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Treatment and Management of Biohazardous Effluent in Chemotherapy Facilities in Sudan – Khartoum state

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Abstract

The effective management and treatment of biohazardous effluent from chemotherapy facilities in Sudan, particularly in Khartoum State, is critical for environmental safety and public health. This research focuses on designing and implementing an automated system employing Programmable Logic Controllers (PLC) and Supervisory Control and Data Acquisition (SCADA) technologies. The system aims to optimize the treatment of liquid waste containing hazardous and radioactive materials, including waste from chemotherapy patients, by automating key processes such as pH adjustment, radiation monitoring, and the addition of neutralizing agents.

Biohazardous waste in healthcare settings poses significant risks, including the transmission of infectious diseases, environmental contamination, and toxic exposure to humans. Proper segregation, monitoring, and disposal of this waste are vital to meet both local and international environmental standards, including those outlined by the World Health Organization (WHO) and the International Atomic Energy Agency (IAEA).

The proposed system integrates real-time data acquisition and control, ensuring precise treatment processes and compliance with safety regulations. Key features include automated monitoring of radiation levels, optimization of treatment parameters, and detailed reporting for regulatory adherence. This study highlights the importance of advanced automation in reducing human error, improving efficiency, and minimizing environmental impact, thus providing a scalable solution for healthcare facilities in developing regions.

Keywords: *Chemotherapy waste, Programmable Logic Controllers (PLC), Supervisory Control and Data Acquisition (SCADA), pH meter, radiation monitoring*.

1. Introduction

Chemotherapy facilities generate liquid waste containing hazardous and radioactive materials, posing significant risks to public health and the environment if improperly managed. This paper outlines the systematic processes and technologies employed in treating and disposing of such effluent, ensuring compliance with environmental and safety standards. Automated systems like PLC and SCADA provide precise monitoring and control of treatment parameters, ensuring efficient and safe disposal.

1.1. Bio-hazard Waste in Hospitals and other healthcare facilities:

Hospitals and other healthcare facilities are responsible for the delivery of patient care services and during this process certain amount of waste is generated in the form of swabs, discarded syringes and plastics, unused specimens etc., which are collectively known as biomedical waste. So, the term “Bio-medical waste” means any solid or liquid waste including its container and any intermediate product, which is generated during the diagnosis, treatment or immunization of human beings or animals or in research pertaining thereto or in the production or testing thereof. As a part of the patient care services, these also need to be disposed of safely and effectively. The physicochemical and biological nature of these components, their toxicity and potential hazard are different, thus necessitating different methods or options for their treatment and final disposal. According to the WHO, incorrect and improper management of healthcare bio waste can have direct impacts on the community, individuals working in health care facilities, and the natural environment [1]. Hence, it is the ethical responsibility of the management of hospitals and health care establishments to have concern for public health and the community.

Wastes generated in healthcare settings include sharps, pathological wastes, infectious wastes, radioactive wastes, mercury containing instruments, and polyvinyl chloride plastics. The WHO has stated that 85% of such hospital wastes are actually nonhazardous, around 10% are infectious, and around 5% are non-infectious but hazardous [1].

1.2. Hazardous Impact of Improper Disposal:

The improper disposal of biohazard liquid waste poses severe risks:

a. **Infectious Disease Transmission**: Biohazard liquid waste, especially in medical and clinical settings, is often contaminated with infectious agents. When this waste is not treated or disposed of properly, it can cause outbreaks of diseases, such as hepatitis, HIV, cholera, or antibiotic-resistant infections [2].
b. **Environmental Contamination**: If not treated properly, biohazard liquid waste can infiltrate the ecosystem. For instance, chemicals such as cytotoxic drugs, solvents, and pharmaceuticals, when discharged into the environment, can contaminate water supplies, leading to long-term ecological damage [3].
c. **Toxic Exposure to Humans**: The presence of toxic chemicals, radioactive materials, and infectious agents in improperly disposed waste poses health risks not only to waste management workers but also to surrounding communities [4].

1.3. Thesis Statements:

This research aims to develop and evaluate an automated modeling system using PLC and SCADA for the efficient treatment and management of biohazard liquid waste in chemotherapy facilities. The system will be designed to minimize human intervention, reduce errors, and ensure compliance with safety and regulatory standards. Key objectives of this study include:

1.3.1. Development of an Automated Waste Treatment System: The system will be designed to continuously monitor, control, and treat biohazard liquid waste in real time using PLC and SCADA technology. The goal is to improve the efficiency, safety, and compliance of waste treatment systems.

1.3.2. Enhancement of Treatment Efficiency: The study aims to optimize treatment processes by automating tasks such as adjusting pH levels, flow rates, and temperatures based on real-time data. This will reduce human intervention, minimize errors, and increase the overall efficiency of the waste treatment process.

1.3.3. Safety and Compliance with Environmental Standards: A major goal is to design a system that ensures the biohazard liquid waste is treated in accordance with local and international regulations, particularly focusing on healthcare waste management standards.

1.3.4. Data-Driven Monitoring and Reporting: SCADA systems will be used to monitor waste treatment processes, provide real-time data on the status of the system, and generate reports for regulatory compliance.

1.4. Classification of Waste:

Waste arises in many different forms and its characterization can be expressed in several forms. Some common characteristics used in the classification of waste includes the physical states, physical properties, reusable potentials, biodegradable potentials, source of production and the degree of environmental impact [5].

Stated that waste can be classified broadly into three main types according to their physical states; these are liquid, solid and gaseous waste. Although it is clear that several classifications exist in different countries. The most commonly used classifications are illustrated below [6].

a. **Physical state:** Solid waste, Liquid waste and Gaseous waste.
b. **Source:** Household/Domestic waste, Industrial waste, Agricultural waste, Commercial waste, Demolition and construction waste.
c. **Environmental impact**: Hazardous waste and Non-hazardous waste

1.5. World Health Organization (WHO):

The World Health Organization (WHO) plays a critical role in the management and treatment of healthcare liquid waste in third-world countries, including Sudan. While the WHO does not directly manage waste disposal systems, its influence is substantial in terms of raising awareness, providing guidelines, offering technical support, and advocating for policies that address the challenges associated with healthcare waste. Here's a breakdown of the WHO's role:

1.5.1. Establishing International Guidelines and Standards:

The WHO has developed comprehensive guidelines for healthcare waste management, which include best practices for the treatment, disposal, and management of liquid waste. These guidelines are meant to:

a. **Provide a Framework for Safe Disposal**: WHO's guidelines offer a step-by-step approach for healthcare facilities on how to handle, treat, and dispose of healthcare liquid waste safely, minimizing the risk to the environment and public health [7].
b. **Promote Safe Practices for Liquid Waste**: Special attention is given to hazardous liquid waste, including chemical, biological, and radioactive waste, which is common in healthcare settings like hospitals and laboratories. These guidelines include specific recommendations for dealing with such waste, ensuring that liquid waste is appropriately segregated and treated [8].

1.6. The International Atomic Energy Agency (IAEA):

The International Atomic Energy Agency (IAEA), as part of its mission to promote the safe and peaceful use of nuclear technology, provides guidelines and standards for the safe management of radioactive materials, including the disposal of patient waste from those exposed to radiation. Specifically, hospitals that treat patients with radioactive isotopes or deliver radiation therapy (such as chemotherapy for cancer patients) are required to follow specific regulations and protocols for handling and disposing of radioactive waste such as urine, saliva, and other bodily fluids [9].

These rules are primarily focused on minimizing radiation exposure to both the patient and healthcare workers, as well as preventing environmental contamination. Below are the key rules and guidelines imposed by the IAEA [9]:

1.7. Classification of Radioactive Waste:

The IAEA categorizes waste based on its radioactive content, and patient waste such as urine and saliva from radiation therapy patients is classified as low-level radioactive waste (LLRW). This classification includes:

a. **Low-Level Radioactive Waste (LLRW)**: Waste that has a low concentration of radioactive materials. Urine and saliva of patients who have received radiation therapy can contain trace amounts of radioactive isotopes, especially after treatments like radiation therapy (external beam radiation or internal treatments like brachytherapy).
b. **Intermediate-Level Waste (ILW)**: If the waste contains higher concentrations of radioactive substances, it may require a more specialized disposal method.

1.8. Radioactive Waste Management Protocols:

Hospitals are required to follow these protocols for managing radioactive waste from patients [9].:

a. Isolation and Containment of Waste:

i. **Patient Isolation:** In some cases, patients receiving radiation therapy are isolated to prevent contamination of the hospital environment. Patients who have been treated with radioactive substances (such as radioactive iodine in the treatment of thyroid cancer) must often remain in isolation for a period, until the radiation levels in their bodily fluids have decreased to safe levels.
ii. **Use of Special Containers:** Bodily fluids like urine, saliva, and vomit should be collected in radiation-proof containers that prevent exposure to hospital staff and visitors.

b. Monitoring Radiation Levels:

Monitoring of Waste: Before disposal, waste from patients, especially urine and saliva, should be monitored for radiation levels. The IAEA recommends using radiation detection devices to assess the activity of waste. If radiation levels exceed permissible limits, the waste may require further treatment or storage.

1.9. Waste Disposal Methods:

a. **Sanitary Sewer Disposal (for low-level waste):** If the radiation levels of the urine and saliva have decayed to a safe level, these bodily fluids may be disposed of in sanitary sewer systems. However, the amount of waste disposed of should be carefully controlled [10].

b. **Incineration or Burial (for contaminated waste):** If patient waste cannot be safely decayed in storage or if it contains higher radiation levels, it may be incinerated in specialized facilities designed for handling radioactive waste, or stored in designated radioactive waste burial sites. These options are more common for high-level radioactive [10].

1.10. Types of Liquid Waste from Chemotherapy from patient:

Chemotherapy liquid waste from patients is considered hazardous and requires special handling. Here are the main types of liquid waste produced [9]:

a. **Urine:**
   i. Patients excrete chemotherapy drugs and their metabolites through urine. Urine may remain contaminated for 48-74 hours after chemotherapy administration, depending on the drug.
   ii. To calculate the half-life of radiation in tanks and determine when to dispose of radioactive liquid waste, it will take approximately 53 days for the radioactive waste in urine to decay to a safe disposal level. for Iodine-131: Half-life = 8 days (used in cancer treatment, thyroid therapy) and the half-life of "Iridium-192" is about "74 days". This means it takes around 74 days for half of the radioactive atoms in a given sample to decay [9].

b. **Vomit:** Patients undergoing chemotherapy may vomit, and the expelled liquid may contain traces of the drugs [9].

c. **Sweat:** Though in smaller quantities, chemotherapy drugs can also be excreted through sweat [9].

d. **Blood:** Blood spills, wound exudates, or other body fluids may contain chemotherapy residues [8].

1.11. Radioactive waste:

Radioactive wastes are materials contaminated with radionuclides. They are produced as a result of procedures such as in vitro analysis of body tissue and fluid, in vivo organ imaging and tumour localization, and various investigative and therapeutic practices [11].

Radionuclides used in health care are in either unsealed (or open) sources or sealed sources. Unsealed sources are usually liquids that are applied directly, while sealed sources are radioactive substances contained in parts of equipment or encapsulated in unbreakable or impervious objects, such as pins, "seeds" or needles [11].

Radioactive health-care waste often contains radionuclides with short half-lives (i.e. half of the radionuclide content decays in hours or a few days); consequently, the waste loses its radioactivity relatively quickly. However, certain specialized therapeutic procedures use radionuclides with longer half-lives; these are usually in the form of small objects placed on or in the body and may be reused on other patients after sterilization. Waste in the form of sealed sources may have a relatively high radioactivity, but is only generated in low volumes from larger medical and research laboratories. Sealed sources are generally returned to the supplier and should not enter the waste stream [11].

The waste produced by health-care and research activities involving radionuclides and related equipment maintenance and storage can be classified as follows [11]:

a. spent radionuclide generators.
b. low-level solid waste (e.g. absorbent paper, swabs, glassware, syringes).

c. residues from shipments of radioactive material and unwanted solutions of radionuclides intended for diagnostic or therapeutic use.
d. residues used in radioimmunoassay.
e. excreta from patients treated or tested with unsealed radionuclides.

1.12. Hazards from radioactive waste:

The nature of illness caused by radioactive waste is determined by the type and extent of exposure. It can range from headache, dizziness and vomiting to much more serious problems. Radioactive waste is genotoxic, and a sufficiently high radiation dose may also affect genetic material. Handling highly active sources, such as those used in diagnostic instruments (e.g. gallium sealed sources) may cause much more severe injuries, including tissue destruction, necessitating the amputation of body parts. Extreme cases can be fatal [11].

The hazards of low-activity radioactive waste may arise from contamination of external surfaces of containers or improper mode or duration of waste storage. Health-care workers, and waste-handling and cleaning personnel exposed to radioactivity are most at risk [11].

1.13. What is Programmable Logic Controller (PLC)?

A PLC (Programmable Logic Controller) is an industrial computer used for automation of electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or light fixtures. PLCs are expected to work flawlessly for years in industrial environments that are hazardous to the very microelectronic components that give modern PLCs their excellent flexibility and precision. Prior to PLCs, many of these control tasks were solved with contactor or relay controls. This is often referred to as hardwired control. Circuit diagrams had to be designed, electrical components specified and installed, and wiring lists created. Electricians would then wire the components necessary to perform a specific task. If an error was made the wires had to be reconnected correctly. A change in function or system expansion required extensive component changes and rewiring [12] Figure 1.

Figure 1. Programmable Logic Controller (PLC)

1.14. Programmable Logic Controllers (PLC):

A PLCs are often defined as miniature industrial computers that contain hardware and software used to perform control functions. More specifically, a PLC would be used for the automation of industrial electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or food processing. They are designed for multiple arrangements of digital and analog inputs and outputs with extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. A PLC will consist of two basic sections: the central processing unit (CPU) and the Input/Output (I/O) interface system [12].

a. Central Processing Unit (CPU) [21]:

i. The CPU controls all system activity primarily through its processor and memory system.
ii. The CPU consists of a microprocessor, memory chip, and other integrated circuits to control logic, monitoring, and communications.
iii. The CPU has different operating modes:
iv. In programming mode, the CPU will accept changes to the downloaded logic from a PC.
v. Input data from connected field devices (e.g., switches, sensors, etc.) is processed, and then the CPU “executes” or performs the control program that has been stored in its memory system.
vi. Since a PLC is a dedicated controller, it will process this one program over and over again.
vii. The time it takes for one cycle through the program is called scan time and happens very quickly (in the range of 1/1000th of a second, depending on your program).

viii. The memory in the CPU stores the program while also holding the status of the I/O and providing a means to store values.

b. Input/Output (I/O) System [12]:

i. The input/output system is physically connected to field devices and provides the interface between the CPU and its information providers (inputs) and controllable devices (outputs).

ii. After the CPU processes the input data (input scan), it will then make any needed output changes after executing the user program (output scan).

iii. There are four basic steps in the operation of all PLCs:

- Input Scan – Detects the state of all input devices that are connected to the PLC.
- Program Scan – Executes the user-created program logic.
- Output Scan – Energizes or de-energizes all output devices that are connected to the PLC.
- Housekeeping – Includes communicating with programming devices and performing internal diagnostics.

1.15 Block Diagram of PLC System

Figure - 3 shows, in block form, the four major units of a PLC system and their interconnections,which are briefly described here [13] Figure 2:

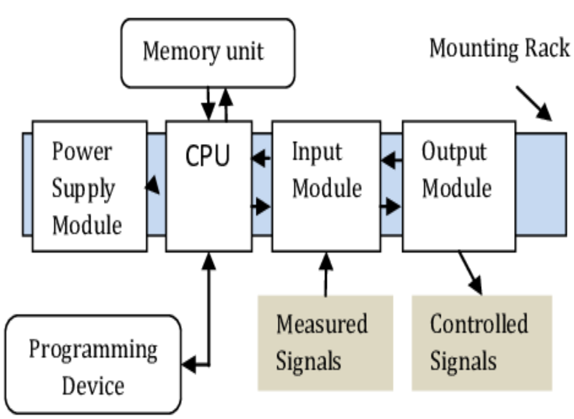

Figure 2. Block Diagram of PLC System

a. Central Processing Unit (CPU):

i. **Microprocessor Unit**: Carries out the mathematical and logical operations of the system.

ii. **Memory Unit**: Stores the system software and the user program data and information.

iii. **Power Supply**: Converts the AC line voltage to various DC operational values. The power supply is filtered and regulated to ensure proper operation of the PLC system.

b. PLC Programmer/Monitor:

i. A programming device used to communicate with the circuits of the PLC. This may be a hand-held terminal, industrial terminal, or a personal computer.

c. Input/Output Modules:

i. **Input Module (I)**: Has terminals into which outside process electrical signals, generated by sensors or transducers, are entered. These sensors or transducers can be thousands of meters away from the CPU.

ii. **Output Module (O)**: Has terminals into which output signals are sent to activate relays, solenoids, various solid-state switching devices, motors, and displays. This output signaling elements may also be thousands of meters away from the CPU.

iii. An electronic system for connecting I/O modules to remote locations can be added as necessary.

d. Racks and Chassis

i. There is a rack on which the PLC parts are mounted and the enclosures on which the CPU, the PM, and the I/O modules are mounted.

e. Optional Devices

i. **Printer**: A device using which the program in the CPU may be printed. In addition, operating information may be printed upon command.

ii. **Program Recorder/Player**: PLCs use fluffy disks, with hard disks for secondary storage. This recorder provides the backup and a way to download the program written-off from the PLC process system.

iii. **Master Computers**: Often used to coordinate many individuals, interconnected PLCs. These interconnected electrical buses are sometimes referred to as "Data Highways" [13].

1.16. Different Types of PLC Programming Languages:

Programmable Logic Controllers (PLCs) are versatile control devices commonly used in plants or manufacturing systems. They can accept inputs from various devices (e.g., motion detectors, joysticks, buttons) and produce outputs to control lights, motors, and sound effects. Key programming resources include timers, counters, and other variables. Although effective, PLCs can have a steep learning curve, especially with program maintenance using traditional Relay Ladder Logic (RLL) [14]**.**

1.17. Delta PLC:

The Delta PLC acts as the brain of the system. It is responsible for controlling and automating the treatment processes. It communicates with sensors to collect real-time data on the waste characteristics and sends control signals to actuators, such as pumps, valves, and chemical dosing systems, to regulate the treatment process. The PLC is programmed with specific logic to manage the various stages of the waste treatment process and ensure that waste is treated in accordance with established safety and environmental standards.

1.18. SCADA System:

The SCADA system serves as the user interface for operators to monitor and control the waste treatment process remotely. It provides real-time feedback on key parameters and system status, generating alarms and notifications when conditions deviate from safe or optimal ranges. SCADA also logs data for future analysis, providing insights into system performance and efficiency.

By integrating PLC and SCADA systems, this research aims to create a more robust and efficient solution for managing biohazard liquid waste.

1.19. Sensors and Actuators:

Sensors are used to measure key parameters of the waste, including pH, temperature, turbidity, flow rate, chemical concentration, counting timer and amount of radiation. These sensors feed data back to the PLC, which adjusts the treatment process based on the sensor inputs. Actuators, such as pumps, valves, and chemical dosing units, are controlled by the PLC based on the instructions it receives from the monitoring system.

1.19.1. Flow Rates:

Flow rate sensors ensure consistent waste flow. The PLC adjusts pump speeds and valve positions to maintain optimal flow rates Figure 3.

Figure 3. Flow meter measuring

1.19.2. pH Control:

pH sensors monitor waste acidity/alkalinity. The PLC regulates chemical dosing systems to keep pH within acceptable levels for effective treatment Figure 4.

Figure 4. Ph meter value and total dissolved solids

1.19.3. Temperature:

Temperature sensors monitor system heat. The PLC adjusts heating/cooling to maintain optimal

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temperature, ensuring efficient physical and chemical processes Figure 5.

Figure 5. temperature meter measuring

1.19.4. Chemical Concentration:

Sensors track real-time chemical levels. The PLC controls dosing to ensure effective treatment, minimizing waste and cost.

1.19.5. Radiation Measurement:

Radiation sensors detect waste radiation levels. The PLC adjusts timing processes to ensure sufficient treatment Geiger Radioactivity Detector Nuclear (GRDN) Figure 6.

Figure 6. Nuclear Radiation detector

1.19.6. Timer Measurement:

Programmable timers enable precise control of multi-channel operations without synchronization errors, ensuring efficient timing cycles Figure 7.

Figure 7. Programmable Timer Relay

1.20. Process Flowchart of Chemotherapy:

This document outlines the systematic process flow of handling, treating, and disposing of chemotherapy waste, with a focus on compliance with environmental and safety standards, adiation exposure is measured in millisieverts (mSv) or millirem (mrem), and the normal range for humans and the environment varies depending on the source, Figure 8.

1.21. Waste Collection and Initial Screening:

Waste from the Chemotherapy units is collected in specially designed containers to prevent contamination. At this stage, large solids, debris and non-hazardous materials are screened. This initial step ensures that only biologically hazardous liquid waste enters the treatment process.

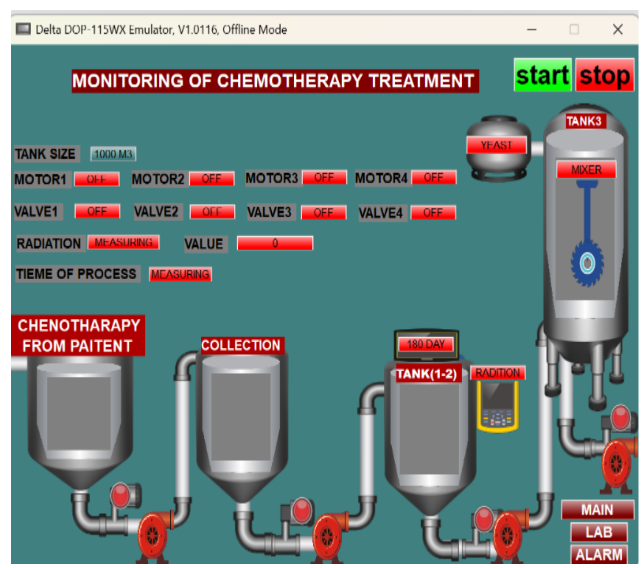

Figure 8. Process Flowchart of Chemotherapy

1.21.1. Pre-treatment:

a. The waste from the Chemotherapy units is Storage into the first tank. The PLC Delta controls the quantification system by level sensors, ensuring the correct amount is calculated and read by the radiation sensor based on real-time data from the sensors.

b. pH Control: pH levels are important for the effectiveness of the quantification of radiation and the overall treatment process based on the total time of the minimum radiation emitted. If the pH level is outside the acceptable range, the PLC adjusts the quantification system to bring the pH to neutral levels rang pH (6.5-7.6).

c. Temperature Control: Waste streams with extreme temperatures can cause malfunction in the system. - Temperature sensors continuously monitor the waste, and the PLC adjusts the cooling or heating systems as needed to ensure that the waste remains within the optimum temperature range for treatment.

d. Controlling the amount of radiation emitted: Radiation emitted from liquid waste can cause harm to staff, co-patient, and other hospital patients, so the PLC increases the time and monitors the radiation level until the permissible level of radiation that can be disposed of in the sewer is well Levels typically range from about (1.5 - 3.5) millisievert per year but can be more than 50 mSv/yr.

1.21.2. Primary Treatment:

During the primary treatment phase, the first stage is to collect all laboratory waste in a tank with a known capacity according to the number of patients, waste generated during chemotherapy, and the number of fluids coming out of the patients. The capacity is determined by the number of patients the chemotherapy center receives, and the PLC adjusts the speed pumps and closes the valves to ensure that the waste flows to the next tank.

1.21.3. Radiation Reduction Stage:

Radiation reduction is a critical stage in the treatment process, as the recommended amount of radiation in the liquid waste should be as low as possible to return to the time of the radioactive materials, which is between (14 - 57) days. This is usually achieved through:

a. Time calculation: The programmable logic controller monitors the time calculation by a timer in the liquid radioactive waste treatment tank and adjusts the time based on the largest treatment time of 60 days and starts after the tank is full and the PLC follows up the real-time feedback from the sensors.

b. Time and temperature are calculated by measuring them with a timer and a temperature sensor so that the radiation is disposed of according to the required time and the amount of radiation is read from the radiation sensor and if the amount emitted from the waste is more than the required value, the PLC increases the time until the amount of emitted radiation becomes the required and recommended value for disposal in the sewage system.

1.21.4. Final disposal:

The final stage of the process is the disposal of the treated waste, after the radioactive decay process to the required value, a special treatment is carried out that may include advanced filtration or fermentation (yeast) to reactivate the decomposing bacteria in the waste, so that it can be disposed of by PLC control in the siphon tank or public sewer so that the radioactive materials are in the fourth stage in the globally agreed amount in the fifth and final stage because they are without decomposing bacteria, unless help the decomposing bacteria to reproduce again to improve the sewer environment. The PLC monitors the final characteristics of the waste, and ensures that it meets all environmental and safety standards before it is discharged or disposed of.

1.22. Simulation Process and treatment of Chemotherapy waste:

Also, an amount of 1000 m^3 of liquid waste (urine and saliva) from patients receiving chemotherapy injections was entered (we use some radioactive materials such as Iodine-131 and Iridium-192) and disposed of in a special toilet to collect the waste to the first stage, which contains a path for the treatment system consisting of several tanks designated for treatment and controlled by the PLC and in controlling the treatment area and SCADA to clarify the process path and control it by the specialized technician for operation and monitoring (process management).The results were as shown in the Figure 9. below:

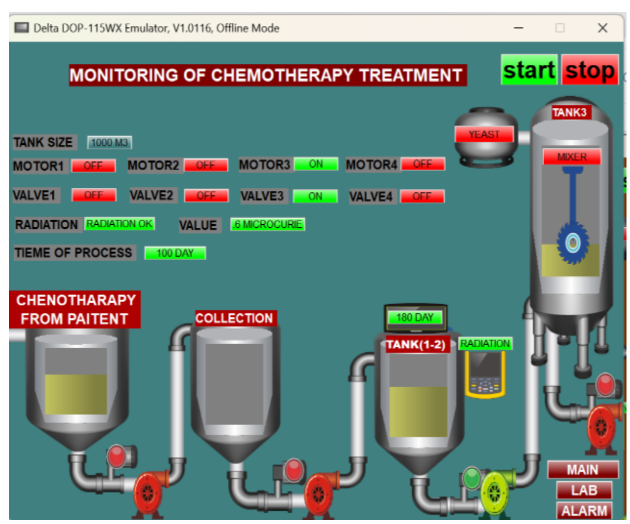

Figure 9. Results of Process and treatment clinical waste of Chemotherapy

1.23. MATLAB simulation:

To simulate the system for treating and managing 1000 m^3 of biohazard liquid waste from Chemotherapy using MATLAB, you can create a model that incorporates the following steps:

a. Define the System Parameters: This includes flow rates, treatment efficiency, and other relevant variables.

b. Model the Treatment Process: Simulate the PLC (Programmable Logic Controller) and SCADA (Supervisory Control and Data Acquisition) system logic.

c. Simulate Waste Treatment: Use differential equations or iterative calculations to represent the treatment process over time.

d. Visualize Results: The results output in digital display to show how the waste is treated over time.

Below is the MATLAB code to simulate the treatment of 1000 m^3 of biohazard liquid waste, appendices 3.

1.23.1. Explanation of the Code:

a. System Parameters:

i. total_waste_volume: The total volume of biohazard liquid waste to be treated (1000 m^3).
ii. inflow_rate: The rate at which waste enters the treatment system (5 m^3/hour).
iii. treatment_efficiency: The percentage of waste treated effectively (95%).

b. Simulation Loop:

i. The loop iterates over time steps, calculating the inflow of waste, the amount treated, and the remaining untreated waste.
ii. The main function ensures that the inflow does not exceed the remaining waste.

c. Outputs:

i. The results output in digital display to show how the waste is treated over time.
ii. This code provides a basic framework for simulating the treatment of biohazard liquid waste.

1.24. PLC and SCADA System Implementation for Simulation:

Each tank's operation should be modeled with the following control logic:

1.24.1. Liquid Chemotherapy Waste Tanks:

a. Tank 1 (Collection after sorting):

i. Level sensors to detect waste levels.
ii. Automatic transfer to Tank 2 when full.

b. Tank 2 (Buffer storage):

i. Volume measurement for dosage calculation = 1000 m^3.
ii. Control logic to start Tank 3 processing when full.

c. Tank 3 (Nuclear Radiation detector**):**

i. Monitoring time and feedback to evolution radiation emitted.

d. Tank 4 (Final treatment with natural yeast):

i. Dosing control for yeast injection (Natural yeasts refer to microorganisms, primarily strains of fungi).
ii. Flow control to drainage system.

1.24.2. Result in monitor:

Radiation =0.6 ≤ (2-3 mSv) and Timer = 100 days (60-180 day).

1.25. International Atomic Energy Agency (IAEA) Guidelines:

The International Atomic Energy Agency (IAEA) provides detailed recommendations on managing biomedical radioactive waste, encompassing handling, packaging, treatment, conditioning, storage, transportation, and disposal. Key measures include:

a. **Segregation and Containment:** Radioactive waste should be segregated at the source and contained to prevent the spread of contamination.

b. **Decay Storage:** Waste containing short-lived radionuclides can be stored until their radioactivity decays to safe levels, after which they can be disposed of as non-radioactive waste.

c. **Treatment and Conditioning:** Processes such as chemical treatment or solidification may be applied to convert waste into a stable form suitable for transportation and disposal.

d. **Disposal:** Depending on the radioactivity level, waste may be disposed of in near-surface facilities or deep geological repositories.

e. **Monitoring Techniques:** Different isotopes require different monitoring periods based on their decay rates.

f. **Safety Measures During Monitoring:**

i. Use of Personal Protective Equipment (PPE): Gloves, lead aprons, and face shields.
ii. Regular calibration of radiation monitoring devices.
iii. Proper sample handling to avoid cross-contamination.
iv. Compliance with safe disposal regulations to minimize environmental impact.

1.26. Comparison Between PLC and SCADA System and chemotherapy for Liquid Waste Treatment;

1.26.1. PLC and SCADA System Implementation for Simulation

a. Advantages:

i. Full automation and real-time monitoring.
ii. Precise control over treatment parameters.
iii. Scalable for large waste volumes (>1000 m3).
iv. Data logging for compliance verification.

b. Disadvantages:

i. High initial cost and complexity.
ii. Requires skilled personnel for operation and maintenance.

1.26.2. International Atomic Energy Agency IAEA Guidelines:

a. Advantages:

i. Globally recognized and standardized approach.
ii. Ensures environmental and human safety.
iii. Cost-effective for long-term waste management.

b. Disadvantages:

i. Longer processing time due to decay storage requirements.
ii. High regulatory compliance burden.
iii. Manual intervention required at various stages.

1.27. Compare Methods:

Table 1: Comparison Between PLC and SCADA System and chemotherapy Methods

Criteria	PLC and SCADA System	IAEA Guidelines
Automation	Fully automated	Manual and semi-automated
Capacity	>1000 m^3	Varies
Monitoring	Real-time via SCADA	Periodic manual monitoring
Safety	High (real-time alerts)	High (strict safety measures)
Disposal Approach	Direct controlled discharge	Long-term storage/disposal
Cost	High initial, low operating	Moderate, long-term cost

1.28. Automation and Monitoring

1.28.1. Role of PLCs and SCADA Systems

a. **Real-time Data Collection:** Sensors monitor pH, temperature, radiation levels, and other critical parameters.
b. **Control Logic Implementation:** PLC systems adjust treatment processes dynamically based on real-time data.
c. **System Integration:** SCADA systems provide centralized monitoring and reporting capabilities,

enabling remote oversight of all stages of effluent treatment.

1.28.2. Benefits of Automation

a. Enhanced safety and efficiency

b. Precise control over treatment parameters

c. Real-time compliance monitoring

1.29. Conclusion

The integration of advanced automation technologies like PLC and SCADA, represents a promising advancement in the field of biomedical waste management. This approach not only mitigates the adverse effects of improper waste disposal but also sets a precedent for adopting innovative solutions in resource-constrained environments. Future work should focus on piloting the system in real-world settings, fostering collaboration between stakeholders, and promoting policy reforms to support sustainable waste management practices globally. By prioritizing the development and implementation of such systems, healthcare facilities can significantly reduce risks to public health and the environment while ensuring compliance with international standards.

References

[1] Park K. Hospital Waste Management: Park′s Textbook of Preventive and Social Medicine. New Delhi, Banarasidas Bhanot Publications, (2005). Pg 8.
[2] Waste medic. “The Hidden Risks of Improper Medical Waste Disposal”, (September 10, 2024), https://wastemedic.com/2024/09/the-hidden-risks-of-improper-medical-waste-disposal.
[3] Megan Chamberlain. “Daniels”, Risks and Consequences of Improper RMW Disposal - Health, Megan Chamberlain, (29 Jul 2020), https://www.danielshealth.com/knowledge-center/improper-rmw-disposal.
[4] Agency for Toxic Substances and Disease Registry. Hazardous Substances Emergency Events Surveillance System (HSEES), annual report. Atlanta, GA: US Department of Health and Human Services, Agency for Toxic Substances and Disease Registry; (September 16, 2005),54(36); Pg 97-99, http://www.atsdr.cdc.gov/HS/HSEES/annual2001.html
[5] Demirbas, A. Waste management, waste resource facilities and waste conversion processes: Energy Conversion & Management, (2011), 52(2), chapter 12 Pg 80-87. https://doi.org/10.1016/j.enconman.2010.09.025.
[6] White, P. R., Franke, M., & Hindle, P. Integrated Solid Waste Management: A Lifecycle Inventory. Berlin: Springer. (1995), Pg 6.
[7] WHO. (2018). Healthcare Waste Management, Pg 5.
[8] WHO. Safe Management of Wastes from Health-Care Activities, (2004), Pg 111 & 112
[9] Low-Level Radioactive Waste Policy Act (LLRWPA): This act regulates the disposal of low-level radioactive waste, including liquid waste, and encourages states to form regional compacts for efficient management. chapter8 Pg 97-98.
[10] Paul C. Szasz, Legal. The Law and Practices of the International Atomic Energy Agency: Publishing Section International Atomic Energy Agency. Vienna International Centre, (1970). Pg 15-17. https://www.pub.iaea.org/MTCD/Publications/PDF/Pub250Main.pdf.
[11] Agency for Toxic Substances and Disease Registry. The public health implications of medical waste: a report to congress. Atlanta, Georgia, US Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, (1990), Pg 27, 29 & 31.
[12] PLC. Practical Guide to Programmable Logic Controllers: Handbook: PLC, Automation Direct, (2020) - v2, ADC-003- Pg 45-47.
[13] M.T. white, Birmingham. PLCs for Beginners: Packt Publishing, B3 1RB, UK ISBN: 978-1-80323-093, (2024), Pg 145-156. www.packtpub.com.
[14] Kevin Collins. PLC Programming for Industrial Automation, (December 2014), Pg 4-7.