Study on Cosmic Ray Subtraction Method for Fixed Gamma Radiation Dose Rate Meters

Authors: Guo Jie

Date: 2025-04-01T00:00:00+00:00

Abstract

This study proposes an innovative method for determining the cosmic ray response of fixed radiation dose rate meters. Based on the theory of homologous measurement, the core premise is that under identical environmental conditions, measurement results from different instruments for the same terrestrial gamma radiation air absorption dose rate should demonstrate consistency. According to this principle, by configuring a reference radiation dose rate meter with a known cosmic ray response value and synchronously measuring radiation sources of varying activities under identical conditions together with the fixed instrument to be tested, this research establishes a correlation model between the two instruments, thereby deriving the specific cosmic ray response value of the fixed gamma radiation dose rate meter. Experimental results indicate that this method can effectively eliminate environmental influences on measurement outcomes and significantly enhance measurement precision. Compared with conventional methods, this approach eliminates the need to dismantle instruments from fixed stations, avoids measurement interruptions, simplifies operational procedures, and reduces calibration costs. This research provides an efficient and reliable technical approach for determining the cosmic ray response of fixed gamma radiation dose rate meters, which is of significant importance for improving the accuracy of dose rate evaluation and the reliability of environmental radiation monitoring networks.

Full Text

Study on a Cosmic Ray Subtraction Method for Fixed γ Radiation Dose Rate Meters

Jie Guo, Hua Zhang, Runlong Xu, Shuiguang Chen
Guangdong Environmental Radiation Monitoring and Nuclear Emergency Response Technical Support Center, Yangjiang City, Guangdong Province, 529500

Abstract

This paper proposes an innovative method for determining the cosmic ray response of fixed radiation dose rate meters. Based on the theory of homologous measurement, the core premise is that under identical environmental conditions, different instruments should yield consistent results when measuring the air absorbed dose rate of terrestrial gamma radiation. Building upon this principle, this study establishes a correlation model between a reference radiation dose rate meter with a known cosmic ray response and the fixed instrument under test by conducting synchronous measurements of radioactive sources with varying activities under the same conditions. This model is then used to calculate the specific cosmic ray response of the fixed gamma radiation dose rate meter.

Experimental results demonstrate that this method effectively eliminates the influence of environmental factors on measurement outcomes, significantly enhancing measurement accuracy. Compared to traditional methods, this approach eliminates the need to dismantle the instrument from its fixed station, avoiding measurement interruptions while simplifying operational procedures and reducing calibration costs. This study provides an efficient and reliable technical means for determining the cosmic ray response of fixed gamma radiation dose rate meters, offering significant implications for improving the accuracy of radiation dose rate assessments and the reliability of environmental radiation monitoring networks.

Keywords: Fixed gamma radiation dose rate meter; Cosmic ray response; Homologous measurement; Linear fitting

1. Introduction

Measuring and subtracting the influence of cosmic rays is of great significance in environmental gamma radiation dose rate monitoring, as cosmic rays account for approximately 40% of the external exposure dose rate from natural background radiation [1]. However, different gamma radiation dose rate meters exhibit varying responses to cosmic rays, resulting in actual monitoring data differences with standard errors reaching 1% to 30%. To ensure comparability of monitoring data across instruments, it is essential to deduct the cosmic ray response component of each measurement instrument when measuring gamma air absorbed dose rates. Furthermore, accurately measuring ground-level cosmic ray dose rates at different altitudes is crucial for evaluating external radiation doses received by residents in various altitude regions [2-3].

By the end of 2024, mainland China had 60 nuclear power units in operation, 18 civilian research reactors, and 20 nuclear fuel cycle facilities; additionally, 15 nuclear power units were under construction with one multi-purpose research reactor in the commissioning phase. Pursuant to the Nuclear Safety Law, all these nuclear facilities must deploy environmental radiation automatic monitoring stations at 16 azimuthal positions around their perimeters, resulting in over 2,500 real-time gamma dose rate monitoring points associated with nuclear facilities nationwide. Concurrently, the national radiation environmental monitoring network has expanded to 550 automatic stations, forming a monitoring network covering 31 provinces (autonomous regions and municipalities), key watersheds, and border regions [4-7].

Notably, the gamma radiation dose rate meters deployed at these 550 national control points and nuclear facility perimeter monitoring systems suffer from significant technical limitations. First, the data traceability system is seriously deficient. Since cosmic ray intensity measurement and dynamic subtraction procedures have not been implemented simultaneously, altitude correction coefficients ranging from 0.12 to 3.85 and geomagnetic latitude correction factors from 1.1 to 2.3 have not been effectively applied, leading to systematic deviations of up to 45 nGy/h between plain and plateau stations. This fails to meet the $±$8% comparison deviation limit specified in the current standard HJ 1009-2024. Second, the dose assessment functionality has fundamental defects. The cosmic ray contribution, which accounts for approximately 40% of natural background with a fluctuation range of 15%, remains unquantified, rendering monitoring data incapable of supporting public annual effective dose calculations. The error exceeds the 0.3 mSv/year threshold, and it is even more difficult to precisely distinguish the proportion of artificial versus natural radiation sources according to occupational dose recording requirements recommended by the International Commission on Radiological Protection [8-10].

2. Methodological Basis

In any environment, the measured terrestrial gamma radiation air absorbed dose rate should be equal across all instruments [11-14], expressed as:

Where *tD* represents the terrestrial gamma radiation air absorbed dose rate at the measurement point; *D*, *Dc*, and *k* are the measured reading, cosmic ray response value, and calibration factor for air absorbed dose rate from 137Cs gamma rays for an environmental gamma dose rate meter, respectively; *D0*, *Dc0*, and *k0* are the corresponding measured reading, cosmic ray response value, and calibration factor for the reference radiation measurement instrument. From equation (1), we derive:

For any environmental gamma dose rate instrument, the calibration factor is constant; the instrument' s cosmic ray response value can also be approximated as constant at similar altitudes. Therefore, during comparative measurements in the same environment, the readings from two instruments will exhibit a linear relationship. By plotting the comparative measurement data with *D0* as the x-axis and *D* as the y-axis for linear fitting, the regression equation $y = ax + b$ is obtained. With known values of *Dc0* and *k0*, equations (3) and (4) can be used to determine *Dc* and *k*, yielding the calibration coefficient and cosmic ray response value of the instrument under test.

3. Equipment and Materials

Transfer Instrument: An RSS-131 high-pressure ionization chamber (manufactured by General Electric, USA) of the same model as the fixed substations was selected. This instrument was verified by the Guangdong Radiation Dosimetry Verification Station [4], obtaining a calibration factor of 1.01 in a standard 137Cs source radiation field. Wanlv Lake' s open water area was chosen as the cosmic ray response test site, meeting the technical requirements of an offshore distance greater than 1 kilometer and water depth exceeding 3 meters [5-6]. During field measurements, the instrument was placed on an unobstructed test platform with operators maintaining a distance of over 15 meters to eliminate human scattering effects. A 30-minute continuous measurement yielded a cosmic ray response value of 38.9 nGy/h.

Standard Reference Radiation Source Configuration: A design combining monoenergetic nuclides and mixed nuclides was adopted. Monoenergetic nuclides of 60Co and 137Cs (0.662 MeV) standard point sources were used, while mixed nuclides consisted of naturally radioactive series equilibrium slag (238U series, 232Th series). The slag samples were crushed to a particle size of $ $0.5 mm, dried to constant weight (moisture content $ $0.5%), and packed in Φ75 mm $\times$ 50 mm polyethylene sample boxes (wall thickness 3 mm $\pm$ 0.2 mm) with a silicone shock absorption layer fixing the slag. The dose gradient design covered from background reference values to approximately 700 nGy/h. The gamma nuclide measurement spectrum of the slag is shown in Figure 1 [Figure 1: see original paper].

Based on the gamma spectral analysis results shown in Figure 1, the detected radionuclides mainly include Pb-214, Bi-214, Ac-228, Th-228, U-235, and U-238, all of which are decay progeny of the uranium and thorium series. The gamma-ray energy range covers 0 to 2522 keV. This study employs such highly concentrated natural radiation sources for gamma dose rate measurement primarily because, compared to single Cs-137 or Co-60 sources, natural nuclide sources offer a broader energy range (from tens of keV to several MeV), more comprehensively meeting the dose rate measurement requirements in complex environments. In contrast, Cs-137 (662 keV) and Co-60 (1.17 MeV and 1.33 MeV) have relatively single energies and cannot adequately simulate the gamma radiation spectrum in actual environments. Furthermore, natural radiation sources contain multiple radionuclides, providing a gamma radiation spectrum closer to real environmental conditions and suitable for calibrating and testing the multi-nuclide response capability of dose rate instruments. Cs-137 and Co-60 only provide radiation characteristics of single nuclides, limiting their application in complex environments. The gamma spectrum of natural radiation sources is more similar to natural background radiation in the environment, enabling better calibration of instrument measurement accuracy in natural settings, whereas the radiation characteristics of Cs-137 and Co-60 differ significantly from natural background radiation, potentially causing measurement biases. Additionally, nuclides in natural radiation sources are typically in decay chains, providing continuous and stable gamma radiation suitable for long-term calibration and testing, while the radiation characteristics of Cs-137 and Co-60 gradually weaken over time, requiring periodic replacement or recalibration. Natural radiation sources also have wide applicability in nuclear industry, environmental monitoring, geological exploration, and other fields, capable of simulating gamma radiation characteristics in complex environments, while Cs-137 and Co-60 are mainly used for laboratory or specific scenario calibrations.

4. Measurement Method

Synchronous Measurement: Let the transfer instrument be A and the fixed substation instrument be B. Instrument A is transported to the fixed substation and placed at the same height as the fixed dose rate meter B under test. After both instruments measure the environmental background dose rate level, radioactive sources 1 through 9 are sequentially placed at the maximum response position of instrument A for measurement, recording at least 10 readings. The sources are then placed at the same position for instrument B for measurement, again recording at least 10 readings. The mean value for each measurement point is calculated for each instrument.

Linear Fitting: Using the transfer instrument A measurement values as the X-axis and the instrument B measurement values as the Y-axis, LINEST linear fitting is performed to obtain the empirical regression equation: $y = ax + b$. Formulas (3) and (4) are then used to calculate the cosmic ray response value Dc and calibration coefficient k for the fixed substation instrument.

5.1 Method Validation Experiment

During cosmic ray response value measurements at Wanlv Lake, two qualified high-pressure ionization chambers were selected with calibration coefficients of $k10 = 0.99$ and $k20 = 0.98$. The cosmic ray response values measured through conventional methods were $D10 = 39.0$ nGy/h and $D20 = 38.9$ nGy/h, respectively. Simultaneously, the proposed method was used to measure background and response values for sources 1# through 9#, yielding a calibration coefficient for instrument No. 2 of $k21 = 0.94$ and a cosmic ray response value of $D21 =$ 36.6 nGy/h.

Detailed data are presented in Table 1 , and the linear fitting graph for the two instruments is shown in Figure 2 [Figure 2: see original paper]. The data in Table 1 indicate that the deviation between the cosmic ray response value measured using the conventional method and that obtained using the proposed method is -5.9%. Additionally, the deviation between the calibration coefficient obtained through verification and that obtained using the proposed method is -4.1%. Despite these deviations, they fall within acceptable ranges, demonstrating that the proposed method exhibits high accuracy and reliability in measuring cosmic ray response values and calibration coefficients.

5.2 Fixed Substation Comparison Measurement

Three fixed substations around a nuclear power plant were selected for measurement using this method, with results summarized in Table 2 . The data show that the linear regression determination coefficients (R^2) between instruments QTC-B, CXZ-B, BMT-B and instrument A all exceed 0.999, confirming the universal applicability of the linear relationship shown in equation (1) across a wide measurement range. The slope parameter a deviation range (1.06–1.09) reveals certain inherent sensitivity differences among different instruments. The cosmic ray response values calculated using this method are 36.5 nGy/h, 41.5 nGy/h, and 37.9 nGy/h, respectively, all falling within the range of cosmic ray response values measured at our center over the years (33.4–41.4 nGy/h). These results indicate that the proposed method demonstrates high accuracy and reliability for measuring cosmic ray response values and calibration coefficients. Therefore, this method can be applied for cosmic ray measurement and calibration coefficient determination at fixed substations.

6. Conclusion

This study proposes a method for determining the cosmic ray response of fixed gamma radiation dose rate meters based on homologous measurement theory. By synchronously measuring data from a reference instrument with known cosmic ray response and the instrument under test at different radioactive source activities, a linear correlation model is established to calculate the cosmic ray response value of the instrument under test. Experiments demonstrate that this method effectively eliminates environmental interference and significantly improves measurement accuracy. Compared with traditional methods, this approach requires no dismantling of fixed station instruments, avoids measurement interruptions, simplifies operational procedures, and reduces calibration costs.

In the method validation experiment, the deviation between cosmic ray response values measured by this method and conventional methods was −5.9%, and the calibration coefficient deviation was −4.1%, both within acceptable ranges, thereby verifying the high accuracy and reliability of the method. In fixed substation comparison measurements, the linear regression determination coefficients (R^2) for three instruments all exceeded 0.999, validating the method' s universal applicability across a wide measurement range. The measured cosmic ray response values of 36.5 nGy/h, 41.5 nGy/h, and 37.9 nGy/h were consistent with historical measurements (33.4–41.4 nGy/h), further confirming the method' s reliability.

This method is suitable for cosmic ray response determination of fixed gamma radiation dose rate meters, effectively resolving the inconvenience of instrument dismantling and measurement interruption inherent in traditional methods while simplifying operational procedures and reducing calibration costs. The application of this method will significantly enhance the accuracy of radiation dose rate assessments and the reliability of environmental radiation monitoring networks, providing efficient and reliable technical support for radiation environmental monitoring at nuclear facility perimeters and national control point automatic stations. In summary, the method proposed in this study demonstrates high applicability and accuracy in cosmic ray response determination for fixed gamma radiation dose rate meters, effectively overcoming the limitations of traditional methods and providing important technical support for environmental radiation monitoring with broad application prospects.

References

[1] United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and Effects of Ionizing Radiation [M]. Shanxi: Shanxi Science and Technology Press, 2002: 109.
[2] Wang Qiliang, He Miaoting. Measurement of Cosmic Ray Ionization Intensity and Its Empirical Spatial Variation Patterns [J]. Nuclear Techniques, 1987, 5: 28-31.
[3] Yue Qingyu, Jin Hua. Measurement of Cosmic Ray Ionization in the Atmosphere [J]. Radiation Protection, 1984, 4(4): 281-287.
[4] General Administration of Quality Supervision, Inspection and Quarantine of the People' s Republic of China. JJG 521-2006 Verification Regulation of X and Gamma Radiation Air Kerma (Absorbed Dose) Rate Meters for Environmental Monitoring [S]. Beijing: China Metrology Press.
[5] State Environmental Protection Administration. HJ/T 61-2021 Technical Specification for Radiation Environmental Monitoring [S]. Beijing: China Environmental Science Press, 2021.
[6] Ministry of Ecology and Environment, State Administration for Market Regulation. GB/T14583-2023 Specification for the Determination of Environmental Terrestrial Gamma Radiation Dose Rate [S]. Beijing: Standards Press of China, 2023.
[7] Ren Tianshan, ed. Environmental Radiation Measurement and Evaluation [M]. Beijing: Atomic Energy Press, 2005: 337-340. State Environmental Protection Administration. China Environmental Natural Radioactivity Level [M]. 1995: 520-521.
[8] Yue Qingyu, Jin Hua. Distribution Measurement of Cosmic Ray Ionization in the Lower Atmosphere [J]. Radiation Protection, 1988, 8(6): 401-409.
[9] State Environmental Protection Administration. GB/T14583–93 Specification for the Determination of Environmental Terrestrial Gamma Radiation Dose Rate [S]. Beijing: Standards Press of China, 1993-08-30.
[10] He Zhenyun, Zhu Xingsheng, Huang Naiming, et al. Variations in Global Outdoor Gamma Radiation Dose Rate Level Data and Issues Requiring Attention in Environmental Monitoring [J]. Radiation Protection Bulletin, 2001, 21(4): 3-12.
[11] Liao Jianhua, Zhang Weizhu, Lai Liming, et al. Indirect Calibration of Cosmic Ray Response and Calibration Factors for Gamma Radiation Dose Rate Meters [J]. Radiation Protection, 2012, 32(3): 150-154.
[12] State Environmental Protection Administration. Specification for the De-

termination of Environmental Terrestrial Gamma Radiation Dose Rate: GB/T 14583–93 [S]. Beijing: Standards Press of China.
[13] General Administration of Quality Supervision, Inspection and Quarantine of the People' s Republic of China. Verification Regulation of X and Gamma Radiation Air Kerma (Absorbed Dose) Rate Meters for Environmental Monitoring: JJG521—2006 [S]. Beijing: China Metrology Press, 2006.
[14] Zhang Hua, Lin Weiwei, Xu Runlong, Huang Zhengxuan, et al. Experimental Determination of Optimal Operating Environment for Radiation Test Fields [J]. Radiation Protection Bulletin, 2019, 39(3): 26-32.

Note: Figure translations are in progress. See original paper for figures.