# NATIONAL BUREAU OF STANDARDS REPORT

6612

IBM 650 Computer Program for
CIE Color Specifications of Objects
Illuminated by Sources Having
Continuous Plus Line Spectra

By

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NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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**NBS PROJECT** **NBS REPORT**

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# IBM 650 Computer Program for CIE Color Specifications of Objects Illuminated by Sources Having Continuous Plus Line Spectra


## Abstract

At the request of the Illuminating Engineering Research Institute of the Illuminating Engineering Society, the National Bureau of Standards has written a computer program, for use on the IBM 650, high speed digital, computer, which converts into terms of the 1931 CIE (International Commission on Illumination) standard observer and coordinate system data of spectral transmittance or spectral directional reflectance of a sample illuminated by any light source, including those sources, such as fluorescent lamps, which have spectral lines superimposed on the continuous spectrum of the source. A description of the data required by the program is given together with detailed instructions for coding the data.

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## I. General description of the computing program.

The purpose of this computing program is the conversion of spectral directional reflectance or spectral transmittance data into colorimetric terms of the 1931 CIE (International Commission on Illumination) standard observer and coordinate system [1]*. The wavelength range covered is 380 to 770 millimicrons. Any light source may be used in the computations including those sources, such as fluorescent lamps, which have spectral lines superimposed on the continuous spectrum of the source.

Up to 5 spectral lines can be included in the data for the source. It is necessary to give only the wavelengths at which the spectral lines occur and the relative radiant fluxes of these lines. The computer program performs a third-difference, osculatory interpolation [2] on the data of the CIE standard observer and the spectral directional reflectance or spectral transmittance data of the sample at the proper wavelengths. The third-difference, osculatory interpolation formula has the condition, however, that no such interpolation can be made within the first and last wavelength interval, namely 380 to 390 millimicrons and 760 to 770 millimicrons. Since the possibility exists that a spectral line could fall within the first or last wavelength interval, the program has been written to perform linear interpolation in these wavelength regions.

Two possibilities for handling data are available. The conversion to CIE colorimetric terms can be made for (1) a series of source-sample combinations where neither the data of the source nor the data of the sample are repeated, or (2) a number of samples relative to the same source.

The resulting data of the computations are punched on a single card giving the identification, tristimulus values, and chromaticity coordinates of the source-sample combination.

A complete listing of the FOR TRANSIT [3] code, used to assemble the program deck, is shown in Appendix A. Since the FOR TRANSIT system, used on the IBM 650 computer, is compatible with the FORTRAN [4,5] system, used on the IBM 704 computer, it was possible to prepare the computing program on the IBM 704 computer at the National Bureau of Standards, and with minor modifications, obtain a program which could be assembled on the IBM 650 computer at the U. S. Department of Agriculture. Thus, the FORTRAN program, described in NBS Report 6613, performs the same computations as the FOR TRANSIT program described herein. The modified FORTRAN [6] program which was assembled on the IBM 704 computer is shown in Appendix B.

The program deck, supplied with these instructions, is this FOR TRANSIT code assembled in "machine language" on a basic IBM 650 computer equipped

* Numbers in brackets refer to bibliography on page 10 of this report.

with a special character device (Group II), using the FOR TRANSIT I(S) [3] compiling program, and the FOR TRANSIT 533 control panel.

The computing program has been checked against data computed manually on desk calculators. The results of the two sets of calculations agree exactly to at least five decimal places which is considered sufficient for the problems to be computed by this program.

The running time on the computer, after the program deck has been loaded, is approximately 1 minute 15 seconds per source-sample combination.

## II. Form of the input data.

The input data are punched on standard 80 column IBM cards and arranged in the following order.

(1) Control card.
(2) Continuum of the source.
(3) Number of spectral lines to be considered.
(4) Wavelengths of the spectral lines.
(5) Radiant fluxes of the spectral lines.
(6) Spectral directional reflectance or spectral transmittance of sample.

The information listed above are punched in the first 70 columns of the cards in accord with instructions to be described in detail later in this section. Columns 71 through 80 are not read by the computer and may be used to number the cards sequentially, or for other identifying information.

In Appendix D is shown the listing of the deck of input data cards used to check this program. Note that the data shown on any line in Appendix D are punched on a single card. The column numbers are shown for reference only as the first two lines at the top of each page. These column number cards do not appear in the original input data deck used for the computations. Each card has been given a number in columns 74 and 75. These card numbers will be used in the description which follows for each type of input data format.

The IBM 650 uses a fixed input and output format consisting of eight 10 column fields per card. A field of a punch card is a specific number of columns in which data may be placed. Thus, the first field consists of columns 1 through 10, the second field columns 11 through 20, and so forth until the eighth field is reached which consists of columns 71 through 80.

### (1) Control card.

The control card, for example cards numbers 1, 17, 33, 49, 56, and 63, Appendix D, serves to control transfers within the program, depending upon the input data to be used, and also to identify the input and output data with a particular source-sample combination.

The first field of the control card, columns 1 through 10, is punched with "0" in columns 1 through 9 and with a "1", "2", or "3" in column 10. The punch in column 10 serves to control the transfers within the program and has the following significance.

| Punch in Column 10 | Significance |
|---|---|
| 1 | Read in data of new source and data of new sample. |
| 2 | Read in data of new sample but use the data of the last given source. |
| 3 | Stop. |

The source-sample combination is identified by a numerical designation punched in the second field, the last digit appearing in column 20 and all unused columns being punched "0". The second field, on output, is punched on each answer card and is therefore needed to correlate the output data with the source-sample combination.

(2) Data for the continuum of the source.

The spectral-irradiance data of the continuum of the light source, at 10 millimicron intervals over the wavelength range 380 to 770 millimicrons, are punched in the first seven fields of the card with the exception of the last card which has the first five fields punched. See cards numbers 2 through 7, Appendix D. There must be 40 values of spectral irradiance of the continuum given, one value for each of the 40 wavelengths from 380 to 770 millimicrons, inclusive. If data of spectral irradiance are not available for any particular wavelengths, it is necessary to extrapolate data for these wavelengths. If the extrapolated data are very small in magnitude, zero value may be assigned to the spectral irradiance at those wavelengths. This can be done by punching "0" in all ten columns of that field. There must be six cards for the spectral-irradiance data on the continuum.

(3) Number of spectral lines to be used in the computation.

This card, for example card number 8, Appendix D, tells the computer the number of spectral lines to be used in the computation. Up to 5 spectral lines may be used. At least one spectral line must be used. The card is punched in the first field, columns 1 through 10. A "0" is punched in columns 1 through 9 and the number of lines is punched in column 10.

(4) Wavelengths of the spectral lines present in the source.

The wavelengths, in millimicrons, of the spectral lines present in the source are punched, as in card number 9, Appendix D, in the first five fields of a single card. If less than five wavelengths are present, it is necessary to punch "0" in all ten columns of the unused fields.

(5) Radiant flux data of the spectral lines.

After the wavelengths of all of the spectral lines present in the source have been read into the computer, the radiant flux of each line relative to the continuum is read in. The relative radiant flux of the spectral line is defined as the peak height of the spectroradiometric curve for the spectral line, above the continuum of the source, determined for a slit-width of 10 millimicrons, the wavelength interval used for summation in this program. These data are punched in a single card as in card number 10, Appendix D, in the first five fields of the card. If less than five wavelengths are present, it is necessary to punch "0" in all ten columns of the unused fields. There must be the same number of data of relative radiant flux as there are wavelengths given, and the flux data must be punched in the same order as the wavelength data.

If it is desired to make the colorimetric conversion, ignoring the contribution of the spectral lines, it is necessary only to assign zero-flux values to all of the lines. The condition stated in (3) above, that at least one line must be given, still holds. Thus, a single line must be indicated with its wavelength, but with a zero flux.

(6) Spectral data of the sample.

The spectral directional reflectance or spectral transmittance data of the sample, at 10-millimicron intervals over the wavelength range 380 to 770 millimicrons, are punched in the first seven fields of the card with the exception of the last card which has the first five fields punched. See, for example, cards numbers 11 through 16, Appendix D. There must be 40 values of spectral directional reflectance or spectral transmittance given. If data are not available for any wavelengths, for example 380, 390, 760, or 770 millimicrons, it is necessary to extrapolate values for these wavelengths. There must be six cards of spectral data for the sample.

## III. Coding the data.

The above discussion indicates the way in which the data are to be prepared on punched cards for introduction into the computer. This section will deal with the coding of the data by the scientist or engineer for use by the key-punch operator in preparing the cards. Since the key-punch operator is usually located at the computing center, away from the laboratory, and has no previous knowledge of the problem, it is necessary to write out the data of the problem in a form that the key-punch operator can follow with the least chance of making errors in punching.

It is suggested that the data be written on squared paper or graph paper which is at least 80 squares wide. The squares at the top of the sheet should be numbered from 1 through 80 and the eight fields, 10 columns wide, should be indicated by vertical rulings. A "+" (plus or "12" punch) must be punched in column 73. This can be accomplished by gang-punching the "+" in all cards to be used in the input data deck before they are given to the key-punch operator, or by having the key-punch operator overpunch (put a "12" punch in) column 73 when the whole card is punched.

The arrangement of the data on cards has been covered in II above for the control card and the card indicating the number of spectral lines. For the remaining cards, the data must be entered in the following manner. Data are located in the first seven fields of the card. If negative values are needed for the data, the minus sign is indicated by an "11" overpunch in the units column of the field containing the negative value, for example, columns 10, 20, 30, and so forth. All data must be represented as decimal numbers in the form .xxxxxxxxPP, where "x" represents the data and the "PP" is 50 plus the power of 10 which is needed to shift the decimal point back to its proper position in the original data. The decimal points are never punched. All blank columns must be punched with "0" between columns 1 through 70. Thus, the following examples would be coded as shown.

| Original Data | Equivalent Form | Coded Data |
|---|---|---|
| 1.46 | $.146 \times 10^{1}$ | 1460000051 |
| .146 | $.146 \times 10^{0}$ | 1460000050 |
| .0146 | $.146 \times 10^{-1}$ | 1460000049 |

For coding purposes, the original data on the continuum of the source and the fluxes of the spectral lines are to be considered as numbers on a scale whose maximum is about 100, that is, 96.3 and not 0.963; the original wavelength data are to be considered as always being in millimicrons, that is, for example 404.7 (or any number of decimal places up to five); and the original spectral data of the sample are to be considered as always being in terms of decimal numbers, such as 0.1742.

In addition to the data of the source-sample combinations to be computed, it is necessary to read into the computer the data of the CIE standard observer and the wavelength range, 380 to 770 millimicrons, over which the computations are to be made. In Appendix C are shown the 24 cards which comprise this data-constants deck. Cards numbers 1 through 6 contain the data of the X tristimulus function; 7 through 12, the data of the Y tristimulus function; 13 through 18, the data of the Z tristimulus function; and 19 through 24, the wavelengths for each 10-millimicron interval between 380 and 770 millimicrons. These 24 cards may be made a part of the program deck or be considered as a part of the input data. In either case, care should be taken to see that the data constants are included only once for any pass through the computer.

The arrangement or order of the cards must now be considered since the cards must be in the proper order to insure operation of the program. A generalized discussion follows of the two types of data handling possibilities available with this program and how the cards are arranged.

The first possibility available is to read into the computer a new source and a new sample for each computation. We shall call this Case 1. The computer is informed that Case 1 type of data input is to be used by a "1" punch in column 10 of the control card. The data deck for Case 1 would, in general, look like the following:

| | | |
|---|---|---|
| Control Card | 0000000001 | (in first field) |
| Continuum data | | (6 cards) |
| Number of spectral lines in source | | (1 card) |
| Wavelengths of the spectral lines | | (1 card) |
| Fluxes of the spectral lines | | (1 card) |
| Spectral data of the sample | | (6 cards). |

The data deck of the type for Case 1 is always used for the first source-sample combination of a particular series of computations since it is the only possibility which allows the computer to read in both a new source and a new sample.

The second possibility available is to read into the computer only the data for a new sample and perform the computation using the source which was last read in. We shall call this Case 2. A "2" punch in column 10 tells the computer to save in memory the last source read into the computer and use it with the new sample data which will be read in to perform this computation. The data deck for Case 2 would, in general, look like the following:

| | | |
|---|---|---|
| Control Card | 0000000002 | (in first field) |
| Spectral data on sample | | (6 cards). |

After all of the data to be computed have been read into the computer and the computations performed, it is necessary to inform the computer that the problem is finished. This is done by placing a card, with "0000000003" punched in the first field, and "0000000000" in the second field, after the last data card in the data deck. This we shall call Case 3. When this card is reached and read into the computer, a transfer is made to a stop instruction in the program and no further instructions are available to the computer.

Thus, a complete deck might, in general terms, look something like the following:

Program Deck
X (read in X tristimulus function)
Y (read in Y tristimulus function)
Z (read in Z tristimulus function)
Lambda (read in wavelengths 380, 390, ..., 760, 770)
Case 1 (read in source M and sample A)
Case 1 (read in source N and sample B)
Case 2 (read in sample C, use source N)
Case 2 (read in sample D, use source N)
Case 2 (read in sample E, use source N)
Case 1 (read in source O and sample F)
Case 2 (read in sample G, use source O)
Case 3 (stop).

The data used to check this program, listed in Appendix D, show how an actual problem was set up for running in the computer. The problem in Appendix D is really 5 sub-problems which are identified in columns 19 and 20 of the control cards as sub-problems 9 through 13. Sub-problem 9 covers cards numbers 1 through 16. This is a Case 1 type of data input (note the "1" punch in column 10 of card number 1) introducing a new source and a new sample. Sub-problems 10 and 11 cover cards numbers 17 through 32 and 33 through 48, respectively. The data input for both of these is of the Case 1 type. Sub-problems 12 and 13, cards numbers 49 through 55 and 56 through 62, respectively, are recomputations of sub-problems 10 and 11 respectively but of the Case 2 type of data input using the data of the source read in for sub-problem 11. Sub-problem 13 is the last conversion to be made during this run on the computer, and therefore, following the last data card of sub-problem 13, which is card number 62, we have the Case 3 card (card number 63) which tells the computer that it has reached the last card of this computing problem and that it is to stop.

## IV. Operation of IBM 650 computer.

The following sequence of operations will cause the computer to execute the complete computation, provided no errors are present in the data deck.

1) Set the console as follows:

| | | |
|---|---|---|
| Storage Entry: | 70 1952 9999 | |
| Switches: | Programmed | STOP |
| | Half Cycle | RUN |
| | Control | RUN |
| | Display | UPPER |
| | Overflow | SENSE |
| | Error | STOP |

2) Insert FOR TRANSIT 533 control panel.

3) Load blank cards in punch hopper.

4) Set Storage Entry Sign Switch to PLUS.

5) Load program deck into read hopper.

6) Load input data deck into read hopper arranged in the order given in III. Coding the data, above, behind the program deck and add three blank cards after the deck.

7) Press "RESET" key on console.

8) Press "PROGRAM START" key on console.

The computer reads in the program deck, the CIE tristimulus function data, the wavelengths, and the first source-sample combination, performs the computation, punches the answer card, then reads the second source-sample combination, and so forth until the last card is reached.

## V. Form of the output data.

The results of the computations are punched on a single card for each source-sample combination. In Appendix E is given a listing of the answer cards resulting from the computations performed with the data shown in Appendix D. As in Appendix D, the column numbers are included for reference as the first two lines at the top of the page. They are not punched out in the normal running of the program.

It will be noted in Appendix E that the data are located in the first seven fields of the card. The data are punched out in the following order: X, first field; Y, second field; Z, third field; x, fourth field; y, fifth field; z, sixth field; and identification, seventh field. The identification which is punched in the seventh field on output is the same number as punched in the second field of the control card on input, and this number therefore correlates the results with the proper source-sample combination.

## VI. Summary.

A computer program has been described which will allow the conversion of spectral directional reflectance or spectral transmittance data of a sample illuminated by any light source, including sources, such as fluorescent lamps, which contain spectral lines. A detailed description of how the various data are to be prepared for introduction into the computer has been given together with a description of the output data from the computer. The program has been completely checked and is able to complete each source-sample combination in an average time of approximately 1 minute 15 seconds per case. Read-in time for the program deck is approximately 5 minutes.

## VII. Acknowledgments.

We wish to thank Dr. V. H. Nicholson and Miss Audrey A. Illig of the U. S. Department of Agriculture computing center for their assistance in assembling and checking this program on the IBM 650 computer. We also thank Miss Dorothy Nickerson, Cotton Division, Agricultural Marketing Service, USDA, for arranging for and furnishing computer time on the USDA computer.

## VIII. Bibliography.

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[2] Judd, D. B., Extension of the standard visibility function to intervals of 1 millimicron by third-difference osculatory interpolation. J. Res. NBS 6, 465 (1931), RP289; also J. Opt. Soc. Am. 21, 267 (1931).

[3] IBM Programmer's Reference Manual, FOR TRANSIT automatic coding system for the IBM 650, Preliminary Manual for revised edition, September, 1958, International Business Machines Corporation, 590 Madison Ave., New York 22, N. Y. (1957).

[4] IBM General Information Manual, Programmer's primer for FORTRAN automatic coding system for the IBM 704 data processing system, International Business Machines Corporation, 590 Madison Avenue, New York 22, N. Y. (1957).

[5] IBM Reference Manual, FORTRAN automatic coding system for the IBM 704 data processing system, International Business Machines Corporation, 590 Madison Avenue, New York 22, N. Y. (1958).

[6] IBM Reference Manual, FORTRAN II for the IBM 704 data processing system, International Business Machines Corporation, 590 Madison Avenue, New York 22, N. Y. (1958).

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## APPENDIX A

Listing of the source program which was assembled by the FOR TRANSIT I(S) system. This assembly produced the program to be used on the IBM 650 computer.

```
C       SPECTRAL LINE COLORIMETRY
C       PROJECT NO.60-449
C       J.P.MENARD     650-CODE
      1 DIMENSIONA(40),B(40),C(40),
       1T(40),AA(5),BB(5),CC(5),
       2TT(5),WLL(40),WL( ),WK(5),
       3S(40)
     40 READ,A
     45 READ,B
     50 READ,C
     55 READ,WLL
     60 READ 10,NN,M
     65 GO TO (70,90,560),NN
     70 READ,S
     75 READ  10,N
     80 READ,WL
     85 READ,WK
     90 READ,T
    100 J=1
    105 DO 135 I=1,N
    110 IF(WL(I)-WLL(1))560,115,305
    115 AA(I)=A(J)
    120 BB(I)=B(J)
    125 CC(I)=C(J)
    130 TT(I)=T(J)
    135 CONTINUE
    140 EXX=0.0
    145 EYY=0.0
    150 EZZ=0.0
    155 EVV=0.0
    160 DO 185I=1,40
    165 D=S(I)*T(I)
    170 EXX=EXX+A(I)*D
    175 EYY=EYY+B(I)*D
    180 EZZ=EZZ+C(I)*D
    185 EVV=EVV+B(I)*S(I)
    190 DO 215I=1,N
    195 D=WK(I)*TT(I)
    200 EXX=EXX+AA(I)*D
    205 EYY=EYY+BB(I)*D
    210 EZZ=EZZ+CC(I)*D
    215 EVV=EVV+BB(I)*WK(I)
    220 EX=EXX/EVV
    225 EY=EYY/EVV
    230 EZ=EZZ/EVV
    235 D=EXX+EYY+EZZ
    240 EXX=EXX/D
    245 EYY=EYY/D
    250 EZZ=EZZ/D
    260 PUNCH 16,EX,EY,EZ,
       1EXX,EYY,EZZ,M
    300 GO TO 60
    305 IF(WL(I)-WLL(2))310,340,350
    310 J=1
    311 D=(WL(I)-WLL(J))/
```

```
     1(WLL(J+1)-WLL(J))
 315 AA(I)=A(J)+D*(A(J+1)-A(J))
 320 BB(I)=B(J)+D*(B(J+1)-B(J))
 325 CC(I)=C(J)+D*(C(J+1)-C(J))
 330 TT(I)=T(J)+D*(T(J+1)-T(J))
 335 GO TO 135
 340 J=2
 345 GO TO 115
 350 IF(WL(I)-WLL(40))355,545,560
 355 IF(WL(I)-WLL(39))360,525,535
 360 IF(WL(I)-WLL(J+1))365,505,515
 365 D=(WL(I)-WLL(J))/
     1(WLL(J+1)-WLL(J))
 370 NN=0
 375 AM1=A(J-1)
 380 A0=A(J)
 385 A1=A(J+1)
 390 A2=A(J+2)
 395 GO TO 600
 400 AA(I)=AAA
 410 AM1=B(J-1)
 415 A0=B(J)
 420 A1=B(J+1)
 425 A2=B(J+2)
 430 GO TO 600
 435 BB(I)=AAA
 440 AM1=C(J-1)
 445 A0=C(J)
 450 A1=C(J+1)
 455 A2=C(J+2)
 460 GO TO 600
 465 CC(I)=AAA
 470 AM1=T(J-1)
 475 A0=T(J)
 480 A1=T(J+1)
 485 A2=T(J+2)
 490 GO TO 600
 495 TT(I)=AAA
 500 GO TO 135
 505 J=J+1
 510 GO TO 115
 515 J=J+1
 520 GO TO 360
 525 J=39
 530 GO TO 115
 535 J=39
 540 GO TO 311
 545 J=40
 550 GO TO 115
 560 STOP
 600 AAA=(D/2.0)*(A2-3.0
     1*A1+3.0*A0-AM1)
 601 AAA=(AAA+(2.0*AM1-5.0
     1*A0+4.0*A1-A2)/2.0)*D
 602 AAA=(AAA+(A1-AM1)/2.0)
```

```
     1*D+A0
 610 NN=NN+1
 620 GO TO (400,435,465,495),NN
     END
```

## APPENDIX B

Listing of the modified source program which was assembled by the FORTRAN II system. This assembly produced a program to be used on the IBM 704 computer in simulation of the IBM 650 computer and served as a program check.

```
C       SPECTRAL LINE COLORIMETRY
C       PROJECT NO.60-449
C       J.P.MENARD     650-CODE
      1 DIMENSIONA(40),B(40),C(40),
       1T(40),AA(5),BB(5),CC(5),
       2TT(5),WLL(40),WL(5),WK(5),
       3S(40)
     10 FORMAT(2I10)
     12 FORMAT(7F10.5)
     16 FORMAT(6F10.5,I10)
     40 READ 12,(A(I),I=1,40)
     45 READ 12,(B(I),I=1,40)
     50 READ  12,(C(I),I=1,40)
     55 READ  12,(WLL(I),I=1,40)
     60 READ 10,NN,M
     65 GO TO (70,90,560),NN
     70 READ  12,(S(I),I=1,40)
     75 READ  10,N
     80 READ  12,(WL(I),I=1,N)
     85 READ 12,(WK(I),I=1,N)
     90 READ  12,(T(I),I=1,40)
    100 J=1
    105 DO 135 I=1,N
    110 IF(WL(I)-WLL(1))560,115,305
    115 AA(I)=A(J)
    120 BB(I)=B(J)
    125 CC(I)=C(J)
    130 TT(I)=T(J)
    135 CONTINUE
    140 EXX=0.0
    145 EYY=0.0
    150 EZZ=0.0
    155 EVV=0.0
    160 DO 185I=1,40
    165 D=S(I)*T(I)
    170 EXX=EXX+A(I)*D
    175 EYY=EYY+B(I)*D
    180 EZZ=EZZ+C(I)*D
    185 EVV=EVV+B(I)*S(I)
    190 DO 215I=1,N
    195 D=WK(I)*TT(I)
    200 EXX=EXX+AA(I)*D
    205 EYY=EYY+BB(I)*D
    210 EZZ=EZZ+CC(I)*D
    215 EVV=EVV+BB(I)*WK(I)
    220 EX=EXX/EVV
    225 EY=EYY/EVV
    230 EZ=EZZ/EVV
    235 D=EXX+EYY+EZZ
    240 EXX=EXX/D
    245 EYY=EYY/D
    250 EZZ=EZZ/D
    260 PUNCH 16,EX,EY,EZ,
       1EXX,EYY,EZZ,M
    300 GO TO 60
```

```
305 IF(WL(I)-WLL(2))310,340,350
310 J=1
311 D=(WL(I)-WLL(J))/
   1(WLL(J+1)-WLL(J))
315 AA(I)=A(J)+D*(A(J+1)-A(J))
320 BB(I)=B(J)+D*(B(J+1)-B(J))
325 CC(I)=C(J)+D*(C(J+1)-C(J))
330 TT(I)=T(J)+D*(T(J+1)-T(J))
335 GO TO 135
340 J=2
345 GO TO 115
350 IF(WL(I)-WLL(40))355,545,560
355 IF(WL(I)-WLL(39))360,525,535
360 IF(WL(I)-WLL(J+1))365,505,515
365 D=(WL(I)-WLL(J))/
   1(WLL(J+1)-WLL(J))
370 NN=0
375 AM1=A(J-1)
380 A0=A(J)
385 A1=A(J+1)
390 A2=A(J+2)
395 GO TO 600
400 AA(I)=AAA
410 AM1=B(J-1)
415 A0=B(J)
420 A1=B(J+1)
425 A2=B(J+2)
430 GO TO 600
435 BB(I)=AAA
440 AM1=C(J-1)
445 A0=C(J)
450 A1=C(J+1)
455 A2=C(J+2)
460 GO TO 600
465 CC(I)=AAA
470 AM1=T(J-1)
475 A0=T(J)
480 A1=T(J+1)
485 A2=T(J+2)
490 GO TO 600
495 TT(I)=AAA
500 GO TO 135
505 J=J+1
510 GO TO 115
515 J=J+1
520 GO TO 360
525 J=39
530 GO TO 115
535 J=39
540 GO TO 311
545 J=40
550 GO TO 115
560 STOP
600 AAA=(((D/2.0)*(A2-3.0*A1+3.0*
   1A0-AM1)+(2.0*AM1-5.0*A0+4.0*
```

```
      1A1-A2)/2.0)*D+(A1-AM1)/2.0)*
      1D+A0
  610 NN=NN+1
  620 GO T) (400,435,465,495),NN
      END(0,0,1,1,0)
```

## APPENDIX C

A listing of the data constants
required by the program.

| 0000000001 | 1111111112 | 2222222223 | 3333333334 | 4444444445 | 5555555556 | 6666666667 | 7777777778 |
|---|---|---|---|---|---|---|---|
| 1234567890 | 1234567890 | 1234567890 | 1234567890 | 1234567890 | 1234567890 | 1234567890 | 1234567890 |
| 1400000052 | 4200000052 | 1430000053 | 4350000053 | 1344000054 | 2839000054 | 3483000054 | +01 |
| 3362000054 | 2908000054 | 1954000054 | 9560000053 | 3200000053 | 4900000052 | 9300000052 | +02 |
| 6330000053 | 1655000054 | 2904000054 | 4334000054 | 5945000054 | 7621000054 | 9163000054 | +03 |
| 1026300055 | 1062200055 | 1002600055 | 8544000054 | 6424000054 | 4479000054 | 2835000054 | +04 |
| 1649000054 | 8740000053 | 4680000053 | 2270000053 | 1140000053 | 5800000052 | 2900000052 | +05 |
| 1400000052 | 7000000051 | 3000000051 | 2000000051 | 1000000051 | | | +06 |
| 0000000000 | 1000000051 | 4000000051 | 1200000052 | 4000000052 | 1160000053 | 2300000053 | +07 |
| 3800000053 | 6000000053 | 9100000053 | 1390000054 | 2080000054 | 3230000054 | 5030000054 | +08 |
| 7100000054 | 8620000054 | 9540000054 | 9950000054 | 9950000054 | 9520000054 | 8700000054 | +09 |
| 7570000054 | 6310000054 | 5030000054 | 3810000054 | 2650000054 | 1750000054 | 1070000054 | +10 |
| 6100000053 | 3200000053 | 1700000053 | 8200000052 | 4100000052 | 2100000052 | 1000000052 | +11 |
| 5000000051 | 3000000051 | 1000000051 | 1000000051 | 0000000000 | | | +12 |
| 6500000052 | 2010000053 | 6790000053 | 2074000054 | 6456000054 | 1385600055 | 1747100055 | +13 |
| 1772100055 | 1669200055 | 1287600055 | 8130000054 | 4652000054 | 2720000054 | 1582000054 | +14 |
| 7820000053 | 4220000053 | 2030000053 | 8700000052 | 3900000052 | 2100000052 | 1700000052 | +15 |
| 1100000052 | 8000000051 | 3000000051 | 2000000051 | 0000000000 | 0000000000 | 0000000000 | +16 |
| 0000000000 | 0000000000 | 0000000000 | 0000000000 | 0000000000 | 0000000000 | 0000000000 | +17 |
| 0000000000 | 0000000000 | 0000000000 | 0000000000 | 0000000000 | | | +18 |
| 3800000053 | 3900000053 | 4000000053 | 4100000053 | 4200000053 | 4300000053 | 4400000053 | +19 |
| 4500000053 | 4600000053 | 4700000053 | 4800000053 | 4900000053 | 5000000053 | 5100000053 | +20 |
| 5200000053 | 5300000053 | 5400000053 | 5500000053 | 5600000053 | 5700000053 | 5800000053 | +21 |
| 5900000053 | 6000000053 | 6100000053 | 6200000053 | 6300000053 | 6400000053 | 6500000053 | +22 |
| 6600000053 | 6700000053 | 6800000053 | 6900000053 | 7000000053 | 7100000053 | 7200000053 | +23 |
| 7300000053 | 7400000053 | 7500000053 | 7600000053 | 7700000053 | | | +24 |

## APPENDIX D

A listing of typical input data cards. (Note: The column numbers appearing as the first two lines on each page are not a part of the input data. They serve in this appendix only to index the 80 columns available on each card.)

| 0000000001 | 1111111112 | 2222222223 | 3333333334 | 4444444445 | 5555555556 | 6666666667 | 7777777778 |
|---|---|---|---|---|---|---|---|
| 1234567890 | 1234567890 | 1234567890 | 1234567890 | 1234567890 | 1234567890 | 1234567890 | 1234567890 |
| 0000000001 | 0000000009 | | | | | | +01 |
| 7000000051 | 1400000052 | 2020000052 | 2450000052 | 2740000052 | 3000000052 | 3150000052 | +02 |
| 3190000052 | 3090000052 | 2920000052 | 2650000052 | 2500000052 | 2490000052 | 2750000052 | +03 |
| 3220000052 | 3300000052 | 3220000052 | 3200000052 | 3380000052 | 3630000052 | 3680000052 | +04 |
| 3480000052 | 3080000052 | 2550000052 | 2040000052 | 1590000052 | 1250000052 | 9000000051 | +05 |
| 6400000051 | 4200000051 | 2400000051 | 1200000051 | 3000000050 | 0000000000 | 0000000000 | +06 |
| 0000000000 | 0000000000 | 0000000000 | 0000000000 | 0000000000 | | | +07 |
| 0000000004 | | | | | | | +08 |
| 4047000053 | 4358000053 | 5461000053 | 5778000053 | 0000000000 | | | +09 |
| 1860000052 | 4950000052 | 2580000052 | 5500000051 | 0000000000 | | | +10 |
| 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | +11 |
| 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | +12 |
| 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | +13 |
| 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | +14 |
| 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | +15 |
| 1000000051 | 1000000051 | 1000000051 | 1000000051 | 1000000051 | | | +16 |
| 0000000001 | 0000000010 | | | | | | +17 |
| 7000000051 | 1400000052 | 2020000052 | 2450000052 | 2740000052 | 3000000052 | 3150000052 | +18 |
| 3190000052 | 3090000052 | 2920000052 | 2650000052 | 2500000052 | 2490000052 | 2750000052 | +19 |
| 3220000052 | 3300000052 | 3220000052 | 3200000052 | 3380000052 | 3630000052 | 3680000052 | +20 |
| 3480000052 | 3080000052 | 2550000052 | 2040000052 | 1590000052 | 1250000052 | 9000000051 | +21 |
| 6400000051 | 4200000051 | 2400000051 | 1200000051 | 3000000050 | 0000000000 | 0000000000 | +22 |
| 0000000000 | 0000000000 | 0000000000 | 0000000000 | 0000000000 | | | +23 |
| 0000000004 | | | | | | | +24 |
| 4047000053 | 4358000053 | 5461000053 | 5778000053 | 0000000000 | | | +25 |
| 1860000052 | 4950000052 | 2580000052 | 5500000051 | 0000000000 | | | +26 |
| 1660000050 | 1590000050 | 1490000050 | 1330000050 | 1270000050 | 1190000050 | 1150000050 | +27 |
| 1110000050 | 1050000050 | 1010000050 | 9900000049 | 9600000049 | 9400000049 | 9400000049 | +28 |
| 9500000049 | 9500000049 | 9700000049 | 1050000050 | 1170000050 | 1420000050 | 1930000050 | +29 |
| 2880000050 | 4320000050 | 5830000050 | 6530000050 | 6830000050 | 6970000050 | 7080000050 | +30 |
| 7180000050 | 7230000050 | 7270000050 | 7330000050 | 7400000050 | 7440000050 | 7490000050 | +31 |
| 7530000050 | 7560000050 | 7580000050 | 7590000050 | 7600000050 | | | +32 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0000000001 | 1111111112 | 2222222223 | 3333333334 | 4444444445 | 5555555556 | 6666666667 | 7777777778 | |
| 1234567890 | 1234567890 | 1234567890 | 1234567890 | 1234567890 | 1234567890 | 1234567890 | 1234567890 | |
| 0000000001 | 0000000011 | | | | | | | +33 |
| 7000000051 | 1400000052 | 2020000052 | 2450000052 | 2740000052 | 3000000052 | 3150000052 | | +34 |
| 3190000052 | 3090000052 | 2920000052 | 2650000052 | 2500000052 | 2490000052 | 2750000052 | | +35 |
| 3220000052 | 3300000052 | 3220000052 | 3200000052 | 3380000052 | 3630000052 | 3680000052 | | +36 |
| 3480000052 | 3080000052 | 2550000052 | 2040000052 | 1590000052 | 1250000052 | 9000000051 | | +37 |
| 6400000051 | 4200000051 | 2400000051 | 1200000051 | 3000000050 | 0000000000 | 0000000000 | | +38 |
| 0000000000 | 0000000000 | 0000000000 | 0000000000 | 0000000000 | | | | +39 |
| 0000000004 | | | | | | | | +40 |
| 4047000053 | 4358000053 | 5461000053 | 5778000053 | 0000000000 | | | | +41 |
| 1860000052 | 4950000052 | 2580000052 | 5500000051 | 0000000000 | | | | +42 |
| 5400000049 | 5400000049 | 5400000049 | 5500000049 | 5500000049 | 5400000049 | 5400000049 | | +43 |
| 5400000049 | 5400000049 | 5600000049 | 6400000049 | 7000000049 | 7700000049 | 8800000049 | | +44 |
| 9700000049 | 1010000050 | 1160000050 | 1430000050 | 1920000050 | 2630000050 | 3270000050 | | +45 |
| 3590000050 | 3660000050 | 3660000050 | 3580000050 | 3490000050 | 3410000050 | 3380000050 | | +46 |
| 3410000050 | 3530000050 | 3760000050 | 4090000050 | 4420000050 | 4770000050 | 4960000050 | | +47 |
| 5050000050 | 5120000050 | 5130000050 | 5140000050 | 5140000050 | | | | +48 |
| 0000000002 | 0000000012 | | | | | | | +49 |
| 1660000050 | 1590000050 | 1490000050 | 1330000050 | 1270000050 | 1190000050 | 1150000050 | | +50 |
| 1110000050 | 1050000050 | 1010000050 | 9900000049 | 9600000049 | 9400000049 | 9400000049 | | +51 |
| 9500000049 | 9500000049 | 9700000049 | 1050000050 | 1170000050 | 1420000050 | 1930000050 | | +52 |
| 2880000050 | 4320000050 | 5830000050 | 6530000050 | 6830000050 | 6970000050 | 7080000050 | | +53 |
| 7180000050 | 7230000050 | 7270000050 | 7330000050 | 7400000050 | 7440000050 | 7490000050 | | +54 |
| 7530000050 | 7560000050 | 7580000050 | 7590000050 | 7600000050 | | | | +55 |
| 0000000002 | 0000000013 | | | | | | | +56 |
| 5400000049 | 5400000049 | 5400000049 | 5500000049 | 5500000049 | 5400000049 | 5400000049 | | +57 |
| 5400000049 | 5400000049 | 5600000049 | 6400000049 | 7000000049 | 7700000049 | 8800000049 | | +58 |
| 9700000049 | 1010000050 | 1160000050 | 1430000050 | 1920000050 | 2630000050 | 3270000050 | | +59 |
| 3590000050 | 3660000050 | 3660000050 | 3580000050 | 3490000050 | 3410000050 | 3380000050 | | +60 |
| 3410000050 | 3530000050 | 3760000050 | 4090000050 | 4420000050 | 4770000050 | 4960000050 | | +61 |
| 5050000050 | 5120000050 | 5130000050 | 5140000050 | 5140000050 | | | | +62 |
| 0000000003 | 0000000000 | | | | | | | +63 |

## APPENDIX E

A listing of answer cards resulting from the computations using the data of Appendix D. (Note: The column numbers appearing as the first two lines on the page are not punched out on output. They serve as reference only in this appendix.

```
0000000001 1111111112 2222222223 3333333334 4444444445 5555555556 6666666667 7777777778
1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1234567890

9198677350 1000000051 1118828751 3027178950 3290884950 3681936650 0000000009 0000010260
2524992750 1888338250 1246576550 4461190950 3336341250 2202468150 0000000010 0000020260
2236982250 2063675350 6360720049 4531303850 4180247950 1288448150 0000000011 0000030260
2524992750 1888338250 1246576550 4461190950 3336341250 2202468150 0000000012 0000040260
2236982250 2063675350 6360720049 4531303850 4180247950 1288448150 0000000013 0000050260
```

U.S. DEPARTMENT OF COMMERCE
Frederick H. Mueller, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

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**Electricity and Electronics.** Resistance and Reactance. Electron Devices. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

**Optics and Metrology.** Photometry and Colorimetry. Photographic Technology. Length. Engineering Metrology.

**Heat.** Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Molecular Kinetics. Free Radicals Research.

**Atomic and Radiation Physics.** Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Radiation Theory. Radioactivity. X-rays. High Energy Radiation. Nucleonic Instrumentation. Radiological Equipment.

**Chemistry.** Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

**Mechanics.** Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

**Organic and Fibrous Materials.** Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

**Metallurgy.** Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

**Mineral Products.** Engineering Ceramics. Glass. Refractories. Enameled Metals. Constitution and Microstructure.

**Building Technology.** Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer. Concreting Materials.

**Applied Mathematics.** Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

**Data Processing Systems.** SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Application Engineering.

- Office of Basic Instrumentation.
- Office of Weights and Measures.

## BOULDER, COLORADO

**Cryogenic Engineering.** Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

**Radio Propagation Physics.** Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships. VHF Research. Radio Warning Services. Airglow and Aurora. Radio Astronomy and Arctic Propagation.

**Radio Propagation Engineering.** Data Reduction Instrumentation. Modulation Research. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation Obstacles Engineering. Radio-Meteorology. Lower Atmosphere Physics.

**Radio Standards.** High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Electronic Calibration Center. Microwave Physics. Microwave Circuit Standards.

**Radio Communication and Systems.** Low Frequency and Very Low Frequency Research. High Frequency and Very High Frequency Research. Ultra High Frequency and Super High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Systems Analysis. Field Operations.

NBS