# NATIONAL BUREAU OF STANDARDS REPORT 

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IBM 704 Computer Program for CIE Color Specifications of Objects<br>Illuminated by Sources Having Continuous Plus Line Spectra

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# U. S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS 

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## U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

# IBM 704 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 704 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[I].* 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 40 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 intensities 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.

Several possibilities for handing 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, (2) a number of samples relative to the same source, or (3)' the same sample relative to a number of sources.

The resulting data of the computations are punched on four cards per sample giving the identification, tristimulus values, and chromaticity coordinates of the sourcessample combination.

A complete listing of the Fortran code [3, 4], together with the data constants, is shown in Appendix $A$. The program deck, supplied with these instructions, is this Fortran code assembled in tmachine language ${ }^{\text {fi }}$ on a 32,000 word memory IBM 704 computer [5], using the Fortran II compiling program [6].

The code should be usable on a smaller IBM 704 computer, that is, a computer having either 4,000 or 8,000 words of memory; however, it has not been checked out on either of the smaller computers.

[^0]The computing program has been checked against data computed manually on desk calculators. The results of the two sets of calculations agree exactly to five decimal places, the maximum number of decimal places given in the output data of the computer.

The running time on the computer, after the program deck has been loaded, is approximately 5 seconds per source-sample combination.

## II. Form of the input data.

The input data are punched on standard 80 column IBM cards [6] and arranged in the following order.
(1) Identification.
(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 is punched in the first 72 columns of the cards in accord with specific formats to be described in detail later in this section. Columas 73 to 80 are not read by the computer and may be used to number the cards sequentially, or for other identifying information.

In Appendix $C$ 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 $C$ 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 73 through 75. These card numbers will be used in the description which follows for each type of input data format.

## (1) Identification card.

The identification card (cards numbers $1,21,41,61,81$, 90,99 and 119 , Appendix C, serve to identify the input and output data with a particular sourcessample combination, and also serve to control transfers within the program, depending upon the input data to be used.

An alphabetic or numeric identification of the source-sample combination is punched in columns 1 through 60.
$\left.A^{\prime \prime \prime}\right]^{\prime \prime}$ "2", "3", or "4" is punched in column 64. These numbers serve as the control'for transfers within the program and have the following significance.

| Number in <br> Column 64 | Significance <br> Read in data of new source and data of <br> new sample. |
| :---: | :---: |
| 2 | Read in data of new sample but use the <br> data of the last given source. |
| 3 | Read in data of new source but use the <br> data of the last given sample. |
| 4. | Stop |

A numerical identification number or sample sequencing number, having a value less than 32,768 , is punched in columns 68 to 72 , with the last digit appearing in column 72. The numbers in columns 68 to 72 are punched, on output, on each answer card and therefore are needed to correlate the output data with the proper output identification card.

## (2) Data for continuum of the source.

The spectral-irradiance data of the continuum of the light source, at lo-millimicron intervals over the wavelength range 380 to' 770 millimicrons, are punched in five fields per card as numbers, on a scale whose maximum is about 100 that is for example 96.3 and not 0.963. A field of a punch card is a specific number of columns in which data may be placed. The data are punched on cards so that the decimal points are in columns 6, $20,34,48$, and 62. See, for example, cards numbers 2 through 9, Appendix' $C$. 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 wavé lengths. There must be eight cards for the spectral irradiance data on the continuum punched five fields to the card.
(3) Number of spectral lines to be used in the computation.

This card tells the computer the number of spectral lines to be used in the computation. Up to 40 spectral lines may be used. At
least one spectral line must be used. The card, for example card number 10, Appendix C, is punched in columns 9 and 10 with the number count of the spectral lines used, with the last digit of the number in column 10. As an example, if four spectral lines are present in the source under consideration, a ${ }^{10} 4$ is punched in column 10. If ten spectral lines were present in the source, a "1* would be punched in column 9 and a "0 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 11, Appendix $C$, so that the decimal points fall in columns $6,20,34,48$, and 62 . The values of the wavelengths can be given to any number of decimal places up to eight. The number of cards needed will depend upon the number of spectral lines present in the source. The cards are punched, five wavelengths per card, with up to 40 wavelengths allowed, or a maximum of eight cards. If the number of wavelengths present in the source is less than an even multiple of 5 , the last card is punched so that the blank fields are to the right of the last punched field. Note on card ll, Appendix C, that only 4 wavelengths are given. The values of the wavelengths are punched in the first four fields with the fifth field blank.

## (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 slitwwidth of 10 millimicrons, the wavelength interval used for summation in this program. These data are punched in cards using the same format as was used for the data on the continuum of the source, that is, as numbers on a scale whose maximum is about 100, five fields per card, with the decimal points in columns $6,20,34,48$, and 62 , as shown on card number 12 , Appendix C. 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 zeroflux 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 five fields per card as decimal numbers, that is for example 0.1742 , as shown on cards numbers 13 through 20 or 33 through 40, Appen dix C. The data are punched so that the decimal points are in columns $6,20,34$, 48 , and 62. There must be 40 values of spec tral 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 eight cards of spectral data of the sample with five fields per card.

## 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 such form that the keyo punch operator can follow with the least chance of making errors in punching.

It is suggested that the IBM Fortran Coding Form (IBM Form 94-7999-0) be used for coding the data since this form has the column numbers given at the head of each column and thus makes the counting and spacing problem much easier. A copy of this form is shown in Appendix B.

The arrangement of the data on the cards has been fully covered in II above; however, the arrangement or order of the cards is also very important to insure operation of the program. A generalized discussion follows of the three types of data handling possibilities available with this program and how the cards are arranged.

The first possibility available is to read into the come puter a new source and a new sample for each computation. We shall call this Case 1. The computer is informed that the Case 1 type of date input is to be used by a "1" punch in column 64 of the identification card. The data deck for Case 1 would, in general, look like the following:

Identification Continuum data
Number of spectral lines in source
l (in golumn 64)
( 8 cards)
(1 card)

Wavelengths of the spectral lines (l or more cards) Fluxes of the spectral lines ( 1 or more cards) Spectral data of the sample. (8 cards)

The data deck of the type for Case 1 is always used for the first sourcessample combination of a particular series of computations since $1 t$ 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 64 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:

> Identification Spectral data of the sample. $2\left(\begin{array}{l}\text { (in column } 64) \\ (8 \text { cards })\end{array}\right.$

The third possibility available is to read into the computer only the data for a new source and perform the computation using the sample which was last given. We shall call this Case 3. For this case, a " 3 punch in column 64 informs the computer to save in memory the last sample read into the computer and use it with the new source data which will be read in to perform the computation. The data deck for Case 3 would, in general, look like the following:

> Identification Continuum data Number of spectral lines in source Wavelengths of spectral lines
> Fluxes of spectral lines
3 (in column 64)
( 8 cards)
(1 card)
(l or more cards)
(l or more 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 a " 4 " punch in column 64 after the last data card in the data deck. This we shall call Case 4. 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 data deck might in general terms look something like the following:

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Case 1 (read in source $U$ and sample A)
Case 1 (read in source $V$ and sample B)
Case 2 (read in sample $C$, use source $V$ )
Case 2 (read in sample D, use source V)
Case 2 (read in sample $E$, use source V)
Case (read in source $W$, and sample F)
Case 3 (read in source $X$, use sample F)
Case 3 (read in source $Y$, use sample F)
Case 2 (read in sample $G$, use source Y)
Case 3 (read in source $Z$, use sample G)
Case 4 (stop).

The data used to check this program, listed in Appendix C, show how an actual problem was set up for running in the computer. The problem in Appendix $C$ is really 8 suboproblems and these subeproblems are numbered in column 72 of the identification cards. Suboproblem 1 covers cards numbers 1 through 20. This is a Case 1 type, (note "1" in column 64) introducing a new source and a new sample. Subeproblem 2 and suboproblem 3 cover cards numbers 21 through 40 and 41 through 60, respectively. The data input for both of these is of the Case lype. Subo problem 4 (cards numbers 61 through 80) introduces a new source, the normalized standard fluorescent rather than the unnormalized standard fluorescent used in subeproblems 1, 2, and 3, and also introduces a new sample. This is therefore, a case 1 type of data input. Note the "l" punch in column 64 of the identification card (card number 61). For sub-problems 5 and 6, (cards numbers 81 through 89 and 90 through 98 , respectively) the same source as was used for subw problem 4 is to be used with two new samples. These are therefore Case 2 types of data input and a "2"punch is present in column 64 of the identification cards (cards numbers 81 and 90). For sub-problem 7 (cards numbers 99 through 118) a new source is to be read into the computer, the unnormalized deluxe fluorescent, and another sample is to be read in. This is again a Case 1 type of input and the "1" punch appears in column 64 of the identification card, card number 99. For sub-problem 8, (cards numbers 119 through'130) another source, normalized deluxe fluorescent, is to be used in the computation, but the same sample as was used for sub-problem 7 is to be used. This is a Case 3 type of data input and a " 3 " punch is present in column 64 of the identification card, card number 119. Subproblem 8 is the last conversion to be made during this run on the computer, and therefore following the last data card of subeproblem 8 , which is card number 130 , we have the Case 4 card or a card having a "4" punch in column 64 (card number 131)。 Card number 131 tells the computer that it has reached the last card of this computing problem and the computer is to stop.

It should be noted that the example given in Appendix C is not in the optimum form for data processing. These data were made up to check the computer program without regard to the length of time required to perform the computations. Since the reading of the cards is about the slowest operation performed by the computer, it is desirable to reduce the number of cards to be read to a minimum. It is therefore suggested that the coder consider the data to be processed carefully and make use of as many Case 2 and Case 3 types of data input as possible.

## IV. Operation of IBM 704 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) Load binary program deck into card reader.
2) Load input data deck into card reader arranged in the order given in III.Coding the Data, above, behind the program deck and add two blank cards after the deck.
3) Ready on-line card punch and load blank cards.
4) Press ${ }^{\text {mCLEAR }}$ key on console to clear memory of computer.
5) Press "START" key on console.

No sense switches are used. The computer reads in the program deck, reads in the first source-sample combination, performs the computation, punches the answer cards, 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 four cards per source-sample combination. In Appendix D is given a listing of the answer cards resultant from the computations performed with the data shown in Appendix C. As in Appendix C, 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.

The identification card is punched on output exactly as it appeared on input. Following the identification card are three cards of output data. The output data are in three fields havo ing the decimal points in columns 6,15 , and 24 . The data given
in each field of the card are identified by the number in column 1 of the answer card. The significance of the number in the first column is as follows:

| Number in <br> First Column | First <br> Field | Second <br> Field | Third <br> Field |
| :---: | :---: | :---: | :---: |
| 0 | X | Y | Z |
| 1 | X | y | Z |
| 2 | X | y | Y |

Thus, the card identified by " 0 " in column l gives the tristime ulus values ( $X, Y, Z$ ), the card identified by "1" in column 1 gives the chromaticity coordinates ( $x, y, z$ ), and the card identified by "2" in column 1 gives the usual form of the colorimetric specification ( $x, y, Y$ ). The three forms of the answer cards were chosen so that listings of data or other types of manipu lation of the data for reporting purposes can be made with a minimum of effort on off-line equipment such as the duplicating punch, card sort, collator, or accounting tabulator.

The number in column 64 indicates the way in which the input data were given to the computer as described in B.(1), above. The number in columns 68 through 72 is the same on each of the three answer cards for each sourcesample combination. It is the number punched in columns 68 through 72 of the identio fication card. Therefore, the number in columns 68 through 72 correlates the data cards with the proper identification card.

## VI. Summary.

A computer program has been described which will allow the conversion of spectral directional reflectance or spectral transo mittance 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 sourcesample combination in an average time of approxio mately 5 seconds. Read in-time for the program deck is approximately 1 minute.

## VII. Bibliography.

[1] Proceedings, Eighth Session, Commission Internationale de 1'Eclairage, Cambridge, England, pp 19 to 29, September, 1931.
[2] Judd, D. B. Extension of the standard visibility function to intervals of 1 millimicron by third-difference osculatory interpolation. J。Res. NBS $\underline{6}, 465$ (1931), RP289, also
J. Opt. Soc. Am. 21, 267 (1931).
[3] IBM General Information Manual, Programmer's primer for FORTRAN automatic coding system for the IBM704 data processing system, International Business Machines Corp., 590 Madison Avenue, New York 22, N. Y. (1957).
[4] IBM Reference Manual, FORTRAN automatic coding system for the IBM 704 data processing system, International Business Machines Corp., 590 Madison Avenue, New York 22, N.Y. (1958).
[5] IBM Reference Manual, 704 data processing system, International Business Machines Corp., 590 Madison Ave, 'New York 22, New York (1958).
[6] IBM Reference Manual, FORTRAN II for the IBM 704 data prom cessing system, International Business Machines Corp., 590 Madison Avenue, New York 22, New York. (1958).

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## APPENDIX A

Listing of the source program which was assembled by the FORTRAN II system. This assembly produced the binary object deck used on the IBM 704 computer.

```
C SPECTRAL LINE COLORIMETRY PROJECT NO.59-449
C J.P.MENARD JULY 24,1959
    1 DIMENSION A(40),B(40),C(40),T(40),AA(40),BB(40),CC(40),TT(
    IWLL(40),WL(40),WK(40),S(40)
    10 FORMAT(60H
    1 [4,18)
    12 FORMAT (5F14.8)
    14 FORMAT(110)
    16 FORMAT (2HO 3F9.5,143)
    18 FORMAT(2H1 3F9.5,143)
    19 FORMAT (2H2 3F9.5,143)
    30 READ 10,NN,M
    35 PUNCH 10,NN,M
    40 GO TO (50,90,191,130),NN
    50 READ 12,(S(1), 1=1,40)
    60 READ 14,N
    70 READ 12,(WL(I),I=1,N)
    80 READ 12,(WK(I),I=1,N)
    90 READ 12;(T(1),I=1,40)
    100 J=2
    110 DO 180 1=1,N
    120 IF(WL(I)-WLL(1))130,140,200
    130 STOP
    140 AA(I)=A(1)
    150 BB(1)=B(1)
    160 CC(1)=C(1)
    170 TT(1)=T(1)
    180 CONTINUE
    190 GO TO 660
    191 READ 12,(S(1),I=1,40)
    192 READ 14.N
    193 READ 12,(WL(I),I=1,N)
    194 READ 12,(WK(I),I=1,N)
    195 GO TO 100
    2 0 0 ~ I F ( W L ( I ) - W L L ( 2 ) 1 2 1 0 , 3 0 0 , 3 5 0
    210 D=(WL(I)-WLL(1))/(WLL(2)-WLL(1))
    220 AA(I) =A(1) +D*(A(2)-A(1))
    230 BR(I)=B(1)+D*(B(2)-B(1))
    240CC(I)=C(1)+D*(C(2)-C(1))
    250TT(1)=T(1)+D*(T(2)-T(1))
    260 GO TO 180
    300 AA(I)=A(2)
    310 BB(I)=B(2)
    320 CC(1)=C(2)
    330 TT(1)=T(2)
    340 GO TO 180
    350 IF(WL(I)-WLL(40))}360,610,13
    360 IF(WL(I)-WLL(39))370,500,550
    370 IF(WL(1)-WLL(J+1))380,440,495
    380 D=(WL(I)-WLL(J))/(WLL(J+1)-WLL(J))
    390 AA(I) =(()D/2.0)*(A(J+2)-3.0*A(J+1)+3.0*A(J)-A(J-1))
    1+(2.0*A(J-1)-5.0*A(J)+4.0*A(J+1)-A(J+2))/2.0)*D
    1+(A(J+1)-A(J-1)//2.0)*D+A(J)
    400 BB(I)=(((D/2.0)*(B.(J+2)-3.0*B(J+1)+3.0*B(J)-8(J-1))
        I+(2.0*B(J-1)-5.0*B(J)+4.0*B(J+I)-B(J+2))/2.0)*D
```

```
    1+(B(J+1)-B(J-1))/2.0)*D+B(J)
    410CC(I)=(((D/2.0)*(C(J+2)-3.0*C(J+1)+3.0*C(J)-C(J-1))
    1+(2.0*((J-1)-5.0*((J)+4.0*C(J+1)-C(J+2))/2.0)*D
    1+(C()+1)-C(J-1))/2.0)*D+C(J)
    420 TT(I)=(((D/2.0)*(T(J+2)-3.0*T(J+1)+3.0*T(J)-T(J-1))
    1+(2.0*T(J-1)-5.0*T(J)+4.0*T(J+1)-T(J+2))/2.0)*D
    1+(T(J+1)-T(J-1)})/2\cdot0)*0+T(j
    430 GO TO 180
    440 AA(I)=A(J+1)
    450 BB(I)=B (J+1)
    460 CC(I) =C(J+1)
    470 TT(1)=T(J+1)
    480 J=J+1
    490 GO TO 180
    4 9 5 ~ J = J ~ + 1 ~
    496 GO TO 370
    500 AA(I)=A(39)
    510 BB(1)=R(39)
    520 CC(I) =C(39)
    530 TT(I)=T(39)
    54O GO TO 180
    550 D = (WL(I)-WLL(39))/(WLL(40)-WLL(39))
    560 AA(I) =A(39)+D*(A(40)-A(39))
    570 BB(I) =B(39)+D*(B(40)-B(39))
    500 CC(I) =C(39)+D*(C(40)-C(39))
    590 TT(I) =T(39)+D*(T(40)-T(39))
    600 GO TO 180
    610 AA(I)=A(40)
    620 BB(I) =B(40)
    630 CC(I)=C(40)
    640-TT(I)=T(40)
    650 GO TO 180
    660 EXX=0.0
    670 EYY =0.0
    680 EZZ=0.0
    690 EVV=0.0
    7 0 0 ~ D O ~ 7 5 0 ~ I ~ = 1 , 4 0
    710 D=S(I)*T(I)
    720 EXX=EXX+A(I)*D
    730 FYY=EYY+R(I)*D
    740 EZZ =EZZ+C(I)*D
    750 EVV=EVV+B(I)*S(I)
    760 DO 810 I=1,N
    770 D=WK(I)*TT(I)
    780 EXX=EXX+AA(I)*D
    790 EYY=EYY+BB(I)*D
    800 EZZ=EZZ+CC(I)*D
    810 EVV=EVV +BB(I)*WK(I)
    820 EX=EXX/FVV
    830 EY=EYY/FVV
    840 EZ=EZZ%FVV
    850 ES=EXX+FYY+FZZ
    860 EXX=EXX/ES
    870 EYY = EYY/ES
    880-EZZ=EZZ/ES
```

890 PUNCH $16, E X, E Y, E Z, M$
900 PUNCH 18,EXX,EYY,EZZ,M
901 PUNCH $19, E X X, E Y Y, E Y, M$
920 GO TO 30
END $(0,0,1,1,0)$

|  | ORG | 0 |
| :---: | :---: | :---: |
| A | SYN | 1192 |
| B | SYN | 1152 |
| C | SYN | 1112 |
| WLL | SYN | 872 |
|  | ORG | A-39 |
|  | DEC | $1.0,2.0,3.0,7.0,14.0,29.0,58.0,114.0$ |
|  | DEC | 227.0,468.0,874.0,1649.0,2835.0,4479.0 |
|  | DEC | 6424.0,8544.0,10026.0,10622.0,10263.0 |
|  | DEC | 9163.0,7621.0,5945.0,4334.0,2904.0 |
|  | DEC | $1655.0,633.0,93.0,49.0,320.0,956.0$ |
|  | DEC | $1954.0,2908.0,3362.0,3483.0,2839.0$ |
|  | DEC | $1344.0,435.0,143.0,42.0$ |
| A | DEC | 14.0 |
|  | ORG | E-39 |
|  | DEC | $0,1.0,1.0,3 \cdot 0,5.0,10.0,21.0,41.0$ |
|  | DEC | $82.0,170.0,320.0,610.0,1070.0$ |
|  | DEC | 1750.0,2650.0,3810.0,5030.0 |
|  | DEC | $6310.0,7570.0,8700.0,9520.0$ |
|  | DEC | 9950.0,9950.0,9540.0,8620.0 |
|  | DEC | $7100.0,5030.0,3230.0,2080.0,1390.0$ |
|  | DEC | $910.0,600.0,380.0 .230 .0,116.0,40.0$ |
|  | DEC | $12.0,4.0,1.0$ |
| B | DEC | 0 |
|  | ORG | C-39 |
|  | DEC | $0,0,0,0,0,0,0,0$ |
|  | DEC | $0,0,0,0,0,0,0,2.0$ |
|  | DEC | $3.0,8.0,11.0,17.0,21.0,39.0,87.0,203.0$ |
|  | DEC | $422.0,782.0,1582.0,2720.0,4652.0$ |
|  | DEC | $8130.0,12876.0,16692.0,17721.0$ |
|  | DEC | $17471 \cdot 0,13856 \cdot 0,6456 \cdot 0,2074 \cdot 0,679.0,201.0$ |
| C | DEC | 65.0 |
|  | ORG | WLL-39 |
|  | DEC | $770.0,760 \cdot 0,750 \cdot 0,740 \cdot 0,730.0$ |
|  | DEC | $720.0,710.0,700.0,690.0,680.0$ |
|  | DEC | $670.0,660.0,650.0,640.0,630.0$ |
|  | DEC | 620.0,610.0,600.0,590.0,580.0 |
|  | DEC | $570.0,560.0,550.0,540.0,530.0$ |
|  | DEC | $520.0,510.0,500.0,490.0,480.0$ |
|  | DEC | $470.0,460.0,450.0,440.0,430.0$ |
|  | DEC | $420.0,410.0,400.0,390.0$ |
| WLL | DEC | 380.0 |
|  | END | 0 |

## APPENDIX B

Sample of the IBM Fortran coding form (IBM Form 94-7999-0) recommended for preparing data for key-punch operator


## APPENDIX C

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.)

00000000011111111112222222222333333333344444444445555555555666666666677777777778
034
035
036
0037
038
0339

000000000111111111122222222223333333333444444444455555555556666666666777 -77777778 34567890
-

100

## APPENDIX D

## A listing of answer cards

 resulting from the computations using the data of Appendix $C$. (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.)| 000000000111111111122222222223333333333444444444455555555556666666666777 |
| :--- |
| 123456789012345678901234567890123456789012345678901234567890123456789012 |



# U.S. DEPARTMENT OF COMMERCH: <br> Frederick H. Mueller, Secretary <br> NATIONAL BULREAU OF STANDARDS <br> A. V. Aatin, Director 

THE NATIONAL BUREAU OF STANDARDS
The scope of activities of the National Burean of Standards at its major lahoratories in Washington, D.C., and Bonlder, Celorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries ont specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

## WASHINGTON, D.C.

Electricity and Elcetronics. Resistance and Reactance. Electron Devices. Electrical Instriments. Mag. netic Measurements. Dielectrics. Engincering Electronics. Electronic Instrumentation. Eleetrochemistry.

Optics and Mctrology. Photometry and Colorimetry. Photographic Technology. Tength. Engincering Metrology.

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

Atomic and Radiation Physics. Spectroseopy. Radiometry. Mass Spectrometry. Soid State Physics. Electron Physics. Atomic Plysies. Neutron Physics. Radiation Theory. Radioactivity. X-rays. High Energy Radiation. Nucleonic Instrumentation. Radiological Equipment.

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

Mechanics. Sound. Mechanical Instruntents. Fluid Mechanics. Engincering Mechanics. Mass and Seale. 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 Plysics.

Mineral Products. Engineering Ceramies. Glass. Refractories. Enameled Metals. Constitution and Microstructure.

Building Technology. Siruetural Engineering. Fire Protection. Air Conditioning, lleating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Ileat Transfer. Conereting Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engincering. Mathematical Physics.
Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Cireuitry. Digital Systems. Analog Systems. Application Engineering.

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


## BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenie Processes. Properties of Matcrials. Gas Liquefaction.

Radio Propagation Physies. Upper Atmosphere Rescarch. Ionospheric Rescarch. Regular Propagation Services. Sum-Earth Relationships. VHF Researelı. Radio Warning Services. Airglow and Aurora. Radio Astronomy and Aretic Propagation.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Researelı. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation Ohstarles linginecring. Radio-Metcorology. Lower Atmosphere Physies.

Radio Standards. Iligh Frequency Eilectrical Standards. Radio Broadeast Scrvice. High Prequeney Impedance Standards. VIectronic Calibration Center. Mierowave Physics. Mierowave Circuit Standards.

Radio Communication and Systems. Row Frequency and Vary Low Rreguency Research. High Frequency and Very lligh Frequency Rescarch. Uleralligh Vrequency and Superligh Virequeney Research. Modulation Research. Antenna Researcli. Navigation Sybtems. Systeme Aıalymis. Fïll Oןrations.

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[^0]:    * Numbers in brackets refer to bibliography on pagell of this report.

