A COMPUTERIZED METHOD FOR DETERMINATION OF REGIONAL BLOOD FLOW USING RADIOACTIVE TRACER MICROSHERES

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Nanoscopics
Blood flow
Computerized program

Studies utilizing radioactive tracer microspheres to determine blood flow to a specific region, tissue, or organ under acceleration were done in this Laboratory. The microspheres were injected into animal subjects and were distributed throughout the body. They were trapped in capillary beds according to size. Tissue samples from areas of interest were taken, and radiation measured. A computer program was developed to calculate corrected counts per minute, regional blood flow, and cardiac output from raw data. This report includes a brief outline of the experimental design, the theory behind the...
program, execution of the program, and the program listing.
SUMMARY

Studies in the Aerospace Medical Research Laboratory utilize radioactive tracer microspheres to determine blood flow to a specific region, tissue or organ under +Gz acceleration. The microspheres are injected and become distributed throughout the body similar to red blood cells. They become trapped in capillary beds according to size. Tissue samples are taken and radiation measured in a gamma counter.

This report describes a computer program developed to calculate corrected counts per minute, regional blood flow, and cardiac output from raw data. The program offers a rapid, easily used method for processing data obtained from the gamma counter.
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INTRODUCTION

Studies similar to those of Sostre (7) utilizing plastic radioactive tracer microspheres to calculate blood flow to a specific region, tissue, or organ under +Gz acceleration are being done in this Laboratory. The microspheres are injected into the left ventricle, and distributed throughout the body in a manner similar to red blood cells. They are entrapped in specific capillary beds according to blood distribution and the size microsphere used. Tissue samples from areas of interest are weighed and placed in a gamma counter for determination of microsphere density in terms of counts per minute (CPM). A computer program was developed to calculate corrected CPM, regional blood flow, and cardiac output from raw data. This program offers a rapid, easily used method for processing data obtained from the gamma counter.

Section 2 is a brief outline of the experimental design. The theory behind the program is presented in Section 3, and Section 4 contains the execution of the program. Section 5 includes the program listing.
EXPERIMENTAL PROCEDURE

The animals used, in this instance baboons, are lightly anesthetized with ketamine. Two femoral artery cutdowns are made; a catheter is inserted into the left ventricle via one femoral artery. Microsphere injections are made through this catheter using a remotely controlled microsphere injection system (2). A small silicone coated polyethylene catheter is inserted into the other femoral artery. It is placed with the tip in the descending aorta just below the arch. Fifteen seconds prior to the injection of microspheres, a constant rate reference sample is withdrawn. A Harvard Pump® (7) is used in this Laboratory, but any constant rate withdrawal system is acceptable. (6) Withdrawal of blood continues throughout the injection series until one minute after the final injection. The volume of blood withdrawn is calculated, and radioactivity is determined. Blood flow to this reference sample is taken to be that of a "known" organ; flow to any other organ then be calculated by relating to the blood flow of the reference sample (1).

The animal is placed in the Oloff Primate Restraint System (PRS) (5), and allowed to recover from the ketamine. The PRS is then placed on the Dynamic Environment Simulator (DES), a large man-rated centrifuge located in this Laboratory. When the animal is fully awake, the acceleration profile begins. Peak acceleration is either at +3Gz or +5Gz, with an equal number of animals exposed to each. Five types of 15 micron radiolabeled microspheres are used for each animal: Cerium 141, Chromium 51, Strontium 85, Scandium 46, and Iodine 125. 0.025 to 0.050 microcuries are injected, depending on the relative activity of the isotope. The first isotope is injected at +lGz and is used to establish a baseline. When peak acceleration is reached, the remaining isotopes are injected at 30 second intervals. After injection of the last isotope, peak acceleration is maintained for 30 seconds bringing total +Gz exposure time to 120 seconds.

When the acceleration profile is completed, the animal is sacrificed with Uthanol® and the brain is removed and fixed in formalin for 72 hours. One half of the brain is sectioned into various regions, such as brainstem, cerebellum, and hypothalamus. The other half is placed in several vials and used to estimate total cerebral blood flow. Tissue samples are also taken from various organs throughout the body, with each location assigned a specific ID number. All samples are weighed and placed in an appropriate vial to be counted in a Packard.
Auto-Gamma Scintillation Spectrometer®. When a sample is too large to fit into one counting vial, it can be sectioned and placed into several vials. All the vials can then be incorporated into a group and treated as one sample. Information from the gamma counter is printed out on a standard teletype with a punch tape capacity.

Disposal of radioactive animal carcasses is in accordance with Appendix B, Title 10, Code of Federal Regulations, Part 20.
Theory

Program GAMMA was written for a Control Data Corporation 6600 computer located at the Aeronautical Systems Division Computer Center at Wright-Patterson Air Force Base, Ohio.

There are three steps involved in using this program:

1. Create a permanent file of data from the gamma counter. This file will contain counts of all reference samples, standards, assay samples, and residue samples. Standards are aliquots of the microsphere solution of the same age as those injected into the animals. Residue samples include samples from the withdrawn catheters, post-experiment syringes, injection catheters, and manifold washouts.

2. Run program GAMMA using the above file, which is given the local file name Tape 1. A local file named Tape 2 will be created, this file contains the corrected CPM, regional blood flow, and cardiac output.

3. Catalog Tape 2.

Computation of corrected CPM, regional blood flow, and cardiac output is as follows:

1. Counts from all samples are corrected for background radiation:

\[ c'_i = c_i - \frac{e_i}{c_i} \]

where \( c_i \) = original count, window \( i \)
\( e_i \) = mean count window \( i \), from empty vials
\( c'_i \) = background corrected count, window \( i \)

2. Counts made on days previous to the assay counts are corrected for radioactive decay during the intervening time:

\[ \text{decay corrected count} = \text{original count} \times e^{(-ct/h)} \]

where \( c = \ln(0.5) \)
\( t = \text{days elapsed since count} \)
\( h = \text{half-life of given isotope, in days} \)
Half-life values (4) used are:

- Iodine 60 days
- Cerium 32 days
- Chromium 28 days
- Strontium 64 days
- Scandium 84 days

Counts of standards are corrected for decay using the same half-life for each window; the isotope is assumed to decay at the same rate over the entire spectrum. Counts of samples that are not standards are corrected for decay using the half-life of the corresponding isotope for each window; the decay rate within each window is assumed to be the decay rate of the predominant isotope.

3. The total amount of each isotope is computed as follows:

\[ z_i = y_i \times \frac{\text{volume injected (ml)}}{\text{volume counted (ml)}} \]

where \( z_i \) = total amount of isotope \( i \) injected, not corrected for residue samples

\[ y_i = \frac{1}{n_i} \sum_{j=1}^{5} \sum_{k=1}^{n_i} c_{ijk} \]

where \( y_i \) = average count of the standard for isotope \( i \)

\( n_i \) = the number of times the count for isotope \( i \) is repeated

\( c_{ijk} \) = the count of the standard for isotope \( i \) in the \( j \)th window repeated the \( k \)th time, corrected for decay and background radiation

Thus \( y_i \) is the average of the total counts in all windows from isotope \( i \).

4. Corrected counts (corrected for overlapping windows) are computed by the formula*:

\[ T = (F'F)^{-1} F'C \]

where \( T \) is a 5x1 matrix; \( t_i \) = corrected counts from isotope \( i \)

\( F \) is a 5x5 matrix; \( f_{ij} \) = proportion of isotope \( i \) in window \( j \)

* Rosenblatt, Judah. Personal communication
C is a $5 \times 1$ matrix; $c_j$ = observed count in window $j$, corrected for decay and background radiation.

$F$ is estimated from the counts of the standards as follows:

$$f_{ij} = \frac{1}{\sum_{k=1}^{n_1} \frac{1}{n_i}} \sum_{k=1}^{n_1} c_{ijk}$$

where $n_i$ and $c_{ijk}$ are as in 3 above.

5. Regional blood flow is computed by the formula (5):

$$g_i = \frac{t_i \times \text{withdrawal rate (ml/min)}}{r_i \times \text{weight of sample (grams)}}$$

where $g_i$ = regional blood flow immediately after injection of isotope $i$, in [ml/min/gram]

$t_i$ = the corrected count from isotope $i$

$r_i$ = the sum of corrected counts from isotope $i$, summed over all reference samples

6. Cardiac output immediately after injection of isotope $i$ is given by the formula (3):

$$s_i = \frac{w_i \times \text{withdrawal rate (ml/min)}}{r_i}$$

where $w_i$ = the total corrected count of isotope $i$ injected, computed by subtracting corrected counts of all residue samples from the total count of isotope $i$ ($z_i$ in 3 above).
EXECUTION OF PROGRAM GAMMA

The permanent data file described in the theory section should contain the following information for each sample:

Line 1  Columns 1-6: sample identification number

Lines 2-6  Counts for each of the five isotopes in ascending order by energy level

Columns 15-20: energy level, center of window

Columns 50-55: count for given window

The sample identification number should be unique; no two samples should have the same ID, with the exception of multiple counts of the standards. The energy level at the center of the window should be within the following ranges:

- Iodine  29-35
- Cerium  142-148
- Chromium 317-323
- Strontium 511-517
- Scandium 1117-1123

The above format is the standard output of the Packard Auto-Gamma Scintillation Spectrometer R (see Appendix A). The program can be changed to accommodate the use of a counter with a different format.

If the data from an experiment are on several different paper tapes they should be read into the computer and combined into one permanent file using Editor.

Execution of program GAMMA is as follows:

1. Attach the permanent file of data from the gamma counter
   ATTACH, TAPE1, FPN, CY=XX, ID=XXXXXXXX

2. Request permanent file space for output file
   REQUEST, TAPE2, *PF

3. Attach the permanent file which contains program GAMMA
   ATTACH, GAMMA, WARD35, CY=1, ID=L740530

4. Attach the subroutine library IMSL*
   ATTACH, IMSL, ID=LIBRARY, SN=ASD, MR=1

* International Mathematical & Statistical Libraries. ASD Computer Subprogram Library
5. Make IMSL part of the local library
   LIBRARY, IMSL
6. Compile program GAMMA
   FTN(I=GAMMA,L=0)
7. Execute the program
   LGO

At this point, the program will ask for certain information which should be typed in as requested. Appendix B contains an abbreviated sample with typed-in information underlined.

8. Catalog Tape 2
   CATALOG, TAPE2,PFN,CY=XX,RP=999

where PFN is the permanent file name and XX is the cycle number. A sample of the output from Tape 2 is included in Appendix C.

NOTES:
1. Entering sample ID numbers
   * A group of numbers may be entered by putting a minus sign in front of the selected number satisfying the range. For example, "580 -592" specifies all thirteen ID numbers between and including 580 and 592. It is important to leave a space between the first number and the minus sign.
   * If too many numbers are specified, the extra numbers will be dropped starting at the end of the list.
   * If too few numbers are specified, the program will not continue until more numbers are given.
   * Do not include ID numbers in the list which do not exist in the file Tape 1. For example, suppose a group consists of samples 33 -45, and 47 and there is no sample 46 in the data file. If the ID numbers for the group are specified as "33 -47" instead of "33 -45 47" sample 47 will be dropped from the group because too many ID numbers are specified.

2. Samples counted previous to assay are grouped by the number of days elapsed from the count of the given sample to the assay counts. Any number of groups may be specified. After all groups have been entered, enter 0 for the number of samples, and 0 for the number of days elapsed.
3. When sample ID and weight are requested for each sample, the sample ID to enter is the identification of the location in the animal from which the sample came.

4. Assay samples may be grouped in any number of groups. After the sample IDs for the last group have been entered, enter 0 for the number of samples in the next group.
PROGRAM GAMA 74/74  OPT=1  FTN 4.6+446  01/21/76  15:46:36  PAGE 1

1  PROGRAM GAMA (INPUT,OUTPUT,TAPE1,1APE2)
2  DIMENSION BAC(5),CVOL(5),TVOL(5),Q(5,5)
3  DIMENSION REF(5),SH(5),H(5),HCP(100),KGP(100,2)
4  DIMENSION NS(100,5),HTOT(5)
5  DIMENSION NS(100),DAY(200)
6  DIMENSION H(5),KGP(100)
7  DIMENSION KOL(100),TOL(5),LIM(5),QCT(5),RGT(5)
8  DIMENSION TOT(5),SIG(100,5),FLON(5),KREF(20),PER(10,5)
9
10  TO CHANGE # ISOTOPES
11  CHANGE DATA STATEMENTS FOR LIM#, REF AND BACK
12  CHANGE DIMENSIONS OF SIGP,PER AND Q
13  CHANGE VALUE OF "NIS" -- # OF ISOTOPES
14  INCREASE DIMENSIONS OF ALL RELEVANT VARS IF NECESSARY
15  INCREASE DIMENSIONS IN SUBROUTINES INV AND ICLS
16
17  DATA LIMK/32,145,328,514,11280/
18  C
19  DATA LIMK/32,323,514,11280/
20  C
21  DATA REF/SM125 ,SM214,SM215,SM216,SM217,SM218 ,SM219 /
22  C
23  DATA REF/SM125 ,SM214,SM215,SM217,SM219 /
24  C
25  PRINT 1
26  FORMT(*1CONNECTED MICROSPHERE COUNTS*/)
27  C
28  NIS=5
29  PRINT 40,NIS,(REF(I),I=1,NIS)
30  400 FORMT(* HUNGER OF ISOTOPES ASSUMED TO BE",I=1,1061
31  1 = ISOTOPES *,1061)
32  PRINT 6
33  5 FORMT(* ENTER SUBJECT ID *)
34  READ 3,SUBJ
35  PRINT 1
36  2 FORMT(* ENTER EXPERIMENT DATE *)
37  READ 3,DAT
38  PRINT 4
39  4 FORMT(* ENTER ASSAY DATE *)
40  READ 3,ASS
41  FORMT(A40)
42  WRITE(3,107SUBJ,DAT,ASS)
43  187 FORMT(3A10)
44  IT=0
45  DO 62 I=1,NIS
46  7 FORMT(* ISOTOPE *,I=2,1X,15)
47  PRINT 403
48  43 FORMT(* ENTER VOLUME COUNTED *)
49  READ *,CVOL(I)
50  PRINT 404
51  40 FORMT(* ENTER VOLUME INJECTED *)
52  READ *,TVOL(I)
53  PRINT 405
54  45 FORMT(* ENTER # SAMPLE IDS *)
55  READ(NKS,KDUN)
56  IF(NKS.LE.0150 TO 62
57  PRINT 14
58  CALL HUN(NKS,KDUN)
59  DO 63 I=1,NKS
60
PROGRAM GAMMA

IM=1
KSHK=0
KST(I)=I
CONTINUE
PRINT 120
CALL REFID(KREF,KREF+KCT,REF+NI)
FORMAT('ENTER REFERENCE SAMPLES')
READ *WTHDM
PRINT 10
FORMAT('ENTER WITHDRAWAL RATE, REFERENCE SAMPLE')
READ *WTHDM
PRINT 10
FORMAT('ENTER # SAMPLES FROM RESIDUE')
READ *ANGAT
IF(ANGAT.LE.0)GO TO 110
PRINT 14
CALL NUMB(ANGAT,KC)
PRINT 106
FORMAT('ENTER # SAMPLES COUNTED PREVIOUS TO ASSAY')
I=0
PRINT 90
FORMAT('ENTER # SAMPLES AND # DAYS ELAPSED')
READ *NNO,DDD
IF(NNO.LE.0)GO TO 91
PRINT 14
CALL NUMB(NNO,KDUM)
DO 92 K=1,NNO
I=K+1
NSEL(I)=KDUM(K)
92
DAY(I)=DDD
DO 93 I=1,NNO
NGP=0
93
ZB=I+1
PRINT 111
FORMAT('ENTER # SAMPLES IN GROUP')
READ *NGP(I)
IF(NGP(I).LE.0)GO TO 13
NGP=I
PRINT 14
FORMAT('ENTER SAMPLE IDS')
CALL NUMB(NGP(I),KDUM)
K=0
DO 15 K=1,NGP(I)
15
KGP(J,K)=KDUM(K)
165
IBIE=K
10
GO TO 16
*PROCESS STANDARDS AND REFERENCE SAMPLES
REWIND 1
KREF=0
DO 13 I=1,NI
MOTF(I)=0
13
REWIND 1
PROGRAM GAMA 74/74 OPT=1

115 TOT(I)=0.
116 DO 120 J=1,NIS
117 PER(I,J)=0.
118 READ(1,17)IID, (IM(I),IGT(I),I=1,NIS)
119 IF(EOP(1))131,132
120 * CHECK IF A STANDARD
121 DO 133 I=1,ITY
122 IF(IID,NE.KS(I))GO TO 133
123 CALL WINDOF(IID,IN,IGT,LMW,NIS,BACK)
124 IS=IGT(I)
125 IF(IS.LE.0.OR.IS.GT.NIS)STOP "INDEX"
126 CALL HALF(IID,IGT,INDEL,NSDEL,DAY,IS,NIS)
127 NTOF(I)=NTOF(IS)+1
128 DO 134 J=1,NIS
129 * TOT(I,J) = SUM FOR ISOTOPE IS OVER ALL WINDOWS
130 TOT(I,J)=TOT(I,J)+IGT(J)
131 PER(I,J)=PER(I,J)+IGT(J)
132 CONTINUE
133 IF(NREF.LE.0)GO TO 135
134 IF(IID,NE,REF(I))GO TO 135
135 GO TO 135
136 CONTINUE
137 RCT(I,J)=RCT(I,J)+IGT(J)
138 GO TO 138
139 CONTINUE
140 DO 141 J=1,NIS
141 SUM=0.
142 DO 150 J=1,NIS
143 SUM=SUM+PER(I,J)
144 IF(SUM.GT.0.1)GO TO 150
145 SPRINT 300,1
146 FORMAT(* NO STANDARD FOUND FOR ISOTOPE*,I3/
147 * ENTER CPM FOR EACH WINDOW*)
148 DO 160 J=1,NIS
149 PRINT 302,J
150 FORMAT(I5,3X,WINDO",",I3,1X)
151 READ *,PER(I,J)
152 TOT(I,J)=TOT(I,J)+PER(I,J)
153 CONTINUE
154 PEP(I,J) = THE COUNT OF ISOTOPE I IN WINDOW J
155 CONTINUE
156 * COMPUTE FREQUENCY ARRAY
157 DO 160 J=1,NIS
158 IF(NTOF(J).LE.0)STOP "STANDARD"
159 XX=1./NTOF(J)
160 TOT(I,J)=TOT(I)*XX
161 CONTINUE
PROGRAM GAMMA 7/4/74 OPT#1

175 DO 65 J=1,NIS
65 PER(I,J)=PER(I,J)*XX
IF(NREF.EQ.NREF)GO TO 160
PRINT 161,NREF,NREF
161 FORMAT(* REF SAMPLES FOUND* I3,5X,** SPECIFIED* I3)
CALL RFPD(NREF,KREF,RCT,REF,NIS)
GO TO 13
160 DO 148 I=1,NIS
148 SUM=0.
OD 141 J=1,NIS
141 SUM=SUM+PER(I,J)
SUM=SUM/J
DO 142 J=1,NIS
142 PER(I,J)=PER(I,J)*SUM
140 CONTINUE
CALL INV(PER,NIS,0)
* COMPUTE CORRECTED CPMS FOR REFERENCE SAMPLES
190 I(1)=RCT(1)
CALL CPMS(I(1),RCT,PER,NIS,0)
PRINT 48, I(1), I(1)-1,NIS)
PRINT 482 (RCT(1)-1,NIS)
199 FORMAT(* REF CPMS* I5,10)
CO R(1)=1,NIS
401 TOT(I(1),TOT(I)+TVOL(I),CVOL(I)
PRINT 988,I(TOT)
580 FORMAT(* STRING* 5G12.5)

200 * PROCESS ASSAY SAMPLES AND RESIDUE SAMPLES

180 REWIND 2
REWIND 2
DO 22 J=1,200
22 NIS(I,J)=0.
DO 22 I=1,NIS
22 SGPF(I,J)=0.
LET=1

210 XX I(1)=1,300
IF(EQ(I(1),1100.131)
* CHECK IF DELAY CORRECTION
131 CHECK IF A STANDARD
215 DO 23 I=1,IT
IF(EQ(I),110(I))GO TO 29
23 CONTINUE
* CHECK IF A REFERENCE SAMPLE
IF(NREF.LE.0)GO TO 160
220 I=1,NREF
IF(I.EQ.KREF(I))GO TO 25
217 CONTINUE
170 CALL WINDOW(I(1),I(1),I(1),LMN,NIS,BACK)
CALL CPMS(I(1),I(1),PER,NIS,0)
* CHECK IF FROM PERIOD SAMPLE
IF(NATH.LE.0)GO TO 34
DO 33 X=X,NATH
33 CONTINUE
IF(I.EQ.KREF(I))GO TO 36
DO 31 J=1,NIS

31 TOT(J)=TOT(J)-XCT(J)
GO TO 30

30 CONTINUE

34 IF(I.E.LE.8160)GO TO 35

35 GO 33 I=1,IE
IF(IID.NE.KGP(I,11))GO TO 33
IGP=KGP(I,1)
PRINT 238,IID,IGP

238 PRINT(I5,* ) IN GROUP*,I3)
DO 36 J=1,NIS
36 SSIP(IIP(J),J)=SSIP(IIP(J),J)+ICT(J)
NGP(IIP(J))=NGP(IIP(J))+1
GO TO 25

33 CONTINUE

25 PRINT 46,IID
50 FORMAT(* SAMPLE*,I5,* -- ENTER SAMPLE ID AND WEIGHT (G) *
READ *KID,WT
GO 42 I=1,NIS
FLOM(2)=
42 IF(XCT(I),EQ.4,8)GO TO 42
FLOM(2)=XCT(I)*WT/ACT(I)*WT)

44 N1=CONTINUE
WRITE(I4,44)LET,IID,KID,WT,(XCT(I),I=1,NIS)
FORMAT(41.X15.6I2.5)
WRITE(41,44)FLOM(I),I=1,NIS)

401 FORMAT(23X,5G12.5)
GO TO 25

180 LET=ING
IF(L=0
260 I=1
IF(I.E.LE.8160)GO TO 260
DO 280 I=1,NIS
IF(NGP(I),EQ.1,NGP(21))GO TO 283
IF(L=0

265 PRINT 281,I,NGP(I),NGP(I)
281 FORMAT(7,3,14) # SAMPLES FOUND, I3,* # SPECIFIED*, I3)

283 IF(I.F.L, EQ.8160)GO TO 294
PRINT 11,1,
READ *NGP(I)

284 PRINT 14
CALL HNUM(NGP(I),KDH) 

270 IE=IB=1,NGP(I)
E=0
DO 282 J=IB,IE
282 KGP(J,1)=KDH
KGP(J,2)=I
IB=IE+1
GO TO 280

284 IB=IB+NGP(I)

288 CONTINUE

288 IF(IIF.LE.8160)GO TO 160
DO 190 I=1,NIS
DO 191 J=1,NIS
191 ICT(J)=SSIP(I,J)
**PROGRAM GAMMA**

```
CALL CP4(ICT,XCT,PER,NES,0)
PRINT 192,
192 FORMAT* GROUP #,I3,* ENTER SAMPLE ID AND HEIGHT (G) *
READ *,KMD,MN
DO 193 J=1,NIS
FLOW(J)=0.
IF (RCT(J).EQ.6.016) GO TO 193
FLOW(J)=XCT(J)*NITHO/(RCT(J)*MN)
193 CONTINUE
WRITE (2,401) FLOW(J),J=1,NIS
CONTINUE
*
CARDIAC OUTPUT
333 PRINT 246,(TOT(J),J=1,NIS)
340 FORMAT* CPM OF ISO TOPE INJECTED#/$X,5G12.5
DO 341 I=1,NIS
IF (RCT(I).EQ.6.016) GO TO 341
TOT(I)=TOT(I)*NITHO/RCT(I)
341 CONTINUE
PRINT 242,(TOT(J),J=1,NIS)
342 FORMAT* CARDIAC OUTPUT AT EACH ISO TOPE (ML/NIS)#/$X,5G12.5
LET=1,11,
WRITE (2,401) LET
310 LET=INF
WRITE (2,243) LET,subj,DATE,ASSAY,(TOT(J),J=1,NIS)
343 FORMAT* (14.3,14.3,14.3,14.3)
CALL EXIT
END
```

**SYMBOLIC REFERENCE MAP (R=1)**

<table>
<thead>
<tr>
<th>ENTRY POINTS</th>
<th>18264 GAMMA</th>
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<tr>
<td><strong>VARIABLES</strong></td>
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**STATISTICS**

| PROGRAM LENGTH | 74748 | 3980 |
| BUFFED LENGTH | 102698 | 4272 |
SUBROUTINE CPM(74/74 OPI=1)
DIMENSION IGT(NIS),XCT(NIS),PER(NIS,NIS)
DIMENSION Q(NIS,NIS)

PER IS INV(A*A TRANS)*A
WHERE A(I,J) IS THE PROPORTION OF COUNTS FROM ISOTOPE
I IN WINDOW J
SUM OF A(I,J) OVER J FOR FIXED I IS 1.0
GO TO 1,NIS

XCT(I) = Q
GO TO 4,NIS

XCT(I) = XCT(I) + PER(I,J)*IGT(J)
CONTINUE
CALL ICLS(Q,XCT,NIS)
RETURN

END

SYMBOLIC REFERENCE MAP (R=1)

ENTRY POINTS
3 CPM

VARIABLES SN TYPE RELOCATION 0 ICT INTEGER ARRAY F.P.
5 J INTEGER 0 NIS INTEGER ARRAY F.P.
0 PER REAL ARRAY F.P.
0 XCT REAL ARRAY F.P.

EXTERNALS TYPE ARGS
ICLS REAL 3

STATEMENT LABELS
0 4 0 5

LOOPS LABEL INDEX FROM-TO LENGTH PROPERTIES NOT INNER
20 5 * I 12 178
20 5 * J 10 11 AB INSTACK

STATISTICS
PROGRAM LENGTH 520009 CM USED 728 56
SUBROUTINE NUMB  74/74  OPT=1  FTN 4, 64446  02/21/74  15:48:36  PAGE  1

1
SUBROUTINE NUMB(INLINH, KC)
DIMENSION KC(299)
I=0
15
READ *, KK
IF (KK.GT.0) GO TO 11
IF (I.LE.0) GO TO 12
II=KC(I)+1
IE=IABS(KK)
DO 13 JM19=IE
13
I=I+1
GO TO 14
12
KK=IABS(KK)
11
I=I+1
16
II=KC(I)+KK
14
IF (I-MLINH)15,20,21
20
RETURN
21
PRINT 22,1
22
FORMAT (*) SPECIFIED 0 IS *,19)
RETURN
END

SYMBOLIC REFERENCE MAP (K=1)
ENTRY POINTS
3 NUMB

VARIABLES SHAPE  TYPE  RELOCATION
61  I  INTEGER  63  I8  INTEGER
64  IE  INTEGER  65  J  INTEGER
2  KC  INTEGER  ARRAY  F.P.
8  MLINH  INTEGER  ARRAY  F.P.

FILE NAMES  MODE  OUTPUT  FMT
INPUT  FREE

INLINE FUNCTIONS  TYPE  ARGS
IABS  INTEGER  1  INTRIN

STATEMENT LABELS
32  11
39
42  21
30  12
6  15
99  22
0  13
0  20  INACTIVE

 LOOPS LABEL  INDEX  FROM-TO  LENGTH  PROPERTIES
24  13  J  9  11  28  INSTACK

STATISTICS
PROGRAM LENGTH  668  54
520000 CM USED.
SUBROUTINE REFID 76/44 OPT=I

1'options
SUBROUTINE REFID(KREF,KCT,REF,NIS)

DIMENSION KREF(200),NCT(NIS),REF(NIS)

DO 1 I=1,NIS
1 RC(T(I))=0.

READ *,NREF

PRINT 121

121 FORMAT('ENTER SAMPLE IDS FOR REFERENCE *')

CALL NUMB(KREF,REF)

RETURN

END

SYMBOLIC REFERENCE MAP (R=1)

ENTRY POINTS
3 REFID

VARIABLES  SB_TYPE_RELOCATION
43 I  INTEGER  0 KREF INTEGER ARRAY F.P.
6 NIS INTEGER  0 NREF INTEGER F.P.
8 NCT REAL ARRAY  0 REF REAL ARRAY F.P.

FILE NAMES
FMT

EXTERNALS  TYPE.Args
2 NUMB

STATEMENT LABELS
36 121 FMT

LOOPS LABEL INDEX FROM-TO LENGTH PRIORITY
36 4 0 20 INSTACK

STATISTICS
PROGRAM LENGTH 36
528890 CH USED 448
SUBROUTINE WINDOW (II0,II1,IGT,ILLW,NIS,BACK)
DIMENSION BACK(NIS)
DIMENSION II(NIS),IGT(NIS),ILLW(NIS)
GO 10 IM=1,NIS
5 21 IF(INN(IJ),II1,II11,IGT(I)) GO TO 10
PRINT 19,II0,II1,II11,IGT(I)
19 FORMAT(* WINDOW,WM*C* CENTROID,C*)
20 5X,*SHOULD BE*,15,* COUNT*,10)
PRINT 20
10 20 FORMAT(* ENTER CORRECT CENTROID AND COUNT *).
6 5X,*IM(I),IGT(I)
GO TO 21
15 CONTINUE
1 CONTINUE
RETURN
END

SYMBOLIC REFERENCE MAP (R=1)

ENTRY POINTS
9 WINDOW

VARIABLES
NAME TYPE RELOCATION
0 BACK REAL ARRAY F.P. 126 - I INTEGER
6 IGT INTEGER ARRAY F.P. 0 XOR INTEGER ARRAY F.P.
8 II INTEGER ARRAY F.P. 0 I1D INTEGER ARRAY F.P.
9 NIS INTEGER ARRAY F.P. 127 XX REAL

FILE NAMES
MODE INPUT FREE OUTPUT FMT

INLINE FUNCTIONS
NAME TYPE ARGS IABS INTEGER 1 INTRIN

STATEMENT LABELS
61 1 1 41 18 FMT 7 19 FMT
113 20 FMT 16 21

LJOPS LABEL INDEX FROM-TO LENGTH PROPERTIES EXT REFS
16 18 * I 4 14 268 PROPERTIES EXT REFS
91 1 I 16 22 130 OPT

STATISTICS
PROGRAM LENGTH 1908 194
520000 CH USED
SUBROUTINE INV  74/74  OPT=1

DIMENSION PER(NIS,NIS),Q(NIS,NIS)
DIMENSION A(NIS,NIS),B(NIS,NIS)

5  COMPUTE INVERSE (PER * PER TRANS) * PER
  A = PER * PER TRANS
  DO 1 I=1,NIS
      DO 1 J=1,NIS
       A(I,J)=0.
  1     DO 1 I=1,NIS
      DO 1 J=1,NIS
       A(I,J)=A(I,J)+PER(I,K)*PER(J,K)

   INVERSE A
   CALL LINVP(A,B,NIS,NIS,G1,G2,W,IER)
  15   DO 4 I=1,NIS
      DO 4 J=1,NIS
       G(I,J)=A(I,J)
  4     DO 4 I=1,NIS
      DO 4 J=1,NIS
       B(I,J)=0.
  20   DO 2 I=1,NIS
      B(I,J)=B(I,J)+A(I,J)*PER(J,K)
  2     DO 2 J=1,NIS
      DO 2 J=1,NIS
       PER(I,J)=B(I,J)
  25   3   RETURN
END

SYMBOLIC REFERENCE MAP (R=1)

ENTRY POINTS
3 INV

VARIABLES   SN TYPE  ARRAY  RELOCATION
161 A REAL ARRAY  224 B REAL ARRAY
156 D REAL ARRAY  157 D2 REAL
153 I INTEGER  150 IER INTEGER
154 J INTEGER  159 K INTEGER
0 NIS INTEGER  0 PER REAL ARRAY  F.P.
0 Q REAL ARRAY  F.P.  212 W REAL ARRAY  F.P.

EXTERNALS   TYPE  ARGS
LINVP  9

STATEMENT LABELS
0 1
6 4
0 2
0 3

LOOPS  LABEL  INDEX  FROM-TO  LENGTH  PROPERTIES
 21  1  E  0 12  250  NOT INNER
 21  1  J  0 12  250  NOT INNER
 34  1  K  11 12  30  INSTACK  NOT INNER
 52  4  I  15 17  150  NOT INNER
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STATISTICS
PROGRAM LENGTH 2768 190
528000 CM USED
SUBROUTINE ICLS
DIMENSION Q(N,N),BETA(N),Y(5),Z(5),B15(5),W(I),IND(9)
DO 2 I=1,N
DO 2 J=1,N
10 DO 3 I=1,N
4 DO 3 J=1,N
3 Z(I)=W(I)-BETA(I)
IND(I)=2
GO TO 9
15 N=2*LET=0
GO 30 I=1,N
30 W(I)=0
DO 5 J=1,N
5 M(X)=IND(I)+SIN(V(I,J))*Z(I)
IFABS(M(I))>=1.E-8*MIN(I)=0.0
9 CONTINUE
IT=0
XMAX=0
DO 6 I=1,N
6 IF(X(I).GT.10) GO TO 7
6 IF(X(I).EQ.0.0) GO TO 7
6 IF(X(I).GE.1.0) GO TO 8
8 IC=0
8 IFABS(N(I)).LE.XMAX GO TO 9
8 XMAX=ABS(N(I))
7 IT=2
7 IFABS(L(E).EQ.0) GO TO 9
7 DO 9 J=1,N
9 SQ(I)=SQ(E(I)+SIN(V(I,J))+B/E(I))
9 IFABS(SQ(I)).LE.1.0E-8*SQ(I)=0.
9 CONTINUE
DO 10 I=1,N
10 IF(SQ(I).NE.0) GO TO 11
11 CONTINUE
11 THETA=SIGN(1.0,TH(I))
GO TO 17
17 THETA=B
DO 13 I=1,N
13 THETA=THETAB+SQ(I)+B/E(V(I,J))
15 IFABS(THETAB).EQ.1.0E-8 GO TO 61
15 THETAB=THETAB+TH(I)
17 IT=0
### SUBROUTINE ICLS

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<td>92 96 220</td>
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### STATISTICS

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ZAAKGEN: END OF LIST
----------
ZAAKGEN: END OF LIST
APPENDIX A
OUTPUT FROM GAMMA COUNTER
<table>
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<th>Counter ID</th>
<th>Counting time(min)</th>
<th>Centroid</th>
<th>Iodine</th>
<th>Cerium</th>
<th>Chromium</th>
<th>Strontium</th>
<th>Scandium</th>
<th>Total CPM</th>
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The centroid is used by the computer to identify the specific isotope with which it is associated.

Total CPM refers to all counts from a specific isotope in the region of interest, accumulated during the counting time—in this case one minute.
APPENDIX B
ABBREVIATED SAMPLE RUN
GOPRECED MICROSPHERE COUNTS

NUMBER OF ISOTOPES ASSUMED TO BE 5

ISOTOPES 1125 CE145 CR141 SR85 SC46

ENTER SUBJECT ID K-30

ENTER EXPERIMENT DATE 27 JUNE 78

ENTER ASSAY DATE 10 JUNE 78

ISOTOPE 1 1125

ENTER VOLUME COUNTED .003

ENTER VOLUME INJECTED .003

ENTER SAMPLE IDS 1 2

ISOTOPE 2 CE145

ENTER VOLUME COUNTED .003

ENTER VOLUME INJECTED .003

ENTER SAMPLE IDS 2 3 4

ISOTOPE 3 CR141

ENTER VOLUME COUNTED .003

ENTER VOLUME INJECTED .003

ENTER SAMPLE IDS 2 3 4 5 6

ISOTOPE 4 SR85

ENTER VOLUME COUNTED .003

ENTER VOLUME INJECTED .003

ENTER SAMPLE IDS 2 3 4 5 6 7 8

ISOTOPE 5 SC46

ENTER VOLUME COUNTED .003

ENTER VOLUME INJECTED .003

ENTER SAMPLE IDS 2 3 4 5 6 7 8 9

ENTER SAMPLE IDS FOR REFERENCE 50 - 63

ENTER WITHDRAWAL RATE, REFERENCE SAMPLE 15.3

ENTER # SAMPLES FROM RESIDUE 1

ENTER SAMPLE IDS 11 - 15 150 - 155

ENTER # SAMPLES COUNTED PREVIOUS TO ASSAY

ENTER # SAMPLES AND # DAYS ELAPSED 177.3

ENTER # SAMPLES AND # DAYS ELAPSED 10 10 - 15 150 - 155 50 - 63 101 - 139 141 - 143

ENTER # SAMPLES IN GROUP 1 1

ENTER SAMPLE IDS 271 - 273

ENTER # SAMPLES IN GROUP 2 0

REF CPM 147707 194252 164324 182223 151607

CORR CPM 15794 94106 60253 152439 497540

SYRINGE .28140E+07 .35366E+07 .32361E+07 .41658E+07 .6924E+07
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<th>Ce-141</th>
<th>Cr-51</th>
<th>Sr-85</th>
<th>Sc-46</th>
</tr>
</thead>
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Code:  
S = individual assay  
G = group assay  
F = cardiac output data  

---Cardiac output (ml/min)
REFERENCES


