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Research and Engineering Practice Analysis of a New Scheme of Volume Reduction Treatment of Radioactive Waste Based on Waste Incineration Process

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Abstract: The disposal and management of radioactive waste has been one of the key challenges in the nuclear energy sector. Among them, the treatment of low-medium level combustible waste is particularly complex, which involves the safe disposal of waste, and needs to consider multiple factors such as environmental protection and cost-effectiveness. Based on the waste incineration process, this paper proposes a new plan for the capacity reduction treatment of radioactive waste, and discusses and analyzes it deeply through practical engineering practice. In this study, combustible radioactive waste is placed in high temperature environment through incineration process to achieve capacity reduction, stabilization and safe disposal of waste. The program takes into account the minimization principle of waste management, while conducting a comprehensive assessment of disposal costs, environmental impacts and safety risks. The design and composition of the radioactive waste incineration system of the Chinese Academy of Materials were discussed in detail. The feasibility and reliability of the system are verified by analyzing the main process conditions and key equipment. The engineering practice results show that the system has high processing capacity and good discharge effect, and the capacity reduction coefficient and weight reduction coefficient reach the expected index. The innovation of this study is the successful application of the incineration process to the treatment of radioactive waste, which realizes the co-treatment of different types of waste, while reducing the need for auxiliary fuels. This scheme can not only improve the efficiency of waste treatment, but also effectively reduce the risk of environmental pollution, which has important engineering application value and theoretical significance. This study provides practical experience for the design and application of radioactive waste incineration system, and provides useful enlightenment for the development of nuclear waste treatment technology in the future.

1. Introduction

Radioactive waste management is a key challenge in the development of contemporary nuclear energy technology, and its treatment and disposal involve many aspects such as environmental safety, public health and social stability. With the rapid development of the nuclear industry, the amount of radioactive waste has increased exponentially, which has brought serious challenges and impacts to human society and the natural environment. In this context, how to safely and effectively treat and dispose of radioactive waste has become an important issue to be urgently solved by governments and scientific research institutions.

Radioactive waste is any material containing or contaminated with radionuclides whose radioactivity exceeds the clean decontamination level and has no use value in the foreseeable future. [1] Its main properties are radioactivity and radiotoxicity [2] from natural radioactivity of uranium and its daughter elements, reactor fission products, transuranic nuclides, and radioisotope production. The activity of radioactive wastes decreases gradually with time.

As a commonly used waste treatment method [3], incineration technology has important application prospects in radioactive waste management. By placing solid or liquid combustible waste in a high temperature incinerator for treatment, inert slag or ash is generated, and the purpose of waste volume reduction, stabilization and safety is realized. This treatment method is in line with the requirements of minimum quantification of waste in the national radioactive waste management principles, and is one of the best measures to reduce the capacity of combustible waste.

Radioactive waste incineration can generally be classified into two main types: dry incineration and wet incineration. In this paper, we will focus on the design principle, engineering practice and effectiveness evaluation of radioactive waste reduction treatment scheme based on waste incineration process. Through the research and analysis of the program, the aim is to provide new ideas and practical experience for solving the problem of radioactive waste management, and make contributions to the realization of waste capacity reduction, resource utilization and environmental protection.

2. Relevant Research

This paper discusses the research and engineering practice of the new plan of radioactive waste reduction treatment based on waste incineration process, covering the research results and engineering applications in many related fields.

The research of Jha AK [4] provides A method for the treatment of radioactive solid waste using DC plasma cutting torch power supply. The toxic compounds produced in the incineration process can be effectively destroyed by high temperature and other ion torches, providing an efficient and safe means of disposal for waste management facilities. The research includes power supply design, circuit simulation and implementation, which verifies the consistency of simulation results and actual characteristics, and provides reliable technical support for radioactive waste treatment.

Mitsuhiro Tada [5] proposed a method and device for treating ash containing radioactive substances. By melting ash containing radioactive cesium in a melting furnace, and adding an adsorbent to adsorb cesium on the discharged slag and solidified it, the purpose of accurately removing radioactive substances from the slag generated by the incineration of waste containing radioactive substances was realized. This technology is of great significance in the aftermath of the Fukushima nuclear accident, providing an effective way to reduce the impact of radioactive waste on ecosystems and human health.

Murasawa N[6] found that the addition of clay minerals can effectively inhibit the leaching of radioactive cesium (r-Cs) in the incineration process of municipal solid waste, especially for fly ash (FA) and chelate treatment of FA (TFA). This study provides important experimental basis and technical support for reducing radioactive material contamination by directly adding and mixing clay minerals into waste ash.

In terms of conversion and utilization of radioactive waste, Li Qinsan [7] designed a technology for the safe generation of radioactive waste and the use of radioisotope thermal converters to generate radiation power. By connecting the radioisotope heat sensor and the new battery, the decay heat is extracted from the waste using the radioisotope thermoelectric converter, which generates radiation and supplies it to the new battery to convert electrical energy. This technology provides new ideas and technical support for the utilization of radioactive waste. In the study of Wang Z[8], low - and medium-level radioactive glass fiber and combustible solid nuclear waste incineration ash were co-treated to minimize the use of additives and meet the requirements of the vitrification template of radioactive waste. This study provides practical experience and technical guidance for the optimization of waste incineration process.

The new radioactive waste capacity reduction treatment scheme based on waste incineration process has shown good application prospect and technical benefit in engineering practice, which provides important research basis and practical experience for the further development of radioactive waste treatment field.

3. Design of Radioactive Waste Capacity Reduction Treatment Scheme

3.1 Key Issues and Challenges of Waste Reduction Treatment

In radioactive waste management, waste capacity reduction is a critical and complex challenge that requires a comprehensive consideration of multiple aspects. The first is the sorting and monitoring of the waste before it enters the incineration stage, which requires the use of advanced radioactive monitors and metal detectors and other equipment to strictly inspect the waste to ensure that the incineration process meets safety requirements. Secondly, the type and characteristics of incineration waste is also an aspect that needs to be focused on, different types of waste in the incineration process may produce different reactions and waste residues, so it is necessary to ensure that the incineration system design can effectively handle various waste types, and limit the radioactive content within a safe range.

Another key issue is exhaust emissions and ash disposal, which may contain radionuclides during incineration, posing a threat to the environment and human health. Therefore, it is necessary to ensure that the flue gas purification system meets national standards and can be discharged after qualified radiation monitoring, and further solidified the radionuclides in the furnace ash to prevent secondary pollution and radioactive diffusion, as shown in Table 1 concentration limits for non-radioactive air pollution. In addition, the operation control and safety of the incineration system is also a focus of attention, and it must be carried out in a reliable combination of automatic, remote and manual operation control to ensure that the system can remain stable and safe under any circumstances.

Emergency measures and monitoring requirements are also important elements. During the incineration process, unexpected situations or accidents may occur, so it is necessary to set up explosion-proof, anti-overpressure measures, and set up emergency measures when the power is interrupted to deal with possible dangerous situations. At the same time, monitoring is also a crucial link in the incineration process, and it is necessary to set up dose monitoring and radioactive concentration monitoring points, and timely discover and deal with potential safety hazards to ensure the safety and stability of the incineration process.

In the treatment of radioactive waste, waste capacity reduction is a crucial task, which needs to overcome many technical problems. Firstly, the forms and types of waste are diverse, including solid waste such as cloth, paper, wood, plastic, rubber, resin, etc., waste liquid such as oil, vacuum pump oil, organic solvent, etc., and waste graphite. These different forms of waste need to use different incineration methods, such as pyrolysis incineration for solid waste, spray incineration for liquid waste, and fixed bed incineration for waste graphite, so it is necessary to design and operate adaptable incineration systems.

Table 1: Concentration limits for non-radioactive air pollution

Pollutant Item	Emission Limit(Mg/M3)	Pollutant Discharge Monitoring Location
So2	200	Combustion (Incineration, Oxidation) Device Exhaust Tube
Nox	200	
Dioxin Class A	0.1ng-Teq/M3	
Hydrogen Chloride	0.2	
Benzene	0.4	
Toluene	0.8	
Total Non-Methane Hydrocarbons	4.0	
Lead And Its Compounds	0.001	
Nickel And Its Compounds	0.02	

Secondly, the processing capacity and effect of incineration system are problems. The incineration system must have sufficient processing capacity to handle different types of waste and ensure complete combustion, while ensuring that there is no black smoke in the flue gas and the CO content is less than 0.2%. In addition, solid waste and waste graphite after incineration also need to achieve a certain capacity reduction ratio and carbon residual limit to ensure that the treatment effect meets the requirements.

In addition, the disposal of radioactive waste is also an important issue in incineration projects. The radioactive flue gas produced in the exhaust gas is treated by purification facilities such as bag filters, alkali washing and high efficiency filters and then released into the atmosphere, while the emission limit of non-radioactive flue gas needs to be controlled. The waste liquid is transported to the low level waste water treatment station through the special drainage pipe for treatment to ensure the discharge standard. The incineration ash needs to be stored after curing treatment to avoid secondary pollution to the environment.

Radioactive waste capacity reduction treatment involves multiple key issues and challenges such as diverse waste types, high processing capacity and effect requirements, and strict radioactive waste treatment technology. It is necessary to comprehensively consider technical means and measures in design, operation, monitoring and other aspects to ensure the safety, efficiency and environmental protection of the waste treatment process.

3.2 Waste Incineration Process Design of Radioactive Waste Capacity Reduction Treatment System

The complete design of the radioactive waste incineration system is divided into three parts, namely, the pre-treatment system, the incineration system and the flue gas purification system. According to different types of waste and treatment requirements, a variety of incineration schemes can be proposed, as shown in Figure 1, the high-temperature process system of waste treatment. After comprehensive analysis, it is determined that the pyrolytic incinerator is used as the main process system because it can realize complete combustion, inhibit the formation of harmful substances, and has lower operating costs and higher flue gas purification efficiency.

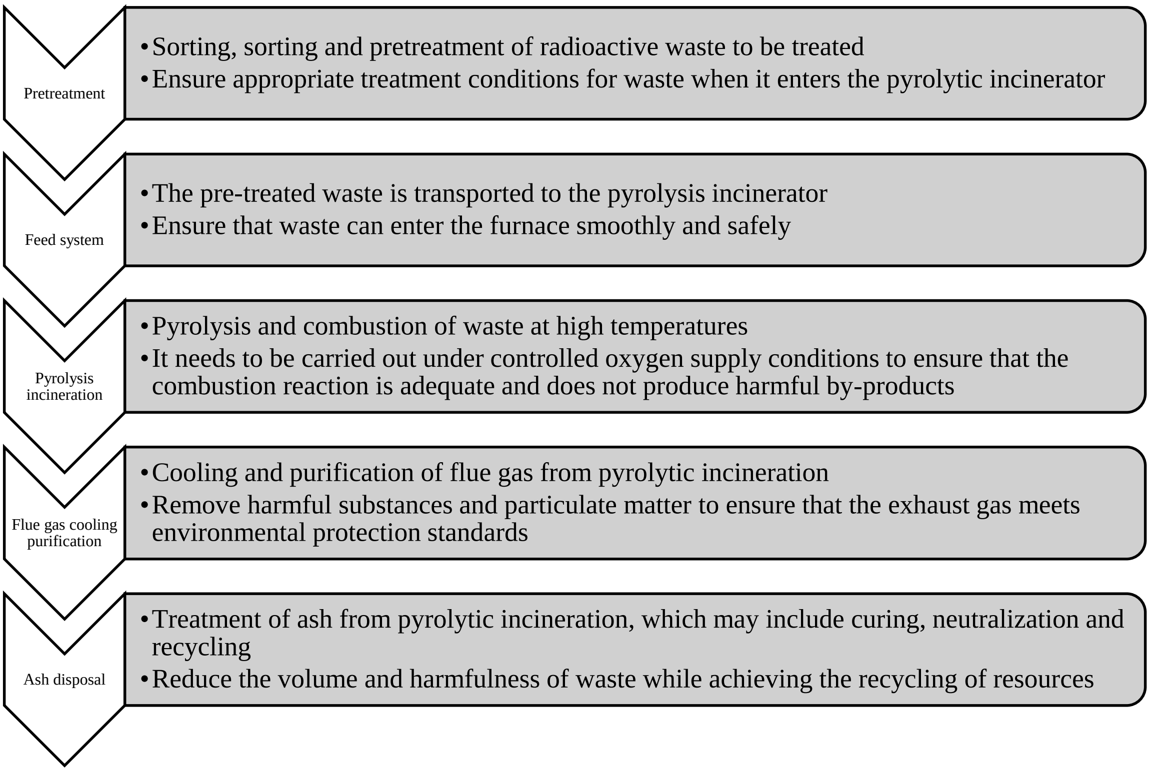

Figure 1: High temperature process system flow of waste treatment

Unlike other incineration schemes, the advantage of pyrolytic incinerators is their advanced process capabilities, the ability to handle multiple types of waste and achieve high efficiency complete combustion, thus reducing the emission of harmful substances. In comparison, although other schemes have advantages in some aspects, they have certain limitations and challenges in complete combustion and flue gas purification. Therefore, considering the overall performance and adaptability of the pyrolytic incinerator [9], this scheme is chosen as the best design scheme.

The objective of waste pre-treatment systems is to treat waste into a state suitable for incineration, including the pre-treatment of solid waste, waste oil and waste graphite. Pre-treatment of solid waste mainly includes sorting, crushing and repackaging. The sorting stage is carried out by a combination of manual and metal detectors, while radiation protection and environmental protection measures are considered to ensure a safe and effective sorting process. The crushing stage pays attention to the design and performance indicators of the crusher, and adopts low-speed crushing, automatic cleaning and other technologies to meet the crushing requirements of different wastes. The repackaging stage aims to solve the safety hazards and system failures caused by the direct feeding of scraps, and achieve the transportation and feeding of waste through appropriate packaging.

4. Engineering Practice Process and Effect Evaluation

4.1 Experimental Process and Data Analysis

The purpose of the experiment is to verify the process design and equipment performance of the incineration system, and to confirm the technical performance of the system. Through the main process system verification, including the pyrolytic combustion and flue gas purification of solid waste, waste resin and waste oil, the results show that the system has the ability and adaptability to handle a variety of wastes. The verification results of flue gas purification system show that the purification efficiency is high and the discharge of various pollutants meets the standard requirements. The test results of continuous operation confirm that the system is stable and reliable under long-term operation, and all indexes meet the design requirements. The verification results of the main non-standard equipment also verify the rationality and feasibility of the equipment, and meet the needs of process design. The purpose of the engineering verification of the radioactive waste incineration system is to verify the process and main equipment design of the incineration system, as well as test and confirm the main technical performance of the system. The content of engineering verification mainly includes main process system verification, flue gas purification system verification, continuous operation test and main non-standard equipment verification.

The verification of the main process system includes the verification of the simulated waste composition, which mainly involves the pyrolytic combustion of solid waste, waste resin and waste oil, and flue gas purification. The verification shows that the system can deal with a variety of wastes, and has strong adaptability and ability of waste composition change. The verification of flue gas purification system includes the test and confirmation of flue gas purification efficiency. The results show that the flue gas purification process route adopted by the system is reasonable and feasible, the purification efficiency is high, and the emission of various pollutants is up to standard. The continuous operation test aims to verify the feasibility, stability and reliability of the main process system under long-term operation. The test results show that the whole system runs smoothly, the equipment, instruments and measurement and control system work normally and reliably, and the main indicators meet the design requirements. The validation of major non-standard equipment includes solid waste crushers, pyrolysis furnaces, gas premixes, combustion furnaces, flue gas cooling systems and bag filters. Through the test and result analysis, it is proved that the rationality and feasibility of these equipment meet the requirements of process design.

4.2 Evaluation of Capacity Reduction Effect of Waste Incineration Treatment on Radioactive Waste

In the solid waste incineration process, by controlling the feeding time interval, adjusting the feeding times, ensuring that there is enough pyrolysis gas combustion in the combustion furnace and keeping the furnace temperature above 900 ° C, the complete combustion of gas can be achieved, and it is necessary to pay attention to controlling the starting time of the grate and the lifting agitator to avoid insufficient oxygen supply or the destruction of the coke layer. During waste oil incineration, it is necessary to control the proportion of low-viscosity fuel oil and maintain the parameters of oil flow, negative pressure at the bottom of the furnace and total gas flow to meet the incineration requirements.

The pilot operation experience of the flue gas purification system includes controlling the pre-feed amount of the bag filter, extending the absorption time of lye, and solving the liquid problem to ensure the system's effectiveness and reduce the amount of solid waste. For incineration ash treatment, it is necessary to solve the problem of increasing the radioactive activity of incineration ash and transferring curing device. In terms of high-level waste treatment, glass curing and geological disposal should be adopted, and temporary storage repositories should be strictly managed to ensure safety. The corrosion problem of incineration system mainly comes from radioactive waste containing plastic and rubber components, which needs to be incinerated with other waste to prevent corrosion when feeding, and it is necessary to delay the corrosion rate and take necessary measures to protect the service life of the equipment.

The system has high processing capacity and can effectively handle three types of waste: solid waste, waste oil, and waste graphite. The capacity reduction coefficient and weight reduction coefficient both meet the design requirements. The flue gas is purified through a process of first dry dust removal and then wet acid gas absorption, successfully avoiding the generation of radioactive waste liquid. The discharge meets the relevant standards, the CO concentration in the flue gas meets the standards, and the residual carbon rate of incineration ash is less than 5%. The system operates stably, requiring almost no or only a small amount of auxiliary fuel, while maintaining good processing efficiency while saving energy. We have also developed our own solid waste crusher and pyrolysis furnace, which have good performance and effectively inhibit the generation of benzo [a] pi. The concentration of benzo [a] pi in the flue gas is lower than the emission standard and can be directly discharged. In addition, we have taken measures to inhibit the production and purification of dioxins, and the expected results are good, but further confirmation and verification are still needed in the future. These results indicate that our system has good engineering application prospects and environmental benefits in the treatment of radioactive waste, providing valuable reference and inspiration for related fields.

5. Conclusion

According to the characteristics of CAS, a set of radioactive waste incineration system based on the basic furnace type of solid waste pyrolysis incineration has been designed and established, taking into account waste oil spray combustion and fixed bed incinerator to treat waste graphite. System features include using different pretreatment methods to make waste meet incineration requirements, using different incineration processes according to different waste, sharing a set of smoke gas purification system for the whole system, using a process combining dry dust removal and wet absorption to ensure that the discharge meets national standards and basically avoids the generation of radioactive waste liquid. Effectively protect the environment and staff safety. In addition, we have successfully inhibited the production of benzo [a] pili and effectively controlled the concentration of harmful substances in the flue gas, which meets the requirements of emission standards. System operation is stable, only in the start-up stage requires a small amount of auxiliary fuel ignition and preheating, normal operation process does not need or only a small amount of auxiliary fuel combustion, saving energy and reducing operating costs. In general, our research and practice show that the new radioactive waste reduction treatment scheme based on waste incineration technology has a good engineering application prospect and environmental benefits, and provides a valuable reference for the field of radioactive waste treatment.

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