Applied Radiation and Isotopes 110 (2016) 183–188

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Evaluation of the uniformity of concentration of radon in a radon chamber☆

Zhang Xiongjie [a,b,*], Zhang Ye [b], Liu Yang [c], Tang Bin [a,b]

[a] Engineering Research Center of Nuclear Technology Application, Ministry of Education, East China Institute of Technology, Nanchang 330013, China
[b] East China Institute of Technology, Fuzhou, Jiangxi 330013, China
[c] Shandong Institute of Metrology, Jinan, Shangdong 250014, China

HIGHLIGHTS

- The mathematical model was built to analyze the uniformity of concentration of radon.
- An evaluation method was proposed to evaluate the uniformity of radon concentration.
- The method was successfully used in evaluating the uniformity in a radon chamber.

ARTICLE INFO

Article history:
Received 7 September 2015
Received in revised form
11 January 2016
Accepted 18 January 2016
Available online 19 January 2016

Keywords:
Radon chamber
Uniformity
Analysis of variance
t-Test

ABSTRACT

In order to solve the problem that the evaluation results of the uniformity of concentration of radon in a radon chamber via various methods were difficult to compare, according to its statistical properties, a mathematical model was built to analyze the uniformity of concentration of radon; an evaluation method for the overall uniformity of concentration of radon was proposed on the basis of single-factor multi-group ANOVA, and a detection method for nonuniform points in a radon chamber was proposed on the basis of single-factor two-group *t*-test; an evaluation process of the uniformity of concentration of radon in a radon chamber was established. The proposed method was applied to evaluate the HD-6 small and medium-sized radon chambers and achieved good results.

1. Introduction

As a system of “controllable and traceable calibration”, radon chamber is the standard facility for calibration of measuring instruments and experimental researches required in the fields including radiation protection, radioactive environmental protection, radon-based prospecting and seismic exploration. The facility can primarily provide a steady and adjustable radon concentration environment, perform unified calibration, verification and performance test on various types of measuring instruments in combination with measurement standards of radon and its progeny, and carry out experimental study on the behavior and control of radon and its progeny with the support of temperature and humidity control system and aerosol generating system (Lee et al., 2004; Paula et al., 2000).

The uniformity of concentration of radon in a radon chamber (hereinafter referred to as the uniformity) is an important indicator of evaluating the performance of radon chamber, mainly by characterizing the uniformity of concentrations of radon at different sampling points. Uniformity directly affects the accuracy of the calibration of radon monitors and the experimental researches on the behavior of radon and its progeny. Therefore, uniformity indicators have been proposed by the radon chambers developed in countries around the world. For instance, International Radon Metrology Program (IRMP) recommended a uniformity of 2.5% in a radon chamber (Xianjie, 2001); the uniformity in a radon chamber of Atomic Energy Commission of Syria (AECS) was 10% (Shweikani and Raja, 2005); the uniformity in a radon chamber of Amirkabir University of Technology in Iran was 10% (Heidarya et al., 2011); the uniformity in a radon chamber of East China Institute of

☆Supported by National High Technology Research and Decelopment Program of China (2012AA061803-04); Supported by Jiangxi Provincial Natural Science Foundation of China (20132BDH80007).

* Corresponding author at: Engineering Research Center of Nuclear Technology Application, Ministry of Education, East China Institute of Technology, Nanchang 330015, China.
E-mail address: xjzhang@ecit.cn (Z. Xiongjie).

http://dx.doi.org/10.1016/j.apradiso.2016.01.021

Technology was less than 3% (Xiongjie, 2008); the uniformity in a radon chamber of University of South China was 1.5–5% (Xianjie, 2001). All these indicators were based on the form of the relative standard deviation (or the maximum relative error), greatly impacted by the measuring instruments and the measurement time, and the uniformity between different chambers was thus difficult to compare. To address this problem, this study explored new evaluation methods for the uniformity, based on the statistical properties of the uniformity of concentration of radon in a radon chamber.

2. Mathematical model for analysis of the uniformity

An evaluation of the uniformity of concentration of radon in a radon chamber refers to the question that whether the expected value of concentration at each uniformity test points is equal to the overall expected value of radon concentration in a radon chamber. To simplify the discussion, a mathematical model should be established to analyze the uniformity of concentration of radon in a radon chamber.

Let E be the overall expected value of radon concentration in a radon chamber, s be the number of test points required for the uniformity test, and the expected values of radon concentration at each test point were recorded as E_j (j=1, 2, 3, …, s), then the effective value of uniformity δ_j can be expressed as:

$$\delta_j = |E_j - E|, \quad j = 1,\ 2,\ 3,\ \dots\ s \tag{1}$$

Eq. (2) showed the ideal uniformity of radon concentration in a radon chamber, that is, all the effective values of uniformity δ_j were equal and equal to 0.

$$\sum_{j=1}^{n} \delta_j = 0 \tag{2}$$

In the actual uniformity test, test instruments (such as radon monitor) were used for multiple measurements at each test point (number of measurement= n). According to the statistical properties of radiation measurements, the measured concentration of radon was the sum of the expected con of radon at test point j and the random error ε_{ij}, and can be expressed as:

$$\left.\begin{array}{c} C_{ij} = E_j + \varepsilon_{ij} \\ i = 1, 2, \cdots, n \\ j = 1, 2, \cdots, s \end{array}\right\} \tag{3}$$

where C_{ij} represents the i-th result of the uniformity measured at the j-th test point (unit: Bq/m^3); E_j represents the expected concentration of radon measured at the j-th test point (unit: Bq/m^3); ε_{ij} represents the i-th measured result of random error, the difference between the i-th result of the uniformity measured at the j-th test point and the expected concentration of radon measured at the j-th test point (unit: Bq/m^3);

The main source of the random error ε_{ij} was the statistical fluctuation, and therefore ε_{ij} should be normally distributed with an expected value of 0. When detecting the uniformity with the same measuring instrument, the random errors ε_{ij} were obviously independent with an equal variance σ^2. Therefore, by substituting Eqs. (1) and (2) into Eq. (3), a mathematical model could be obtained to analyze the uniformity of concentration of radon in a radon chamber. It can be expressed as:

$$\left.\begin{array}{c} C_{ij} = E + \delta_j + \varepsilon_{ij} \\ \varepsilon_{ij} \sim N(0, \sigma^2), \\ \varepsilon_{ij}\,\text{independent} \\ i = 1, 2, \cdots, n \\ j = 1, 2, \cdots, s \\ \sum_{j=1}^{n} \delta_j = 0 \end{array}\right\} \tag{4}$$

where $N(0, \sigma^2)$ represents normally distributed.

To analyze the uniformity of concentration of radon in a radon chamber was to test whether the effects δ_j of the uniformity statistics were all equal and equal to 0. Obviously, this ideal uniformity could not be achieved, therefore, the uniformity of concentration of radon in a radon chamber was detected at a certain level of significance, and the effects δ_j of the uniformity could be considered to be all equal and equal to 0.

3. Evaluation method for the uniformity

3.1. Analysis method for the overall uniformity of concentration of radon

Let H_0 be the acceptance domain and H_1 be the rejection domain of testing hypothesis for the overall uniformity of concentration of radon, then there was:

$$\begin{cases} H_0\colon \delta_j = 0, \quad j = 1, 2, \cdots, s \\ H_1\colon \delta_j \text{ not all } 0,\ j = 1, 2, \cdots, s \end{cases} \tag{5}$$

The mathematical model which was used to analyze the uniformity of concentration of radon in a radon chamber shared the same form of expression with the mathematical model for the single-factor multi-group ANOVA (Ju et al., 2010; Marini et al.,2015).

Let SS_B be the difference between the expected values of radon concentration at each test point and the overall expected value of radon concentration in a radon chamber, named as the sum of squares of variations between groups, It can be expressed as:

$$SS_B = \sum_{j=1}^{s}\sum_{i=1}^{n} (E_j - E)^2 = \sum_{j=1}^{s} (n_j E_j^2 - n{\cdot}s{\cdot}E^2)$$

So the expected value of SS_B can be expressed as:

$$E(SS_B) = (s-1)\sigma^2 + \sum_{j=1}^{s} n_j \delta_j^2$$

or

$$E\left(\frac{SS_B}{s-1}\right) = \sigma^2 + \frac{1}{s-1}\sum_{j=1}^{s} n_j \delta_j^2$$

In the same way, let SS_W be the difference between the measurement values of radon concentration at each test point and the overall expected value of radon concentration in a radon chamber, named as the sum of squares of variations within groups. The expected value of SS_W can be expressed as:

$$E\left(\frac{SS_W}{n-s}\right) = \sigma^2$$

When H_1 was true, there would be:

$$\sigma^2 + \frac{1}{s-1}\sum_{j=1}^{s} n_j \delta_j^2 > \sigma^2$$