COMPUTER PROGRAM FOR THE SENSITIVITY CALCULATION OF CR-39 DETECTOR IN DIFFUSION CHAMBER FOR RADON MEASUREMENTS

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Abstract

Computer software for the calculation of sensitivity of CR-39 detector closed in diffusion chamber to radon is described in this work. The software is consists of two programs, both written in standard Fortran90 programming language. Physical background and numerical example are given.

Keywords: CR-39 detector, ^{222}Rn, diffusion chamber, Monte Carlo

PROGRAM SUMMARY

Manuscript title: *COMPUTER PROGRAM FOR THE SENSITIVITY CALCULATION OF CR-39 DETECTOR IN DIFFUSION CHAMBER FOR RADON MEASUREMENTS*

Authors: **Dragoslav Nikezic**
Program title: **SENSITIVITY**
Licensing provisions:
Programming language: **Fortran 90**
Computer(s) for which the program has been designed: **Pentium PC**
Operating system(s) for which the program has been designed: **Windows**
RAM required to execute with typical data: **128 MB**
Has the code been vectorised or parallelized?: **Not**
Number of processors used: **2**
Supplementary material:
Keywords: **CR-39 detector, ^{222}Rn, diffusion chamber, Monte Carlo simulation**
CPC Library Classification:
External routines/libraries used: **No external routines**
CPC Program Library subprograms used: **TRACK_TEST, and TRACK_VISION**
*Catalogue identifier of previous version:** **ADWT_v1_0 and AEAF_v1_0**
*Journal Reference of previous version:** **Comput. Phys. Commun. 174(2006)160 and Comput. Phys. Commun 178 (2008) 591–595**
*Does the new version supersede the previous version?:** **YES**
Nature of problem: **Response of detector CR-39 to radon and progeny irradiation depends on etching conditions, readout procedure and design of the diffusion chamber used in measurements. It is necessary to provide a computer software which can calculate detector sensitivity, which will help optimisation and calibration of such device.**
Solution method: **Simulation with Monte Carlo method.**
*Reasons for the new version:** **This is original submission**
*Summary of revisions:**
Restrictions: **Applying for conical and cylindrical diffusion chamber and to CR-39 detectors.**
Unusual features:
Additional comments:
Running time: **Software consists of two programs, QUEST and SENSITIVITY. First program runs about 30 minutes, while the second program run only few seconds.**
References:

1. Introduction

Long term, passive measurements of radon (^{222}Rn) concentration in air are performed with solid state nuclear track detectors (SSNTD), that are sensitive to alpha particles emitted by radon and its short lived progeny. Detectors are usually located within a cup that is closed with some permeable substance, like filter papers, which allows radon diffusion and prevents penetration of radon progeny, dust and humidity into the chamber. Such devices are usually called “diffusion chamber”, “cup” or “radon dosimeter” [1,2]. Survey of various designs and combinations of SSNTD with other media (electrets, active charcoal, etc) used for radon measurements was given in [3]. Newer development in construction of radon dosimeters were described in [4].

Track density on detector, N, which is a measurable quantity, is related with average radon concentration C_0 during the irradiation time t, through the sensitivity, ρ, as follows:

$$N = \rho C_0 t \tag{1}$$

Sensitivity (reciprocal is calibration coefficient, k) is determined experimentally or theoreticaly. It is defined as track density (in track per m^2) per unit exposure (Bqs/m^3). Experimental conditions during calibration and measurements should be the same, or, if it is not possible, as similar as possible. Any changes in experimental setup, exposure, etching or readout procedure request additional calibration and determination new calibration factor.

Several authors presented various calculation methods for sensitivity determination. An analytical method and nice analysis of all possible cases of geometrical relationships between effective volume and chamber walls were reported in [5]. Unfortunately, consideration given in [5] was limited to point like detector located in the centre of the bottom of cylindrical diffusion chamber, while in reality the detector has some real physical dimensions. Other authors presented Monte Carlo calculations of calibration coefficient, [6-16]. Monte Carlo approach is more convenient than analytical when real physical dimensions of detector are considered.

Although a lot of effort was devoted in development of models and calculation of sensitivity, there is not any widely available computer software for this purpose. The objective of this work is to provide computer software for the calculation of sensitivity of CR-39 detector in diffusion chamber for radon measurements. Program is related to the conical or cylindrical diffusion chamber, assuming that circular detector is located in the bottom of the chamber. Presented computer software may be used for optimization of diffusion chamber, detector dimension and shape and whole measurements procedure.

2.Description of computer programs and input parameters

Software is consist of two programs written in standard Fortran 90 programming language. The codes are relatively simple and may be easily translated in other computer languages. Executable versions are also provided.

Program QUEST.F90.

The first program that should be executed is called QUEST (shortcut from question). This program calculates effective volume in front of point like CR-39 detector for alpha particles of a given energy. Effective volume is defined as space from where emitted alpha particles can be detected. The algorithm of this program is described in the following text. Alpha particle is emitted with one of the energy in ^{222}Rn chain (5.49 MeV, 6 MeV or 7.69 MeV) at the distance that is equal to the alpha particle range in air R - naturally the incident energy on the detector is equal to 0. Then the the distance, *d*, between emitting point and point like detector is reduced for predetermined step and impact energy on the detector was calculated. Computer programs TRACK_TEST.F90 [17] and TRACK_VISION.F90 [18] are called now to calculate track parameters and to determine whether the track is visible or not, based on incident angle, impact energy, etching conditions, gray level and visibility criterion. Whole space in front of detector is systematically examined, the distance is varied with the step less than 0.1 mm and the incident angle is varied with the step of 1^0. The steps could be setup smaller, but it will result in longer calculation time without significant increasing of accuracy of final result. The reducing of alpha particle energy from emission point to the detector, caused by air was calculated previously by SRIM 2003 software [18] and energy–distance dependence is given in file OUTPUT_A1000.DAT.

Program TRACK_TEST [17] was described earlier, and details will not be repeated here. This program is used here as subroutine. The program was modified so that all graphical functions and presentations were canceled, because here only numerical calculations are needed.

By systematical varying of distances and angle, all points in front of detector are characterized and effective volume was determined. Program automatically varies initial alpha particle energy, 5.49 MeV (^{222}Rn), 6 MeV (^{218}Po) and 7.69 MeV (^{214}Po) and the outputs are separately written in files EVCR_1.DAT, EVCR_2.DAT and EVCR_3.DAT (acronym from effective volume CR-39) which give effective volumes for specific isotope, respectively. These files are consist of five columns. The first column is incident angle measured from the normal in respect to the surface; the second column is the minimal distance, r_{min} from where alpha particle should be emitted to cause visible track (this distance can be zero), particles emitted closer than r_{min} will not produce visible track. The third column is the maximal distance, r_{max} from where emitted particle can be detected, particles emitted further than r_{max} will not produce visible track. Fourth and fifth column give the energy detection window, i.e., the minimal and maximal energy between the detection occurs for a given incident angle, while out of this window, the detection does not take place.

Before executing the program QUEST.F90 the input parameters must be defined in file INPUTCR.DAT as follows:

- *etching time* in *hours*,
- *bulk etch rate* of CR-39 for defined etching conditions, in *micrometers per hour*,
- *visibility* in micrometer (recommended about 1), the smallest object that can be distinguish as a track, and
- *number of V* function which correspond to CR-39 used in real experiment.

Discussion about V function

There were many determination of V function of CR-39 detector for alpha particles. Discrepancy between reported results is probably caused by different types of CR-39 used in examination (prepared from various row material or with somewhat different procedure), as well as by methods applied in measurements. Recently, excellent critical review of published V function was given in [20,21]. Here the following V functions are build in software:

$N^0$1 Function was published in [22,23] in the form

$$V = 1 + (A_1 e^{-A_2 R'} + A_3 e^{-A_4 R'})(1 - e^{-A_5 R'}) \qquad (2)$$

with constants A_1=11.45, A_2=0.339, A_3= 4, A_4=0.044 and A_5=0.58 and R' is residual range.

$N^0$2 Function was published in [24] as

$$V = 1 + e^{-A_1 R' + A_4} - e^{-A_2 R' + A_3} + e^{A_3} - e^{A_4} \qquad (3)$$

with constants A_1=0.1, A_2=1., A_3=1.27 and A_4=1.

Functions $N^0$3 , taken from [25] is in the form

$$V = 1 + e^{-A_1 R' + A_2} - e^{-A_3 R' + A_2} \quad (4)$$

with constants A_1=0.069, A_2=1.1784 and A_3=0.6513

and $N^0 4$ have the same form as function $N^0 3$ but slightly different coefficients [26] A_1=0.06082, A_2=1.119 and A_3=0.8055.

And finally function $N^0 5$ is taken from [20] and has the form

$$V = 1 + \frac{A_1}{(R' + A_2)^{A_3}} \ln(R' + A_4) \cdot (1 - e^{-R'/A_5}) + R'/A_5 \quad (5)$$

with constants A_1=390, A_2= 2, A_3=2.35, A_4=1, A_5=5 and A_6=80.
User can chose any of these functions by simply changing the last number from 1 to 5 in file INPUTCR.DAT. Application of some another number for the function will probably generate an error.

This program runs about 20-30 minutes (machine dependent). It is not necessary to run it again until the input parameters in INPUTCR.DAT are changed.

3.Calculation of detector sensitivity

Three different sources contribute to total track density (and sensitivity): (a) radon and progeny in chamber air (volume fraction), (b) progeny deposited on inner chamber wall including the filter opposite to the detector (wall fraction) and (c) progeny deposited on detector itself (plateout). Three separate subroutines were prepared, one for each source. They are called sequentially from the main program which is named SENSITIVITY.F90.

To calculate detector sensitivity, the data about chamber and detector dimensions are needed. It is necessary to define input parameters before execution of SENSITIVITY.F90. They are given in file INPUTCHAMBER.DAT in the following order: first parameter is number of "registered alpha particles" ; for example, 10^4 ensures 1 % of relative standard error. Since this calculation is not time consuming, the user can chose larger number of registered particles. Second line defines dimensions of conical chamber, lower radius R_1, upper radius R_2 and height, H all in *cm*. Since the chamber is conical, R_1 should be smaller than R_2, i.e., $R_1 <= R_2$. If cylindrical chamber was considered, $R_1 = R_2$. Program will not work if R_1 was larger than R_2 or it would work incorrectly. User can change any of these parameters. It is not necessary to define incident alpha particle energy (i.e. isotopes) because program automatically changes them.

For the reason of simplicity, it is assumed that the detector is in circular shape, (although is difficult to cut CR-39 detector in circular form). User of this program should determine the diameter of a circle that has the same surface area as his detector which is usually in rectangular form.

Subroutine CHAMBER_VOLUME.F90

When the effective volume was determined, the calculation of partial sensitivities to particular progeny is feasible to perform. Subroutine CHAMBER_VOLUME.F90 calculates sensitivity of CR-39 that is located in the bottom of conical (or cylindrical) diffusion chamber, assuming that alpha emitters are in volume of the chamber. Program calculates partial sensitivities of CR-39 detector in given diffusion chamber to radon and progeny, for predetermined etching and readout conditions. This program is executed three times, for all alpha particles energies emitted in radon chain. Output results are given in System International (in *m*) and in $track/cm^2$ per $Bq\ day/m^3$. They are printed on the screen and written in separate file called OUTPUT.DAT.

Subroutine CHAMBER_WALL.F90

Part of radon progeny was deposited on the inner chamber wall before emission of alpha/beta particles. Irradiation geometry is different in comparison to the previous case, and separate subroutine is used in this case which is also called from SENSITIVITY.F90. Subroutine *CHAMBER_WALL.F90* calculates partial sensitivities of detector to radon progeny deposited onto inner chamber wall. Input parameters are the same as in previous case, and they are transferred from file *INPUTCHAMBER.DAT* through the main program. This subroutine is executed two times, first with energy of 6 MeV (^{218}Po) and second with 7.69 MeV (^{214}Po) with corresponding input file EVCR_2.DAT and EVCR_3.DAT. Output result is partial sensitivity to radon and progeny in System International (*m*) and in *track/cm*^{2} per *Bq day/m*^{3}. It is assumed that radon progeny are uniformly deposited on the inner chamber wall. This might not be true, but there is lack of experimental data on this topic. Some theoretical work claims [25-27] that deposition is not uniform but this was not implemented in subroutine *CHAMBER_WALL.F90*. Output is printed on the screen and written in separate file OUTPUT.DAT.

Subroutine CHAMBER_PLATE.F90

Some progeny are deposited on the detector itself. This is termed plate out. Progeny are in contact with detector surface and there is 2π irradiation geometry. However, due to the existence of critical angle, the detection efficiency is less than 50 % and also depends on etching conditions and readout procedure. Program *CHAMBER_PLATE.F90* calculates sensitivity to progeny deposited onto detector (plate out). This subroutine also uses the same input parameters from file *INPUTCHAMBER.DAT* that are transferred through main program. Program also runs two times with energies of 6 MeV (^{218}Po) and 7.69 MeV (^{214}Po) using corresponding effective volumes in files with corresponding input files EVCR_2.DAT and EVCR_3.DAT. It was assumed that progeny are deposited homogeneously onto inner chamber wall including detector itself. Results are also given in *m* and in *track/cm*^{2} per *Bq day/m*^{3}. They are printed on the screen and written in the same file as above, OUTPUT.DAT.

4. Final results

As result of the previous executions, the following results were obtained and written in OUTPUT.DAT:

ρ_0 partial sensitivity to 222Rn in chamber volume , i.e. in air;
ρ_{1a} sensitivity to ^{218}Po in chamber volume , i.e. in air;
ρ_{4a} sensitivity to ^{214}Po in chamber volume , i.e. in air;
ρ_{1w} sensitivity to ^{218}Po deposited on chamber wall;
ρ_{4w} sensitivity to ^{214}Po deposited on chamber wall;
ρ_{1p} sensitivity to ^{218}Po deposited on detector (plate out) and
ρ_{4p} sensitivity to ^{214}Po deposited on detector (plate out)

Total sensitivity is calculated by the formula

$$\rho_{tot} = \rho_0 + f_1\rho_{1a} + f_4\rho_{4a} + (1-f_1)\rho_{1w} + (1-f_4)\rho_{4w} + \rho_{1p} + \rho_{4p} \quad (6)$$

where f_1 is fraction of ^{218}Po that is decay in air and f_4 is fraction of ^{214}Po decayed in air.

Two extreme cases exist here: (a) all radon progeny decay in chamber volume (i.e. in air) before deposition when $f_1=f_4=1$ and (b) all progeny are deposited before decay $f_1=f_4=0$. Sensitivities are given for both extreme cases, and real one is between these two values. It is reasonably to assume that ^{214}Po is decay as fully deposited, $f_4=0$ while f_1 is between 0 and 1. This case is also programmed but the user should provide input value for f_1 after the query by program, through the keyboard.

Numerical example

Input parameters given in file INPUTCR.DAT:

Etching time 6 hours.
Bulk etch rate 1.2 μm/h.
Visibility 1μm.
V function 5.

Input parameters in file INPUTCHAMBER.DAT
Number of register particles 10000
Lower radius (R1), upper radius (R2), and chamber height (H) 2.6 3.2 5.2.
Detector radius Rdet<R1, 2.
Number of function 2.

This input will give the following in file OUTPUT.DAT.

```
SENSITIVITIES TO RN222,Po218 AND Po214 IN CHAMBER VOLUME ARE   .7617E-02     .8327E-02     .9436E-02
 SENSITIVITIES TO Po218 AND Po214 IN CHAMBER WALLS ARE   .1399E-02     .2723E-02
 SENSITIVITIES TO Po218 AND Po214 PLATEOUT ARE   .1940E-02     .1901E-02
 ALL SENSITIVITIES IN Si UNITS, I.E. IN m
TOTAL SENSITIVITY IS BETWEEN    2.922188E-02 AND     1.558059E-02
 VOLUMETRIC FRACTION OF Po218 IS   4.000000E-01
 TOTAL SENSITIVITY FOR GIVEN VOLUMETRIC FRACTION OF Po218 IS   1.835187E-02
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5. Conclusion

Computer program for calculation of sensitivity of CR-39 for radon measurements with diffusion chamber is described in this work. Software can be used for optimization of diffusion chamber and measurement procedure. If the sensitivity is known from experimental work, this program can be used to determine other parameters related to this kind of detector.

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