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PUQFUA: AN IBM-704 FORTRAN CODE FOR DETERMINING
PLUTONIUM BODY BURDEN FROM URINE ASSAYS
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PUQFUA: AN IBM-704 FORTRAN CODE FOR DETERMINING
PLUTONIUM BODY BURDEN FROM URINE ASSAYS

by

James N. P. Lawrence

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ABSTRACT

PUQFUA is an IBM-704 FORTRAN program, written primarily for Pu$^{239}$, which calculates from urinalyses the plutonium body burden in microcuries and the per cent of the maximum permissible body burden. It is based on a set of power function elimination equations developed by Wright H. Langham for the excretion of plutonium over a five year period. Results with PUQFUA compare favorably with those of other methods. In general, it is easy to apply for a large number of individual samples, and the validation method is objective and requires no past experience with plutonium body burden calculations on the part of the evaluator.
INTRODUCTION

For a number of years there has been a serious need of some relatively simple method of estimating personnel body burdens of radioisotopes from urinalysis results. In recent years adequate methods have been reported\(^1,2\) for certain specific isotopes, such as \(^3\)H and \(^{235}\)U; however, the only known methods for determining plutonium body burden have required individual treatment combined with long experience and subjective consideration by the evaluator.

This report describes a specialized procedure for plutonium developed at this Laboratory which is not subject to the drawbacks inherent in earlier procedures. Called "PUQFUA" (PU, plutonium; Q, body burden; F, from; U, urine; A, Assays), it consists in an IBM-704 program which calculates the body burden in microcuries and the per cent of the maximum permissible body burden. Although it was written primarily for Pu\(^{239}\), this being the only commonly encountered plutonium isotope, it is applicable also to Pu\(^{238}\) and Pu\(^{240}\), since the permissible body burden and body

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chemistry are the same for all three. As given in NBS Handbook No. 69, the permissible body burden is 0.04 μc, based on the critical organ being the bone. It is assumed for FUQFUA that all personnel exposures to plutonium are acute exposures occurring at a known time.

MATHEMATICAL BASIS

FUQFUA is based on an article entitled, "The Application of Excretion Analyses to the Determination of Body Burden of Radioactive Isotopes," by Wright H. Langham. Based on experimental evidence with humans, Langham developed a set of power function elimination equations for the excretion of plutonium over a five year period. These equations are:

\[ Y_u = 0.002t^{-0.74} \]
\[ Y_{u+f} = 0.0079t^{-0.94} \]

where \( Y_u \) and \( Y_{u+f} \) are the fractions of the injected dose of plutonium excreted per day in the urine and in the urine plus faeces, respectively, and \( t \) is the time in days after injection. Langham emphasizes that the errors in the constants of the above expressions may be of the order of 10 per cent.

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Since body elimination is by both urinary and faecal excretion, an integration of the expression $Y_{uf}$ from $1/2^*\text{x} + 1/2$ days will give total fraction of the acute body burden which has been eliminated in $x$ days ($x=t$). Subtracting this value from unity will give the fraction of the body burden retained ($R_t$) at $x$ days after exposure.

The fraction of the original body burden ($D_E$) eliminated on a given day $t$, i.e., $Y_u$, will be equal to the amount of plutonium in the 24 hr urine on that day $t$ divided by the original body burden, or

$$Y_u = \frac{U}{D_E} \quad (3)$$

where $U$ is the amount of plutonium excreted on day $t$ in the same unit as $D_E$ is expressed. Combining the two expressions for $Y_u$, we obtain

$$D_E = 500 \cdot U t^{0.74} \quad (4)$$

Thus, by measuring the 24 hr urinary excretion on any day $t$, we are able to compute the body burden from a single acute exposure.

In order to compute the additional body burden after another exposure, we now extend Langham's development. We calculate the urine sample to be expected from the original exposure on day $t'$, where $t'$ is greater than $t$. We then subtract this calculated daily urinary excretion from

*Arbitrarily chosen as a lower limit of integration since the power function is divergent for small values of $t$. 
the measured value on day \( t' \) and compute \( D_E' \), using this difference as the value of \( U \).

For successive exposures, the sum of the expected 24 hr urinary excretions is subtracted from the measured value and this difference is used in equation 4 as \( U \) to give the additional incremental body burden at the time of exposure.

By manipulating the equations previously given, the 24 hr urine specimen at some later time, \( t' \), is given by

\[
U' = 0.002D_E' t' - 0.74
\]

Thus, by a series of successive calculations of \( D_E' \), the expected partial 24 hr urinary excretion corresponding to each urine sample may be calculated.

Once all of the partial \( D_E' \)'s are calculated for all the urine specimens listed, the amount of plutonium retained by the body in each case is given by

\[
D_R = D_E R_t = D_E \left( 1 - 0.0079 \int_{1/2}^{x+1/2} t^{-0.94} dt \right)
\]

or

\[
D_R = D_E \left[ 1 - 0.1317(x + 1/2)^{0.06} + 0.1317 \left( 1/2 \right)^{0.06} \right]
\]

where \( x \) is the number of days between the date of calculation and the date each partial body burden was received. Equation 6a accounts for the
elimination of plutonium from the date of the exposure to the date on
which the computation of body burden is made.

Hence, the total body burden on the date of calculation is given by
the sum of all $D_r$'s.

PROBLEMS IN APPLICATION

Although the theory outlined above is relatively simple, there are
a number of problems which come up in the actual application. Primarily,
the problem of calculating the partial body burdens from more than two
or three urine specimens is a lengthy process. In order to devise an
applicable system, it was decided to code the problem for the IBM-704.
As presently coded, the 704 can handle the data for 500 individual uri-
nary excretions per man. At the present rate of sampling, this capacity
should be sufficient for some 50 years of data collection.

Another problem concerns the validity of plutonium urinalyses.
Since about January, 1957, the method of analysis at LASL is believed to
be satisfactory. However, up until about the middle of 1958 there was
a possibility of contamination of the specimens submitted, arising from
the re-use of the metal buckets for the collection of the glass sample
bottles. For these reasons, it seemed desirable to initiate a system of
validation of all urinalyses before calculations of body burden were

5. Jean McClellan et al., Los Alamos Scientific Laboratory Report LA-
performed. This validation is accomplished in the following manner. Each successive sample is used to validate the preceding sample. Based purely on the magnitude of the preceding sample, the expected urinary excretion on the date of the immediate successive sample is calculated using equation 5. If the successive sample (in d/m) is equal to, or greater than, the calculated value (in d/m) minus 0.1 d/m, then the preceding sample is considered valid. If the successive sample result is less than this number, the preceding sample is set equal to zero for purposes of calculation.

At first glance this method may seem arbitrary. However, it should be realized that the several samples preceding the one to be validated also may indicate an incremental body burden, part of which is constantly being eliminated. The effect of these incremental body burdens will tend to increase the measured excretion rate over that predicted by only the immediately preceding sample. Thus, the only possible flaw would be validation of samples which do not add to the total body burden, and these will be eliminated in the complete calculation. This technique automatically makes the latest urine sample of a series valid (i.e., until another sample is submitted).

Another minor difficulty was experienced in supplying the IBM-704 with dates of sampling in terms suitable for calculation. This problem was overcome by establishing an initial date of January 1, 1944, and having the 704 compute the time interval in days from this date for all dates appearing in the input data.
Since this system assumes all exposures to be acute, the date of actual exposure is required in the calculation. If a known accident occurred, then this date is directly fed into the calculation. If no known accident occurred, then it is assumed that the exposure occurred on the date half-way between two successive submissions of urine samples. At LASL, plutonium urine sampling is done on approximately a monthly basis for the persons most likely to be exposed. Thus, in the majority of cases, the exposure would be assumed to occur about fifteen days before the sample was taken. Therefore, in coding quite arbitrarily the date of exposure for the first sample submitted is assumed to be 15 days before the sample submission date, unless a known accident occurred, and then the actual date is used.

In certain cases following an accident, treatment with EDTA or other drugs is administered to the person involved. Urine samples submitted during the treatment and for a period after the treatment has ceased are omitted from the input data. In such cases, the urinary excretion rate is substantially higher than that predicted by the Langham equations, and such urine samples should not be included in the calculations.

For convenience, all primary calculations of body burden are done in terms of disintegrations per minute. For clarity of presentation, these are converted to microcuries (μc) and fraction of permissible body burden. Also the partial body burden received during the preceding six months and during each preceding year is calculated.
The system devised for calculation of body burden is immediately applicable at other installations which have access to IBM-704 equipment with 16 K word capacity, provided the input data are supplied in the form specified below. No claim is made as to the conciseness of the form in which the problem was originally coded. Other simpler and more economical codings are undoubtedly possible.

Primarily PUQFUA is a FORTRAN coding. However, in order to convert months expressed as numbers from 1 through 12 to numbers from 1 through 9 plus letters O, N, D, a short 871 compilation was required, and the basic FORTRAN program was slightly modified to permit inclusion of this sub program. Incorporated in the basic program are instructions to write on peripheral tape equipment the data necessary to punch the required information in an INTERNAL EXPOSURE RECORD CARD, shown below.
The FORTRAN statements, which comprise the program, follow:

```
DIMENSION ID(500), IDUS(500), EDUS(500), US(500), FEUS(500), UUS(500),
XIDPQ(500), PQ(500), EUS(500), EXC(500), CPQ(500), ICD(1), CQ(1), PCQ(1),
XCCQ(1), IDATE(24), ELCPQ(500), ELCQ(24), FELCQ(24), AFCQ(24),
XDELMQ(24), IDELDA(24), DELLYR(24), KMO(500), KYR(500), KDA(500),
XLYR(24), IMO(13), LILO(13), IDMO(500), IDDA(500), IDYR(500), DUMMY(12)
REWIND8
REWIND2
REWIND3
READINPUTTAPE8,4,(LYR(J), J=1,24)
READINPUTTAPE8,4,(IMO(J), J=1,13)
READINPUTTAPE8,4,(LILO(J), J=1,13)
READINPUTTAPE8,6,(IDELMO(J), IDELDA(J), IDELLYR(J), J=1,24)
DO650 J=1,24
LL=IDELLYR(J)-43
IF(LL)664,664,665
665 IYR=LYR(LL)
   IF(LL-1)1001,661,651
651 IF(LL-5)662,661,652
652 IF(LL-9)662,661,653
653 IF(LL-13)662,661,654
654 IF(LL-17)662,661,655
655 IF(LL-21)662,661,656
656 IF(LL-25)662,661,1001
```

-13-
661  KM=IDEIMO(J)
     IMO=LMO(KM)
     GOTO663
662  KM=IDEIMO(J)
     IMO=LMO(KM)
663  IDATE(J)=IYR+IMO+IDEDLA(J)
     GOTO650
664  IDATE(J)=0
650  CONTINUE

READINPUTTAPE8,3,NNN
110 READINPUTTAPE8,3,N,ICDMO,ICDDA,ICDYN
  READINPUTTAPE8,4,(ID(J),J=1,N)
  READINPUTTAPE8,6,(KMO(J),KDA(J),KYR(J),J=1,N)
  READINPUTTAPE8,5,(US(J),J=1,N)
  LL=ICDYN-43
  IYR=LYR(LL)
  IF(LL-1)1001,681,682
  IF(LL-5)680,681,683
  IF(LL-9)680,681,684
  IF(LL-13)680,681,685
  IF(LL-17)680,681,686
  IF(LL-21)680,681,687
  IF(LL-25)680,681,1001
  681  IMO=LMO(ICDMO)
GOT0688

680  IMO=IMO(ICDMO)

688  ICD=IYR+IMO+ICDDA

DO750J=1,N

LL=KVR(J)-43

IYR=LYR(LL)

IF(LL-1)1001,761,751

751  IF(LL-5)762,761,752

752  IF(LL-9)762,761,753

753  IF(LL-13)762,761,754

754  IF(LL-17)762,761,755

755  IF(LL-21)762,761,756

756  IF(LL-25)762,761,1001

761  KM=KMO(J)

IMO=LIMO(KM)

GOT0763

762  KM=KMO(J)

IMO=LIMO(KM)

763  IDUS(J)=IYR+IMO+KDA(J)

750  CONTINUE

EDUS(2)=FLOATF(IDUS(2)-IDUS(1)+15)

FEUS(2)=US(1)*(15.*0.74)*1./EDUS(2)**0.74

IF(US(2)-FEUS(2)+0.1)300,301,301

300  UUS(1)=0.
GOTO400
301 UUS(1)=US(1)

400 DO401 J=3,N

   EDUS(J)=FLOATF(2*IDUS(J)-IDUS(J-1)-IDUS(J-2))/2.
   FEUS(J)=US(J-1)*((FLOATF(IDUS(J-1)-IDUS(J-2))/2.)*0.74)*
   XL./EDUS(J)**0.74
   IF(US(J)-FEUS(J)+0.1)302,303,303

302 UUS(J-1)=0.
   GOTO401

303 UUS(J-1)=US(J-1)

401 CONTINUE

501 UUS(N)=US(N)

   IDPQ(L)=IDUS(L)-ID(L)
   PQ(L)=500.*UUS(L)*((FLOATF(ID(L)))*0.74
   DO60L=2,N
   M=L-1
   DO30K=1,M
   EUS(K)=0.002*PQ(K)*L./((FLOATF(IDUS(L)-IDPQ(K)))*0.74)

30 CONTINUE

   SEUS=0.
   DO33K=1,M

33 SEUS=SEUS+EUS(K)

   EXC(L)=UUS(L)-SEUS

34 IF(EXC(L) )35,40,40
35 IDPQ(L)=0
  PQ(L)=0.
  GOTO60
40 IF(ID(L))47,47,50
50 IDPQ(L)=IDUS(L)-ID(L)
  PQ(L)=500.*EXC(L)*(FLOATF(ID(L))**0.74)
46 GOTO60
47 CD=FLOATF(IDUS(L)-IDUS(L-1))/2.
  IDPQ(L)=IDUS(L)-XFIXF(CD)
  PQ(L)=500.*EXC(L)*(CD**0.74)
60 CONTINUE
  DO80L=1,N
     CNST=1.+0.1317*(0.5**0.06)
80 CPQ(L)=PQ(L)*(CNST-0.1317*((FLOATF(IDC-IDPQ(L))+0.5)**0.06))
     CQ=0.
     DO100L=1,N
100 CQ=CQ+CPQ(L)
     FCQ=CQ/97680.
     CCQ=FCQ*0.044
  DO204K=1,24
  DO200J=1,N
     IF(IDPQ(J)-IDATE(K))201,201,202
201 ELSECPQ(J)=0
     GOTO200

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202 ELCFQ(J) = CFQ(J)
200 CONTINUE
   ELCQ(K) = 0.
   DO203 J = 1, N
203 ELCQ(K) = ELCQ(K) + ELCFQ(J)
   FEICQ(K) = ELCQ(K)/97680.
204 CONTINUE
   AFCQ(1) = FELCQ(1)
   AFCQ(2) = FELCQ(2)
   DO205 K = 3, 24
205 AFCQ(K) = FELCQ(K) - FELCQ(K - 1)
   CAFCQ = FELCQ(1)*0.044
   DO940 J = 1, N
   IF(IDPQ(J)) 1001, 948, 949
948 IDMO(J) = 0
   IDDA(J) = 0
   IDYR(J) = 0
   GOTO940
949 K = 1
952 K = K + 1
   III = IDPQ(J) - Lyr(K)
   KKK = IDPQ(J) - Lyr(K - 1)
   IF(III) 950, 951, 952
951 IDYR(J) = K + 42
IDMO(J)=12
IDDA(J)=31
GOTO940
950 IDYR(J)=K+42
   IF(K-2)1001,961,953
   IF(K-6)962,961,954
   IF(K-10)962,961,955
   IF(K-14)962,961,956
   IF(K-18)962,961,957
957 IF(K-22)962,961,1001
961 L=1
965 L=L+1
   LLL=KKK-LIMO(L)
   JJJ=KKK-LIMO(L-1)
   IF(LLL)964,964,965
964 IDMO(J)=L-1
   IDDA(J)=JJJ
   GOTO940
962 L=1
967 L=L+1
   LLL=KKK-LIMO(L)
   JJJ=KKK-LIMO(L-1)
   IF(LLL)966,966,967
966 IDMO(J)=L-1
IDDA(J)=JJJ

940 CONTINUE

IFCQ=FCQ*1000.
ICCQ=CCQ*10000.
IAFCQ=AFCQ(1)*1000.
ICAFCQ=CAFCQ*10000.

KKMO=KMO(N)

801 READINPUTTAPE8,2,IH,IC,IFIC,ICFIC,ISMFIC,ISMCFI,IA,IG,NUM
DIOT=DUMMY(KKMO)
WRITEOUTPUTTAPE3,2,ICDMO,ICDYM,IFCQ,ICCQ,IAFCQ,ICAFCQ,
XKDA(N),KYR(N),NUM
WRITEOUTPUTTAPE2,1
WRITEOUTPUTTAPE2,2,ICDMO,ICDYM,IFCQ,ICCQ,IAFCQ,ICAFCQ,
XKDA(N),KYR(N),NUM
IF(SENSESWITCH1)111,112

111 PRINT2
112 IF(SENSESWITCH2)502,503

502 WRITEOUTPUTTAPE2,13

WRITEOUTPUTTAPE2,10,(IDMO(J),IDDA(J),IDYR(J),CPQ(J),KMO(J),
XKDA(J),KYR(J),US(J),UUS(J),J=1,N)

503 WRITEOUTPUTTAPE2,15

WRITEOUTPUTTAPE2,16,FCQ,(AFCQ(K),K=1,11)
WRITEOUTPUTTAPE2,17
WRITEOUTPUTTAPE2,16,(AFCQ(K),K=12,24)
IF(NNN-NUM)810,810,110

810 ENDFILE2
ENDFILE3
REWIND2
REWIND3
REWIND8
STOP7777
1001 PRINT7
STOP7777
1 FORMAT(73H
 XDATE LAST SAMPLE)
2 FORMAT(29H
 X11H I2,I2,9H I4)
3 FORMAT(I12,I8,2I2)
4 FORMAT(I2I6)
5 FORMAT(7F10.4)
6 FORMAT(12(3I2))
7 FORMAT(15H MACHINE ERROR )
10 FORMAT(I33,2I5,E11.4,3I5,2E11.4)
13 FORMAT(90H
 X KMO KDA KYR US UUS )
15 FORMAT(97H
 FCQ 1/2 YEAR 1 YEAR 2 YEAR 3 YEAR 4 YEAR 5 YEAR
 X 6 YEAR 7 YEAR 8 YEAR 9 YEAR 10 YEAR )
16 FORMAT(15F8.4)

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In order of their appearance in the listing above a short description follows of each of the variables used.

**ID**
Number of days before urine sample submission date on which accident occurred; if no known accident, zeros are used, except for the first sample when 15 is used.

**IDUS**
Date of submission of urine sample converted to days since 1/1/44 (machine date)

**EDUS**
Elapsed days from exposure for immediately previous urine sample to date of current sample

**US**
Urine assay data in d/m - 24 hr sample

**FEUS**
Estimated urine sample (in d/m - 24 hr sample) from immediately previous sample

**UUS**
Validated urine assay data in d/m - 24 hr sample

**IDPQ**
Date of exposure for current urine sample (machine date)

**PQ**
Partial body burden (in d/m) at time of exposure (IDPQ)

**EUS**
Estimated partial urine sample based on PQ

**EXC**
Actual urine sample minus sum of EUS's

**CPQ**
Partial body burden (in d/m) due to PQ at date of calculation

**ICD**
Date of calculation (machine date)

**CQ**
Sum of CPQ's (or total body burden) in d/m

**FCQ**
Total body burden as fraction of permissible

**CCQ**
Total body burden in microcuries

**IDATE**
Machine date for determining partial exposure which occurred in successive years

**ELCPQ**
CPQ occurring between IDATE and ICD
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELCQ</td>
<td>Sum of ELCQ's for successive years in d/m</td>
</tr>
<tr>
<td>FEICQ</td>
<td>Fraction of body burden acquired between IDATE and ICD</td>
</tr>
<tr>
<td>AFCQ</td>
<td>Difference in two successive values of FEICQ, or fraction of body burden acquired in successive years</td>
</tr>
<tr>
<td>IDEIMO</td>
<td>Month, day, and year (2 digit notation) of previous years to date of calculation</td>
</tr>
<tr>
<td>IDELYR</td>
<td>Month, year, and day of submission of urine sample</td>
</tr>
<tr>
<td>IDMO</td>
<td>Number of days from 1/1/44 to the first of each successive year</td>
</tr>
<tr>
<td>IMO</td>
<td>Number of days from first day of any non-leap year to first day of each month</td>
</tr>
<tr>
<td>IDMO</td>
<td>Number of days from first day of any leap year to first day of each month</td>
</tr>
<tr>
<td>IDDA</td>
<td>Month, day, and year date of exposure to plutonium, IDPQ converted to month, day, and year</td>
</tr>
<tr>
<td>IDYR</td>
<td>A set of twelve constants which are compiled by an 871 assembly, and which alter the FORTRAN assembly as mentioned earlier</td>
</tr>
<tr>
<td>DUMMY</td>
<td>Calculation constant defined variously in FORTRAN statements</td>
</tr>
<tr>
<td>LL</td>
<td>Calculation constant defined variously in FORTRAN statements</td>
</tr>
<tr>
<td>IYR</td>
<td>Partial date used to compute IDATE or ICD</td>
</tr>
<tr>
<td>KM</td>
<td>Calculation constant defined variously in FORTRAN statements</td>
</tr>
<tr>
<td>IMO</td>
<td>Partial date used to compute IDATE or ICD</td>
</tr>
<tr>
<td>NNN</td>
<td>Total number of persons for whom body burden calculations are to be made</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>N</td>
<td>Total number of urine samples to be used for a single calculation of body burden</td>
</tr>
<tr>
<td>ICDMO</td>
<td>Month, day, and year date of calculation</td>
</tr>
<tr>
<td>ICDDA</td>
<td>Month, day, and year date of calculation</td>
</tr>
<tr>
<td>ICDYR</td>
<td>Month, day, and year date of calculation</td>
</tr>
<tr>
<td>M</td>
<td>Calculation constant defined in FORTRAN statements</td>
</tr>
<tr>
<td>SEUS</td>
<td>Sum of EUS's</td>
</tr>
<tr>
<td>CD</td>
<td>Half the number of days between successive urine samples</td>
</tr>
<tr>
<td>CNST</td>
<td>Constant defined in FORTRAN statements</td>
</tr>
<tr>
<td>III</td>
<td>Calculation constants variously defined in FORTRAN statements</td>
</tr>
<tr>
<td>KKK</td>
<td>Calculation constants variously defined in FORTRAN statements</td>
</tr>
<tr>
<td>LLL</td>
<td>Calculation constants variously defined in FORTRAN statements</td>
</tr>
<tr>
<td>JJJ</td>
<td>Calculation constants variously defined in FORTRAN statements</td>
</tr>
<tr>
<td>IFCQ</td>
<td>FCQ, CCQ, AFCQ, CAFCQ multiplied by a constant and truncated, suitable for punching on INTERNAL EXPOSURE RECORD cards</td>
</tr>
<tr>
<td>ICCQ</td>
<td>FCQ, CCQ, AFCQ, CAFCQ multiplied by a constant and truncated, suitable for punching on INTERNAL EXPOSURE RECORD cards</td>
</tr>
<tr>
<td>IAFCQ</td>
<td>FCQ, CCQ, AFCQ, CAFCQ multiplied by a constant and truncated, suitable for punching on INTERNAL EXPOSURE RECORD cards</td>
</tr>
<tr>
<td>ICAFCQ</td>
<td>FCQ, CCQ, AFCQ, CAFCQ multiplied by a constant and truncated, suitable for punching on INTERNAL EXPOSURE RECORD cards</td>
</tr>
<tr>
<td>KKMO</td>
<td>Month of submission of last urine sample in current calculation</td>
</tr>
<tr>
<td>IH</td>
<td>Dummy functions required to fill spaces in input statements</td>
</tr>
<tr>
<td>IC</td>
<td>Dummy functions required to fill spaces in input statements</td>
</tr>
<tr>
<td>IFIC</td>
<td>Dummy functions required to fill spaces in input statements</td>
</tr>
<tr>
<td>ICFIC</td>
<td>Dummy functions required to fill spaces in input statements</td>
</tr>
</tbody>
</table>
Dummy functions required to fill spaces in input statements

Four digit identification for each person whose body burden is calculated. No number should exceed NNN and the last person to be calculated should have NUM=NNN

Causes one bit of FORMAT to be changed according to value of DUMMY selected.

As mentioned earlier, an 871 assembly was required. After assembling FUQFUA by FORTRAN, the location of the storage for DUMMY must be obtained. In the original compilation, this occurred from 23545 through 23534. The following deck, assembled by 871, provides the data to be stored as DUMMY.

5006  FUQFUA

188000000  00+23545
H880001JO  D12,1
H880001-0  N12,1
H880000RO  012,1
H880000Q0  912,1
H880000PO  812,1
H88000000  712,1
H880000NO  612,1
H880000MO  512,1
H880000LO  412,1
In addition, the binary deck of PUQFUA must be altered by changing the address of the instruction STO DIOT from the address of DIOT to the address of the 13th bit of the assembled FORMAT statement #2.

With the modifications as described, by using peripheral equipment, a tape-controlled printer, and a tape-to-card converter, PUQFUA can supply the following:

1. INTERNAL EXPOSURE RECORD cards for each individual.

2. Listings containing the identification of the person, FCQ, CCQ, AFCQ, CAFCQ, date of last sample and the person's identification number; the fractional body burden acquired in the last half year, the last year, the next to last year (2nd year), third year, etc., from the
(3) If SENSE SWITCH 2 is depressed, in addition to the listing described in (2) above, the individual dates of assumed exposure, the calculated exposure in disintegrations per minute, the date of each urine sample, the value of each urine sample, and the corresponding validated urine samples.
INPUT DATA

In order to minimize the time required for entry of the input data, FUQFUOA was written to accept all input data from tapes and not cards. All input data is first written from cards on Tape 8 by means of peripheral equipment. The order of the input data can be obtained from the FORTRAN statements; however, a short description of each block of data follows.

The first deck of input data consists of the LYR table. In this table are the 24 numbers corresponding to the total number of days at the end of 24 consecutive years starting January 1, 1944. This deck must be punched by FORMAT (12I6).

The second deck is the LMO table. This table consists of the number of days at the beginning of each month as counted from the first day of non-leap years, punched by FORMAT (12I6). The table contains thirteen entries, the last being the number of days in the year.

The third deck is the LIMO table. This table is the leap year table corresponding to the LMO table.

The fourth deck is comprised of dates. The first date is that six months prior to the calculation date. Thereafter, the dates are those for each year through the twenty-third year prior to the date of the calculation. A set of three two-digit numbers comprises the date, with the first being the month, the second the day, and the last the year. These dates are arranged according to FORMAT (12(3I2)).

The fifth deck consists of the single number NNN punched according
to FORMAT (112, I8, 2I2).

The sixth deck contains all the remaining necessary information for computing body burden. It is comprised of NNN sets of five subdecks, where the number NNN is the total number of persons whose body burdens are to be evaluated.

Subdeck 1 (or the NCDL deck) consists of a single card with the numbers N, ICDMO, ICDDA, ICDYR punched according to FORMAT (112, I8, 2I2). Although not called for by the FORMAT, in columns 73 through 76 are the letters NCDL, and in columns 77 through 80 the identification number of the person (NUM).

Subdeck 2 (or the ID deck) consists of a table of N entries corresponding to the various ID's of each urine sample, punched according to FORMAT (1216). While not called for by the FORMAT, in columns 73 and 74 are the letters ID and in columns 77 through 80, the corresponding NUM.

Subdeck 3 (or DU deck) consists of the dates of the N urine samples punched according to FORMAT (12(312)). Again not called for by the FORMAT, in columns 73 and 74 are the letters DU and in columns 77 through 80 the corresponding NUM.

Subdeck 4 (or US deck) consists of N actual urine assay results in d/m - 24 hr sample for the person concerned, punched according to FORMAT (7F10.4). Again not called for by the FORMAT, in columns 73 and 74 are the letters US, and in columns 77 through 80 the corresponding NUM.

Subdeck 5 (or PLUTONIUM deck) is a single card deck containing the identification of the individual. The information is punched by the
following FORMAT:

FORMAT (29H II, I2, 4I5, I1H I2, I2 9H I4):

Column 1, blank
Columns 2 through 19, last name and the initials of person being evaluated
Columns 20 through 24, Z number (LASL identification number) of person being evaluated
Columns 25 through 27, current LASL group code
Columns 28 and 29, last digits of the birth year of person being evaluated
Columns 30 through 67, no punches
Columns 68 through 76, the word PLUTONIUM
Columns 77 through 80, NUM of person being evaluated

DISCUSSION OF RESULTS

FUQfuq purports to measure the body burden exclusive of the lung burden. Since it is based on urinalysis data, only that plutonium which has been absorbed into the system influences the calculations. It has been found that the body burden of certain persons appears to increase continuously at a slow rate, even though these persons are no longer exposed to plutonium. This is believed to be due to a slow absorption of a suspected plutonium lung burden into the blood stream. Thus, for all intents and purposes, persons with significant lung burdens have
constant sources of exposure to plutonium.

Any system of computing body burden is only as reliable as the data which go into the calculation. When Langham estimated the body burdens of the cases in his paper, he had his own system of validating urine samples based on his past experience and extensive knowledge of the subject. The validation method of PUQFUA requires no past experience on the part of the person performing the calculation and is objective in treatment of data.

PUQFUA calculations were compared with Langham's original calculations, and the listing below gives Langham's estimated body burden (converted to microcuries) and the body burdens as calculated by PUQFUA. Positive exposures in these cases occurred during the period 1944-46. On the average the body burdens computed by PUQFUA are about 1.6 times those of Langham.

Based on tissue analysis of a recently deceased Los Alamos employee, his total body burden was found to be 0.0175 μc.* Because of the small tissue samples taken and the assumption of uniform distribution throughout each organ tissue, there is an undetermined uncertainty in the body burden figure. PUQFUA calculation on the same man, using urinanalysis records, gives body burden of 0.0191 μc.

In view of the wide spread of the data entering the urinanalysis

*Private communication with H. Foreman and W. H. Langham - Group H-4, LASL
<table>
<thead>
<tr>
<th>Case code</th>
<th>Langham's body burden</th>
<th></th>
<th>FUQFUA body burden</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>µc(±50%)</td>
<td></td>
<td>µc(±50%)</td>
</tr>
<tr>
<td>W. G.</td>
<td>0.08</td>
<td></td>
<td>0.12</td>
</tr>
<tr>
<td>W. B.</td>
<td>0.07</td>
<td></td>
<td>0.13</td>
</tr>
<tr>
<td>D. D.</td>
<td>0.07</td>
<td></td>
<td>0.14</td>
</tr>
<tr>
<td>D. W.</td>
<td>0.06</td>
<td></td>
<td>0.07</td>
</tr>
<tr>
<td>W. A.</td>
<td>0.06</td>
<td></td>
<td>0.11</td>
</tr>
<tr>
<td>G. F.</td>
<td>0.06</td>
<td></td>
<td>0.08</td>
</tr>
<tr>
<td>R. D. B.</td>
<td>0.05</td>
<td></td>
<td>0.03</td>
</tr>
<tr>
<td>F. C.</td>
<td>0.04</td>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td>H. R.</td>
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<td>0.09</td>
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<td></td>
<td>0.04</td>
</tr>
<tr>
<td>T. M.</td>
<td>0.03-0.06</td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td>H. L.</td>
<td>0.03</td>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td>T. E.</td>
<td>0.02</td>
<td></td>
<td>0.03</td>
</tr>
<tr>
<td>R. A. B.</td>
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<td></td>
<td>0.02</td>
</tr>
<tr>
<td>M. W.</td>
<td>0.02</td>
<td></td>
<td>0.03</td>
</tr>
<tr>
<td>D. K.</td>
<td>0.02</td>
<td></td>
<td>0.03</td>
</tr>
<tr>
<td>D. H.</td>
<td>0.02</td>
<td></td>
<td>0.02</td>
</tr>
<tr>
<td>K. E.</td>
<td>0.02</td>
<td></td>
<td>0.03</td>
</tr>
<tr>
<td>J. C.</td>
<td>0.02</td>
<td></td>
<td>0.04</td>
</tr>
<tr>
<td>J. B.</td>
<td>0.02</td>
<td></td>
<td>0.04</td>
</tr>
<tr>
<td>J. A.</td>
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<td></td>
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</tr>
<tr>
<td>E. R.</td>
<td>0.01</td>
<td></td>
<td>0.04</td>
</tr>
<tr>
<td>C. H.</td>
<td>0.01</td>
<td></td>
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</tr>
<tr>
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<td>0.006</td>
<td></td>
<td>0.01</td>
</tr>
<tr>
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<td></td>
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</tr>
<tr>
<td>A. B.</td>
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<td></td>
<td>0.01</td>
</tr>
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</table>
calculation prior to the adoption of the nuclear track plate technique and the uncertainties in the tissue sample calculation, PUQFU is in excellent agreement with the other methods of determining plutonium body burden. Also since the adoption of the nuclear track plate method of plutonium urinalysis, the results have been far more consistent. As a consequence, practically all samples are validated. When all data entering the calculations are of this type, even closer agreement is anticipated between the various methods of computing plutonium body burden based on urine assays.