Research on Radiation Shielding Technology of Nuclear Emergency Robot

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Abstract

With the continuous development and utilization of nuclear energy by human beings, nuclear safety and nuclear emergency have increasingly become the focus of attention of various countries, and the requirements for robots that can be used for nuclear emergency disaster relief are also getting higher and higher. When an accident occurs in a nuclear power plant, nuclear emergency robots need to enter a highly radioactive environment for rescue and disaster relief. At this time, it is easy to cause great damage to the electronic equipment. The key to the disaster relief mission is that the nuclear emergency robot can still maintain normal working ability under radiation conditions. Therefore, it is necessary to measure the radiation resistance of the controller in the electronic equipment box, and design a corresponding shielding device according to the radiation resistance of the controller. This paper firstly studies the radiation shielding technology of electronic components and the method of radiation shielding reinforcement, studies the epec2024 controller and its failure principle, and expounds the radiation damage mechanism from the aspects of total dose effect, component radiation damage effect and related factors. The radiation damage mechanism describes the influence of the irradiation environment dominated by high-dose γ-rays on the nuclear emergency robot controller with semiconductor as the main structure. After comparing and exploring the shielding performance index of pure metal, the method of using tungsten as the base material and mixing tungsten alloy with other elements to improve the mechanical properties, thermal conductivity and shielding performance of tungsten was determined. After 3 times the irradiation time of the unshielded state, the epec2024 controller can still work normally, and it is concluded that the shielding structure design scheme is safe, which effectively prolongs the use time of the epec2024 controller. An additional shielding scheme is designed for the strong radiation field, and the neutron and photon transport calculations are carried out, and the effects of different distances and different superimposed shielding methods on the shielding effect are discussed.

Keywords

Nuclear Emergency Robot; Radiation Protection; Monte Carlo; Radiation Shielding.

1. Research Background and Research Significance

In recent years, the rapid growth of population and economy has led to a great increase in human demand for energy, and the existing reserves of non-renewable energy have gradually been unable to keep up with the rapid economic and population growth. As a traditional energy source, petroleum and coal, its world reserves are decreasing year by year. At the same time, the burning of traditional energy sources such as petroleum, coal and other fuels has caused a series of environmental problems,

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restricting the survival and development of human beings, and posing a huge threat to the harmonious coexistence of human beings and nature. Renewable and clean energy such as wind energy, solar energy, nuclear energy and so on have been paid more and more attention by various countries. However, due to the limited use of wind energy and solar energy, nuclear energy is currently the main clean energy that can replace a large amount of fossil fuels [1]. The change in the world's energy structure also benefits from the use of nuclear energy, which is gradually replacing traditional energy sources and becoming the mainstream power generation method [2]. As a country with a large energy production and consumption, the development of nuclear power industry has become the general trend, and it is also an important foothold and support point for my country's economic transformation. Through the analysis of the development history of nuclear power (from one generation to the fourth generation), it can be seen that the development and utilization of nuclear energy has almost no dependence on natural resources, and almost zero emissions of polluting gases can be achieved [3], so the public has a high degree of acceptance of nuclear energy. As the main site of nuclear energy utilization, nuclear power plants have strong radioactivity. Therefore, mankind has placed nuclear safety in an increasingly important position. Several major nuclear accidents in history were devastating, such as the Chernobyl nuclear accident in the former Soviet Union, the Three Mile Island nuclear accident in the United States, and the Fukushima nuclear accident in Japan [4-5]. Due to the strong internal radioactive environment, human beings cannot enter the accident site for rescue and disaster relief at the first time, and cannot achieve a better control effect. In turn, terms such as nuclear power safety development and nuclear emergency rescue have become the focus of human attention, which has accelerated the research and development of nuclear emergency robots. Therefore, the design and development of nuclear emergency robots has increasingly become the focus of attention of countries around the world. For my country, as a major country in nuclear power operation, the development and utilization of nuclear emergency robots is particularly important [4].

2. Analysis of Research History and Current Situation at Home and Abroad

2.1 Research Status of Nuclear Emergency Robots

After the Chernobyl nuclear accident, the nuclear emergency rescue robot has received extensive attention, and more and more scientists have begun to develop nuclear emergency rescue robots. The United States and Russia jointly developed the "pioneer" nuclear emergency robot [5] , mainly used to detect the internal situation of Chernobyl Unit 4, the whole is a crawler-type design, with various detectors and sensors. The power source is the cable, and the controller using the shielding device is separated from the robot and placed at the control end [16]. Between 1983 and 1990, robotic systems were used in nuclear power plants in the United States and Canada. For example, the garbage in the sewage sedimentation tank is mainly cleaned and removed by the MiniRover Mk1 robot; the detection work of the steam return pipeline is mainly determined by the Rovver robot; whether the condensing tower or the steam generator is in normal operation is mainly by the Super Scavenger. robot to judge. Working in a lower radioactive environment is difficult to cause the robot to lose its ability to work, so the above three robots do not use radiation protection technology [4]. The level of robot research and development in Japan is at the world-class level, and a variety of robots were produced in response to the critical accident of the enrichment shaft in 1999. The Japanese government allocated 3 billion yen for research and development, and completed the design, development and construction of 6 nuclear environment operating robots [5].

Figure 1(a) shows a high radiation-resistant robot, which is mainly used for operations such as cutting off water pipes. This robot has radiation protection for internal electronic components. The dose rate during operation can reach 100Gy/h, and the cumulative dose can be Up to 104Gy; Figure 1.2(b) is a Toshiba inspection robot, the chassis is designed with dual tracks, and its functions include on-site landform detection and data collection; the robot shown in Figure 1.2(c) belongs to Hitachi, which can be operated remotely. It is more flexible, and the special pulley at the bottom can overcome steps of 20cm; Figure 1.2(d) is a heavy-duty robot developed by Mitsubishi Heavy Industries, which can

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perform heavy-duty operations such as cleaning water pipes and moving materials, and can also adapt to stairs and complex operations. environment [6].

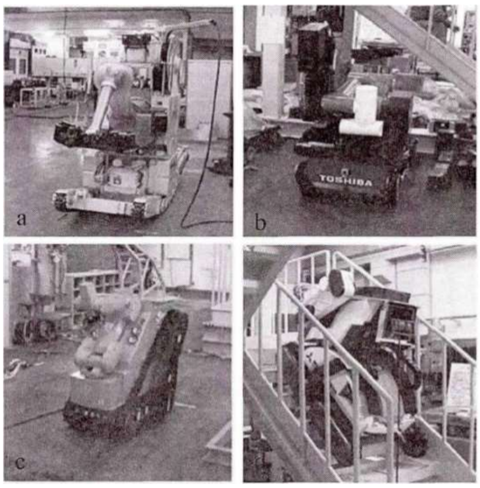

Figure 1. (a) High radiation tolerance robot (b) Toshiba test robot (c) Light operation robot (d) Heavy operation robot

2.2 Research Status of Controller Radiation Effect

At present, ionizing radiation can be mainly divided into three cases [7]: single event effect, dose rate effect, and total dose effect. For the research on the radiation effect of the controller, S. Popa; Popa S.; Mărtoiu S; Ivanovici M. et al[7] studied the dose and flux of the controller under the neutron irradiation environment, and obtained The data corruption rate in memory is quite high and statistics of the error in the results are given. Ane[8] studied the main effect of radiation on the changes in electrical characteristics of comparators, operational amplifiers, etc. in pwm integrated circuits.

In China, Wang Peng [80] studied the radiation resistance design, through measures such as radiation resistance performance simulation, layout radiation resistance reinforcement design, etc., to strengthen the design of the device against total dose radiation and single particle radiation, so as to meet the requirements of the device in space applications. Reliability of environmental work. Cao Tianjiao [9] studied a variety of single event effects and total dose effects to make radiation hardening designs for DLL circuits. Wang Yiyuan, Shen Zongyue, Zhao Zhiming, Han Dongmei, Liu Zhengyong et al. [10] found the relationship between component function and device parameters and instantaneous dose rate. Du Chuanhua, Xu Xianguo, Zhao Hailin, Zhao Hongchao et al [11] studied the reinforced circuit design of programmable devices. Yuan Ziyang [9] conducted the ground simulation experiment of anti-radiation effect and the test of chip anti-radiation ability for the first time.

3. Radiation Shield Reinforcement

There are two ways of shielding reinforcement: direct shielding reinforcement and indirect shielding reinforcement [42]. Direct reinforcement is aimed at the total radiation dose of the equipment, mainly to improve its total radiation dose resistance; indirect reinforcement is aimed at the working method and operation method of the equipment, as long as the state and working method of the working equipment are improved, it is a kind of indirect method. The radiation shielding reinforcement of the controller studied in this paper really applies the radiation shielding reinforcement theory.

3.1 Direct Shielding and Strengthening

There are many methods for direct shielding and strengthening. The commonly used methods are as follows:

(1) For the components themselves, choose the ones with strong radiation resistance;

(2) Strengthen the radiation shielding device;

(3) Design the redundant system according to the scheme.

When shielding γ-rays, high atomic number elements are generally used as shielding layers, so that the radiation level after the rays pass through the shielding layer is reduced, and the radiation resistance of the protected unit is improved [43]. In theory, the penetration of gamma rays cannot be blocked 100%. Even if the thickness increases infinitely, what can be done is to block most of the rays for the protected object and control the dose rate to a level that does not cause harm to the protected object. If a low atomic number element is used as the shielding layer, the thickness of the shielding layer is often quite large, which is contrary to the actual application environment and purpose. For neutron shielding, materials with higher atomic numbers cannot be used, so low-density light elements and hydrogen-rich substances (such as H2O or paraffin) are mostly used. However, it can be seen from the actual environment that the use environment of electronic components is usually dominated by the γ-ray environment, so the shielding design of electronic components is mainly based on the γ-ray environment.

Before the shielding design, the material of the shielding layer needs to be selected first. The choice of shielding material is determined by many factors, such as the type of radioactive source, the design requirements of the robot and so on. Because different radioactive sources can emit γ-rays with different energies, the shielding effect of the same shielding layer material will be different in many cases [11].

In the robot system, some control parts are very important, so for some special parts, it is very important to do shielding design under the premise of considering structural problems, which involves the volume, weight, center of gravity distribution of the robot, and whether it affects A range of factors at work. After the weight increases, whether the robot can still drive normally is also one of the factors that often needs to be considered. In an environment dominated by gamma rays, the dose rate absorbed by the robot is usually similar. When a hot backup system is used, the failure time of each part during irradiation is relatively close. At present, Kong Fujia et al [12] have proved that the use of cold backup can significantly improve the radiation tolerance of the system.

3.2 Indirect Shielding Reinforcement

The method of indirect shielding reinforcement is generally the replacement of space, time and the system itself. Reinforcement in space generally refers to the location of the protected unit away from the radioactive source, so as to achieve the purpose of reducing the total dose. For a nuclear emergency robot, the controller is installed at a farther position from the radioactive source, so that the total radiation dose received by the controller will be smaller [13].

Reinforcement in time is also a very effective way, but it is often overlooked. Under the radiation environment, the nuclear emergency robot will be exposed to radiation, and its total radiation dose is determined by the dose rate and operation time. It can be seen that the way to reduce the total dose is to reduce the operation time, which can be improved by increasing the speed of the robot and optimizing the system. According to the actual work, if the operation speed of the nuclear emergency robot is only pursued, it is very likely to cause operation errors. Obviously, such a simple pursuit of speed is not worth the loss. Therefore, in the design process, attention should be paid to efficiency, not just operation speed.

The replacement of the system itself refers to the replacement of the original parts inside the robot after a period of work, and the maximum tolerated dose is not reached during replacement. The system replacement of nuclear emergency robots needs to ensure the absolute safety of a single operation. When the nuclear emergency robot is replaced, a margin should be designed for the total dose tolerance to ensure the reliability of the system [14].

At present, based on the above research, it can be seen that the working robot in the nuclear environment has a single function and cannot complete more complex tasks. However, few literatures have been published on the research on automatic replacement technology of multifunctional robots.

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For a nuclear emergency robot that can be used in a nuclear environment, the total radiation dose of the controller and the radiation shielding reinforcement of the controller in the nuclear emergency system with special performance requirements are relatively small. At present, the research on radiation damage at home and abroad mainly focuses on the camera of the camera, and there is relatively little research on other electronic components of nuclear emergency robots. Therefore, it has certain practical significance to study the total radiation dose tolerance and radiation shielding reinforcement of the controller of the nuclear emergency robot.

4. epec2024 Controllers and Failure Principles

4.1 epec2024 Controller

Compared with single-chip microcomputer, PLC (Programmable Logic Controller) has the advantages of simple peripheral hardware design and high reliability [15]. The PLC controller selected for the research in this paper is the epec2024 controller designed and produced by the Finnish EPEC oy company. It has good stability and can work in a variety of extreme environments. It is a commonly used controller for nuclear emergency robots. "Huluwa" series robots, as shown in Figure 2.

Figure 2. epec2024 controller

The epec2024 controller can adapt to extreme environments such as high vibration, wide temperature changes and humidity, and is mainly used in engineering fields. At the same time, epec2024 can directly drive the electro-hydraulic proportional valve, eliminating the proportional valve driver board, simplifying the circuit, and making the system more reliable [16].

4.2 Radiation Damage Mechanism of epec2024 Controller

Components used in various electronic systems are often composed of semiconductors and other composite materials, and microscopic damage to critical components will have a significant impact on their performance. In the epec2024 controller, there are some MOS (Metal-Oxide-Semiconductor) devices. Once the MOS device fails due to radiation damage, the controller will lose some functions and affect the normal operation.

4.2.1 Total dose effect Metal-Oxide-Semiconductor (MOS)

Total dose effect Metal-Oxide-Semiconductor (MOS) is a major semiconductor production process, usually consisting of a silicon substrate, an oxide layer and a metal conductor layer laminated. MOS is often used as a material for integrated circuits, and when there are many integrated circuits in the controller, it is susceptible to radiation damage. According to the type of infiltrated metal, MOS can be divided into N (negative) type channel and P (positive) type channel, and the direction of the applied electric field is different. The gamma rays released by the radioactive source will have a total dose effect (TID-Total Ionizing Dose effect) on the chip part of the MOS. When the gamma rays pass through the entire chip, there are hole-electron pairs in the material of the controller chip. It is more capable of free electron mobility than holes. Some of the hole-electron pairs in the oxide layer will

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be neutralized, so that the internal carrier density will decrease accordingly. The density of hole-electron pairs generated in the silicon matrix is much higher than that of the oxide layer (SiO2) [17], but its effect is relatively weak compared to the hole-electron pairs generated in SiO2.

In the ideal structure of MOS, bulk charges or defects do not appear in the oxide layer, so the SiO2 layer can exist as an ideal insulator. Ideally, if the controller of the nuclear emergency robot is structured such that the metal oxide interface and the oxide/semiconductor interface can control the interface charge as well as the existence of the interface state. However, in the actual production process, the conductor of MOS cannot reach the ideal state, and there must be some magazines and primary defects, thus forming the interface state. The formation of internal microscopic physical defects in MOS through a series of ionizing radiation is mainly divided into three stages [18], namely the generation of hole-electron pairs, the immediate recombination and disappearance of hole-electron pairs, and the freedom of free carriers in oxides. move. Some of the electrons or holes in the third stage will be captured by primary defects and traps containing hydrogen bonds around the interface [19]. Different radiation conditions have different effects on hole-electron pairs. For example, under the irradiation of γ-rays and X-rays, the proportion of hole-electron pairs increases with the applied electric field. Moreover, under the same external electric field conditions, the recombination rate of free carriers of γ-ray radiation is much higher than that of X-ray radiation [20].

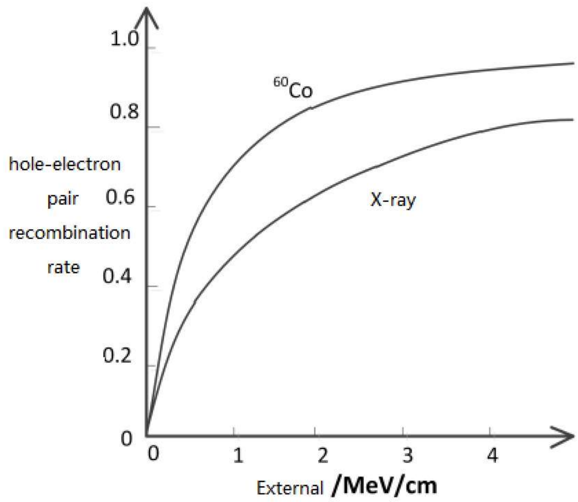

Figure 3. Hole electron pair recombination rate under 60Co or X-ray radiation condition

According to the above analysis, two kinds of carriers are generated because the ionization effect promotes the transition of some covalent bond electrons in the semiconductor to the conduction band to become free electrons, thereby generating positively charged holes. However, the carriers of these two carriers are quite different. Under the action of an external electric field, free electrons can move out of the dielectric faster [21], because the moving speed of free electrons in the oxide layer is much faster than that of holes. Also, a small amount of holes may be trapped by shallow traps of dominant defects in the SiO2 layer during the migration process, which occurs almost simultaneously with the radiation. After ionization, the positive and negative charges move slowly and recombine. At the interface between the silicon substrate and the oxide deep well, if the positively charged holes are trapped by another major defect, they are converted to fixed-position positive charges [22]. Namely, oxide trap charges and interface state trap charges. These two important charges are also the main factors affecting the performance of MOS electronic devices.

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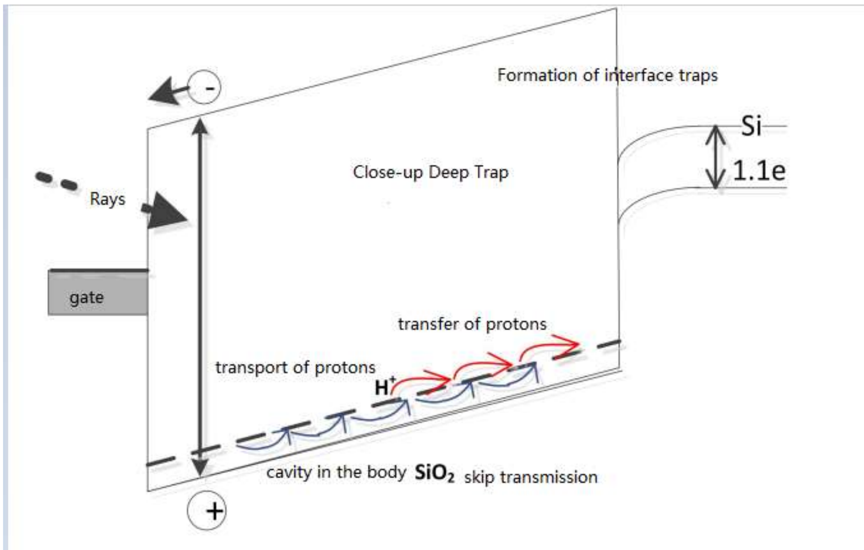

Figure 4. Production process of total dose effect

(1)Oxide trap charge and its influence

Taking the positive bias applied to the N-type MOS as an example here, positive and negative charges are generated in the SiO2 layer within t0, and they recombine after t0+. As shown in Figure 2.4, the transition free electrons in this layer move for a short time, leaving only positively charged holes. The holes accumulate at the interface between the silicon substrate and the oxide layer under the action of the applied electric field, and are finally trapped.

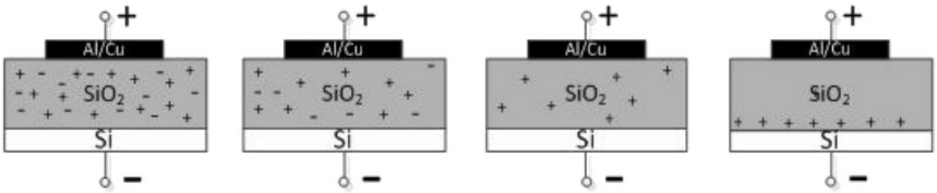

Figure 5. Transfer process of oxide trap charge

The oxide trap charge is positively charged because the charge trapped by the neutral oxygen vacancies in the semiconductor material is positive [21]. As mentioned above, the ideal interface between the silicon substrate and the oxide layer should be compact, free of inclusions, and free of interfacial charges. However, due to the influence of impurities and defects, the charges generated in the SiO2 layer can be exchanged with those in the silicon substrate. The charge absorbed by SiO2 can significantly affect the electrical performance of MOS transistors, especially leakage current and threshold voltage. After the oxide trap charge is generated, the leakage current will change and the final threshold voltage will change accordingly. When the external circuit stabilizes, the closing speed, drive capability, and turn-on conditions of the circuit may change due to threshold voltage drift. The subthreshold swing separation method defines the threshold voltage as [23]:

$$\Delta V_t = \Delta V_{ot} + \Delta V_{it}$$

Among them, Vt is the threshold voltage variation; Vot and Vit are the voltage variation caused by the oxidation trap charge and the interface trap charge, respectively.

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(2) Interface state trap charge and its influence

Interfacial trapped charges mainly affect the performance of electronic components at the interface between the silicon substrate and oxide. There are certain differences between the interface in the actual product and the ideal interface. The ideal interface is seen as infinitely thin, free of body defects and charges, and with defects and the ability to trap charges due to the presence of impurities. The actual product interface thickness is about 1~3nm, which is similar to the value of the tunnel effect. In addition, the actual interface has no obstacle to the capture or release of carriers, which will greatly reduce the mobility and recombination rate of carriers [24]. According to the formula, Vit causes the threshold voltage change by trapping charges at the interface, because the gate voltage changes the process from accumulation to reversal of positive and negative charges related to the capture and release of positive bias and negative charges.

5. epec2024 Controller Radiation Resistance Test

5.1 Purpose of the Experiment

When conducting radiation shielding of epec2024 controller, it is necessary to know the limit cumulative dose of epec2024 controller, to optimize the design of shielding scheme, to make corresponding shielding devices according to the simulation results, and then to conduct the irradiation experiment again to compare the shielding effect before and after. Verify that the shielding device meets the requirements. Therefore, it is necessary to test the maximum cumulative dose that the Finnish epec2024 programmable controller can bear when it keeps working normally under γ-ray irradiation.

5.2 Experimental Components

The object of this experiment is a control system composed of Finland epec2024 programmable controller and Italian HCEV31 electromagnetic proportional valve. The weight is 0.7kg, the operating temperature range is -40°C~+70°C, the storage temperature range is -50°C~+85°C, the power supply voltage is 24VDC (10-30VDC), and the power supply voltage must be greater than 19VDC when programming (flash memory). It has the function of monitoring voltage overvoltage and overheating.

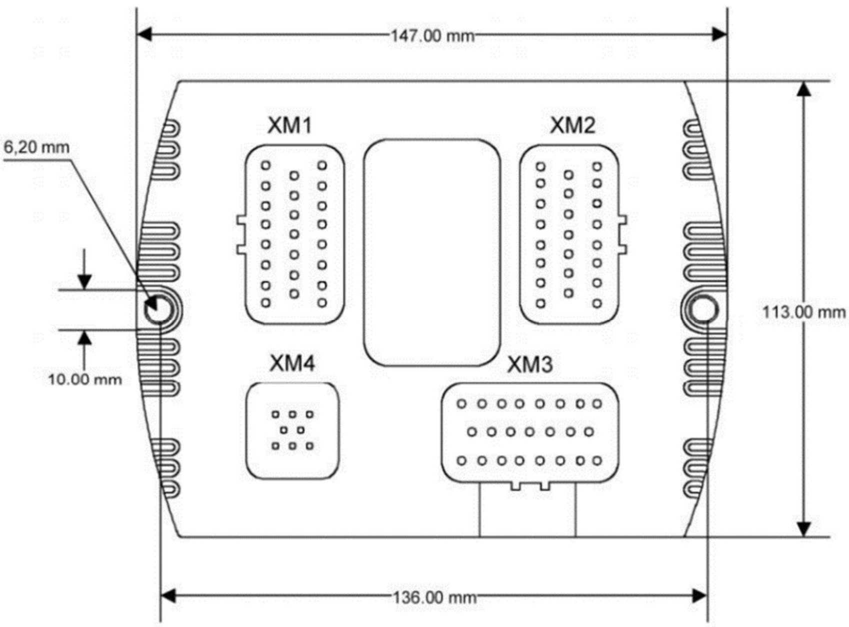

Figure 6. Top view of dimensions

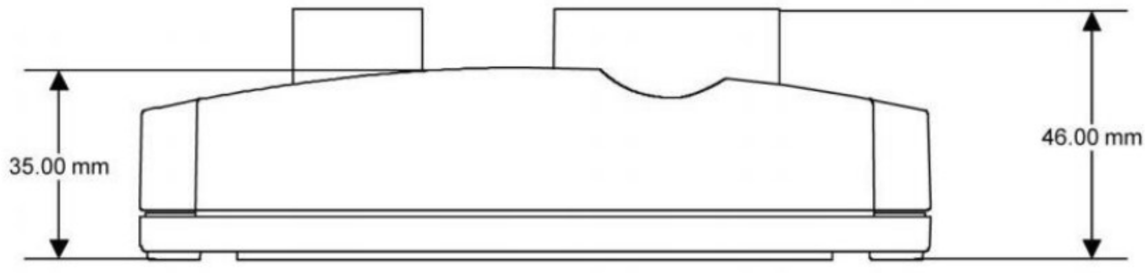

Figure 7. Dimensions main view

As shown in the figure, it can be installed numerically or horizontally, and it can be fixed by two M6 screws (DIN912 standard). Vertical installation was used in this experiment.

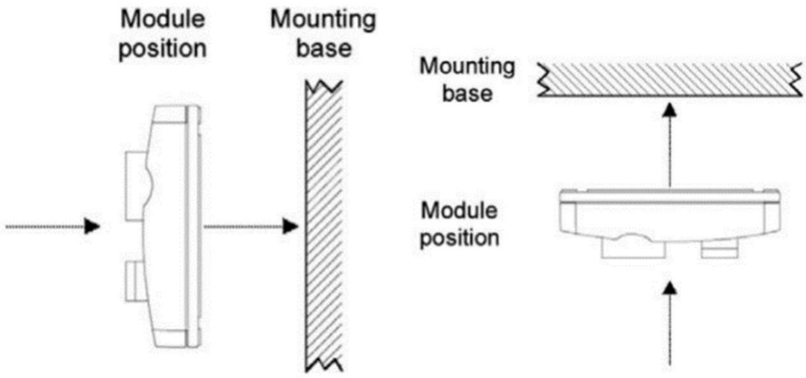

Figure 8. Installation mode

5.3 Radiation Resistance Test

5.3.1 Experimental Environment

When carrying out the radiation resistance test of epec2024 controller, the experimental conditions need to determine the experimental parameters according to the standard. According to relevant information, the available reference standards for radiation resistance experiments of nuclear emergency robots currently include Chinese military standards [25], US military standards [26] and European Space Agency standards [64]. Since the difference between the Chinese military standard and the American military standard is small, most of them use similar or similar methods and conditions, so the relevant experimental data of the two standards are compared and combined in the irradiation test, so that the data collected in the experiment is more representative and accurate. authenticity.

The site of this epec2024 controller radiation resistance experiment is Liuyang City Irradiation Center. The radiation source used in the experiment is 60Co, and the arrangement is a single grid plate plane arrangement. There are a total of 504 source rods, which are divided into four layers, and each layer has two There are 63 doors for each door, and the distance between each two is 21mm. Before the experiment, the radioactive source needs to be lowered to the sink below the source tank under professional control and wait five minutes. The controller was then placed in the position of the specified dose rate, and the source lift time was 25s.

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Figure 9. Placement point of epec2024 controller device

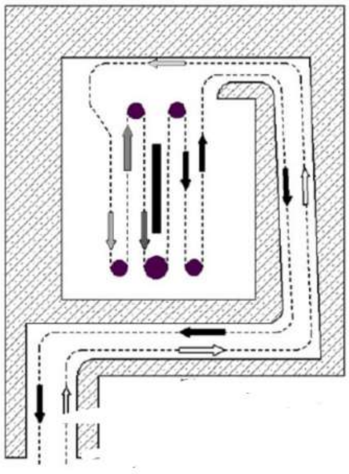

Figure 10. Diagram of irradiation center in hunan province

6. epec2024 Controller Radiation Shielding Simulation and Simulation

6.1 Procedure and Method

6.1.1 Mask Calculation

At present, the programs used for shielding calculation at home and abroad mainly fall into two categories: deterministic methods and probabilistic methods.

The deterministic method, represented by the discrete ordinate method, is a method of directly solving the transport equation to obtain the average behavior of particles. The discrete ordinate method is customarily called the discrete SN method, commonly known as the SN method.

Common discrete coordinate method programs, such as the one-dimensional discrete coordinate method program ANISN, the two-dimensional discrete coordinate method program DORT, the three-dimensional discrete coordinate program TORT, etc. ANISN, DORT and TORT series of versions are developed by the Oak Ridge National Laboratory (ORNL) It is a standard general procedure that is widely used internationally. The TORT program was developed by the Oak Ridge National Laboratory in the mid-1980s on the basis of the two-dimensional program DORT, which was used to solve the transport problem of neutrons/photons in the three-dimensional geometry XYZ or RZ. In addition, The eigenvalue problem of the reactor can also be solved. It has many outstanding features, such as coarse grid technology, vector programming technology, discontinuous grid technology, etc. In addition, it adopts a variety of advanced accelerated iteration techniques, thus significantly reducing the storage space requirements and greatly improving the calculation speed With precision, it is especially suitable for solving "deep penetration" radiation shielding problems.

In the shield design calculation of the SNAP space station in the United States, DOT3.5 is used to provide neutron and photon doses and ray spectra, and the radiation levels that penetrate the shield are calculated by DOT3.5, MORSE and 06R.

The Institute of Plasma Physics of the Chinese Academy of Sciences has used DOT3.5 to conduct shielding research and calculations on ground reactors and radiation devices, and used TORT to conduct radiation shielding design calculations for nuclear fusion devices such as HT-7U, all of which have achieved certain results and experience.

Another deterministic method is the point kernel integration method. The theoretical core of the point kernel integration method is to discretize the source geometry into a point source. First, the dose rate contribution of the point source to the detection point is calculated, and then the integral of all point sources is summed to obtain the total contribution of the source geometry to the detection point. This method is also a basic method suitable for calculating and dealing with complex geometric space radiation shielding problems. The QAD-CG program is the representative of the QAD program series developed in the United States, and is one of the basic programs for the calculation of radiation shielding design of nuclear power plants and other types of reactors. The QAD-CG program is formed on the basis of the QAD-P5A program by introducing the combined geometry technology in the well-known MORCE-CG program. It is the combined geometry version of the QAD-P5A program. The shielding design of large reactor nuclear power plants mostly adopts the deterministic method.

6.2 Optimum Design of Shield Material Thickness

For gamma shielding, the best material is depleted uranium, followed by tungsten (W). Rhenium (Re) performs on par with tungsten and provides better neutron shielding, but is expensive and not conducive to mass use. Since the radiation source of the reactor is not only pure gamma rays, but also accompanied by a large number of neutron rays, the secondary gamma generated by neutrons is an important factor affecting the shielding effect. If the gamma shielding material is placed directly close to the reactor, lead of the same thickness may provide better shielding than W and be much lighter, but this arrangement should be avoided. Stainless steel and boron-containing stainless steel have slightly poor shielding effect on gamma rays, but they can be used as structural materials of shielding bodies or materials to enhance heat transfer. The shielding effect of nickel alloys is comparable to that of stainless steel and is not necessary unless the shielding operating temperature is higher than the stainless steel limit.

The density of tungsten (W) is as high as 19.25g/cm3 (20℃), and the melting point is as high as 3410℃. Tungsten interacts with neutrons through resonant capture and inelastic scattering, producing secondary gamma. However, only 6% of neutrons produce gamma above 5MeV, and the highest gamma energy is 7.42MeV. In contrast, more than 25% of the neutrons in stainless steel produce gamma above 5MeV with a maximum energy of 10.16MeV. The mechanical properties of pure tungsten are not ideal, and W alloys mixed with nickel and carbon elements are commonly used in engineering, generally 90%W+6%Ni+4%C.

The density of lead (Pb) is 11.34g/cm3 (20℃), and the melting point is 327.5℃. The usable temperature is just staggered from LiH, which is not convenient for use. Lead has poor mechanical properties and can be supported by structural materials or strengthened by adding antimony and boron carbide to lead. The comparison of lead and tungsten gamma ray shielding ability is shown in Figure 11.

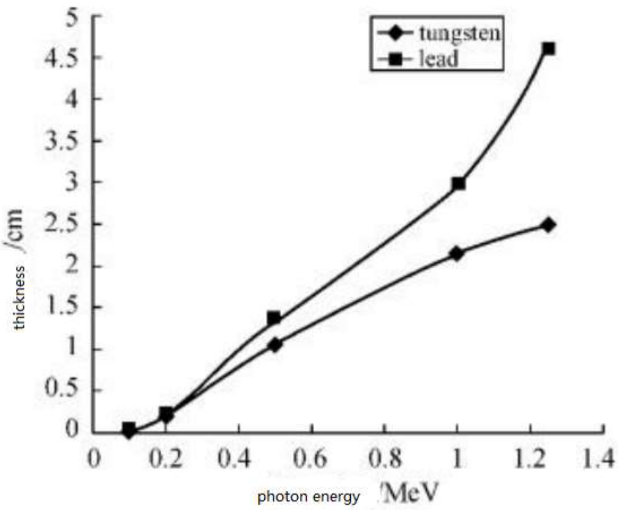

Figure 11. Comparison of gamma ray shielding capacities of lead and tungsten

7. Conclusion

In this paper, the radiation-tolerant total dose of the epec2024 controller was measured by irradiation experiments, and the average cumulative dose was measured to be 156.925 Gy. Firstly, several typical γ-ray shielding materials are calculated and analyzed, and the optimal shielding materials are obtained. Second, the Ni-W combination shielding scheme and Ni-W combination determine the required 5cm shielding thickness. Among the four shielding materials of tungsten, tantalum, lead and iron, tungsten has the largest linear attenuation coefficient and the strongest ray shielding ability. Lead shielding per unit mass is the best, followed by tungsten and tantalum. Then, based on the multi-objective genetic algorithm, the 5cm thickness and material arrangement order are sampled and calculated iteratively, and the optimized plan with lower weight and surface flux than the initial plan is output. Finally, the feasibility of adding shadow shielding and back-end shielding schemes in the case of strong radiation field is designed and verified. Put the epec2024 controller into it and repeat the radiation resistance experiment to verify the shielding performance of the shielding box. The results show that this shielding box design can effectively protect the controller and greatly prolong the working time. At the same time, considering the complex operating environment of the nuclear robot, which may face strong radiation sources for a long time, a comparative experiment was set up to verify the effect of shadow shielding and back-end shielding. Overall shielding performance improved. The neutron fluence and photon fluence can be significantly reduced on the basis of the shielding box.

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