Establishment of a Procedure to Calculate the Measurement Uncertainties in Radiation Survey Meters Calibration

J.E. Manzoli* and M.P.A. Potiens
Instituto de Pesquisas Energéticas e Nucleares (IPEN)
Comissão Nacional de Energia Nuclear (CNEN)
Travessa R, 400, Cidade Universitária,
São Paulo, Brasil
jmanzoli@net.ipen.br
Poster No.292, Proffered Poster Session No.04a.

INTRODUCTION

Error analysis works with the fact that any measurement procedure has imperfections that give rise to an *error* in the measurement result. Error is the result of a measurement minus the *true value* of the measurand. There are many good books on this subject (1,2). Since the true value cannot be determined, in practice a conventional true value is used. Based on these errors it is constructed a parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand and is called *uncertainty* (3). It's quite important to know the uncertainty in a measurement, mainly in a calibration laboratory, because it is the clear expression of the capability and quality of theirs services (4).

The *Calibration Laboratory of IPEN* (LCI/IPEN) calibrates more than one thousand gamma ray survey meters a year, beside other kinds of radiotherapy, diagnostic radiology and radiation protection instruments. In the gamma ray survey meter calibration procedure there are two values that have to get theirs uncertainties clearly known: measurements in the instrument under calibration and the true value. The uncertainty in the instrument under calibration is normally an *A* kind and is obtained by a series of measurements, at least ten, and then its standard deviation is multiplied by the t-factor to express the confidence level of the instrument (1). For the physical quantities exposure, absorbed dose or dose equivalent rates the true value is obtained through the indirect measurements performed with a reference ionization chamber. It is measured the integral of electrical current in a time interval, a charge, ($Q \pm \Delta Q$), formed in the active volume of the chamber when it is submitted to the radiation in a precisely distance ($x \pm \Delta x$) and instant ($t \pm \Delta t$). The measurement with the instrument under calibration (and its uncertainty) is compared with the true value (and its uncertainty) and if the normalization (5-7) is not obeyed adjustments are made in the instrument.

The LCI has a reference ($600 cm^3$) cylinder ionization chamber (*Nuclear Enterprises Ltd*. model 2511/3) traceable to the *Brazilian Secondary Standard Dosimetry Laboratory* (*SSDL*) which is traceable to the *BIPM*. Annually the beam dosimetry is performed using this ionization chamber and the results are used for the *true values* determination for calibration purposes. The uncertainties present in every direct or indirect measurement during the calibration procedure must be evaluated for purposes of laboratory quality control. All calculation steps in the propagation of errors are presented in this work starting from the ionization chamber charge measured with the reference instrument. Such propagation was made in space and time, considering even the pressure and temperature uncertainties. The propagation was necessary in space, because the ionization chamber measurements were performed at only one space position, that is *(1,000±0,005)m.* Actually we use a new procedure based in five measured positions and it will be published soon. The time propagation was essential due to the fact that the activity is a peculiar physical quantity, which changes with the time according to precise relations for a specific radionuclide. Nowadays the achievement of calibration laboratory quality systems requires the expression of all uncertainties and the procedure used to evaluate it. The FORTRAN program was used to calculate the true values, theirs uncertainties and an example of this procedure in the case of the calibration of a typical scale of a portable radiation survey meter is presented.

UNITS AND QUANTITIES

The majority of the survey meters calibrated at LCI use old units (8). If necessary, primarily it is converted the new units in the exposure rate old unit Roentgen/hour and after calculations, it is "re"-converted. For survey meters, the quantities used are: *Exposure, X*, which has unit *1R*(old) = $2.85 \times 10^{-4} C/kg$(new); *Absorbed Dose, D*, unit *1Gy*(new) = *100rad*(old) and in air or water *1C/kg = 3876R* produces *33,8Gy* and so *"1Gy=115R"*; *Dose Equivalent, H*, unit *1Sv*(new) = *100rem*(old), and for gamma rays, the relation *"1Sv=1Gy"* is straightforward. The equalities inside inverted commas means *numerically equality* because the left and right side of them are not the same physical quantity but theirs numerical values are the same.

The variables involved that is considered as having some uncertainty are:

* Physics teacher at *Universidade de Mogi das Cruzes* and *Universidade Bandeirantes*.

Q – the charge measured in 60 seconds at the reference ionization chamber
ΔQ – *its uncertainty*
t – the time interval between the beam dosimetry and the calibration instant.
Δt – *its uncertainty*, assumed as 12 hours because only once a day the calculation is made.
x – the distance from the source
Δx – *its uncertainty*, assumed as 5mm, due to not-punctual form of sources, parallax errors or little distortions in the meter instrument.
N – the calibration factor of the reference ionization chamber, here 6.0680×10^{6} R/C.
ΔN – *its uncertainty*, as 5×10^{10} *R/C*.
s – the radiation quality factor. It is *0.9990* for ^{60}Co and 1 for ^{137}Cs.
Δs – *theirs uncertainties* are *0.0005* for ^{60}Co and *0.0* for ^{137}Cs.
f – the pressure and temperature correction factor.
Δf – *its uncertainty*.
T – the temperature at beam dosimetry instant in ºC.
ΔT – *its uncertainty*, *0.5 ºC*.
P – the pressure at beam dosimetry instant in *kPa*.
ΔP – *its uncertainty*, *0.5kPa*.
X_o' – the exposure rate at beam dosimetry instant and at one meter of distance from the source.
$\Delta X_o'$ – *its uncertainty*.
$X'_{t,x}$ – the exposure rate at calibration instant and at x distance from the source.
$\Delta X'_{t,x}$ – *its uncertainty*.
A_o – the apparent activity (based on the exposure rate) at beam dosimetry instant.
ΔA_o – *its uncertainty*.
A_t – the apparent activity (based on the exposure rate) at calibration instant.
ΔA_t – its uncertainty.
Γ – the exposure rate constant, *1.321* $Rm^2/(Ci.h)$ for ^{60}Co and *0.329* $Rm^2/(Ci.h)$ for ^{137}Cs.
$\Delta\Gamma$ – *theirs uncertainties*: 4×10^{-3} $Rm^2/(Ci.h)$ for ^{60}Co and ^{137}Cs.
$T_{1/2}$ – the half-life of radionuclide, $46.08\times10^{3}h$ for ^{60}Co and $262.8\times10^{3}h$ for ^{137}Cs.
$\Delta T_{1/2}$ – *theirs uncertainties*: $1\times10^{2}h$ for ^{60}Co and $7\times10^{2}h$ for ^{137}Cs.

UNCERTAINTIES IN TRUE VALUES

The LCI has two free in air ^{60}Co sources for 4π steradians of irradiation, two ^{60}Co and three ^{137}Cs collimated sources for survey meter calibration. The irradiator exposure could be made through lead filters and every "4π source" and every lead filter combination is numbered as been a different and individual source with an respective apparent activity. So, as an example, the irradiator ^{60}Co source with two filters is labeled as *source 7* and with three filters is labeled *source 8*.

After making five measurements of the integral charge, Q, in 60 seconds of irradiation at one meter of distance from every source with the reference ionization chamber it is calculated theirs standard deviations, σ, from this five values and it is multiplied by 2.8, the t-factor for 5 samples to achieve 95% of confidence level. If the five values are the same or the standard deviation is smaller than the half of the last decimal digit in the electrometer display the last is used instead of σ. So it is obtained ΔQ. Multiplying [$Q\pm\Delta Q$] by 60 minutes we have [$i\pm\Delta i$] the charge per hour produced by such an exposure (or source).

The pressure and temperature correction factor and its uncertainty are:

$$f = \frac{101,3}{P}\times\frac{273,15+T}{273,15+20}$$

$$\Delta f = \frac{101,3}{293,15}\times\frac{1}{P}\left[\frac{273,15+T}{P}\times\Delta P+\Delta T\right] \qquad \text{(eq.01)}$$

If not defined, terms used in equations here and thereafter are in previous section.

The exposure rate and its uncertainty at one meter and beam dosimetry instant is:

$$\dot{X}_0 = N.s.f.i$$

$$\Delta\dot{X}_0 = \Delta N\times(s.f.Q)+\left[\Delta s\times(f.Q)+(\Delta f.Q+\Delta Q.f)\times s\right]\times N \qquad \text{(eq.02)}$$

The apparent activity of every source at dosimetry instant is:

$$A_0 = (\Gamma B)^{-1}\,\dot{X}_0.x^2.e^{\mu x} \qquad \text{(eq.03)}$$

where B is the build-up coefficient, consider as 1 in our laboratory rooms.

μ is the air attenuation coefficient, number as small as $10^{-5}cm^{-1}$ and makes the previous exponential term very close to *1* at distances used in the laboratory, which are from *50* to *350 cm*.

So, the equation 03 becomes:

$$A_0 = \frac{1}{\Gamma}.\dot{X}_0.x^2$$

$$\Delta A_0 = \Delta\dot{X}_0\left(\frac{x^2}{\Gamma}\right) + \dot{X}_0.\left\{\frac{1}{\Gamma^2}\left[x^2(\Delta\Gamma) + \Gamma(2x\Delta x)\right]\right\} \quad \text{(eq.04)}$$

The exposure rate at any instant, and therefore the true value used in calibration sections is:

$$\dot{X}_{t,x} = \frac{\Gamma B e^{-\mu x}}{x^2}.A_0.e^{-\frac{\ln 2.t}{T_{1/2}}} \cong \frac{\Gamma}{x^2}.\left(A_0.e^{-\frac{\ln 2.t}{T_{1/2}}}\right)$$

(eq.05a)

To make easier the uncertainty calculation explanation split the equation 05 into:

$$\dot{X}_{t,x} = g.A_t$$

where $g = g(\Gamma, x) = \frac{\Gamma}{x^2}$

$$A_t = A_t(A_0, T_{1/2}, t) = A_0.e^{-\frac{(\ln 2).t}{T_{1/2}}}$$

So, the uncertainty in the exposure rate is:

$$\Delta X'_{t,x} = \Delta g.A_t + \Delta A_t.g \quad \text{(eq.05b)}$$

where:

$$\Delta g = \frac{1}{x^2}\left[x^2.(\Delta\Gamma) + \Gamma(2x\Delta x)\right]$$

$$\Delta A_t = \left[\Delta A_0 + A_0\left(\frac{\ln 2}{T_{1/2}}\sqrt{\Delta t^2 + \frac{t^2}{T_{1/2}^2}\Delta T_{1/2}^2}\right)\right].e^{-\frac{(\ln 2).t}{T_{1/2}}}$$

In summary, the equations 05a and b give the true value and its uncertainty for the exposure rate at any distance from the source. To obtain other physical quantities than exposure rates, the factors explained in the beginning of the previous section should be multiplied or divided for.

CONCLUSION

It was explained an equation set which allows to calculate the uncertainties involved in the survey meter calibration. The error propagation in space and time is accounted for. To get a desired exposure rate it is possible to choose, among many possible setups, that one which has the minimum uncertainty. In busy labs, like the LCI, for one instrument scale calibration these procedure permits to show the setups that use the same source for all exposure rate. This represents time economy and minimum worker exposure to the radiation when changing the sources.

This procedure is being adapted to compose the *Best Memory Capability* document(9), part of the requirements for the LCI certification.

As a note, it is not recommended to use the symbol ± before the uncertainty in formal documents like calibration certificates. Such a signal suggests some operation with the quantity related and not its true usefulness, which is to express the smallest mathematical interval where the measurement is achievable with a given instrument.

EXAMPLE OF PROGRAM OUTPUT

Next it is presented an output file from the TAXA program in a situation where it is necessary to calibrate the scale of a survey meter whose endscale is 10mGy/h. So it is needed to submit the instrument active sensitive volume at radiation fields with values of 20, 50 and 80% of this endscale. The program shows all the sources present in LCI and all distances between 50cm and 3,50m where the desired rates happens in the calibration date, and theirs uncertainties. It is chosen the setup that is common to all the rates, making easier the calibration than a situation where changes are required, or it is chosen the one with the smallest uncertainty. For another endscales or units the procedure is the same until all the survey meter scales are tested.

file TAXA.DAT:

CALIBRATION DATE:
input> 01/09/1999
INSTRUMENT UNIT:
DIGIT (1) for mR/h, (2) for mGy/h,
(3) for mrad/h, (4) for microSv/h, (5) for mrem/h
input> 2
DESIRED TAXES (3 values):
input> 2.0 5.0 8.0

setups achievable at (LCI-IPEN):

machine output:	**correct expression:**
SOURCE: 4 (60Co)	
TAX = 4.991367 (+-) 1.314686E-01	**or (5.0± 0.1) mGy/h**
DISTANCE = 2.605000 m	**implicit (2,605± 0.005) m**
appar.ativ.= 2.949068 (+-) 5.705224E-02 Ci	**or (2,95± 0.06) Ci**
--	
SOURCE: 4	
TAX = 7.981795 (+-) 2.183404E-01	**or (8.0± 0.2) mGy/h**
DISTANCE = 2.060000 m	**implicit (2,060± 0.005) m**
--	
SOURCE: 5 (60Co)	
TAX = 1.996181 (+-) 5.310377E-02	**or (2.00± 0.05) mGy/h**
DISTANCE = 1.925000 m	**implicit (1,925± 0.005) m**
appar.ativ.= 6.440377E-01 (+-) 1.175581E-02 Ci	**or (0,64± 0.01) Ci**
--	
SOURCE: 5	
TAX = 5.010821 (+-) 1.485123E-01	**or (5.0± 0.1) mGy/h**
DISTANCE = 1.215000 m	**implicit (1,215± 0.005) m**
--	
SOURCE: 5	
TAX = 8.026367 (+-) 2.554354E-01	**or (8.0± 0.2) mGy/h**
DISTANCE = 9.600000E-01 m	**implicit (0,960± 0.005) m**
--	
SOURCE: 10 (137Cs)	
TAX = 2.005005 (+-) 1.229043E-01	**or (2.0± 0.1) mGy/h**
DISTANCE = 1.355000 m	**implicit (1,355± 0.005) m**
appar.ativ.= 1.286104 (+-) 5.306523E-02 Ci	**or (1,29± 0.05) Ci**
--	
SOURCE: 10	
TAX = 4.977339 (+-) 3.262476E-01	**or (5.0± 0.3) mGy/h**
DISTANCE = 8.600000E-01 m	**implicit (0,860± 0.005) m**
--	
SOURCE: 10	
TAX = 7.961160 (+-) 5.463310E-01	**or (8.0± 0.5) mGy/h**
DISTANCE = 6.800000E-01 m	**implicit (0,680± 0.005) m**
--	

In this example, it's better to use only source 5 to calibrate this scale for use with ^{60}Co or source 10 for use with ^{137}Cs. Although source 4 has the same uncertainties for 5 or 8 mGy/h than source 5, it has no reasonable distance when 2 mGy/h is required and so the source 5 setup should be prepared anyway.

ALGORITHM AND FORTRAN PROGRAM

A sketch of the fluxogram is shown in figure 1.

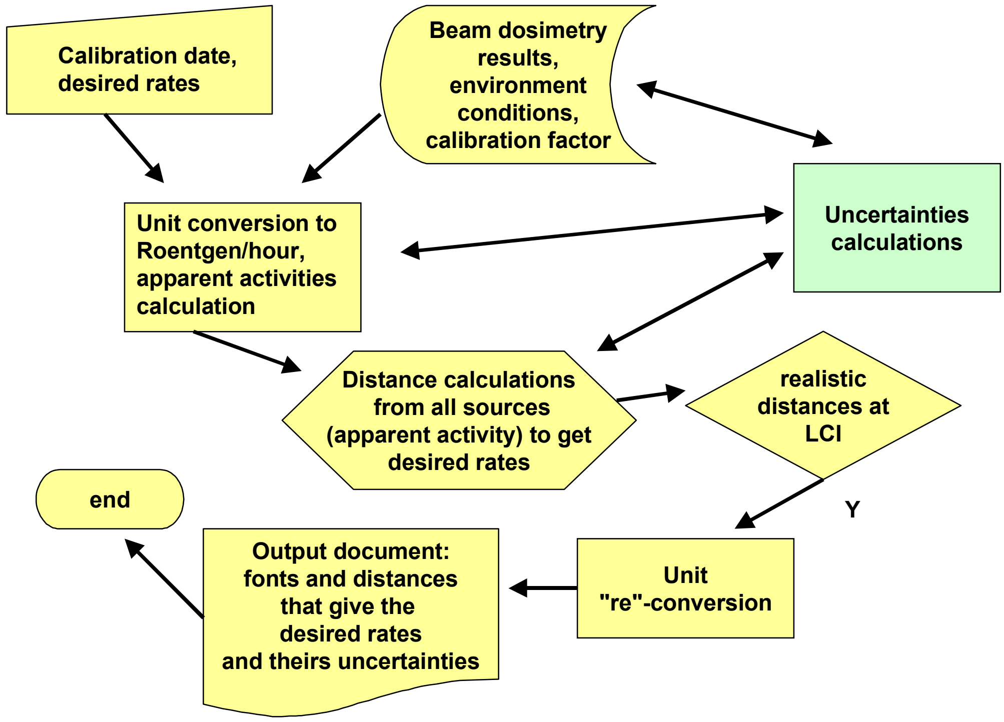

Figure 1: simplified fluxogram: once given the desired rates and calibration date the computer program execution gives the LCI sources and distances from it that permit an irradiation under a rate very close to the desired ones. Your main utility is to calculates all the uncertainties in such a rates.

The execution of the program expends ~1 second in an old Pentium 90MHz. Some important stretches of the source program are following.

```
      PROGRAM TAXA
c-----------------
c   Algorithm and Compilation by
c    Jose' Eduardo Manzoli
c--------------------------
c    Calculation of Exposure,Absorbed Dose in Air
c    or Dose Equivalent for Gamma Ray Rates,
c    with corresponding uncertainties and
c    irradiation distances achievable at LCI-IPEN-CNEN
c-----------------------------------------------------
       INTEGER  U,DIA,MES,ANO,DD(12),MM(12),AA(12)
       REAL     TAX(3),N,DN,QU,DQU,F(12),DF(12),Q(12),DQ(12),
            TEMP(12),DTEMP(12),PRES(12),DPRES(12),X(12),DX(12),
            MEI(12),DMEI(12),A0(12),DA0(12),DIS,DDIS,NDAY(12),
            RAIZ,Y(12),S(3),DS(3),GAM(12),DGAM(12),
            A(12),DA(12),TAXN(3),DTAXN(3),BG,DBG
      COMMON/BL1/DD,MM,AA,DIA,MES,ANO,NDAY
formats.
      OPEN(UNIT=5,FILE='taxa.dat' ,STATUS='OLD')
c  observations:
c     Exposure, X
c           1 R = 2,85E-4 C/kg
c     Absorbed Dose, D
c           1 Gy = 100 rad
c           in air (water) => 1 C/kg = 3876 R <=> 33,8 Gy
c            " 1Gy=115R "
c     Dose Equivalent, H
```

```
c               1 Sv = 100 rem
c               for gamma rays
c                " 1Sv=1Gy "
input calibration date.
input instrument unit:
      WRITE(*,*)'    *********************'
      WRITE(*,*)'    * INSTRUMENT UNIT:   *'
      WRITE(*,*)'    * DIGIT (1) for mR/h        *'
      WRITE(*,*)'    *           (2) for mGy/h      *'
      WRITE(*,*)'    *           (3) for mrad/h      *'
      WRITE(*,*)'    *           (4) for microSv/h  *'
      WRITE(*,*)'    *           (5) for mrem/h      *'
      WRITE(*,*)'    *********************'
      READ (*,1)U
input desired radiation  exposure rates.
c unit "conversion" to Roentgen/hour::
      IF(U.EQ.1)THEN
        DO 10 I=1,3
          TAX(I)=TAX(I)/1000.0
   10   CONTINUE
      ELSE
       IF(U.EQ.2)THEN
          DO 20 I=1,3
            TAX(I)=TAX(I)*0.115
   20     CONTINUE
        ELSE
          IF((U.EQ.3).or.(U.EQ.5))THEN
            DO 30 I=1,3
              TAX(I)=TAX(I)*1.15E-3
   30       CONTINUE
          ELSE
            IF(U.EQ.4)THEN
             DO 40 I=1,3
               TAX(I)=TAX(I)*0.115E-3
   40        CONTINUE
            ELSE
            ENDIF
          ENDIF
        ENDIF
      ENDIF
C-----
C charge measured with standard ionization chamber (C/h), Q
C and its uncertainty, DQ (uncertainties always with D)
C date of the last beam dosimetry (DD-day/MM-month/AA-year)
C Temperature in oC, Pressure in kPa
C charge generate by background radiation, BG
c
c source 1 (60Co, 4pi):
c moisture 60%
       Q(1)  =  3.48E-11
      DQ(1)  =  1.0E-11
      DD(1)  =  5
      MM(1)  =  1
      AA(1)  =  1998
      TEMP(1)=  24.7
      PRES(1)=  92.2
       BG     =  2.0E-11
       DBG    =  1.0E-11
       Q(1)   =  Q(1)-BG
       DQ(1)  =  DQ(1)+DBG
```

```
c
c source 2 (60Co, 4pi):
       Q(2)  =  1.64E-10
      DQ(2)  =  1.0E-11
      DD(2)  =  5
      MM(2)  =  1
      AA(2)  =  1998
      TEMP(2)=  24.7
      PRES(2)=  92.2
      BG     =  2.0E-11
      DBG    =  1.0E-11
      Q(2)   =  Q(2)-BG
      DQ(2)  =  DQ(2)+DBG
c
c source 5
c irradiator of room 5 (60Co):
c no filter:
c moisture 57%
       Q(5)  =  1.2617E-7
      DQ(5)  =  8.0E-11
      DD(5)  =  11
      MM(5)  =  5
      AA(5)  =  1998
      TEMP(5)=  23.4
      PRES(5)=  92.8
c
c source 6
c one filter:
       Q(6)  =  3.072E-8
      DQ(6)  =  3.0E-11
      DD(6)  =  11
      MM(6)  =  5
      AA(6)  =  1998
      TEMP(6)=  23.4
      PRES(6)=  92.8
etc.
C-----
C number of days since beam dosimetry:
      CALL JULIAN
c   these subroutine converts the dates involved (Gregorian date) into a
c   Julian Day Number with base year zero (or supposing such an year JD=0.0),
c   and then computes the number of days passed by since beam dosimetry,
c   avoiding leap years.
C-----
C exposure rate constant for null delta (R.m2/(Ci.h)), GAM
C and radionuclide half-life (hours), MEI:
      DO 50 I=1,8
          GAM(I)=31.7/24.0
         DGAM(I)=0.1/24.0
          MEI(I)=1920.0*24.0
         DMEI(I)=4.0*24.0
   50 CONTINUE
      DO 60 I=9,12
          GAM(I)=7.9/24.0
         DGAM(I)=0.1/24.0
          MEI(I)=10950.0*24.0
         DMEI(I)=30.0*24.0
   60 CONTINUE
C-----
C calibration factor of standard ionization chamber, 60Co (R/C):
```

```
      N = 6.0680E+6
      DN= 0.0005E+6
C-----
C quality factor of radiation for 60Co:
      QU = 0.9990
      DQU= 0.0005
C-----
C temperature and pressure correction factor
C uncertainties in temperature, 0,5oC, in pressure, 0,5kPa:
      DO 70 I=1,12
        DTEMP(I)=0.5
        DPRES(I)=0.5
        F(I) =(101.3/PRES(I))*((273.15+TEMP(I))/(273.15+20.))
        DF(I)=(101.3/293.15)*((1/PRES(I))*(((273.15+TEMP(I))/PRES(I))
     .               *DPRES(I)+DTEMP(I)))
   70 CONTINUE
C-----
C real exposure rate indirectly calculated at dosimetry instant:
      DO 80 I=1,8
        X(I) =N*QU*F(I)*Q(I)
        DX(I)=DN*(QU*F(I)*Q(I))+N*(DQU*(F(I)*Q(I))+
     .      QU*(DF(I)*Q(I)+DQ(I)*F(I)))
   80 CONTINUE
      DO 90 I=9,12
        X(I) =N*F(I)*Q(I)
        DX(I)=DN*(F(I)*Q(I))+N*(DF(I)*Q(I)+F(I)*DQ(I))
   90 CONTINUE
C-----
c apparent activities at dosimetry instant:
      DIS = 1.0
      DDIS= 0.005
      DO 100 I=1,12
        A0(I) =(1.0/GAM(I))*X(I)*(DIS**2)
        DA0(I)=DX(I)*((DIS**2)/GAM(I))
     .      +X(I)* ((1/GAM(I)**2)*((DIS**2)*DGAM(I)+
     .       GAM(I)*2.0*DIS*DDIS))
  100 CONTINUE
C-----
c actual apparent activities:
      DO 120 I=1,12
        A(I) = A0(I)*EXP(0.6931471*NDAY(I)/MEI(I))
        RAIZ = 144.0+(((24.0*NDAY(I))**2)/(MEI(I)**2))*DMEI(I)**2
        DA(I)= ( DA0(I) + A0(I)*( (0.6931471/MEI(I))*SQRT(RAIZ) ))*
     .       EXP(-0.6931471*24.0*NDAY(I)/MEI(I))
        DO 110 J=1,3
          Y(I) = 1000.0*SQRT(GAM(I)*A(I)/TAX(J))
c distance steps of 5 mm:
          Y(I) = ANINT(Y(I)/5.0)*5.0/1000.0
C-----
c calculation and output of achievable doses:
          IF((Y(I).GE.(0.5)).AND.(Y(I).LT.(4.0)))THEN
            S(J)   = GAM(I)/(Y(I)**2)
            DS(J)  = (1/Y(I)**4)*((Y(I)**2)*DGAM(I)+
     .             GAM(I)*(2.0*Y(I)*0.005))
            TAXN(J) = S(J)*A(I)
            DTAXN(J)= DS(J)*A(I)+DA(I)*S(J)
C-----
C unit 're'-conversion:
            IF(U.EQ.1)THEN
              TAXN(J)=TAXN(J)*1000.0
```

```
              DTAXN(J)=DTAXN(J)*1000.0
            ELSE
              IF(U.EQ.2)THEN
                TAXN(J)=TAXN(J)/0.115
                DTAXN(J)=DTAXN(J)/0.115
              ELSE
                IF((U.EQ.3).or.(U.EQ.5))THEN
                  TAXN(J)=TAXN(J)/1.15E-3
                  DTAXN(J)=DTAXN(J)/1.15E-3
                ELSE
                  IF(U.EQ.4)THEN
                    TAXN(J)=TAXN(J)/0.115E-3
                    DTAXN(J)=DTAXN(J)/0.115E-3
                  ELSE
                  ENDIF
                ENDIF
                         ENDIF
            ENDIF
            WRITE(*,*)'FONT:      ',I
            WRITE(*,*)'TAX =      ',TAXN(J),' (+-)',DTAXN(J)
            WRITE(*,*)'DISTANCE = ',Y(I),' m'
            WRITE(*,*)'appar.ativ.= ',A(I),' (+-)',DA(I),' Ci'
            WRITE(*,*)'---------------------------------------------'
          ELSE
          ENDIF
110     CONTINUE
120   CONTINUE
      STOP
      END
```

REFERENCES

1. W.Lichten, *Data and Error Analysis*. Prentice-Hall, New Jersey(1999).
2. S.Rabinovich, *Measurement Errors: Theory and Pratice*. American Institute of Physics, New York (1995).
3. ISO/IEC/OIML/BIPM, *Guide to the Expression of Uncertainty in Measurement* (1992).
4. EA-4/02, *Expression of Uncertainty in Calibration*.
5. Norma Brasileira NBR10011/1987, *Medidores e Monitores Portáteis de Taxa de Exposição de Raios X e Gama, para Uso em Radioproteção*.
6. ANSI N323-78, *Radiation Protection Instrumentation Test and Calibration*.
7. ANSI N13.4-71, *American National Standard for the Specification of Portable X or Gamma-Radiation Survey Instruments.*
8. B.N.Taylor, *Guide for the Use of the International System of Units (SI)* (1995), NIST Special Publication 811.
9. ISO/IEC GUIDE 25:1997, *General Requirements for the Competence of Testing and Calibration Laboratories.*