Research and application of nuclear radiation protection materials

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Abstract: Protective material as one of the keys to radiation protection technology research, therefore, the development and design a new type of efficient economic applicable protective material is very necessary to radiation protection can be divided into main radioactive dust protective and neutron gamma ray protective three, this paper has strong penetrability of gamma and neutron shielding and protective material, the paper summarized the current situation of the development, and further discussed in view of the current problems existing in the development direction of protective material performance improvement.

Key words: Nuclear radiation, protection, gamma rays, neutrons.

1. Introduction

Nuclear power technology is one of the important means to solve the problem of energy shortage in the world today, and nuclear energy in the use of equipment, storage, inspection and scrap process, may produce radioactive pollution, will inevitably cause harm to the personal safety of workers [1] Nuclear radioactive radiation mainly includes α particles and β particles γ-rays and neutrons, and according to the scope of use of radioactive protective clothing can also be divided into two categories: medical protection of nuclear radiation protection in which alpha particles beta particles and radioactive aerosols, protection is easier; In nuclear radiation protection, radioactive dust contains gamma ray neutrons, wherein gamma rays are high-energy nuclear rays (electromagnetic waves), and neutrons are high-energy particles produced by reactions such as nuclear fission and fusion. Both of them have strong penetrating power. Therefore, nuclear radiation protection research is mainly based on the protection of gamma rays and neutrons

At present, the traditional radiation protection clothing is mainly through the metal fiber in the clothing to build a loop, the radiation generated by the induced current, the induced current generated by the reverse electromagnetic field for shielding, but the harm to human body is still large. In addition, the existing gamma and neutron shielding materials remain shielding efficiency is low Thick material and so on On market at present, the use of radioactive protection ability of the single protective apparel, bulky protective clothing Poor permeability comfortable enough, cannot meet the practical needs in order to overcome the above problems, this paper mainly to distinguish the gamma rays Neutron and γ-neutron comprehensive protection of protective clothing material type protection efficiency and other aspects are summarized and analyzed, for the next step of the research and development of new protective materials to explore new directions
2. Gamma ray protection material
Gamma ray energy increase with distance and weakening, however, for radiation protection, distance protection can't be infinity, therefore, gamma rays must interact with other substances and energy attenuation continuously to achieve the effect of radiation protection Can block gamma-ray material has a lot of, the common concrete Metal single substance, as well as some high polymer composite system, such as lead, boron, polyethylene, boron, polypropylene and other materials

2.1. Concrete
In the early days, concrete was the most common shielding material for nuclear radiation protection [2]. However, in order to improve its structural technology and protection efficiency, other materials are often added to concrete for modification in current researches. For example, Makarious et al. [3] found in 1996 that adding heavy metals can improve the density of concrete, which is not only conducive to improving the shielding performance of material against gamma rays, but also can reduce the requirement for the thickness of concrete In addition, the study found that the size of the added material also affects the shielding effect. For example, Azez et al. [4] found that the attenuation coefficient of the material to γ-rays decreases with the increase of the size of the added iron ball Studies have found that the addition of lead materials can greatly improve the shielding effect. For example, Sharma et al. [5] added lead fibers to concrete can enhance the mechanical properties of the material and greatly improve the shielding effect of γ-rays. However, due to the large difference in thermal expansion coefficient between lead and cement, the mixing of lead and cement will lead to poor durability of concrete, so the researchers used other kinds of metal oxides as additives to modify the shielding effect of concrete. Shen Zhiqiang et al. [6] added yellow and blue tungsten oxide micro-powders as fine aggregates to cement-based materials, and compared the penetration rates of 60Co-γ 137Cs-γ rays from 54.3% 42.5% to 37.0% 26.9% and 41.5% 29.7% respectively by comparing the samples without tungsten oxide. Therefore, the addition of other metal oxides to enhance the shielding performance of γ-rays is also one of the research hotspots.

However, there are many shortcomings in concrete based materials, such as large volume and poor mobility. Therefore, concrete nuclear radiation shielding materials are mainly used in fixed buildings. Moreover, the shielding ability of concrete will be affected by moisture content, which will make its shielding ability an uncertain value [1].

2.2. Compound system
At present, nuclear radiation materials are mainly composed of composite materials. According to the intrinsic properties of composite materials, they can be divided into metal and its oxide composite system, ceramic glass composite system, and rare earth element doping composite system

2.2.1. Composite system of metals and their oxides. Theoretically, the higher the density of γ-ray shielding material, the better the effect. Therefore, the composite system is mainly heavy metal elements, such as Pb, W, Bi, etc

(1) PbO matrix composites
PbO, base materials are the most widely studied. For example, Noor et al. [7] found that epoxy resin was used as the matrix, as a functional component for shielding gamma rays. The shielding effect is best when the PbO filling volume reaches 50%. Some researchers [8] found that PbO, PbWO4 rubber and PbO rubber composite materials were prepared with PbWO4 and other fillers. Under the condition of 241Am as a point source of 59.5keV energy radiation, they had excellent shielding performance against gamma rays. However, Pb is easy to migrate, resulting in heavy metal pollution sources, leading to heavy metal poisoning, and posing a safety threat to workers engaged in radioactivity. In addition, Singh et al. [9] found that PBO radio-proof glass would cause damage to the environment and human health to a certain extent. In order to overcome the disadvantages of Pb material, protective materials with light quality, low cost and low toxicity have gradually become the focus of research.
order to overcome the disadvantages of Pb material, protective materials with light weight, low cost and low toxicity have gradually become the focus of research.

(2) Other metal oxide composite materials

Bi, as an element of high subordinal number, because of the high attenuation coefficient of γ photons, and non-toxic, It is promising to replace Pb as a γ-ray shielding material. Other metal-based materials mainly include Bi2O3 WO3, etc.

Manohara and others[10] used γ photonic irradiation test onto PbO-B2O3, Bi2O3-B2O3, PbO-Bi2O3-B2O3 and other systems, found that systems contain Pb-Bi are having better shield ability against γ radiation. In addition, Kaewkhaos research about PbO-Bi2O3-BaO’s glass system and its shield ability against γ radiation at power level 661.5KeV, gave us result that with the increase of mass fraction of Bi2O3 and PbO, the material’s attenuation factor against γ radiation also increased.

Liao Yizhan and others[12] found that the material containing W can be used to protect low-energy γ-rays, and the protective effect of the material against γ-rays of 70~90keV is better than that of Pb to protect the flexible film from irradiation aging by low-energy γ-rays; Carboxylated butyronitrile (XNBR) flexible membrane was prepared with WO3 as filler. The results show that the WO3 of 50% percent has a good protective effect against γ-rays under 81.0keV energy irradiation.

In addition, it is found that the size of the additive will affect the shielding performance of the composites, Dong Yu and others [13] added WO3 particles with different particle sizes into epoxy resin, and found that nano-WO3 could significantly improve the shielding efficiency of γ-rays and the mechanical properties of the composites.

In addition, Kim and others [14] found that composite materials prepared with different percentage of tungsten-molybdenum and barium sulfate particles also have a good shielding effect against gamma rays.

2.2.2. Ceramic glass composite system. Ceramic-glass composite system mainly refers to the change of matrix material based on the needs of different uses. With the wide application of γ-ray shielding materials in various fields, there are higher requirements for the shielding performance. In some radiation places, the mechanical properties such as elongation at break and tensile strength of materials are also required. At this time, concrete and some glass added with heavy metals will be limited in use.

2.2.3. Rare earth element doped composite system. With the development of research, rare earth elements with large atomic number are considered as the functional components of shielding. Research [16] found that under the condition of the same number of moles of Ta element and a certain thickness of material, with the increase of rare earth La or Ce, the shielding performance of rubber matrix composites to γ-rays is increasing. When the doping amount of Ce is 16mol%, the shielding rate of γ-ray reaches the maximum, which is about 38.66%; When the doping amount of La is 12mol%, the shielding rate of γ-ray reaches 37.25%.

At present, the protective clothing with Pb as the main shielding material in the market is bulky and inconvenient to wear, and will cause harm to people and the environment, and it is not easy to recycle and dispose. Therefore, it is very necessary to study the protective shielding materials for γ-rays. To sum up, in order to optimize the advantages and disadvantages of a single system of materials, the current research on gamma ray protection materials is mainly composite system materials, with different material performance to carry out complementary research.

3. Neutron protection material

For neutrons, the scattering surface varies with the types of elements and the neutron energy is relatively complex. The elements with small atomic numbers are easy to undergo absorption reactions similar to radiation capture reactions, so the neutron energy can be greatly reduced through elastic collision, especially those substances with high hydrogen content, such as paraffin wax Polyethylene and polypropylene, etc., both show obvious moderating effect for neutrons[18]. There are many elements
with a high neutron absorption cross section, but the absorption of thermal neutrons is often accompanied by the generation of secondary gamma rays. In addition to the neutron absorption performance of materials in the shielding environment, heavy metals should also be used to shield the gamma rays generated during neutron-moderating process. Therefore, when choosing shielding materials, not only the absorption cross section of thermal neutron should be considered, but also the energy of secondary gamma rays should be investigated[19,20], The lower the energy of the secondary gamma rays, the easier it is to shield them.

3.1. Boron and borides
Among the many neutron shielding materials, B-10 has the highest thermal neutron absorption cross section, which can reach 3837b. It produces up to 0.479MeV of secondary gamma rays, and boron compounds are abundant in nature, which is cheaper than other neutron moderators, Such as gadolinium, cadmium and lithium, therefore, can be used as an ideal thermal neutron shielding material[21,22]. In addition, Kim and others[23,24]studies have found that the shielding performance of shielding materials for neutrons is not only related to the content of the filler, but also related to the particle size of the filler. When the same amount of B2O3 is filled, the shielding rate of the composite to neutron increases with the decrease of the particle size of B2O3 . It is also found that the shielding rate of the composite to neutron increases with the increase of the filler content and decreases with the increase of the particle size of the filler.

3.2. The base materials of B₄C
In recent years,B₄C can absorb large amounts of neutrons without forming any radioactive isotopes, making it an ideal neutron absorber. B₄C polymer materials with high content of hydrogen and matrix materials are also one of the research hotspots. In our country, there are many researches on anti-neutron radiation materials, and there are also remarkable achievements. In 1985, Tianjin Polytechnic University[18] adopted composite spinning method to mix coupling agent and B₄C powder into the core layer, The protective composite fiber with skin core structure has been developed successfully, and its shielding effect to thermal neutrons is up to 96%.

Polymers matrix composites, as anti-neutron radiation fibers, usually consist of polymer fibers and neutron absorption additives. Because polyethylene, polypropylene, polyvinyl chloride and polycarbonate have good fast neutron moderating ability, Therefore, they can be used as the polymer matrix to obtain the corresponding fibers by melt spinning: Neutron absorbers mainly include heavy elements with large absorption cross sections of elements and compounds. Kim and others[26] added different sizes of B₄C and BN to the polyethylene, The neutron shielding B₄C and -BN polyethylene composites were prepared, It is found that the composite material with nanoscale B₄C and BN shows better shielding effect to thermal neutrons, and its mechanical properties are also greatly improved.

In addition, the adhesive polymer materials such as epoxy resin and paraffin wax also have a good protective effect against neutron radiation. Dong and others[13] found that B₄C had better neutron shielding performance by studying the transmittance of neutrons with different energies and comparing the commonly used neutron shielding fillers. However, there are obvious weak absorption regions. Epoxy resin is used as the base material, it can make up for the weak absorption zone of B₄C packing.Kipcak and others[27] added different amounts of B₄C to paraffin wax to prepare circular pie materials of different thickness. The test results show that the shielding rate of thermal neutrons can reach about 63.3%. Moreover, for the same thickness, magnesium-rich and multimagnesium-boron ores show higher shielding rate than B₄C ores. In addition, filling metal base materials with B₄C is also one of the common materials, for example, Garden and others[28] found that 60% B₄C metal matrix composites have the best shielding effect on neutrons.

To overcome the possibility that there may be gaps or uneven distribution between different materials, the researchers developed organoboride shielding materials. The metallic Materials
Some researchers believe that metallic materials are more efficient at neutron-energy than polymers. Zhang Yun and others [30] proposed a nickel-based foam-metal neutron shielding composite material. Under the neutron source condition, the neutron shielding performance of the 6cm thick nickel base metal foam composite material is more than 5% higher than that of the filling material. The shielding performance of γ source with different energy is better than that of filler with the same thickness. Compression tests show that the mechanical properties of paraffin foam nickel are generally much better than those of paraffin foam or nickel foam, and the compressive strength of paraffin foam nickel increases by 30 percent.

3.3. Rare earth materials
Because some rare earth elements have a large thermal neutron absorption cross section, and most of the rare earth elements are paramagnetic and have good protection against gamma ray radiation, rare earth elements are usually used with polymer materials or metal-based materials composite. The National Center for Neutron Cross Section [31] of the United States prepared the composite material by taking the polymer material as the matrix and adding rare earth elements into it. After testing, it was found that the thermal neutron shielding performance of the composite material was better than that of the rare earth free polymer material, and its shielding rate was 5~6 times that of the ordinary polymer material.

It can be seen that the traditional neutron shielding materials are mainly iron concrete, polyethylene, boron and borides, etc., while the selection of neutron shielding materials tends to be inorganic materials, organic materials and polymer materials, etc. The focus is to say good night to the disadvantages of the original materials and develop materials more suitable for new nuclear radiation protection.

Currently, there has been no column shape new neutrons protective clothing For troops demand, to carry out the new materials, new technology development and application of ionizing radiation protection research, explore multifunction lightweight neutron radiation shielding materials, improve the radioactive protective apparel protection performance, to improve the wearing comfort, choose more effective shielding protection for different protective parts material is the key content of research and development.

In conclusion, the shielding effect of composite materials on neutron-gamma rays is related to the morphology and structure of materials, but the practical application research of various composites is few, the influencing factors lack of systematic comparative study and application effect detection, and the interaction mechanism between materials needs to be further explored and studied.

4. Interim summary
In the future, nuclear radiation protection equipment will be integrated, portable and multifunctional, and the key of its technology is to make a breakthrough in the research of new protective materials.

Because of the protective equipment to the human body physiological lightweight breathable comfort demand is higher, but the protective equipment shielding efficiency with the combination of flexible material is not enough, has not yet reached optimal performance, shielding effect and the comfort level is still a difficult to reconcile the contradiction, therefore, the development of protective clothing materials and mechanical structure design is the research focus of this field. The development and design of protective materials tend to nanometer, optimize the morphology and structure of filling functional materials, material nanometer is conducive to improve the shielding performance of neutron and gamma rays, while the selection of high hydrogen content is conducive to absorb neutron mechanical properties of suitable matrix materials, in order to achieve both mechanical properties and protective properties of materials.

The research and use of composite materials should be a key field, and the choice of matrix materials and the filling of functional fillers are the main components of radiation protective clothing. For example, the matrix material, natural rubber is a better choice, natural rubber is a kind of comprehensive rubber class, hardness of about 40, because of the strong comprehensive, so it is good to combine when adding functional materials, the re vulcanization stage structure is stable, easy to form process products. In the
later research, it is necessary to further analyze and study its microscopic morphology, mechanical structure, air permeability, moisture permeability and other aspects, and to better optimize the comprehensive performance of the combination of matrix material and functional material in combination with its radiation protection efficiency.

In short, the nuclear radiation protection composite material should have the energy of long-term service, and its anti-aging performance and mechanical properties are the basic work to be studied.

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