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Study on experiment and simulation shielding properties of security work chamber based on MCNP[1]

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Abstract. In this paper, excavator safety chamber for work and internal driver model of radiation absorbed dose are constructed in a Monte Carlo program MCNP5 code. Different spacing and shielding layer thickness on the influence of each part of the human body absorbed dose rate are analyzed, and experimental result is verified. The experimental results show that as the lead shield thickness increase, the absorbed dose rate of the body parts under different shielding thickness is the trend of the small; when the distance between the radiation of point source and work chamber increases, the absorbed dose rate of human body each part fell sharply. The experimental measured data with MCNP simulation results are basically identical. On this basis, the shielding thickness and shielding materials for each part of the human body absorbed dose rate are studied, which can provide theoretical and technical support for shield for radioactive environment design.

Key words. MCNP Code, safety chamber, shielding properties, Simulation.

1. Introduction

In the process of decommissioning nuclear facilities, high-dose, high-dose rate of nuclear radiation on the engineering equipment on the electrical and electronic equipment hazards, serious crisis workers will be the safety of life. In order to protect people's lives and property safety, so that ordinary engineering equipment with shielding characteristics, the design must take effective reinforcement measures to

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increase the size and quality of work equipment, manufacturing costs. The decay characteristic of the engineering equipment refers to the energy attenuation of the nuclear radiation that the high-energy electromagnetic wave is tried to be equipped with the cockpit through the engineering equipment, that is, the shielding effect of the engineering equipment. If the engineering equipment cockpit is sufficiently shielded, cockpit operators and equipment can work in less severe nuclear radiation environments. The shielding effectiveness of the cockpit depends on the characteristics and structure of the cockpit, as well as the nature of the radiation source, the frequency of radiation and other factors. Experience at home and abroad shows that middle and high doses of systemic radiation the greatest harm, excessive exposure to small doses can also cause people's gonads, red bone marrow, bone, lung, thyroid, breast, skin, eye crystals and other lesions. Because of the long incubation period of these lesions, the effect appears late, so it is easy for people to ignore, and thus great harm to people. Therefore, excessive doses of small doses of radiation on the human body caused by chronic injury and late effects to attract people's attention [1]–[4]. In the decommissioning of nuclear facilities, neutrons, γ-ray have a lot of harm to human body the greatest harm. Shielding neutrons, γ-ray are the main task of cockpit radiation shielding design [5], [6]. For the medium and high doses of radiation shielding, at home and abroad scholars have done a considerable job, accumulated a wealth of experience. Switzerland EMPA laboratory using thermal spraying process prepared with W, B, Be and other elements of the coating, shielding radiation effect is obvious [7], [8]. Bolt et al. [9], [10] used a plasma spray technique to prepare a B_4C coating with a thickness of $200\,\mu$m applied to the TORESUPRA (TS) device. But there is little research on the design of cockpit for engineering equipment.

Therefore, in order to ensure the safety of radiation protection for workers in nuclear radiation environment, it is essential to optimize cabin structure and material design of the existing engineering equipment. It is important to improve the shielding performance of the cockpit to ensure the safety of nuclear facilities decommissioning operation personnel and the normal operation of electrical and electronic. In this paper, we study the effect of cockpit material and structure on radiation of the whole body in human by using the method of combining Monte Carlo simulation and experiment. On this basis, in order to shield shielding performance as the optimization goal, the shield of shielding performance difference under different conditions, optimizing the structure design of the shield.

2. Simulation analysis of shield effectiveness in safety operation

2.1. Geometric model construction

Based on self-made radiation protection engineering equipment safety work chamber ($160\,\mathrm{cm} \times 110\,\mathrm{cm} \times 160\,\mathrm{cm}$), set up a closed structure shield, security field, people working through a periscope observation as shown in Fig. 1.

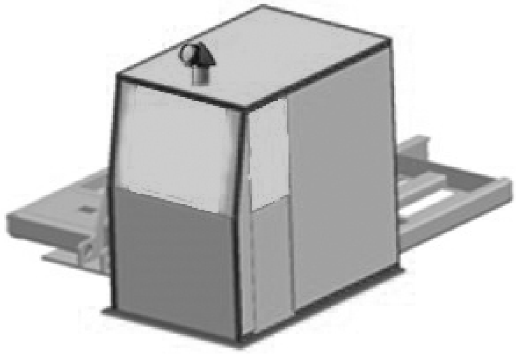

Fig. 1. Safe working chamber geometry model

2.2. Material selection

Lead to typical shielding materials as the main body of the cockpit shielding materials, research different lead thickness of 17 mm, 21 mm, 25 mm to various parts of the human body size of the irradiation dose rate, to evaluate the shielding performance of the work chamber.

2.3. The establishment of the dose calculation model

For accurate and fast simulation safety board dose in the process of people working in the actual operation situation, internal structure, our model simplifies the ORNL human body model to person's head, body, arm and leg muscle and bone as an important part of five. By using MCNP software to establish safe work chamber radiation shielding experimental model, as shown in Fig. 2. And according to the actual work chamber working distance, the design of gamma co-60 source and the distance of the work chamber is respectively 2 m, 4 m, 6 m, 8 m. Calculation of each part of the human body absorbed dose assessment cockpit shielding effect.

According to the structure of Fig. 2, calculated by using MCNP program, a total of $1 \cdot 10^9$ a particle simulation transport process. F6 counting CARDS, calculated unit mass deposition energy of human body, unit MeV/g. Reuse FM6 product of card, unit conversion, and multiplied by the photon source activity, energy deposition conversion into dose equivalent rate, unit mSv/h. Eventually determine the photon dose rate calculation FM6 card $6.912 \cdot 10^9$, the calculation results are shown in Table 1.

By MCNP simulation calculation shows that when the point source and shielding devices for the distance to test the distance of 2 m, 4 m, 6 m, 8 m. Human body absorbed dose rate value increases with the thickness of the lead alloy shield, accepted by the human body the irradiation dose rate of decline in gross value, as shown in Fig. 3. Through ORIGIN 8.5 accepted the dose rate value of the human body and the thickness of the relationship between the synthesis exponential function, in the form of dose rate of the different parts of the accepted value can be

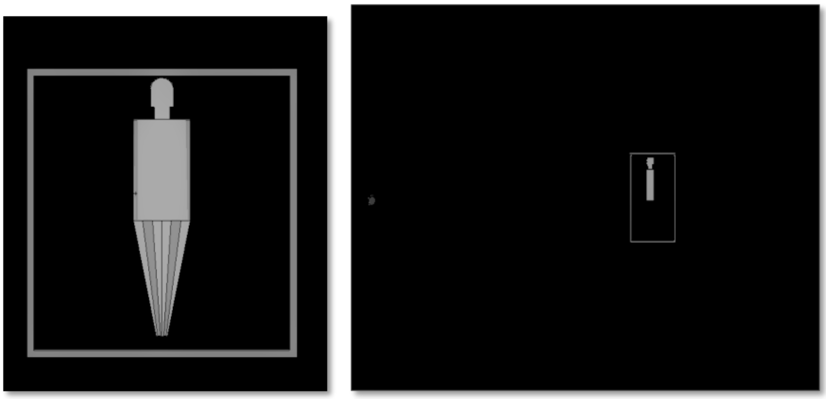

Fig. 2. Safe working class MCNP model: Working cabin and the front view of driver (left), Radioactive source and the side elevation of working cabin (right)

Table 1. The equivalent working chamber absorbed dose rate of different thickness of the lead with MCNP

Distance from the cockpit (m)	The thickness of the shielding layer (mm)	Simulated results(mSv/h)			
		head	Body and arm muscles	The bones of arm	The bones of Legs
2	17	2.83E+00	3.29E+00	3.56E+00	3.34E+00
	21	2.12E+00	2.53E+00	2.70E+00	2.59E+00
	25	1.65E+00	1.96E+00	2.10E+00	2.00E+00
4	17	9.80E-01	1.07E+00	1.15E+00	1.06E+00
	21	7.55E-01	8.24E-01	8.97E-01	8.19E-01
	25	5.76E-01	6.36E-01	6.81E-01	6.32E-01
6	17	4.73E-01	5.20E-01	5.73E-01	5.21E-01
	21	3.59E-01	4.01E-01	4.37E-01	4.07E-01
	25	2.75E-01	3.10E-01	3.24E-01	3.18E-01
8	17	2.82E-01	3.02E-01	3.24E-01	3.06E-01
	21	2.17E-01	2.33E-01	2.45E-01	2.36E-01
	25	1.69E-01	1.79E-01	1.93E-01	1.87E-01

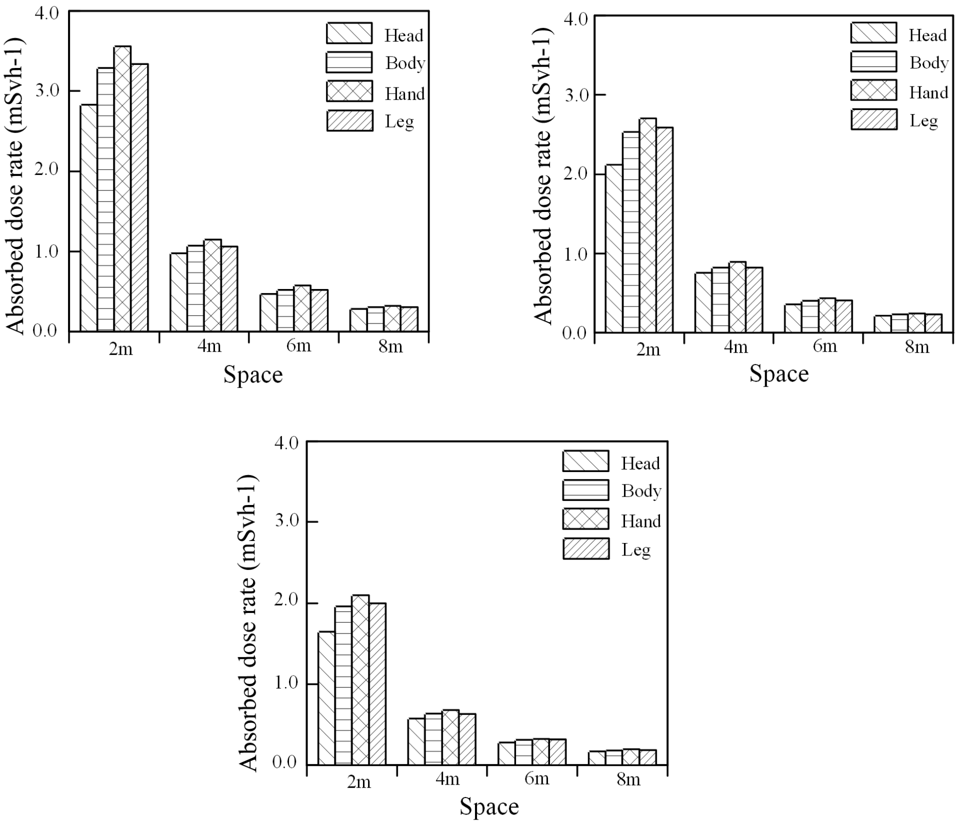

Fig. 3. Influence of different spacing for the human body absorbed dose rate under the different shielding thickness – (a) 17 mm, (b) 21 mm, (c) 25 mm

obtained and the expressions of the shield thickness, different organs of absorbed dose rate with D, x represents the thickness of the shield. Including, the head of the relationship between the dose rate and the thickness of shield can be expressed as: $D_{\text{head}} = 1.157 \exp(0.95x)$. Body and arm muscles of dose rate and the thickness of shield relations can be expressed as: $D_{\text{body}} = 1.25 \exp(0.94x)$. Arm bones of dose rate and the thickness of shield relations can be expressed as: $D_{\text{arm}} = 1.69 \exp(1.05x)$. The leg bone of the relationship between the dose rate and the thickness of shield can be expressed as: $D_{\text{leg}} = 1.21 \exp(0.92x)$. According to the head, body and arm muscles, bones, leg bones of the relationship between the dose rate and the thickness of shield after fitting the function relations, acceptable to all parts of the body parts of dose rate are increased with the increase of thickness of shielding materials according to the index rules attenuation.

3. Experiments verify the shielding effect of safe operation cockpit

3.1. Co-60 irradiation device

In order to verify the MCNP simulation human body each part under different shielding thickness of absorbed dose rate change rule, analog source for irradiation center of hunan province isotropic co-60 γ-radiation source, energy spectrum peak of 1.17 MeV and 1.33 MeV. Experimental source for irradiation center of hunan province single grating 60 Co source, activity of $1.2e13$ Bq. Because of Co-60 exist two kinds of common forms of storage, is a point source is stored in the water, the other is a lead after container shielding collimation, in MCNP software adopts the collimation narrow beam source (radius of 1 cm unidirectional plane source), as shown in Fig. 4.

Fig. 4. Co-60 irradiation center operation flow chart: Principle diagram (left), System diagram (right)

3.2. Set the parameters of the experiment

Homemade three different shielding layer thickness of shield security work chamber laboratory model (160 mm $\times$ 110 mm $\times$ 160 cm), lead shield layer thickness of 17 mm respectively, 21 mm, 25 mm, as shown in Fig. 5. Silver dichromate dosimeter record shielding radiation dose in the body, in order to evaluate the shielding effect of the shield.

Lead box placed dosimeter in front, through the cumulative dose of dosimeter measurement to evaluate operating cockpit operating personnel under the cumulative dose of radiation.Dose rate through the dosimeter measured cumulative dose divided by the time to get, to improve the accuracy of measurement results, each dose meter measuring 6 h removed in reading.

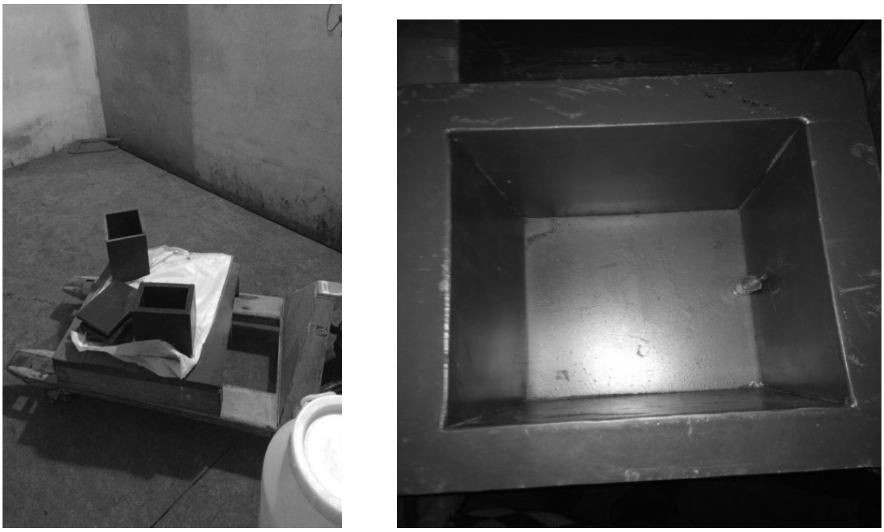

Fig. 5. Lead box for use in experiments: Assembly diagram (left), Internal diagram (right)

3.3. Analyze the results of the experiment

Experimental results show that with the thickness of the lead shield increases, the human body each part under different shielding thickness are in the trend of the smaller the absorbed dose rate. When the radiation of point source and work chamber distance increases, the human body each part absorbed dose rate fell sharply. The Table 2 shows that with different thickness of lead as a shield, from different source module cases homework cockpit human body absorbed dose experimental value and MCNP simulation results are basically identical, maximum error of 9.29 %. Visible, MCNP simulation results can be predicted in each part of the human body under the environment of radiation shielding body absorbed dose of radiation.

4. Predict the shielding effect of the safety work compartment

4.1. The influence of the thickness of the shield

When the point source and shielding devices for 7 m to test the distance, the distance each part of the human body in thickness of 2 cm, 3 cm, 4 cm respectively, 5 cm, 6 cm, 7 cm tungsten nickel alloy shielding body absorbed dose rate value, as shown in Table 3. Visible, along with the tungsten nickel alloy decreases with the increasing of the thickness of the shield.

The Fig. 6 shows that as the tungsten nickel alloy shield (one of the shielding materials) increased, the thickness of the each part of the human body absorbed dose rate decreased, the dose rate, the largest arm bones suffered head suffered

Table 2. Comparison of experimental data and simulation result of homework cockpit human body absorbed dose

Distance from the cockpit (m)	Thickness of the shielding layer (mm)	Simulated results (mSv/h)	Experimental results (mSv/h)	Deviation(%)
2	17	3.26 E+00	3.18E+00	2.51
	21	2.49E+00	2.39E+00	4.12
	25	1.93E+00	1.86E+00	3.76
4	17	1.07E+00	9.79E-01	9.29
	21	8.24E-01	8.45E-01	0.48
	25	6.31E-01	6.12E-01	3.10
6	17	5.22E-01	5.19E-01	0.57
	21	4.01E-01	4.16E-01	0.36
	25	3.07E-01	3.04E-01	0.98
8	17	3.04E-01	2.85E-01	6.66
	21	2.33E-01	2.51E-01	7.72
	25	1.82E-01	1.78E-01	2.24

Table 3. Effect of the thickness of the tungsten-nickel alloy on human body absorbed dose(mSv/h)

human body	Shielding layer(cm)					
	2	3	4	5	6	7
Head	1.73E-01	6.90E-02	2.40E-02	9.12E-03	3.80E-03	2.21E-03
Body and arm muscles	1.90E-01	7.33E-02	2.85E-02	1.22E-02	5.67E-03	2.54E-03
The bones of arm	2.08E-01	6.81E-02	2.76E-02	1.49E-02	5.43E-03	9.89E-04
The bones of Legs	1.93E-01	7.40E-02	3.28E-02	1.37E-02	4.64E-03	2.30E-03
Legs muscles	1.75E-01	6.78E-02	2.72E-02	1.09E-02	4.58E-03	1.93E-03

minimal dose rate; As the thickness of the continued increase, each part of the human body absorbed dose rate of decline is not obvious;Dose rate of the different parts of the accepted values and the thickness of the shield is not a linear

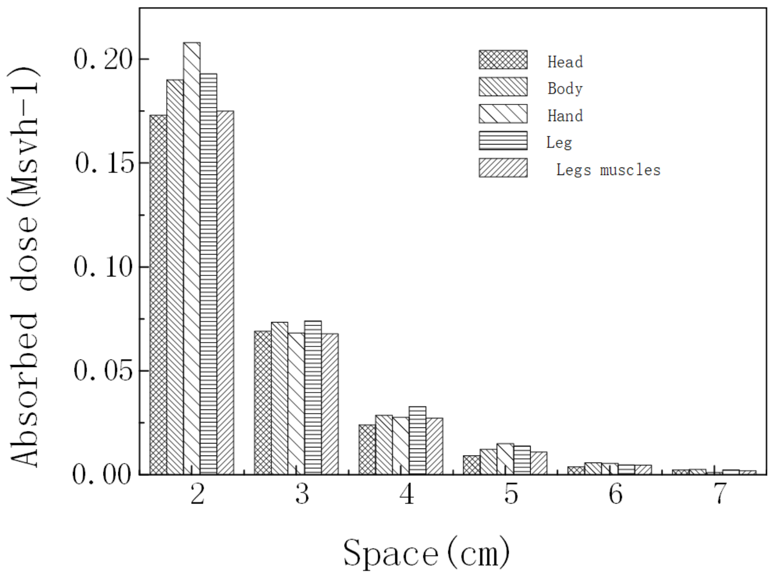

Fig. 6. The relationship between the absorbed dose rate of different parts of human body and the thickness of tungsten - nickel alloy

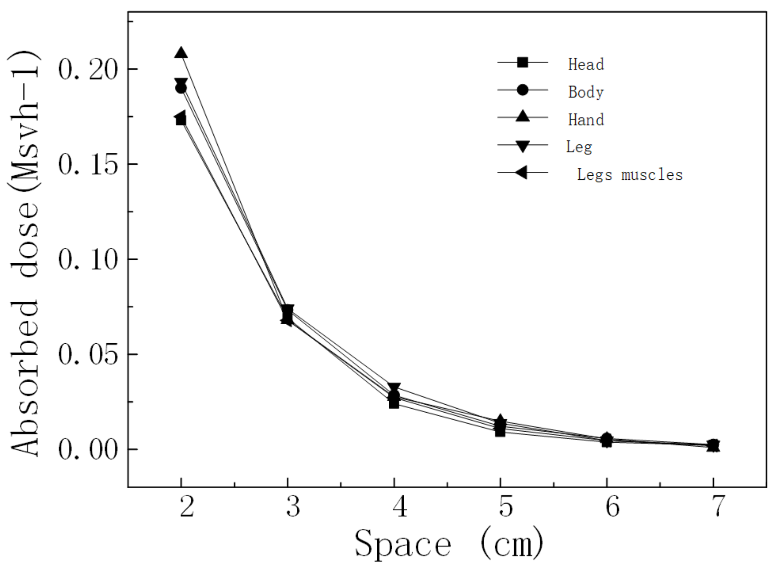

Fig. 7. The absorbed dose of different organs of the body varies with the thickness of the shielding layer

relationship. After fitting, available dose rate value of the different parts of the acceptance and the relation between the thickness of shield, people accepted the head of the relationship between the dose rate and the thickness of shield can be expressed as: $D_{\text{head}} = 1.157\exp(0.95x)$. Body and arm muscles of dose rate and the thickness of shield relations can be expressed as: $D_{\text{body}} = 1.25\exp(0.94x)$. Arm bones of dose rate and the thickness of shield relations can be expressed as: $D_{\text{arm}} = 1.69\exp(1.05x)$. The leg bone of the relationship between the dose rate and the thickness of shield can be expressed as: $D_{\text{leg}} = 1.21\exp(0.92x)$. Leg muscle of dose rate and distance relationship can be expressed as: of $D_{\text{leg}} = 1.14\exp(0.93x)$, where D table of different organs of absorbed dose rate, x represents the thickness of the shield. By the above equation, the various parts of the human body dose rate are increased with the increase of thickness of shielding materials according to the index law of attenuation, as shown in Fig. 7.

4.2. The effect of the material on the shield

Selecting the thickness of the same (both for 7 cm) tungsten 304 stainless steel, nickel alloy, lead the three different materials do cockpit shield, radiation source is point-source Co-60. Each part of the human body are calculated respectively in different shielding material shielding of the radiation dose rate size, as shown in Table 4. Visible, in tungsten nickel alloy in various parts of the human body radiation dose rate than 304 stainless steel, lead shield by human body to accept the small dose of radiation. The Fig. 8 shows that in 304 stainless steel, nickel alloy, tungsten lead three different material inside the human body to accept the biggest irradiation dose rate is respectively 0.0023 mSv/h, 0.0149 mSv/h, 0.132 mSv/h. By comparison, tungsten nickel alloy shielding performance is best, followed by lead, the worst is 304 stainless steel.

Table 4. Effect of different shielding materials on human body absorbed dose(mSv/h)

human body	Tungsten-nickel alloy (mSv/h)	304 stainless steel (mSv/h)	Lead (mSv/h)
head	0.00221	0.1112	0.00968
Body and arm muscles	0.00254	0.12804	0.01379
The bones of arm	9.88887E-4	0.12935	0.01465
The bones of Legs	0.0023	0.13159	0.01494
Legs muscles	0.00193	0.11623	0.01356

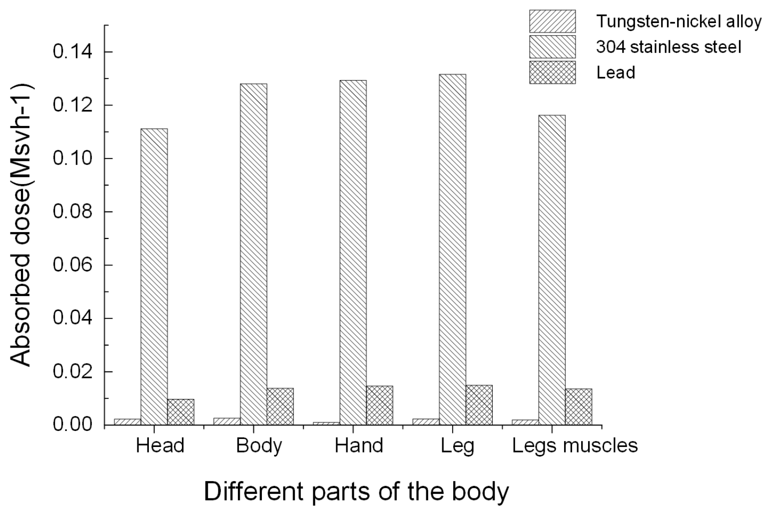

Fig. 8. Different materials in different parts of the body affect the shielding effect

5. Analysis and summary

For accurate and fast simulation safety board dose in the process of people working in the actual operation situation, based on the person's head, body, arm and leg muscles and bones of five important part as the research object, by using MCNP software to establish safe work chamber radiation shielding calculation and experimental verification model, analysis of the human body size of various parts of the irradiation dose rate, to evaluate the shielding performance of the work chamber.

By MCNP program simulation calculation and experimental verification, the results are as follows:

1. The human body absorbed dose rate value increases with the thickness of the lead alloy shield, accepted by the human body the irradiation dose rate of decline in gross value. Accepted by fitting the posterity the head of the relationship between the dose rate and the thickness of shield can be expressed as: $D_{\text{head}} = 1.157\exp(0.95x)$. Body and arm muscles of dose rate and the thickness of shield relations can be expressed as: $D_{\text{body}} = 1.25\exp(0.94x)$. Arm bones of dose rate and the thickness of shield relations can be expressed as: $D_{\text{arm}} = 1.69\exp(1.05x)$. The leg bone of the relationship between the dose rate and the thickness of shield can be expressed as: of $D_{\text{leg}} = 1.21\exp(0.92x)$.

2. When the point source and shielding devices for 7 m to test the distance, the distance the human body each part respectively in the thickness of 2 cm, 3 cm, 4 cm, 5 cm, 6 cm, 7 cm tungsten nickel alloy shielding each part of the human body absorbed dose rate decreases with the increase of the thickness of the shield.

3. Tungsten nickel alloy in various parts of the human body radiation dose rate

than 304 stainless steel, lead shield by human body to accept the small dose of radiation. Maximum irradiation dose rate were 0.0023 mSv/h, 0.0149 mSv/h, 0.132 mSv/h. By comparison, tungsten nickel alloy shielding performance is best, followed by lead, the worst is 304 stainless steel.

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