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MASTER

COMPUTER PROGRAMS FOR CALCULATING
PEAK TEMPERATURE DISTRIBUTION
IN WELDING

R. A. Huber
D. Bradway
C. M. Wiedemann
P. W. Turner

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE Y-12 PLANT

operated for the **ATOMIC ENERGY COMMISSION** under **U. S. GOVERNMENT Contract W-7405 eng 26**

**UNION
CARBIDE**

OAK RIDGE Y-12 PLANT
P. O. Box Y
OAK RIDGE, TENNESSEE 37830

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Nuclear Division

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ABSTRACT

Computer programs have been developed for solving cumbersome heat-transfer equations relating to moving heat sources encountered in welding operations. The objective is to provide the welding engineer and designer with a reference that will guide them in making practical use of heat-transfer equations that describe the thermal history at weld heat-affected zones.

Solutions for four types of problems are now available: (1) thermal mapping to determine the "temperature hill" enveloping the welding heat source on a semi-infinite plate; (2) determining peak temperatures at some distance from the weld centerline or from the bond line; (3) determining the surface peak temperature at an edge of a plate parallel to the weld; (4) determining the peak temperature on the bottom side of plates having partial-penetration welds.

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SUMMARY

Computer programs for handling heat-transfer problems relating to fusion welding were designed for use on the CEIR system; and, in the case of three-dimensional heat transfer, for use on the Control Data 1604A computer. Three of these programs can be used to calculate peak temperatures at a reference point by stating welding parameters and material constants; the fourth program can map the temperatures around the weld-affected zones and make graphic plots of temperature as a function of a moving coordinate that represents a moving heat source traveling at welding speeds.

Results of experiments comparing peak-temperature measurements with calculated values on Type 1100 aluminum at two energy inputs showed good correlation provided that the appropriate heat-transfer equation was applied.

Instructions and data sheets for programs pertaining to a number of welding conditions were developed in a step-by-step sequence that can be followed by the engineer and designer without the need of special training in computer technology.

INTRODUCTION

It is of interest in welding to know the effects of the heat source on the structure and properties of the welded materials, particularly the quantitative extent to which mechanical properties change as a result of heating during a welding cycle. Also, the peak temperature and cooling rate at the point of interest in the workpiece must be known in order to predict metallurgical changes in the material. Measurements of heat flow have yielded results with good correlations between the calculated temperature and metallurgical changes. This knowledge provides some insight into the crack susceptibility, mechanical properties, and size of the area in question.

However, it is not always convenient nor possible to measure the temperatures accurately; and, even if it were convenient, it would be very tedious and expensive to determine temperatures for the many welding parameter variations available. The total "temperature-heat effect" correlations can be calculated when there exists some known relationship between temperature and the welding parameters.

A number of authors,⁽¹⁻⁴⁾ through the use of Fourier heat-flow analyses and mathematical approximations, have derived reliable engineering relationships for peak-temperature distribution. These relationships have proved effective for deriving thermal cycles at interior locations, and modified versions have allowed for the useful determination of heat-transfer efficiencies. Unfortunately, however, some of these mathematical expressions are far too cumbersome to be evaluated manually, especially when there are many such calculations to be performed for different data. Also, there is the problem of finding the "right" equation. A laborious search must be made through a multitude of texts and journals for the one equation most suitable for the boundary conditions and application.

The purpose of this work was twofold: (1) to gather some of the useful thermal equations and to explain briefly for what and under what conditions each would be useful, and (2) to provide for quick evaluation of the equations. Computer evaluation of equations was found to be effective, making possible the practical use of equations which, heretofore, were not generally useful because of the time required to solve them manually.

The programs developed utilize two different computers and languages: One, a Control Data 1604A computer which uses the FORTRAN 63 language;⁽⁵⁾ the other, a GE 265, which uses a teletype hookup and the BASIC language.⁽⁶⁾ The greatest difference, other than the difference between computer languages, is the procedure for running a program.

THE COMPUTER PROGRAMS

GENERAL DESCRIPTION

For the 1604A computer, the programmer supplies the required input data on IBM data cards which are then placed at the bottom of the FORTRAN program deck (the deck of IBM cards on which statements of operation are punched) in correct order. From then on, the program is handled by computer personnel who send the program back to the requestor together with the printed sheets containing the output. Details on supplying input data will be explained later by the use of examples.

With the CEIR computer (GE 265), the procedure is quite different. Here, the programmer runs the computer more directly. The operator calls the program from a teletype terminal and commands it to be run by punching "RUN" on the teletype. The teletype sends the command by telephone cable to the CEIR computer, located in Silver Springs, Maryland, where the operation is carried out. During execution of the program, the required input data are called for by the computer. The programmer transmits the input data by teletype in the order asked for by the computer. The program continues to run until other questions concerning output or additional data input are encountered, when the computer again asks the programmer to supply the necessary information. Finally, the answers are printed out and the program finished when the computer operating time is printed out. The CEIR procedure will be presented in steps that should result in a do-it-yourself operation for the engineer or designer.

The choice of which computer to use depends on many factors. With the CEIR system, several advantages for the beginner are apparent. First, the computer language described in the BASIC manual⁽⁶⁾ is easy to learn and use, and is well adapted to the peak-temperature problems which are treated in this report because of their relative simplicity and small computer storage requirements. Second, since the programmer is actually directing commands to the computer, the program can be edited and changed on the spot. Third, the answer to the problem is printed out immediately on the teletype machine so modifications of welding parameters or other changes in input can be made rapidly. The main disadvantage of the CEIR computer is that the user must sit at the teletype machine and type in the data by hand. Where large amounts of input are to be compared, this is tedious.

The advantages of the 1604A computer consist in the plotting subroutines available and the fact that large amounts of input data can be handled with IBM cards. Its disadvantages are the more difficult FORTRAN language and the usual one-day wait for output.

DESCRIPTION OF EACH PROGRAM

Program Format

For expediency in finding essential information, all programs are listed according to the format that follows.

Description - Included here is a brief description of the program and its application.

Boundary Conditions - Included in boundary conditions are the simplifying assumptions made in formulating these mathematical equations. Limitations as to parameters, heat source, and materials are given. References that provide a more detailed description are also listed.

The Equation - The formal equation in mathematical notation, complete with a list of parameters, constants, and notations is presented.

Input Data to the Computer - Listed first under this heading are the names of all parameters that are to be supplied as input with the program to the computer. It should be noted that there is a difference in notation for those parameters used in the equation and in the program (eg, "h" is used for plate thickness in the equation, whereas "H" is used in the program because no lower-case letters are available in the computer languages). It should also be noted that, because of the previously mentioned limitation and other language limitations, the names of variables are different for the two computers used in this report. Beside the information on the data required there are instructions for operating the computer being used. Where the input data is in FORTRAN, sample cards are listed with the parameter locations and names.

Output - The output is printed by the computer when the program is run. This information, which is the solution to the problem (input) given to the computer, is described and explained by reference to sample programs and output data.

TDIST Program

Description - This program will give tabulated time-temperature data for a specified fixed point in a "thick" plate from a moving heat source.⁽¹⁻⁴⁾ The 1604A computer program will also provide a graph (temperature versus time) showing the temperature distribution at the point. The reference point can be changed to provide a complete graphical representation of the temperature distribution in the weld area.

For example, this program can be used to thermally map a weld heat-affected zone of a semi-infinite plate. The special time-temperature profile of the zone can be analyzed with respect to peak temperatures and cooling rates that may physically or metallurgically influence welding procedures and the design criteria for the weldment and adjacent components.

Boundary Conditions - This program is applicable to all types of fusion welds regardless of the welding process used. However, there are certain boundary conditions (simplifying assumptions) which impose restrictions on the use of this program. These conditions as described by Udin, Funk, and Wulff⁽⁴⁾ are:

1. The physical constants of the material do not change with temperature and the metal is isotropic.
2. No heat transfer from the surfaces of the plate; ie, radiation loss is negligible. Therefore, the plate being studied must not be chilled by hold down bars and/or heavy backing plates which act as heat sinks.
3. At large distances from the heat source, there is no heating of the plate.
4. All the heat enters the plate at a true moving point. Error caused by this assumption is appreciable when points are chosen very close to the weld centerline. As the distance from the centerline increases, this type of error becomes negligible.

The Equation⁽⁴⁾ - The temperature distribution in an infinitely wide, thick plate is:

$$T = T_o + AE,$$

where:

$$E = e^{-\alpha v \lambda} \left[\frac{e^{-\alpha v \lambda}}{R} + \sum_{n=1}^{\infty} \left(\frac{e^{-\alpha v R_n}}{R_n} + \frac{e^{-\alpha v R'_n}}{R'_n} \right) \right],$$

$$R = (\lambda^2 + y^2 + z^2)^{1/2},$$

$$R_n = \left[\lambda^2 + y^2 + (2nh - z)^2 \right]^{1/2}$$

$$R'_n = \left[\lambda^2 + y^2 + (2nh + z)^2 \right]^{1/2},$$

$$A = Q_p / 2\pi k \quad Q_p = C \cdot V \cdot q$$

$$\alpha = 1/2K, \text{ and}$$

$$K = k/\rho C_p.$$

In these equations:

K represents the thermal diffusivity,

k the thermal conductivity,

C_p the specific heat,

ρ the density,

v the velocity (travel speed),

h the plate thickness,

Q_p the energy input per unit time or power,

C the current,

q the arc efficiency,

V the voltage,

t the time,

λ the moving coordinate $= x - vt$,

x the distance along the weld centerline to the reference point,

y the perpendicular distance to the reference point from the weld centerline and heat-source path,

z the distance normal from the x - y plane or the top surface of the plate, to the reference point (this distance is positive into the plate),

T_0 the initial temperature, and

T the actual temperature of the plate at time, t , for a set of coordinates at any arbitrary reference point, R , the distance to the point of interest which is defined by (x, y, z) .

Reference Conditions - To use the equation, certain reference conditions must be imposed to get meaningful results. A coordinate system should be established at some arbitrary location on the plate. Thus, the z axis (see sketch) will correspond to the distance normal to the plate surface (x-y plane); the x axis, the distance to the weld centerline; and, the y axis, the perpendicular distance from the weld centerline or x axis.

Explanation of the Coordinate System - When time, t , equals zero, the distance along the proposed weld centerline from the reference origin to the arbitrary point, p , (shown in the sketch) is measured. Position p is the point at which the temperature distribution is to be determined.

The moving coordinate, λ , will vary, however, after timing has begun as the heat source moves according to the expression: $\lambda = x - vt$, as shown in the accompanying sketch.

Input Data to the Computer - The following data are required for computer evaluation (units must be as indicated):

- CP - specific heat capacity (cal/gm/C)
- TK - thermal conductivity (cal/cc/sec)
- RHO - density (gm/cc)
- H - plate thickness (inches)

ARC - arc efficiency (decimal form)

C - current (amperes)

V - voltage (volts)

VEL - travel speed (inches/minute)

TIN - initial temperature ($^{\circ}\text{C}$)

X,Y,Z - positional coordinates (inches)

The TDIST program is available on both the CEIR and 1604A computers; however, the graphing routine is only available on the 1604A which requires data to be punched out on FORTRAN data cards. Data can also be written on the FORTRAN sheets from which they will be punched onto cards. An example FORTRAN sheet with sample data is given in Appendix A.

On the CEIR program, the data are typed in by teletype. Features of this program allow for the selection of arbitrary time intervals over which temperatures can be determined, and new coordinate positions can be fed in for the same material. Instructions for calling programs on the CEIR are simple and are given in the BASIC manual. A sample program appears in Appendix B.

The input for the 1604A TDIST program appears on three FORTRAN cards, illustrated in Figures 1 through 3.

304 STAINLESS STEEL										.12	.0376	7.9	.3656	
MATERIAL										CP	TK	RHO	H	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	9	9	9	9	9	9	9	9

HACKETT 5081

Figure 1. MATERIAL DATA CARD FOR THE TDIST PROGRAM SHOWING THE MATERIAL CONSTANTS AND THEIR PROPER LOCATIONS. (Accurate Placement of Decimal Points is essential for Correct Input)

1.	-1	.3656
X	Y	Z
00000000	00000000	00000000
1 2 3 4 5 6 7	8 10 11 12 13 14 15	17 18 19 20 21 22 23
1 1 1 1 1 1 1	1 1 1 1 1 1 1	1 1 1 1 1 1 1
2 2 2 2 2 2 2	2 2 2 2 2 2 2	2 2 2 2 2 2 2
3 3 3 3 3 3 3	3 3 3 3 3 3 3	3 3 3 3 3 3 3
4 4 4 4 4 4 4	4 4 4 4 4 4 4	4 4 4 4 4 4 4
5 5 5 5 5 5 5	5 5 5 5 5 5 5	5 5 5 5 5 5 5
6 6 6 6 6 6 6	6 6 6 6 6 6 6	6 6 6 6 6 6 6
7 7 7 7 7 7 7	7 7 7 7 7 7 7	7 7 7 7 7 7 7
8 8 8 8 8 8 8	8 8 8 8 8 8 8	8 8 8 8 8 8 8
9 9 9 9 9 9 9	9 9 9 9 9 9 9	9 9 9 9 9 9 9
1 2 3 4 5 6 7	8 10 11 12 13 14 15	17 18 19 20 21 22 23
HACKETT 508		

If new materials are to be supplied for new time-temperature data output, the three input cards should be punched for the new data and the cards should be stacked after the last position card in the deck. A blank card should be placed at the end of the data stack to end the execution of the program. A maximum of four sets of data can be run at one time.

Output - The output from the 1604A TDIST program includes material identification along with all the accompanying parameters and time-temperature data from time equals -10 to 80 seconds in one-second intervals. The 1604A "EZ" plot subprogram plots a time-temperature graph from 1,800 data points at equal time intervals from

time equals -10 to 80 seconds. Material identification and the accompanying weld and position parameters are also included on the time-temperature graph. Example output listings and accompanying plots are given in Appendix B.

Some discussion of the graph in Appendix B is needed. The arc heat source is moving at a rate of 11.8 ipm, and the temperature is being determined at a point 1.27 inches to the left or right of the weld centerline, 0.525 inch deep in the base metal, and two inches ahead of the welding arc. The temperature at this point rises rapidly as the arc approaches it and reaches a maximum of 185° C within about 17 seconds after the arc passes by the point. The maximum cooling rate at this point was approximately 2° C per second, but 80 seconds after the arc passed the point, the temperature still exceeded 100° C. A similar analysis can be made at higher temperatures which would be of greater metallurgical interest. For example, the cooling rate at the critical temperature for martensite formation could be derived from the plot for steel in Appendix B. It would apply, of course, only to a particular steel and to the given welding procedure. For the CEIR programs, data must be plotted manually.

The time coordinate can be transformed to a space coordinate by using $x = vt$, where v and t are the velocity of the heat source and time printed on the output sheet, respectively. Then, a graph of temperature versus x gives a distance-temperature distribution with the heat source being the origin at any instant of time. The X and Y values can be varied and Z held constant to determine a "temperature wave" that moves along the X - Y plane in dynamic equilibrium when the welding parameters are held constant.

The CEIR output has several features which allow for versatility in its use. Normal data output is from time equals -10 to 60 seconds in one-second intervals. Arbitrary intervals can be selected together with the desired time increments. In this manner, a close approximation of the peak temperatures can be determined by consecutively "scanning" smaller time intervals in which the peak temperature lies. An example of this type of procedure is shown with some sample data in Appendix B:

PEK3M Program

Description - This program calculates the peak temperature of a surface point at a distance outside of the fusion zone of a weld made by a moving heat source. (1-4) A correction for the fact that the specific heat of a metal or alloy changes with temperature is made by first calculating the mean temperature between the peak temperature at the point in question and the melting temperature of the material, and then calculating the value of the specific heat at that temperature. Iterations are made until the peak temperature calculated differs only slightly from the previously calculated value.

Boundary Conditions - Restrictions governing the use of this program consist of the following: (1) constant density properties; (2) constant speed and straight-line

travel; (3) no transfer of heat from the surfaces to the surroundings; (4) no edges near enough to influence thermal conditions; (5) essentially two-dimensional heat conduction; and (6) a point source of heat. Corrections can be made for surface heat transfer when its influence is substantial.

The equation gives optimum results when the point is chosen at a given distance from a full-penetration weld or at some distance greater than 1.5 times the plate thickness from a partial-penetration weld. At extreme distances, losses due to surface heat transfer becomes significant and, for distances less than 1.5 times the plate thickness, error is incurred (especially when the heat source is an arc) because the incident heat source has a finite width. (The assumption was that the source of heat was a point.)

The Equation⁽²⁻³⁾ - The equation giving peak temperature as a function of surface distance is:

$$\frac{1}{T_p - T_o} = 4.13 \rho \bar{C}_p Y t \left(\frac{V}{zQ} \right) + \frac{1}{T_m - T_o}$$

$$Q = V \cdot C$$

In these equations:

T_p represents the peak temperature,

T_m the melting temperature,

T_o the initial or ambient temperature,

ρ the density,

$\bar{C}_p$ the specific heat capacity,

v the work speed,

Q the power input,

C the current,

V the voltage,

Y the surface distance from the fusion zone, and

z the arc efficiency.

Input Data to the Computer - The following data are required for computer evaluation (units must be as indicated). Quantities identified with an asterisk(*) are not required for materials which have a material code number.

D - density(gm/cc)*

C - specific heat capacity (cal/gm/C)*

- T1 - melting temperature of material (°C)*
- Y - surface distance from fusion line (inches)
- V - travel speed (inches/minute)
- V0 - voltage (volts)
- I - current (amperes)
- A - arc efficiency (decimal)
- T0 - initial temperature (°C)
- H - thickness of plate (inches)

Material Codes

- 0 unlisted material
- 1 pure uranium
- 2 Type 1100 aluminum
- 3 AISI Type 304 stainless steel
- 5 pure thorium

The PEK3M program is available on the CEIR only. For the CEIR computer, the input data are typed in on the teletype. The physical constants for several materials may be called by typing in a material code number. Provision is also made for entering the material constants for materials not programmed. Other data are called for by the computer as needed. Instructions for calling programs on the CEIR are simple and are given in the BASIC manual. An example program which appears in Appendix C will clarify the procedure of execution.

Output - The CEIR output prints the peak temperature expressed in both degrees centigrade and fahrenheit. Also included in this output are the final value of the specific heat used and the number of iterations used to obtain the peak temperature. A provision has been made to allow additional welding data and/or additional Y data to be supplied for the same material.

PEK5M Program

Description - This program, with only slight modifications, is the same as the PEK3M program. It gives the peak temperature of a surface-edge point at a distance greater than or equal to 1.5 times the plate thickness from the centerline of a moving heat source. (2)

Boundary Conditions - The boundary conditions are the same as for PEK3M. An explanation for the fact that the peak temperature rise at an edge location is just twice that which would be observed if there were no edge present is given by Adams, et al.⁽²⁾

The Equation - The equation is the same as for the PEK3M program, except for a factor of two:

$$\frac{1}{T_p - T_o} = 2.07 \rho \bar{C}_p \gamma t \left(\frac{V}{zQ} \right) + \frac{0.5}{T_m - T_o} .$$

Input Data to the Computer - The input data are identical to that of the PEK3M program.

Output - The output is also the same as for PEK3M. A sample run is shown in Appendix D.

BPEKEC Program

Description - BPEKEC will give the bottom peak temperature of a point directly below the weld centerline of a plate over which there is a moving heat source.⁽²⁾ The error function is used along with the average value of specific heat to correct for changing specific heat and the fact that the heat source has a finite width.

Boundary Conditions - The boundary conditions are the same as for PEK3M. Emphasis in this program is given to the fact that the moving heat source is not a point source but rather assumes some effective width, b . Without loss in generality, answers of the proper magnitude are attainable if b , the effective width of the heat source, is taken to be equal to the width of the weld bead.⁽²⁾

The Equation - The equation for the bottom peak temperature is as follows:

$$\frac{1}{T_p - T_o} = 2.41 \rho \bar{C}_p \left(\frac{Vt^2}{zQ} \right) \left[\frac{b/t}{\text{erf}(b/t)} \right] + \frac{0.5}{T_m - T_o} ,$$

where:

$$\text{erf } n = \frac{2}{\sqrt{\pi}} \int_0^n e^{-u^2} du .$$

The "Gaussian error function" indicated as "erf" appears frequently in heat-conduction problems.

Equation Parameters - The parameters and units are the same as for the PEK3M program except for the addition of b , the weld-bead width.

Input Data to the Computer - This program is available on the CEIR only. The running procedure is the same as for PEK3M, except that the value of the bead width, b , must be entered when called for by the computer. When the value of the bead width is not known, it must be estimated.

Output - The output is the same as for the PEK3M program. A sample run is shown in Appendix E.

EXPERIMENTAL VERIFICATION

A small number of bead-on-plate welds were made on AISI Type 304L stainless steel and Type 1100 aluminum. Temperature measurements were made using both chromel-alumel thermocouples and temperature-sensitive lacquers. A motor-driven gas tungsten-arc torch was used to make the weld beads. After each weld was made, the appropriate computer program was used to calculate the temperature at points of interest; ie, where temperature measurements had been made. The resulting data were examined quantitatively as to the difference between the calculated and measured values and nondimensionally as a function of the plate thickness and distance from the weld fusion zone. In this way, differences could be better analyzed as a function of the proximity to the weld bead.

The test plates were 6 by 18 inches by the thickness to be tested. The welds were run along the major axis of the 6 by 18-inch face. Four thermocouples were spot welded to each plate and the temperature recorded on strip-chart recorders. The thermocouples on the torch side of the plate were shielded from the radiant heat of the arc by thin-foil heat shields. Temperature-sensitive lacquers were painted on the back side of the plate, perpendicular to the direction of the weld. After completing the weld bead, the length of lacquer that had melted was measured; then, assuming the heat source moved across the center of the melted area, the length was divided in half to give the distance to the peak temperature from the center of the weld bead. Also, the distance from the fusion zone of the weld to each of the thermocouples on the bead surface and the average bead width were measured. One source of error is that there may be a large voltage drop in the welding cables. To eliminate this error, the voltage for each weld was measured directly across the arc with a voltmeter.

The data from each plate were compared, point for point, with calculated values, then each set of measured and calculated data for a point was handled as follows: The calculated temperature, CT , was divided by the measured temperature, MT , to get a correlation ratio; then, the distance of the point from the weld, Y , was divided by the thickness, t , of the test plate to get a figure for relative thickness. The correlation ratio, CT/MT , was plotted on the ordinate and the relative thickness, y/t , on the abscissa.

Table 1 contains data from the six plates that were welded; Figures 4 and 5 show two plots of the relative thickness as a function of the correlation ratio. Figure 4 is of the high-energy-input weld for the 0.525-inch-thick Type 1100 aluminum plate; Figure 5 is of the low-energy-input weld on the same thickness of plate. The first plate reached an overall temperature of about 325° F and the heat flow was essentially two dimensional. This conclusion is verified by the plot in Figure 4 which shows that the PEK3M program (a two-dimensional equation) was in good agreement with the measured values and that the TDIST program (a three-dimensional equation) calculates values that are high. The low-energy-input weld appears to give three-dimensional heat flow (as shown by the excellent correlation of the measured values and those calculated by the TDIST program). The downward slope of the TDIST data points is probably due to several factors: One factor could be that there is no correction for the variation in specific heat or thermal conductivity with temperature. Also, losses by surface heat transfer become relatively more significant at extreme distances from the heat source.

Table 1
WELDING TEST CONDITIONS USED
TO CHECK THEORETICAL EQUATIONS.

Material	Thickness (inch)	Run Number	Energy Input (Btu/ft)
AISI Type 304L Stainless Steel	0.515	1	121.4
	0.515	2	121.4
	1.0	1	158.9
Type 1100 Aluminum	0.380	1	78.6
	0.525	1	292.5
	0.525	2	82.4

Figure 4. COMPARISON OF PROGRAMS AT A HIGH-ENERGY INPUT.
(Run 2 - 0.525" Type 1100 Aluminum Plate)

Figure 5. COMPARISON OF PROGRAMS AT A LOW-ENERGY INPUT.
(Run 2 - 0.525" Type 1100 Aluminum Plate)

In the experimental work that has been completed, a great majority of the data have fallen above the 1.0 perfect correlation line, which indicates a constant error of some type. The most likely cause is the arc-efficiency term in the equations being used. No data have been obtained and no calculations have been made to verify this assumption. An approximate value of 87.5 percent, taken from Adams,⁽²⁾ has been used in this work.

RECOMMENDATIONS

Further work is recommended in four areas: computer programs, equation modification, material data, and experimental verification.

An investigation into the feasibility of making three-dimensional plots of the 1604A TDIST program should be made. Three-dimensional plots would give an excellent picture of the thermal gradients around a weld. Such subprograms are available but would need to be adapted to welding use. Multiple plots on the same two-dimensional grid would show the differences in different energy inputs and could lower the running time of the present program.

The preliminary investigation has shown a need for correcting the value for specific heat. The correction has been made for the BPEKEC, PEK3M, and PEK5M programs and it does increase the accuracy of the programs. The TDIST program has not been so modified but needs such a correction for both the 1604A and the CEIR programs. Also, since the equation used in the TDIST program has a thermal conductivity term, a correction for temperature-dependent thermal conductivity should be made. The correct figure for arc efficiency should be determined experimentally. Present

practice is to use an approximate value. Also, measured values reported in the literature could be incorporated in the programs.

An effort should be made to secure data or equations for specific heat, thermal conductivity, and other material constants for the special alloys for which welding data are being assembled at the present time. The limitations on the equations being used should be defined. Several more materials should be investigated and a larger number of heat inputs and plate thicknesses should be tested. A special emphasis should be made to include materials which undergo phase changes in welding; ie, uranium or low-carbon steel. At the same time, a parallel program on the correlation of the equations with welds made by the electron-beam process should be initiated.

REFERENCES

- (1) Rosenthal, D; "Mathematical Theory of Heat Distribution During Welding and Cutting", The Welding Journal, 20 (5), pp 220-S— 225-S (1941).
- (2) Adams, C. M., Paley, ZVI, and Barry, J. M.; "Heat Conduction from Moving Arcs in Welding", The Welding Journal, 42 (3); March 1963.
- (3) Adams, C. M.; "Cooling Rates and Peak Temperatures in Fusion Welding", The Welding Journal, 37 (5), pp 210-S — 215-S; May 1958.
- (4) Funk, E. R., Udin, H., and Wulff, J; Welding for Engineers, pp 112-122; John Wiley and Sons, Inc, New York, New York (1954).
- (5) McCracken, D. D.; A Guide to FORTRAN IV Programming; John Wiley and Sons, Inc, New York, New York (1965).
- (6) Kemeny, J. G. and Kurtz, T. E.; A Manual for BASIC; Dartmouth College Printing Office, Hanover, New Hampshire (1965).

BIBLIOGRAPHY

Kelley, K. K.; "High-Temperature Heat Content, Heat Capacity, and Entropy Data for the Elements and Inorganic Compounds", Contributions to the Data on Theoretical Metallurgy, XIII, Bureau of Mines Bulletin 584; US Government Printing Office, Washington, D. C. (1960).

Adams, C. M., Jr., Moffett, W. G., and Jhaveri, Pravin; "The Effect of Plate Thickness and Radiation of Heat Flow in Welding and Cutting", The Welding Journal, 41 (1), pp 12-S — 16-S (1962).

Carslaw, H. S. and Jaeger, J. C.; Conduction of Heat in Solids, p 219; Clarendon Press, Oxford, England (1959).

Wells, A. A.; "Heat Flow in Welding", The Welding Journal, 31 (5), pp 263-S — 267-S (1952).

Wilson, H. A.; Proc: Cambridge Phil Soc, 12, p 406 (1904).

Paley, ZVI, Lynch, J. H., and Adams, C. M., Jr; "Heat Flow in Welding Heavy Steel Plate", The Welding Journal, 43 (2), pp 71-S — 79-S.

Ingersoll, L. R., et al; Heat Conduction; McGraw Hill, Inc, New York, New York (1948).

Christensen, N.; Distribution of Heat Around Finite Moving Sources, Contract DA-91-508-EUC-378; US Department of the Army, European Research Office; September 1959.

Christensen, N. and Gjermundsen, K; Measurements of Temperatures Outside and In the Weld Pool in Submerged-Arc Welding, AD-273091, Contract DA-91-591-EUC-1530; US Department of the Army, European Research Office; January, 1962.

Apps, R. L. and Milner, D. R.; "Heat Flow in Argon-Arc Welding", British Welding Journal, pp 475 — 485; October 1955.

Robkin, D. M.; "Temperature Distribution through the Weld Pool in the Automatic Welding of Aluminum", British Welding Journal, pp 132 — 137; March 1959.

Rykalin, N. N.; "Calculation of the Thermal Processes in Welding," Mashgiz; Moscow, USSR (1951).

Pokhodnya, I. K. and Frumin, I. I; "Temperature in the Weld Pool", Avto-maticheskaya Svarka, (5) (1955).

White, S. S.; "Experimental Determination of Dimensional Heat Flow in Weldments", The Welding Journal, 40 (7) pp 317-S — 319-S (1961).

Meyers, P. S., Uyehara, O. A., and Borman, G. L.; Fundamentals of Heat Flow in Welding, WRC Bulletin 123; American Welding Society; July 1967.

Nippes, E. F. and Nelson, E. C.; "Prediction of Weld Heat-Affected Zone Microstructures from Continuous Cooling Transformation Data", The Welding Journal, 37 (7), pp 289-S — 294-S (1958).

Dorshu, K. E; "Control of Cooling Rates in Steel Weld Metal", The Welding Journal, 47 (2), pp 49-S — 62-S (1968).

GLOSSARY OF TERMS

PROGRAM

The BASIC manual defines a program as "a set of directions" that is used to provide an answer to some problem. It usually consists of a set of instructions to be performed or carried out in a certain order. It starts with the given data parameters and ends up with a set of answers. A program must fulfill two requirements: (1) it must be represented in a language that is understood by the computer; and (2) it must be completely and precisely stated.

FORTRAN

FORTRAN refers to a language for expressing problem-solving procedures by a computer into computer language. The name arises from the translation aspect that led to the original meaning of the work — FORmula TRANslation.

BASIC

BASIC is the name of a computer language. The acronym means Beginner's All-purpose Symbolic Instruction Code.

CEIR (C-E-I-R)

This is the designation used for an on-site computing service based on the Multi-Access Computing Facility being operated by C-E-I-R, Incorporated.

PLATES

Thick Plate

A plate which is sufficiently thick so that the bottom heats up, but not as much as the top, and the peak temperature on the bottom is reached after the arc has passed.

Semi-Infinite Plate

A plate which is so thick that the bottom never heats up appreciably.

Thin Plate

A plate which is sufficiently thin so that the bottom of the plate will be just as hot as the top of the plate. In other words, the isotherms are perpendicular to the surface.

FORTRAN DATA SHEET - TDIST PROGRAM

APPENDIX A

STATEMENT		C O N T		FORTRAN STATEMENT																																																																											IDENTIFICATION									
T Y P E	N U M B E R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80							
1	100	ALUMINUM RUN NO. 2										2.3										5.3										21.71																																																								
		MAT L.										CP										TK										RHO																																																								
		80.0										17.0										11.8										24.0										0.380										0.875																																				
		C										V										VEL										TIN										H										ARC																																				
		1.0										1.25										0.380																																																																		
		X										Y										Z																																																																		

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APPENDIX B

TDIST PROGRAM FOR THE CEIR COMPUTER

TDIST

```

01 REM RICKIE A. HAMILTON      3-7346      3/4/68
10 PRINT "TIME TEMPERATURE DISTRIBUTION PROGRAM FOR"
15 PRINT "THICK PLATES"
20 PRINT
25 PRINT
2600 DIM L(100),S(100),T(100)
2650 PRINT "ENTER MATERIAL CONSTANTS"
2700 PRINT
2750 PRINT "ENTER THERMAL CONDUCTIVITY K IN (CAL/CM.SEC.C)"
2800 PRINT "ENTER AVERAGE SPECIFIC HEAT CAPACITY C IN (CAL/GM.C)"
2850 PRINT "ENTER DENSITY D IN (GM/CM3)"
2900 INPUT K,C,D
2950 LET K=K*418
3000 LET C=C*4180
3050 LET D=D*1000
3100 PRINT
3150 PRINT
3200 PRINT "ENTER WELDING PARAMETERS"
3250 PRINT
3300 PRINT "ENTER CURRENT I IN AMPS"
3350 PRINT "ENTER VOLTAGE V0 IN VOLTS"
3400 PRINT "ENTER TRAVEL SPEED V IN IPM"
3450 PRINT "ENTER INITIAL TEMPERATURE T0 IN DEGREES C"
3500 PRINT "ENTER PLATE THICKNESS H IN INCHES"
3525 PRINT "ENTER ARC EFFICIENCY,0"
3550 INPUT I,V0,V,T0,H,0
3600 PRINT
3650 PRINT
3700 PRINT "IF ARBITRARY TIME INTERVALS ARE DESIRED ON"
3750 PRINT "THE FIRST RUN, TYPE 2, OTHERWISE TYPE 1"
3800 INPUT C5
3850 LET P=C5
3900 PRINT
3950 IF P=1 THEN 4200
4000 PRINT "ENTER THE INITIAL TIME AT WHICH TEMPERATURE"
4050 PRINT "IS TO BE CALCULATED , M1, THE FINAL TIME, M2, "
4100 PRINT "AND THE INCREMENT , M3, (TIME STEP INTERVAL IN SEC.)"
4150 INPUT M1,M2,M3
4200 PRINT "ENTER X,Y, AND Z POSITIONS IN INCHES"
4250 INPUT X,Y,Z
4300 PRINT
4350 PRINT
4400 PRINT
4450 PRINT "TIME ","TEMPERATURE"
4500 PRINT " ","DEGREES C."
4550 PRINT
4600 IF C9 =1 THEN 4750
4650 LET V=V*2.54/6000
4700 LET H=H*2.54/100
4750 LET X=X*2.54/100
4800 LET Y=Y*2.54/100
4850 LET Z=Z*2.54/100
4900 LET A = D*C/(2*K)
4950 LET T9=T0
5000 IF P>1 THEN 5200
5050 LET M1 = -10
5100 LET M2 = 60
5150 LET M3 =1
5200 FOR J = M1 TO M2 STEP M3
5250 LET P =P+1
5300 LET S(J+1) =J
5350 LET L(J+1)=X -V*S(J+1)
5400 LET R1 =SQR(L(J+1)*2+Y*2+Z*2)
5450 LET S1 = 0
5500 LET N =0
5550 LET N =N+1
5600 LET R2 =SQR(L(J+1)*2+Y*2+(2*N*H-Z)*2)
5650 LET R3=SQR(L(J+1)*2+Y*2+(2*N*H+Z)*2)
5700 LET S2=S1+EXP(-A*V*R2)/R2+EXP(-A*V*R3)/R3
5750 IF S2=0 THEN 5950
5800 IF ABS(1-S1/S2)<.01 THEN 5950
5850 LET S1=S2
5900 GOTO 5550
5950 LET E = EXP(-A*V*L(J+1))*(EXP(-A*V*R1)/R1+S2)
6000 LET T(J+1)=T0+(V0*0*I/(6.28318*K))*E
6050 PRINT S(J+1),T(J+1)
6100 IF T(J+1)<T9 THEN 6250
6150 LET T9=T(J+1)
6200 NEXT J
6250 PRINT
6300 PRINT
6350 PRINT "IF NEW TIME INCREMENTS OR INTERVALS ARE DESIRED FOR"
6400 PRINT "THE MATERIAL, TYPE 1, OTHERWISE TYPE 0"
6450 INPUT C9
6500 IF C9 =1 THEN 4000
6550 PRINT "IF NEW POSITION DATA WILL BE SUPPLIED, TYPE 1,"
6600 PRINT "OTHERWISE TYPE 0"
6650 INPUT C9
6700 IF C9 =1 THEN 4200
6750 END

```

TDIST PROGRAM FOR THE 1604A COMPUTER

```

PROGRAM TDIS?
C
  DIMENSION TIM(180),LAM(180),T(180),B(1000),MATL(4),LPHA(6)
  DIMENSION IXYZ(3)
  TYPE REAL LAM
  CALL PUOTS (B,1000,7)
C
C READ MATERIAL IDENTIFICATION AND CONSTANTS
C
  5 READ (5,1) MATL,CP,TK,RHO
C
  IF (CP.EQ.0.0) 163,8
C
C HEAT CAPACITY (CAL/GM.C) = CP, THERMAL CONDUCTIVITY (CAL/CM3/SEC)=TK
C DENSITY (GM/CM3) = RHO, PLATE THICKNESS (INCHES) = H
C READ WELDING PARAMETERS
C
  8 READ (5,17) LPHA
  9 DECODE (48,18,LPHA(1)) C,V,VEL,TIN,H,ARC
C
C CURRENT = I, VOLTAGE = V (KV=MA OR VOLTS=AMPS)
C VELOCITY OF WORKPIECE = VEL (INCHES PER MINUTE), INITIAL TEMPERATURE = TIN
C READ POSITION OF POINT
C X = ARBITRARY VALUE DEPENDS ONLY ON REFERENCE FRAME (INCHES)
C Y = PERPENDICULAR DISTANCE FROM SOURCE (INCHES)
C Z = DISTANCE INSIDE PLATE (INCHES)
C
  10 READ (5,22) IXYZ
  12 DECODE (24,23,IXYZ(1)) X,Y,Z
  WRITE (6,157) MATL,CP,TK,RHO,H,C,V,ARC,VEL,TIN,X,Y,Z,
C
C INPUT EQUATIONS
C
  CP=CP*4180,
  RHO=RHO*1000,
  TK=TK*418.0
C DIFFUSIVITY FUNCTION = ALF
C
  ALF = CP*RHO/(2.*TK)
C
C POWER INPUT FUNCTION = A
C
  A = ARG*C*V/(2.*3.14159*TK)
C
C CONVERT ALL UNITS TO CGS: VELOCITY, PLATE THICKNESS, X,Y,Z
C
  VEL = VEL*2.54/6000,
  H = H*2.54/100,
  X = X*2.54/100,
  Y = Y*2.54/100,
  Z = Z*2.54/100,
C
C INTRODUCE TIME (0.05 SEC INTERVALS) = TIM
C
  TIM(1) = -10.05
  LAM(1) = X = VEL*TIM(1)
  T(1)=TIN
C
  WRITE (6,209)
  209 FORMAT (6H TIME ,6X,12HTEMPERATURE ,6X, 7HLAMBDA )
C
  DO 150 MM=1,92
  DO 150 M=1,20
  M19 = M*20*MM*20
  TIM(M19) = -12.00+.05*M*MM
  LAM(M19) = X+VEL*TIM(M19)
  R = SQRT(LAM(M19)**2+Y**2+Z**2)
C
C PROCEED TO CALCULATE TEMPERATURE AS A FUNCTION OF TIME
C CALCULATE B
C CALCULATE SUM
  SUM = 0,
  J = 1
  50 RN = SQRT(LAM(M19)**2+Y**2+(2*J*M*Z)**2)
  RNP = SQRT(LAM(M19)**2+Y**2+(2*J*M*Z)**2)
  ASM = SUM + EXPF(-ALF*VEL*RN)/RN + EXPF(-ALF*VEL*RNP)/RNP
  IF (ABS(ASM-SUM)/ASM) .GT. 0.01 140,54
  54 SUM = ASM
  J = J+1
  GO TO 50
C
  140 E = EXPF(-ALF*VEL*LAM(M19))*(EXPF(-ALF*VEL*R)/R+ASM)
  TIM(9) = TIM+E
  150 CONTINUE
  151 WRITE(6,141) (TIM(I),T(I),LAM(I),I=20,1800,20)
C
  CALL LNPLOT (.1800,1,TIM,1,0.00,T)
  CALL SYMBOL (1.5,9.5,140,MATL(1),0.0,32)
  CALL SYMBOL (1.5,9.25,105,7HCURRENT,0.0,7)
  CALL SYMBOL (2.5,9.25,105,LPHA(1),0.0,8)
  CALL SYMBOL (1.5,9.00,105,7HVOLTAGE,0.0,7)
  CALL SYMBOL (2.5,9.00,105,LPHA(2),0.0,8)
C
  CALL SYMBOL (1.5,8.75,105,8HVELOCITY,0.0,8)
  CALL SYMBOL (2.5,8.75,105,LPHA(3),0.0,8)
  CALL SYMBOL (1.75,8.50,105,1HX,0.0,1)
  CALL SYMBOL (2.5,8.50,105,1XYZ(1),0.0,8)
  CALL SYMBOL (1.75,8.25,105,1HY,0.0,1)
  CALL SYMBOL (2.5,8.25,105,1XYZ(2),0.0,8)
  CALL SYMBOL (1.75,8.00,105,1HZ,0.0,1)
  CALL SYMBOL (2.5,8.00,105,1XYZ(3),0.0,8)
  CALL SYMBOL (3.15,3.9,28,20HTEMPERATURE (DEG. C),90,0,20)
  CALL SYMBOL (9,12,035,28,11HTIME (SEC.),0.0,11)
  CALL PUOT (13.0,5,3)
C
  GO TO 5
C
C LAYOUT FOR OUTPUT RECOGNITION
C
  11 FORMAT (4A8,3F8,5 )
  17 FORMAT (6A8)
  18 FORMAT (6F8,3)
  22 FORMAT (3A8)
  23 FORMAT (3F8,3)
  141 FORMAT(P6,1,6X,P9,2,6X,P9,3,8X)
  157 FORMAT (26H MATERIAL IDENTIFICATION ,4A8, /16H HEAT CAPACITY ,
  1P8,3,7H CAL/GM.C /25H THERMAL CONDUCTIVITY ,P6,3,18H CAL/SQCM/CM
  2/C/SEC /10H DENSITY ,P6,3, 9H GM/CM3 /17H PLATE THICKNESS ,P8,3,
  3,7H INCHES /// 20H WELDING PARAMETERS /10H CURRENT ,P8,2, 19H AMP
  4S OR MILLIAMPS / 10H VOLTAGE ,P5,1,20H VOLTS OR KILOVOLTS
  5/ 16H ARC EFFICIENCY ,P4,3 / 8H SPEED ,P5,1
  6, 13H INCHES /MIN / 22H INITIAL TEMPERATURE ,P5,1,
  7, 14H DEGREES CENY,///27H DISTANCE ALONG SOURCE (X) ,P8,3,5H INCH,
  8/28H PERPENDICULAR DISTANCE (Y) ,P8,3,5H INCH, /27H DISTANCE FROM
  9SURFACE (Z) ,P8,3,5H INCH /// )
C
  163 RETURN & END

```

CEIR COMPUTER OUTPUT DATA - TDIST PROGRAM

READY.

RUN

TDIST 14:10 TUE. 03-12-68

TIME TEMPERATURE DISTRIBUTION PROGRAM FOR
THICK PLATES

ENTER MATERIAL CONSTANTS

ENTER THERMAL CONDUCTIVITY K IN [CAL/CM.SEC.C]
ENTER AVERAGE SPECIFIC HEAT CAPACITY C IN [CAL/GM.C]
ENTER DENSITY D IN [GM/CM3]
?.53,.23,2.71

ENTER WELDING PARAMETERS

ENTER CURRENT I IN AMPS
ENTER VOLTAGE V0 IN VOLTS
ENTER TRAVEL SPEED V IN IPM
ENTER INITIAL TEMPERATURE T0 IN DEGREES C
ENTER PLATE THICKNESS H IN INCHES
?80,17,11.8,24,.380

IF ARBITRARY TIME INTERVALS ARE DESIRED ON
THE FIRST RUN, TYPE 2, OTHERWISE TYPE 1
?1

ENTER X,Y, AND Z POSITIONS IN INCHES
?0,.22,.380

TIME	TEMPERATURE DEGREES C.
-10	29.1173
-9	31.1843
-8	34.0944
-7	38.32
-6	44.4508
-5	53.453
-4	66.8616
-3	86.9075
-2	117.123
-1	157.825
0	194.461
1	203.468
2	191.477

IF NEW TIME INCREMENTS OR INTERVALS ARE DESIRED FOR
THE MATERIAL, TYPE 1, OTHERWISE TYPE 0
?1

ENTER THE INITIAL TIME AT WHICH TEMPERATURE
IS TO BE CALCULATED, M1, THE FINAL TIME, M2,
AND THE INCREMENT, M3, [TIME STEP INTERVAL IN SEC.]
?0,2,.1

ENTER X,Y, AND Z POSITIONS IN INCHES
?0,.22,.380

TIME	TEMPERATURE DEGREES C.
------	---------------------------

0	194.461
.1	196.801
.2	198.811
.3	200.486
.4	201.826
.5	202.836
.6	203.527
.7	203.916
.8	204.021
.9	203.864

IF NEW TIME INCREMENTS OR INTERVALS ARE DESIRED FOR
THE MATERIAL, TYPE 1, OTHERWISE TYPE 0

?0

IF NEW POSITION DATA WILL BE SUPPLIED, TYPE 1,
OTHERWISE TYPE 0

?0

TIME: 21 SECS.

1604A COMPUTER OUTPUT DATA - TDIST PROGRAM

MATERIAL IDENTIFICATION 1100 ALUMINUM
 HEAT CAPACITY .23000 CAL/GM/C.
 THERMAL CONDUCTIVITY .530 CAL/SQCM/CM/C/SEC
 DENSITY 2.710 GM/CUCM
 PLATE THICKNESS .52500 INCHES

WELDING PARAMETERS
 CURRENT 230.00 AMPS OR MILLIAMPS
 VOLTAGE 22.0 VOLTS OR KILOVOLTS
 ARC EFFICIENCY .875
 SPEED 11.8 INCHES /MIN
 INITIAL TEMPERATURE 24.0 DEGREES CENT.

DISTANCE ALONG SOURCE (X) 2.000 INCH
 PERPENDICULAR DISTANCE (Y) 1.270 INCH
 DISTANCE FROM SURFACE (Z) .525 INCH

TIME	TEMPERATURE	LAMBDA
-10.0	24.35	.80050
-9.0	24.51	.096
-8.0	24.70	.091
-7.0	24.95	.086
-6.0	25.29	.081
-5.0	25.76	.076
-4.0	26.40	.071
-3.0	27.26	.066
-2.0	28.42	.061
-1.0	30.00	.056
0	32.11	.051
1.0	34.96	.046
2.0	38.77	.041
3.0	43.80	.036
4.0	50.38	.031
5.0	58.81	.026
6.0	69.36	.021
7.0	82.13	.016
8.0	96.87	.011
9.0	112.94	.006
10.0	129.26	.001
11.0	144.59	.004
12.0	157.84	.009
13.0	168.40	.014
14.0	176.17	.019
15.0	181.41	.024
16.0	184.58	.029
17.0	186.13	.034
18.0	186.48	.039
19.0	185.97	.044
20.0	184.83	.049
21.0	183.80	.054
22.0	182.00	.059
23.0	180.02	.064
24.0	177.92	.069
25.0	175.76	.074
26.0	173.57	.079
27.0	171.38	.084

28.0	169.21	.089
29.0	167.08	.094
30.0	164.98	.099
31.0	163.46	.104
32.0	161.49	.109
33.0	159.57	.114
34.0	157.71	.119
35.0	155.90	.124
36.0	154.14	.129
37.0	152.44	.134
38.0	150.78	.139
39.0	149.17	.144
40.0	147.60	.149
41.0	146.08	.154
42.0	144.61	.159
43.0	143.70	.164
44.0	142.34	.169
45.0	141.01	.174
46.0	139.71	.179
47.0	138.46	.184
48.0	137.23	.189
49.0	136.04	.194
50.0	134.88	.199
51.0	133.75	.204
52.0	132.65	.209
53.0	131.57	.214
54.0	130.52	.219
55.0	129.50	.224
56.0	129.00	.229
57.0	128.04	.234
58.0	127.11	.239
59.0	126.19	.244
60.0	125.30	.249
61.0	124.43	.254
62.0	123.58	.259
63.0	122.74	.264
64.0	121.92	.269
65.0	121.12	.274
66.0	120.34	.279
67.0	119.57	.284
68.0	118.82	.289
69.0	118.08	.294
70.0	117.36	.299
71.0	116.65	.304
72.0	116.43	.309
73.0	115.76	.314
74.0	115.10	.319
75.0	114.46	.324
76.0	113.83	.329
77.0	113.21	.334
78.0	112.60	.339
79.0	112.00	.344

MATERIAL IDENTIFICATION CARBON STEEL
 HEAT CAPACITY 15000 CAL/GM/C
 THERMAL CONDUCTIVITY .072 CAL/SQCM/CM/C/SEC
 DENSITY 7.200 GM/CUCH
 PLATE THICKNESS 2.00000 INCHES

WELDING PARAMETERS

CURRENT 275.00 AMPS OR MILLIAMPS

VOLTAGE 30.0 VOLTS OR KILOVOLTS

ARC EFFICIENCY .875

SPEED 6.0 INCHES /MIN

INITIAL TEMPERATURE 24.0 DEGREES CENT

DISTANCE ALONG SOURCE (X) 2.000 INCH

PERPENDICULAR DISTANCE (Y) .446 INCH

DISTANCE FROM SURFACE (Z) 0 INCH

TIME	TEMPERATURE	LAMBDA
10.0	.15	80.050
9.0	24.00	.074
8.0	24.00	.071
7.0	24.00	.069
6.0	24.00	.066
5.0	24.00	.064
4.0	24.00	.061
3.0	24.00	.058
2.0	24.00	.056
1.0	24.00	.053
0.0	24.00	.051
1.0	24.00	.048
2.0	24.00	.046
3.0	24.00	.043
4.0	24.00	.041
5.0	24.00	.038
6.0	24.00	.036
7.0	24.00	.033
8.0	24.01	.030
9.0	24.02	.028
10.0	24.05	.025
11.0	24.15	.023
12.0	24.41	.020
13.0	25.10	.018
14.0	26.96	.015
15.0	31.80	.013
16.0	43.95	.010
17.0	72.60	.008
18.0	133.74	.005
19.0	245.98	.003
20.0	413.38	0
21.0	608.24	.003
22.0	784.23	.005
23.0	910.03	.008
24.0	981.32	.010
25.0	1009.35	.013
26.0	1008.20	.015
27.0	989.28	.018

28.0	960.43	.020
29.0	926.66	.023
30.0	890.99	.025
31.0	855.23	.028
32.0	820.39	.030
33.0	787.02	.033
34.0	755.38	.036
35.0	725.57	.038
36.0	697.58	.041
37.0	671.35	.043
38.0	646.80	.046
39.0	623.81	.048
40.0	602.28	.051
41.0	582.11	.053
42.0	563.18	.056
43.0	545.40	.058
44.0	528.68	.061
45.0	512.95	.063
46.0	498.11	.066
47.0	484.11	.069
48.0	470.88	.071
49.0	458.36	.074
50.0	446.49	.076
51.0	435.24	.079
52.0	424.56	.081
53.0	414.40	.084
54.0	404.74	.086
55.0	395.53	.089
56.0	386.75	.091
57.0	378.37	.094
58.0	370.36	.097
59.0	362.70	.099
60.0	355.37	.102
61.0	348.35	.104
62.0	341.63	.107
63.0	335.17	.109
64.0	328.97	.112
65.0	323.02	.114
66.0	317.30	.117
67.0	311.79	.119
68.0	306.49	.122
69.0	301.38	.124
70.0	296.47	.127
71.0	291.72	.130
72.0	287.15	.132
73.0	282.73	.135
74.0	278.46	.137
75.0	274.34	.140
76.0	270.36	.142
77.0	266.51	.145
78.0	262.78	.147
79.0	259.17	.150

TIME-TEMPERATURE DISTRIBUTION READOUTS

Figure B-1. TIME-TEMPERATURE DISTRIBUTION FOR CARBON STEEL.

Figure B-2. TIME-TEMPERATURE DISTRIBUTION FOR TYPE 1100 ALUMINUM.

APPENDIX C

PEK3M PROGRAM LIST

```

PEK3M

1 REM SURFACE PEAK TEMPERATURE PROGRAM WITH SPECIFIC HEAT CORRECTION
2 REM REFERENCE WELDING JOURNAL MARCH 1963, PG 99S E0. 3\4
10 PRINT "MATERIAL CODES"
20 PRINT "0 UNLISTED MATERIAL"
25 PRINT "1 PURE URANIUM"
30 PRINT "2 PURE ALUMINIUM"
40 PRINT "3 304 STAINLESS STEEL"
50 PRINT "4 PURE THORIUM"
100 PRINT "ENTER MATERIAL ID NUMBER"
200 INPUT M
300 IF M=0 THEN 2600
400 IF M=1 THEN 500
410 IF M=2 THEN 2510
415 IF M=3 THEN 902
420 IF M=4 THEN 925
500 LET T6=20
520 LET D=19.07*1000
530 LET T1=1133
600 IF T6<=662 THEN 1000
700 IF T6<=772 THEN 1800
800 IF T6 <=1133 THEN 2200
900 IF T6>1133 THEN 2200
902 LET D=7.9*1000
904 LET T1=1454.4
906 LET T6=20
908 LET C=.12*4180
910 GOTO 3600
925 LET D=11.2*1000
927 LET T1=1845
929 LET T6=20
931 LET T7=T6+273
933 LET C=5.17+4.56E-3*T7
935 LET C=C*4180/232.05
937 GOTO 3600
1000 LET T7=T6+273
1100 LET C=3.39+8.02E-3*T7+.70E5*T7*(-2)
1400 LET C=C/270.07
1500 LET C=C*4180
1600 GOTO 3600
1800 LET C=10.18*4180/270.07
2100 GOTO 3600
2200 LET C=9.20*4180/270.07
2500 GOTO 3600
2510 LET T6=20
2520 LET D=2.7*1000
2530 LET T1=654
2535 LET T7=T6+273
2540 LET C=4.94+2.96E-3*T7
2550 LET C=C*4180/26.98
2560 GOTO 3600
2600 PRINT "ENTER MATERIAL PARAMETERS"
2700 PRINT
2800 PRINT "ENTER CP EQUATION CONSTANTS A1,A2,A3,A4,A5,A6"
2900 PRINT "FOR CONSTANT CP ENTER VALUE AS A1 AND A2 THROUGH "
3000 PRINT "A6 AS ZERO(0)"
3100 PRINT "ENTER DENSITY D IN (GM/CM3)"
3200 PRINT "ENTER MELTING TEMPERATURE T1 IN C"
3300 INPUT A1,A2,A3,A4,A5,A6,D,T1
3350 LET D=D*1000
3400 LET C=A1+A2*T6+A3*T6+2+A4*T6+3+A5*T6+4+A6*T6+5
3450 LET C=C*4180
3600 LET L=L+1
3750 IF L>1 THEN 5600
3800 PRINT
3900 PRINT "ENTER WELD PARAMETERS"

```

```

4000PRINT
4100 PRINT "ENTER CURRENT IN AMPS"
4200 PRINT "ENTER VOLTAGE V0 IN VOLTS"
4300 PRINT "ENTER VELOCITY V IN IPM"
4400 PRINT "ENTER INITIAL TEMPERATURE IN C"
4500 PRINT "ENTER ARC EFFICIENCY A IN DECIMAL FORM"
4600 PRINT "ENTER PLATE THICKNESS IN INCHES"
4700 INPUT I,V0,V,T0,A,H
4800 LET H=H*2.54/100
4900 LET V=V*2.54/6000
5100 PRINT "ENTER Y POSITION IN INCHES"
5200 INPUT Y
5300 LET Y=Y*2.54/100
5400 PRINT
5500 PRINT
5600 LET Q = V0*I
5700 LET F=4.13*D*C*Y*H*V/(A*Q)
5800 LET P=T0+1/(F+1/(T1-T0))
5900 LET P3=T8-P
6000 LET P4=ABS(P3)
6100 IF P4<=.001 THEN 6350
6110 LET F0= (P-T0)/(T1-T0)
6111 LET F1=F0/SQR(2)
6112 LET B1=1/(1+.32759*F1)
6114 LET C0=.25482*B1
6116 LET C1=-.284496*B1^2
6118 LET C2=1.42141*B1^3
6120 LET C3=-1.45315*B1^4
6122 LET C4=1.06141*B1^5
6124 LET C5=C0+C1+C2+C3+C4
6126 LET D1=-(F1^2)
6128 LET D2=EXP(D1)
6130 LET E1=1-(D2*C5)
6134 LET P2=2.07/(1-F0)
6136 LET T6=T0+(P-T0)*((P2)*(.682767-E1))
6200 LET T8=P
6250 IF M=0 THEN 3400
6260 IF M=1 THEN 600
6270 IF M=2 THEN 2535
6280 IF M=3 THEN 910
6285 IF M=4 THEN 931
6350 LET C1=C/4180
6400 PRINT "CP=", C1
6450 PRINT "NUMBER OF ITERATIONS",L
6452 LET L=1
6500 PRINT
6600 PRINT "PEAK TEMPERATURE IN DEGREES C. IS", P
6700 LET P1=9/5*P+32
6800 PRINT
6900 PRINT "PEAK TEMPERATURE IN DEGREES F. IS",P1
7000 PRINT
7100PRINT "IF NEW Y POSITION DATA IS TO BE SUPPLIED, "
7200 PRINT "TYPE 1 ; IF NEW WELD PARAMETERS ARE TO BE "
7205 PRINT "SUPPLIED, TYPE 2 ; OTHERWISE TYPE 0"
7300INPUT C9
7400IF C9=1 THEN 5100
7450 IF C9=2 THEN 3900
7500 END

```

PEK3M PROGRAM OUTPUT DATA

```
OLD
OLD PROBLEM NAME--PEK3M
WAIT.

READY.

RUN
WAIT.

PEK3M      10:56   CEIR   02/29/68

MATERIAL CODES
0 UNLISTED MATERIAL
1 PURE URANIUM
2 PURE ALUMINIUM
3 304 STAINLESS STEEL
4 PURE THORIUM
ENTER MATERIAL ID NUMBER
?2

ENTER WELD PARAMETERS

ENTER CURRENT IN AMPS
ENTER VOLTAGE V0 IN VOLTS
ENTER VELOCITY V IN IPM
ENTER INITIAL TEMPERATURE IN C
ENTER ARC EFFICIENCY A IN DECIMAL FORM
ENTER PLATE THICKNESS IN INCHES
?250,20,10,24,.875,.25
ENTER Y POSITION IN INCHES
?2

CP=          .243848
NUMBER OF ITERATIONS          6

PEAK TEMPERATURE IN DEGREES C. IS          218.74
PEAK TEMPERATURE IN DEGREES F. IS          425.733

IF NEW Y POSITION DATA IS TO BE SUPPLIED,
TYPE 1 ; IF NEW WELD PARAMETERS ARE TO BE
SUPPLIED, TYPE 2 ; OTHERWISE TYPE 0
?0

TIME:      7 SECS.
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APPENDIX D

PEK5M PROGRAM LIST

PEK5M

```

1 REM SURFACE EDGE PEAK TEMPERATURE PROGRAM
2 REM WITH SPECIFIC HEAT CORRECTION
3 REM REFERENCE: WELDING JOURNAL MARCH 1963, PG 100S EQ. 5/4
10 PRINT "MATERIAL CODES"
20 PRINT "0 UNLISTED MATERIAL"
25 PRINT "1 PURE URANIUM"
30 PRINT "2 PURE ALUMINUM"
40 PRINT "3 304 STAINLESS STEEL"
50 PRINT "4 PURE THORIUM"
100 PRINT "ENTER MATERIAL ID NUMBER"
200 INPUT M
300 IF M=0 THEN 2600
400 IF M=1 THEN 500
410 IF M=2 THEN 2510
415 IF M=3 THEN 902
420 IF M=4 THEN 925
500 LET T6=20
520 LET D=19.07*1000
530 LET T1=1133
600 IF T6<=662 THEN 1000
700 IF T6<=772 THEN 1800
800 IF T6<=1133 THEN 2200
900 IF T6>1133 THEN 2200
902 LET D=7.9*1000
904 LET T1=1454.4
906 LET T6=20
908 LET C=.12*4180
910 GO TO 3600
925 LET D=11.2*1000
927 LET T1=1845
929 LET T6=20
931 LET T7=T6+273
933 LET C=5.17+4.56E-3*T7
935 LET C=C*4180/232.05
937 GO TO 3600
1000 LET T7=T6+273
1100 LET C=3.39+8.02E-3*T7+.7E5*T7*(-2)
1400 LET C=C/270.07
1500 LET C=C*4180
1600 GO TO 3600
1800 LET C=10.18*4180/270.07
2100 GO TO 3600
2200 LET C=9.20*4180/270.07
2500 GO TO 3600
2510 LET T6=20
2520 LET D=2700
2530 LET T1=654
2535 LET T7=T6+273
2540 LET C=4.94+2.96E-3*T7
2550 LET C=C*4180/26.98
2560 GO TO 3600
2600 PRINT "ENTER MATERIAL PARAMETERS"
2700 PRINT
2800 PRINT "ENTER CP EQUATION CONSTANTS A1,A2,A3,A4,A5,A6"
2900 PRINT "FOR CONSTANT CP ENTER VALUE OF A1 THROUGH A6"
3000 PRINT "AS ZERO(0)"
3100 PRINT "ENTER DENSITY D IN GM/CC"
3200 PRINT "ENTER MELTING TEMPERATURE T1 IN DEG. C"
3300 INPUT A1,A2,A3,A4,A5,A6,D,T1
3350 LET D=D*1000
3400 LET C=A1+A2*T6+A3*T6+2+A4*T6+3+A5*T6+4+A6*T6+5
3450 LET C=C*4180
3600 LET L=L+1
3750 IF L>1 THEN 5600
3800 PRINT
3900 PRINT "ENTER WELD PARAMETERS"

```

```

4000 PRINT
4100 PRINT "ENTER CURRENT I IN AMPS"
4200 PRINT "ENTER VOLTAGE V0 IN VOLTS"
4300 PRINT "ENTER VELOCITY V IN IPM"
4400 PRINT "ENTER INITIAL TEMPERATURE IN DEG.C"
4500 PRINT "ENTER ARC EFFICIENCY A IN DECIMAL FORM"
4600 PRINT "ENTER PLATE THICKNESS H IN INCHES"
4700 INPUT I,V0,V,T0,A,H
4800 LET H=H*2.54/100
4900 LET V=V*2.54/6000
5100 PRINT "ENTER Y POSITION IN INCHES"
5200 INPUT Y
5300 LET Y=Y*2.54/100
5400 PRINT
5500 PRINT
5600 LET Q=V0*I
5700 LET F=2.065*D*C*Y*H*V/(A*Q)
5800 LET P=T0+1/(F+.5/(T1-T0))
5900 LET P3=T8-P
6000 LET P4=ABS(P3)
6100 IF P4<=.001 THEN 6350
6110 LET F0=(P-T0)/(T1-T0)
6111 LET F1=F0/SQR(2)
6112 LET B1=1/(1+.32759*F1)
6114 LET C0=.25482*B1
6116 LET C1=-.284496*B1+2
6118 LET C2=1.42141*B1+3
6120 LET C3=-1.45315*B1+4
6122 LET C4=1.06141*B1+5
6124 LET C5=C0+C1+C2+C3+C4
6126 LET D1=-(F1+2)
6128 LET D2=EXP(D1)
6130 LET E1=1-(D2*C5)
6134 LET P2=2.07/(1-F0)
6136 LET T6=T0+(P-T0)*((P2)*(.682767-E1))
6200 LET T8=P
6250 IF M=0 THEN 3400
6260 IF M=1 THEN 600
6270 IF M=2 THEN 2535
6280 IF M=3 THEN 910
6285 IF M=4 THEN 931
6350 LET C1=C/4180
6400 PRINT "CP=",C1
6450 PRINT "NUMBER OF ITERATIONS",L
6452 LET L=L+1
6500 PRINT
6600 PRINT "PEAK TEMPERATURE IN DEGREES C. IS",P
6700 LET P1=9/5*P+32
6800 PRINT
6900 PRINT "PEAK TEMPERATURE IN DEGREES F. IS",P1
7000 PRINT
7100 PRINT "IF NEW Y POSITION DATA IS TO BE SUPPLIED,"
7200 PRINT "TYPE 1; IF NEW WELD PARAMETERS ARE TO BE"
7205 PRINT "SUPPLIED, TYPE 2; OTHERWISE TYPE 0"
7300 INPUT C9
7400 IF C9=1 THEN 5100
7450 IF C9=2 THEN 3900
7500 END

```

PEK5M PROGRAM OUTPUT DATA

```
OLD
OLD PROBLEM NAME--PEK5M

WAIT.

READY.

RUN
WAIT.

PEK5M      10:59   CEIR   02/29/68

MATERIAL CODES
0 UNLISTED MATERIAL
1 PURE URANIUM
2 PURE ALUMINUM
3 304 STAINLESS STEEL
4 PURE THORIUM
ENTER MATERIAL ID NUMBER
?2

ENTER WELD PARAMETERS

ENTER CURRENT I IN AMPS
ENTER VOLTAGE V0 IN VOLTS
ENTER VELOCITY V IN IPM
ENTER INITIAL TEMPERATURE IN DEG.C
ENTER ARC EFFICIENCY A IN DECIMAL FORM
ENTER PLATE THICKNESS H IN INCHES
?250,20,10,24,.875,.25
ENTER Y POSITION IN INCHES
?2

CP=.          .264308
NUMBER OF ITERATIONS      7

PEAK TEMPERATURE IN DEGREES C. IS      392.14
PEAK TEMPERATURE IN DEGREES F. IS      737.852

IF NEW Y POSITION DATA IS TO BE SUPPLIED,
TYPE 1; IF NEW WELD PARAMETERS ARE TO BE
SUPPLIED, TYPE 2; OTHERWISE TYPE 0
?0

TIME:   7 SECS.
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APPENDIX E

BPEKEC PROGRAM LIST

BPEKEC

```

1 REM BOTTOM PEAK TEMPERATURE PROGRAM WITH SPECIFIC HEAT CORRECTION
2 REM REFERENCE: WELDING JOURNAL MARCH 1963, PG. 100S, EO. 417
10 PRINT "MATERIAL CODES"
20 PRINT "0 UNLISTED MATERIAL"
25 PRINT "1 PURE URANIUM"
30 PRINT "2 PURE ALUMINIUM"
40 PRINT "3 304 STAINLESS STEEL"
50 PRINT "4 PURE THORIUM"
120
199 PRINT "ENTER MATERIAL CODE NUMBER"
200 INPUT M
300 IF M=0 THEN 2600
400 IF M=1 THEN 500
410 IF M=2 THEN 2510
500 LET T6=20
520 LET D=19.07*1000
530 LET T1=1133
600 IF T6<=662 THEN 1000
700 IF T6<=772 THEN 1800
800 IF T6 <=1133 THEN 2200
900 IF T6>1133 THEN 2200
902 LET D=7.9*1000
904 LET T1=1454.4
906 LET T6=20
908 LET C=.12*4180
912 GOTO 3350
925 LET D=11.2*1000
927 LET T1=1845
929 LET T6=20
931 LET T7=273+T6
933 LET C=5.17+4.56E-3*T7
935 LET C=C*4180/232.05
937 GOTO 3350
1000 LET T7 =T6+273
1100 LET C=3.39+8.02E-3*T7+.70E5*T7*(-2)
1400 LET C=C/270.07
1500 LET C=C*4180
1600 GOTO 3350
1800 LET C=10.18*4180/270.07
2100 GOTO 3350
2200 LET C=9.20*4180/270.07
2500 GOTO 3350
2510 LET T6=20
2520 LET D=2.7*1000
2530 LET T1=654
2535 LET T7=T6+273
2540 LET C=4.94+2.96E-3*T7
2550 LET C=C*4180/26.98
2560 GOTO 3350
2600 PRINT "ENTER MATERIAL PARAMETERS"
2700 PRINT
2800 PRINT " ENTER CP EQUATION CONSTANTS A1,A2,A3,A4,A5,A6"
2810 PRINT "FOR CONSTANT CP ENTER VALUE AS A1 AND"
2820 PRINT "A2 THROUGH A6 AS ZERO (0)"
2900 PRINT "ENTER DENSITY D IN GM/CM^3"
3000 PRINT "ENTER MELTING TEMPERATURE IN DEG. C."
3100 INPUT A1,A2,A3,A4,A5,A6,D,T1
3200 LET D=D*1000
3205 LET C=A1+A2*T6+A3*T6^2+A4*T6^3+A5*T6^4+A6*T6^5
3210 LET C=C*4180
3350 LET L=L+1
3355 IF L>1 THEN 4800
3400 PRINT "ENTER WELDING PARAMETERS"
3500 PRINT
3600 PRINT "ENTER CURRENT I IN AMPS"
3700 PRINT "ENTER VOLTAGE V0 IN VOLTS"

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3800 PRINT "ENTER TRAVEL SPEED IN IPM, V"
3900 PRINT "ENTER ARC EFFICIENCY IN DECIMAL FORM, A"
4000 PRINT "ENTER INITIAL TEMPERATURE IN DEGREES C."
4100 INPUT I,V0,V,A,T0
4200 LET V=V*2.54/6000
4300 PRINT "ENTER PLATE THICKNESS IN INCHES"
4400 PRINT "ENTER BEAD WIDTH IN INCHES"
4500 INPUT H,B0
4600 LET B0=B0*2.54/100
4700 LET H=H*2.54/100
4800 LET 0=1*V0
4900 LET X=B0/H
5000 LET B1=1/(1+.327591*X)
5100 LET C0=.25482*B1
5200 LET C1=-.284496*B1^2
5300 LET C2=1.42141*B1^3
5400 LET C3=-1.45315*B1^4
5500 LET C4=1.06141*B1^5
5600 LET C5=C0+C1+C2+C3+C4
5700 LET D1=-(X^2)
5800 LET D2=EXP(D1)
5900 LET E1=D2*C5
6000 LET E2 =1-E1
6100 LET F1=X/E2
6600 LET F2=2.41*D*C*V
6700 LET W=H^2/(A*0)
6800 LET F3=.5/(T1-T0)
6900 LET B=T0+1/((F2*W*F1)+F3)
7000 LET P3=T8-B
7100 LET P4=ABS(P3)
7200 IF P4<=.001 THEN 7500
7205 LET F7=(B-T0)/(T1-T0)
7210 LET F8=F7/SQR(2)
7215 LET Q1=1/(1+.32759*F8)
7220 LET R0=.25482*Q1
7225 LET R1=-.284496*Q1^2
7230 LET R2=1.42141*Q1^3
7235 LET R3=-1.45315*Q1^4
7240 LET R4=1.06141*Q1^5
7245 LET R5=R0+R1+R2+R3+R4
7250 LET S1=-(F8^2)
7255 LET S2=EXP(S1)
7260 LET S3=1-R5*S2
7265 LET S4=2.07/(1-F7)
7270 LET T6=T0+(B-T0)*((S4)*(.682767-S3))
7300 LET T8=B
7305 IF M=0 THEN 3205
7310 IF M=1 THEN 600
7315 IF M=2 THEN 2535
7320 IF M=3 THEN 908
7325 IF M=4 THEN 933
7500 PRINT
7550 LET N1=C/4180
7600 PRINT "CP=" , N1
7625 PRINT "NUMBER OF ITERATIONS",L
7650 LET L=1
7700 PRINT
7800 PRINT "BOTTOM PEAK TEMPERATURE IN DEGREES C. IS",B
7900 PRINT
8000 LET M1=B*(9/5)+32
8100 PRINT "BOTTOM PEAK TEMPERATURE IN DEGREES F. IS", M1
8200 PRINT
8300 PRINT "IF ADDITIONAL PLATE THICKNESS DATA IS TO BE"
8400 PRINT "SUPPLIED ,TYPE 1; IF NEW WELD PARAMETERS ARE TO BE"
8405 PRINT "SUPPLIED ,TYPE 2; OTHERWISE TYPE 0"
8500 INPUT G7
8600 IF G7=1 THEN 4300
8650 IF G7=2 THEN 3400
8700 END

```

BPEKEC PROGRAM OUTPUT DATA

READY.

RUN
WAIT.

BPEKEC 16:01 CEIR 03/12/68

MATERIAL CODES

0 UNLISTED MATERIAL

1 PURE URANIUM

2 PURE ALUMINIUM

3 304 STAINLESS STEEL

4 PURE THORIUM

ENTER MATERIAL CODE NUMBER

?2

ENTER WELDING PARAMETERS

ENTER CURRENT I IN AMPS

ENTER VOLTAGE V0 IN VOLTS

ENTER TRAVEL SPEED IN IPM, V

ENTER ARC EFFICIENCY IN DECIMAL FORM, A

ENTER INITIAL TEMPERATURE IN DEGREES C.

?230,22,11.8,.875,24

ENTER PLATE THICKNESS IN INCHES

ENTER BEAD WIDTH IN INCHES

?0.525,0.32

CP= .271292

NUMBER OF ITERATIONS 7

BOTTOM PEAK TEMPERATURE IN DEGREES C. IS 464.579

BOTTOM PEAK TEMPERATURE IN DEGREES F. IS 868.243

IF ADDITIONAL PLATE THICKNESS DATA IS TO BE
SUPPLIED ,TYPE 1; IF NEW WELD PARAMETERS ARE TO BE
SUPPLIED ,TYPE 2; OTHERWISE TYPE 0

?0

TIME: 8 SECS.