

## Mini Review

# Advancing Medical Waste Management in China: Leveraging Technological Innovations and Strategic Disposal Practices for Sustainable Development

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**Abstract**

Global epidemic prevention and control has entered the normalization stage, but the situation of local epidemic prevention and control is still complex and severe. In the new historical period, how to build on past successes to further advance our cause, and how to grasp the key issues and solve specific problems need to be examined and discussed from the perspective of technological change and development. Based on the systematic analysis of the current situation of China's existing medical waste disposal technology, and based on the opportunities and challenges faced by management and disposal technology, this paper analyzes the specific practices, work results and experience the enlightenment of the existing disposal technology and disposal mode, and puts forward the research and judgment of the future development pattern of China's medical waste, which provides a basis for the future treatment and disposal of China's medical waste and fine management.

**INTRODUCTION**

Medical waste refers to the directly or indirectly infectious, toxic, and other hazardous waste generated by medical and health institutions in medical treatment, prevention, health care, and other related activities [1]. In major public health emergencies, medical waste shows the characteristics of a large increase in a short period, stronger infectivity, concentrated sources of production, complex components [2-4], etc., which requires the environmental management system for medical waste to have adequate disposal capacity and rapid emergency response capacity [5-7]. In this situation, 10 ministries and commissions, including the National Health Commission and the Ministry of Ecology and Environment, jointly issued the *Work Plan for Comprehensive Treatment of Waste in Medical Institutions* [8], which proposed that we would improve the disposal capacity of medical waste by optimizing new technologies, updating equipment and facilities and other measures in China. The occurrence of COVID-19 has raised new challenges and requirements for the existing environmental management of medical waste in China [9-12]. According to the requirements of medical waste management under the new situation, the management idea and requirements of "combining peacetime and wartime" [13] have

been put forward to realize the efficient and safe management and treatment of medical waste. At present, national epidemic prevention and control has entered the normalization stage, and the situation of local epidemic prevention and control is still complex and severe. In the new historical period, how to build on past successes to further advance our cause, grasp the key issues, and solve specific problems need to be examined and discussed from the perspective of technological change and development.

After nearly 20 years of development, the incineration disposal technology with rotary kiln and fixed bed as the core and the non-incineration disposal technology of medical waste with high-temperature steam, chemistry, microwave, and high-temperature dry heat as the core have been widely applied, showing a situation of simultaneous development of multiple technologies and coexistence of incineration technology and non-incineration technology [14]. According to the 2020 National Annual Report on the Prevention and Control of Solid Waste Pollution in Large and Medium Cities issued by the Ministry of Ecology and Environment, the amount of medical waste generated in 196 large and medium cities nationwide in 2019 was  $84.3 \times 10^4$  t [15], the disposal rate is 100% [16]. As of March 21, 2020, the national medical waste disposal capacity is  $6066.8 \text{ t} \cdot \text{d}^{-1}$ , an

increase of 1164.0 t · d<sup>-1</sup> compared with 4902.8 t · d<sup>-1</sup> before the COVID-19 [17]. In addition, the detailed information on APCDs is summarized in Figure S1. China has gradually established a medical waste management and disposal model with cities as the core. Generally, one centralized medical waste disposal center will be built in one city, and comprehensive treatment measures for waste gas, waste water, and solid waste will be provided in combination with technical characteristics. The application path of medical waste treatment and disposal technology [18] is shown in Figure S2. Medical waste treatment and disposal technologies are generally divided into incineration and non-incineration. The comparative analysis of conventional medical waste treatment and disposal technologies [14, 19] is shown in Table S1. It can be seen from [Table S1] that the incineration technology is a relatively thorough medical waste disposal method due to its indiscriminate incineration of medical waste, which has the advantages of good disposal effect, strong adaptability, and large disposal capacity. Incineration technology can dispose of infectious, pathological, injurious, pharmaceutical, and chemical medical wastes. Non-incineration treatment technology refers to the use of low heat, chemistry, radiation, and other methods to disinfect and sterilize medical waste. It has the characteristics of low operating cost, strong adaptability, less secondary pollution, and no dioxins. However, this type of technology is only applicable to the treatment of infectious, traumatic, and part of pathological medical waste. High temperature steam, chemical disinfection, microwave, and dry heat are the four most widely used non-incineration treatment technologies [20,21].

The evolving landscape of medical waste management in China presents both opportunities and challenges. There is an urgent need for continuous improvement in management systems, matching management requirements with technological advancements, and enhancing the capacity for emergency response.

(1) The medical waste management system needs continuous improvement. Most of China's current medical waste policy standards were released in 2001-2006 when the hardware facilities for centralized treatment and disposal of medical waste and the pollution control system had not yet been formed, and the management policies for medical waste treatment and disposal were not perfect. With the continuous updating of the management system, the continuous implantation of new management ideas, and the continuous absorption and digestion of international management experience, China's medical waste management system is also making progress, but there are still some improvements in the connection of management in the system.

(2) Management requirements and technical development levels need to match each other. At present, China's medical waste treatment and disposal technology system is still dominated by incineration and disinfection technologies. In terms of disinfection and treatment of medical waste, the continuous emergence of new technologies has expanded the field of disinfection

technology and methods and has significantly improved the disinfection and treatment capacity of medical waste. In contrast to the rapid development of technology, the facility performance indicators and pollutant emission limits specified in the existing standards and specifications and other technical documents are increasingly incompatible with the current development level of medical waste treatment and disposal technology. Establishing new targeted standards and specifications or revising and improving the existing standards is urgent. There is a lack of high-level emergency disposal technology for medical waste and miniaturized or mobile disposal technology suitable for remote areas. Especially, emergency disposal technology and equipment for major outbreaks are seriously insufficient. It is urgent to improve China's emergency technology for medical waste and promote the development of miniaturized or mobile equipment technology.

(3) The management and supervision capacity of medical waste needs to be improved, and the whole chain of intelligent management means needs to be strengthened. Medical waste management is a complex process involving multiple departments, links, and personnel. Therefore, ensuring the accuracy, integrity, and timeliness of medical waste management information is the key point of medical waste management. The medical waste treatment industry chain of medical institutions generally consists of three parts: collection, storage, and transportation of medical waste within hospitals; The transit transportation of medical wastes from medical institutions to destruction or reuse enterprises; Destruction and reuse of medical wastes by institutions. It is necessary to further use intelligent and diversified technical means to gradually realize intelligence in source classification, control and guidance, transportation management and facility operation and maintenance management, and further improve the safety and efficiency of medical waste disposal.

Additionally, addressing the shortcomings in disposal capacity, especially in rural and remote areas, and improving the overall technological and management aspects of medical waste disposal are critical for the country's environmental management efforts.

(1) The capacity of facility planning and layout needs to be further improved. Most of the treatment and disposal facilities built at the initial stage of the promulgation of the *National Plan for the Construction of Hazardous Waste and Medical Waste Disposal Facilities* [22] have reached the service life of facilities and have entered the upgrading period; There are also a certain number of small incineration facilities in operation, whose stable operation, stable up to standard emissions and ability to resist risks need to be further improved. In addition, there are still quite a few areas where the layout of regional facilities does not match the actual demand. In some areas, the disposal capacity is excessive, but in some areas, the disposal capacity is insufficient, the facility operation capacity is weak, and the professional level of operators is not high; The emergency disposal facilities in the region are lack of reasonable planning, emergency

reserve capacity is insufficient, and the overall technical level of temporary equipment is low, which makes the emergency disposal of medical waste always in a passive state. How to face the needs of medical waste disposal technology and management in the new era, guide the rational planning and layout of regional facilities, improve the overall operational capacity of facilities, and promote the large-scale and standardized development of the industry are the urgent needs of the current planning and layout of medical waste disposal facilities.

(2) Inadequate consideration was given to the applicability of medical waste treatment and disposal technology, and the overall disposal capacity of regional medical waste needs to be strengthened. Any medical waste treatment and disposal technology is not omnipotent and has its applicability [20]. In principle, incineration disposal technology can dispose of five types of medical waste, but incineration facilities are not available in every city. Many cities in China have only built non-incineration treatment facilities. The non-incineration treatment technology is mainly used to eliminate infection, and cannot deal with pharmaceutical wastes, chemical wastes, and some pathological wastes, so it is necessary to find an effective way to solve their safe disposal. The treatment and disposal technology of medical waste in most domestic cities is single, and the existing facilities available in the region and the cross-regional coordination measures are not considered and implemented enough. In addition, for the sanitary landfilling of the sterilized residue of medical waste with domestic waste, this method not only does not realize the recycling treatment of waste but also occupies a large amount of land, which does not conform to the principles of waste reduction and recycling. To realize the scientific, reasonable, comprehensive, and safe disposal of medical waste, it is still necessary to further strengthen the overall coordination.

(3) The medical waste disposal capacity in rural and remote areas is insufficient, and the coverage of collection and disposal is insufficient. China's centralized medical waste disposal system basically covers urban built-up areas and most rural areas. However, for medical waste in remote areas, some problems cannot be taken into account due to scattered sources, small production, long transportation distance, inconvenient transportation, and other factors. Especially during the epidemic, the phenomenon became more prominent. Considering the problem of long-distance transportation, there is also a greater risk of scattering and leakage of medical waste during the handover process [19,23]. In response to such problems, the Plan issued and implemented in February 2020 proposed that "by the end of June 2022, regional medical waste collection, transfer or disposal facilities should be set up in consideration of the geographical distribution, service population, and other factors, so that each county (city) can build a medical waste collection, transfer and disposal system" [8]. However, how to further clarify the disposal requirements from a technical perspective, strengthen and coordinate the disposal capacity, and solve the problem of the mechanism and system in the process of unsmooth

operation, to effectively improve the coverage of medical waste collection and disposal, still requires the joint efforts of all parties involved.

(4) There are shortcomings in the emergency disposal capacity of medical waste, and the cooperative disposal mechanism is not perfect. Currently, most medical waste disposal centers are planned and constructed in cities with districts. The centralized disposal of medical waste is mainly based on the franchise mode. In most regions, medical waste is not allowed to be transferred to other regions for disposal. In addition, the lack of cross-administrative coordination and management mechanisms and relevant laws and regulations support makes the management of medical waste relatively passive in response to emergencies. In case of troubleshooting treatment equipment or emergencies such as major epidemics and disasters, the amount of medical waste generated will increase rapidly; The amount of medical waste generated in areas with the severe epidemic situation has increased sharply and the reserves of transfer vehicles, transfer boxes, emergency disposal facilities, etc. are insufficient. Only some cities (prefectures) have emergency disposal capacity [24]. In addition, in the process of collection and transportation of medical waste, long-distance transportation across counties and districts is required, with transportation distances ranging from tens to hundreds of kilometers, which is easy to cause the scattering and leakage of medical waste, causing environmental pollution accidents and the spread of infectious diseases [2,25]. Under the situation of normalization of epidemic prevention and control, it will be an important part of building a medical waste disposal technology system [26-29] in the new era to vigorously strengthen the emergency disposal capacity of medical waste during the epidemic and orderly coordinate the collaborative disposal of medical waste.

## MATERIALS AND METHODS

We analyzed the specific practices, work results and experience the enlightenment of the existing disposal technology and disposal mode, and puts forward the research and judgment of the future development pattern of China's medical waste. For large cities with a permanent population of over one million or a daily generation of medical waste exceeding 10 tons, a technical approach for the coordinated disposal of medical waste involves leveraging hazardous waste incineration facilities and municipal solid waste incineration facilities. Alternatively, a predominant use of medical waste incineration technology with supplementary non-incineration techniques is also feasible. For medium-sized cities (or county towns) with a permanent population ranging from 200,000 to one million or a daily generation of medical waste between 2 and 10 tons, a technical strategy for the coordinated disposal of medical waste can be implemented by integrating hazardous waste incineration facilities with municipal solid waste disposal facilities. For small cities (or county towns) with a permanent population below 200,000 or a daily generation of medical waste less than 2 tons, a technical approach for the coordinated disposal of medical waste involves utilizing hazardous waste incineration facilities in conjunction with municipal solid waste disposal facilities.

## RESULTS AND DISCUSSION

### Application cases of the hospital in situ treatment and disposal + domestic waste incineration power plant

In *Linan Traditional Chinese Medicine Hospital in Hangzhou*, after classified collection in various departments of the hospital, the internal hospital was treated by friction heat treatment in situ, and then incinerated and generated power by the domestic waste incinerator of *Green Energy Company* to achieve the resource utilization of medical waste.

#### Specific practices: *Classified collection and pretreatment of medical waste for source reduction:*

(1) Separate the general waste and medical waste generated in medical activities thoroughly, train the collectors, clarify the scope of medical waste management, avoid the mixing of medical waste and normal household waste, and realize the source reduction.

(2) Reduce the incorporation of non-medical waste, such as dialyzer flushing without blood residue at the end of dialysis after contact with blood; Dialysis pipelines are not in contact with blood and are therefore not listed as medical waste management. Waste urine or cerebrospinal fluid, pleural and ascites, etc. can be directly poured into the sewer by medical institutions with sewage treatment systems after the use of chemical reagents and disinfectants. Conditional hospitals can recycle formaldehyde, formaldehyde, xylene, etc. from pathological and tissue laboratories using chemical waste liquid recycling instruments.

(3) According to the relevant requirements in the 2021 edition of the *Catalogue of Medical Waste Classification* [30], further differentiate the collection of infectious, injurious, pathological, medicinal, and chemical medical waste, put medical waste of the same disposal method in the same packaging container, and reduce the use of disposable packaging containers [31].

(4) Other non-medical wastes specified in the *Catalogue of Classification of Medical Waste* [30] shall not be collected according to medical waste, such as; Waste generated by patients with Class A infectious diseases (including those with Class B infectious diseases under Class A management), patients with infectious diseases of unknown origin, and patients infected with multi-resistant bacteria (referred to as MRSA, pan-resistant *Acinetobacter baumannii*, pan-resistant *Pseudomonas aeruginosa*) shall be disposed of as infectious waste. The household waste of patients with infectious diseases other than those mentioned above shall not be included in the management of medical waste because they do not have the risk of causing the spread of infectious diseases.

(5) Introducing advanced non-incineration friction heat equipment for in-hospital on-site treatment, directly treating the culture media, bacteria, and virus seed preservation liquid produced in the laboratory, without pre-treatment process, reducing the output of related medical waste and achieving the reduction of the source.

### On-site and harmless disposal of medical waste to reduce the risk of secondary pollution

In 2020, the hospital introduced the non-incineration friction heat treatment technology (micro-shield WD15) for medical waste according to the actual situation. After upgrading and renovating existing medical waste temporary storage rooms, installing WD15 devices into the temporary storage room carrying out on-site harmless pretreatment of medical waste, a realizing the whole process of collection, transporting, and disposal of medical waste hospital closed-loop traceable management, specific operations:

(1) Layout upgrade and transformation of temporary storage room

- a) **The rational zoning plan for the temporary storage of raw medical waste is divided into four main zones as a whole:** the treatment area, the disposal area, the temporary storage area after treatment, and the cleaning area.
- b) **Installation of related equipment:** main equipment, integrated friction heat disposal equipment, monitoring video device, ultraviolet killing equipment, air conditioning, and ventilation system.
- c) **Interim management:** operating standards and corresponding specifications are constrained.

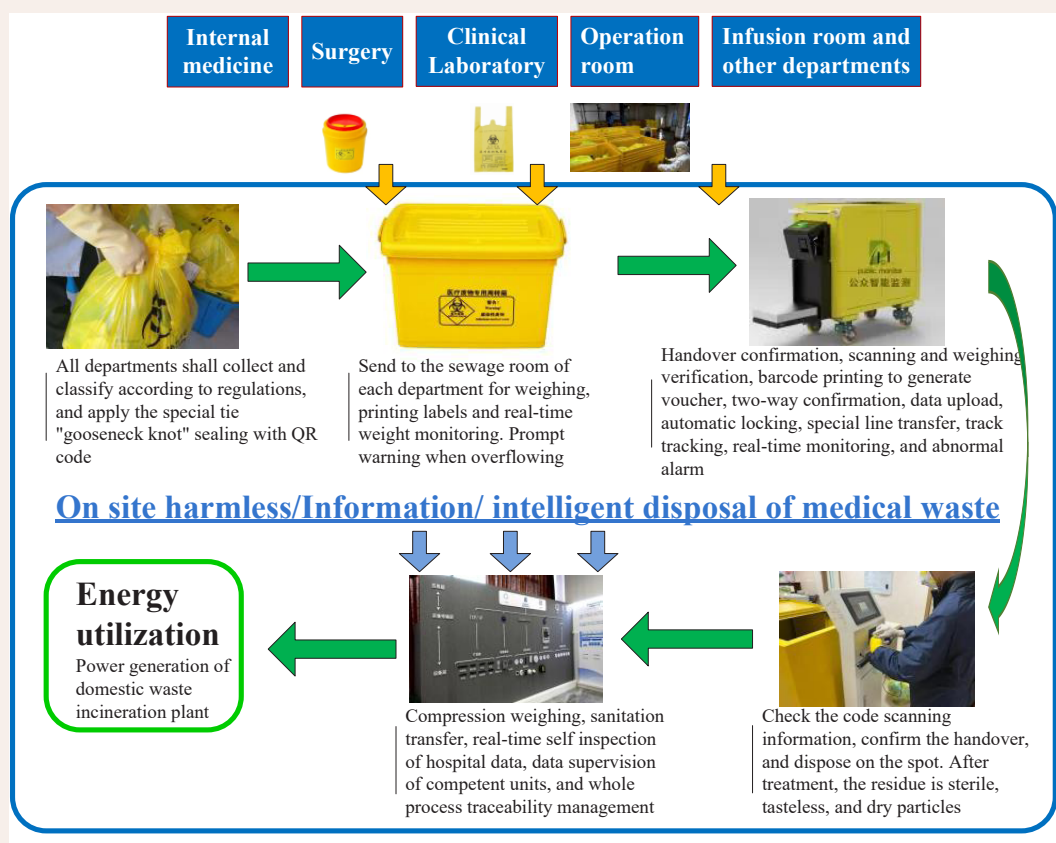
(2) The overall process of collection, transportation, and disposal within the hospital

**a) Collection:** Intelligent digital transfer vehicle [32] is used for hospital collection of medical waste, which can classify and collect infectious, injurious, and pathological medical waste, special car code, automatic weighing, automatic generation of two-dimensional code labels, and synchronized data upload to cloud monitoring platform.

**b) Transport:** The intelligent transporter locks automatically after the collector has collected the medical waste from each department, transports the special line to the temporary disposal room of the medical waste, tracks can be monitored in real-time and abnormalities in the way trigger alarm reminders. The medical waste is transported to the temporary storage room, the collector and the equipment operator carry out the handover of the medical waste, and after the handover is completed, the medical waste enters the medical waste disposal room. (Part 1 and 2 are operated by hospital personnel and transferred to the medical waste temporary storage room to complete the handover (Figure 1).

**c) Disposal:** The equipment operator puts medical waste into the disposal equipment, opens the auto-operation mode, locks the door, and the equipment automatically detects the operation status and disinfection effect in the whole process. Each batch of medical waste disposed of automatically generates a travel record to ensure the disinfection effect sounds an alarm





**Figure 1** Flowchart of Medical Waste Collection, Transport, and Disposal in Hospital

reminder after completion, opens the door to remove the waste residue, which is non-toxic, harmless, dry, and even particles and placed in the grey bin of domestic waste.

(3) On-line data monitoring and information synchronization management

1) On-line monitoring of medical waste departments, medical waste information collectors are placed in each department, and the weight of medical waste is recorded in real-time by the bottom weighing sensor; The weight of medical waste is uploaded to the medical waste management platform in real-time (instant reminder of medical waste overflow and loss).

2) The Intelligent Medical Waste Transport Vehicle integrates touch integrated machine, scanner, camera module, etc. to realize the visual monitoring of the transport and disposal process. Transport trucks are equipped with operational software for collectors to carry out operations such as medical waste information entry and temporary storage. Scanning guns are used to collect medical waste information by scanners of human-vehicle associations and scanners of garbage bag labels. The camera module is used for video recording of the handover and transportation process, and the disposal process is monitored by video.

3) Production and waste data of each department, data collected by collectors, handover data transferred to temporary storage, and data of household waste disposed of are uploaded in time, to track and upload data information throughout the process.

**Medical waste treated by thermal friction technology will be burned in a domestic waste power plant for energy utilization**

Medical waste treated by friction heat treatment technology has completely changed its original form, achieved effective crushing, volume reduction, and drying, and met the conditions of final disposal of medical waste after sterilization by the *Standard for Pollution Control of Medical Waste Treatment and Disposal* (GB 39707-2020) [33]. The final product is uniformly dried granular sterilized household waste less than 0.5 cm, which is stable in nature and has a high heat value. It is transported directly to a household waste incinerator for energy generation.

**Major Work Achievements**

(1) The overall reduction effect of medical waste is obvious

The case implementation process can reduce the production of medical waste from the source, and the effect of volume

reduction and weight reduction of medical waste after disposal is also obvious. Taking September 2020 to August 2021 as an example, the micro-shield environmental DW15 disposal system disposed of 89 tons of infectious medical waste, 10.84 tons of injurious waste, and 0.27 tons of pathological waste generated by hospitals. The sterilization rate of disposed medical waste is 99.9999%. The disposed medical waste residues are dry granules less than 50 mm. The final residual volume after disposal is 20-25% of the initial volume. Reduced space required for storage of medical waste in temporary storage. The specific output of medical waste in the last two years is shown in Table S2 and Table S3.

### (2) Reduction of medical waste disposal costs

After *Friction Heat technology* was used in the hospital, the cost of medical waste expenditure decreased significantly, mainly including medical waste expenditure, temporary storage management expenditure, and pretreatment expenditure, as shown in Table S4.

After using friction heat technology, the total hospital medical waste expenditure (excluding the extra cost of disposal) decreased from 561463 yuan for the original disposal method to 10850 yuan for the present disposal method, with a decrease of 550613 yuan and a decrease of 98%.

### (3) Promotion of hospital information management level

The equipment is provided free of charge by the manufacturer, and the medical waste temporary storage room of the hospital is scientifically transformed, and upgraded to a clean and tidy visual management room, to realize the visual management of monitoring the entire process of disposal.

In the process of case implementation, the on-site and harmless treatment of medical waste can be achieved within the hospital, which can achieve "daily cleanliness and on-the-job cleanliness". It can greatly shorten the stay time of medical waste with bacteria and viruses in the hospital, avoid the risk of infection, and improve and ensure the safety of the staff.

Implement information-based and intelligent real-time management of the whole process. The system realizes the fine and digitized supervision of the whole process of medical waste disposal. A complete closed-loop information management system of medical waste is built through an information management platform, a large information database, a collection of smart scales, and monitoring camera terminals. Achieve automatic weighing collection, automatic "code" output, automatic generation of accounts, real-time data upload, effectively avoiding weighing and recording errors, and realize digital monitoring of each medical waste production point, which provides a digital basis for further optimization. Provides convenience for remote inspection and facilitates the entire process of supervision by medical institutions and regulatory authorities.

### Lessons Learned:

(1) The holistic solution of "on-site, harmless, reduction and

intellectualization" of medical waste used by hospitals meets the policy requirements of national medical waste capacity building and deeply meets the core requirements of "waste-free city" construction "source reduction, harmless treatment, resource utilization", and achieves the reduction and scientific management of medical waste by exploring the implementation details of collection, classification, and treatment.

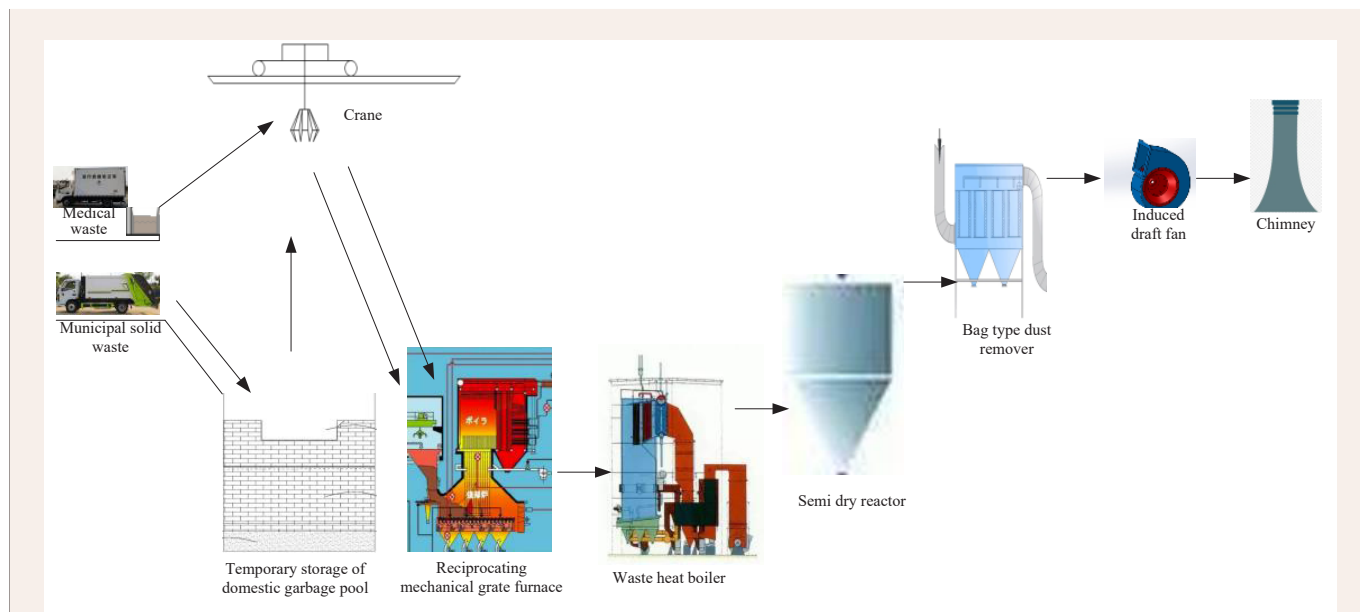
(2) The friction heat disposal system introduced enables medical waste to be safely disposed of without leaving the hospital gate, avoiding the infection risk of temporary transportation in the hospital. This system can effectively, safely, and quickly dispose of medical waste generated every day by miniaturized equipment, and it can also be used as a reference for the management of medical waste in other hospitals.

(3) After the implementation of the case, the number of pre-treatment and temporary room managers in the hospital was reduced, and handed over to the processing company, the pre-treatment part of department collection was exempted, and other extra expenses for hospital logistics management were reduced, and the economy of the micro-shield friction heat technology in-place mode disposal was very obvious compared with the traditional mode.

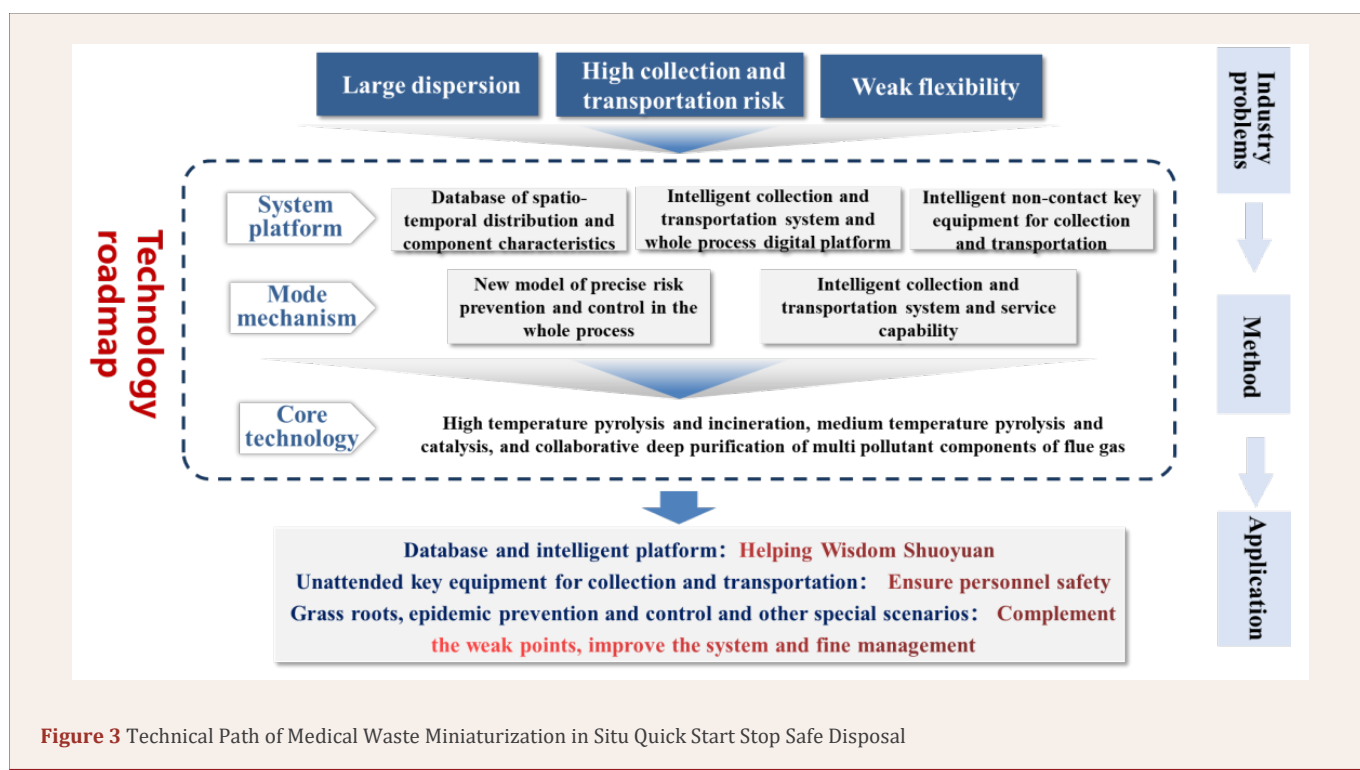
(4) Informationization and the whole process monitoring provide a strong guarantee for the closed-loop traceability of medical waste, avoid the drawbacks of manual registration in the past, realize scientific management, make up for the shortage of medical waste supervision, improve the technical level of information management, and help to improve the quality of logistics service and promote the high-quality development of hospitals.

(5) The medical waste treated by friction heat treatment technology has completely changed its original form and has achieved effective crushing, volume reduction, and drying. The authoritative authorities have detected that the final product meets the requirements of the Standard for Pollution Control of Medical Waste Disposal and Disposal (GB 39707-2020) [33] after disinfection and disfiguration treatment. The final product is in a uniform dry granular shape of less than 55 mm, which can be directly put into the household waste bin for environmental sanitation for incineration and landfill treatment. The waste residue after each treatment is stable in nature and has a high heat value, and has the nature of energy reuse.

(6) Medical waste after friction heat treatment meets the exemption conditions in the exemption management lists of the National Hazardous Waste List [34] 2021 and the Classified Medical Waste List<sup>[30]</sup> 2021. The in-hospital storage and out-of-hospital transportation processes do not conform to the management of medical waste and can be transported by using sanitary living garbage trucks, which reduces the risk of virus transmission, improves safety, and saves the cost of waste transportation. It is also a strong guarantee to block the black industry chain of medical waste.



**Figure 2** The process of co-disposal of medical waste by municipal solid waste incineration power plant



**Figure 3** Technical Path of Medical Waste Miniaturization in Situ Quick Start Stop Safe Disposal

## Case Study on Cooperative Disposal of Medical Waste in Domestic Waste Incineration Power Plant

Guangda Environmental Energy (Lankao) Co., Ltd. actively responds to the requirements of the *Notice of the Kaifeng Eco-environment Bureau on the Issuance of the Emergency Treatment Plan for Medical Waste of a New Coronavirus Infected Pneumonia Epidemic Situation* (Bianhuan [2021] 339) and uses two

reciprocating mechanical stove incineration systems with a capacity of 300 t/d to dispose of medical waste in collaboration.

### Specific practices: *Material Transport*

#### (1) Transport and discharge of medical waste

Medical waste is not transferable and needs to be transported by the person or by car. Information about vehicles and drivers

for transporting domestic waste at quarantine points shall be provided by the Guidance Center for Urban Management and Disposal of Domestic Waste in Lankao County. Packaging bags containing medical waste from patients with "new type coronavirus" or suspected "new type coronavirus" should be sealed with double-layer packages. The striking words "new type coronavirus" should be affixed to the outside of the packages. Before sealing the packages, adequate amounts of effective disinfectants should be sprinkled, and containers and vehicles should be collected and transported with sealing bars. Other vehicles shall be prohibited from entering the factory within the prescribed period. Before entering the factory, the pounds must be disinfected by automatic spray or by artificial spray. The disinfection should be sprayed with a chlorine-containing disinfectant containing more than 1000 mg/L of effective chlorine. Other operations of adjacent parks should be stopped during the unloading of vehicles, and special guards should be arranged to prohibit other vehicles and personnel from entering the warning area. Operations should be strict with the relevant technical specifications for medical waste disposal. The unloading parks and their surrounding areas should be cleaned up and disinfected immediately after unloading is completed. Vehicles and tools should also be disinfected. Transport personnel should not disembark at will and should not enter areas outside the unloading parks.

**Material Incineration:** Guarantee a lower level of waste in the incinerator chute one hour in advance so that medical waste can be incinerated as soon as it is put into the bin.

Special areas, such as quarantine zones, designate special areas for receiving and discharging garbage and medical waste, enter the factory at regular times, plan special driving routes for medical waste transport vehicles, configure special management, and the management personnel of the discharging platform must maintain a distance of 2 meters from the medical waste transport vehicles. Warnings and warning restrictions should be set up at the receiving site. No one concerned should enter. Such medical waste should be disposed of first, no more mixing and storage should be carried out, and fully fermented garbage should be laid as a bedding layer 15 minutes in advance in the garbage bin to ensure that medical waste does not come into contact with leachate, and it should be incinerated directly in the incinerator and the bedding garbage laid in advance should also be incinerated in the hopper. Make sure no residue is left (destroyed medical waste is mixed with fermented waste at 1:6 and undestroyed medical waste is not mixed). After all the emergency medical waste has been disposed of, the designated discharging spout and discharging area should be disinfected, sterilized, and cleaned in time, and then continue to be used as domestic waste to ensure that the emergency medical waste and domestic waste are basically separated in the discharging and feeding stages. All personnel entering garbage warehouses must wear disposable medical protective clothing, disposable gloves, and N95 masks for personal protection.

**Personnel Protection Management:** Medical waste disposal

should be carried out strictly by the special requirements for medical waste disposal in the Technical Specifications for Centralized Disposal of Medical Waste [35] for the Epidemic Period of Major Infectious Diseases. Workers must wear work clothing, isolation clothing, protective boots, work caps, and medical protective masks (when medical protective masks are in short supply, particulate matter masks up to the standard of N95/KN95 or above) and goggles.

Hands should be washed and disinfected immediately after the disposal operation is completed, and personnel should be cleaned all over the body after the operation. After the operation is completed, the protective equipment will be collected and disposed of in a unified way, and thoroughly cleaned and disinfected separately. It is strictly forbidden to bring them into the office or living area.

Operators and on-site supervisors involved in emergency treatment should take temperature measurements every morning and afternoon and submit them to Annual Department. Those with abnormal body temperature or other characteristics should timely visit designated hospitals and report to the Leading Group for Emergency Management.

### Major Work Achievements

(1) Mixed incineration medical waste has significantly increased the overall heat value of combustibles. Due to the relatively high heat value and low water content of medical waste, it is easy to have short-side fire lines and long-side fire lines in the emergency treatment process. At this time, the grate speed and primary air flow should be adjusted in time to reduce the burning of medical waste side in emergency treatment. In addition, when feeding, waste with low heat value can be mixed on the side of medical waste to keep the fire line as consistent as possible and prevent the occurrence of unburned waste.

(2) Reduced fuel consumption for incineration disposal. According to the statistical average of heat energy utilization data of medical waste for emergency disposal of household waste over the past years, because the heat value of medical waste is higher than that of household waste, the fuel consumption decreases significantly from 23.88 t per year to 1.39 t per year when the statutory incineration control temperature is also reached.

(3) Increase in residual heat steam power generation. According to data analysis, after emergency disposal of medical waste, the pressure and steam production of boilers are also partially increased, which promotes a small increase in steam power generation and has a certain economic value.

(4) The flue gas handling capacity meets the requirements of daily emission indicators. After the emergency disposal of medical waste, the concentration of HCl and SO<sub>2</sub> in the flue gas fluctuates, but it is still within the range of concentration fluctuations (600~1 200 mg/m) of the flue gas purifier design and will not exceed the purifying capacity of the flue gas purifier. Due to the high concentration of dioxins from the sources of medical waste



incineration, there is a possibility that dioxin concentrations will increase after the emergency disposal of medical waste.

### Lessons Learned

(1) To meet the discharge standards when burning medical waste, it is necessary to increase the cost of daily flue gas treatment. (2) Due to the burning of medical waste, the intensity of environmental monitoring has been strengthened, making the annual environmental monitoring fee increase. (3) The staff costs are specially allocated for burning medical waste. (4) Anti-epidemic measures taken for the daily needs of epidemic prevention. (5) Improvement of the feeding system for the needs of medical waste and epidemic prevention. (6) Modification of the soot blower to reduce the accumulation of dust. (7) To prevent the dust bucket of the bag filter from corroding, the dust bucket shall be rebuilt and poured.

By timely adjusting the operation control of the incinerator such as grate speed and primary air flow or mixing with the household waste with low heat value, the fire line of the grate can be effectively kept consistent, the waste can be burned out, and the maintenance cycle and annual continuous operation rate of the household waste incinerator system will not be significantly adversely affected.

## Case Study on Safe Disposal Technology of Miniaturized in Situ Quick Start-up and Stop of Medical Waste

### Specific practices

(1) In grass-roots and remote areas, medical institutions with a total number of beds less than 19 (including 19) will dispose of medical waste by configuring in-situ facilities for quick start and stop of safe disposal of medical waste and supporting secondary pollution control facilities. Equipped with professional environmental protection personnel, to implement the "Standards for Pollution Control of Medical Waste Disposal and Disposal" [33]

(2) In the epidemic situation and emergency period, medical institutions or epidemic and emergency sites shall dispose of medical waste by configuring medical waste in situ to quickly start and stop safety disposal facilities and supporting secondary pollution control facilities. Equipped with professional environmental protection personnel, to implement the "Standards for Pollution Control of Medical Waste Disposal and Disposal"

### Major Work Achievements

**a) Social benefits:** It will help to greatly improve the in-situ rapid and safe disposal of medical waste at the grass-roots level and under epidemic conditions in China, scientifically guard against infections and environmental risks of medical waste, and make up for the shortboard of medical waste disposal in China. At the same time, it will help to realize intelligent information enabling the whole process of medical waste collection,

transportation, and disposal, innovate integrated application mode, build a standardization support system, and form a promotion mechanism of the domestic and international two-way cycle, which will provide strong technical and management support for safe disposal in remote grassroots and epidemic emergencies.

**b) Economic Benefits:** It will help to promote the development and upgrading of existing industries, promote the development of related miniaturization industries originally for the disposal of environmental protection technology and equipment, products, and services, create a large number of high-quality employment opportunities, and create new market development space for emergency security and medical waste disposal in remote areas.

**c) Eco-benefits:** It will help to improve the safe disposal in remote grass-roots and epidemic emergencies, improve the ability to supervision and control related environmental risks, reduce the infection risk and environmental risk of medical waste collection and transportation, and reduce the cost of collection and transportation, disposal, prevention and control of secondary pollution and prevention and control of environmental risks.

### Lessons Learned

For grass-roots mixed medical waste, high-temperature pyrolysis and incineration technology and equipment are used to optimize the configuration of material flow (high-efficiency pyrolysis of medical waste, deep purification of smoke pollution components, safe disposal of waste water and solid waste), information flow (intelligent tracing of medical waste, on-line monitoring of the whole process of treatment), energy flow (rapid heating, full pyrolysis, residual heat utilization). This will provide a differential and systematic solution for the in-situ rapid and safe disposal of the remediation board for medical waste disposal in China, and meet the needs of medical waste disposal and disposal in China in the new era.

## Case Study on Centralized Medical Waste Treatment and Disposal Centers in Urban Areas

In 2003, the outbreak of SARS promoted the standardization of medical waste disposal in China. In 2004, the State Council approved the National Plan for the Construction of Hazardous Waste and Medical Waste Disposal Facilities [22], and initially established the management system for the treatment and disposal of medical waste in China. It also marked that China has entered a new stage of development in the management and disposal of medical waste. After the promulgation of the Plan, 300 facilities for the centralized disposal of medical waste in cities were planned. The new disposal capacity of medical waste is 2080 t.d-1, which establishes a disposal route with incineration technology as the main technology and non-incineration technology as the supplement. By 2021, the total number of medical waste disposal and disposal in China was 602, of which 215 (35.7%) were incinerated. 284 cases (47.2%) were treated with high temperature steam. 25 (4.2%) were treated by



**Figure 4** Future development pattern of medical waste in China

chemical disinfection. 69 (11.5%) were treated by microwave sterilization. Nine (1.5%) were processed by other technologies. This centralized disposal mode will continue to exist to a certain extent and continue to play a leading role.

### Specific practices

#### (1) Source classification of medical waste

Medical waste has many characteristics of hazardous waste. Scientific classification is helpful to prevent or cut off the transmission of pathogenic microorganisms. Medical and health institutions shall classify the sources of medical waste, prohibit the mixing of medical waste into household waste, cut off the transmission routes of pathogenic microorganism diseases, standardize the collection of classified materials, tight seals, temporary storage in hospitals, and so on, to avoid the health and environmental risks caused by the spread of pathogenic microorganisms in medical waste.

#### (2) Collection and transportation of medical waste

Centralized treatment and disposal centers for medical waste shall collect and transfer medical waste in turnaround boxes/barrels, and shall implement the management system of joint sheets for hazardous waste transfer [36]. Special medical waste transport vehicles shall be used. The transportation process shall

follow the prescribed routes. The doors of cars shall be closed during the driving process to avoid the loss and loss of medical waste.

#### (3) Handling and storage of medical waste

The Centralized Treatment and Disposal Center for Medical Waste temporarily stores weighed medical waste in a storage warehouse. The storage temperature and time shall comply with the *Standard Requirements for Pollution Control of Medical Waste Treatment and Disposal*.

#### (4) Treatment or disposal of medical waste

Based on the technology of medical waste centralized treatment and disposal center, medical waste disposal and disposal are carried out through incineration [37,38], steam sterilization [39], chemical sterilization [40], microwave sterilization [41], high-temperature dry-heat sterilization and other technologies.

**Major Work Achievements:** China has gradually established a city-centric model for the management and disposal of medical waste. In general, one city will build a centralized Center for the disposal of medical waste, and integrated measures for the treatment of waste gas, wastewater, and solid waste will be configured in light of the technical characteristics. According to

statistics, in 2021, 139.96 million tons of medical waste were disposed of, of which 786.4 million tons were disposed by incineration technology, accounting for 56.2%; 477,500 tons of high temperature steam treatment, accounting for 34.1%; 54.3 million tons (3.9%) were treated by chemical disinfection. 62,000 tons (4.7%) were disinfected by microwave; Other technologies process 151,000 tons, accounting for 1.1%.

**Lessons Learned:** The centralized disposal system of medical waste in China has been operating for many years. The main short-board problems are:

(1) Lagging of capacity building for centralized disposal of medical waste in some cities;

(2) some medical waste in rural and remote areas is not properly disposed of;

(3) Emergency disposal capability is not included in the overall consideration of the centralized disposal system;

(4) The current management system does not meet the actual operation requirements of the centralized disposal system. Therefore, the treatment and disposal of medical waste in China need to be considered innovatively in the new era.

## CONCLUSIONS

*The Guidelines on Enhancing the Ability of Environmental Supervision, Utilization and Disposal of Hazardous Waste and the Ability to Prevent Environmental Risks* (issued in October 2019) [42] require that all provinces (districts and municipalities) establish a mechanism for coordinated emergency disposal of medical waste to ensure the capability of emergency disposal of medical waste during the period of an outbreak of an epidemic situation and the inspection and repair of disposal facilities. Emergency management technical requirements include encouraging the development of mobile medical waste disposal facilities and providing on-site disposal services to remote grass-roots units.

In the field of medical waste disposal, the government has proposed to release exclusive franchising and break the life-long system of disposal units. Establish a franchise exit mechanism. At present, most medical waste disposal centers are planned and constructed with districts and cities as units. It is suggested that referring to the experience of developed countries, hospitals should be allowed to dispose of medical waste by themselves, adopt on-site treatment as the main method, centralized treatment as the supplementary method, and give priority to treatment facilities with high integration and excellent discharge indicators. For chemical and pharmaceutical medical wastes that cannot be disposed of by hospitals themselves, specialized incineration and treatment centers shall be planned and constructed, and unified collection and centralized treatment shall be carried out. Disinfected residues from medical waste are landfilled with household waste hygienically. This approach not only fails to achieve the recycling of garbage but also takes

up a large amount of land as a dangerous practice to preserve the source of pollution for future generations. It also does not conform to the principles of waste reduction and recycling.

Based on the above considerations, the future development pattern of China's medical waste in the new era is proposed as follows: Centralized treatment and disposal centers with the city as the core exist objectively in a certain period and will still play an important role. Under the premise of the epidemic situations and remote areas, miniaturized in situ quick start-stop safe disposal technology of medical waste is preferred. For in-situ treatment technology in hospitals, disinfection technology can be used to eliminate its infectivity, and then domestic waste incineration power plants can be used for resource utilization. At the same time, the domestic waste incineration power plant can also be used to dispose of medical waste in collaboration. Appropriate technological routes can be determined according to actual conditions in different regions. The specific suggestions can be found in Table 1.

### Mode 1: Disposal of medical waste by the hospital in situ disinfection + incineration power plant

After the medical waste has been collected by different departments in the hospital, after in-situ treatment with chemical disinfection, high-temperature steam disinfection, microwave disinfection, high-temperature dry heat, and other disinfection methods, the local domestic waste incineration power plant will incinerate and generate electricity to realize the resource utilization of medical waste.

Hospitals need to configure medical waste disinfection treatment facilities and auxiliary secondary pollution control facilities internally, equip professional environmental protection personnel, and strictly implement the "Standards for Pollution Control of Medical Waste Disposal and Disposal" and related technical specifications for disinfection treatment. Domestic waste incineration power plants need to consider the medical waste feeding facilities and the proportion of medical waste mixed.

### Mode 2: Collaborative Disposal of Medical Waste by Domestic Waste Incineration Power Plants

Relying on domestic waste incineration facilities to form the capacity of collaborative disposal of medical waste. Medical waste is collected and transported to a domestic waste incineration power plant. After temporary storage, medical waste can be disposed of by special feeding ports and related supporting facilities. In general and emergencies, medical waste can be disposed of by domestic waste incineration facilities.

The domestic waste incineration power plant needs to configure special vehicle passageways, cleaning rooms of vehicles and transporters, medical waste storage rooms, and medical waste feeding facilities on the site, and do a good job of safety protection for the operators. In general, the proportion of medical waste blended is not more than 5%~13%.

**Table 1:** Technical Suggestions for Medical Waste Disposal in the New Period

Number	technology roadmap	Application scenarios	Disposal measures
1	Hospital in situ disinfection treatment+domestic waste incineration power plant treatment	Cities with domestic waste incineration facilities.	The hospital shall be relied on to carry out in-situ disinfection of medical waste, and the medical waste after disinfection shall be delivered to domestic waste incineration facilities for incineration.
2	Cooperative disposal of domestic waste incineration facilities	Cities with domestic waste incineration facilities.	The collaborative disposal capacity of medical waste is formed by relying on domestic waste incineration facilities. By setting up special feeding ports for medical waste and relevant supporting facilities, the domestic waste incineration facilities are used for collaborative disposal of medical waste in routine and emergencies, and the proportion of medical waste mixed burning is generally not more than 5%.
3	Centralized treatment facilities for medical wastes	All cities in the country.	Use the facilities of the centralized disposal center of medical expenses and materials to realize the treatment and disposal of medical waste. It applies to traditional and emergency disposal of medical wastes.
4	Miniaturized in-situ quick start-stop safety disposal technology	Epidemic situation and remote areas.	Emergency treatment of medical waste in cities (or counties) during traditional and epidemic periods; Emergency treatment of medical waste in the earthquake and other disaster areas; Routine treatment and emergency treatment of medical waste in remote areas.

### Mode 3: Miniaturized In-Situ Quick Start-Stop Safe Disposal Technology for Medical Waste

To solve the problems of medical waste such as wide dispersion, high risk of collection and transportation, and weak flexible disposal ability in grass-roots and epidemic prevention and control scenarios, the intelligent and untouched collection and transportation technology of medical waste was used. The effective disposal of medical waste was achieved by fast pyrolysis in situ and intelligent management and control systems, and fast pyrolysis and medium-temperature catalytic pyrolysis technology under dynamic constraints. At the same time, the technology of physical catalytic pyrolysis, chemical catalytic oxidation, and multi-pollutant component discharge control is used to achieve stable discharge of pollutants, such as dioxins, in the rapid treatment process. Form a small mobile pyrolysis and incineration set of equipment to support the safe disposal and emergency capacity building of medical waste.

Medical institutions need to configure medical waste in-situ quick start-up and shutdown safety treatment facilities and supporting secondary pollution control facilities, equip professional environmental protection personnel, and strictly implement the "Standards for Pollution Control of Medical Waste Disposal and Disposal" and related technical specifications for disinfection treatment.

### Mode 4: Centralized Treatment and Disposal Center for Medical Waste with City as the Core

After classifying and collecting medical waste, the medical waste centralized treatment and disposal center collects and transports it to the centralized treatment and disposal center. Within the storage time, the technology of the centralized treatment and disposal center is used to dispose of medical waste by means of incineration, high-temperature steam sterilization, chemical sterilization, microwave sterilization, high-temperature dry-heat sterilization, etc. This centralized disposal mode will continue to exist to a certain extent and continue to play a leading role.

The existing centralized treatment and disposal center for

medical waste production and management mode remains unchanged.

### Construction of Monitoring Platform for Medical Waste Informationization

Using the Internet of Things technology, we build a perception network of all-process monitoring elements to ensure that medical waste has no dead-end monitoring perception from the key links of classification, temporary storage, transfer, transportation, and disposal. We provide information management systems for medical institutions, centralized disposal units, environmental protection, and health regulatory bodies in the whole process, and standardize the operation of medical waste collection and disposal. It can be traced back and monitored online. End the loss of medical waste.

In accordance with the requirements of the State, it is recommended that provinces and municipalities carry out top-level design to modernize the management of medical waste and construct information-based supervision and control over the whole process of medical waste. Medical institutions in charge of health and health administration and units in charge of the ecological environment administration should be designed as a whole, and electronic labels of packaging containers, standards for identifying terminal equipment, unified data flow, and unified system platform should be unified. To achieve a universal network of health and environmental supervision, and consistent data, the whole process is clear and traceable.

### Implication

(1) Based on the applicability of medical waste treatment and disposal technology, a rational layout of medical waste disposal technology is put forward. Source classification collection and management are essential for the suitability of medical waste disposal technologies. The combination of source classification and end disposal technologies should be further promoted<sup>[20]</sup>. If the chemical waste and drug waste in the medical waste cannot be disposed of by non-incineration facilities, corresponding measures should be taken to classify them. Incineration facilities have limitations on the disposal of chlorine and mercury-



containing substances. It is necessary to separate and reduce them from their sources, promote resource utilization, or use garbage power generation facilities to achieve energy utilization in collaboration with each other, to reduce the discharge of pollutants such as dioxins and mercury from waste gas. In view of the characteristics of five different types of medical waste and the applicability of medical waste disposal technology, based on the regional-related infrastructure conditions for medical waste disposal, such as hazardous waste incineration, medical waste incineration, crematorium, industrial kiln, garbage incineration, and power generation, the applicability of classification collection and subsequent disposal facilities for medical waste sources should be well coordinated, and the procedures should be opened boldly and conditionally, simplified and the costs reduced. Avoid omissions.

(2) Solve the problem of medical waste disposal in outlying areas, expand technical methods, and achieve full coverage of medical waste disposal. In terms of disposal capacity, in addition to the upgrade and replacement of conventional facilities for centralized treatment of medical waste, shortboards are mainly reflected in the disposal capacity of medical waste in remote areas. In such areas, the output of medical waste is small and the local supervision is insufficient, which is easily ignored by the administrative departments. Based on the actual needs of the collection, transportation, transshipment, and temporary storage, a flexible treatment mechanism of "transport + self-construction" should be established based on the current pattern of centralized disposal of medical waste. On the one hand, in outlying areas, medical waste collection networks covering all township-level and village-level medical institutions and private clinics should be implemented in a multi-point-to-one way, medical waste transporting stations should be established, and medical waste should be centralized step by step, then transported to existing centralized treatment facilities at the municipal level for disposal<sup>[23]</sup>. On the other hand, small pre-treatment facilities and mobile treatment and disposal facilities should be developed at local sites in remote areas. Medical and health institutions that do not have the conditions for centralized disposal should set up self-built medical waste disposal facilities to provide on-site disposal services for remote grass-roots units [42]. At the same time, the cooperation mechanism and benefit compensation mechanism for the centralized treatment of medical waste across regions should be explored. Ultimately, the operation mechanism with a responsibility system and linkage system as the core should be established to promote environmental awareness and professional ability and to achieve the end of medical waste collection and disposal in remote areas.

(3) Make full use of local technical and facility resources, rationally allocate them, and improve the emergency disposal capacity of medical waste. In terms of the technical system of emergency disposal, the combination of local facilities disposal + other areas disposal + local emergency disposal facilities disposal should be further reflected. Reflects the technical route of "preferential incineration followed by other types of technology". Optional medical waste emergency disposal facilities include

mobile medical waste disposal facilities, hazardous waste incineration facilities, household waste incinerators, industrial kilns [43], etc., reflecting the mode combination of "centralized disposal + infectious disease hospitals when necessary, designated hospitals for influenza patients and emergency center (station) on-site emergency disposal". In addition, the emergency response to the management and disposal of medical waste during the epidemic, including the preparation of emergency facilities and protective materials, should gradually be "preferred to be available but not available". Local governments should, in line with local conditions, determine appropriate and appropriate lists of resources for emergency treatment of medical waste, and strengthen the health protection of personnel in the process of collection, storage, transportation, and treatment of medical waste.

(4) Promote scientific and technological innovation and create a technical system for medical waste in the new era. In view of the management and disposal technologies and management needs of chemical and pharmaceutical wastes, we develop and disseminate dioxin deep purification technologies and odor control technologies to promote waiting from the source, process, and end to achieve the corresponding secondary pollution control objectives. The small-scale application technology of microwave, chemical, thermal friction, etc., which has been developed in recent years, should be supported. Under the emergency of the epidemic situation, we should vigorously promote the construction and operation of mobile medical waste disposal facilities and cooperative disposal facilities for household waste incineration. Develop the cloud platform and smart network of the Internet of Things, make decision analysis based on the data obtained by the sensor network, and gradually realize the "closed-loop management, fixed-point orientation, full tracing" for medical waste generation, classification, collection, storage, transportation, treatment, disposal, and other links to achieve intelligent control. Therefore, with the aid of scientific and technological innovation, practical measures for the whole process management of medical waste are adopted, the requirements of the "Program" are fully implemented, and an integrated management mode combining source classification, process control, and end control is implemented, to solve the key problems in the management and disposal of medical waste effectively.

In conclusion, all parts of China should actively promote the mode of unified recycling, centralized storage, unified disposal, and closed-circuit recycling to form a technical system for the treatment and disposal of medical waste suitable for centralized, dispersed, and emergency periods, promote the upgrade and standardization of technology and equipment, and intelligently build a platform for scientific and technological innovation and achievements transformation of medical waste, and strengthen the building of a contingent of talents in the field of medical waste management and disposal. To improve the capability of scientific and technological innovation and business management, China's comprehensive management of medical waste will surely make new progress and breakthroughs in the near future.

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