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(54) CIRCULAR CALCULATOR FOR THE SOLUTION OF PROBLEMS CONNECTED WITH ELECTROMAGNETIC RADIATION PENETRATION

(71) We, EUROPEAN ATOMIC ENERGY COMMUNITY (EURATOM), 51–53 rue Belliard, Brussels, Belgium, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

In the problems connected with electromagnetic radiation penetration (e.g. gammagraphy, radiography, gammaprotection, radioprotection) one can frequently encounter a configuration of the following type: the radiation emitted by a point-source diffuses through a slab-geometry homogeneous shield of variable thickness (possibly preceded or followed by fixed thickness filters) and interacts with a target (e.g. film, tissue, detector).

This invention relates to a circular calculator which permits for the above described configuration, the rapid determination of anyone of the following five parameters as a function of the remaining four ones:

I, source intensity
T, exposure time
L, thickness of the shield
K, source-target distance

$$Y = \begin{cases} R, \text{ radiation dose at the target position or} \\ X, \text{ a quantity related to the radiation effect on the target (e.g. film-blackening, biological-damage)} \end{cases}$$

The state of the art in the field of such calculators may be summarized by following documents:

Patent UK 859.063—The calculator is confined to gamma-protection problems and consequently the dose parameter is replaced by the dose rate. Both in the " straight " and the circular forms the calculator consists of only two movable members since the parameters exposure time, T, and target response, X, are not considered. The know-how for the determination of the attenuation curves needed for the actual design of the calculator is not given in the patent specifications.

Patent FR 1.244.823 and FR 76.103—The calculator is confined to gamma and radioprotection problems. The dose rate is correlated to the parameters I, L, K, E (radiation source energy). It appears clearly that the practical utilization of the calculator is confined to monokinetic radiation sources. Furthermore, the calculator being based on the representation of a family of curves it appears impractical to deal on the same calculator with different materials, unless by the use of approximate equivalent thickness correlations. Finally no procedure is given for the determination of the involved correlations, nor for the automatic design of the calculator.

Patent US 1.609.972—The calculator is only directed to assist the surgeon in treatment of diseased tissues by means of radioactive materials, and in rapid calculation of the radiation intensity within the tissues.

The circular calculator according to the present invention is a calculator for the rapid solution of calculations associated with gammagraphy, radiography, gamma and radioprotection, i.e. for the determination of anyone of the five parameters, I, T, K, L, Y, (Y=R or X), as a function of the remaining four, based on the formulae (1) and (2), comprising three concentric discs of different radii movable relatively to one another around an axis, two of which discs have each two scales in opposition (i.e. with the positive directions in opposition) associated with the first four parameters I, T, L, K, the third disc has adjacent scales (with the same positive direction) associated with the remaining two parameters R, X, and carries on an indicator in front of the R scale.

Said formulae (1) and (2) are:

$$R\,(I,T,K,L) = I \cdot T \cdot K^{-2} \cdot F(L) \qquad (1)$$

$$X = G(R) \qquad (2)$$

where:

F(L) (i.e. the dose for unit values of parameters I, T, K) depends on the energy spectrum of the radiation source, on the material composition of the shield and of the filters, and on the relative position of the filters in respect to the shield;

G(R) depends on the response property of the target.

The function G(R) is supposed known for each particular application. The function F(L) may be directly determined experimentally or theoretically evaluated.

Preferably said theoretical evaluation of F(L) is based on the correlation:

$$F(L)=f\cdot\int_{0}^{\infty} y(E).B(E,L).e^{-\mu(E).L}.e^{-\Sigma j\mu j(E).sj}.dE \quad (3)$$

where:

E =energy

y(E) =radiation yield for the actual radiation source

μ(E) =absorption coefficient

f =normalization factor

B(E,L)=dose build-up factor for the actual configuration

j =filters index

s =filter thickness

In the case of a source spectrum constituted by monocromatic lines, the integral in equation (3) is replaced by a summation.

The above defined dose build-up factors, B(E,L), are obtained by using high order double interpolation on a matrix $B^*(E_n,L_m)$, the elements of which are the results of exact theoretical calculations described in detail later on.

It appears clearly that for given geometrical configuation and material composition a same precalculated set $B^*(E_n,L_m)$ can be used to evaluate F(L) for many different radiation sources (e.g. Co^{60},Ir^{192},x-ray spectra).

The theoretical determination of F(L) presents two major advantages with respect to the experimental one; a) an higher reliability of results (this item will be discussed in more detail later on), b) no need to repeat the whole calculations to treat different types of radiation sources for given configuration.

By translating equation (1) into common logarithms, it is found:

$$\text{Log } R=\text{Log } I+\text{Log } T-2 \text{ Log } K+\text{Log } F(L) \quad (4)$$

It appears evident that the parameters, R,I,T,K,L can be arranged in the form of a calculator.

To facilitate the automatic design of the calculator a FORTRAN computer program has been developed, which starting from precomputed values of build-up factors, absorption coefficients, source spectrum, thickness of filters, normalization factor, ranges of the variables I,T,K,L, function G(R), and scale specifications, evaluates F(L) according to formula (3) and gives in output the actual angles of the different scales according to formulae (4) and (2).

As for the scale relative to the variable L, its form depends on the type of source and on the material composition, and whatever number of L scales can be constructed and inserted into the calculator. Similarly a number of X scales can be inserted in the calculator.

The described automatic procedure and a listing of the program are set out hereinafter.

```
C          MAIN PROGRAM
           DIMENSION PAGI(60),PAGT(60),PAGK(60),PAGR(60),PALL(150),
        1  ENERGB(60),ENERGM(60),AL(60),S(10),AMU(60),AMUF(60,10),
        1  B(100,150),SORG(100),YIELD(100),A(100),AMUN(100),AMUFN(100,10),
        1  BN(100,60),VETT(100),FF(150)
C
           READ (5,3) NTRAKT,NTRAKI,NTRAKK,NTRAKR,NLL
           READ (5,4) (PAGT(I),I=1,NTRAKT)
           READ (5,4) (PAGI(I),I=1,NTRAKI)
           READ (5,4) (PAGR(I),I=1,NTRAKR)
           READ (5,4) (PAGK(I),I=1,NTRAKK)
           READ (5,4) (PALL(I),I=1,NLL)
C
C          NTRAKT,NTRAKI,NTRAKK,NTRAKR REPRESENT THE NUMBER
             OF TRACKS
C          WANTED ON A TYPICAL INTERVAL 10**(I)--10**(I+1) OF A
             LOGARITHMIC
C          SCALE FOR THE PARAMETERS T,I,K,R
C          THE VALUES ON THE TRACKS WILL BE PAG*10*10**(I).
C          NLL REPRESENTS THE NUMBER OF TRACKS FOR THE L SCALE
             CORESPONDING
C          TO THE VALUES PALL
C
           WRITE (6,301)
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          CALL ANGLE(NTRAKT,PAGT)
          WRITE (6,302)
          CALL ANGLE(NTRAKI,PAGI)
          WRITE (6,304)
          CALL ANGLE2(NTRAKK,PAGK)
          READ (5,3) NSM,NSX
C
C         NSM=NUMBER OF SCALES TO BE TRACED FOR L PARAMETER
C         NSX=NUMBER OF SCALES TO BE TRACED FOR X PARAMETER
C
          ICONTM=1
     100  CONTINUE
          READ (5,3) NEB,NFM,NF,NES,NL
          READ (5,4) (ENERGB(I),I=1,NEB)
          READ (5,4) (ENERGM(I),I=1,NEM)
          READ (5,4) (AL(I),I=1,NL)
          READ (5,4) (S(I),I=1,NF)
          READ (5,4) (AMU(I),I=1,NEM)
          DO 5 K=1,NF
       5  READ (5,4) (AMUF(I,K),I=1,NEM)
          DO 6 I=1,NEB
       6  READ (5,4) (B(I,K),K=1,NL)
          READ (5,4) EFFE,ATTMIN,TEMMIN,DISMAX,ALMAX
          READ (5,4) (SORG(I),I=1,NES)
          READ (5,4) (YIELD(I),I=1,NES)
C
C         NEB =NUMBER OF ENERGY POINTS IN B SET
C         NEM=NUMBER OF ENERGY POINTS IN MU SETS
C         NL  =NUMBER OF SHIELD THICKNESS POINTS IN B SET
C         NF  =NUMBER OF FILTERS
C         NES =NUMBER OF ENERGY POINTS IN SOURCE SPECTRUM
C         ENERGB =ENERGY VALUES IN B SET
C         ENERGM=ENERGY VALUES IN MU SETS
C         AL       =SHIELD THICKNESS VALUES IN B SET
C         S        =FILTER THICKNESS
C         AMU      =MU VALUES FOR SHIELD
C         AMUF     =MU VALUES FOR THE FILTERS
C         B        =DOSE BUILD-UP FACTORS
C         FFFE     =NORMALIZATION FACTOR
C         ATTMIN =MINIMUM SOURCE INTENSITY
C         TEMMIN =MINIMUM EXPOSURE TIME
C         DISMAX =MAXIMUM SOURCE-TARGET DISTANCE
C         ALMAX  =MAXIMUM SHIELD THICKNESS
C         SORG     =ENERGY VALUES FOR THE SOURCE SPECTRUM
C         YIELD    =SOURCE SPECTRUM YIELDS ASSOCIATED WITH
                    ENERGY VALUES
C
          DO 8 JJ=1,NES
          EX=SORG(JJ)
       8  AMUN(JJ)=PARAB(ENERGM,AMU,EX,NEM)
          DO 7 KF=1,NF
          DO 9 JJ=1,NEM
       9  VETT(JJ)=AMUF(JJ,KF)
          DO 7 JJ=1,NES
          EX=SORG(JJ)
       7  AMUFN(JJ,KF)=PARAB(ENERGM,VETT,EX,NEM)
          DO 10 KK=1,NL
          DO 11 JJ=1,NEB
      11  VETT(JJ)=B(JJ,KK)
          DO 10 JJ=1,NES
          EX=SORG(JJ)
      10  BN(JJ,KK)=PARAB(ENERGB,VETT,EX,NEB)
          DO 23 J1=1,NES
          DO 24 KK=1,NL
```

```
     24  VETT(KK)=BN(J1,KK)
         DO 23 JJ=1,NLL
         EX=PALL(JJ)
     23  B(J1,JJ)=PARAB(AL,VETT,EX,NL)
         DO 12 KK=1,NLL
         FF(KK)=0.
         DO 13 JJ=1,NES
         ACCUM=0.
         DO 14 II=1,NF
     14  ACCUM=ACCUM+AMUFN(JJ,II)*S(II)
     13  FF(KK)=FF(KK)+YIELD(JJ)*B (JJ,KK)*EXP(-AMUN(JJ)*PALL(KK))
           *EXP(-*UM)
     12  FF(KK)=FF(KK)*EFFE
         TEMP=(ATTMIN*TEMMIN*FF(NLL))/(DISMAX**2)
         DO 1000 JK=1,NLL
   1000  FF(JK)=ALOG10(FF(JK)/FF(NLL))
         WRITE (6,305) ICONTM
         CALL THICK(NLL,FF)
         WRITE (6,300) TEMP
         IF(ICONTM.GE.NSM)GO TO 101
         ICONTM=ICONTM+1
         GO TO 100
    101  ICONTX=1
         WRITE (6,303)
         CALL ANGLE(NTRAKR,PAGR)
         IF(NSX.EQ.0) GO TO 201
    200  CONTINUE
         READ (5,3) NBL
         READ (5,4) (A(I),I=1,NBL)
C
C        NBL=NUMBER OF POINTS IN WHICH THE FUNCTION X=G(R) IS
                 GIVEN I.E. NUMBER OF TRACKS ON THE X SCALE
C        A   =VALUES OF R PARAMETER IN THE NBL POINTS
C
         WRITE (6,306) ICONTX
         CALL XPAR(NBL,A)
         IF(ICONTX.GE.NSX)GO TO 201
         ICONTX=ICONTX+1

         GO TO 200
    201  CONTINUE
         STOP
C
      3  FORMAT (12I6)
      4  FORMAT (6E12.4)
    300  FORMAT (38HOPOSITION OF THE ARROW ON THE R SCALE, E15.3)
    301  FORMAT (1H1,3X,'EXPOSURE TIME SCALE ANGLES'//)
    302  FORMAT (1H1,3X,'SOURCE INTENSITY SCALE ANGLES'//)
    303  FORMAT (1H1,3X,'EXPOSURE DOSE SCALE ANGLES'//)
    304  FORMAT (1H1,3X,'SOURCE-TARGET DISTANCE SCALE ANGLES'//)
    305  FORMAT (1H1,3X,'SHIELD THICKNESS SCALE ANGLES (SCALE
           NO.',I2,')'//*)
    306  FORMAT (1H1,3X,'FUNCTION X=G(R) SCALE ANGLES (SCALE NO.',
           I2,')'//)
         END
C
C        * * * * * * * * * * * * * * * * * * * * * * *
C
         SUBROUTINE ANGLE(NAA,V1)
         DIMENSION V1(100),V2(100),L1(100),L2(100),L3(100)
         DO 7 K=1,NAA
      7  V2(K)=ALOG10(V1(K))
         DO 8 K=1,NAA
```

```
    8 V2(K)=V2(K)*30.
      DO 9 K=1,NAA
      L1(K)=V2(K)
      V2(K)=V2(K)-L1(K)
      V2(K)=V2(K)*60.
      L2(K)=V2(K)
      V2(K)=V2(K)-L2(K)
      V2(K)=V2(K)*60.
    9 L3(K)=V2(K)
      DO 21 K=1,NAA
      A=FLOAT(L1(K))
      B=FLOAT(L2(K))
      C=FLOAT(L3(K))
   21   PUNCH 20,A,B,C
      WRITE (6,10) (L1(K),L2(K),L3(K),K=1,NAA)
      DO 11 M=1,11
      DO 12 K=1,NAA
   12 L1(K)=L1(K)&30
      DO 22 K=1,NAA
      A=FLOAT(L1(K))
      B=FLOAT(L2(K))
      C=FLOAT(L3(K))
   22   PUNCH 20,A,B,C
   11 WRITE (6,10) (L1(K),L2(K),L3(K),K=1,NAA)
      RETURN
   10 FORMAT (8X,I5,I6,1H',I5,2H")
   20 FORMAT (1X,F5.0,2F6.0)
      END
C
C     * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE ANGLE2(NAA,W1)
      DIMENSION W1(100),W2(100),LL1(100),LL2(100),LL3(100)
      DO 7 K=1,NAA
    7 W2(K)=ALOG10(W1(K))
      DO 8 K=1,NAA
    8 W2(K)=W2(K)*60.
      DO 9 K=1,NAA
      LL1(K)=W2(K)
      W2(K)=W2(K)-LL1(K)
      W2(K)=W2(K)*60.
      LL2(K)=W2(K)
      W2(K)=W2(K)-LL2(K)
      W2(K)=W2(K)*60.
    9 LL3(K)=W2(K)
      DO 31 K=1,NAA
      A=FLOAT(LL1(K))
      B=FLOAT(LL2(K))
      C=FLOAT(LL3(K))
   31 PUNCH 30,A,B,C
      WRITE (6,11) (LL1(K),LL2(K),LL3(K),K=1,NAA)
      DO 18 MAO=1,5
      DO 12 K=1,NAA
   12 LL1(K)=LL1(K)&60
      DO 32 K=1,NAA
      A=FLOAT(LL1(K))
      B=FLOAT(LL2(K))
      C=FLOAT(LL3(K))
   32 PUNCH 30,A,B,C
      WRITE (6,11) (LL1(K),LL2(K),LL3(K),K=1,NAA)
   18 CONTINUE
      RETURN
   11 FORMAT (8X,I5,I6,1H',I5,2H")
   30 FORMAT (1X,F5.0,2F6.0)
      END
```

```
C
C     * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE THICK(NL,F)
      DIMENSION F(150),A(150),L1(150),L2(150),L3(150)
      DO 5 K=1,NL
      A(K)=F(K)*30.
      IF(K.EQ.1) AA=A(1)
      A(K)=AA-A(K)
      L1(K)=A(K)
      A(K)=A(K)-L1(K)
      A(K)=A(K)*60.
      L2(K)=A(K)
      A(K)=A(K)-L2(K)
      A(K)=A(K)*60.
    5 L3(K)=A(K)
      DO 1000 K=1,NL
      AHA=FLOAT(L1(K))
      B=FLOAT(L2(K))
      C=FLOAT(L3(K))
      PUNCH 30,AHA,B,C
      WRITE (6,6) L1(K),L2(K),L3(K)
 1000 CONTINUE
      RETURN
    6 FORMAT (8X,I5,I6,1H',I5,2H")
   30 FORMAT (1X,F5.0,2F6.0)
      END
C
C     * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE XPAR(NBL,V1)
      DIMENSION V1(100),V2(100),L1(100),L2(100),L3(100)
      DO 13 K=1,NBL
      DO 11 INDIC=1,100
      TPAR=10.E-06*(10.**INDIC)
      IF(V1(K).LT.TPAR)GO TO 12
   11 CONTINUE
   12 NUMERO=INDIC-1
      V1(K)=V1(K)*10.**(6-NUMERO)
      V2(K)=ALOG10(V1(K))*30.
      L1(K)=V2(K)
      V2(K)=(V2(K)-L1(K))*60.
      L2(K)=V2(K)
      V2(K)=(V2(K)-L2(K))*60.
      L3(K)=V2(K)
      L1(K)=L1(K)+(NUMERO*30)
   13 CONTINUE
      DO 31 K=1,NBL
      A=FLOAT(L1(K))
      B=FLOAT(L2(K))
      C=FLOAT(L3(K))
   31 PUNCH 30,A,B,C
      WRITE (6,18) (L1(K),L2(K),L3(K),K=1,NBL)
      RETURN
   18 FORMAT (8X,I5,I6,1H',I5,2H")
   30 FORMAT (1X,F5.0,2F6.0)
      END
C
C     * * * * * * * * * * * * * * * * * * * * * * *
C
      FUNCTION PARAB(EPS,QRZ,ARG,NN)
      DIMENSION EPS(NN),QRZ(NN)
      IF(ARG-EPS(NN))206,726,230
  206 IF(ARG.GT.EPS(NN-1))GO TO 230
      IF(ARG.GT.EPS(3))GO TO 217
```

```
      T1=EPS(1)
      T2=EPS(2)
      T3=EPS(3)
      FT1=QRZ(1)
      FT2=QRZ(2)
      FT3=QRZ(3)
      GO TO 600
 217  DO 222 I=4,NN
      IF(ARG-EPS(I))227,725,222
 222  CONTINUE
 227  EPT=(EPS(I-1)+EPS(I))*0.5
      IF(ARG.GT.EPT)GO TO 225
      T1=EPS(I-2)
      T2=EPS(I-1)
      T3=EPS(I)
      FT1=QRZ(I-2)
      FT2=QRZ(I-1)
      FT3=QRZ(I)
      GO TO 600
 225  T1=EPS(I-1)
      T2=EPS(I)
      T3=EPS(I+1)
      FT1=QRZ(I-1)
      FT2=QRZ(I)
      FT3=QRZ(I+1)
 600  AY=(FT2-FT1)/(T2-T1)
      BY=(FT3-FT2)/(T3-T2)
      C=T3-T1
      D=(BY-AY)/C
      E=ARG-T2
      G=(D*E)+AY
      PARAB=(ARG-T1)*G+FT1
      GO TO 2000
 726  I=NN
 725  RARAB=QRZ(I)
      GO TO 2000
 230  T1=EPS(NN-2)
      T2=EPS(NN-1)
      T3=EPS(NN)
      FT1=QRZ(NN-2)
      FT2=QRZ(NN-1)
      FT3=QRZ(NN)
      GO TO 600
2000  RETURN
      END
```

The actual construction of the calculator can be done on the basis of drawings completely executed by means of a FORTRAN program

> "ACCESS-A PROGRAM FOR THE CALCOMP DATA PLOTTING OF CIRCULAR CALCULATORS", H. I. De Wolde, EURATOM Report Ex2965/A (Ref. I)

which utilizes the Calcomp-Data-Plotter (the word "Calcomp" is a Registered Trade Mark). Input to the program are the angles previously calculated, the dimensions and the relative position of the various scales.

As concerning the higher reliability of the theoretical method in respect to the experimental one, a discussion follows.

The advanced computational techniques and the fast computers now available allow the theoretical determination of reliable dose values. Moreover the computational errors can be evaluated to a high precision. The advantages of the theoretical method become quite strong in the case of considerable radiation diffusion (i.e. for high values of shield thickness), in which case the experimental determination of dose requires the use of detectors surrounded by lead to cut the wall scattered radiation. The presence of lead produces an enforcing effect which bias the measurements. In addition the experiments are somewhat influenced by the shape of the dosimeters. The adoption of theoretical models allows the elimination of all the enforcing and the collimation effects.

As concerning the build-up factors calculations, one-dimensional models may be used (plane or spherical geometry); the results are then converted to the actual point-plane geometry by using well known formulae.

To ascertain the reliability of calculated results a series of test problems has been set up by the inventors and three computer programs based on different theoretical methods appropriate to the solution of the radiation transport-equation were actually used. The results so obtained were in fairly good agreement over the explored range of the involved parameters.

A systematic source of error in the above calculation could derive from the choice of a cross-section library. In order to evaluate the effect of such an error on the calculated dose, some calculations have been performed twice adding and subtracting the known error to the absorption cross-section. The results are found to differ by less than 2 to 3%.

The programs considered are:

DTF-4, based on Carlson's S_n method;

"DTF-4, A FORTRAN-IV PROGRAM FOR SOLVING THE MULTIGROUP TRANSPORT EQUATION WITH ANISOTROPIC SCATTERING", K. D. Lathrop, Loss Alamos–1965 (Ref. II)

BIGGI-4, based on a direct numerical solution of the integral transport equation;

"USER'S MANUAL FOR THE GAMMA TRANSPORT CODES BIGGI 3P AND BIGGI 4T", H. Penkuhn, EUR 3555e–1967 (Ref. III)

SALOMON, based on Monte Carlo techniques.

"ON THE TRANSFORMATION OF THE TRANSPORT EQUATION FOR SOLVING DEEP PENETRATION PROBLEMS BY THE MONTE CARLO METHOD", K. Leimdörfer, Transactions of Chalmers University of Technology n. 286–1964 (Ref. IV)

All the above mentioned programs cannot deal with radiation energies below the threshold under which fluorescence effects come into play (e.g. below 0.1 MeV for lead).

As a conclusion we can summarize the major characteristics of the invention:

a) the invention covers whatever type of radiation problems (radio and gamma-protection, radiography and gammagraphy) to which the described geometrical configuration and the formula (1) or (1) and (2) apply;

b) the invention includes the theoretical evaluation of F(L) based on formula (3), showing the advantages of high reliability of results and great flexibility in treating different types of radiation sources;

c) the invention includes an automatic procedure to obtain the actual drawings of the calculator to be constructed starting from known dose build-up factors and given problem specifications;

d) the proposed calculator shows high sensibility characteristics and it is accompanied with limited overall dimensions, whenever one source, one shield material, one target response, are concerned. It will be understood that by enlarging the dimensions of the calculator or reducing the sensibility, it is possible to provide scales for many sources, materials, target responses.

An application particularly fitted to illustrate the present invention is given in the following. It is understood that the inventors do not intend to limit in any way the generality of the invention by this application.

The application refers to the determination of exposure time in gammagraphy for non-destructive controls of concrete buildings, (i.e. for the determination of the distribution of rods in reinforced concrete structure and for the detection of inhomogeneities in concrete works).

The details of the gammagraphy technique are as follows. The gamma-rays produced by a point source at one side of the concrete diffuse through the concrete. At the other side of the concrete a film detects gamma-rays, through the effect of their secondary electrons. In fact, a charged particle (i.e. electron) passing through a grain of silver bromide in a photographic emulsion will generally cause changes which will result in the conversion of grain to atomic silver when the film is developed. Such developed grains cause a blackening of the emulsion.

One of the central problems connected with the gammagraphy practice is the accurate and quick determination of the exposure time required to obtain pictures of good quality, on the basis of irradiation conditions such as: 1) source type, 2) source intensity, 3) source-film distance, 4) shield thickness, 5) thickness and type of the filters, 6) type of the film and of the film-container, developing conditions, 7) film-blackening.

The need for a calculator for the determination of exposure time as a function of other parameters was felt since the beginning of gammagraphy practice.

In the references

"NOMOGRAMS FOR DETERMINING THE TIME OF IRRADIATION IN PENETRATING THROUGH CONCRETE BY MEANS OF THE RADIOACTIVE ISOTOPES Co^{60}, Cs^{137}, Ir^{192}" Hönig, Leipzig (1960) p. 40–41 (Ref. V)

"RADIOGRAFICZMA KONTROLA ZBROJENA W ZELBECIE INZYNIERIA I BUDOWNICTOWO", L. Brunarski, No. 8–9 Warszawa Sierpen Wrzesien (1965) p. 256–261 (Ref. VI)

"PAPERS ON RADIOGRAPHY", Kahn, Inbembo, Bland (Ref. VII)

nomograms or circular calculators for the solution of the problem are proposed, all based on experimental measurements. They differ from each other especially in the treatment of two of the discussed parameters; namely a) the type of the film (including enforcing screens) and the developing conditions, b) the source type. It must be noted that such parameters are not continuously varying parameters and hence they are somewhat difficult to handle.

As for the filter one can observe that its type and thickness are normally standard, being used just to "cut" gamma-rays below a certain energy threshold ($\approx$0, 18 MeV).

As far as the source type is concerned, the problem has been solved in the above mentioned literature by elimination of the parameter, i.e. by considering only nomograms or calculators for given source types. In particular in reference (V) nomograms are presented for Co^{60}, Ir^{192}, Cs^{137} sources, while in references (VI) and (VII) Co^{60} and Radium sources respectively are treated.

Concerning the film type (the developing conditions are considered standard), different choices are possible and consequently the problem to treat such information like a continuously varying parameter is very difficult.

In reference (V) the adopted solution is the elimination of the parameter, since each of the considered nomograms is valid just for a particular film-type. This fact can seriously prevent the use of the nomograms, whenever the film type is different from those there considered. Note that such a situation can frequently arise, the films treated in the nomograms being very special and difficult to find. A further limitation is represented by the fact that the film blackening does not appear in the nomograms as a parameter (a constant value in the range 1,5—1,75 is assumed).

As for the reference (VI), the author proposes a circular calculator in which the variation of film-type is taken into account in continuously varying form, by the introduction of the parameter "film-speed", being defined as the inverse of the exposure dose (in Roentgen) necessary to obtain a fixed blackening density, generally around unity. It must be noted however that a one-to-one correspondence between film-type and film-speed exists only in the neighbourhood of blackening equal to unity. The calculator cannot then be used successfully whenever one is interested in blackening densities far from unity.

In the reference (VII) a circular calculator is presented originally developed for gammagraphy of steel, but containing correction factors to treat the case of materials other than steel. In this calculator too the film-speed is considered as representing the film-type

We suggest the realization of a calculator which is independent of the film-type, which can be done simply by introducing a new parameter, that is the "dose" (in Roentgen) at the entering surface of the film container.

The problem is now confined to the correlation as previously described, for fixed source and film, of the following parameters: 1) source intensity, 2) source-film distance, 3) shield thickness, 4) exposure time, 5) dose (Roentgen).

As for the dose-blackening correlation, it depends solely on the film type; in fact whenever the gamma-ray energy is greater than about 0,18 MeV, spectral variations for a fixed dose do not influence the blackening, since the photoelectric interactions in silver do not come into play (see Ref. VIII, IX).

"RADIATION DOSIMETRY", G. N. White, J. Wiley & Sons (Ref. VIII)

"PHOTOGRAPHIC DOSIMETRY OF X AND GAMMA-RAYS", M. Ehrlich, N.B.S. Handbook 57 (Ref. IX)

The experimental determination of the curve dose-blackening for a given film requires just a few experimental "points", each corresponding to the measure of the blackening for a given dose.

The introduction of the dose parameter according to the invention allows the here proposed calculator to be actually independent of the film, and just the experimental determination of the dose-blackening curve for each new film is required.

Besides, as it has been already pointed out, the use of the proposed theoretical model for the determination of dose greatly increases the reliability of results.

As an example of a calculator for the exposure time determination in gammagraphy problems according to the invention, a particular form of the calculator is illustrated. It refers to a shield constituted by concrete, having average density 2.30 gr/cm^3, followed by a lead filter 0.2 cm thick. Two radiation sources are considered, namely Co^{60} and Ir^{192}. The film is a Kodax Definix with two enforcing lead screens 0.2 mm thick.

The dose build-up factors were first calculated, then the computer program appropriate to the determination of the angles for the different scales was utilized. Finally the drawings for the actual construction of the calculator were obtained by means of the Calcomp Data Plotter and are shown in Figs. 1 and 2.

From the figures it can be seen that the couples of scales reported on the calculator starting from the interior disc are: (I,T), (L,K), (R, Blackening). The external scale carries an indicator in the form of a reference arrow in front of the Rontgen scale to be used in calculations. In a particular realization, the exterior diameter of the calculator was 14 cm.

The following selected example illustrates the manner in which the calculator, as described with reference to Fig. 6 is intended to operate.

To find the exposure time required to produce a film blackening 1.5 with a Co^{60} source of 100 Curie intensity, a concrete shield of 50 cm thickness, a source-film distance of 90 cm:

a) point source-film distance (90 cm) against the reference arrow,

b) point source intensity (100 Curie) against concrete thickness (50 cm),

c) read exposure time against blackening (1.5).

A value of 3.25 hours will be found for the exposure time.

WHAT WE CLAIM IS:—

(1) A circular calculator for the rapid solution of calculations associated with gammagraphy, radiography, gamma and radioproptection, for the determination of anyone of the five parameters I,T,K,L,Y, (Y=R or X), hereinbefore defined, as a function of the remaining four, based on the formulae (1) and (2), hereinbefore defined, comprising three concentric discs of different radii movable relatively to one another around an axis, two of which discs have each two scales in opposition associated with the first four parameters I,T,L,K, the third disc has adjacent scales associated with the remaining two parameters, R,X, and carries an indicator in front of the R scale.

(2) A circular calculator as claimed in Claim 1, in which the function F(L) appearing in formula (1) is theoretically evaluated by means of the formula (3) hereinbefore defined and wherein the scalings for the different parameters are obtained by the automatic procedure, based on formula (4) hereinbefore defined, and described in the specification.

(3) A circular calculator as claimed in Claim 1 or 2, comprising more than one shield thickness scale (L scale), to provide readings for different shield materials or radiation sources, and in which the parameter X may be omitted or may be present with more than one scale to provide responses for different types of targets.

(4) A circular calculator as claimed in any of the preceding claims, applied specifically to gammagraphy problems, in which calculator the blackening is evaluated from the dose at the film position, with reference to the accompanying drawings.

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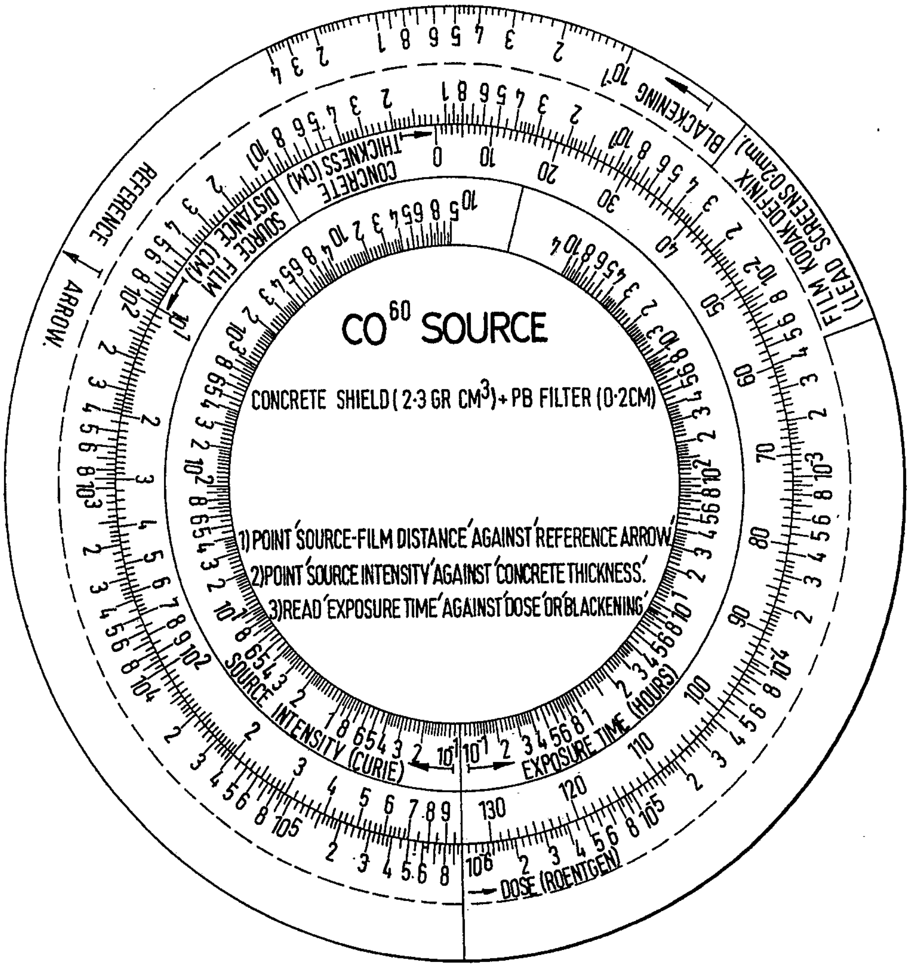
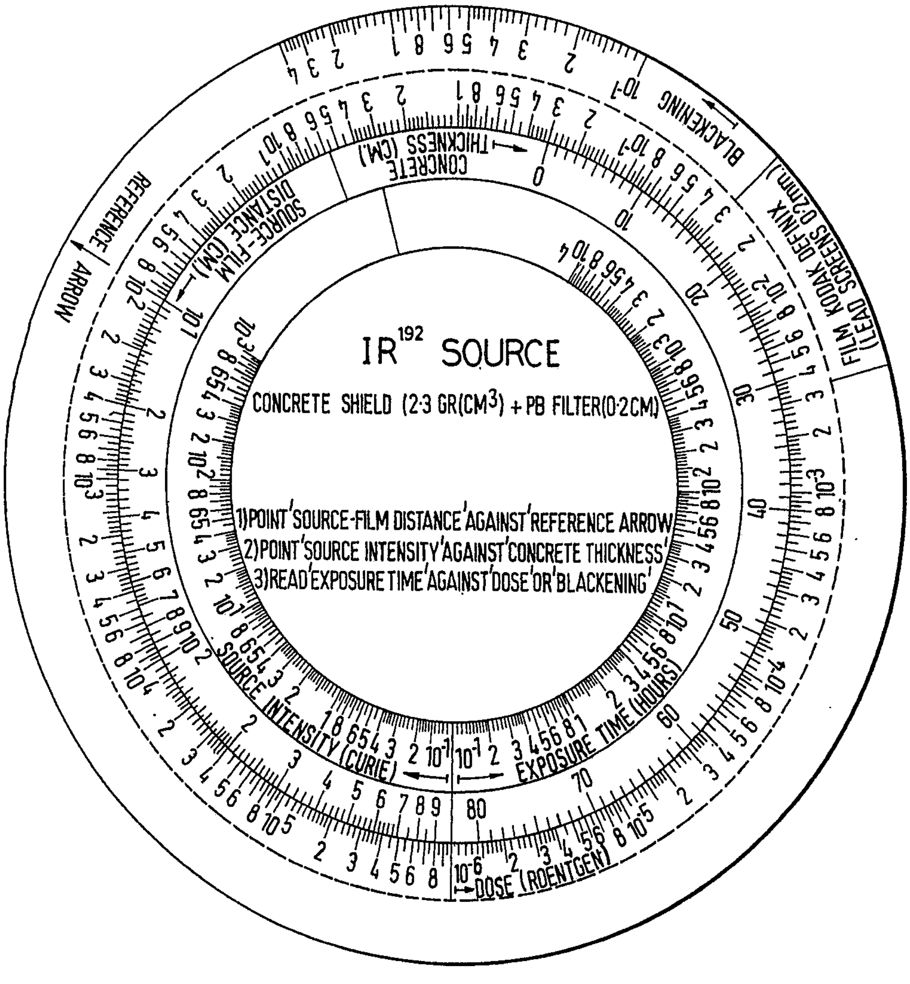


1) POINT 'SOURCE-FILM DISTANCE' AGAINST 'REFERENCE ARROW'
2) POINT 'SOURCE INTENSITY' AGAINST 'CONCRETE THICKNESS.'
3) READ 'EXPOSURE TIME' AGAINST 'DOSE' OR 'BLACKENING'

FIG. 1.



1)POINT 'SOURCE-FILM DISTANCE' AGAINST 'REFERENCE ARROW'
2)POINT 'SOURCE INTENSITY' AGAINST 'CONCRETE THICKNESS'
3)READ 'EXPOSURE TIME' AGAINST 'DOSE' OR 'BLACKENING'

FIG.2.