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Research on on-Site Calibration Method of Gamma Dosimeter based on Energy Response

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Abstract

Aiming at the problem of on-site calibration of fixed gamma dosimeters, the method of energy response correction is used to study on-site calibration technology. Through Monte Carlo (MC) simulation, the energy response change law of ionization chamber type and scintillator type gamma dosimeters was studied, the energy response curve was obtained, and the low-energy range and high-energy range were distinguished by experiments, which proved the reliability of MC simulation. The sensitive volume size and medium pressure have almost no effect on the energy response of the ionization chamber-type dosimeter, and as the size of the detector increases, the energy response of the scintillator-type dosimeter gradually decreases.

Keywords

On-Site Calibration, Monte Carlo, Energy Response, Reliability.

1. Introduction

With the widespread application of nuclear technology in industry, agriculture, and national defense [1-3], more and more industries will be involved in radiation, so radiation monitoring has become particularly important [4]. Usually, the radiation monitor needs to be moved to a standard laboratory for calibration every year. However, for special monitoring tasks or fixed dose instruments, the laboratory calibration method has certain difficulties, and the on-site calibration of the dose instrument needs to be solved. In recent years, researchers have started with calibration sources, reference instruments, and on-site calibration methods, and conducted a lot of research on on-site calibration techniques [5,6].

This paper studies the on-site calibration technology of gamma dosimeter based on energy response. Starting from the calibration principle of the same type of instrument, the on-site calibration process is analyzed, and the energy response of different types of gamma dosimeters is studied by MC simulation [7], and verified by experiments. The reliability of the MC simulation method is proved. Research results provides a basis for on-site calibration.

2. Principle of on-Site Calibration

On-site calibration technology belongs to the routine calibration in the instrument inspection. As a routine calibration, the measurement of the radiation characteristics of the dosing instrument should be traceable to the appropriate national standard, which means:

(1) The frequency of calibration is related to factors such as instrument model, stability, quality, usage, and working environment with lower quality standards. The instrument to be calibrated should establish appropriate credibility to ensure that the measured value between two calibrations is not exceed the specified limit;

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(2) The reference instrument used for calibration should be calibrated with a higher level of reference radiation until it can be traced back to the recognized national standard;

(3) Strictly speaking, for any standard instrument to calibrate a reference instrument, the calibration result is only valid at that time.

2.1 Calibration Principle of the Same Type of Instrument

On-site calibration usually uses the same type of gamma dosimeter as the reference instrument to be calibrated. The reference instrument is calibrated in a standard laboratory, and the calibration factor given is K0, and the reference source given by the calibration factor is 137Cs. Since the scale factor of the detector and the response value are reciprocal to each other, the response value of the detector is R0=1/K0.

In the on-site calibration process, assuming that the X-ray with energy Ex is irradiated on the reference instrument, the instrument's indication value is Mx, and the response value of the detector at this energy point is Rx, then the theoretically agreed true value of the detector at this point is Mx/Rx, but in the actual process, because the gamma dosimeter does not have the energy recognition function, the agreed true value measured by the detector is Mx/R0. For most detectors, Rx is not equal to R0, so the energy response correction to the agreed true value is required, and the energy response correction coefficient K can be expressed as.

$$K = R_0 / R_x \tag{1}$$

Then the agreed true value Ms of the detector is:

$$M_s = M_x \cdot K \tag{2}$$

When the same X-ray source is irradiated to the on-site gamma dosimeter, its display value is Mi, then the calibration coefficient Kx of the detector at the energy Ex is:

$$K_x = M_s / M_i = (M_x K)/(M_i) \tag{3}$$

The calibration coefficient is relative to the energy Ex. The calibration coefficient usually given in the actual calibration process is for 137Cs. Therefore, the energy response curve is required to correct the calibration result, namely:

$$K'_x = K_x \cdot R_x / R_0 = M_x / M_i \tag{4}$$

It can be seen from formula (4) that for the same type of gamma dosimeter, because the energy response curve is consistent, as long as the radiation source is stable, the calibration coefficient of the on-site gamma dosimeter only depends on the value of the reference instrument and the instrument to be calibrated. The ratio has nothing to do with the energy response of the detector.

2.2 1.2 THE BASIC PROCESS OF ON-SITE CALIBRATION

The basic process of on-site calibration of gamma dosimeter is shown in the figure.

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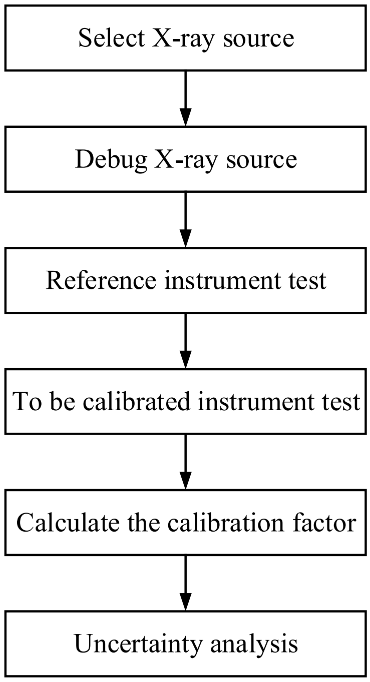

Figure 1. The basic process of on-site calibration

Select several groups of X-ray sources covering the response interval of different dose instruments according to the calibration needs; adjust the X-ray source according to the specified conditions, use the adjusted X-ray reference instrument, record the measurement results of the reference instrument under different conditions, and take the average of multiple measurements ; Use the same series of X-rays to irradiate the instrument to be calibrated, record the display results of the instrument under different conditions, and average multiple measurements; Calculate the on-site calibration results of the detector based on the exposure results, and perform uncertainty analysis on the calibration results.

3. Energy Response Mc Simulation

As a linear time-invariant system, the detector can calculate the output of other energy spectra by calibrating the intensity of one energy spectrum. At this time, it is necessary to study the energy response of the dosing instrument. In a specific energy photon radiation field, the ratio between the measured value of the radiation dose measured by the dosimeter and the agreed true value of the radiation dose at this point is called the energy response of the dosimeter at this energy point. The energy response of the γ-ray detector reflects the trend of the sensitivity of the detector with the energy of the incident particles. To accurately measure the dose rate of a certain point in a pulsed gamma radiation field with spectral distribution, it is necessary to grasp the energy response of the detector to gamma rays. In the on-site calibration process, the energy response of the on-site gamma dosimeter needs to be obtained. The MCNP software was used to study the energy response of ionization chamber type and scintillator type environmental gamma dosimeters.

3.1 Energy Response of Ionization Chamber Type Gamma Dosimeter

The detector type is a high-pressure ionization chamber, and its structure is shown in Figure 2. The sensitive area of the detector is composed of a cylinder and a hemisphere, and is filled with pure Argon at 25 atmospheres; the center of the ionization chamber is the central electrode, the structure is cylindrical, and the material is Duralumin; the volume of the sensitive area of the ionization chamber is 2.9L, the outdoor side of the ionization is made of 0.25cm thick stainless steel material. The radioactive source is a gamma source, the energy is 20keV~2MeV, and the exit angle is 40°. The volume of the sensitive area and the argon pressure in the sensitive area are changed respectively to simulate the change trend of the energy response of the detector.

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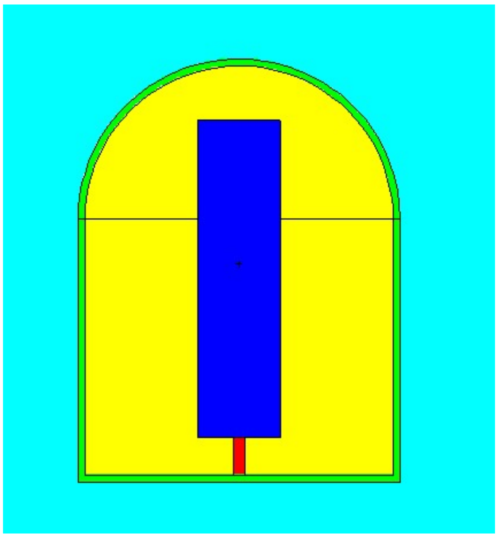

Figure 2. Schematic diagram of the ionization chamber gamma dosimeter structure

For detectors with different sensitive volumes, the geometric center of the detector is 100cm away from the radiation source, and the sensitive volumes of the detector are 1.2L, 2.9L, 5.7L, 9.8L, 15.5L and 23.2L, filled with 25 atmospheres of Argon gas. Using MCNP software to simulate the energy deposition of different energy γ-ray sources in the sensitive volume, and calculate the kerma rate of the detector for different energy γ sources. Divide by the agreed true value of the measurement point under the same conditions to obtain the detection for the energy response curves of different sensitive volumes of the detector. The results are shown in Figure 3.

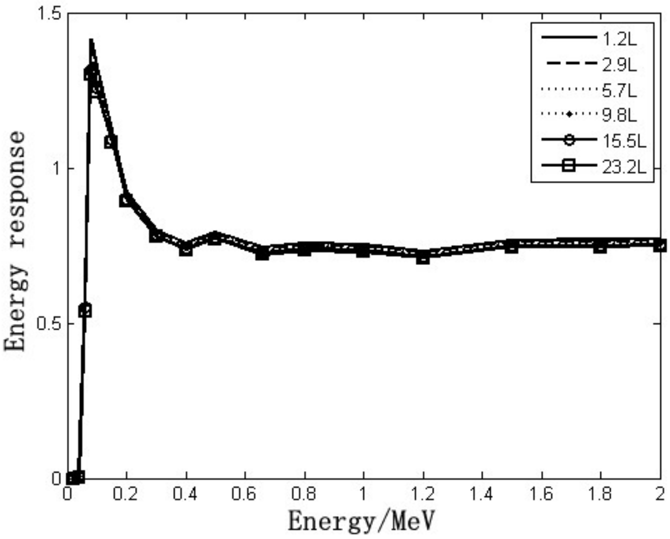

Figure 3. Energy response curves of detectors with different sensitive volumes

It can be seen from the simulation results that for gamma dosimeters with different sensitive volumes, the energy response change trend is the same. The energy response of the ionization chamber to the low energy region (<300keV) changes greatly. When the energy is greater than 300keV, the energy response of the gamma source is basically consistent, so when using a low-energy X-ray source to calibrate the ionization chamber on-site, the impact of energy response should be considered.

For different detector media pressures, the geometric center of the detector is 100cm away from the radiation source, the sensitive volume of the detector is 2.9L, and the pressure is 1atm, 5atm, 10atm,

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15atm, 20atm, 25atm, 30atm. MCNP software is used to simulate gamma sources of different energy. For the energy deposition in the sensitive volume, the energy response curves of the detector to different energy γ sources are calculated, as shown in Figure 4.

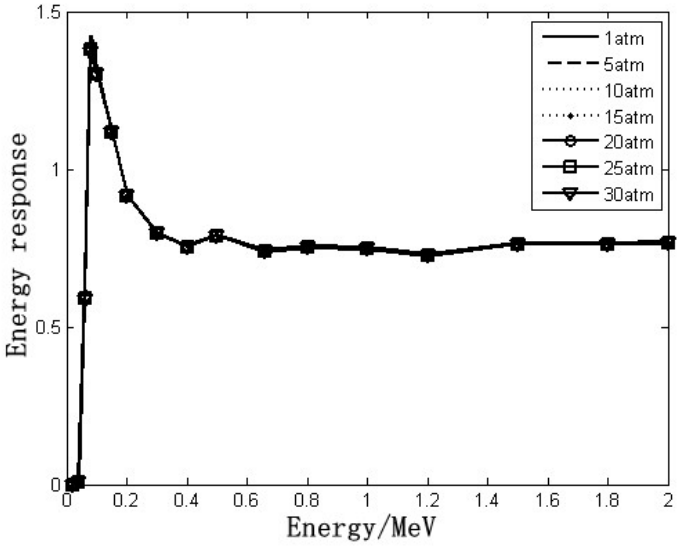

Figure 4. The energy response curves of different high-voltage of the detector's sensitive volume

It can be seen from the simulation results that the change of the detection medium pressure in the detector has little effect on the change trend of the energy response of the detector. Therefore, for on-site calibration of ionization chamber-type gamma dosimeters, the detection efficiency and energy response of common detectors of different shapes and materials can be studied, and a database of energy response can be established for the correction of energy response in the on-site calibration process.

3.2 Energy Response of Scinitillator-Type Gamma Dosimeter

The NaI scintillator detector is studied. The shape of NaI is a right cylinder with a stainless steel material with a thickness of 0.25 cm on the outside. The radioactive source is a gamma source, the energy is 20keV~2MeV, the exit angle is 40°, and the distance from the detector is 100cm. The energy responses of different sizes of NaI gamma dosimeters are counted, and the results are shown in Figure 5.

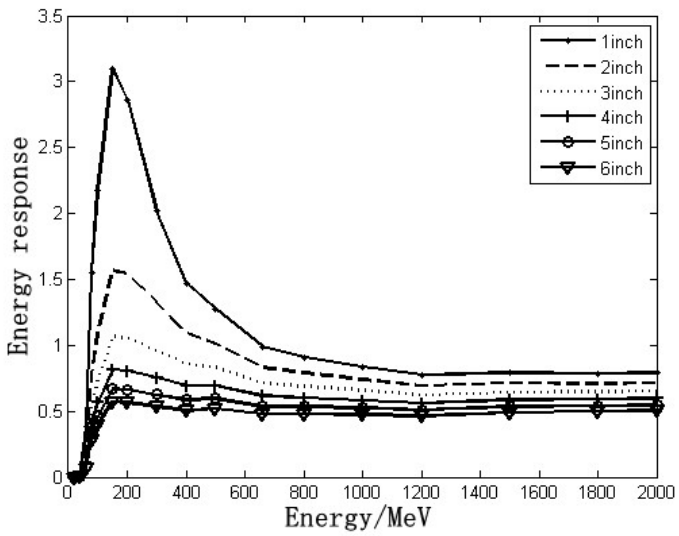

Figure 5. The energy response curves of different sizes of scintillators

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It can be seen from the simulation results that the change trend of energy response of NaI γ dosimeters of different sizes is quite different. For smaller NaI scintillators, the energy response of the dosimeter in the low-energy region changes greatly. As the size of the scintillator increases, the energy response of the detector gradually decreases. The larger the size, the flatter the energy response. When calibrating the scintillator type gamma dosimeter on site, the energy response of the detector structure and the size of the scintillator should be studied.

For ionization chamber type gamma dosimeters, although there may be differences between the built-in pressure of the detection medium or the components, the change trend of the energy response depends on the microscopic cross-section of the interaction between gamma rays and the substance, and the change trend is the same, that is, the corresponding relationship of the energy response of different energy γ-rays is consistent. Based on this, the same type of instrument as the γ dosimeter can be selected as a reference instrument. The error caused by the difference in energy response can be ignored, and the environmental scattering can effectively offset the influence of on-site calibration.

4. Experimental Verifications

In order to verify the accuracy of the simulation results, the energy response of the ionization chamber gamma dosimeter was verified experimentally. According to the radioactive source in the laboratory, the energy response experiment of the gamma dosimeter is divided into two parts: the low-energy area and the high-energy area. The energy response experiment in the low-energy area is carried out with an X-ray machine, and the energy response experiment in the high-energy area is carried out with 137Cs and 60Co sources. The response values of different energy intervals are measured, and the integrated data is shown in Figure 6.

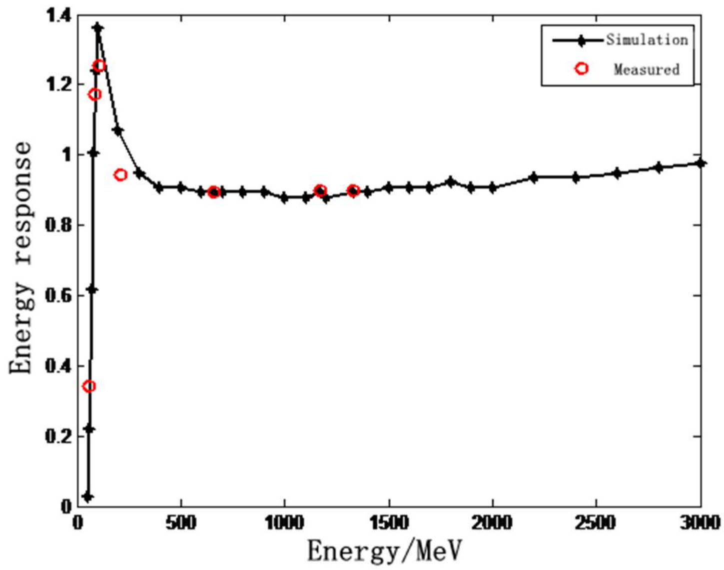

Figure 6. Energy response value of the detector to different energy gamma rays

It can be seen from the experimental results that the simulation results in the low-energy region and the high-energy region are consistent with the measured values. The correlation coefficient between the simulated value and the measured value at the corresponding energy point is 0.992, indicating that the model is correct. Monte Carlo simulation can be used as the detector auxiliary research method of energy response curve.

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5. Conclusion

Energy response characteristics research is an important part of on-site calibration, which directly affects the effect of on-site calibration. In this paper, starting from the calibration principle of the same type of instrument, using a combination of MC simulation and experimental verification, the research on the trend of energy response is carried out.

(1) For ionization chamber gamma dosimeters, changing the sensitive volume and medium pressure, the energy response has the same changing trend; the energy response in the low-energy region (<300keV) changes greatly, while for the high-energy region (>300keV), the energy response is basically consistent.

(2) For scintillator-type gamma dosimeters, the energy response change trend of NaI gamma dosimeters of different sizes is quite different; in the low-energy region, the energy response changes greatly. As the size of the scintillator increases, the energy response of the detector gradually decreases, and be consistent.

(3) The energy response of the ionization chamber type gamma dosimeter was obtained through experiments on the low-energy region and the high-energy region separately, and compared with the MC simulation results to verify the correctness of the MC simulation.

Therefore, in the on-site calibration process, it is necessary to conduct research on the energy response of the reference instrument to correct the calibration results.

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