The research of the energy and the fluence of the primary and the secondary γ -ray in the n/γ hybrid radiation field

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Abstract. According to the "little boy" data from the United States, this paper simulates the primary γ -ray of the nuclear explosion and the secondary γ -ray produced by neutron, γ -ray and material interaction. At the same time, the linear attenuation coefficient spectra of 0.001mev to 100mev was calculated. The information was obtained from the point of the source projection of 500 meters to 1km. The results showed in the observation distance: The attenuation of the primary γ -ray energy was in line with the spectral γ -ray passing through the law of shielding the decay of the material. and it showed the phenomenon of the "hardening" of the energy spectrum. The fluence decreases an order of magnitude. The energy of the secondary γ -ray does not showed obvious attenuation laws, and the fluence decreases by about two orders of magnitude. It was worth noting that the average energy of the two kinds of γ -ray was around 2.100 MeV, and the fluence was in the same order of magnitude at 1km from the distance simulation.

1 Geometric model of transport simulation

The "little boy" atomic bomb was produced when it exploded in the atmosphere γ radiation, can be divided into primary γ radiation and secondary γ radiation. According to the definition of reference, primary γ radiation mainly includes fission released during fission γ Fission fragments released by rays and fission products γ -ray, and then there are homoenergetic transitions γ Etc; secondary γ radiation comes from the interaction of neutrons with projectile materials and surrounding media (such as air, soil, etc.) γ radiation, mainly capture γ 、 Inelastic scattering γ And induced radioactivity γ radiation, etc. This article was elementary γ Ray refers to the "little boy" atomic bomb source term data given in the shell γ Rays, secondary γ Ray refers to the "little boy" atomic bomb source data given out of the shell neutrons and matter produced by the interaction γ Rays.

In the process of simulation, the transport geometric model of particles was showed in figure 1. The detectors adopts point detectors and ring detectors^[1]. At different measuring points, the measuring points of the two detectors are the same, and the detection sites are set at equidistant sampling points with an interval of 100m and 500m to 1km from the projection point of the blast center. The height of the measuring point of the detectors was set to 1.500m. The simulation source set according to the "Little Boy" atomic bomb source term data^[2] was 60m above the ground. The air adopts dry air composition at sea level, the soil adopts average soil structure, the density was 1.520g/ cm³, and the thickness was 3.000m^[3]. It is necessary to be clear that the neutron energy spectrum of

the instantaneous fission leakage of nuclear explosion is different from that of single heavy nuclear fission. The former will be shielded and attenuated by the shell, material and different structure design of nuclear weapons, and the latter is produced by the heavy nuclear fission in ideal state without doping other shielding layers. Due to the strict confidentiality of nuclear weapon parameters and the different structure of nuclear weapons, it is difficult for the former scholars at home and abroad to give a unified expression of neutron leakage energy spectrum. In the process of simulation, the transport calculations of the neutron source and γ source in the "Little Boy" source term data are carried out respectively, as showed in Table 1.

Figure 1. Transport geometry model.

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Table 1. "Little boy" source data.

	Total quantity of particles /moles/kt	The average energy of a particle /MeV
Neutron source	1.756×10^{-1}	3.051×10^{-1}
γ -ray source	6.665×10^{-3}	1.398

2 Parameter setting

In the process of Monte Carlo simulation transport calculation, the relative parameter R0 of the mean free path of the point and ring detectors needs to be set, and the set soil thickness needs to be calculated to avoid errors due to soil thickness. It was worth noting that the point and ring detectors parameter R0 and soil thickness are directly related to the mean free path of the detected particles, that was, this paper was directly related to the linear attenuation coefficient of γ -rays.

There are two rules for setting the parameter R0 of point and ring detectors^[4]: one was to calculate directly by using the default parameters, which was simple in logic, but may increase the error.

In this paper, another method was used to design the parameter R0 of the point and ring detectors through the mean free path of the γ -ray source in the "Little Boy" source term data. the parameter R0 should be set to the mean free path of the γ -ray corresponding to the mean free path of the γ -ray. If the error at the measuring point does not meet the requirements, the parameter R0 was modified according to the mean free path of γ -rays at the measuring point.

The mean free path and the linear attenuation coefficient of γ -ray are reciprocal to each other, so the solution of the mean free path can be transformed into the solution of the linear attenuation coefficient of γ -ray in matter. In this paper, two methods are adopted to solve the linear attenuation coefficient of γ -rays in matter.

2.1 Look-up table method

By consulting the data of the relationship between γ -rays with different energy and the mass attenuation coefficient of each element^[5], the relationship between mass attenuation coefficient and energy of the main elements in soil was fitted directly. the fitting results showed that the mass attenuation coefficient of each element showed a good power series distribution, and then the linear attenuation coefficient can be obtained according to the composition of the elements in the soil. The linear attenuation coefficient of γ -rays with certain energy in soil was obtained.

The average energy of the γ -ray source used in this paper was 1.398MeV. According to the fitting results, the mass attenuation coefficients of the main elements of γ -rays in soil and air are obtained, as showed in Table 2. The linear attenuation coefficient and mean free path in soil and air are showed in tables 2 and 3.

Table 2. The mass attenuation coefficient of the $E_\gamma=1.398$ MeV in each element.

Elements	Mass attenuation coefficient $\mu / \rho \times 10^{-2} / (cm^2 / g) \times 10^{-2} / (cm^2 / g)$
N	5.542
O	5.537
Na	5.284
Mg	5.405
Al	5.280
Si	5.431
K	1.195
Ca	5.093
Fe	4.562

Table 3. The linear attenuation coefficient of the $E_\gamma=1.398$ MeV in the soil and the air (Lookup table method).

Interacting medium	Linear attenuation coefficient μ / cm^{-1}	Mean free path λ / cm
Soil	8.239×10^{-2}	1.214×10^1
Air	6.692×10^{-5}	1.494×10^4

2.2 Theoretical calculation.

In the theoretical calculation of the interaction between γ -rays and matter, three main interactions are considered: photoelectric effect^[5], Compton scattering^[5] and electron pair effect^[6, 7]. After considering each interaction of γ -rays in matter, the sum fitting was carried out in order to obtain the linear attenuation coefficients of γ -rays with different energy in matter.

The total cross section of photoelectric effect σ_τ , Compton scattering cross section σ_s and electron pair effect cross section σ_k , which expressions are:

$$\sigma_\tau \approx K \times Z^4 / (h\nu)^3 \quad (1)$$

$$\sigma_s \approx \pi r_e^2 \left[\frac{\ln(1+2\alpha)}{\alpha^3} + \frac{2(1+\alpha)(2\alpha^2-2\alpha-1)}{\alpha^2(1+2\alpha)^2} + \frac{8\alpha^2}{3(1+2\alpha)^3} \right] \quad (2)$$

$$\sigma_k \approx \frac{r_e^2 Z^2}{137} \left(\frac{28}{9} \ln 2\alpha - \frac{218}{27} \right) \quad (3)$$

The linear attenuation coefficient was equal to the sum of the linear attenuation coefficients of each interaction process, so:

$$\mu = \sigma_\tau \cdot n + \sigma_s \cdot n_e + \sigma_k \cdot n \quad (4)$$

In the formula, α was a constant; Z was the atomic number of absorbing matter; r_e was the classical electron radius, unit cm; n was the number of atoms in unit volume matter, and unit atom/ cm^3 was the number of electrons in unit volume matter, unit electron/ cm^3 ; μ was the linear attenuation coefficient, unit cm^{-1} .

The relationship between the linear attenuation coefficient of γ -rays in air and soil and energy calculated according to the above formula was showed in figure 2.

The total linear attenuation coefficient of γ -rays in air and soil was fitted to determine the parameters in the process of parameter transport simulation. The fitting results showed that the fitting determination coefficients (R-square) are 0.955 and 0.999 respectively, and the results are ideal, and their expressions are as showed in formula 5 and formula 6. When the average energy of γ -ray source was 1.398MeV, the theoretically calculated attenuation parameters in soil and air are showed in Table 4.

$$\mu_{air} \approx 7.812 \times 10^{-7} \cdot (h\nu)^{-1.991} + 2.072 \times 10^{-5} \quad (5)$$

$$\mu_{soil} \approx 6.935 \times 10^{-5} \cdot (h\nu)^{-2.907} + 3.524 \times 10^{-2} \quad (6)$$

(a) γ -ray interact with the air.

(b) γ -ray interact with the soil.

Figure 2. The linear attenuation coefficient of γ -ray in the air and the soil.

Table 4. The linear attenuation coefficient of the $E_\gamma=1.398$ MeV in the soil and the air (Theoretical calculation results).

Interacting medium	Linear attenuation coefficient μ / cm^{-1}	Mean free path λ / cm
Soil	3.530×10^{-2}	2.833×10^1
Air	2.112×10^{-5}	4.735×10^4

To sum up, the mean free paths of γ -rays with energy of 1.398 MeV in soil and air are 1.214×10^1 cm and 1.494×10^4 cm, respectively. Through theoretical calculation, the mean free paths of γ -rays of this energy in soil and air are 2.833×10^1 cm and 4.735×10^4 cm, respectively. There was a certain gap in the mean free path obtained by the two methods. With regard to the selection of the mean free path of the detector R0, this paper selects the theoretical calculation results, that was, when R0 was set to 1.480×10^4 cm; in order to reduce the influence of the soil layer thickness on the parameters of the detector, and refer to the look-up table method and theoretical calculation

results, it meets the requirement that the attenuation of γ -rays in the soil was more than ten mean free paths, that was, the thickness of the soil layer was set to 3m.

3 Simulation results

Through the simulated transport calculation of the radiation source by Monte Carlo, the error diagrams of primary and secondary gamma rays at the measuring point are obtained, as showed in figure 3. According to Monka's evaluation of the accuracy of the transport results, when the error R of the point detector was less than 0.050 and that of the ring detector was less than 0.100, the calculation results can be trusted. Therefore, both the midpoint detector and the ring detector in figure 3 have untrusted results and reliable results, and the measurement results of the two detectors can complement each other. If the data are screened, the data with lower error and higher credibility are closer to the real situation.

(a) Detection error of the primar γ -ray.

(b) Detection error of the secondary γ -ray.

Figure 3. Detection errors in primary γ -ray and secondary γ -ray at the point of measurement.

After screening and processing the data, the errors of primary and secondary γ -rays at each measuring point from 500m to 1km are less than 0.050, and the energy Fluence and error of primary and secondary γ -rays at each measuring point are showed in figure 4. The results showed that the primary γ -ray Fluence was reduced by about one order of magnitude, and the average energy of γ -ray was also increasing. It was also consistent with the cognition that spectral hardening will occur when a γ -ray source with a certain spectral distribution passes through

the shielding material (the shielding material in this paper was air). Compared with the primary γ -rays, the secondary γ -ray Fluence excited by the interaction between neutrons and matter was reduced by about two orders of magnitude, but the average energy of the secondary γ -rays does not appear obvious "hardening" phenomenon, but was maintained at about 2.190MeV.

At the 500m measuring point, the Fluence of secondary gamma rays was one order of magnitude higher than that of primary gamma rays. However, with the increase of distance, the flux intensities of primary γ -rays and secondary γ -rays are getting closer and closer, especially at the 1km measuring point, they belong to the same order of magnitude. Similarly, with the increase of distance, the average energy of primary γ -rays was closer to that of secondary γ -rays, and the average energies of both are about 2.1MeV at the 1km point.

(a) The fluence and error of the γ -ray in the measuring point.

(b) Average energy of the γ -ray at the measuring point.

Figure 4. The primary γ -ray and the secondary γ -ray parameters at the point of measurement.

4 Conclusions

In this paper, through the transport simulation of the source term data of the "Little Boy" atomic bomb, the energy flux parameters of the primary γ -ray and the secondary γ -ray and the average energy parameters of the two kinds of γ -ray at the measuring point within the range of 500m to 1km from the simulated source center are obtained. The variation rules of the average energy and flux of the primary and secondary γ -rays with distance are obtained, and their changing rules are analyzed and explained. It was worth mentioning that in the process of

related simulation calculation, if a detector was difficult to provide reliable data, a variety of detector cooperative measurement methods can be adopted for simulation calculation, which was more conducive to obtaining convergent counting results.

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