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BPE and BPD - BASIC Programs for Microcomputers to Calculate the Local Boiling Point and the Boiling-Point Depth Curve for "Pure" Water

by

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BPE and BPD--BASIC PROGRAMS FOR MICROCOMPUTERS TO CALCULATE THE LOCAL BOILING POINT AND THE BOILING-POINT DEPTH CURVE FOR "PURE" WATER

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ABSTRACT

The programs included in this report are designed to calculate the local boiling point (BPE) for a given elevation and the boiling-point depth curve (BPD) for "pure" water. The programs were originally developed for the Tektronix 4051 Graphic Computer System and have been modified to run on the NBI 4100 (IBM PC compatible) using the GW-Basic Interpreter, that is, BASICA (Version 2) operating under the Microsoft MS-DOS (Version 2) operating system. Programs for both microcomputers are included. The BPE program requests an elevation in feet and outputs a local boiling point in °C. The BPD program requests an elevation and boiling point (from BPE) and the temperature interval. Output from BPD defaults to the line printer and optionally to a disk drive. If the disk output is selected, then only the depth (feet) and temperature (Celsius) are written to the disk, along with the total number of depth-temperature pairs. The data written to the sequential disk file could be retrieved at a later date and plotted on various temperature-depth curves along with measured well temperatures, for example.

The data calculated are for "pure" water, and are meant to only be an indication of the temperatures of the boiling point as a function of depth. By "pure" water, we mean water of very low salinity. Although salinity will modify this curve, no attempt has been made to incorporate this into the programs due to the complexity of such a calculation and the lack of pertinent information required for such a calculation for most wells.

An example of the use of the boiling-point depth curve is illustrated for a well (Mammoth No. 1) in Long Valley Caldera, Mono County, California, in which the shallow temperatures are controlled by the boiling-point depth curve (BPD).

INTRODUCTION

Analysis of temperatures in geothermal wells requires a knowledge of the local boiling point and the boiling-point curve as a function of depth. With the advent of inexpensive tabletop computers, temperature data can be obtained, plotted, and examined in relatively convenient form, even in the field at the well site. To facilitate this examination, it is very often desirable to plot the boiling-point depth curve along with the measured temperatures. Although curves and short tables of such information have been published (for example, White, 1968; Haas, 1971; White and others, 1971; and Elder, 1981), they are not very convenient and the tables tend to be relatively short. In addition, the details of the calculation of the reference boiling point curve and local boiling point are neither presented nor obvious. This report was generated, after the authors spent considerable effort in producing the programs, in the hope that they might be useful to others or at least illustrate one approach to calculating this type of data.

The programs were originally developed on a Tektronix 4051 Graphics Computer system and were modified to run on an NBI 4100 (IBM PC compatible) computer. Because of the length of the programs and the limited memory of the Tektronix 4051 (about 30K-bytes), it was necessary to divide the original program into two programs: BPE (Boiling Point Elevation) and BPD (Boiling Point Depth). This allowed more of the Steam Tables (table 2; and Keenan and others, 1969, table 1) to be included. For an IBM-compatible microcomputer there is sufficient memory remaining so that more of the Steam Table data could be incorporated than we have used. However, for the purposes that these programs are used and in the manner in which the calculations are done, additional data would not change the results significantly but would increase the amount of time for the computations. The NBI 4100 program was written in Microsoft's GW BASIC Interpreter (BASICA) operating under MS-DOS Version 2.0. Although other BASICs are available, GW BASIC was chosen because of its availability on many, if not most, IBM and IBM-compatible machines.

PROGRAM DESCRIPTION

Introduction

The programs included in this report (App. I-IV) contain numerous comment statements (REMarks). They can be eliminated and by doing so the computation time will be reduced (by an unknown amount). However, some caution should be exercised in removing these REM statements since a GOTO or GOSUB might branch to them. The authors have tried to eliminate branches to REM statements, but a few may have been overlooked. Program variables for both BPE and BPD are listed in table 1.

The program descriptions are in outline form with the line numbers of the Tektronix 4051 version listed in brackets followed by that of the NBI 4100 (IBM PC compatible) in parentheses, for example: Line [100-340] (100-340). Although in this example both sets of numbers are identical, this is not always the case. If no comparable lines exist for one of the programs, then the line numbers are blank: Line [100-340] (-) or Line [-] (100-340). There are some differences between the BASICs used in these programs, particularly in regards to some of the "CALL" statements used by the Tektronix 4051. The 4051 "CALL" statements refer to ROM (Read-Only-Memory) Pack routines that are used in conjunction with the floppy disks or to implement faster routines, usually to eliminate FOR-NEXT loops. Program arrays are always assumed to start with index 1, for example, A(1), A(2)... In the Tektronix 4051 BASIC arrays can be read in with a single call: READ T, where T is a one-dimensional array (that is, vector) of N elements. Note that reference to arrays refers to a one-dimensional array or vector throughout this report.

TABLE 1.--List of variables used in the BPE and BPD programs

Variable	Description
A	N x M array divided-difference table for pressure.
B	N x M array divided-difference table for specific volume.
C	N2 x M array divided-difference table for atmospheric pressure.
D	Degree of interpolating polynomial.
G	0.09807 acceleration of gravity and constant for proper units.
I	Subscripts (counter or index).
J	Do.
K	Do.
M	Highest order divided difference to be computed.
N	Number of paired values for temperature and pressure.
P	Pressure--water at saturation (bars).
T	Temperature--water at saturation (°C).
V	Specific volume--water at saturation--liquid (cm^3gm).
Y	Variable = D5*(V0+4V1+V2)/3 for Simpson's Rule integration.
Z	Depth below elevation E0 (feet)--starting at Z = 0.
D0	Temperature increment (°C).
D1	D1 = D - 1.
D5	(delta P)/2 = (P2 - P0)/2 for Simpson's Rule integration.
E0	Elevation (feet) above sea level.
I0	Subscript: I+1-J.
I1	Subscript: M1-I or M1-D.
I2	Subscript: D-I.
M1	Subscript of largest base point used to determine the interpolating polynomial.
M5	Constant (100) - rounding of depth to 0.01 ft
N0	Number of points (depths) calculated for file storage.
N1	N1 = N-1.
N2	Number of atm pressure/elevation pairs.
P0	First interpolated pressure at temperature T0 (bars).
P1	Second interpolated pressure at temperature T0 + D0/2 (bars).
P2	Last interpolated pressure at new temperature T0 + D0 (bars).
P5	Atmospheric pressure array at Z5 elevations (bars).
P9	Value of pressure interpolated and returned by subroutine (bars).
T0	Boiling point at depth Z below "surface" (°C).
T5	Boiling point at elevation E0 (°C).
T9	Computational flag: = 1 if argument inconsistency is encountered, otherwise set to zero.
U0	Primary GPIB printer address.
U1	Secondary GPIB printer address.
V0	Specific volume at temperature T0 (cm^3/gm).
V1	Specific volume at temperature T0 + D0/2 (cm^3/gm).
V2	Specific volume at temperature T0 + D0 (cm^3/gm).
V9	Specific volume returned by subroutine (cm^3/gm).
Y5	Variable used in nested evaluation of interpolating polynomial.
Z5	Elevation array (feet) for atmospheric pressures.
A$	Variable format for data printing.
F$	Disk file information returned on opening file.
O$	Disk file output name.
Q$	Question variable--for branch decision.

PROGRAM BPE: Appendix [I] (III)

Line [1-2] (-): Program title and END statement used to prevent execution of to program when loaded under program control from disk.
Line [-] (1-2): Program title.
Line [4-8] (-): Executes program from User-Definable Key #1, clears screen, and jumps to start at Line 150.
Line [100-150] (100-150): Clears all variables and resets system to a known state (Tektronix 4051); clears screen (NBI 4100).
Line [160-220] (160-190): Requests elevation in FEET.
Line [230-410] (200-410): Dimensions variables and reads data into variables and arrays.
Line [420-510] (420-500): Goes to Subroutine DTABLE3 and computes the values for Matrix C - divided-differences of atmospheric pressure as a function of the elevation. If the degree of the interpolation polynomial is larger than the number of atmospheric-pressure values, then terminate the program.
Line [520-610] (510-590): Goes to Subroutine DTABLE4 and computes the values for matrix A - divided-differences of the temperature as a function of pressure. If the degree of the interpolation polynomial is greater than the number of water pressure values, then terminate the program.
Line [620-710] (600-680): Go to subroutine Z_PRESS and calculate the atmospheric pressure for elevation E0.
Line [720-780] (690-740): Go to Subroutine P_TEMP and calculate the local boiling point.
Line [790-800] (750-810): Print the local boiling point on the screen and end the program.
Line [810-1070] (820-1080): Subroutine DTABLE3 - Computes the finite divided differences of P5(1)...P5(N2) for all orders M or less and stores them in the lower triangular portion of the first M columns of the first N2-1 rows of the matrix C. For inconsistent arguments, T9 = 1 on exit, which halts the program. Otherwise T9 = 0 on exit.
Line [1080-1340] (1090-1350): Subroutine DTABLE4 - Computes the finite divided differences of T(1)...T(n) for all orders M or less and stores them in the lower triangular portion of the first M columns of the first N-1 rows of the matrix A. For inconsistent arguments, T9 = 1 on exit, which halts the program. Otherwise, T9 = 0 on exit.
Line [1350-1840] (1360-1830): Subroutine Z_PRESS - Assumes that Z5(1)...Z5(N2) are in ascending order and first scans the Z5 vector to determine which element is nearest (.GE.) the interpolation argument, E0. The D+1 base points needed for the evaluation of the divided-difference polynomial of degree D+1 are then centered about the chosen element with the largest having the subscript M1. It is assumed that the first M divided differences have been computed by the subroutine DTABLE3 and are already present in matrix C. M1 is checked to insure that all required base points are available, and the interpolant value is computed using nested polynomial evaluation. The interpolant is returned as the value, P9, of the subroutine. For inconsistent arguments, T9 = 1 on exit, which halts the program. Otherwise, T9 = 0 on exit.
Line [1850-2330] (1840-2300): Subroutine P_TEMP - Assumes that P(1)...P(N) are in ascending order and first scans the P array to determine which element is nearest (.GE.) the interpolation argument, P9. The D+1 base points needed for the evaluation of the divided-difference polynomial of degree D+1 are then centered about the chosen element with the largest having the subscript

M1. It is assumed that the first M divided differences have been computed by the subroutine DTABLE4 and are already present in matrix A. M1 is checked to insure that all required base points are available, and the interpolant value is computed using nested polynomial evaluation. The interpolant is returned as the value, T0, of the subroutine, i.e., the local boiling point. For inconsistent arguments, T9 = 1 on exit, which halts the program. Otherwise, T9 = 0 on exit.

Line [2340-2430] (2310-2400): Array dimensions and water at saturation data from Keenan, Keyes, Hill and Moore [1969].

Line [2440-2650] (2410-2620): U.S. Standard Atmosphere pressures, 1976, in bars for range 0-12,000 feet at 100 foot intervals.

Line [2660-2690] (2630-2660): Degree of the interpolating polynomial.

PROGRAM BPD: Appendix [II] (IV)

Line [1-2] (-): Title and END to prevent execution when loaded under program control from disk.

Line [-] (1-2): Program title.

Line [4-8] (-): Executes program from User-Definable key No. 1, clears screen and goes to line 100.

Line [100-150] (100-150): Clears all variables and resets system to a known state.

Line [160-250] (-): Resets pointer to first data statement (optional after INIT) and sets GPIB primary and secondary printer addresses. A secondary address of 32 means ignore the secondary address. This may vary from one printer interface to another.

Line [260-290] (160-200): Heading for printer (also clears screen on NBI 4100).

Line [300-480] (210-350): Input elevation, boiling point and temperature increment and set various variables.

Line [490-600] (360-510): Dimension arrays and read in data from DATA statements. For the Tektronix 4051, the arrays may be read with a single READ statement after they are dimensioned, e.g., READ T, where T is a 1-dimensional array (vector) of N elements. The disk filename is set to a NULL string.

Line [610-640] (520-550): The local boiling point value T0 is saved in T5, since the value of T0 is incremented during program execution.

Line [650-740] (560-650): Go to DTABLE1 and compute the water at saturation pressure divided differences as a function of temperature and store the results in matrix A. If the order of the divided differences are greater than the number of points, N, then T9 = 1 and halt execution.

Line [750-840] (660-740): Go to subroutine DTABLE2 and compute the specific volume divided differences as a function of pressure and store the results in matrix B. If the order of the divided differences is greater than the number of points, N, then T9 = 1 and halt execution.

Line [850-890] (750-790): Format for the first line only of the printer output, i.e., the local boiling point data.

Line [900-1310] (800-1260): Disk file initialization section. The program requests if data is to be written to the disk. If yes then the filename is requested and the disk is checked to see if the file exists. Significant differences exist between the Tektronix 4051 and NBI 4100 (IBM PC compatible) computer functions to accomplish this task. If the file exists, then is it to be deleted or retained. A decision is requested and the program either deletes the file or requests a new filename. If the file does not exist, it is created and the number of depth-temperature pairs is written to disk.

Line [1320-1350] (1270-1300): Headings are printed on the printer.

Line [1360-1420] (1310-1370): For the boiling point, go to FNEWPV and calculate the water at saturation pressure and specific volume. Save the results in P2 and V2.

Line 1430-1550] (1380-1500): Print the results for the boiling point, increment the printer line counter, and redefine the printer format statement with the temperatures as integers. See Appendix V for change.

Line [1560-1630] (1510-1580):If filename is NULL, then skip. Otherwise, write depth and temperature to disk.

Line [1640-1740] (1590-1690): For boiling point, P2 and V2 have been calculated above in Line [1360-1420] (1310-1370). Save P2 and V2. This is the re-entry point for the loop for subsequent temperatures.

Line [1750-1860] (1700-1810): Get the next temperature and check it against the last temperature to be used (critical point) and set accordingly.

Line [1870-1950] (1820-1900): Calculate the new pressure and specific volume and save the results in P2 and V2.

Line [1960-2080] (1910-2030): Calculate the mid-pressure and specific volume and save in P1 and V1.

Line [2090-2160] (2040-2110): Calculate P_DIFFERENCE/2 for use by Simpson's Rule and calculate the new depth using Simpson's Rule.

Line [2170-2280] (2120-2230): Check for last temperature. If it is the last temperature, then change the printer output format and print data. Otherwise, just print data.

Line [2290-2360] (2240-2310): If filename is not equal to NULL then write depth-temperature data to disk. Otherwise, skip.

Line [2370-2480] (2320-2430): Increment printer line counter. If 50 lines of data have been printed, then page printer and print new headings. Otherwise, skip.

Line [2490-2680] (2440-2610): Has the last temperature been printed? If it has, then finish up - page printer, close disk (if used), and end program.

Line [2690-2950] (2620-2880): Subroutine DTABLE1 - Computes the finite divided differences of P(1)...P(N) for all orders M or less and stores them in the lower triangular portion of the first M columns of the first N-1 rows of the matrix A. For inconsistent arguments, T9 = 1 on exit, which halts execution. Otherwise, T9 = 0 on exit.

Line [2960-3220] (2890-3150): Subroutine DTABLE2 - Computes the finite divided differences of V(1)...V(N) for all orders M or less and stores them in the lower triangular portion of the first M columns of the first N-1 rows of the matrix B. For inconsistent arguments, T9 =1 on exit, which halts execution. Otherwise, T9 =0 on exit.

Line [3230-4000] (3160-3850): Subroutine FNEWPV - Assumes that T(1)...T(N) are in ascending order and first scans the T array to determine which element is nearest (.GE.) the interpolation argument, T0. The D+1 base points needed for the evaluation of the divided-difference polynomial of degree D+1 are then centered about the chosen element with the largest having the subscript M1. It is assumed that the first M divided differences have been computed by the subroutines DTABLE1 and DTABLE2 and are already present in matrix A and B. M1 is checked to insure that all required base points are available, and the interpolant values are computed using nested polynomial evaluation. The interpolant is returned as the values, P9 and V9, of the subroutine. For inconsistent arguments, T9 = 1 on exit, which halts execution. Otherwise, T9 =0 on exit.

Line [4010-4080] (3860-3910): Calculate new depth using Simpson's Rule.
Line [4090-4410] (3920-4240): Data for water at saturation from Keenan, Keyes, Hill and Moore [1969, Table 1]. It consists of temperatures, pressure and specific volume.
Line [4420-4450] (4250-4280): Degree of the interpolating polynomial.
Line [4460-4590] (4290-4450): Print statements for headings of printer output. Reset printer data line counter to zero.

DISCUSSION

The procedure for calculating both the boiling point and the boiling-point depth curve depend heavily on the use of Newton's divided-difference polynomial. Newton's divided differences are used because of the unequal intervals in the data sets. The derivation and discussion of the divided-difference polynomial can be found in Carnahan and others (1969, p. 9-20) and in numerous other texts dealing with numerical interpolation and integration. The subroutines used in both BPE and BPD were modified from the FORTRAN routines DTABLE and FNEWT (Carnahan and others, 1969, p. 22-24). A sixth-degree polynomial interpolation was used throughout both programs. This provided sufficient accuracy without undue computational time.

The local boiling point is determined by the BASIC program BPE starting from the U.S. Standard Atmosphere, 1976 data (USCOESA, 1976), which is a compilation of geometric altitude and atmospheric pressure. From the elevation of the drill site, the atmospheric pressure is calculated using the divided-difference interpolating polynomial. The local boiling point is then interpolated using the steam tables (Keenan and others, 1969, table 1) and the divided-difference interpolating polynomial generated from this data. This local boiling point is the standard boiling point. This approach was utilized because the local atmospheric pressure is usually an unknown quantity. Also, the variations in atmospheric pressure with changes in weather can be quite large and we think that the use of a standard number is more appropriate in making comparisons to the observed data. A sample output from program BPE is given below (Tektronix 4051 version, App. I).

```
ELEVATION (FEET): 7244
PLEASE WAIT ABOUT 60 SECONDS - CALCULATIONS IN PROGRESS
BOILING POINT = 92.67 CELSIUS
```

The U.S. Standard Atmosphere Supplements, 1966 (USCOESA, 1967, table 5.2) tabulates atmospheric pressure versus geometric altitude variations for several latitudes in January and July at intervals of 1,000 ft. In order to illustrate the variations involved, the boiling points for Yellowstone for January and July at 7,300 ft (Upper Basin) were calculated and are used as examples:

TB January: 92.4 °C July: 92.9 °C Standard: 92.6 °C

Unfortunately, the variation due to weather is larger than either of the above. From White (1968, fig. 22), the barometric pressure variation over a period of 2 weeks (at Steamboat Springs) was about 0.02 bars, which is equivalent to a change in local boiling of 0.7 °C. Given the uncertainties in elevation, atmospheric pressure, and salinity of the water (usually unknown), it is doubtful that such minor corrections are warranted. Haas (1971) illustrates the effects of salinity on the boiling-point depth curve.

Once the local boiling point has been determined, the boiling-point depth curve can be calculated from

$$dP/dZ = g/v_f \ ,$$

where P is the water-at-saturation fluid-pressure, Z is the depth, g is the local acceleration of gravity and v_f is the specific volume of the water at saturation. In the programs, a constant acceleration of gravity was used which corresponds to the theoretical value at 45° N. latitude. Alternately, an actual local acceleration could be used based on the theoretical acceleration of gravity as a function of latitude or the actual measured value of the acceleration of gravity if available. In general, this is a second order effect and is not critical, especially in view of other uncertainties mentioned above. Solving for dZ and multiplying the right-hand side of the equation by dT/dT, that is, by 1:

$$dZ = (v_f/g)\cdot(dP/dT)\cdot dT \ .$$

Upon integrating both sides of this equation and adjusting the units so that the depths are in meters yields:

$$Z - Z_o|m = (1/9.807\times10^{-2})\int_{T_o}^{T} v_f|cm^3/gm\cdot(dP/dT)|bars/{}^\circ C\cdot dT|{}^\circ C \qquad (1)$$

where the depth Z_o corresponding to T_o is usually zero (the surface). Although equation (1) can be integrated from the "surface", that is from T_o, dP/dT is nonlinear and the tabular values for v_f and P as a function of T make this impractical. Thus, in practice equation (1), letting $C = 1/9.807 \times 10^{-2}$, is expanded as follows:

$$Z - Z_o = C\int_{T_o}^{T} = C\int_{T_o}^{T_1} + \int_{T_1}^{T_2} + \cdots + \int_{T_{i-1}}^{T}$$

where the integrands, $v_f\cdot(dP/dT)\cdot dT$, to the right of the integral have been left out for clarity. Each of these integrals is a ΔZ_i that when summed are equal to $Z - Z_o$. Also, each integral defines a new depth in that

$$Z_1 - Z_o = C\int_{T_o}^{T_1} \ , \ Z_2 - Z_1 = C\int_{T_1}^{T_2} \ , \ Z_3 - Z_2 = C\int_{T_2}^{T_3} \ , \text{ etc.}$$

This method of breaking up the integral has an advantage if $T_{i+1} - T_i$ is small, 1°C for example. For in this case $(dP/dT) \times dT \cong dP$ and can be assumed to be approximately linear over dT without introducing any significant error. The evaluation of the integral, $C\int_{T_{i-1}}^{T_i}$, is usually done numerically due to the tabular form of the steam tables. A convenient method of numerical integration is Simpson's rule (Carnahan and others, 1969, p. 73). Since the temperature interval (1 °C) we will use is small, we can limit the series to three terms without significant error: the result for the i-th temperature interval is

$$Z_{i+1} = Z_i + (C \cdot h/3)\,[v_i(P_i) + 4 \cdot v_{i+1/2}(P_{i+1/2}) + v_{i+1}(P_{i+1})] \qquad (2)$$

where $P_i = P(T_i)$, $P_{i+1} = P(T_{i+1})$, $P_{i+1/2} = (P_i + P_{i+1})/2$, $2h = P_{i+1} - P_i$,

and $C = 1/9.807\text{x}10^{-2}$.

The procedure to do the above calculation involves starting with a temperature, T_o (the local boiling point), calculating the pressure (P_i) using the divided difference polynomial, and using this pressure, calculate the specific volume (v_i). The temperature is then incremented to the next required temperature (usually to the next 1 °C increment). For example, if the boiling point is 92.6 °C, then the next temperature would be 93 °C. From this temperature (93 °C), the pressure and specific volume (P_{i+1} and v_{i+1}, respectively) are then calculated using their respective divided-difference interpolating polynomials. The pressure for the midpoint, $P_{i+1/2}$, is the average of P_i and P_{i+1}, from which the specific volume $v_{i+1/2}$ is calculated as above. The starting depth, Z_i, is usually zero for T_o, but may be any starting depth. Once all the pressures and specific volumes have been determined, the evaluation of equation (2) yields a new depth, Z_{i+1}. The next iteration of the program would replace Z_i by Z_{i+1} and the temperature would be incremented by delta T (for example, from 93° to 94 °C). The initial pressure and specific volume at 93 °C has been calculated for P_{i+1} and $v_{i+1}(P_{i+1})$ and only requires substitution into P_i and $v_i(P_i)$. This procedure is repeated until the last temperature, the critical point, is reached, after which the program terminates. The data printed consist of the temperature, depths in feet and meters, pressure, specific volume and density. If the option to save to disk is in effect then the program writes the depth in FEET and the temperature (°C) to the disk. The first disk record is the number of depth-temperature pairs on the disk. A sample printer output is listed in Appendix V. It should be noted that an excessive number of significant figures are included in the depths presented. In fact, the number of significant figures is limited to a maximum of about four. The inclusion of the extra digits allows the data to be plotted as a smooth curve and avoids a step-like appearance. In addition, density decreases with depth; that is, with increasing temperature, as shown. Although the increasing pressure tends to increase the density, it is more than compensated by the effect of temperature on density as is shown in table 2.

At this point it may be well to reiterate the obvious. The BDP curve is a quantity derived from an experimentally determined equation of state for "pure" water (that is, the steam tables, table 2) and the assumption that water is at the boiling point at all depths above any point in question. This assumption as to density permits the coversion of pressure to depth. Other assumptions could be made and the pressure-to-depth conversion could be different, quite different, if significant quantitites of gas or dissolved solids are contained in a fluid column or if a significant part of a fluid column is well below the boiling point. It is also clear that a large-diameter fluid-column of "pure" water could not follow the BPD curve; it would be hydrodynamically unstable, because density decreases with depth/pressure along the BPD curve (table 2). However, density may decrease with depth in small-diameter tubes or porous media provided the Rayleigh number is sufficiently small (for example, Elders, 1981, p. 183).

It may be best to think of the BPD curve as a reference boiling-point curve, as White and others (1971) and White (1973) called it, which can be modified when the appropriate information exists. Such modifications are best handled on case-by-case basis because the uncertainties may be large and the complex interplay among them may not be fully understood. Nonetheless, we allude to some of these problems in subsequent paragraphs, but reserve quantitative assessment for particular cases.

The above discussion assumes that the fluid column is entirely liquid ($e = 1$). The programs in Appendices I-IV also make this assumption. If, however, the column is not entirely liquid (volume fraction $e < 1$) then a modification to the calculation for the specific gravity is required in the program BPD. The specific volume of the vapor phase (v_g) also must be included and another divided-difference interpolating polynomial must be determined. One method to include the vapor phase was suggested by Elder (1981, p. 490). If we let the

$$\text{density} = e/v_f + (1-e)/v_g,$$

and if the reciprocal of this equation is taken and some terms rearranged, then

$$v = v_f \cdot v_g / [e \cdot v_g + (1-e) \cdot v_f].$$

If $e \rightarrow 1$, then $v \rightarrow v_f$, as before. In order to facilitate this calculation, the values for v_g are included in table 2, along with the temperature, pressure and specific volume of the liquid (v_f) (abstracted from Keenan and others, 1969, table 1]. Elder (1981, p. 488) plots the temperatures as a function of depth for several values of $e < 1$.

As an example of the utility of the Boiling-Point-Depth calculation, figure 1 is a plot of the temperatures as a function of depth for Mammoth No. 1, Long Valley Caldera, Mono County, California, obtained on September 23, 1983 (see also, Diment and others, 1985). Also plotted on the figure is the reference boiling point depth curve (BPD) calculated for the elevation of the

TABLE 2.--Properties of water
[from Keenan and others, 1969, table 1]

		Specific Volume (cm^3/gm)				Specific Volume (cm^3/gm)	
Temperature (°C)	Pressure bars	Liquid at Saturation	Vapor at Saturation	Temperature (°C)	Pressure bars	Liquid at Saturation	Vapor at Saturation
80	0.4739	1.0291	3407.	300	85.81	1.4036	21.67
85	.5783	1.0325	2828.	305	92.02	1.4247	19.948
90	.7014	1.0360	2361.	310	98.56	1.4474	18.350
95	.8455	1.0397	1981.9	315	105.47	1.4720	16.867
100	1.0135	1.0435	1672.9	320	112.74	1.4988	15.488
105	1.2082	1.0475	1419.4	324	118.83	1.5221	14.451
110	1.4327	1.0516	1210.2	330	128.45	1.5607	12.996
115	1.6906	1.0559	1036.6	334	135.20	1.5893	12.086
120	1.9853	1.0603	891.9	340	145.86	1.6379	10.797
125	2.321	1.0649	770.6	344	153.33	1.6750	9.982
130	2.701	1.0697	668.5	350	165.13	1.7403	8.813
135	3.130	1.0746	582.2	354	173.42	1.7927	8.059
140	3.613	1.0797	508.9	360	186.51	1.8925	6.945
145	4.154	1.0850	446.3	362	191.06	1.9345	6.570
150	4.758	1.0905	392.8	364	195.71	1.9833	6.189
155	5.431	1.0961	346.8	366	200.46	2.0416	5.795
160	6.178	1.1020	307.1	368	205.31	2.1145	5.380
165	7.005	1.1080	272.7	370	210.3	2.213	4.925
170	7.917	1.1143	242.8	371	212.8	2.280	4.671
175	8.920	1.1207	216.8	372	215.3	2.369	4.380
180	10.021	1.1274	194.05	373	217.9	2.509	4.019
185	11.227	1.1343	174.09	374	220.5	2.880	3.322
190	12.544	1.1414	156.54	374.136	220.9	3.155	3.155
195	13.978	1.1488	141.05				
200	15.538	1.1565	127.36				
205	17.230	1.1644	115.21				
210	19.062	1.1726	104.41				
215	21.04	1.1812	94.79				
220	23.18	1.1900	86.19				
225	25.48	1.1992	78.49				
230	27.95	1.2088	71.58				
235	30.60	1.2187	65.37				
240	33.44	1.2291	59.76				
245	36.48	1.2399	54.71				
250	39.73	1.2512	50.13				
255	43.19	1.2631	45.98				
260	46.88	1.2755	42.21				
265	50.81	1.2886	38.77				
270	54.99	1.3023	35.64				
275	59.42	1.3168	32.79				
280	64.12	1.3321	30.17				
285	69.09	1.3483	27.77				
290	74.36	1.3656	25.57				
295	79.93	1.3839	23.54				

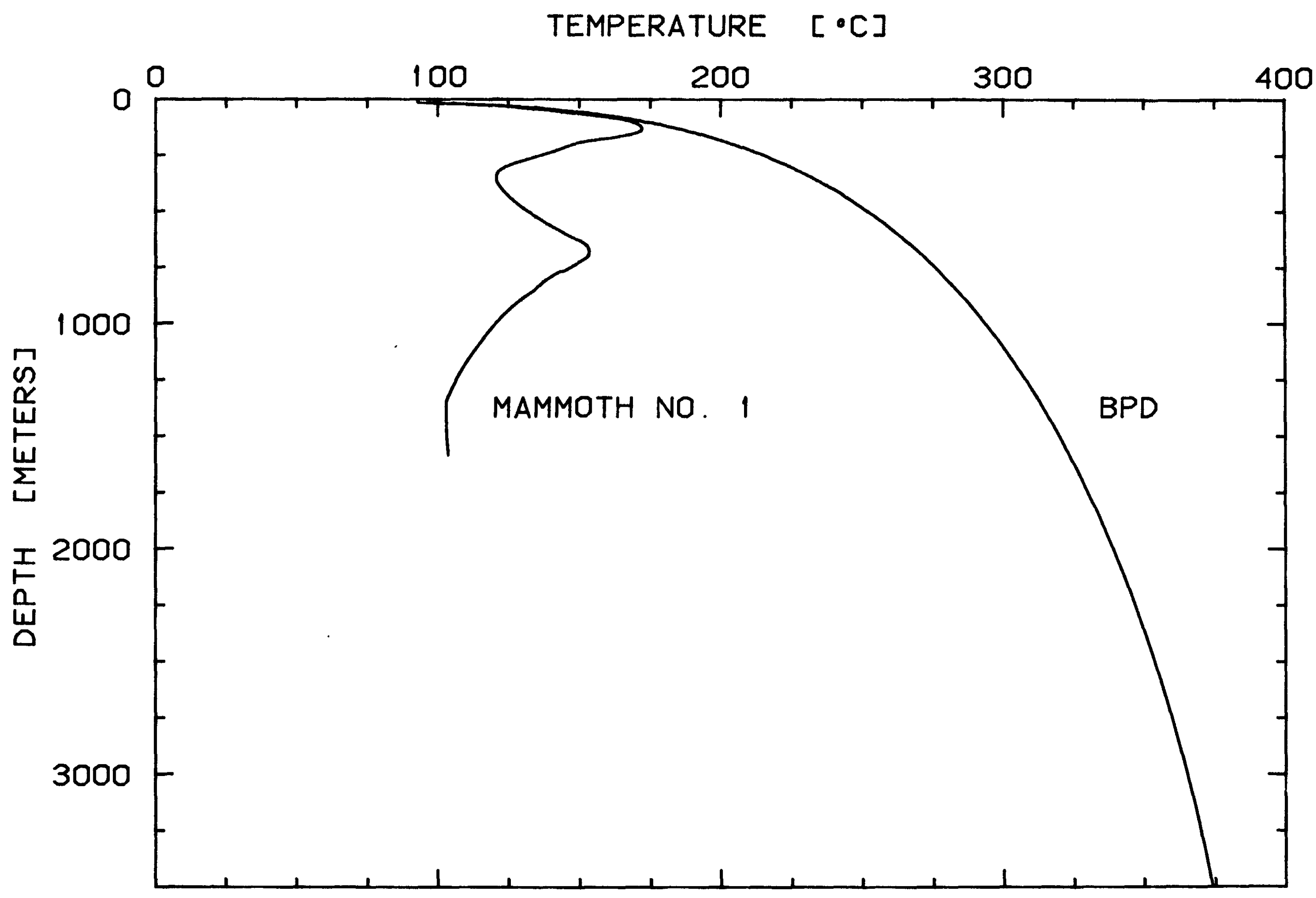

FIGURE 1. Temperature-depth profile for Mammoth No. 1, Long Valley Caldera, Mono County, Calif., measured on September 23, 1983. BPD is the reference boiling-point depth curve for an elevation of 7,244 ft.

water in the well (7,244 ft). The actual water level is about 60 ft below the ground level (7,304 ft) and the calculations of BPD were based on this elevation (7,244 = 7,304 - 60 ft). The shallow part of this temperature profile is controlled by the boiling-point depth curve (Diment and others, 1985). The boiling-point depth curve (BPD) is plotted down to the critical point, 374.136 °C, for reference. Although the details of BPD would vary depending upon the local boiling point, the general shape would remain the same and figure 1 could be used to give a gross estimate of the boiling-point at depth if caution concerning this number is exercised. Since the point of this report is to provide a means for making the actual calculation, the use of figure 1 in this manner is not encouraged.

In making these calculations, several time trials were run in order to compare performance of the two systems. For the program BPE, the Tektronix 4051 version ran in about 50 s, while the NBI 4100 averaged about 23 s. Program BPD runs in 15 min and 11 s without disk access and 15 min and 32 s when storing data on the disk. For the NBI 4100, BPD runs in 9 min without disk access and 9 min and 27 s when storing data on the disk. The variable types are double precision for the Tektronix 4051 (only type) and single precision for the NBI 4100. If the variable type for the NBI 4100 is changed to double precision, then the computation time is increased about a minute. It should be noted that these times (for BPD only) include response times to queries about whether to store on disk and if so the file name, and may vary from one user to another. Variations in execution time have also been noted for other systems with different interfaces and printers. No difference in computed values were noted for the NBI 4100 between single and double precision, and it is felt that the extra time consumed by the use of double precision variables is not warranted.

CONCLUSIONS

This report was prepared in order to facilitate the calculation of the local boiling point and the reference boiling-point depth curve. The calculation of the local boiling point (program BPE) utilizes the U.S. Standard Atmosphere 1976 data to determine the pressure at a given elevation. From this the local boiling point can be calculated using the steam tables of Keenan and others (1969, table 1). Once the local boiling point has been determined, the reference boiling point curve as a function of depth can be calculated (program BPD). This provides a depth-temperature profile for "pure" water. Neither of these programs account for salinity (see Haas, 1971, for effects of salinity); thus the reference to "pure" water. The boiling-point depth curve is one bound on the temperatures that can be measured in a geothermal well and is a guide to the interpretation of the observed temperatures in the well.

The programs were originally written for the Tektronix 4051 Graphics System and modified for the NBI 4100 (IBM PC compatible). The various versions run on their respective systems with computation times for BPE from 21 to 60 s and for BPD from 9 to 16 min (NBI 4100 and Tektronix 4051). The run times vary depending upon the system configuration. Undoubtedly the programs could be speeded up by removing REMark statements and by perhaps other improvements in the programming. We have suggested one variation that could be incorporated for systems that are not entirely liquid, although this is not included in any of the enclosed programs.

Finally, as an example, Mammoth No. 1, Long Valley Caldera, Mono County, California, is a geothermal well in which the shallow temperatures are controlled by the reference boiling-point curve (Diment and others, 1985).

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APPENDIX I

Boiling-Point Calculation Program BPE for
Tektronix 4051 Graphic System Computer

```
1 REM ...BOILING POINT CALCULATION - 5/2/86...
2 END
4 REM ************************************
5 REM * USER-DEFINABLE KEY NO. 1 - START *
6 REM ************************************
7 PAGE
8 GO TO 150
100 REM ...READ DATA AND PRINT...
110 REM ******************************************
120 REM * CLEARS ALL VARIABLES AND RESETS SYSTEM *
130 REM * TO A KNOWN STATE; CLEARS GPIB BUS      *
140 REM ******************************************
150 INIT
160 PRINT "ELEVATION (FEET): ";
170 INPUT E0
180 PRINT
190 PRINT
200 PRINT "PLEASE WAIT ABOUT 60 SECONDS - CALCULATIONS IN PROGRESS"
210 PRINT
220 PRINT
230 REM ******************************************************
240 REM * N IS NUMBER OF T,P PAIRS FOR WATER AT SATURATION; *
250 REM * M IS HIGHEST ORDER DIVIDED DIFFERENCE TO BE        *
260 REM * CALCULATED; AND N2 IS NUMBER OF ATM PRESSURE &     *
270 REM * ELEVATION PAIRS                                    *
280 REM ******************************************************
290 READ N,M,N2
300 REM ***************************************
310 REM * SEE VARIABLE TABLE FOR DEFINITIONS *
320 REM ***************************************
330 DIM T(N),P(N),A(N,M),Z5(N2),P5(N2),C(N2,M)
340 READ T,P,P5,D
350 REM **************************************
360 REM * GENERATES ATM PRESSURE ELEVATIONS *
370 REM * RANGE IS 0 - 12000 X 100 FEET     *
380 REM **************************************
390 Z5=1
400 CALL "INT",Z5,Z5
410 Z5=100*Z5
420 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::::
430 REM : COMPUTE ATM PRESSURE/ELEVATION DIVIDED-DIFFERENCES :
440 REM : SUBROUTINE DTABLE3 - MATRIX C                       :
450 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::::
460 GOSUB 900
470 REM ************************
480 REM * IF PROBLEM,THEN STOP *
490 REM ************************
500 IF T9=0 THEN 560
510 STOP
520 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::
530 REM : COMPUTE TEMPERATURE/PRESSURE DIVIDED-DIFFERENCES :
540 REM : SUBROUTINE DTABLE4 - MATRIX A                     :
550 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::
560 GOSUB 1170
570 REM **********************
580 REM * IF ERROR THEN STOP *
590 REM **********************
600 IF T9=0 THEN 660
610 STOP
620 REM :::::::::::::::::::::::::::::::::::::::::::
630 REM : CALCULATE ATM PRESSURE FOR ELEVATION E0 :
640 REM : SUBROUTINE Z_PRESS                      :
650 REM :::::::::::::::::::::::::::::::::::::::::::
```

```
660 GOSUB 1530
670 REM *************************
680 REM * IF PROBLEM, THEN STOP *
690 REM *************************
700 IF T9=0 THEN 760
710 STOP
720 REM ::::::::::::::::::::::::::::::::::::::::::::
730 REM : CALCULATE BOILING POINT FOR ATM PRESSURE :
740 REM : SUBROUTINE P_TEMP                        :
750 REM ::::::::::::::::::::::::::::::::::::::::::::
760 GOSUB 2030
770 IF T9=0 THEN 790
780 STOP
790 PRINT USING "FA,3D.2D,FA":"BOILING POINT = ";T0;" CELSIUS"
800 END
```

```
810 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
820 REM @                       ...SUBROUTINE DTABLE3...                  @
830 REM @ COMPUTES THE FINITE DIVIDED DIFFERENCES OF                      @
840 REM @ P5(1)...P5(N2) FOR ALL ORDERS M OR LESS AND STORES THEM IN     @
850 REM @ THE LOWER TRIANGULAR PORTION OF THE FIRST M COLUMNS OF THE     @
860 REM @ FIRST N2-1 ROWS OF THE MATRIX C. FOR INCONSISTENT ARGUMENTS,@
870 REM @ TRUBL, T9=1 ON EXIT.  OTHERWISE, T9=0 ON EXIT.                 @
880 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
890 REM ...CHECK FOR ARGUMENT CONSISTENCY...
900 IF M<N2 THEN 940
910 T9=1
920 RETURN
930 REM ...CALCULATE FIRST ORDER DIFFERENCES...
940 N1=N2-1
950 FOR I=1 TO N1
960 C(I,1)=(P5(I+1)-P5(I))/(Z5(I+1)-Z5(I))
970 NEXT I
980 IF M<=1 THEN 1060
990 REM ...CALCULATE HIGHER ORDER DIFFERENCES...
1000 FOR J=2 TO M
1010 FOR I=J TO N1
1020 I0=I+1-J
1030 C(I,J)=(C(I,J-1)-C(I-1,J-1))/(Z5(I+1)-Z5(I0))
1040 NEXT I
1050 NEXT J
1060 T9=0
1070 RETURN
1080 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
1090 REM @                       ...SUBROUTINE DTABLE4...                  @
1100 REM @ COMPUTE THE FINITE DIVIDED DIFFERENCES OF                       @
1110 REM @ T(1)...T(N) FOR ALL ORDERS M OR LESS AND STORES THEM IN        @
1120 REM @ THE LOWER TRIANGULAR PORTION OF THE FIRST M COLUMNS OF THE     @
1130 REM @ FIRST N-1 ROWS OF THE MATRIX A.  FOR INCONSISTENT ARGUMENTS,@
1140 REM @ TRUBL, T9=1 ON EXIT.  OTHERWISE, T9=0 ON EXIT.                 @
1150 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
1160 REM ...CHECK FOR ARGUMENT CONSISTENCY...
1170 IF M<N THEN 1210
1180 T9=1
1190 RETURN
1200 REM ...CALCULATE FIRST ORDER DIFFERENCES...
1210 N1=N-1
1220 FOR I=1 TO N1
1230 A(I,1)=(T(I+1)-T(I))/(P(I+1)-P(I))
1240 NEXT I
1250 IF M<=1 THEN 1330
1260 REM ...CALCULATE HIGHER ORDER DIFFERENCES...
1270 FOR J=2 TO M
1280 FOR I=J TO N1
1290 I0=I+1-J
1300 A(I,J)=(A(I,J-1)-A(I-1,J-1))/(P(I+1)-P(I0))
1310 NEXT I
1320 NEXT J
1330 T9=0
1340 RETURN
```

```
1350 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
1360 REM @                 ...SUBROUTINE Z_PRESS...                    @
1370 REM @ ASSUMES THAT Z5(1)...Z5(N2) ARE IN ASCENDING ORDER AND      @
1380 REM @ FIRST SCANS THE Z5 VECTOR TO DETERMINE WHICH ELEMENT IS     @
1390 REM @ NEAREST (.GE.) THE INTERPOLATION ARGUMENT, E0.              @
1400 REM @ THE D+1 BASE POINTS NEEDED FOR THE EVALUATION OF THE        @
1410 REM @ DIVIDED-DIFFERENCE POLYNOMIAL OF DEGREE D+1 ARE THEN        @
1420 REM @ CENTERED ABOUT THE CHOSEN ELEMENT WITH THE LARGEST HAVING   @
1430 REM @ THE SUBSCRIPT M1.  IT IS ASSUMED THAT THE FIRST M DIVIDED   @
1440 REM @ DIFFERENCES HAVE BEEN COMPUTED BY THE SUBROUTINE            @
1450 REM @ DTABLE3 AND ARE ALREADY PRESENT IN MATRIX C.                @
1460 REM @ M1 IS CHECKED TO INSURE THAT ALL REQUIRED BASE POINTS ARE   @
1470 REM @ AVAILABLE, & THE INTERPOLANT VALUE IS COMPUTED USING NESTED @
1480 REM @ POLYNOMIAL EVALUATION. THE INTERPOLANT IS RETURNED AS       @
1490 REM @ THE VALUE, P9, OF THE SUBROUTINE. FOR INCONSISTENT ARGUMENTS@
1500 REM @ TRUBL, T9=1 ON EXIT.  OTHERWISE, T9=0 ON EXIT.              @
1510 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
1520 REM ...CHECK FOR ARGUMENT CONSISTENCY...
1530 IF D<=M THEN 1580
1540 T9=1
1550 P9=0
1560 RETURN
1570 REM ...SEARCH Z5 VECTOR FOR ELEMENT .GE. TO E0...
1580 I=1
1590 IF I=N2 OR E0<=Z5(I) THEN 1660
1600 I=I+1
1610 GO TO 1590
1620 REM :::::::::::::::::::::::::::::::::::::::::::::::::
1630 REM : CALCULATE SUBSCRIPT OF LARGEST BASE POINT USED :
1640 REM : TO DETERMINE THE INTERPOLATING POLYNOMIAL      :
1650 REM :::::::::::::::::::::::::::::::::::::::::::::::::
1660 M1=I+D/2
1670 REM ...INSURE THAT ALL REQUIRED DIFFERENCES ARE IN TABLE...
1680 IF M1>D THEN 1700
1690 M1=D+1
1700 IF M1<=N2 THEN 1720
1710 M1=N2
1720 REM ...COMPUTE INTERPOLANT VALUE...
1730 Y5=C(M1-1,D)
1740 IF D<=1 THEN 1810
1750 D1=D-1
1760 FOR I=1 TO D1
1770 I1=M1-I
1780 I2=D-I
1790 Y5=Y5*(E0-Z5(I1))+C(I1-1,I2)
1800 NEXT I
1810 I1=M1-D
1820 T9=0
1830 P9=Y5*(E0-Z5(I1))+P5(I1)
1840 RETURN
```

```
1850 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
1860 REM @                     ...SUBROUTINE P_TEMP...                         @
1870 REM @ ASSUMES THAT P(1)...P(N) ARE IN ASCENDING ORDER AND                 @
1880 REM @ FIRST SCANS THE P VECTOR TO DETERMINE WHICH ELEMENT IS              @
1890 REM @ NEAREST (.GE.) THE INTERPOLATION ARGUMENT, P9.                      @
1900 REM @ THE D+1 BASE POINTS NEEDED FOR THE EVALUATION OF THE                @
1910 REM @ DIVIDED-DIFFERENCE POLYNOMIAL OF DEGREE D+1 ARE THEN                @
1920 REM @ CENTERED ABOUT THE CHOSEN ELEMENT WITH THE LARGEST HAVING           @
1930 REM @ THE SUBSCRIPT M1. IT IS ASSUMED THAT THE FIRST M DIVIDED            @
1940 REM @ DIFFERENCES HAVE BEEN COMPUTED BY THE SUBROUTINE                    @
1950 REM @ DTABLE4 AND ARE ALREADY PRESENT IN MATRIX A.                        @
1960 REM @ M1  IS CHECKED TO INSURE THAT ALL REQUIRED BASE POINTS ARE          @
1970 REM @ AVAILABLE, & THE INTERPOLANT VALUE IS COMPUTED USING NESTED         @
1980 REM @ POLYNOMIAL EVALUATION.  THE INTERPOLANT IS RETURNED AS              @
1990 REM @ THE VALUE, TO, OF THE SUBROUTINE. FOR INCONSISTENT ARGUMENTS@
2000 REM @ TRUBL, T9=1 ON EXIT.  OTHERWISE, T9=0 ON EXIT.                      @
2010 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
2020 REM ...CHECK FOR ARGUMENT CONSISTENCY...
2030 IF D<=M THEN 2080
2040 T9=1
2050 TO=0
2060 RETURN
2070 REM ...SEARCH P VECTOR FOR ELEMENT .GE. P9...
2080 I=1
2090 IF I=N OR P9<=P(I) THEN 2120
2100 I=I+1
2110 GO TO 2090
2120 M1=I+D/2
2130 REM ...INSURE THAT ALL REQUIRED DIFFERENCES ARE IN TABLE...
2140 IF M1>D THEN 2160
2150 M1=D+1
2160 IF M1<=N THEN 2190
2170 M1=N
2180 REM ...COMPUTE INTERPOLANT VALUE...
2190 Y5=A(M1-1,D)
2200 IF D<=1 THEN 2270
2210 D1=D-1
2220 FOR I=1 TO D1
2230 I1=M1-I
2240 I2=D-I
2250 Y5=Y5*(P9-P(I1))+A(I1-1,I2)
2260 NEXT I
2270 I1=M1-D
2280 T9=0
2290 REM ********************************
2300 REM * ROUND TO NEAREST 0.01 DEGREES *
2310 REM ********************************
2320 TO=INT(100*(Y5*(P9-P(I1))+T(I1))+0.5)/100
2330 RETURN
```

```
2340 REM ...WATER AT SATURATION: KEENAN, KEYES, HILL, & MOORE [1969]...
2350 DATA 8,6,121
2360 REM **************************
2370 REM * TEMPERATURES - CELSIUS *
2380 REM **************************
2390 DATA 50,60,70,80,90,100,110,120
2400 REM ******************
2410 REM * PRESSURE - BARS *
2420 REM ******************
2430 DATA 0.12349,0.1994,0.3119,0.4739,0.7014,1.0135,1.4327,1.9853
2440 REM ***************************************
2450 REM * U.S. STD ATM, 1976: 0-12000 x 100 FT *
2460 REM * PRESSURE - BARS                      *
2470 REM ***************************************
2480 DATA 1.01325,1.0095,1.0059,1.0023,0.99868,0.99507,0.99147,0.98788
2490 DATA 0.98429,0.98072,0.97716,0.97361,0.97007,0.96654,0.96303
2500 DATA 0.95952,0.95602,0.95253,0.94905,0.94559,0.94213,0.93868
2510 DATA 0.93525,0.93182,0.92841,0.925,0.92161,0.91822,0.91485
2520 DATA 0.91148,0.90813,0.90478,0.90145,0.89812,0.89481,0.8915
2530 DATA 0.88821,0.88492,0.88165,0.87838,0.87513,0.87188,0.86864
2540 DATA 0.86542,0.8622,0.85899,0.8558,0.85261,0.84943,0.84626
2550 DATA 0.84311,0.83996,0.83682,0.83369,0.83057,0.82746,0.82436
2560 DATA 0.82126,0.81818,0.81511,0.81204,0.80899,0.80594,0.80291
2570 DATA 0.79988,0.79687,0.79386,0.79086,0.78787,0.78489,0.78192
2580 DATA 0.77896,0.776,0.77306,0.77013,0.7672,0.76428,0.76138
2590 DATA 0.75848,0.75559,0.75271,0.74984,0.74697,0.74412,0.74127
2600 DATA 0.73844,0.73561,0.73279,0.72998,0.72718,0.72439,0.7216
2610 DATA 0.71883,0.71606,0.71331,0.71056,0.70782,0.70509,0.70236
2620 DATA 0.69965,0.69694,0.69424,0.69155,0.68887,0.6862,0.68354
2630 DATA 0.68088,0.67824,0.6756,0.67297,0.67034,0.66773,0.66513
2640 DATA 0.66253,0.65994,0.65736,0.65479,0.65222,0.64967,0.64712
2650 DATA 0.64458
2660 REM **************************************
2670 REM * DEGREE OF INTERPOLATING POLYNOMIAL *
2680 REM **************************************
2690 DATA 6
```

APPENDIX II

Boiling-Point Depth Curve Program BPD for
Tektronix 4051 Graphics System Computer

```
1 REM ...BOILING POINT DEPTH CURVE CALCULATION - 5/2/86...
2 END
4 REM ***********************************
5 REM * USER-DEFINABLE KEY NO. 1 - START *
6 REM ***********************************
7 PAGE
8 GO TO 100
100 REM ...READ DATA AND PRINT...
110 REM ****************************************
120 REM * CLEARS ALL VARIABLES AND RESETS SYSTEM *
130 REM * TO A KNOWN STATE; CLEARS GPIB BUS       *
140 REM ****************************************
150 INIT
160 REM ****************************************
170 REM * RESETS POINTER TO FIRST DATA STATEMENT *
180 REM ****************************************
190 RESTORE
200 REM ...U0,U1 - PRIMARY & SECONDARY GPIB PRINTER ADDRESSES...
210 U0=6
220 REM **********************************
230 REM * 32 => SECONDARY ADDRESS IGNORED *
240 REM **********************************
250 U1=32
260 REM *****************************
270 REM * HEADING FOR PRINTER OUTPUT *
280 REM *****************************
290 H$="BOILING POINT DEPTH CURVE FOR ""PURE"" WATER"
300 PRINT "ELEVATION, BOILING POINT AND TEMPERATURE INCREMENT: ";
310 INPUT E0,T0,D0
320 PRINT
330 PRINT
340 PRINT "PLEASE WAIT - DIVIDED-DIFFERENCE TABLES ARE BEING CALCULATED"
350 PRINT
360 PRINT
370 REM ***********************************
380 REM * ACCELERATION OF GRAVITY COMBINED *
390 REM * WITH CONSTANT TO ADJUST UNITS    *
400 REM ***********************************
410 G=980.7*1.0E-4
420 REM ***********************************
430 REM * ROUND DEPTH TO NEAREST 0.01 FEET *
440 REM ***********************************
450 M5=100
460 M6=3.2808*M5
470 Z=0
480 Z2=0
490 REM ****************************************************
500 REM * N IS NUMBER OF T,P PAIRS FOR WATER AT SATURATION; *
510 REM * M IS HIGHEST ORDER DIVIDED DIFFERENCE TO BE       *
520 REM * CALCULATED.                                       *
530 REM ****************************************************
540 READ N,M
550 REM *************************************
560 REM * SEE VARIABLE TABLE FOR DEFINITIONS *
570 REM *************************************
580 DIM T(N),P(N),V(N),A(N,M),B(N,M),Q$(1),F$(300)
590 Q$=""
600 READ T,P,V,D
610 REM *********************
620 REM * SAVE BOILING POINT *
630 REM *********************
640 T5=T0
```

```
650 REM ::::::::::::::::::::::::::::::::::::::::::::::::::::
660 REM : COMPUTE PRESSURE/TEMPERATURE DIVIDED DIFFERENCES :
670 REM : SUBROUTINE DTABLE1 - MATRIX A                    :
680 REM ::::::::::::::::::::::::::::::::::::::::::::::::::::
690 GOSUB 2780
700 REM **************************
710 REM * IF PROBLEMS, THEN STOP *
720 REM **************************
730 IF T9=0 THEN 790
740 STOP
750 REM ::::::::::::::::::::::::::::::::::::::::::::::::::::::::
760 REM : COMPUTE SPECIFIC VOLUME/PRESSURE DIVIDED-DIFFERENCES :
770 REM : SUBROUTINE DTABLE2 - MATRIX B                        :
780 REM ::::::::::::::::::::::::::::::::::::::::::::::::::::::::
790 GOSUB 3050
800 REM *************************
810 REM * IF PROBLEM, THEN STOP *
820 REM *************************
830 IF T9=0 THEN 890
840 STOP
850 REM **************************************************
860 REM * FORMAT FOR PRINTING FIRST LINE ONLY OF OUTPUT, *
870 REM * I.E., THE BOILING POINT DATA                   *
880 REM **************************************************
890 A$="10X,3D.2D,2X,4D.2D,2X,5D.2D,2X,3D.2D,2(2X,D.4D)"
900 PRINT "OUTPUT TO DISK? - Y/N: ";
910 INPUT Q$
920 IF Q$<>"Y" THEN 1350
930 REM ******************************************
940 REM * NO IS THE TOTAL NUMBER OF DATA RECORDS *
950 REM ******************************************
960 NO=374-INT(TO)+2
970 PRINT "FILENAME: ";
980 INPUT O$
990 REM *************************
1000 REM * DOES DISK FILE EXIST? *
1010 REM *************************
1020 CALL "FILE",0,O$,F$
1030 REM *****************************
1040 REM * LENGTH > 0 => FILE EXISTS *
1050 REM *****************************
1060 IF LEN(F$)=0 THEN 1230
1070 REM **********************
1080 REM * FILE EXISTS, KEEP? *
1090 REM **********************
1100 PRINT "FILE EXISTS - DELETE? - Y/N: ";
1110 INPUT Q$
1120 REM **********************************
1130 REM * IF KEEP, THEN GET NEW FILENAME *
1140 REM **********************************
1150 IF Q$<>"Y" THEN 970
1160 REM ****************************
1170 REM * NO, DELETE EXISTING FILE *
1180 REM ****************************
1190 KILL O$
1200 REM ******************************
1210 REM * CREATE NEW SEQUENTIAL FILE *
1220 REM ******************************
1230 CREATE O$;2*NO*10+100,0
1240 REM ***********************
1250 REM * OPEN FILE FOR WRITE *
1260 REM ***********************
1270 OPEN O$;8,"F",F$
```

```
1280 REM ***********************************************
1290 REM * WRITE (IN BINARY) NUMBER OF RECORDS TO FILE *
1300 REM ***********************************************
1310 WRITE #8:NO
1320 REM ******************************
1330 REM * PRINT HEADINGS ON PRINTER *
1340 REM ******************************
1350 GOSUB 4470
1360 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
1370 REM : FOR BOILING POINT, CALCULATE PRESSURE & SPECIFIC VOLUME :
1380 REM : SUBROUTINE FNEWPV - SAVE IN P2 & V2                     :
1390 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
1400 GOSUB 3410
1410 P2=P9
1420 V2=V9
1430 REM ******************************************
1440 REM * PRINT RESULTS FOR BOILING POINT - Z=0 *
1450 REM ******************************************
1460 PRINT @U0,U1: USING A$:T0,Z,Z2,P2,V2,1/V2
1470 REM **************************
1480 REM * INCREMENT LINE COUNTER *
1490 REM **************************
1500 K=K+1
1510 REM ******************************
1520 REM * REDEFINE FORMAT STATEMENT *
1530 REM * TEMPERATURES ARE INTEGERS *
1540 REM ******************************
1550 A$="10X,3D,5X,4D.2D,2X,5D.2D,2X,3D.2D,2(2X,D.4D)"
1560 REM ***********************************************
1570 REM * IF FILENAME NULL, THEN DO NOT WRITE TO DISK *
1580 REM ***********************************************
1590 IF O$="" THEN 1730
1600 REM ***************_***********
1610 REM * OTHERWISE, WRITE TO DISK *
1620 REM ****************************
1630 WRITE #8:Z2,T0
1640 REM *********************************************
1650 REM * FOR BOILING POINT, P2 & V2 HAVE BEEN      *
1660 REM * CALCULATED ABOVE - SKIP SUBROUTINE FNEWPV *
1670 REM *********************************************
1680 REM *******************************
1690 REM * RE-ENTRY POINT FOR LOOP FOR *
1700 REM * SUBSEQUENT TEMPERATURES     *
1710 REM * SAVE FIRST P & V PAIR       *
1720 REM *******************************
1730 P0=P2
1740 V0=V2
1750 REM ********************
1760 REM * NEXT TEMPERATURE *
1770 REM ********************
1780 T0=INT(T0)+D0
1790 REM ********************************************
1800 REM * LAST TEMPERATURE? - I.E., CRITICAL POINT *
1810 REM ********************************************
1820 IF T0<=T(N) THEN 1900
1830 REM ***************************************
1840 REM * NO, EXCEEDS - SET TO CRITICAL POINT *
1850 REM ***************************************
1860 T0=T(N)
1870 REM :::::::::::::::::::
1880 REM : CALCULATE P & V :
1890 REM :::::::::::::::::::
```

```
1900 GOSUB 3410
1910 REM **************
1920 REM * SAVE P & V *
1930 REM **************
1940 P2=P9
1950 V2=V9
1960 REM ::::::::::::::::::::::::::
1970 REM : CALCULATE MID-PRESSURE :
1980 REM ::::::::::::::::::::::::::
1990 P9=(P0+P2)/2
2000 REM :::::::::::::::::::::::::::::
2010 REM : CALCULATE SPECIFIC VOLUME :
2020 REM :::::::::::::::::::::::::::::
2030 GOSUB 3730
2040 REM **************
2050 REM * SAVE P & V *
2060 REM **************
2070 P1=P9
2080 V1=V9
2090 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2100 REM : CALCULATE P_DIFFERENCE/2 - FOR USE BY SIMPSONS RULE INTEGRAL:
2110 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2120 D5=(P2-P0)/2
2130 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::::
2140 REM : CALCULATE NEW DEPTH USING SIMPSONS RULE INTEGRATION :
2150 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::::
2160 GOSUB 4040
2170 REM ************************************
2180 REM * LAST TEMPERATURE? - NO, CONTINUE *
2190 REM ************************************
2200 IF T0<>T(N) THEN 2280
2210 REM ************************************************
2220 REM * YES, LAST TEMPERATURE - CHANGE OUTPUT FORMAT *
2230 REM ************************************************
2240 A$="10X,3D.3D,X,4D.2D,2X,5D.2D,2X,3D.2D,2(2X,D.4D)"
2250 REM ************************
2260 REM * PRINT NEW DEPTH DATA *
2270 REM ************************
2280 PRINT @U0,U1: USING A$:T0,Z,Z2,P2,V2,1/V2
2290 REM ********************************************
2300 REM * FILENAME = NULL? => DO NOT WRITE TO DISK *
2310 REM ********************************************
2320 IF O$="" THEN 2400
2330 REM *********************************
2340 REM * OTHERWISE, WRITE DATA TO DISK *
2350 REM *********************************
2360 WRITE #8:Z2,T0
2370 REM ******************************
2380 REM * INCREMENT PRINT LINE COUNT *
2390 REM ******************************
2400 K=K+1
2410 REM *******************************
2420 REM * HAVE 50 LINES BEEN PRINTED? *
2430 REM *******************************
2440 IF K<50 THEN 2530
2450 REM **********************************
2460 REM * YES, PAGE & PRINT NEW HEADINGS *
2470 REM **********************************
2480 GOSUB 4460
2490 REM **************************************
2500 REM * HAS LAST TEMPERATURE BEEN PRINTED? *
2510 REM * NO, CONTINUE WITH NEXT TEMPERATURE *
2520 REM **************************************
```

```
2520 REM **************************************
2530 IF TO<T(N) THEN 1730
2540 REM **************************************
2550 REM * YES, FINISH UP                     *
2560 REM **************************************
2570 REM ****************
2580 REM * PAGE PRINTER *
2590 REM ****************
2600 PRINT @U0,U1: USING "P":
2610 REM ************************************************
2620 REM * CLOSE DISK FILE - NO EFFECT IF DISK NOT USED *
2630 REM ************************************************
2640 CLOSE 8
2650 REM ######################
2660 REM ### END OF PROGRAM ###
2670 REM ######################
2680 END
```

```
2690 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
2700 REM @                  SUBROUTINE DTABLE1                         @
2710 REM @ DTABLE COMPUTES THE FINITE DIVIDED DIFFERENCES OF           @
2720 REM @ P(1)...P(N) FOR ALL ORDERS M OR LESS AND STORES THEM IN     @
2730 REM @ THE LOWER TRIANGULAR PORTION OF THE FIRST M COLUMNS OF THE  @
2740 REM @ FIRST N-1 ROWS OF THE MATRIX A. FOR INCONSISTENT ARGUMENTS, @
2750 REM @ TRUBL, T9 = 1 ON EXIT.  OTHERWISE T9 = 0 ON EXIT.           @
2760 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
2770 REM ...CHECK FOR ARGUMENT CONSISTENCY...
2780 IF M<N THEN 2820
2790 T9=1
2800 RETURN
2810 REM ...CALCULATE FIRST ORDER DIFFERENCES...
2820 N1=N-1
2830 FOR I=1 TO N1
2840 A(I,1)=(P(I+1)-P(I))/(T(I+1)-T(I))
2850 NEXT I
2860 IF M<=1 THEN 2940
2870 REM ...CALCULATE HIGHER ORDER DIFFERENCES...
2880 FOR J=2 TO M
2890 FOR I=J TO N1
2900 I0=I+1-J
2910 A(I,J)=(A(I,J-1)-A(I-1,J-1))/(T(I+1)-T(I0))
2920 NEXT I
2930 NEXT J
2940 T9=0
2950 RETURN
2960 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
2970 REM @                  SUBROUTINE DTABLE2                         @
2980 REM @ DTABLE2 COMPUTES THE FINITE DIVIDED DIFFERENCES OF          @
2990 REM @ V(1)...V(N) FOR ALL ORDERS M OR LESS AND STORES THEM IN     @
3000 REM @ THE LOWER TRIANGULAR PORTION OF THE FIRST M COLUMNS OF THE  @
3010 REM @ FIRST N-1 ROWS OF THE MATRIX B. FOR INCONSISTENT ARGUMENTS, @
3020 REM @ TRUBL, T9 = 1 ON EXIT.  OTHERWISE T9 = 0 ON EXIT.           @
3030 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
3040 REM ...CHECK FOR ARGUMENT CONSISTENCY...
3050 IF M<N THEN 3090
3060 T9=1
3070 RETURN
3080 REM ...CALCULATE FIRST ORDER DIFFERENCES...
3090 N1=N-1
3100 FOR I=1 TO N1
3110 B(I,1)=(V(I+1)-V(I))/(P(I+1)-P(I))
3120 NEXT I
3130 IF M<=1 THEN 3210
3140 REM ...CALCULATE HIGHER ORDER DIFFERENCES...
3150 FOR J=2 TO M
3160 FOR I=J TO N1
3170 I0=I+1-J
3180 B(I,J)=(B(I,J-1)-B(I-1,J-1))/(P(I+1)-P(I0))
3190 NEXT I
3200 NEXT J
3210 T9=0
3220 RETURN
```

```
3230 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
3240 REM @                 ...SUBROUTINE FNEWPV...                          @
3250 REM @ FNEWPV ASSUMES THAT T(1)...T(N) ARE IN ASCENDING ORDER AND  @
3260 REM @ FIRST SCANS THE T VECTOR TO DETERMINE WHICH ELEMENT IS      @
3270 REM @ NEAREST (.GE.) THE INTERPOLATION ARGUMENT, TO.              @
3280 REM @ THE D+1 BASE POINTS NEEDED FOR THE EVALUATION OF THE        @
3290 REM @ DIVIDED-DIFFERENCE POLYNOMIAL OF DEGREE D+1 ARE THEN        @
3300 REM @ CENTERED ABOUT THE CHOSEN ELEMENT WITH THE LARGEST HAVING   @
3310 REM @ THE SUBSCRIPT M1.  IT IS ASSUMED THAT THE FIRST M DIVIDED   @
3320 REM @ DIFFERENCES HAVE BEEN COMPUTED BY THE SUBROUTINES           @
3330 REM @ DTABLE1 & 2 AND ARE ALREADY PRESENT IN MATRIX A & B.        @
3340 REM @ M1  IS CHECKED TO INSURE THAT ALL REQUIRED BASE POINTS ARE  @
3350 REM @ AVAILABLE, & THE INTERPOLANT VALUES ARE COMPUTED USING      @
3360 REM @ NESTED POLYNOMIAL EVALUATION. THE INTERPOLANT IS RETURNED   @
3370 REM @ AS THE VALUES, P9 & V9, OF THE SUBROUTINE. FOR INCONSISTENT @
3380 REM @ ARGUMENTS, TRUBL, T9=1 ON EXIT.  OTHERWISE, T9=0 ON EXIT.   @
3390 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
3400 REM ...CHECK FOR ARGUMENT CONSISTENCY...
3410 IF D<=M THEN 3510
3420 T9=1
3430 P9=0
3440 RETURN
3450 REM ...SEARCH T VECTOR FOR ELEMENT .GE. TO TO
3460 REM ...LINES 3400-3420 CAN BE REPLACED BY 3360-3390
3470 REM I=1
3480 REM IF I=N OR TO<=T(I) THEN 3430
3490 REM I=I+1
3500 REM GO TO 3400
3510 CALL "CROSS",T,TO,I
3520 IF I=INT(I) THEN 3540
3530 I=INT(I)+1
3540 M1=I+D/2
3550 REM ...INSURE THAT ALL REQUIRED DIFFERENCES ARE IN TABLE...
3560 IF M1>D THEN 3580
3570 M1=D+1
3580 IF M1<=N THEN 3610
3590 M1=N
3600 REM ...COMPUTE INTERPOLANT VALUE...
3610 Y5=A(M1-1,D)
3620 IF D<=1 THEN 3690
3630 D1=D-1
3640 FOR I=1 TO D1
3650 I1=M1-I
3660 I2=D-I
3670 Y5=Y5*(TO-T(I1))+A(I1-1,I2)
3680 NEXT I
3690 I1=M1-D
3700 T9=0
3710 P9=Y5*(TO-T(I1))+P(I1)
3720 REM ...CHECK FOR ARGUMENT INCONSISTENCY...
3730 IF D<=M THEN 3780
3740 T9=1
3750 V9=0
3760 RETURN
3770 REM ...SEARCH P VECTOR FOR ELEMENT .GE. TO P9
3780 I=1
3790 IF I=N OR P9<=P(I) THEN 3820
3800 I=I+1
3810 GO TO 3790
3820 M1=I+D/2
3830 REM ...INSURE THAT ALL REQUIRED DIFFERENCES ARE IN TABLE...
3840 IF M1>D THEN 3860
3850 M1=D+1
```

```
3860 IF M1<=N THEN 3890
3870 M1=N
3880 REM ...COMPUTE INTERPOLANT VALUE...
3890 Y5=B(M1-1,D)
3900 IF D<=1 THEN 3970
3910 D1=D-1
3920 FOR I=1 TO D1
3930 I1=M1-I
3940 I2=D-I
3950 Y5=Y5*(P9-P(I1))+B(I1-1,I2)
3960 NEXT I
3970 I1=M1-D
3980 T9=0
3990 V9=Y5*(P9-P(I1))+V(I1)
4000 RETURN
```

```
4010 REM ::::::::::::::::::::::::::::::::::::::
4020 REM : CALCULATE NEW Z USING SIMPSONS RULE :
4030 REM ::::::::::::::::::::::::::::::::::::::
4040 Y=D5*(V0+4*V1+V2)/3
4050 Z=Z+Y/G
4060 Z=INT(M5*Z+0.5)/M5
4070 Z2=INT(M6*Z+0.5)/M5
4080 RETURN
```

```
4090 REM ...WATER AT SATURATION:KEENAN, KEYES, HILL & MOORE [1969]...
4100 DATA 67,6
4110 REM **************************
4120 REM * TEMPERATURES - CELSIUS *
4130 REM **************************
4140 DATA 80,85,90,95,100,105,110,115,120,125,130,135,140,145,150
4150 DATA 155,160,165,170,175,180,185,190,195,200,205,210,215,220
4160 DATA 225,230,235,240,245,250,255,260,265,270,275,280,285,290
4170 DATA 295,300,305,310,315,320,324,330,334,340,344,350,354,360
4180 DATA 362,364,366,368,370,371,372,373,374,374.136
4190 REM *******************
4200 REM * PRESSURE - BARS *
4210 REM *******************
4220 DATA 0.4739,0.5783,0.7014,0.8455,1.0135,1.2082,1.4327,1.6906
4230 DATA 1.9853,2.321,2.701,3.13,3.613,4.154,4.758,5.431,6.178
4240 DATA 7.005,7.917,8.92,10.021,11.227,12.544,13.978,15.538
4250 DATA 17.23,19.062,21.04,23.18,25.48,27.95,30.6,33.44,36.48
4260 DATA 39.73,43.19,46.88,50.81,54.99,59.42,64.12,69.09,74.36
4270 DATA 79.93,85.81,92.02,98.56,105.47,112.74,118.83,128.45
4280 DATA 135.2,145.86,153.33,165.13,173.42,186.51,191.06,195.71
4290 DATA 200.46,205.31,210.3,212.8,215.3,217.9,220.5,220.9
4300 REM ****************************
4310 REM * SPECIFIC VOLUME - CC/GM *
4320 REM ****************************
4330 DATA 1.0291,1.0325,1.036,1.0397,1.0435,1.0475,1.0516,1.0559
4340 DATA 1.0603,1.0649,1.0697,1.0746,1.0797,1.085,1.0905,1.0961
4350 DATA 1.102,1.108,1.1143,1.1207,1.1274,1.1343,1.1414,1.1488
4360 DATA 1.1565,1.1644,1.1726,1.1812,1.19,1.1992,1.2088,1.2187
4370 DATA 1.2291,1.2399,1.2512,1.2631,1.2755,1.2886,1.3023,1.3168
4380 DATA 1.3321,1.3483,1.3656,1.3839,1.4036,1.4247,1.4474,1.472
4390 DATA 1.4988,1.5221,1.5607,1.5893,1.6379,1.675,1.7403,1.7927
4400 DATA 1.8925,1.9345,1.9833,2.0416,2.1145,2.213,2.28,2.369,2.509
4410 DATA 2.88,3.155
4420 REM ***************************************
4430 REM * DEGREE OF INTERPOLATING POLYNOMIAL *
4440 REM ***************************************
4450 DATA 6
```

```
4460 REM ...HEADINGS...
4470 PRINT @U0,U1: USING 4510:H$
4480 PRI @U0,U1: USI 4520:"ELEVATION = ";E0;" FT - BOILING POINT = ";T5
4490 PRINT @U0,U1: USING 4530:"T","Z","Z","P","V","D"
4500 PRI @U0,U1: USI 4540:"(C)","(M)","(FT)","(BARS)","(CC/G)","(G/CC)"
4510 IMAGE P,/L,10X,FA
4520 IMAGE 10X,FA,5D,FA,3D.2D," C",/L
4530 IMAGE 11X,A,10X,A,9X,A,7X,A,2(7X,A),S
4540 IMAGE /10X,3A,8X,3A,7X,4A,2X,6A,2(2X,6A),/
4550 REM **********************
4560 REM * RESET LINE COUNTER *
4570 REM **********************
4580 K=0
4590 RETURN
```

APPENDIX III

Boiling-Point Calculation Program BPE for
NBI 4100 (IBM PC Compatible) Computer

```
1 REM ...BOILING POINT CALCULATION - 5/2/86...
2 REM ...MODIFIED FROM TEKTRONIX 4051 BASIC 5/6/86...
100 REM ...INITIALIZE AND READ DATA...
110 REM ************************
120 REM * CLEARS ALL VARIABLES *
130 REM ************************
140 CLEAR
150 CLS
160 INPUT "ELEVATION (FEET): ",E0
170 PRINT: PRINT
180 PRINT "PLEASE WAIT - CALCULATIONS IN PROGRESS"
190 PRINT: PRINT
200 REM ****************************************************
210 REM * N IS NUMBER OF T,P PAIRS FOR WATER AT SATURATION *
220 REM * M IS HIGHEST ORDER DIVIDED DIFFERENCE TO BE      *
230 REM * CALCULATED; AND N2 IS NUMBER OF ATM PRESSURE AND *
240 REM * ELEVATION PAIRS                                  *
250 REM ****************************************************
260 READ N,M,N2
270 REM ****************************************
280 REM * SEE VARIABLE TABLE FOR DEFINITIONS *
290 REM ****************************************
300 DIM T(N),P(N),A(N,M),Z5(N2),P5(N2),C(N2,M)
310 FOR I=1 TO N: READ T(I): NEXT I
320 FOR I=1 TO N: READ P(I): NEXT I
330 FOR I=1 TO N2: READ P5(I): NEXT I
340 READ D
350 REM ***************************************
360 REM * GENERATES ATM-PRESSURE ELEVATIONS *
370 REM * RANGE IS 0 - 12000 x 100 FEET     *
380 REM ***************************************
390 FOR I=1 TO N2
400 Z5(I)=100*(I-1)
410 NEXT I
420 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::
430 REM : COMPUTE ATM PRESSURE/ELEVATION DIVIDED-DIFFERENCES :
440 REM : SUBROUTINE DTABLE3 - MATRIX C                       :
450 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::
460 GOSUB 910
470 REM **************************
480 REM * IF PROBLEM, THEN STOP *
490 REM **************************
500 IF T9=1 THEN STOP
510 REM ::::::::::::::::::::::::::::::::::::::::::::::::::
520 REM : COMPUTE TEMPERATURE/PRESSURE DIVIDED-DIFFERENCES :
530 REM : SUBROUTINE DTABLE4 - MATRIX A                    :
540 REM ::::::::::::::::::::::::::::::::::::::::::::::::::
550 GOSUB 1180
560 REM ************************
570 REM * IF ERROR, THEN STOP *
580 REM ************************
590 IF T9=1 THEN STOP
600 REM :::::::::::::::::::::::::::::::::::::::::::::
610 REM : CALCULATE ATM PRESSURE FOR ELEVATION E0 :
620 REM : SUBROUTINE Z_PRESS                        :
630 REM :::::::::::::::::::::::::::::::::::::::::::::
640 GOSUB 1540
```

```
650 REM *************************
660 REM * IF PROBLEM, THEN STOP *
670 REM *************************
680 IF T9=1 THEN STOP
690 REM ::::::::::::::::::::::::::::::::::::::::::::
700 REM : CALCULATE BOILING POINT FOR ATM PRESSURE :
710 REM : SUBROUTINE P_TEMP                        :
720 REM ::::::::::::::::::::::::::::::::::::::::::::
730 GOSUB 2020
740 IF T9=1 THEN STOP
750 PRINT USING "&###.##&";"BOILING POINT = ";TO;" CELSIUS"
760 REM
770 REM ######################
780 REM ### END OF PROGRAM ###
790 REM ######################
800 END
810 REM
```

```
820 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
830 REM @                        ...SUBROUTINE DTABLE3...                @
840 REM @ COMPUTES THE FINITE DIVIDED DIFFERENCES OF                     @
850 REM @ P5(1)...P5(N2) FOR ALL ORDERS M OR LESS AND STORES THEM IN     @
860 REM @ THE LOWER TRIANGULAR PORTION OF THE FIRST M COLUMNMS OF THE    @
870 REM @ FIRST N2-1 ROWS OF THE MATRIX C. FOR INCONSISTENT ARGUMENTS,   @
880 REM @ TRUBL, T9 = 1 ON EXIT.  OTHERWISE, T9 = 0 ON EXIT.             @
890 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
900 REM ...CHECK FOR ARGUMENT CONSISTENCY...
910 IF M<N2 THEN 950
920 T9=1
930 RETURN
940 REM ...CALCULATE FIRST ORDER DIFFERENCES...
950 N1=N2-1
960 FOR I=1 TO N1
970 C(I,1)=(P5(I+1)-P5(I))/(Z5(I+1)-Z5(I))
980 NEXT I
990 IF M<=1 THEN 1070
1000 REM ...CALCULATE HIGHER ORDER DIFFERENCES...
1010 FOR J=2 TO M
1020 FOR I=J TO N1
1030 I0=I+1-J
1040 C(I,J)=(C(I,J-1)-C(I-1,J-1))/(Z5(I+1)-Z5(I0))
1050 NEXT I
1060 NEXT J
1070 T9=0
1080 RETURN
1090 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
1100 REM @                         ...SUBROUTINE DTABLE4...                @
1110 REM @ COMPUTES THE FINITE DIVIDED DIFFERENCES OF                      @
1120 REM @ T(1)...T(N) FOR ALL ORDERS M OR LESS AND STORES THEM IN         @
1130 REM @ THE LOWER TRIANGULAR PORTION OF THE FIRST M COLUMNS OF THE      @
1140 REM @ FIRST N-1 ROWS OF THE MATRIX A. FOR INCONSISTENT ARGUMENTS,     @
1150 REM @ TRUBL, T9 = 1 ON EXIT.  OTHERWISE, T9 = 0 ON EXIT.              @
1160 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
1170 REM ...CHECK FOR ARGUMENT CONSISTENCY...
1180 IF M<N THEN 1220
1190 T9=1
1200 RETURN
1210 REM ...CALCULATE FIRST ORDER DIFFERENCES...
1220 N1=N-1
1230 FOR I=1 TO N1
1240 A(I,1)=(T(I+1)-T(I))/(P(I+1)-P(I))
1250 NEXT I
1260 IF M<=1 THEN 1340
1270 REM ...CALCULATE HIGHER ORDER DIFFERENCES...
1280 FOR J=2 TO M
1290 FOR I=J TO N1
1300 I0=I+1-J
1310 A(I,J)=(A(I,J-1)-A(I-1,J-1))/(P(I+1)-P(I0))
1320 NEXT I
1330 NEXT J
1340 T9=0
1350 RETURN
```

```
1360 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
1370 REM @                     ...SUBROUTINE Z_PRESS...                  @
1380 REM @ ASSUMES THAT Z5(1)...Z5(N2) ARE IN ASCENDING ORDER AND        @
1390 REM @ FIRST SCANS THE Z5 VECTOR TO DETERMINE WHICH ELEMENT IS       @
1400 REM @ NEAREST (.GE.) THE INTERPOLATION ARGUMENT, EO.                @
1410 REM @ THE D+1 BASE POINTS NEEDED FOR THE EVALUATION OF THE          @
1420 REM @ DIVIDED-DIFFERENCE POLYNOMIAL OF DEGREE D+1 ARE THEN          @
1430 REM @ CENTERED ABOUT THE CHOSEN ELEMENT WITH THE LARGEST HAVING     @
1440 REM @ THE SUBSCRIPT M1.  IT IS ASSUMED THAT THE FIRST M DIVIDED     @
1450 REM @ DIFFERENCES HAVE BEEN COMPUTED BY THE SUBROUTINE              @
1460 REM @ DTABLE3 AND ARE ALREADY PRESENT IN MATRIX C.                  @
1470 REM @ M1 IS CHECKED TO INSURE THAT ALL REQUIRED BASE POINTS ARE     @
1480 REM @ AVAILABLE, & THE INTERPOLANT VALUE IS COMPUTED USING NESTED   @
1490 REM @ POLYNOMIAL EVALUATION. THE INTERPOLANT IS RETURNED AS         @
1500 REM @ THE VALUE, P9, OF THE SUBROUTINE. FOR INCONSISTENT ARGUMENTS @
1510 REM @ TRUBL, T9 = 1 ON EXIT.  OTHERWISE, T9 = 0 ON EXIT.            @
1520 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
1530 REM ...CHECK FOR ARGUMENT CONSISTENCY...
1540 IF D<=M THEN 1590
1550 T9=1
1560 P9=0
1570 RETURN
1580 REM ...SEARCH Z5 VECTOR FOR ELEMENT .GE. TO EO...
1590 I=1
1600 IF I=N2 OR EO<=Z5(I) THEN 1670
1610 I=I+1
1620 GOTO 1600
1630 REM ::::::::::::::::::::::::::::::::::::::::::::::::::::
1640 REM : CALCULATE SUBSCRIPT OF LARGEST BASE POINT USED :
1650 REM : TO DETERMINE THE INTERPOLATING POLYNOMIAL      :
1660 REM ::::::::::::::::::::::::::::::::::::::::::::::::::::
1670 M1=I+D/2
1680 REM ...INSURE THAT ALL REQUIRED DIFFERENCES ARE IN TABLE...
1690 IF M1<=D THEN M1=D+1
1700 IF M1>N2 THEN M1=N2
1710 REM ...COMPUTE INTERPOLANT VALUE...
1720 Y5=C(M1-1,D)
1730 IF D<=1 THEN 1800
1740 D1=D-1
1750 FOR I=1 TO D1
1760 I1=M1-I
1770 I2=D-I
1780 Y5=Y5*(EO-Z5(I1))+C(I1-1,I2)
1790 NEXT I
1800 I1=M1-D
1810 T9=0
1820 P9=Y5*(EO-Z5(I1))+P5(I1)
1830 RETURN
```

```
1840 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
1850 REM @                         ...SUBROUTINE P_TEMP...                    (
1860 REM @ ASSUMES THAT P(1)...P(N) ARE IN ASCENDING ORDER AND                (
1870 REM @ FIRST SCANS THE P VECTOR TO DETERMINE WHICH ELEMENT IS             (
1880 REM @ NEAREST (.GE.) THE INTERPOLATION ARGUMENT, P9.                     @
1890 REM @ THE D+1 BASE POINTS NEEDED FOR THE EVALUATION OF THE               (
1900 REM @ DIVIDED-DIFFERENCE POLYNOMIAL OF DEGREE D+1 ARE THEN               @
1910 REM @ CENTERED ABOUT THE CHOSEN ELEMENT WITH THE LARGEST HAVING          (
1920 REM @ THE SUBSCRIPT M1.  IT IS ASSUMED THAT THE FIRST M DIVIDED          @
1930 REM @ DIFFERENCES HAVE BEEN COMPUTED BY THE SUBROUTINE                   (
1940 REM @ DTABLE4 AND ARE ALREADY PRESENT IN MATRIX A.                       (
1950 REM @ M1 IS CHECKED TO INSURE THAT ALL REQUIRED BASE POINTS ARE          (
1960 REM @ AVAILABLE, AND THE INTERPOLANT VALUE IS COMPUTED USING NESTED      (
1970 REM @ POLYNOMIAL EVALUATION.  THE INTERPOLANT IS RETURNED AS             (
1980 REM @ THE VALUE, TO, OF THE SUBROUTINE. FOR INCONSISTENT ARGUMENTS       (
1990 REM @ TRUBL, T9 = 1 ON EXIT.  OTHERWISE, T9 =0 ON EXIT.                  (
2000 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
2010 REM ...CHECK FOR ARGUMENT CONSISTENCY...
2020 IF D<=M THEN 2070
2030 T9=1
2040 T0=0
2050 RETURN
2060 REM ...SEARCH P VECTOR FOR ELEMENT .GE. TO P9...
2070 I=1
2080 IF I=N OR P9<=P(I) THEN 2110
2090 I=I+1
2100 GOTO 2080
2110 M1=I+D/2
2120 REM ...INSURE THAT ALL REQUIRED DIFFERENCES ARE IN TABLE...
2130 IF M1<=D THEN M1=D+1
2140 IF M1>N THEN M1=N
2150 REM ...COMPUTE INTERPOLANT VALUE...
2160 Y5=A(M1-1,D)
2170 IF D<=1 THEN 2240
2180 D1=D-1
2190 FOR I=1 TO D1
2200 I1=M1-I
2210 I2=D-I
2220 Y5=Y5*(P9-P(I1))+A(I1-1,I2)
2230 NEXT I
2240 I1=M1-D
2250 T9=0
2260 REM **********************************
2270 REM * ROUND TO NEAREST 0.01 DEGREES *
2280 REM **********************************
2290 T0=INT(100*(Y5*(P9-P(I1))+T(I1))+.5)/100
2300 RETURN
```

```
2310 REM ...WATER AT SATURATION: KEENAN, KEYES, HILL & MOORE [1969]...
2320 DATA 8,6,121
2330 REM **************************
2340 REM * TEMPERATURES - CELSIUS *
2350 REM **************************
2360 DATA 50,60,70,80,90,100,110,120
2370 REM *************************
2380 REM * WATER PRESSURE - BARS *
2390 REM *************************
2400 DATA 0.12349,0.1994,0.3119,0.4739,0.7014,1.0135,1.4327,1.9853
2410 REM *****************************************
2420 REM * U.S. STD ATM, 1976: 0-12000 × 100 FT *
2430 REM * PRESSURE - BARS                       *
2440 REM *****************************************
2450 DATA 1.01325,1.0095,1.0059,1.0023,0.99868,0.99507,0.99147,0.98788
2460 DATA 0.98429,0.98072,0.97716,0.97361,0.97007,0.96654,0.96303
2470 DATA 0.95952,0.95602,0.95253,0.94905,0.94559,0.94213,0.93868
2480 DATA 0.93525,0.93182,0.92841,0.925,0.92161,0.91822,0.91485
2490 DATA 0.91148,0.90813,0.90478,0.90145,0.89812,0.89481,0.8915
2500 DATA 0.88821,0.88492,0.88165,0.87838,0.87513,0.87188,0.86864
2510 DATA 0.86542,0.8622,0.85899,0.8558,0.85261,0.84943,0.84626
2520 DATA 0.84311,0.83996,0.83682,0.83369,0.83057,0.82746,0.82436
2530 DATA 0.82126,0.81818,0.81511,0.81204,0.80899,0.80594,0.80291
2540 DATA 0.79988,0.79687,0.79386,0.79086,0.78787,0.78489,0.78192
2550 DATA 0.77896,0.776,0.77306,0.77013,0.7672,0.76428,0.76138
2560 DATA 0.75848,0.75559,0.75271,0.74984,0.74697,0.74412,0.74127
2570 DATA 0.73844,0.73561,0.73279,0.72998,0.72718,0.72439,0.7216
2580 DATA 0.71883,0.71606,0.71331,0.71056,0.70782,0.70509,0.70236
2590 DATA 0.69965,0.69694,0.69424,0.69155,0.68887,0.6862,0.68354
2600 DATA 0.68088,0.67824,0.6756,0.67297,0.67034,0.66773,0.66513
2610 DATA 0.66253,0.65994,0.65736,0.65479,0.65222,0.64967,0.64712
2620 DATA 0.64458
2630 REM ***************************************
2640 REM * DEGREE OF INTERPOLATING POLYNOMIAL *
2650 REM ***************************************
2660 DATA 6
```

APPENDIX IV

Boiling-Point Depth Curve Program BPD for
NBI 4100 (IBM PC Compatible) Computer

```
1 REM ...BOILING POINT CURVE CALCULATION - 5/2/86...
2 REM ...MODIFIED FROM TEKTRONIX 4051 BASIC - 5/6/86...
100 REM ...INITIALIZE AND READ DATA...
110 REM ******************************************
120 REM * CLEARS ALL VARIABLES AND RESETS SYSTEM *
130 REM * TO A KNOWN STATE                       *
140 REM ******************************************
150 CLEAR
160 REM ******************************
170 REM * HEADING FOR PRINTER OUTPUT *
180 REM ******************************
190 H$="REFERENCE BOILING POINT DATA FOR "+CHR$(34)+"PURE"+CHR$(34)+" WATER
200 CLS
210 INPUT "ELEVATION, BOILING POINT AND TEMPERATURE INCREMENT: ",E0,T0,D0
220 PRINT: PRINT: PRINT
230 PRINT "PLEASE WAIT - DIVIDED DIFFERENCE TABLES ARE BEING CALCULATED"
240 PRINT: PRINT
250 REM ************************************
260 REM * ACCELERATION OF GRAVITY COMBINED *
270 REM * WITH CONSTANT TO ADJUST UNITS    *
280 REM ************************************
290 G=980.7*.0001
300 REM ************************************************
310 REM * CONSTANT TO ROUND DEPTH TO NEAREST 0.01 FEET *
320 REM ************************************************
330 M5=100
340 Z=0
350 Z2=0
360 REM ******************************************************
370 REM * N IS NUMBER OF T,P PAIRS FOR WATER AT SATURATION; *
380 REM * M IS HIGHEST ORDER DIVIDED DIFFERENCE TO BE       *
390 REM * CALCULATED.                                       *
400 REM ******************************************************
410 READ N,M
420 OPTION BASE 1
430 REM ***************************************
440 REM * SEE VARIABLE TABLE FOR DEFINITIONS *
450 REM ***************************************
460 DIM T(N),P(N),V(N),A(N,M),B(N,M)
470 O$=""
480 FOR I=1 TO N: READ T(I): NEXT I
490 FOR I=1 TO N: READ P(I): NEXT I
500 FOR I=1 TO N: READ V(I): NEXT I
510 READ D
520 REM **********************
530 REM * SAVE BOILING POINT *
540 REM **********************
550 T5=T0
560 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::
570 REM : COMPUTE PRESSURE/TEMPERATURE DIVIDED DIFFERENCES :
580 REM : SUBROUTINE DTABLE1 - MATRIX A                     :
590 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::
600 GOSUB 2710
610 REM **************************
620 REM * IF PROBLEMS, THEN STOP *
630 REM **************************
640 IF T9=0 THEN 700
```

```
650 STOP
660 REM ::::::::::::::::::::::::::::::::::::::::::::::::::::::::
670 REM : COMPUTE SPECIFIC VOLUME/PRESSURE DIVIDED-DIFFERENCES :
680 REM : SUBROUTINE DTABLE2 - MATRIX B                        :
690 REM ::::::::::::::::::::::::::::::::::::::::::::::::::::::::
700 GOSUB 2980
710 REM *************************
720 REM * IF PROBLEM, THEN STOP *
730 REM *************************
740 IF T9=1 THEN STOP
750 REM ***************************************************
760 REM * FORMAT FOR PRINTING FIRST LINE ONLY OF OUTPUT,  *
770 REM * I..E., THE BOILING POINT DATA                   *
780 REM ***************************************************
790 A$="          ###.##  ####.##  #####.##  ###.##  #.####   #.####"
800 PRINT "OUTPUT TO DISK? - Y/N: ";: Q$=INPUT$(1): PRINT Q$
810 IF Q$<>"Y" THEN 1300
820 REM ******************************************
830 REM * NO IS THE TOTAL NUMBER OF DATA RECORDS *
840 REM ******************************************
850 NO=374-INT(TO)+2
860 PRINT "FILENAME: ";
870 INPUT O$
880 REM *************************
890 REM * DOES DISK FILE EXIST? *
900 REM *************************
910 ON ERROR GOTO 970
920 NAME O$ AS O$
930 STOP
940 REM ***************
950 REM * FILE EXISTS *
960 REM **************
970 IF ERR=58 THEN 1090
980 REM ********************************************
990 REM * BRANCH IF OTHER THAN FILE DOES NOT EXIST *
1000 REM ********************************************
1010 IF ERR<>53 THEN 1170
1020 REM ****************************************
1030 REM * SINCE FILE DOES NOT EXIST, CREATE IT *
1040 REM ****************************************
1050 GOTO 1220
1060 REM **********************
1070 REM * FILE EXISTS, KEEP? *
1080 REM **********************
1090 PRINT "FILE EXISTS - DELETE? - Y/N: ";
1100 INPUT Q$
1110 REM **********************************
1120 REM * IF KEEP, THEN GET NEW FILENAME *
1130 REM **********************************
1140 IF Q$<>"Y" THEN 860
1150 KILL O$
1160 GOTO 1220
1170 ON ERROR GOTO 0
1180 END
1190 REM ***********************
1200 REM * OPEN FILE FOR WRITE *
1210 REM ***********************
```

```
1220 OPEN "O",#1,O$
1230 REM ************************************
1240 REM * WRITE NUMBER OF RECORDS TO FILE *
1250 REM ************************************
1260 WRITE#1,NO
1270 REM ******************
1280 REM * PRINT HEADINGS *
1290 REM ******************
1300 GOSUB 4300
1310 REM ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
1320 REM : FOR BOILING POINT, CALCULATE PRESSURE & SPECIFIC VOLUME :
1330 REM : SUBROUTINE FNEWPV - SAVE IN P2 & V2                      :
1340 REM ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
1350 GOSUB 3340
1360 P2=P9
1370 V2=V9
1380 REM ******************************************
1390 REM * PRINT RESULTS FOR BOILING POINT - Z=0 *
1400 REM ******************************************
1410 LPRINT USING A$;TO,Z,Z2,P2,V2,1/V2
1420 REM ***************************
1430 REM * INCREMENT LINE COUNTER *
1440 REM ***************************
1450 K=K+1
1460 REM ********************************
1470 REM * REDEFINE FORMAT STATEMENT *
1480 REM * TEMPERATURES ARE INTEGERS *
1490 REM ********************************
1500 A$="          ###      ####.##  #####.##  ###.##  #.####   #.####"
1510 REM ***********************************************
1520 REM * IF FILENAME NULL, THEN DO NOT WRITE TO DISK *
1530 REM ***********************************************
1540 IF O$="" THEN 1680
1550 REM ******************************
1560 REM * OTHERWISE, WRITE TO DISK *
1570 REM ******************************
1580 WRITE#1,Z2,TO
1590 REM ********************************************
1600 REM * FOR BOILING POINT, P2 & V2 HAVE BEEN      *
1610 REM * CALCULATED ABOVE - SKIP SUBROUTINE FNEWPV *
1620 REM ********************************************
1630 REM *******************************
1640 REM * RE-ENTRY POINT FOR LOOP FOR *
1650 REM * SUBSEQUENT TEMPERATURES     *
1660 REM * SAVE FIRST P & V PAIR       *
1670 REM *******************************
1680 PO=P2
1690 VO=V2
1700 REM ********************
1710 REM * NEXT TEMPERATURE *
1720 REM ********************
1730 TO=INT(TO)+DO
1740 REM *******************************************
1750 REM * LAST TEMPERATURE? - I.E., CRITICAL POINT *
1760 REM *******************************************
1770 IF TO<=T(N) THEN 1850
```

```
1780 REM ***************************************
1790 REM * NO, EXCEEDS - SET TO CRITICAL POINT *
1800 REM ***************************************
1810 TO=T(N)
1820 REM :::::::::::::::::::
1830 REM : CALCULATE P & V :
1840 REM :::::::::::::::::::
1850 GOSUB 3340
1860 REM **************
1870 REM * SAVE P & V *
1880 REM **************
1890 P2=P9
1900 V2=V9
1910 REM ::::::::::::::::::::::::::
1920 REM : CALCULATE MID-PRESSURE :
1930 REM ::::::::::::::::::::::::::
1940 P9=(PO+P2)/2
1950 REM :::::::::::::::::::::::::::::
1960 REM : CALCULATE SPECIFIC VOLUME :
1970 REM :::::::::::::::::::::::::::::
1980 GOSUB 3600
1990 REM **************
2000 REM * SAVE P & V *
2010 REM **************
2020 P1=P9
2030 V1=V9
2040 REM ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2050 REM : CALCULATE P_DIFFERENCE/2 - FOR USE BY SIMPSONS RULE INTEGRAL :
2060 REM ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2070 D5=(P2-PO)/2
2080 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::::
2090 REM : CALCULATE NEW DEPTH USING SIMPSONS RULE INTEGRATION :
2100 REM :::::::::::::::::::::::::::::::::::::::::::::::::::::::
2110 GOSUB 3870
2120 REM ************************************
2130 REM * LAST TEMPERATURE? - NO, CONTINUE *
2140 REM ************************************
2150 IF TO<>T(N) THEN  2230
2160 REM ************************************************
2170 REM * YES, LAST TEMPERATURE - CHANGE OUTPUT FORMAT *
2180 REM ************************************************
2190 A$="          ###.### ####.##  #####.##  ###.##  #.####   #.####"
2200 REM ************************
2210 REM * PRINT NEW DEPTH DATA *
2220 REM ************************
2230 LPRINT USING A$;TO,Z,Z2,P2,V2,1/V2
2240 REM ********************************************
2250 REM * FILENAME = NULL? => DO NOT WRITE TO DISK *
2260 REM ********************************************
2270 IF O$="" THEN 2350
2280 REM *********************************
2290 REM * OTHERWISE, WRITE DATA TO DISK *
2300 REM *********************************
2310 WRITE#1,Z2,TO
2320 REM ******************************
2330 REM * INCREMENT PRINT LINE COUNT *
2340 REM ******************************
```

```
2350 K=K+1
2360 REM *******************************
2370 REM * HAVE 50 LINES BEEN PRINTED? *
2380 REM *******************************
2390 IF K<50 THEN 2480
2400 REM **********************************
2410 REM * YES, PAGE & PRINT NEW HEADINGS *
2420 REM **********************************
2430 GOSUB 4290
2440 REM **************************************
2450 REM * HAS LAST TEMPERATURE BEEN PRINTED? *
2460 REM * NO, CONTINUE WITH NEXT TEMPERATURE *
2470 REM **************************************
2480 IF TO<T(N) THEN 1680
2490 REM ******************
2500 REM * YES, FINISH UP *
2510 REM * PAGE PRINTER   *
2520 REM ******************
2530 LPRINT CHR$(12);
2540 REM ************************************************
2550 REM * CLOSE DISK FILE - NO EFFECT IF DISK NOT USED *
2560 REM ************************************************
2570 CLOSE 1
2580 REM ######################
2590 REM ### END OF PROGRAM ###
2600 REM ######################
2610 END
```

```
2620 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
2630 REM @                          SUBROUTINE: DTABLE1                      @
2640 REM @ DTABLE1 COMPUTES THE FINITE DIVIDED DIFFERENCES OF                @
2650 REM @ P(1)...P(N) FOR ALL ORDERS M OR LESS AND STORES THEM IN         @
2660 REM @ THE LOWER TRIANGULAR PORTION OF THE FIRST M COLUMNS OF THE      @
2670 REM @ FIRST N-1 ROWS OF THE MATRIX A. FOR INCONSISTENT ARGUMENTS,     @
2680 REM @ TRUBL, T9 = 1 ON EXIT.  OTHERWISE, T9 = 0 ON EXIT               @
2690 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
2700 REM ...CHECK FOR ARGUMENT CONSISTENCY...
2710 IF M<N THEN 2750
2720 T9=1
2730 RETURN
2740 REM ...CALCULATE FIRST ORDER DIFFERENCES...
2750 N1=N-1
2760 FOR I=1 TO N1
2770 A(I,1)=(P(I+1)-P(I))/(T(I+1)-T(I))
2780 NEXT I
2790 IF M<=1 THEN 2870
2800 REM ...CALCULATE HIGHER ORDER DIFFERENCES...
2810 FOR J=2 TO M
2820 FOR I=J TO N1
2830 I0=I+1-J
2840 A(I,J)=(A(I,J-1)-A(I-1,J-1))/(T(I+1)-T(I0))
2850 NEXT I
2860 NEXT J
2870 T9=0
2880 RETURN
2890 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
2900 REM @                          SUBROUTINE: DTABLE2                       @
2910 REM @ DTABLE2 COMPUTES THE FINITE DIVIDED DIFFERENCES OF                 @
2920 REM @ V(1)...V(N) FOR ALL ORDERS M OR LESS AND STORES THEM IN           @
2930 REM @ THE LOWER TRIANGULAR PORTION OF THE FIRST M COLUMNS OF THE        @
2940 REM @ FIRST N-1 ROWS OF THE MATRIX B. FOR INCONSISTENT ARGUMENTS,       @
2950 REM @ TRUBL, T9 = 1 ON EXIT.  OTHERWISE, T9 = 0 ON EXIT.                @
2960 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
2970 REM ...CHECK FOR ARGUMENT CONSISTENCY...
2980 IF M<N THEN 3020
2990 T9=1
3000 RETURN
3010 REM ...CALCULATE FIRST ORDER DIFFERENCES...
3020 N1=N-1
3030 FOR I=1 TO N1
3040 B(I,1)=(V(I+1)-V(I))/(P(I+1)-P(I))
3050 NEXT I
3060 IF M<=1 THEN 3140
3070 REM ...CALCULATE HIGHER ORDER DIFFERENCES...
3080 FOR J=2 TO M
3090 FOR I=J TO N1
3100 I0=I+1-J
3110 B(I,J)=(B(I,J-1)-B(I-1,J-1))/(P(I+1)-P(I0))
3120 NEXT I
3130 NEXT J
3140 T9=0
3150 RETURN
```

```
3160 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
3170 REM @                      SUBROUTINE: FNEWPV                         @
3180 REM @ FNEWPV ASSUMES THAT T(1)...T(N) ARE IN ASCENDING ORDER AND  @
3190 REM @ FIRST SCANS THE T VECTOR TO DETERMINE WHICH ELEMENT IS      @
3200 REM @ NEAREST (.GE.) THE INTERPOLATION ARGUMENT, TO.               @
3210 REM @ THE D+1 BASE POINTS NEEDED FOR THE EVALUATION OF THE        @
3220 REM @ DIVIDED-DIFFERENCE POLYNOMIAL OF DEGREE D+1 ARE THEN        @
3230 REM @ CENTERED ABOUT THE CHOSEN ELEMENT WITH THE LARGEST HAVING   @
3240 REM @ THE SUBSCRIPT M1.  IT IS ASSUMED THAT THE FIRST M DIVIDED   @
3250 REM @ DIFFERENCES HAVE BEEN COMPUTED BY THE SUBROUTINES           @
3260 REM @ DTABLE1 & 2 AND ARE ALREADY PRESENT IN MATRIX A & B.        @
3270 REM @ M1 IS CHECKED TO INSURE THAT ALL REQUIRED BASE POINTS ARE   @
3280 REM @ AVAILABLE, & THE INTERPOLANT VALUE IS COMPUTED USING NESTED @
3290 REM @ POLYNOMIAL EVALUATION.  THE INTERPOLANT IS RETURNED AS      @
3300 REM @ THE VALUE, Z, OF THE SUBROUTINE. FOR INCONSISTENT ARGUMENTS,@
3310 REM @ TRUBL, T9 = 1 ON EXIT.  OTHERWISE, T9 = 0 ON EXIT.          @
3320 REM @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
3330 REM ...CHECK FOR ARGUMENT CONSISTENCY...
3340 IF D<=M THEN 3390
3350 T9=1
3360 P9=0
3370 RETURN
3380 REM ...SEARCH T VECTOR FOR ARGUMENT .GE. TO
3390 I=1
3400 IF I=N OR TO<=T(I) THEN 3430
3410 I=I+1
3420 GOTO 3400
3430 M1=I+D/2
3440 REM ...INSURE THAT ALL REQUIRED DIFFERENCES ARE IN TABLE...
3450 IF M1<=D THEN M1=D+1
3460 IF M1>N THEN M1=N
3470 REM ...COMPUTE INTERPOLANT VALUE...
3480 Y5=A(M1-1,D)
3490 IF D<=1 THEN 3560
3500 D1=D-1
3510 FOR I=1 TO D1
3520 I1=M1-I
3530 I2=D-I
3540 Y5=Y5*(TO-T(I1))+A(I1-1,I2)
3550 NEXT I
3560 I1=M1-D
3570 T9=0
3580 P9=Y5*(TO-T(I1))+P(I1)
3590 REM ...CHECK FOR ARGUMENT CONSISTENCY...
3600 IF D<=M THEN 3650
3610 T9=1
3620 V9=0
3630 RETURN
3640 REM ...SEARCH P VECTOR FOR ELEMENT .GE. TO P9...
3650 I=1
3660 IF I=N OR P9<=P(I) THEN 3690
3670 I=I+1
3680 GOTO 3660
3690 M1=I+D/2
3700 REM ...INSURE THAT ALL REQUIRED DIFFERENCES ARE IN TABLE...
3710 IF M1<=D THEN M1=D+1
3720 IF M1>N THEN M1=N
```

```
3730 REM ...COMPUTE INTERPOLANT VALUE...
3740 Y5=B(M1-1,D)
3750 IF D<=1 THEN 3820
3760 D1=D-1
3770 FOR I=1 TO D1
3780 I1=M1-I
3790 I2=D-I
3800 Y5=Y5*(P9-P(I1))+B(I1-1,I2)
3810 NEXT I
3820 I1=M1-D
3830 T9=0
3840 V9=Y5*(P9-P(I1))+V(I1)
3850 RETURN
3860 REM ...CALCULATE NEW Z USING SIMPSONS RULE...
3870 Y=D5*(V0+4*V1+V2)/3
3880 Z=Z+Y/G
3890 Z=INT(M5*Z+.5)/M5
3900 Z2=INT(3.2808*M5*Z+.5)/M5
3910 RETURN
```

```
3920 REM ...WATER AT SATURATION: KEENAN, KEYES, HILL & MOORE [1969]...
3930 DATA 67,6
3940 REM **************************
3950 REM * TEMPERATURES - CELSIUS *
3960 REM **************************
3970 DATA 80,85,90,95,100,105,110,115,120,125,130,135,140,145,150
3980 DATA 155,160,165,170,175,180,185,190,195,200,205,210,215,220
3990 DATA 225,230,235,240,245,250,255,260,265,270,275,280,285,290
4000 DATA 295,300,305,310,315,320,324,330,334,340,344,350,354,360
4010 DATA 362,364,366,368,370,371,372,373,374,374.136
4020 REM ********************
4030 REM * PRESSURE - BARS *
4040 REM ********************
4050 DATA 0.4739,0.5783,0.7014,0.8455,1.0135,1.2082,1.4327,1.6906
4060 DATA 1.9853,2.321,2.701,3.130,3.613,4.154,4.758,5.431,6.178
4070 DATA 7.005,7.917,8.920,10.021,11.227,12.544,13.978,15.538
4080 DATA 17.230,19.062,21.04,23.18,25.48,27.95,30.60,33.44,36.48
4090 DATA 39.73,43.19,46.88,50.81,54.99,59.42,64.12,69.09,74.36
4100 DATA 79.93,85.81,92.02,98.56,105.47,112.74,118.83,128.45
4110 DATA 135.20,145.86,153.33,165.13,173.42,186.51,191.06,195.71
4120 DATA 200.46,205.31,210.3,212.8,215.3,217.9,220.5,220.9
4130 REM ****************************
4140 REM * SPECIFIC VOLUME - CC/GM *
4150 REM ****************************
4160 DATA 1.0291,1.0325,1.0360,1.0397,1.0435,1.0475,1.0516,1.0559
4170 DATA 1.0603,1.0649,1.0697,1.0746,1.0797,1.0850,1.0905,1.0961
4180 DATA 1.1020,1.1080,1.1143,1.1207,1.1274,1.1343,1.1414,1.1488
4190 DATA 1.1565,1.1644,1.1726,1.1812,1.1900,1.1992,1.2088,1.2187
4200 DATA 1.2291,1.2399,1.2512,1.2631,1.2755,1.2886,1.3023,1.3168
4210 DATA 1.3321,1.3483,1.3656,1.3839,1.4036,1.4247,1.4474,1.4720
4220 DATA 1.4988,1.5221,1.5607,1.5893,1.6379,1.6750,1.7403,1.7927
4230 DATA 1.8925,1.9345,1.9833,2.0416,2.1145,2.213,2.280,2.369,2.509
4240 DATA 2.880,3.155
4250 REM ****************************************
4260 REM * DEGREE OF INTERPOLATING POLYNOMIAL *
4270 REM ****************************************
4280 DATA 6
```

```
4290 REM ...HEADINGS...
4300 H1$="           &"
4310 H2$="           &#####&###.##&"
4320 H3$="            !         !         !       !       !       !"
4330 H4$="           &        &       &  &  &  &"
4340 LPRINT CHR$(12);
4350 LPRINT USING H1$;H$
4360 LPRINT USING H2$;"ELEVATION = ",E0," FT - BOILING POINT = ",T5," C"
4370 LPRINT
4380 LPRINT USING H3$;"T","Z","Z","P","V","D"
4390 LPRINT USING H4$;"(C)","(M)","(FT)","(BARS)","(CC/GM)","(GM/CC)"
4400 LPRINT
4410 REM **********************
4420 REM * RESET LINE COUNTER *
4430 REM **********************
4440 K=0
4450 RETURN
```

Appendix V

Sample Output for Mammoth No. 1 from Program BPD

BOILING POINT DEPTH CURVE FOR "PURE" WATER
ELEVATION = 7244 FT - BOILING POINT = 92.67 C

T (C)	Z (M)	Z (FT)	P (BARS)	V (CC/G)	D (G/CC)
92.67	0.00	0.00	0.78	1.0380	0.9634
93	0.10	0.33	0.79	1.0382	0.9632
94	0.41	1.35	0.81	1.0389	0.9625
95	0.73	2.39	0.85	1.0397	0.9618
96	1.07	3.51	0.88	1.0405	0.9611
97	1.42	4.66	0.91	1.0412	0.9604
98	1.78	5.84	0.94	1.0420	0.9597
99	2.15	7.05	0.98	1.0427	0.9590
100	2.53	8.30	1.01	1.0435	0.9583
101	2.92	9.58	1.05	1.0443	0.9576
102	3.32	10.89	1.09	1.0451	0.9569
103	3.73	12.24	1.13	1.0459	0.9561
104	4.16	13.65	1.17	1.0467	0.9554
105	4.60	15.09	1.21	1.0475	0.9547
106	5.05	16.57	1.25	1.0483	0.9539
107	5.52	18.11	1.29	1.0491	0.9532
108	6.00	19.68	1.34	1.0499	0.9524
109	6.49	21.29	1.39	1.0508	0.9517
110	7.00	22.97	1.43	1.0516	0.9509
111	7.52	24.67	1.48	1.0524	0.9502
112	8.06	26.44	1.53	1.0533	0.9494
113	8.61	28.25	1.58	1.0542	0.9486
114	9.18	30.12	1.64	1.0550	0.9478
115	9.77	32.05	1.69	1.0559	0.9471
116	10.37	34.02	1.75	1.0568	0.9463
117	10.99	36.06	1.80	1.0576	0.9455
118	11.63	38.16	1.86	1.0585	0.9447
119	12.28	40.29	1.92	1.0594	0.9439
120	12.95	42.49	1.99	1.0603	0.9431
121	13.64	44.75	2.05	1.0612	0.9423
122	14.35	47.08	2.11	1.0621	0.9415
123	15.08	49.47	2.18	1.0630	0.9407
124	15.83	51.94	2.25	1.0640	0.9399
125	16.60	54.46	2.32	1.0649	0.9391
126	17.39	57.05	2.39	1.0658	0.9382
127	18.20	59.71	2.47	1.0668	0.9374
128	19.03	62.43	2.54	1.0678	0.9365
129	19.88	65.22	2.62	1.0687	0.9357
130	20.75	68.08	2.70	1.0697	0.9348
131	21.64	71.00	2.78	1.0707	0.9340
132	22.55	73.98	2.87	1.0716	0.9331
133	23.49	77.07	2.95	1.0726	0.9323
134	24.45	80.22	3.04	1.0736	0.9314
135	25.44	83.46	3.13	1.0746	0.9306
136	26.45	86.78	3.22	1.0756	0.9297
137	27.49	90.19	3.32	1.0766	0.9288
138	28.55	93.67	3.41	1.0776	0.9280
139	29.64	97.24	3.51	1.0787	0.9271
140	30.75	100.88	3.61	1.0797	0.9262
141	31.89	104.62	3.72	1.0807	0.9253

BOILING POINT DEPTH CURVE FOR "PURE" WATER
ELEVATION = 7244 FT - BOILING POINT = 92.67 C

T (C)	Z (M)	Z (FT)	P (BARS)	V (CC/G)	D (G/CC)
142	33.06	108.46	3.82	1.0818	0.9244
143	34.25	112.37	3.93	1.0829	0.9235
144	35.47	116.37	4.04	1.0839	0.9226
145	36.72	120.47	4.15	1.0850	0.9217
146	38.00	124.67	4.27	1.0861	0.9207
147	39.31	128.97	4.39	1.0872	0.9198
148	40.65	133.36	4.51	1.0883	0.9189
149	42.02	137.86	4.63	1.0894	0.9179
150	43.42	142.45	4.76	1.0905	0.9170
151	44.85	147.14	4.89	1.0916	0.9161
152	46.32	151.97	5.02	1.0927	0.9152
153	47.82	156.89	5.15	1.0938	0.9142
154	49.35	161.91	5.29	1.0950	0.9133
155	50.92	167.06	5.43	1.0961	0.9123
156	52.52	172.31	5.57	1.0973	0.9114
157	54.16	177.69	5.72	1.0984	0.9104
158	55.83	183.17	5.87	1.0996	0.9094
159	57.54	188.78	6.02	1.1008	0.9084
160	59.29	194.52	6.18	1.1020	0.9074
161	61.08	200.39	6.34	1.1032	0.9065
162	62.90	206.36	6.50	1.1044	0.9055
163	64.76	212.46	6.66	1.1056	0.9045
164	66.66	218.70	6.83	1.1068	0.9035
165	68.60	225.06	7.01	1.1080	0.9025
166	70.58	231.56	7.18	1.1092	0.9015
167	72.60	238.19	7.36	1.1105	0.9005
168	74.67	244.98	7.54	1.1118	0.8995
169	76.78	251.90	7.73	1.1130	0.8985
170	78.93	258.95	7.92	1.1143	0.8974
171	81.13	266.17	8.11	1.1156	0.8964
172	83.37	273.52	8.31	1.1168	0.8954
173	85.66	281.03	8.51	1.1181	0.8944
174	87.99	288.68	8.71	1.1194	0.8933
175	90.37	296.49	8.92	1.1207	0.8923
176	92.80	304.46	9.13	1.1220	0.8913
177	95.27	312.56	9.35	1.1233	0.8902
178	97.79	320.83	9.57	1.1247	0.8891
179	100.36	329.26	9.79	1.1260	0.8881
180	102.98	337.86	10.02	1.1274	0.8870
181	105.66	346.65	10.25	1.1288	0.8859
182	108.39	355.61	10.49	1.1301	0.8848
183	111.17	364.73	10.73	1.1315	0.8838
184	114.00	374.01	10.98	1.1329	0.8827
185	116.89	383.49	11.23	1.1343	0.8816
186	119.83	393.14	11.48	1.1357	0.8805
187	122.83	402.98	11.74	1.1371	0.8794
188	125.89	413.02	12.00	1.1385	0.8783
189	129.00	423.22	12.27	1.1400	0.8772
190	132.17	433.62	12.54	1.1414	0.8761
191	135.40	444.22	12.82	1.1429	0.8750

BOILING POINT DEPTH CURVE FOR "PURE" WATER
ELEVATION = 7244 FT - BOILING POINT = 92.67 C

T (C)	Z (M)	Z (FT)	P (BARS)	V (CC/G)	D (G/CC)
192	138.69	455.01	13.10	1.1443	0.8739
193	142.04	466.00	13.39	1.1458	0.8728
194	145.45	477.19	13.68	1.1473	0.8716
195	148.92	488.58	13.98	1.1488	0.8705
196	152.46	500.19	14.28	1.1503	0.8693
197	156.06	512.00	14.59	1.1519	0.8682
198	159.73	524.04	14.90	1.1534	0.8670
199	163.46	536.28	15.22	1.1549	0.8658
200	167.26	548.75	15.54	1.1565	0.8647
201	171.13	561.44	15.87	1.1581	0.8635
202	175.06	574.34	16.20	1.1596	0.8623
203	179.06	587.46	16.54	1.1612	0.8612
204	183.13	600.81	16.88	1.1628	0.8600
205	187.28	614.43	17.23	1.1644	0.8588
206	191.50	628.27	17.59	1.1660	0.8576
207	195.79	642.35	17.95	1.1676	0.8564
208	200.16	656.68	18.31	1.1693	0.8552
209	204.60	671.25	18.68	1.1709	0.8540
210	209.11	686.05	19.06	1.1726	0.8528
211	213.70	701.11	19.45	1.1743	0.8516
212	218.36	716.40	19.83	1.1760	0.8503
213	223.11	731.98	20.23	1.1777	0.8491
214	227.94	747.83	20.63	1.1795	0.8478
215	232.85	763.93	21.04	1.1812	0.8466
216	237.85	780.34	21.46	1.1829	0.8454
217	242.94	797.04	21.88	1.1847	0.8441
218	248.11	814.00	22.30	1.1864	0.8429
219	253.37	831.26	22.74	1.1882	0.8416
220	258.71	848.78	23.18	1.1900	0.8403
221	264.14	866.59	23.63	1.1918	0.8391
222	269.65	884.67	24.08	1.1936	0.8378
223	275.25	903.04	24.54	1.1955	0.8365
224	280.94	921.71	25.01	1.1973	0.8352
225	286.72	940.67	25.48	1.1992	0.8339
226	292.60	959.96	25.96	1.2011	0.8326
227	298.57	979.55	26.45	1.2030	0.8313
228	304.63	999.43	26.94	1.2049	0.8299
229	310.79	1019.64	27.44	1.2069	0.8286
230	317.05	1040.18	27.95	1.2088	0.8273
231	323.41	1061.04	28.47	1.2107	0.8259
232	329.87	1082.24	28.99	1.2127	0.8246
233	336.43	1103.76	29.52	1.2147	0.8233
234	343.09	1125.61	30.06	1.2167	0.8219
235	349.86	1147.82	30.60	1.2187	0.8205
236	356.73	1170.36	31.15	1.2207	0.8192
237	363.71	1193.26	31.71	1.2228	0.8178
238	370.80	1216.52	32.28	1.2249	0.8164
239	378.00	1240.14	32.86	1.2270	0.8150
240	385.31	1264.13	33.44	1.2291	0.8136
241	392.73	1288.47	34.03	1.2312	0.8122

BOILING POINT DEPTH CURVE FOR "PURE" WATER
ELEVATION = 7244 FT - BOILING POINT = 92.67 C

T (C)	Z (M)	Z (FT)	P (BARS)	V (CC/G)	D (G/CC)
242	400.26	1313.17	34.63	1.2334	0.8108
243	407.91	1338.27	35.24	1.2355	0.8094
244	415.68	1363.76	35.86	1.2377	0.8079
245	423.57	1389.65	36.48	1.2399	0.8065
246	431.59	1415.96	37.11	1.2421	0.8051
247	439.73	1442.67	37.76	1.2444	0.8036
248	447.99	1469.77	38.41	1.2466	0.8022
249	456.37	1497.26	39.06	1.2489	0.8007
250	464.87	1525.15	39.73	1.2512	0.7992
251	473.48	1553.39	40.40	1.2535	0.7977
252	482.22	1582.07	41.09	1.2559	0.7962
253	491.09	1611.17	41.78	1.2583	0.7947
254	500.09	1640.70	42.48	1.2607	0.7932
255	509.22	1670.65	43.19	1.2631	0.7917
256	518.49	1701.06	43.91	1.2655	0.7902
257	527.90	1731.93	44.64	1.2680	0.7887
258	537.45	1763.27	45.38	1.2705	0.7871
259	547.14	1795.06	46.12	1.2730	0.7856
260	556.97	1827.31	46.88	1.2755	0.7840
261	566.95	1860.05	47.65	1.2781	0.7824
262	577.07	1893.25	48.42	1.2807	0.7808
263	587.34	1926.95	49.21	1.2833	0.7793
264	597.76	1961.13	50.00	1.2859	0.7776
265	608.34	1995.84	50.81	1.2886	0.7760
266	619.08	2031.08	51.63	1.2913	0.7744
267	629.97	2066.81	52.45	1.2940	0.7728
268	641.01	2103.03	53.29	1.2967	0.7712
269	652.21	2139.77	54.13	1.2995	0.7695
270	663.56	2177.01	54.99	1.3023	0.7679
271	675.06	2214.74	55.86	1.3051	0.7662
272	686.72	2252.99	56.73	1.3080	0.7645
273	698.55	2291.80	57.62	1.3109	0.7628
274	710.55	2331.17	58.51	1.3138	0.7611
275	722.72	2371.10	59.42	1.3168	0.7594
276	735.07	2411.62	60.34	1.3198	0.7577
277	747.59	2452.69	61.27	1.3228	0.7560
278	760.28	2494.33	62.21	1.3259	0.7542
279	773.15	2536.55	63.16	1.3290	0.7525
280	786.19	2579.33	64.12	1.3321	0.7507
281	799.40	2622.67	65.09	1.3353	0.7489
282	812.79	2666.60	66.07	1.3385	0.7471
283	826.37	2711.15	67.07	1.3417	0.7453
284	840.14	2756.33	68.07	1.3450	0.7435
285	854.11	2802.16	69.09	1.3483	0.7417
286	868.29	2848.69	70.12	1.3517	0.7398
287	882.67	2895.86	71.16	1.3551	0.7380
288	897.25	2943.70	72.22	1.3586	0.7361
289	912.04	2992.22	73.28	1.3621	0.7342
290	927.03	3041.40	74.36	1.3656	0.7323
291	942.23	3091.27	75.45	1.3692	0.7304

BOILING POINT DEPTH CURVE FOR "PURE" WATER
ELEVATION = 7244 FT - BOILING POINT = 92.67 C

T (C)	Z (M)	Z (FT)	P (BARS)	V (CC/G)	D (G/CC)
292	957.63	3141.79	76.55	1.3728	0.7285
293	973.24	3193.01	77.67	1.3764	0.7265
294	989.07	3244.94	78.79	1.3801	0.7246
295	1005.11	3297.56	79.93	1.3839	0.7226
296	1021.36	3350.88	81.08	1.3877	0.7206
297	1037.84	3404.95	82.24	1.3916	0.7186
298	1054.55	3459.77	83.42	1.3956	0.7166
299	1071.49	3515.34	84.61	1.3995	0.7145
300	1088.67	3571.71	85.81	1.4036	0.7125
301	1106.10	3628.89	87.03	1.4077	0.7104
302	1123.77	3686.86	88.26	1.4119	0.7083
303	1141.68	3745.62	89.50	1.4161	0.7062
304	1159.83	3805.17	90.75	1.4204	0.7040
305	1178.22	3865.50	92.02	1.4247	0.7019
306	1196.84	3926.59	93.30	1.4291	0.6997
307	1215.72	3988.53	94.59	1.4336	0.6976
308	1234.86	4051.33	95.90	1.4381	0.6954
309	1254.28	4115.04	97.22	1.4427	0.6931
310	1273.98	4179.67	98.56	1.4474	0.6909
311	1293.98	4245.29	99.91	1.4522	0.6886
312	1314.26	4311.82	101.28	1.4570	0.6863
313	1334.83	4379.31	102.66	1.4619	0.6840
314	1355.68	4447.71	104.06	1.4669	0.6817
315	1376.82	4517.07	105.47	1.4720	0.6793
316	1398.24	4587.35	106.89	1.4772	0.6770
317	1419.96	4658.60	108.33	1.4824	0.6746
318	1441.98	4730.85	109.79	1.4878	0.6721
319	1464.30	4804.08	111.26	1.4932	0.6697
320	1486.93	4878.32	112.74	1.4988	0.6672
321	1509.88	4953.61	114.24	1.5045	0.6647
322	1533.16	5029.99	115.75	1.5102	0.6622
323	1556.77	5107.45	117.28	1.5161	0.6596
324	1580.72	5186.03	118.83	1.5221	0.6570
325	1605.02	5265.75	120.39	1.5282	0.6544
326	1629.67	5346.62	121.97	1.5345	0.6517
327	1654.68	5428.67	123.57	1.5408	0.6490
328	1680.05	5511.91	125.18	1.5473	0.6463
329	1705.79	5596.36	126.81	1.5539	0.6435
330	1731.91	5682.05	128.45	1.5607	0.6407
331	1758.41	5768.99	130.11	1.5676	0.6379
332	1785.30	5857.21	131.79	1.5747	0.6351
333	1812.60	5946.78	133.49	1.5819	0.6322
334	1840.31	6037.69	135.20	1.5893	0.6292
335	1868.45	6130.01	136.93	1.5969	0.6262
336	1897.01	6223.71	138.68	1.6047	0.6232
337	1926.01	6318.85	140.45	1.6127	0.6201
338	1955.45	6415.44	142.24	1.6209	0.6170
339	1985.33	6513.47	144.04	1.6293	0.6138
340	2015.67	6613.01	145.86	1.6379	0.6105
341	2046.47	6714.06	147.70	1.6468	0.6072

BOILING POINT DEPTH CURVE FOR "PURE" WATER
ELEVATION = 7244 FT - BOILING POINT = 92.67 C

T (C)	Z (M)	Z (FT)	P (BARS)	V (CC/G)	D (G/CC)
342	2077.75	6816.68	149.56	1.6559	0.6039
343	2109.53	6920.95	151.43	1.6653	0.6005
344	2141.82	7026.88	153.33	1.6750	0.5970
345	2174.63	7134.53	155.25	1.6850	0.5935
346	2207.99	7243.97	157.18	1.6953	0.5899
347	2241.91	7355.26	159.14	1.7060	0.5862
348	2276.41	7468.45	161.11	1.7170	0.5824
349	2311.50	7583.57	163.11	1.7284	0.5786
350	2347.20	7700.69	165.13	1.7403	0.5746
351	2383.54	7819.92	167.17	1.7526	0.5706
352	2420.52	7941.24	169.23	1.7654	0.5664
353	2458.16	8064.73	171.32	1.7788	0.5622
354	2496.48	8190.45	173.42	1.7927	0.5578
355	2535.50	8318.47	175.55	1.8073	0.5533
356	2575.25	8448.88	177.69	1.8226	0.5487
357	2615.75	8581.75	179.86	1.8386	0.5439
358	2657.04	8717.22	182.06	1.8556	0.5389
359	2699.15	8855.37	184.27	1.8735	0.5338
360	2742.13	8996.38	186.51	1.8925	0.5284
361	2786.02	9140.37	188.77	1.9128	0.5228
362	2830.88	9287.55	191.06	1.9345	0.5169
363	2876.76	9438.07	193.37	1.9579	0.5107
364	2923.73	9592.17	195.71	1.9833	0.5042
365	2971.88	9750.14	198.07	2.0110	0.4973
366	3021.16	9911.82	200.46	2.0416	0.4898
367	3071.61	10077.34	202.86	2.0757	0.4818
368	3123.86	10248.76	205.31	2.1145	0.4729
369	3177.98	10426.32	207.79	2.1590	0.4632
370	3233.80	10609.45	210.30	2.2130	0.4519
371	3291.02	10797.18	212.80	2.2800	0.4386
372	3349.83	10990.12	215.30	2.3690	0.4221
373	3414.88	11203.54	217.90	2.5090	0.3986
374	3483.66	11429.19	220.50	2.8800	0.3472
374.136	3495.93	11469.45	220.90	3.1550	0.3170