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Draft Indian Standard

MEASUREMENT OF RADIOACTIVITY IN THE ENVIRONMENT-AIR: RADON-222- PART 4 INTEGRATED MEASUREMENT METHOD FOR DETERMINING AVERAGE ACTIVITY CONCENTRATION USING PERSONAL PASSIVE DOSIMETER

ICS 17.240

Nuclear Energy for Peaceful Application Sectional Committee, CHD 30 | **Last date of comments: 18th April 2024**

Nuclear Energy for Peaceful Application Sectional Committee, CHD 30

FOREWORD

(*Formal clause will added later*).

Radon isotopes 222, 219 and 220 are radioactive gases produced by the disintegration of radium isotopes 226, 223 and 224, which are decay products of uranium-238, uranium-235 and thorium-232 respectively, and are all found in the earth's crust (see Annex A of IS 18066 (Part 1) for further information). Solid elements, also radioactive, followed by stable lead are produced by radon disintegration.

Radon (^{222}Rn), along with its progeny, is considered to be main source of human exposure to natural radiation. UNSCEAR[1] suggests that, at the worldwide level, radon accounts for around 52 % of global average exposure to natural radiation. The radiological impact of isotope 222 (48 %) is far more significant than isotope 220 (4 %), while isotope 219 is considered negligible (see Annex A of IS 18066 (Part 1)). For this reason, references to radon in this document refer only to radon-222.

Inadequately ventilated dwellings, confined workplaces, tourist caves, and underground workings, including mines, are identified as significant potential sources of radon. Prolonged exposure to elevated levels of ^{222}Rn (radon) and its progeny has been linked to an increased risk of lung cancer. Additionally, confounding factors such as smoking can exacerbate the carcinogenic potential of 222Rn and its progeny. The soil gas is identified as the primary source of residential radon through infiltration pathways.

The scientific findings of the International Commission on Radiological Protection (ICRP) have put forward a reference level for radon gas in dwellings at 300 Bq/m^3. Additionally, the ICRP, as per Ref 00/902/09, recommends a concentration level of 1,000 Bq/m^3 for the application of conditions within occupational radiation protection programs for existing exposure situations. Similarly, specific guidelines for implementing radiation protection criteria for exposure to radon and its short-lived progeny are being applied in underground mines.

Radon activity concentration can vary from one to more orders of magnitude over time and space. Exposure to radon and its decay products varies tremendously from one area to another, as it depends on the amount of radon emitted by the soil and building materials, weather conditions, and on the degree of containment in the areas where individuals are exposed.

Considering the limitations of spot measurement methods, which is intended for rapid assessment of radon activity concentration in air. The result of same cannot be extrapolated to an annual estimate of the radon activity concentration. Bhabha Atomic Research Center (BARC) Mumbai has developed an indigenous system on Personal radon Dosimeter (PRD), which is based on integrated measurement with passive air sampling. Which is consider more effective and reliable measurement of radon activity.

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1. SCOPE

This standard (Part 4) prescribes the detailed procedure for radon (^{222}Rn) concentration measurement in dwellings, work places and mining and mineral handling facilities using Personal Passive Radon Dosimeter (PPRD).

2. TERMINOLOGY

2.1. Activity — The number of spontaneous nuclear disintegrations occurring in a certain quantity (weight/ volume) of material during a specified time interval, divided by that time interval. It is expressed in Becquerel (Bq), where 1 Bq = 1 disintegration/ second. Earlier unit of activity was Curie (Ci), where 1 Ci = 3.7 x 10^{10} disintegrations/ second.

2.2. Action Level — The concentration of radon at which intervention is recommended to reduce the exposure in a dwelling or workplace.

2.3. Radon — A radioactive gas (^{222}Rn) of atomic number 86, mass number 222 and alpha emitter with half life of 3.82 days.

2.4. Short Lived Radon Progeny — The decay products of ^{222}Rn, used herein, are the short-lived products from ^{218}Po through ^{214}Po.

2.5. Reference level — Used to establish values or measured quantities such as recording level or investigation level, above which some specific action/ decision should be taken.

2.6. Radon Prone Areas — An area in which the characteristics of the ground causes elevated radon levels in dwellings than usual.

3. PRINCIPLE

The passive (integrated) ^{222}Rn measurement technique uses the principle of track formation in a Solid State Nuclear Track Detector (SSNTD) following the interaction of alpha particle with detector. Cellulose Nitrate (CN) film is used as detector material due to its specificity for alpha particle. The tracks so formed are enlarged after chemical etching with standard alkali solution. The tracks can be visualized and counted using an optical microscope/spark counter. Due to high precision and stability of the calibration factor, track detector is normally placed in a closed container allowing entry of only ^{222}Rn gas by passive diffusion (NCRP 97, 1988).

4. EQUIPMENT

4.1. Measurement Device— Personal Passive Radon Dosimeter consists of dimensionally optimized cylindrical aluminium chamber (59 mm diameter x 37 mm height), one end of which is covered with a thin latex membrane (50 µm), protected by a perforated cover. The other end is covered with a gasketed lid (with loop on outer side) with cellulose nitrate detector mounted on its collar between two rubber discs so that the sensitive surface of the detector always views the membrane.

4.2. Etching Bath and Stand — Etching stand holds multiple films fixed with rubber gasket that can safely be subjected to etching in an etching bath with etching solution of 10 percent NaOH kept in separate container.

4.3. Constant Temperature Water Bath — Accuracy ± 0.5 °C or less.

4.4. Microscope — 10x or higher magnification (preferably with image processer / analyser).

4.5. Spark Counter — Spark counter model PSI-SC1

5. MATERIAL AND REAGENT

5.1. Latex Membrane — Thickness 50 µm**.**

5.2. Sodium Hydroxide (Analytical Grade) — 10 percent w/v

5.3. Solid State Nuclear Track Detector (SSNTD) — KODAK LR-115, Type II Pelleculable (12 µm film thickness and 100 µm base).

6. DOSIMETER ASSEMBLY

Schematic diagram of the dosimeter assembly is provided in Fig 1. The dosimeter is a cylindrical aluminium chamber with technical features provided in section **5.1**. Radon gas is allowed to diffuse through the perforated end cap. The membrane barrier ensures removal of particulates and short-lived isotopes of radon (^{220}Rn).

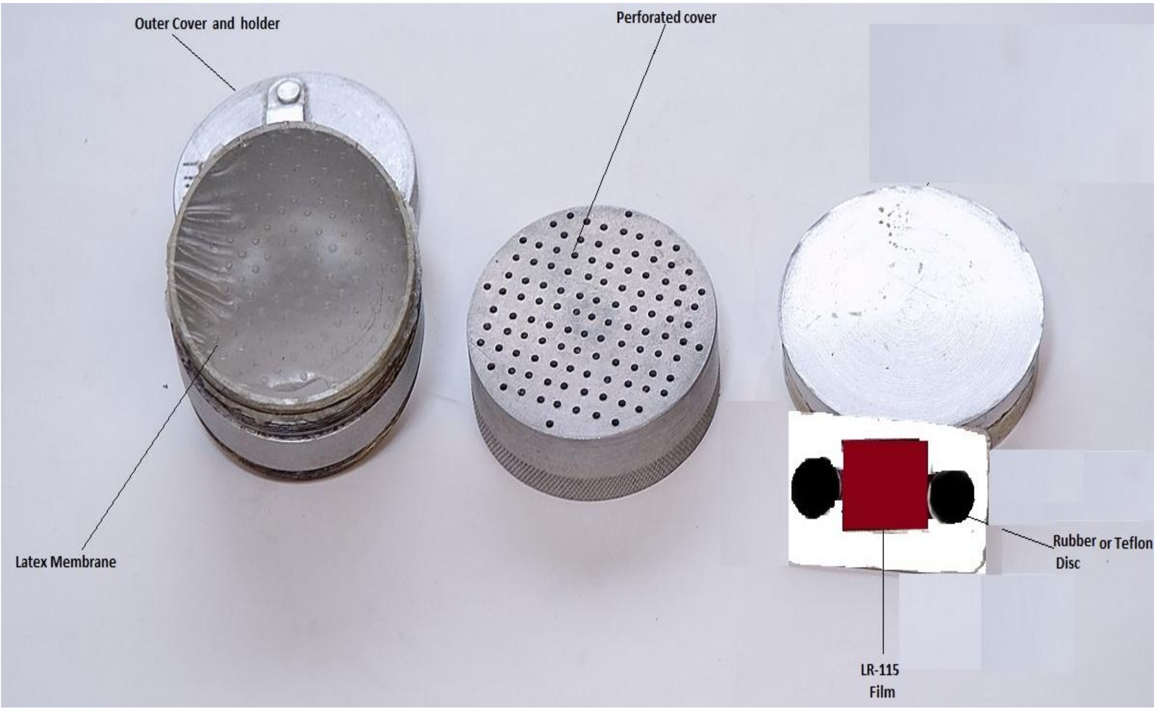

FIG. 1 PERSONAL PASSIVE RADON DOSIMETER ASSEMBLY

7. CALIBRATION

7.1. Calibration System

(a) A calibration system is a cylindrical aluminium chamber of 60 litre capacity, with provision of keeping multiple dosimeter receptacles (for spatial distribution of ^{222}Rn) and one PMT assembly connected with Lucas cell through scintillation cell and alpha counter.

(b) A standard ^{226}Ra-^{222}Rn source of Pylon RN-1025 with a radon release rate of 12.24 Bq min^{-1} leak tight may be used of calibration**.**

Alternatively, a Certified Reference Material of Uranium Ore Powder IAEA-RGU-1 Traceable to SI and International Standard of Mass with known concentration of U and ^{226}Ra can also be used for calibration of dosimeter. Theoretical calculations of emanation parameters of gaseous radon can be done using the standard equations. The powder is uniformly placed inside the calibration chamber under leak tight condition. Before deploying the dosimeter, the ^{222}Rn concentration should be measured using scintillation cell-PMT-alpha counter assembly.

8. MEASUREMENT

The ^{222}Rn concentration in the chamber is estimated using the attached evacuated Lucas cell or standard device like Alpha Guard. After the desired exposure duration, the dosimeters are subjected to further processing. The receptacle opening is immediately sealed for subsequent measurements, if required. The tracks formed in the SSNTD film due to irradiation become visible under a microscope after chemical etching and counting.

9. FILM PROCESSING AND COUNTING

After exposing in calibration chamber, the SSNTD films are subjected to etching at (60 ± 0.5) °C (strictly) for 120 minutes and after equilibration in atmospheric conditions the stripped film is thoroughly washed in running water and dried for microscopic viewing. Depending on the film characteristics the period of etching may vary (90 minutes to 120 minutes) which can be optimized through experiment for different intervals under other specified standard conditions. The developed tracks are usually counted under a microscope to determine actual number of tracks under the field of view. However, counting large number of irradiated films using microscope becomes tedious and time consuming and a faster counting system is used, which is known as spark counter.

10. CALIBRATION FACTOR

To calculate the Exposure (E) from the Track Density data a Calibration Factor is required to be experimentally worked out. From the above calibration system (60 litre chamber) with multiple PPRD in place, this factor has been worked out to be 0.554. The plot between Calibration Factor and Period of Exposure is provided in Fig. 2.

$$E = 0.554\ T_N$$

Where E = Exposure in Bq l^{-1} h and T_N is track density in Tracks cm^{-2}.

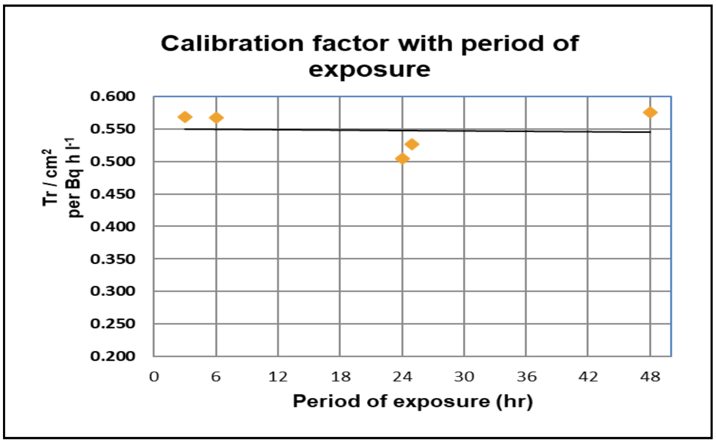

FIG 2 CALIBRATION FACTOR AND PERIOD OF EXPOSURE

11. LOWER LIMIT OF DETECTION

The lower limit of detection (LLD) is the lowest possible exposure of ^{222}Rn (Bq h l^{-1}) that can be statistically distinguished from the control. LLD is a function of the variability of the control and the sensitivity of the procedure. Mathematically the LLD can be worked out using the formula

$$\text{Lower Limit of Detection} = \frac{2 \times (1 + \sqrt{1+2Tb})}{r}$$

Where,

r is response defined as inverse of the calibration factor**,**

T_b is the track density of laboratory control, typically 20-30

For field measurement the exposure (Bq h l^{-1}) should be optimized to at least three times the Lower-limit of detection.

12. LINEARITY OF TRACK DENSITY IN UNIFORM ^{222}RN CONCENTRATION

Using the uranium ore powder in the calibration chamber (60 l) with reproducible ^{222}Rn concentration and different exposure durations the linearity between track density and exposure duration with multiple PPRD is provided in Fig 3. Similar plot can be generated using identical sources traceable to SI and International standard of mass or NIST. Under steady condition with uniform ^{222}Rn concentration track density increases with period of exposure.

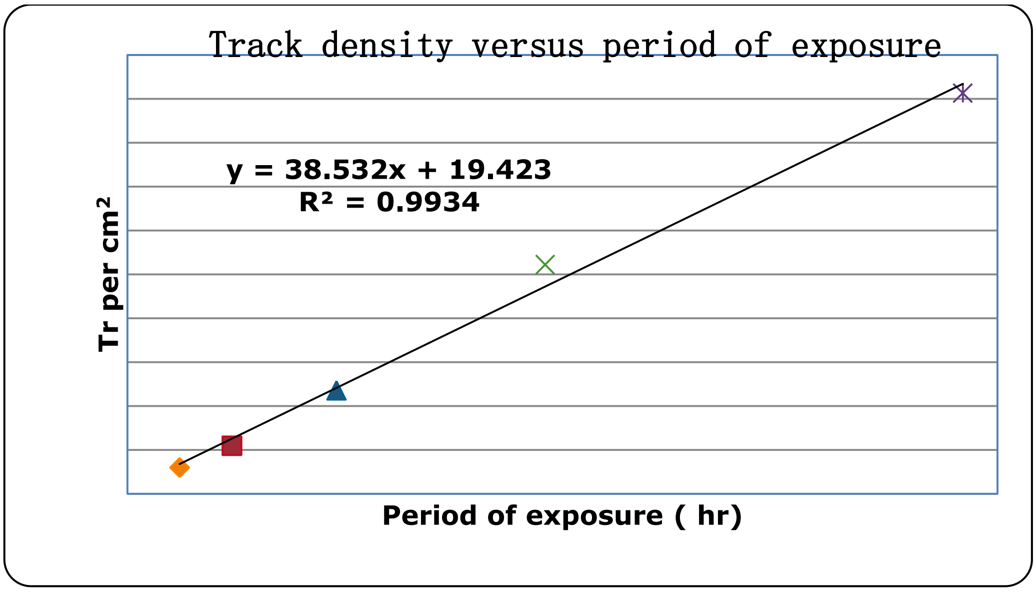

FIG. 3 LINEARITY BETWEEN TRACK DENSITY AND EXPOSURE DURATION

14. DEPLOYMENT AND RETRIEVAL OF THE DOSIMETER

For conducting the radon mapping or inhalation dose assessment program the dosimeters can be deployed at desirable height (preferably at breathing zone) and away from any obstruction in the dwelling or work place. Before deployment it should be ensured that the representative conditions meeting the objective are maintained, throughout the measurement duration. Period of exposure can be optimized as suggested. The dosimeters are provided with unique identification number and additional details such as date & time of deployment. The integrity of the system is cross checked before the deployment. Before retrieval it is ensured that the outer membrane is intact (without physical damage, hole or partial removal). For use as personal dosimeter the system is tied with belt during the occupational hours. A suitable field control is used. The films are replaced at specified intervals (after more than three months of use). The films are processed at the laboratory and average radon concentration is estimated as provided in section 12. The dosimeters are taken back to the laboratory after completion of the measurement cycle if complete annual cycle is considered for the assessment program.

15. QA/QC

a) Only Analytical Reagent (AR) grade chemicals and reagents to be used.

b) Ultrapure / Type I reagent grade water to be used for preparation of stock standards and reagents.

c) Glassware to be used for sample processing and storage are to be soaked in 10 percent nitric acid followed by rinsing with ultrapure water before use.

d) The films should be visualized for the integrity and damage, if any. If damage is observed it should be discarded.

e) The laboratory and field control of the dosimeter should be suitably chosen to account for background track density.

f) From each set some films should be microscopically counted to compare with the results from spark counting.

g) The operating voltage of spark counter should be derived from the plateau region of the curve generated.

16. REFERENCES

1. Jha, G., 1986. Development of a passive radon dosimeter for application in radiation protection and uranium exploration. India: University of Bombay, PhD Thesis.
2. Pooya, SH. and Taheri,M., 2013. A calibration setting with uncertainty measurements for passive/active radon monitors using flow-through source type. Applied Radiation and Isotopes, 73, pp.49-51.
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ANNEX A

(*Informative*)

BRIEF INFORMATION ABOUT RADON (^{222}Rn)

The radioactive ^{222}Rn (Radon) gas emanation from rocks, soils and construction materials may lead to its accumulation in confined spaces like dwellings, workplaces and underground workings areas. Radon along with its progeny is a major contributor of the population radiation exposure through the inhalation pathway. Continued exposure at elevated levels of ^{222}Rn and progeny has been reported to have positive association with lung cancer. Also, confounding factors like smoking can enhance the carcinogenic potential of ^{222}Rn and its progeny. The wide range of seasonal and diurnal variability in radon profile has been reported across the globe. Such variations are mostly dependent on the regional geological characteristics, climatic conditions and ventilation patterns systems. Apart from these factors occupancy pattern (indoor and outdoor) is an important aspect for dwellings and workplaces. Naturally occurring Radioactive Material (NORM) handling facilities, in general, and nuclear mineral, mining and processing facilities in particular are potential sources of radon build up. These anthropogenic sources are regulated through engineering and administrative control mechanism. Despite this the extent of the concern and the ubiquitous nature of the gas necessitates its measurement in different regions, both for screening and mitigation strategy planning. A simple standalone system as personal dosimeter for the measurement of in time integrated radon and its progeny mode has been developed and is in use for more than three decades in uranium mining sector. Also, the system has been used successfully implemented for measurement in work places and dwellings for public exposure assessment. In the document radon measurement protocol using Personal Passive Radon Dosimeter (PPRD) specially designed for uses in dwellings, work places and underground is provided.

ANNEX B

(*Informative*)

FLOWCHART FOR MEASURING RADON CONCENTRATION USING DOSIMETER