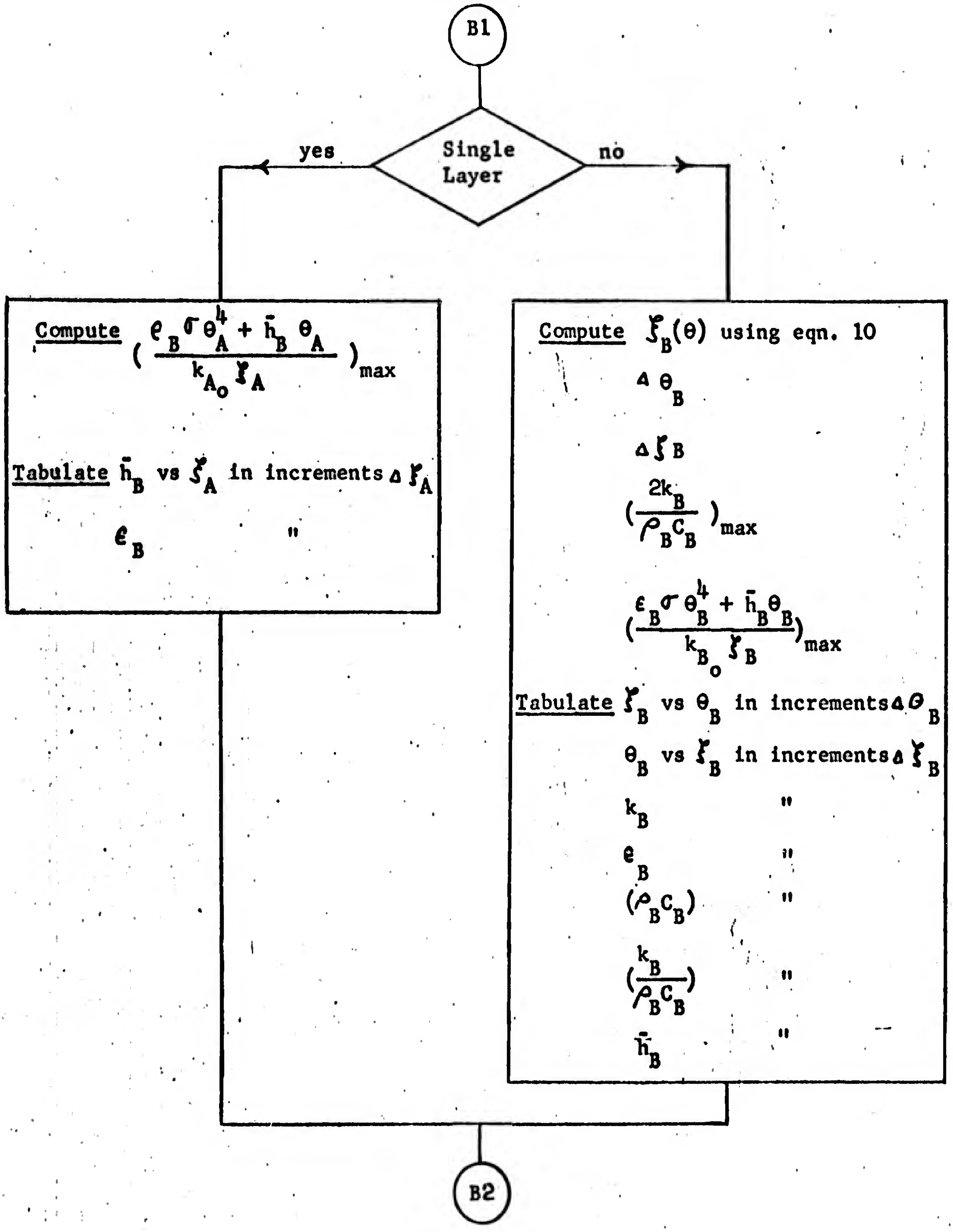

A1
Single Layer?
yes
no
Read m
m=o?
yes
no
Read θ max
m=1?
yes
no
Read CAPTION
Read x, ϵ B i, ρ i, c i, k i, θ i
i=1,..., m-2
Material "B" Properties Deck
Read m
m=o?
yes
no
Read θ A∞, θ B∞
m=1?
yes
no
Read h̄ Ai, h̄ Bi, θ i
i=1,...,m-1
Convection Data Deck
A2

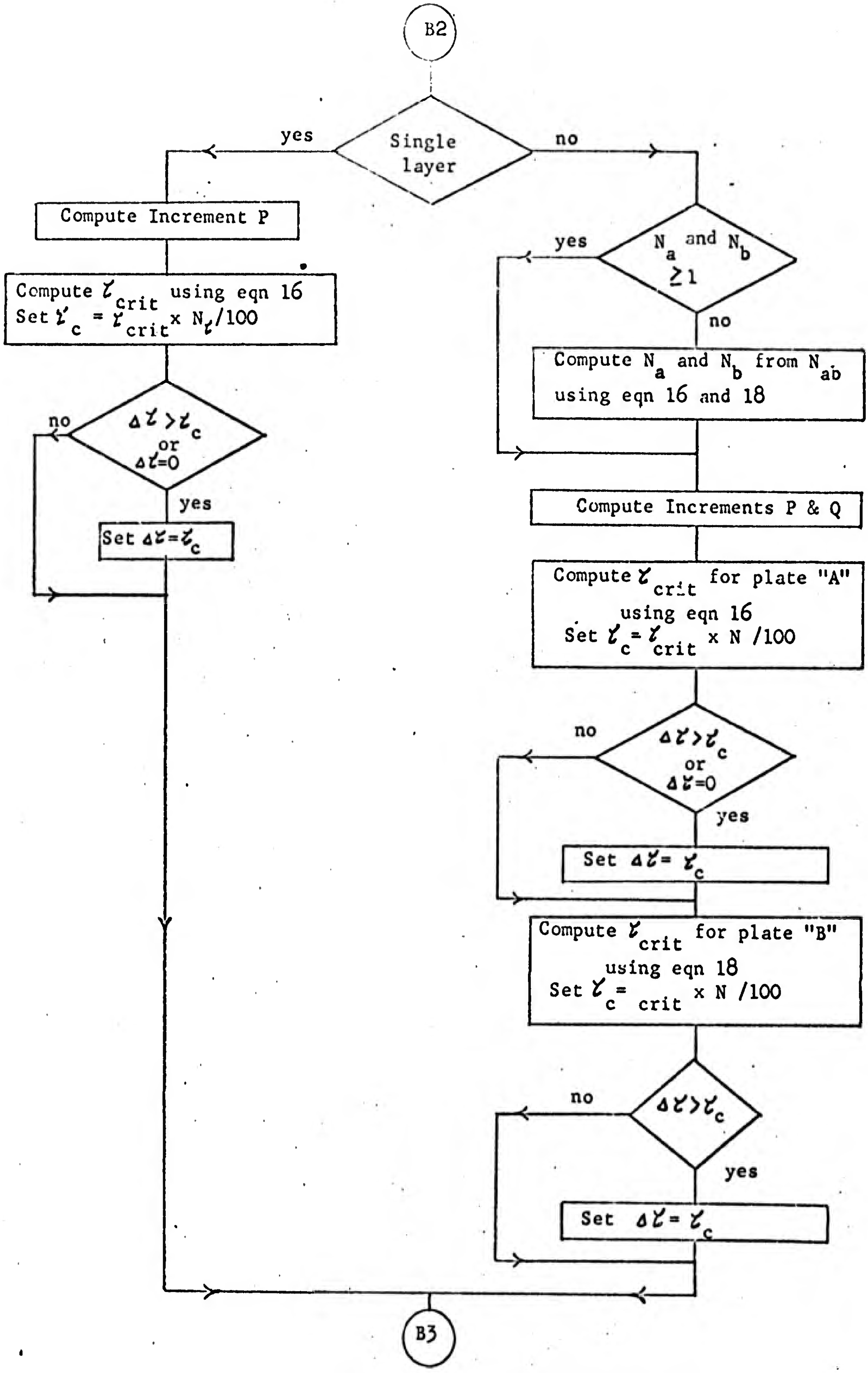

A2
Read m
yes
m=o?
no
Read θ_i, X_i i=1, m
Initial Temperature Data Deck
Read m
yes
m=o?
no
Read θ_i, α_i i=1, m
Absorptance Data Deck
Read m
yes
Standard Weapon Pulse
no
yes
m=o?
no
Read W,Q
yes
m=1?
no
Read $\theta'_{A\infty}$, $\theta'_{B\infty}$
yes
m=o?
no
Read $\theta'_{A\infty}$, $\theta'_{B\infty}$
yes
m=1?
no
Read Caption
Read H_i, τ_i i=1,...,m-2
Irradiation Data Deck
A EXIT

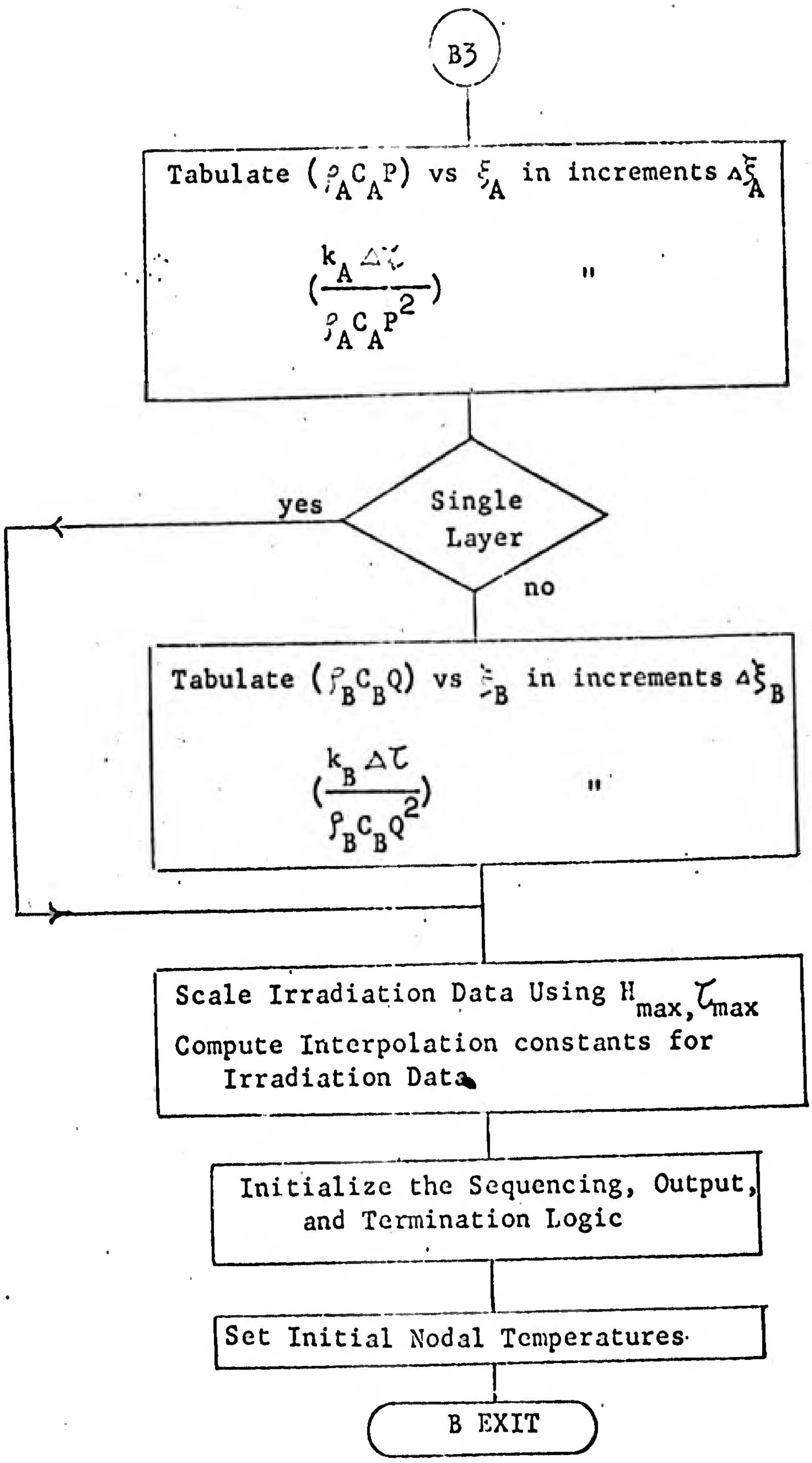
Appendix IIb

Preliminary Computations (Bloc B)



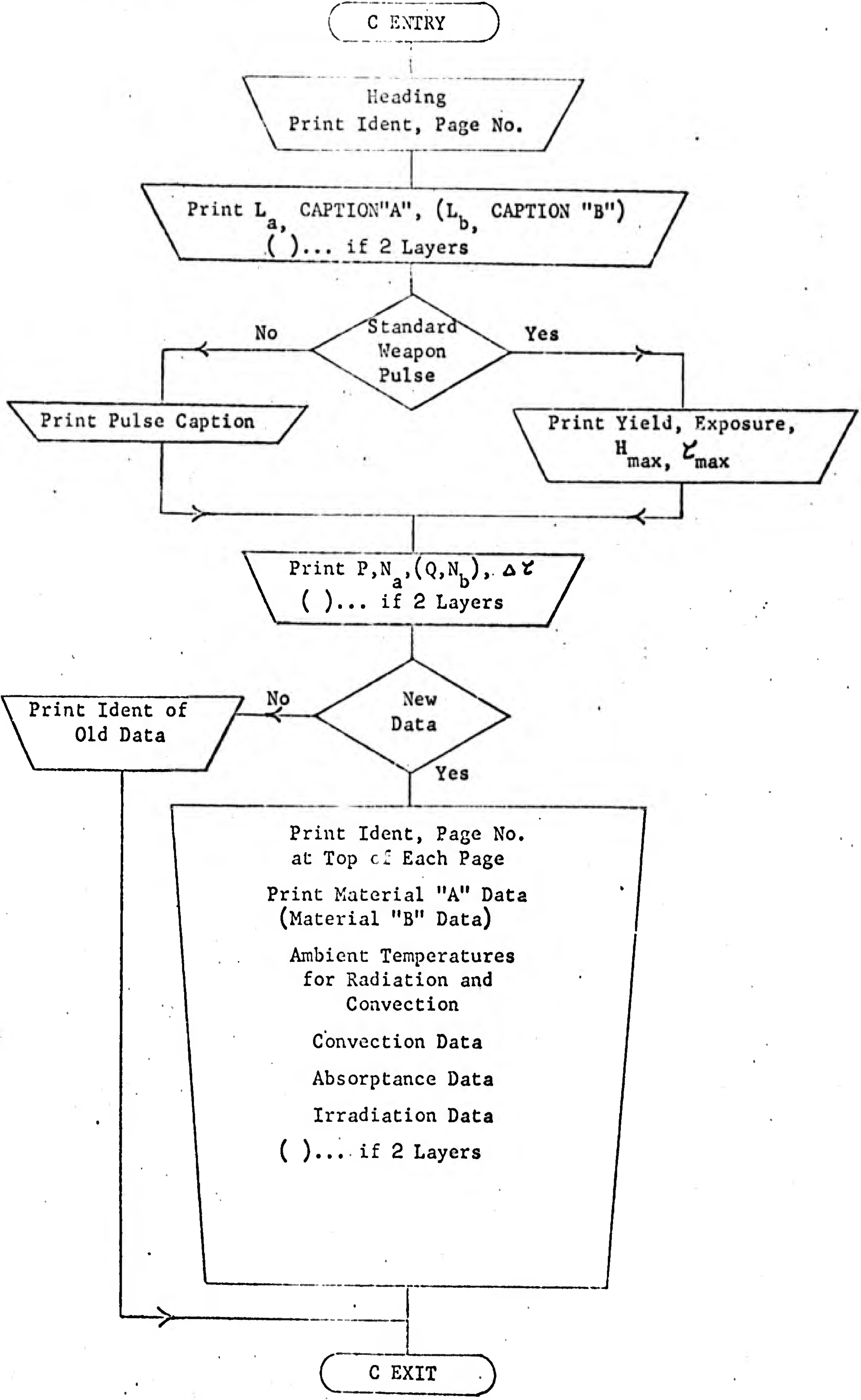

B1
Single Layer
yes
no
Compute $\left(\frac{\epsilon_B \sigma \theta_A^4 + \bar{h}_B \theta_A}{k_{A_o} \zeta_A}\right)_{max}$
Tabulate $\bar{h}_B$ vs ζ_A in increments $\Delta \zeta_A$
ϵ_B "
Compute $\zeta_B(\theta)$ using eqn. 10
$\Delta \theta_B$
$\Delta \zeta_B$
$\left(\frac{2k_B}{\rho_B C_B}\right)_{max}$
$\left(\frac{\epsilon_B \sigma \theta_B^4 + \bar{h}_B \theta_B}{k_{B_o} \zeta_B}\right)_{max}$
Tabulate ζ_B vs θ_B in increments $\Delta \theta_B$
θ_B vs ζ_B in increments $\Delta \zeta_B$
k_B "
ϵ_B "
$(\rho_B C_B)$ "
$\left(\frac{k_B}{\rho_B C_B}\right)$ "
$\bar{h}_B$ "
B2


B2
Single layer
yes
no
Compute Increment P
Compute τ_{crit} using eqn 16
Set $\tau_c = \tau_{crit} \times N_\tau/100$
$\Delta\tau > \tau_c$ or $\Delta\tau=0$
no
yes
Set $\Delta\tau=\tau_c$
N_a and N_b ≥ 1
yes
no
Compute N_a and N_b from N_{ab} using eqn 16 and 18
Compute Increments P & Q
Compute τ_{crit} for plate "A" using eqn 16
Set $\tau_c = \tau_{crit} \times N/100$
$\Delta\tau > \tau_c$ or $\Delta\tau=0$
no
yes
Set $\Delta\tau = \tau_c$
Compute τ_{crit} for plate "B" using eqn 18
Set $\tau_c = {}_{crit} \times N/100$
$\Delta\tau > \tau_c$
no
yes
Set $\Delta\tau = \tau_c$
B3


B3
Tabulate $(\rho_A C_A P)$ vs ξ_A in increments $\Delta\xi_A$
$\left(\frac{k_A \Delta\tau}{\rho_A C_A P^2}\right)$ "
Single Layer
yes
no
Tabulate $(\rho_B C_B Q)$ vs ξ_B in increments $\Delta\xi_B$
$\left(\frac{k_B \Delta\tau}{\rho_B C_B Q^2}\right)$ "
Scale Irradiation Data Using H_{max}, τ_{max}
Compute Interpolation constants for Irradiation Data
Initialize the Sequencing, Output, and Termination Logic
Set Initial Nodal Temperatures
B EXIT

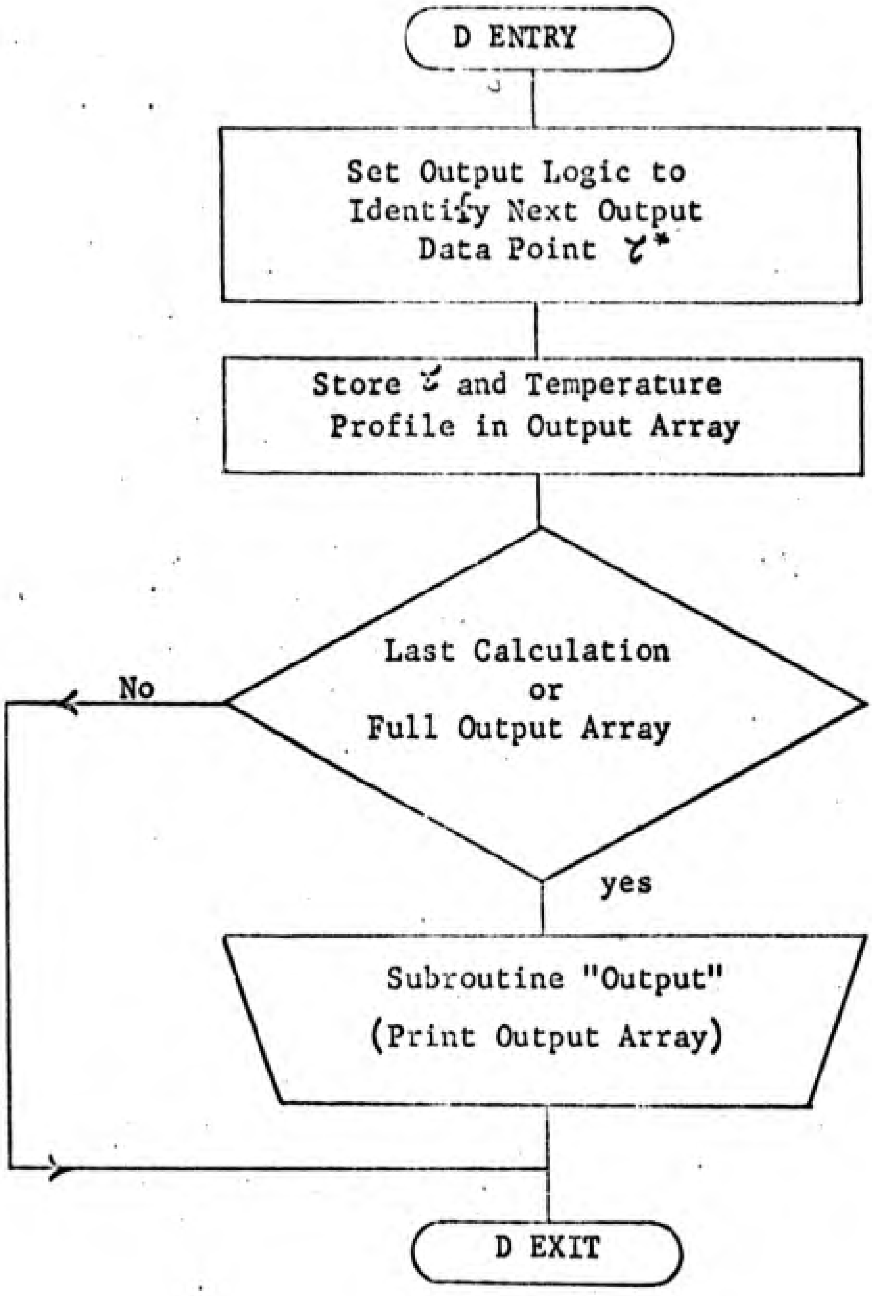
Appendix IIc

Print Input Data (Block C)



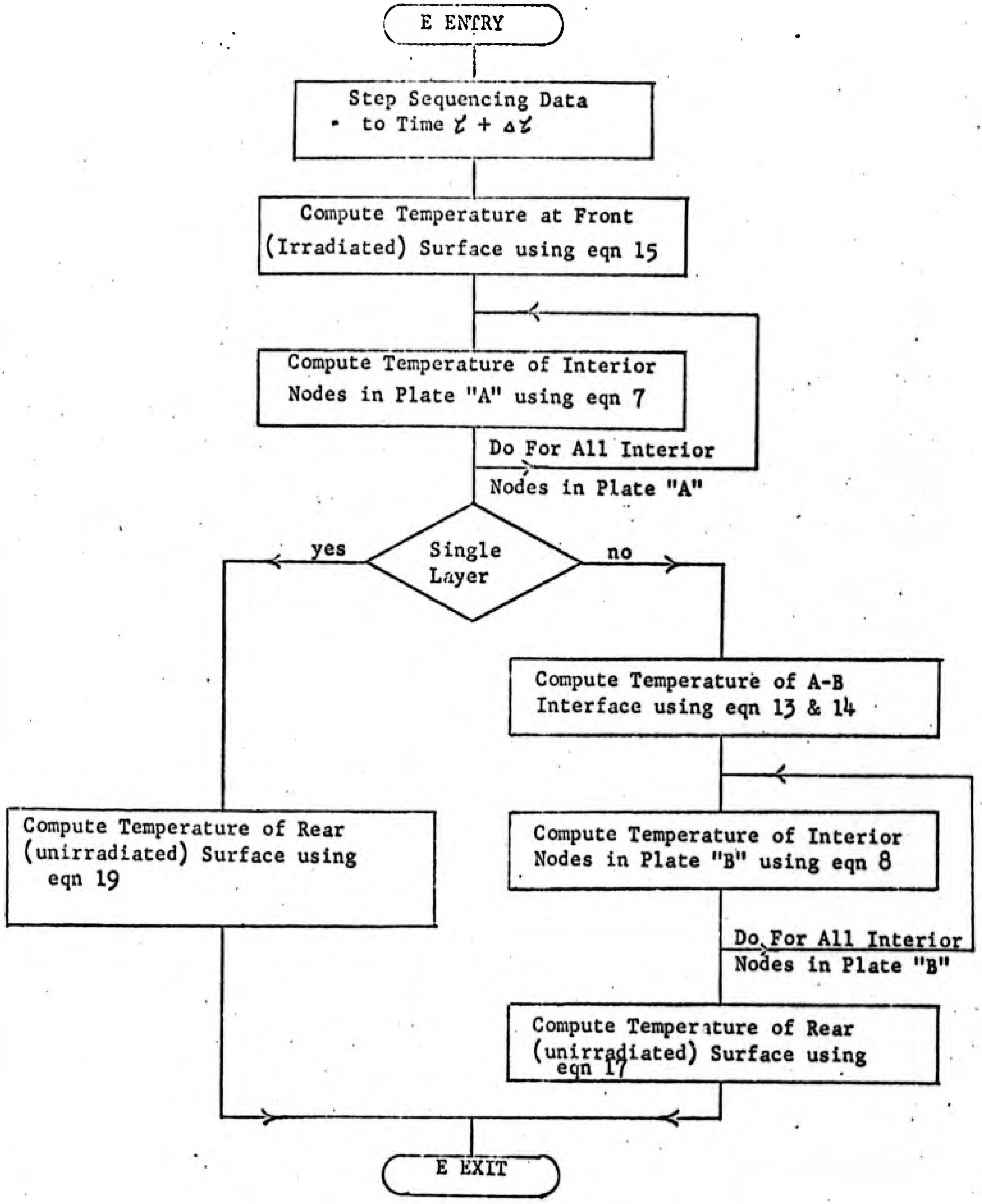
Appendix IId

Print Output Data (Block D)



Appendix IIe

Compute Temperatures at Time $\tau + \Delta\tau$ (Block E)



APPENDIX III

COMPUTER PROGRAM AND SUBROUTINES

```
C         TEMP1
C
C         A PROGRAM TO DETERMINE THE TEMPERATURE DISTRIBUTION AND HISTORY
C         IN SINGLE AND DUAL LAYERED PLATES SUBJECTED TO A THERMAL PULSE
C
C
C
C         ENTRY POINT
C
 1        FORMAT(I10)
 2        FORMAT(I10,F10.4)
 3        FORMAT(6F10.4)
 4        FORMAT(2F10.4)
 5        FORMAT(3F10.4)
 6        FORMAT(4I10,3F10.4)
 7        FORMAT(F10.4)
 8        FORMAT(11A6)
 9        FORMAT(4A6)
 20       FORMAT(1H0)
 21       FORMAT(1H0,///////,10X36HTEMPERATURE DISTRIBUTION AND HISTORY,
 21    1       33H IN A TWO LAYERED COMPOSITE PLATE//
 21    2       15X21HPLATE A THICKNESS....,F8.4,
 21    3       21H CM       MATERIAL....,11A6/
 21    4       15X21HPLATE B THICKNESS....,F8.4,
 21    5       21H CM       MATERIAL....,11A6)
 22       FORMAT(1H0,///////,10X36HTEMPERATURE DISTRIBUTION AND HISTORY,
 22    1       26H IN A SINGLE LAYERED PLATE//
 22    2       15X19HPLATE THICKNESS....,F8.4,
 22    3       23H CM         MATERIAL....,11A6)
 23       FORMAT(1H0,/////,10X15HEXPOSED TO....   ,11A6//
 23    1       15X46H(DETAILED DESCRIPTION PRINTED WITH INPUT DATA))
 24       FORMAT(1H0,/////,10X33HEXPOSED TO THERMAL RADIATION FROM,
 24    1       36H THE FOLLOWING STANDARD WEAPON PULSE//
 24    2      15X27HWEAPON YIELD.........(W) = ,F6.1, 3H KT/
 24    3      15X27HTOTAL IRRADIATION....(Q) = ,F6.1,10H CAL/SQ-CM /
 24    4      15X27HMAXIMUM INTENSITY.(HMAX) = ,F6.1,14H CAL/SQ-CM/SEC /
 24    5      15X27HAT TIME...........(TMAX) = ,F6.3, 8H SECONDS)
 25       FORMAT(1H ,/,10X22HAMBIENT CONDITIONS....//
 25    1      15X36HAMBIENT TEMPERATURE FOR RADIATION  = ,F7.2,
 25    2      18H K (FRONT SURFACE)/50X1H= ,F7.2,18H K (REAR  SURFACE)/
 25    3      15X36HAMBIENT TEMPERATURE FOR CONVECTION = ,F7.2,
 25    4      18H K (FRONT SURFACE)/50X1H= ,F7.2,18H K (REAR  SURFACE))
 26       FORMAT(1H0,/////,10X30HSPACE AND TIME INCREMENTS USED//
 26    1       15X5HP   = ,E11.4, 5H CM (,I3,13H INCREMENTS )/
 26    2       15X5HQ   = ,E11.4, 5H CM (,I3,13H INCREMENTS )/
 26    3       15X5HTAU = ,E11.4, 8H SECONDS)
 27       FORMAT(1H0,/////,10X30HSPACE AND TIME INCREMENTS USED//
 27    1       15X5HP   = ,E11.4, 5H CM (,I3,13H INCREMENTS )/
```

```
27      2       15X5HTAU = ,E11.4, 8H SECONDS)
28         FORMAT(1H0,/////,10X21HINPUT DATA UNCHANGED.,
28      1       28H SEE PREVIOUS COMPUTATION ( ,4A6,2H ))
29         FORMAT(1H0,/////,10X24HINPUT DATA PRINTED BELOW)
30         FORMAT(1H /10X18HINPUT DATA LISTING////10X11HPLATE A....,11A6)
31         FORMAT(1H /15X35HFRONT EMISSIVITY    REAR EMISSIVITY,
31      1       12X7HDENSITY, 6X13HSPECIFIC HEAT,
31      2       7X12HCONDUCTIVITY,8X11HTEMPERATURE)
32         FORMAT(20XE11.4,19X,4(8XE11.4))
33         FORMAT(12X6(8XE11.4))
34         FORMAT(31X5(8XE11.4))
35         FORMAT(1H /10X11HPLATE B....,11A6)
36         FORMAT(1H /10X36HCONVECTIVE HEAT TRANSFER COEFFICIENT//
36      1     15X13HFRONT SURFACE, 4X12HREAR SURFACE, 5X11HTEMPERATURE)
37         FORMAT(12X,3(5XE11.4))
38         FORMAT(1H /10X25HABSORPTIVITY (FRONT FACE),14X11HTEMPERATURE)
39         FORMAT(17XE11.4,21XE11.4)
40         FORMAT(1H /10X34HINCIDENT THERMAL RADIATION HISTORY)
41         FORMAT(1H /15X37H(STANDARD DIMENSIONLESS WEAPON PULSE))
42         FORMAT(1H /15X13HINTENSITY (H),6X10HTIME (SEC))
43         FORMAT(12X,2(5XE11.4))
           DIMENSION AA(250),AB(250),BA(250),CA(250),CB(250),DA(250),
        1       DB(250),EA(250),EB(250),FA(250),FB(250),GA(250),GB(250),
        2       HA(250),HB(250)
           DIMENSION PA(50),PB(50),QA(50),QB(50),RA(50),RB(50),SA(50),
        1       SB(50),TA(50),TB(50),ALF(50),TD(50),UA(50),UB(50),TC(50),
        2       XO(50),TO(50)
           DIMENSION LP(11),TIME(11),HZ(120),TH(120),HY(122),TY(122),
        1       FN(2,202),GN(201),HT(101),MATA(11),MATB(11),IDENT(4),
        2       TEMP(11,203),IIDENT(4),RAY(11)
           IA=250
           IB=250
           MX=10000
           JTLIM=11
           ZERO=0.0
           SIGMA=1.356E-12
C
C
C          A...READ INPUT DATA
C
90         CONTINUE
98         READ(5,9)IDENT
99         READ(5,6) NA,NB,NAB,NTAU,DT,WA,WB
           KX=1
           NO1=0
           IW=1
           IF(WB.EQ.ZERO) IW=2
           READ(5,2) NSTOP,TSTOP
995        READ(5,1)M
           IF(M.EQ.0)GO TO 100
           MP=M
           READ(5,2)(LP(I),TIME(I),I=1,MP)
100        READ(5,1)M
           IF(M.EQ.0)GO TO 101
           KX=2
           READ(5,7)TMAXA
1005       IF(M.EQ.1)GO TO 101
           MA=M-2
```

```
      READ(5,8)MATA
      READ(5,3)(PA(I),PB(I),QA(I),RA(I),SA(I),TA(I),I=1,MA)
 101  GO TO (102,103),IW
 102  READ(5,1)M
      IF(M.EQ.0)GO TO 103
      KX=2
      READ(5,7)TMAXB
 1025 IF(M.EQ.1)GO TO 103
      MB=M-2
      READ(5,8)MATB
      READ(5,3)(BLANK,PB(I),QB(I),RB(I),SB(I),TB(I),I=1,MB)
 103  READ(5,1)M
      IF(M.EQ.0)GO TO 104
      KX=2
      READ(5,4)TAMBA,TAMBB
 1035 IF(M.EQ.1) GO TO 104
      MC=M-1
      READ(5,5)(UA(I),UB(I),TC(I),I=1,MC)
 104  READ(5,1)M
      IF(M.EQ.0) GO TO 105
      KX=2
      MT=M
      READ(5,4)(TO(I),XO(I),I=1,MT)
 105  READ(5,1)M
      IF(M.EQ.0) GO TO 106
      KX=2
      MD=M
      READ(5,4)(ALF(I),TD(I),I=1,MD)
 106  READ(5,1)M
      IF(M.EQ.2)KZ=1
      IF(M.GT.2)KZ=2
 107  GO TO(1075,108),KZ
 1075 IF(M.EQ.0)GO TO 109
      READ(5,4)YIELD,HEAT
      CALL PULSE(HZ,TH,MH)
      IF(M.EQ.1)GO TO 109
      KX=2
      READ(5,4)TRADA,TRADB
      GO TO 109
 108  IF(M.EQ.0)GO TO 109
      KX=2
      READ(5,4)TRADA,TRADB
      IF(M.EQ.1)GO TO 109
      MH=M-2
      READ(5,8)RAY
      READ(5,4)(HZ(I),TH(I),I=1,MH)
```

```
C        B...PRELIMINARY CALCULATIONS
C
109      FC=TAMBA
         I=1
110      IF((I.GT.MT).OR.(XO(I).GT.WA))GO TO 111
         FC=AMIN1(FC,TO(I))
         I=I+1
         GO TO 110
111      FC=AMAX1(FC,TA(1))
         GO TO(112,115),IW
112      I=I-1
         FD=TAMBB
113      FD=AMIN1(FD,TO(I))
         IF((I.GE.MT).OR.(XO(I).GE.WA+WB))GO TO 114
         I=I+1
         GO TO 113
114      FD=AMAX1(FD,TB(1))
115      GN(1)=TA(1)
         IF(MA.EQ.1)GO TO 1152
         GO TO 1159
1152     GN(2)=TMAXA
         TA(2)=TMAXA
         M=2
         GO TO 1161
1159     DO 116 I=2,MA
116      GN(I)=GN(I-1)+(SA(I-1)+SA(I))*(TA(I)-TA(I-1))/(2.0*SA(1))
         M=MA
1161     DC=(TMAXA-FC)/FLOAT(IA-1)
1163     CALL TABLE(TA,GN,HA,FC,DC,M,IA)
         CC=HA(IA)
         AD=HA(1)
1165     AC=(CC-AD)/FLOAT(IA-1)
         CALL TABLE(GN,TA,DA,AD,AC,M,IA)
         DD=DA(1)
1168     CALL TABLE(GN,SA,GA,AD,AC,MA,IA)
         CALL TABLE(GN,PA,CA,AD,AC,MA,IA)
         DO 117 I=1,MA
117      HT(I)=QA(I)*RA(I)
         CALL TABLE(GN,HT,FA,AD,AC,MA,IA)
         GC=0.0
         DO 118 I=1,MA
         HT(I)=SA(I)/HT(I)
118      GC=AMAX1(GC,HT(I))
         GC=2.0*GC
         CALL TABLE(GN,HT,AA,AD,AC,MA,IA)
         KA=IA*MX
         AF=DC/FLOAT(MX)
1185     AG=AC/FLOAT(MX)
         DO 119 I=1,MD
         K=NODE(TD(I),FC,AF,KA,MX)
119      CALL FIND1(HT(I),HA,K,MX)
         CALL TABLE (HT,ALF,BA,AD,AC,MD,IA)
         DO 120 I=1,MC
         K=NODE(TC(I),FC,AF,KA,MX)
120      CALL FIND1(HT(I),HA,K,MX)
         CALL TABLE(HT,UA,EA,AD,AC,MC,IA)
         HC=0.0
         DO 121 I=1,MA
```

```
 1215   K=NODE(GN(I),AD,AG,KA,MX)
        CALL FIND1(X,EA,K,MX)
        P=(PA(I)*SIGMA*TA(I)**4+X*TA(I))/(SA(1)*GN(I))
 121    HC=AMAX1(HC,P)
        GO TO (124,122),IW
 122    CALL TABLE (HT,UB,EB,AD,AC,MC,IA)
        CALL TABLE(GN,PB,CB,AD,AC,MA,IA)
        HD=0.0
 1225   DO 123 I=1,MA
        K=NODE(GN(I),AD,AG,KA,MX)
        CALL FIND1(X,EB,K,MX)
        P=(PB(I)*SIGMA*TA(I)**4+X*TA(I))/(SA(1)*GN(I))
 123    HD=AMAX1(HD,P)
        HC=AMAX1(HD,HC)
        GO TO 130
 124    GN(1)=TB(1)
        IF(MB.EQ.1)GO TO 1242
        GO TO 1249
 1242   GN(2)=TMAXB
        TB(2)=TMAXB
        M=2
        GO TO 1251
 1249   DO 125 I=2,MB
 125    GN(I)=GN(I-1)+(SB(I-1)+SB(I))*(TB(I)-TB(I-1))/(2.0*SB(1))
        M=MB
 1251   EC=(TMAXB-FD)/FLOAT(IB-1)
        CALL TABLE(TB,GN,HB,FD,EC,M,IB)
        CD=HB(IB)
        BD=HB(1)
        BC=(CD-BD)/FLOAT(IB-1)
 1255   CALL TABLE(GN,TB,DB,BD,BC,M,IB)
        ED=DB(1)
        CALL TABLE(GN,SB,GB,BD,BC,MB,IB)
        CALL TABLE(GN,PB,CB,BD,BC,MB,IB)
        DO 126 I=1,MB
 126    HT(I)=QB(I)*RB(I)
        CALL TABLE(GN,HT,FB,BD,BC,MB,IB)
        GD=0.0
        DO 127 I=1,MB
        HT(I)=SB(I)/HT(I)
 127    GD=AMAX1(GD,HT(I))
        GD=2.0*GD
        CALL TABLE(GN,HT,AB,BD,BC,MB,IB)
        KB=IB*MX
        BF=EC/FLOAT(MX)
 1275   BG=BC/FLOAT(MX)
        DO 128 I=1,MC
        K=NODE(TC(I),FD,BF,KB,MX)
 128    CALL FIND1(HT(I),HB,K,MX)
        CALL TABLE (HT,UB,EB,BD,BC,MC,IB)
        HD=0.0
        DO 129 I=1,MB
 1285   K=NODE(GN(I),BD,BG,KB,MX)
        CALL FIND1(X,EB,K,MX)
        P=(PB(I)*SIGMA*TB(I)**4+X*TB(I))/(SB(1)*GN(I))
 129    HD=AMAX1(HD,P)
 130    GO TO (132,131),IW
 131    NC=NA
```

```
      NB=0
      IF(NA.EQ.0)NC=MAX0(1,NAB)
      NA=NC
      NAB=NC
      P=WA/FLOAT(NC)
      DTAU=DT
 1315 TCRIT=(P**2/(GC*(1.0+P*HC)))*FLOAT(NTAU)*0.01
      X=10.0**(AINT(ALOG10(TCRIT)+100.0)-100.0)
      TCRIT=0.1*AINT(10.0*TCRIT/X)*X
      IF((DT.GT.TCRIT).OR.(DT.EQ.ZERO))DTAU=TCRIT
      GO TO 134
 132  IF((NA.GE.1).AND.(NB.GE.1)) GO TO 133
      NC=MAX0(2,NAB)
      P=1.0+GC*WB*(HC+SQRT(HC**2+4.0))/(GD*WA*(HD+SQRT(HD**2+4.0)))
 1325 NA=INT(0.5+FLOAT(NAB)/P)
      NA=MAX0(1,NA)
      NA=MIN0(NA,NAB-1)
      NB=NAB-NA
 133  NAB=NA+NB
      P=WA/FLOAT(NA)
      Q=WB/FLOAT(NB)
      DTAU=DT
      TCRIT=(P**2/(GC*(1.0+P*HC)))*FLOAT(NTAU)*0.01
      X=10.0**(AINT(ALOG10(TCRIT)+100.0)-100.0)
      TCRIT=0.1*AINT(10.0*TCRIT/X)*X
 1335 IF((DTAU.GT.TCRIT).OR.(DTAU.EQ.ZERO))DTAU=TCRIT
      TCRIT=(Q**2/(GD*(1.0+Q*HD)))*FLOAT(NTAU)*0.01
      X=10.0**(AINT(ALOG10(TCRIT)+100.0)-100.0)
      TCRIT=0.1*AINT(10.0*TCRIT/X)*X
      IF(DTAU.GT.TCRIT)DTAU=TCRIT
 134  CONTINUE
      TEMP(1,1)=DTAU
      NV=NA+1
      NW=NA+2
      NX=NB+1
      NY=NAB+2
      NZ=NAB+1
 1342 A=P/SA(1)
      B=TRADA**4
      C=TAMBA
      E=SA(1)
 1344 G=TRADB**4
      H=TAMBB
      GO TO(1346,1348),IW
 1346 D=Q/SB(1)
      F=SB(1)
 1348 TIME(MP+1)=AMIN1(DTAU*FLOAT(NSTOP),TSTOP)
      LP(MP+1)=LP(MP)
      HC = DTAU/P**2
      DO 135 I=1,IA
      AA(I) = HC*AA(I)
 135  FA(I) = P*FA(I)
      GO TO (136,138),IW
 136  HC = DTAU/Q**2
      DO 137 I=1,IB
      AB(I) = HC*AB(I)
 137  FB(I) = Q*FB(I)
 138  GO TO (1382,1384),KZ
```

```
 1382 CALL BLAST(THMAX,HMAX,YIELD,HEAT)
      GO TO 1386
 1384 THMAX=1.0
      HMAX=1.0
 1386 IF(TH(1).EQ.ZERO)GO TO 140
      MM=MH+1
      HY(1)=0.0
      TY(1)=0.0
      DO 139 I=2,MM
      HY(I) = HZ(I-1)*HMAX
  139 TY(I) = TH(I-1)
      MY = MH+1
      GO TO 142
  140 DO 141 I=1,MH
      HY(I) = HZ(I)*HMAX
  141 TY(I) = TH(I)
      MY = MH
  142 DTH = DTAU/THMAX
      TMAX = THMAX*TY(MY)
      TLIM = FLOAT(NSTOP)*DTAU
      TLIM = AMIN1(TLIM,TSTOP)
 1425 HY(MY+1) = 0.0
      TY(MY+1) = TY(MY) + DTH
      IF(TMAX.GE.TLIM) GO TO 143
      TY(MY+1) = TLIM/THMAX
  143 NLIM=(0.5+TLIM/DTAU)
      TEMP(1,2)=0.0
      DO 144 I=1,NA
  144 TEMP(1,I+2)=TEMP(1,I+1)+P
      GO TO (145,147),IW
  145 TEMP(1,NA+3)=TEMP(1,NA+2)
      DO 146 I=1,NB
      IZ=I+NA
  146 TEMP(1,IZ+3)=TEMP(1,IZ+2)+Q
  147 IJ=1
      IG=2
      J=0
      JJ=1
      TAU=0.0
      JT=1
 1475 N=1
      JZ=0
      IK=1
      IC=1
      ID=1
      IE=1
      II=1
      LSTOP=(TSTOP/DTAU)+0.5
      CALL TABLE(XO,TO,GN,0.0,P,MT,NA+1)
      DO 148 I=1,NV
      K=NODE(GN(I),DD,AF,KA,MX)
  148 CALL FIND1(FN(1,I),HA,K,MX)
      GO TO(149,1500),IW
  149 CALL TABLE (XO,TO,GN,WA,Q,MT,NB+1)
      DO 150 I=1,NX
      K=NODE(GN(I),ED,BF,KB,MX)
      IZ=I+NA
  150 CALL FIND1(FN(1,IZ+1),HB,K,MX)
```

```
C         C...PRINT INPUT DATA
C
1500      LINE=0
          CALL PAGE(IDENT,NO1,LINE,70,1,60)
          GO TO(1501,1502),IW
1501      WRITE(6,21)WA,MATA,WB,MATB
          GO TO 1503
1502      WRITE(6,22)WA,MATA
1503      GO TO(1505,1504),KZ
1504      WRITE(6,23)RAY
          GO TO 1506
1505      WRITE(6,24)YIELD,HEAT,HMAX,THMAX
1506      GO TO(1507,1508),IW
1507      WRITE(6,26)P,NA,Q,NB,DTAU
          GO TO 1509
1508      WRITE(6,27)P,NA,DTAU
1509      GO TO(1510,1511),KX
1510      WRITE(6,28)IIDENT
          GO TO 1526
1511      WRITE(6,29)
          CALL PAGE(IDENT,NO1,LINE,70,1,52)
          WRITE(6,30)MATA
          WRITE(6,31)
          DO 1515 I=1,MA
          GO TO(1512,1513),IW
1512      WRITE(6,32)PA(I),QA(I),RA(I),SA(I),TA(I)
          GO TO 1514
1513      WRITE(6,33)PA(I),PB(I),QA(I),RA(I),SA(I),TA(I)
1514      CALL PAGE(IDENT,NO1,LINE,0,1,59)
1515      CONTINUE
          WRITE(6,20)
          GO TO(1516,1518),IW
1516      CALL PAGE(IDENT,NO1,LINE,4,6,55)
          WRITE(6,35)MATB
          WRITE(6,31)
          DO 1517 I=1,MB
          WRITE(6,34)PB(I),QB(I),RB(I),SB(I),TB(I)
          CALL PAGE(IDENT,NO1,LINE,0,1,59)
1517      CONTINUE
          WRITE(6,20)
1518      CALL PAGE(IDENT,NO1,LINE,0,9,50)
          WRITE(6,25)TRADA,TRADB,TAMBA,TAMBB
          CALL PAGE(IDENT,NO1,LINE,4,6,55)
          WRITE(6,20)
          WRITE(6,36)
          DO 1519 I=1,MC
          WRITE(6,37)UA(I),UB(I),TC(I)
          CALL PAGE(IDENT,NO1,LINE,0,1,59)
1519      CONTINUE
          WRITE(6,20)
          CALL PAGE(IDENT,NO1,LINE,4,4,57)
          WRITE(6,38)
          DO 1520 I=1,MD
          WRITE(6,39)ALF(I),TD(I)
          CALL PAGE(IDENT,NO1,LINE,0,1,59)
1520      CONTINUE
          WRITE(6,20)
          GO TO(1521,1522),KZ
```

```
 1521     CALL PAGE(IDENT,NO1,LINE,0,6,55)
          WRITE(6,40)
          WRITE(6,41)
          GO TO 1524
 1522     CALL PAGE(IDENT,NO1,LINE,4,6,55)
          WRITE(6,40)
          WRITE(6,42)
          DO 1523 I=1,MY
          WRITE(6,43)HY(I),TY(I)
          CALL PAGE(IDENT,NO1,LINE,0,1,59)
 1523     CONTINUE
 1524     DO 1525 I=1,4
 1525     IIDENT(I)=IDENT(I)
 1526     CONTINUE
 C
 C
 C        D...PRINT OUTPUT DATA USING PRINTER CONTROL DIRECTIONS
 C
 1530     JZ=JZ+LP(N)
          JY=(TIME(N)/DTAU)+0.5
          IF(JZ.LT.JY)GO TO 151
          JZ=JY
          IF(N.EQ.MP+1)GO TO 151
          N=N+1
 151      JT=JT+1
          TEMP(JT,1)=TAU
          DO 152 I=1,NV
          K=NODE(FN(IJ,I),AD,AG,KA,MX)
 152      CALL FIND1(TEMP(JT,I+1),DA,K,MX)
          GO TO (153,155),IW
 153      DO 154 I=NW,NY
          K=NODE(FN(IJ,I),BD,BG,KB,MX)
 154      CALL FIND1(TEMP(JT,I+1),DB,K,MX)
 155      IF((JT.EQ.JTLIM).OR.(IK.EQ.2))GO TO 176
          GO TO 156
 176      CALL OUTPUT(NO1,IDENT,JT,NA,NB,TEMP)
 C
 C
 C        TEST TERMINATION LOGIC...
 C                IF FINAL COMPUTATION GO TO 'EXIT POINT'
 C                IF NOT CONTINUE TO POINT 'E'
 C
          GO TO(177,178),IK
 177      JT=1
```

```
C         E...COMPUTE TEMPERATURE DISTRIBUTION AT TIME = TAU + DTAU
C
156       IH=IJ
          IJ=IG
          IG=IH
1565      J=J+1
          JJ=JJ+1
          TAU=DTAU*FLOAT(J)
          IF(J.EQ.1)GO TO 1575
157       IF(JJ.LE.101)GO TO 160
1575      NLIMA=101
          IF(NLIM.GT.100)GO TO 158
          NLIMA=NLIM+1
          GO TO 159
158       NLIM=NLIM-100
159       JJ=2
          START=(TAU-DTAU)/THMAX
          CALL TABLE(TY,HY,HT,START,DTH,MY+1,NLIMA)
160       K=NODE(FN(IG,1),AD,AG,KA,MX)
          CALL FIND4(W,X,Y,Z,AA,CA,DA,EA,K,MX)
          CALL FIND1(V,BA,K,MX)
1605      FN(IJ,1)=2.0*W*(A*(V*(HT(JJ-1)+HT(JJ))*0.5+X*SIGMA*(B-Y**4)
1605  1         +Z*(C-Y))+FN(IG,2)-FN(IG,1))+FN(IG,1)
          DO 161 I=2,NA
          K=NODE(FN(IG,I),AD,AG,KA,MX)
          CALL FIND1(X,AA,K,MX)
161       FN(IJ,I) = X*(FN(IG,I+1)+FN(IG,I-1)-2.0*FN(IG,I))+FN(IG,I)
          GO TO(1612,163),IW
1612      I=NA+1
          K=NODE(FN(IG,I),AD,AG,KA,MX)
1613      M=I+1
          MM=M+1
          L=NODE(FN(IG,M),BD,BG,KB,MX)
          CALL FIND2 (W,X,GA,FA,K,MX)
          CALL FIND2(Z,Y,GB,FB,L,MX)
1616      FN(IJ,I)=2.0*DTAU*((FN(IG,I-1)-FN(IG,I))/A
1616  1         +(FN(IG,M+1)-FN(IG,M))/D)/(X+Y)
          FN(IJ,M)=FN(IG,M)+Z*FN(IJ,I)/F
          FN(IJ,I)=FN(IG,I)+W*FN(IJ,I)/E
          DO 162 I=MM,NZ
          K=NODE(FN(IG,I),BD,BG,KB,MX)
          CALL FIND1(X,AB,K,MX)
162       FN(IJ,I)=X*(FN(IG,I+1)+FN(IG,I-1)-2.0*FN(IG,I))+FN(IG,I)
          I=NZ+1
          K=NODE(FN(IG,I),BD,BG,KB,MX)
          CALL FIND4(W,X,Y,Z,AB,CB,DB,EB,K,MX)
1625      FN(IJ,I)=2.0*W*(FN(IG,I-1)-FN(IG,I)+D*(X*SIGMA*(G-Y**4)
1625  1         +Z*(H-Y)))+FN(IG,I)
          GO TO 164
163       I=NA+1
          K=NODE(FN(IG,I),AD,AG,KA,MX)
          CALL FIND4(W,X,Y,Z,AA,CB,DA,EB,K,MX)
          FN(IJ,I)=2.0*W*(FN(IG,I-1)-FN(IG,I)+A*(X*SIGMA*(G-Y**4)
      1         +Z*(H-Y)))+FN(IG,I)
```

```
C         SET TERMINATION LOGIC
C
 164      DO 165 I=1,NV
          IF(FN(IJ,I).GE.CC)GO TO 166
 165      CONTINUE
          GO TO 167
 166      IC=2
          IK=2
 167      GO TO (168,171),IW
 168      DO 169 I=NW,NY
          IF(FN(IJ,I).GE.CD)GO TO 170
 169      CONTINUE
          GO TO 171
 170      ID=2
          IK=2
 171      IF(J.GE.LSTOP) GO TO 172
          GO TO 173
 172      IE=2
          IK=2
 173      IF(J.GE.NSTOP)GO TO 174
          GO TO 175
 174      II=2
          IK=2
C
C
C         TEST TERMINATION AND PRINTER CONTROL LOGIC...
C               IF TERMINATION POINT OR PRINTER DATA POINT GO TO 'D'
C               IF NOT GO TO 'E'
C
 175      IF((IK.EQ.2).OR.(J.GE.JZ))GO TO 1530
          GO TO 156
C
C
C         EXIT POINT...
C               TERMINATE COMPUTATION AND PRINT EXIT DATA
C               RE-ENTER PROGRAM AT POINT 'A' FOR NEXT COMPUTATION
C
 178      CALL EXPUT(IDENT,NO1,IC,CC,ID,CD,IE,TSTOP,II,NSTOP)
          GO TO 90
 179      END
```

```
      SUBROUTINE BLAST(T,H,W,Q)
C
      T= 0.032*SQRT(W)
      H= Q/(T*2.57)
      RETURN
      END
```

```
      SUBROUTINE EXPUT(IDENT,NO1,IC,CC,ID,CD,IE,TSTOP,II,NSTOP)
C
      DIMENSION IDENT(4)
1     FORMAT(1H1,9X4A6,20X5HPAGE ,I2////10X22HCOMPUTATION TERMINATED)
2     FORMAT(1H0,19X,20HTEMPERATURE REACHED ,F7.1,13H K IN PLATE A)
3     FORMAT(1H0,19X,20HTEMPERATURE REACHED ,F7.1,13H K IN PLATE B)
4     FORMAT(1H0,19X,13HREAL TIME IS ,F6.2,19H SECONDS OR GREATER)
5     FORMAT(1H0,19X,
5    1    22HCOMPUTATION HAS TAKEN ,I5,19H OR MORE TIME STEPS)
      NO1=NO1+1
      WRITE(6,1)IDENT,NO1
      GO TO(101,100),IC
100   WRITE(6,2)CC
101   GO TO (103,102),ID
102   WRITE(6,3)CD
103   GO TO (105,104),IE
104   WRITE(6,4)TSTOP
105   GO TO (107,106),II
106   WRITE(6,5)NSTOP
107   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FIND1(U,X,N,M)
C
      DIMENSION X(250)
      N1=N/M
      N2=N1*M
      IF(N2.EQ.N)GO TO 100
      FN2=FLOAT(N-N2)/FLOAT(M)
      U=X(N1)+(X(N1+1)-X(N1))*FN2
      GO TO 110
100   U=X(N1)
110   RETURN
      END
```

```
      SUBROUTINE FIND2(U,V,X,Y,N,M)
C
      DIMENSION X(250),Y(250)
      N1=N/M
      N2=N1*M
      IF(N2.EQ.N)GO TO 100
      N3=N1+1
      FN2=FLOAT(N-N2)/FLOAT(M)
      U=X(N1)+(X(N3)-X(N1))*FN2
      V=Y(N1)+(Y(N3)-Y(N1))*FN2
      GO TO 110
  100 U=X(N1)
      V=Y(N1)
  110 RETURN
      END
```

```
      SUBROUTINE FIND4(S,T,U,V,W,X,Y,Z,N,M)
C
      DIMENSION W(250),X(250),Y(250),Z(250)
      N1=N/M
      N2=N1*M
      IF(N2.EQ.N)GO TO 100
      N3=N1+1
      FN2=FLOAT(N-N2)/FLOAT(M)
      S=W(N1)+(W(N3)-W(N1))*FN2
      T=X(N1)+(X(N3)-X(N1))*FN2
      U=Y(N1)+(Y(N3)-Y(N1))*FN2
      V=Z(N1)+(Z(N3)-Z(N1))*FN2
      GO TO 110
  100 S=W(N1)
      T=X(N1)
      U=Y(N1)
      V=Z(N1)
  110 RETURN
      END
```

```
      FUNCTION NODE(FN,FNI,DF,N,M)
C
      NODE=INT(0.5+FLOAT(M)+(FN-FNI)/DF)
      NODE=MAX0(NODE,M)
      NODE=MIN0(NODE,N)
      RETURN
      END
```

```
      SUBROUTINE OUTPUT(NO1,IDENT,JT,NA,NB,TEMP)
C
      DIMENSION IDENT(4),TEMP(11,203)
1     FORMAT(1H1,9X4A6,15X5HPAGE ,I2,9H,  SHEET ,I1)
5     FORMAT(1H0,//12X10(F8.4,4H SEC))
6     FORMAT(1H0,//12X10(1XF8.7,3HSEC))
7     FORMAT(1H0,//12X10(F9.8,3HSEC))
8     FORMAT(1X)
9     FORMAT(1H ,F7.4,3H CM,10(F9.1,3H K ))
10    FORMAT(11H  INTERFACE)
      NO1=NO1+1
      J=1
      IW=1
      IF(NB.EQ.0)IW=2
      LINE=55
      NO2=1
      WRITE(6,1)IDENT,NO1,NO2
      N=1
      IF(TEMP(1,1).LT.0.001)N=2
      IF(TEMP(1,1).LT.0.000001)N=3
105   K=1
106   GO TO(1062,1064,1066),N
1062  WRITE(6,5)(TEMP(I,1),I=2,JT)
      GO TO 1068
1064  WRITE(6,6)(TEMP(I,1),I=2,JT)
      GO TO 1068
1066  WRITE(6,7)(TEMP(I,1),I=2,JT)
1068  WRITE(6,8)
107   GO TO(108,110,111),K
108   IF(LINE.EQ.0)GO TO 114
      J=J+1
      LINE=LINE-1
      WRITE(6,9)(TEMP(I,J),I=1,JT)
      IF(J.LT.NA+2)GO TO 107
      GO TO (109,112),IW
109   K=2
      IF(LINE.LT.5)GO TO 113
110   WRITE(6,10)
      LINE=LINE-3
      K=3
111   IF(LINE.EQ.0)GO TO 114
      LINE=LINE-1
      J=J+1
      WRITE(6,9)(TEMP(I,J),I=1,JT)
      IF(J.LT.NA+NB+3)GO TO 111
112   RETURN
113   WRITE(6,10)
114   NO2=NO2+1
      WRITE(6,1)IDENT,NO1,NO2
      LINE=55
      IF(NA+NB+3-J.LT.LINE)LINE=NA+NB+3-J
      GO TO 106
      END
```

```
      SUBROUTINE PAGE(I,J,K,L,M,N)
C
      DIMENSION I(4)
    1 FORMAT(1H1,9X4A6,,20X5HPAGE ,I2//)
      K=K-M
      IF(K.GT.L)GO TO 2
      J=J+1
      WRITE(6,1)I,J
      K=N
    2 RETURN
      END
```

```
      SUBROUTINE TABLE(X,Y,Z,XO,DX,M,N)
C
      DIMENSION X(122),Y(122),Z(250)
      A=XO
      I=1
      J=0
      IF(M.EQ.1)GO TO 50
   10 J=J+1
      R=(Y(J+1)-Y(J))/(X(J+1)-X(J))
   20 IF(A.GT.X(J+1))GO TO 40
   30 IF(I.GT.N)GO TO 70
      Z(I)=Y(J)+R*(A-X(J))
      I=I+1
      A=A+DX
      GO TO 20
   40 IF((J+1).LE.M)GO TO 10
      GO TO 30
   50 DO 60 I=1,N
   60 Z(I)=Y(1)
   70 RETURN
      END
```

```
      SUBROUTINE PULSE(H,T,I)
C
      DIMENSION H(109),T(109)
      I=109
      T(1  )=  .1
      T(2  )=  .15
      T(3  )=  .2
      T(4  )=  .25
      T(5  )=  .3
      T(6  )=  .35
      T(7  )=  .4
      T(8  )=  .45
      T(9  )=  .5
      T(10 )=  .55
      T(11 )=  .6
      T(12 )=  .65
      T(13 )=  .7
      T( 14)=  .75
      T( 15)=  .8
      T( 16)=  .85
      T( 17)=  .9
      T( 18)=  .95
      T( 19)=  1.
      T( 20)=  1.05
      T( 21)=  1.1
      T( 22)=  1.15
      T( 23)=  1.2
      T( 24)=  1.25
      T( 25)=  1.3
      T( 26)=  1.35
      T( 27)=  1.4
      T( 28)=  1.45
      T( 29)=  1.5
      T( 30)=  1.55
      T( 31)=  1.6
      T( 32)=  1.65
      T( 33)=  1.7
      T( 34)=  1.75
      T( 35)=  1.8
      T( 36)=  1.85
      T( 37)=  1.9
      T( 38)=  1.95
      T( 39)=  2.
      T( 40)=  2.05
      T( 41)=  2.1
      T( 42)=  2.15
      T( 43)=  2.2
      T( 44)=  2.25
      T( 45)=  2.3
      T( 46)=  2.35
      T( 47)=  2.4
      T( 48)=  2.45
      T( 49)=  2.5
      T( 50)=  2.55
      T( 51)=  2.6
      T( 52)=  2.65
      T( 53)=  2.7
      T( 54)=  2.75
```

```
T( 55)=  2.8
T( 56)=  2.9
T( 57)=  3.
T( 58)=  3.1
T( 59)=  3.2
T( 60)=  3.3
T( 61)=  3.4
T( 62)=  3.5
T( 63)=  3.6
T( 64)=  3.7
T( 65)=  3.8
T( 66)=  3.9
T( 67)=  4.
T( 68)=  4.1
T( 69)=  4.2
T( 70)=  4.3
T( 71)=  4.4
T( 72)=  4.5
T( 73)=  4.6
T( 74)=  4.7
T( 75)=  4.8
T( 76)=  4.9
T( 77)=  5.
T( 78)=  5.125
T( 79)=  5.25
T( 80)=  5.375
T( 81)=  5.5
T( 82)=  5.625
T( 83)=  5.75
T( 84)=  5.875
T( 85)=  6.
T( 86)=  6.125
T( 87)=  6.25
T( 88)=  6.375
T( 89)=  6.5
T( 90)=  6.625
T( 91)=  6.75
T( 92)=  6.875
T( 93)=  7.
T( 94)=  7.125
T( 95)=  7.25
T( 96)=  7.375
T( 97)=  7.5
T( 98)=  7.625
T( 99)=  7.75
T(100)=  7.875
T(101)=  8.
T(102)=  9.
T(103)=  10.
T(104)=  15.
T(105)=  20.
T(106)=  30.
T(107)=  40.
T(108)=  50.
T(109)=  90.
H(  1)=  .026
H(  2)=  .064
H(  3)=  .105
```

```
H(  4)=  .155
H(  5)=  .209
H(  6)=  .27
H(  7)=  .357
H(  8)=  .444
H(  9)=  .54
H( 10)=  .633
H( 11)=  .717
H( 12)=  .784
H( 13)=  .84
H( 14)=  .89
H( 15)=  .926
H( 16)=  .96
H( 17)=  .988
H( 18)=  .997
H( 19)=  1.
H( 20)=  .997
H( 21)=  .988
H( 22)=  .967
H( 23)=  .946
H( 24)=  .91
H( 25)=  .88
H( 26)=  .84
H( 27)=  .79
H( 28)=  .73
H( 29)=  .7
H( 30)=  .624
H( 31)=  .59
H( 32)=  .554
H( 33)=  .53
H( 34)=  .503
H( 35)=  .483
H( 36)=  .463
H( 37)=  .445
H( 38)=  .43
H( 39)=  .415
H( 40)=  .4
H( 41)=  .387
H( 42)=  .37
H( 43)=  .36
H( 44)=  .35
H( 45)=  .34
H( 46)=  .33
H( 47)=  .32
H( 48)=  .31
H( 49)=  .3
H( 50)=  .292
H( 51)=  .284
H( 52)=  .276
H( 53)=  .27
H( 54)=  .263
H( 55)=  .256
H( 56)=  .244
H( 57)=  .23
H( 58)=  .219
H( 59)=  .209
H( 60)=  .199
H( 61)=  .19
```

```
      H( 62)=  .182
      H( 63)=  .174
      H( 64)=  .165
      H( 65)=  .157
      H( 66)=  .15
      H( 67)=  .143
      H( 68)=  .138
      H( 69)=  .133
      H( 70)=  .127
      H( 71)=  .122
      H( 72)=  .118
      H( 73)=  .114
      H( 74)=  .11
      H( 75)=  .107
      H( 76)=  .103
      H( 77)=  .1
      H( 78)=  .097
      H( 79)=  .092
      H( 80)=  .08[illegible]
      H( 81)=  .085
      H( 82)=  .082
      H( 83)=  .08
      H( 84)=  .077
      H( 85)=  .074
      H( 86)=  .071
      H( 87)=  .069
      H( 88)=  .067
      H( 89)=  .065
      H( 90)=  .062
      H( 91)=  .061
      H( 92)=  .06
      H( 93)=  .058
      H( 94)=  .056
      H( 95)=  .054
      H( 96)=  .053
      H( 97)=  .051
      H( 98)=  .05
      H( 99)=  .049
      H(100)=  .048
      H(101)=  .047
      H(102)=  .039
      H(103)=  .034
      H(104)=  .0175
      H(105)=  .011
      H(106)=  .0057
      H(107)=  .0036
      H(108)=  .0025
      H(109)=  .001
      RETURN
      END
```

Appendix IVa

Input Data for Sample Calculations

```
TEST CASE A.....(SAMPLE)
         0         0        10       100     0.005     0.395     0.395
        80       0.4
         2
         1      0.05
        10       1.0
         3
     848.0
 TYPE 5456 ALUMINUM-MAGNESIUM ALLOY (ASSUMING CONSTANT PROPERTIES)
       0.0       0.0      2.66      0.22      0.28     300.0
         3
     848.0
 TYPE 5456 ALUMINUM-MAGNESIUM ALLOY (ASSUMING CONSTANT PROPERTIES)
       0.0       0.0      2.66      0.22      0.28     300.0
         2
     300.0     300.0
       0.0       0.0     300.0
         2
     300.0       0.0
     300.0      0.79
         1
       1.0     300.0
         4
     300.0     300.0
A CONSTANT HEAT SOURCE OF INTENSITY 100 CAL/SQ-CM/SEC
     100.0       0.0
     100.0     100.0
TEST CASE B.....(SAMPLE)
         0         0        10        50     0.005     0.395     0.395
        80       0.4
         1
        10       1.0
         0
         0
         0
         0
         0
         0
TEST CASE C.....(SAMPLE)
         0         0        10       100     0.005      0.79       0.0
        80       0.4
         2
         1      0.05
        10       1.0
         0
         0
         0
         0
         2
      30.0     165.0
     300.0     300.0
```

Appendix IVb

Output From Sample Calculations

BLANK PAGE

```
TEST CASE A.....(SAMPLE)                              PAGE  1




TEMPERATURE DISTRIBUTION AND HISTORY IN A TWO LAYERED COMPOSITE PLATE

     PLATE A THICKNESS.....  0.3950 CM        MATERIAL.... TYPE 5456 ALUMINU
     PLATE B THICKNESS.....  0.3950 CM        MATERIAL.... TYPE 5456 ALUMINU



EXPOSED TO.... A CONSTANT HEAT SOURCE OF INTENSITY 100 CAL/SQ-CM/SEC

     (DETAILED DESCRIPTION PRINTED WITH INPUT DATA)



SPACE AND TIME INCREMENTS USED

     P   = 0.7900E-01 CM (   5 INCREMENTS )
     Q   = 0.7900E-01 CM (   5 INCREMENTS )
     TAU = 0.5000E-02 SECONDS



INPUT DATA PRINTED BELOW
```

A

```
E  I



LAYERED COMPOSITE PLATE

RIAL.... TYPE 5456 ALUMINUM-MAGNESIUM ALLOY (ASSUMING CONSTANT PROPERTIES)
RIAL.... TYPE 5456 ALUMINUM-MAGNESIUM ALLOY (ASSUMING CONSTANT PROPERTIES)



ITY 100 CAL/SQ-CM/SEC

ATA)
```

58 B 88

```
TEST CASE A.....(SAMPLE)                    PAGE  2


INPUT DATA LISTING


PLATE A.... TYPE 5456 ALUMINUM-MAGNESIUM ALLOY (ASSUMING CONSTANT PROPERT

     FRONT EMISSIVITY    REAR EMISSIVITY                 DENSITY      SPECIFIC
          0.                                          0.2660E 01       0.220


PLATE B.... TYPE 5456 ALUMINUM-MAGNESIUM ALLOY (ASSUMING CONSTANT PROPERT

     FRONT EMISSIVITY    REAR EMISSIVITY                 DENSITY      SPECIFIC
                              0.                      0.2660E 01       0.220


AMBIENT CONDITIONS....

     AMBIENT TEMPERATURE FOR RADIATION  = 300.00 K (FRONT SURFACE)
                                        = 300.00 K (REAR  SURFACE)
     AMBIENT TEMPERATURE FOR CONVECTION = 300.00 K (FRONT SURFACE)
                                        = 300.00 K (REAR  SURFACE)


CONVECTIVE HEAT TRANSFER COEFFICIENT

     FRONT SURFACE    REAR SURFACE     TEMPERATURE
        0.               0.             0.3000E 03


ABSORPTIVITY (FRONT FACE)              TEMPERATURE
     0.1000E 01                         0.3000E 03


INCIDENT THERMAL RADIATION HISTORY

     INTENSITY (H)     TIME (SEC)
       0.1000E 03      0.
       0.1000E 03      0.1000E 03
```

A

```
 2



(ASSUMING CONSTANT PROPERTIES)

    DENSITY         SPECIFIC HEAT            CONDUCTIVITY            TEMPERATURE
  0.2660E 01           0.2200E 00              0.2800E 00              0.3000E 03


(ASSUMING CONSTANT PROPERTIES)

    DENSITY         SPECIFIC HEAT            CONDUCTIVITY            TEMPERATURE
  0.2660E 01           0.2200E 00              0.2800E 00              0.3000E 03



00 K (FRONT SURFACE)
00 K (REAR  SURFACE)
00 K (FRONT SURFACE)
00 K (REAR  SURFACE)



TURE
E 03


TURE
E 03
```

B

```
         TEST CASE A......(SAMPLE)                    PAGE  3,  SHEET 1

                   0.0000 SEC  0.0050 SEC  0.0100 SEC  0.0150 SEC  0.0200 SEC  0.

     0.0000 CM      300.0 K     321.6 K     326.7 K     334.2 K     338.9 K
     0.0790 CM      300.0 K     300.0 K     308.5 K     312.2 K     317.2 K
     0.1580 CM      300.0 K     300.0 K     300.0 K     303.2 K     305.4 K
     0.2370 CM      300.0 K     300.0 K     300.0 K     300.0 K     301.2 K
     0.3160 CM      300.0 K     300.0 K     300.0 K     300.0 K     300.0 K
     0.3950 CM      300.0 K     300.0 K     300.0 K     300.0 K     300.0 K
     INTERFACE
     0.3950 CM      300.0 K     300.0 K     300.0 K     300.0 K     300.0 K
     0.4740 CM      300.0 K     300.0 K     300.0 K     300.0 K     300.0 K
     0.5530 CM      300.0 K     300.0 K     300.0 K     300.0 K     300.0 K
     0.6320 CM      300.0 K     300.0 K     300.0 K     300.0 K     300.0 K
     0.7110 CM      300.0 K     300.0 K     300.0 K     300.0 K     300.0 K
     0.7900 CM      300.0 K     300.0 K     300.0 K     300.0 K     300.0 K
```

A

```
, SHEET 1

 SEC  0.0200 SEC  0.0250 SEC  0.0300 SEC  0.0390 SEC  0.0400 SEC  0.0450 SEC
2 K      338.9 K      343.9 K      348.0 K      351.9 K      355.5 K      358.9 K
2 K      317.2 K      321.0 K      324.9 K      328.4 K      331.7 K      334.4 K
2 K      305.4 K      308.3 K      310.9 K      313.6 K      316.1 K      [illegible] K
0 K      301.2 K      302.4 K      303.9 K      305.5 K      307.2 K      308.9 K
0 K      300.0 K      [illegible] K      301.0 K      301.8 K      302.7 K      303.7 K
0 K      300.0 K      300.0 K      300.2 K      300.4 K      300.8 K      301.3 K

0 K      300.0 K      300.0 K      300.2 K      300.4 K      300.8 K      301.3 K
0 K      300.0 K      300.0 K      300.0 K      300.1 K      300.2 K      300.4 K
0 K      300.0 K      300.0 K      300.0 K      300.0 K      300.0 K      300.1 K
0 K      300.0 K      300.0 K      300.0 K      300.0 K      300.0 K      300.0 K
0 K      300.0 K      300.0 K      300.0 K      300.0 K      300.0 K      300.0 K
0 K      300.0 K      300.0 K      300.0 K      300.0 K      300.0 K      300.0 K
```

B

```
        TEST CASE A......(SAMPLE)                        PAGE  4,  SHEET 1

                    0.0500 SEC  0.1000 SEC  0.1500 SEC  0.2000 SEC  0.2500 SEC

   0.0000 CM     362.1 K      388.0 K      407.8 K      424.6 K      439.7 K
   0.0790 CM     337.9 K      362.6 K      381.9 K      398.4 K      413.0 K
   0.1580 CM     321.1 K      342.8 K      360.6 K      376.2 K      390.2 K
   0.2370 CM     310.7 K      327.9 K      343.6 K      357.8 K      370.9 K
   0.3160 CM     304.8 K      317.4 K      330.4 K      343.0 K      355.0 K
   0.3950 CM     301.9 K      310.3 K      320.6 K      331.3 K      342.1 K
   INTERFACE
   0.3950 CM     301.9 K      310.3 K      320.6 K      331.3 K      342.1 K
   0.4740 CM     300.6 K      305.7 K      313.5 K      322.[illegible] K      332.0 K
   0.5530 CM     300.2 K      303.0 K      308.7 K      316.0 K      324.5 K
   0.6320 CM     300.0 K      301.5 K      305.6 K      311.7 K      319.3 K
   0.7110 CM     300.0 K      300.8 K      303.9 K      309.3 K      316.3 K
   0.7900 CM     300.0 K      300.6 K      303.4 K      308.5 K      315.3 K
```

A

4, SHEET 3

```
2000 SEC  0.2500 SEC  0.3000 SEC  0.3500 SEC  0.4000 SEC

24.6 K      439.4 K     452.9 K     465.6 K      477.6 K
98.4 K      413.0 K     426.4 K     438.9 K      451.0 K
76.2 K      390.2 K     403.2 K     415.5 K      427.4 K
57.8 K      370.9 K     383.3 K     395.2 K      406.8 K
43.0 K      355.0 K     366.6 K     378.0 K      389.2 K
31.3 K      342.1 K     352.9 K     363.7 K      374.5 K

31.3 K      342.1 K     352.9 K     363.7 K      374.5 K
22.5 K      332.0 K     342.0 K     352.2 K      362.7 K
16.0 K      324.5 K     333.7 K     343.9 K      353.9 K
11.7 K      319.3 K     328.0 K     337.3 K      347.1 K
09.3 K      316.3 K     324.6 K     333.6 K      343.2 K
08.5 K      315.3 K     323.4 K     332.4 K      342.0 K
```

B

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```
TEST CASE A.....(SAMPLE)                              PAGE  5

COMPUTATION TERMINATED

          REAL TIME IS   0.40 SECONDS OR GREATER

          COMPUTATION HAS TAKEN    80 OR MORE TIME STEPS
```

```
TEST CASE B.....(SAMPLE)                              PAGE  1




TEMPERATURE DISTRIBUTION AND HISTORY IN A TWO LAYERED COMPOSITE PLATE

     PLATE A THICKNESS....  0.3950 CM        MATERIAL.... TYPE 5456 ALUMINU
     PLATE B THICKNESS....  0.3950 CM        MATERIAL.... TYPE 5456 ALUMINU



EXPOSED TO.... A CONSTANT HEAT SOURCE OF INTENSITY 100 CAL/SQ-CM/SEC

     (DETAILED DESCRIPTION PRINTED WITH INPUT DATA)



SPACE AND TIME INCREMENTS USED

     [illegible]  = 0.7900E-01 CM (  5 INCREMENTS )
     D    = 0.7900E-01 CM (  5 INCREMENTS )
     TAU  = 0.3200E-02 SECONDS



INPUT DATA UNCHANGED. SEE PREVIOUS COMPUTATION ( TEST CASE A.....(SAMPLE)
```

A

```
1

AYERED COMPOSITE PLATE

RIAL.... TYPE 5456 ALUMINUM-MAGNESIUM ALLOY (ASSUMING CONSTANT PROPERTIES)
RIAL.... TYPE 5456 ALUMINUM-MAGNESIUM ALLOY (ASSUMING CONSTANT PROPERTIES)


ITY 100 CAL/SQ-CM/SEC

TA)


 TEST CASE A.....(SAMPLE) )
```

61 B 18

```
        TEST CASE B.....(SAMPLE)                            PAGE  2,  SHEET 1


                  0.0000 SEC  0.0320 SEC  0.0640 SEC  0.0960 SEC  0.1200 SEC   0.
    0.0000 CM      300.0 K     349.2 K     370.1 K     386.0 K     399.4 K     4
    0.0790 CM      300.0 K     326.0 K     349.4 K     360.7 K     373.7 K     38
    0.1580 CM      300.0 K     311.9 K     327.6 K     341.1 K     353.0 K     36
    0.2370 CM      300.0 K     304.7 K     315.6 K     326.5 K     336.8 K     34
    0.3160 CM      300.0 K     301.5 K     308.1 K     316.3 K     324.7 K     3
    0.3950 CM      300.0 K     300.4 K     303.9 K     309.5 K     316.0 K     3
    INTERFACE
    0.3950 CM      300.0 K     300.4 K     303.9 K     309.5 K     316.0 K     32
    0.4740 CM      300.0 K     300.1 K     301.7 K     305.3 K     310.0 K     31
    0.5530 CM      300.0 K     300.0 K     300.7 K     302.8 K     306.0 K     31
    0.6320 CM      300.0 K     300.0 K     300.2 K     301.4 K     303.6 K     30
    0.7110 CM      300.0 K     300.0 K     300.1 K     300.7 K     302.3 K     30
    0.7900 CM      300.0 K     300.0 K     300.0 K     300.5 K     301.9 K     30
```

A

AGE 2, SHEET 1

0.0960 SEC	0.1280 SEC	0.1600 SEC	0.1920 SEC	0.2240 SEC	0.2560 SEC
386.0 K	399.4 K	411.2 K	421.9 K	431.7 K	440.9 K
360.7 K	373.7 K	385.3 K	395.8 K	405.4 K	414.5 K
341.1 K	352.0 K	363.8 K	373.7 K	383.0 K	391.7 K
326.5 K	336.8 K	346.5 K	355.5 K	364.1 K	372.4 K
316.3 K	324.7 K	332.9 K	340.9 K	348.7 K	356.4 K
309.5 K	316.0 K	322.7 K	329.6 K	336.5 K	343.4 K
309.5 K	316.0 K	322.7 K	329.6 K	336.5 K	343.4 K
305.3 K	310.0 K	315.9 K	321.0 K	327.0 K	333.2 K
302.8 K	306.0 K	310.1 K	314.9 K	320.1 K	325.7 K
301.4 K	303.6 K	306.8 K	310.7 K	315.3 K	320.4 K
300.7 K	302.3 K	304.9 K	308.4 K	312.6 K	317.4 K
300.5 K	301.9 K	304.3 K	307.6 K	311.7 K	316.4 K

B

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```
TEST CASE B.....(SAMPLE)                          PAGE  3

COMPUTATION TERMINATED
          COMPUTATION HAS TAKEN    80 OR MORE TIME STEPS
```

```
TEST CASE C.....(SAMPLE)                          PAGE  1




TEMPERATURE DISTRIBUTION AND HISTORY IN A SINGLE LAYERED PLATE

     PLATE THICKNESS.....  0.7900 CM         MATERIAL.... TYPE 5456 ALUMINUM-MA




EXPOSED TO THERMAL RADIATION FROM THE FOLLOWING STANDARD WEAPON PULSE

     WEAPON YIELD...........(W) =   30.0 KT
     TOTAL IRRADIATION.....(Q) =  165.0 CAL/SQ-CM
     MAXIMUM INTENSITY.(QMAX) =  365.3 CAL/SQ-CM/SEC
     AT TIME..............(TMAX) =  0.175 SECONDS




SPACE AND TIME INCREMENTS USED

     P   = 0.7900E-01 CM ( 10 INCREMENTS )
     TAU = 0.5000E-02 SECONDS




INPUT DATA PRINTED BELOW
```

SE 1

2

SIC LAYERED PLATE

TERIAL... TYPE 5456 ALUMINUM-MAGNESIUM ALLOY (ASSUMING CONSTANT PROPERTIES)

IG STANDARD WEAPON PULSE

-CM
-CM/SEC
S

B4

B

A3

```
TEST CASE C......(SAMPLE)                          PAGE  2


INPUT DATA LISTING


PLATE A...1. TYPE 5456 ALUMINUM-MAGNESIUM ALLOY (ASSUMING CONSTANT PROPERTIE
     FRONT EMISSIVITY    REAR EMISSIVITY                DENSITY       SPECIFIC H
           0.                  0.                   0.2660E 01          0.2200E


AMBIENT CONDITIONS....

     AMBIENT TEMPERATURE FOR RADIATION  = 300.00 K (FRONT SURFACE)
                                        = 300.00 K (REAR  SURFACE)
     AMBIENT TEMPERATURE FOR CONVECTION = 300.00 K (FRONT SURFACE)
                                        = 300.00 K (REAR  SURFACE)


CONVECTIVE HEAT TRANSFER COEFFICIENT

     FRONT SURFACE    REAR SURFACE     TEMPERATURE
        0.                0.            0.3000E 03


ABSORPTIVITY (FRONT FACE)              TEMPERATURE
      0.1000E 01                        0.3000E 03


INCIDENT THERMAL RADIATION HISTORY

     (STANDARD DIMENSIONLESS WEAPON PULSE)
```

A

```
 2




(ASSUMING CONSTANT PROPERTIES)

     DENSITY      SPECIFIC HEAT        CONDUCTIVITY          TEMPERATURE
  0.2660E 01        0.2200E 00           0.2800E 00            0.3000E 03



00 K (FRONT SURFACE)
00 K (REAR  SURFACE)
00 K (FRONT SURFACE)
00 K (REAR  SURFACE)



TURE
E 03


TURE
E 03
```

```
    1 TEST CASE C.....(SAMPLE)                    PAGE  3.  SHEET 1

                 0.0000 SEC  0.0050 SEC  0.0100 SEC  0.0150 SEC  0.0200 SEC  0.0

    0.0000 CM    300.0 K     300.3 K     301.0 K     301.8 K     303.1 K     30
    0.0790 CM    300.0 K     300.0 K     300.2 K     300.4 K     300.8 K     30
    0.1580 CM    300.0 K     300.0 K     300.0 K     300.0 K     300.2 K     30
    0.2370 CM    300.0 K     300.0 K     300.0 K     300.0 K     300.0 K     30
    0.3160 CM    300.0 K     300.0 K     300.0 K     300.0 K     300.0 K     30
    0.3950 CM    300.0 K     300.0 K     300.0 K     300.0 K     300.0 K     30
    0.4740 CM    300.0 K     300.0 K     300.0 K     300.0 K     300.0 K     30
    0.5530 CM    300.0 K     300.0 K     300.0 K     300.0 K     300.0 K     30
    0.6320 CM    300.0 K     300.0 K     300.0 K     300.0 K     300.0 K     30
    0.7110 CM    300.0 K     300.0 K     300.0 K     300.0 K     300.0 K     30
    0.7900 CM    300.0 K     300.0 K     300.0 K     300.0 K     300.0 K     30
```

A

```
 SHEET 1

 SEC  0.0700 SEC  0.0250 SEC  0.0300 SEC  0.0350 SEC  0.0400 SEC  0.0450 SEC

 K     303.1 K     305.1 K     307.8 K     311.0 K     314.9 K     319.4 K
 K     300.8 K     301.4 K     302.4 K     303.8 K     305.6 K     307.7 K
 K     300.2 K     300.3 K     300.6 K     301.1 K     301.8 K     302.6 K
 K     300.0 K     300.1 K     300.2 K     300.3 K     300.5 K     300.9 K
 K     300.0 K     300.0 K     300.0 K     300.1 K     300.1 K     300.2 K
 K     300.0 K     300.0 K     300.0 K     300.0 K     300.0 K     300.1 K
 K     300.0 K     300.0 K     300.0 K     300.0 K     300.0 K     300.0 K
 K     300.0 K     300.0 K     300.0 K     300.0 K     300.0 K     300.0 K
 K     300.0 K     300.0 K     300.0 K     300.0 K     300.0 K     300.0 K
 K     300.0 K     300.0 K     300.0 K     300.0 K     300.0 K     300.0 K
 K     300.0 K     300.0 K     300.0 K     300.0 K     300.0 K     300.0 K
```

88 B 88

```
        TEST CASE C....(SAMPLE)                    PAGE   4,  SHEET 1

                     0.0500 SEC  0.1000 SEC  0.1500 SEC  0.2000 SEC  0.2500 SEC  0.3
     0.0000 CM        324.5 K      420.0 K      546.9 K      640.2 K      677.3 K     6
     0.0790 CM        310.3 K      365.7 K      461.7 K      548.1 K      600.7 K     6
     0.1580 CM        303.9 K      334.4 K      401.7 K      475.5 K      531.7 K     55
     0.2370 CM        301.4 K      317.3 K      361.4 K      419.7 K      472.2 K     50
     0.3160 CM        300.4 K      308.3 K      335.7 K      379.1 K      424.5 K     4
     0.3950 CM        300.1 K      303.8 K      319.9 K      350.6 K      387.7 K     42
     0.4740 CM        300.0 K      301.7 K      310.7 K      332.9 K      360.6 K     39
     0.5530 CM        300.0 K      300.7 K      305.6 K      319.2 K      341.3 K     3
     0.6320 CM        300.0 K      300.3 K      302.9 K      311.8 K      328.8 K     3
     0.7110 CM        300.0 K      300.1 K      301.6 K      307.9 K      321.0 K     34
     0.7900 CM        300.0 K      300.1 K      301.2 K      306.7 K      319.6 K     33
```

A

```
PAGE  4.  SHEET 1

0.2000 SEC  0.2500 SEC  0.3000 SEC  0.3500 SEC  0.4000 SEC

 640.2 K     677.3 K     667.3 K     654.9 K     643.9 K
 548.2 K     600.7 K     612.2 K     610.9 K     607.5 K
 475.5 K     531.2 K     557.3 K     566.2 K     570.0 K
 419.7 K     472.2 K     505.8 K     523.0 K     533.2 K
 379.1 K     424.5 K     460.2 K     483.0 K     498.5 K
 350.6 K     387.7 K     421.8 K     447.6 K     467.2 K
 331.9 K     360.4 K     391.1 K     418.0 K     440.3 K
 319.2 K     341.3 K     368.1 K     394.7 K     418.6 K
 311.8 K     328.8 K     352.2 K     378.0 K     402.8 K
 307.9 K     321.8 K     342.9 K     367.9 K     393.2 K
 306.7 K     319.6 K     339.2 K     364.6 K     390.0 K
```

B

```
COMPUTATION TERMINATED

                   REAL TIME IS   0.40 SECONDS OR GREATER

                   COMPUTATION HAS TAKEN    80 OR MORE TIME STEPS
```

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13. ABSTRACT

A generalized computational technique to be used in the calculation of the temperature profiles and histories in single and dual-layered plates exposed to the thermal pulse of a nuclear weapon is presented. The program has been written to accommodate materials whose thermophysical properties are an arbitrary function of the local temperature. In addition, quite general boundary conditions are permitted. Sample calculations are presented in order to illustrate the nature of the output format.

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Thermal Radiation						
Shipboard Structures						
Blast Environment						

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Progress Report 3

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