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Blockchain Enabled Decentralized Nuclear Waste Supply Chain Management

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Abstract
As nuclear waste has long-term effects on the environment and society, managing it safely and effectively is a major global concern. Conventional nuclear waste management systems may face challenges related to record keeping, transparency, and reliance on manual monitoring, potentially affecting operational efficiency and stakeholder confidence. This study presents a blockchain-based platform designed to enhance accountability, data integrity, and traceability in nuclear waste management procedures. The proposed system leverages the decentralized and tamper-resistant nature of blockchain technology to record and track waste-related information throughout its lifecycle. It provides a user-friendly interface to support interaction among stakeholders, including waste producers, storage facilities, and the general public. The system's development and testing demonstrate the implementation of blockchain-based record keeping, waste tracking, and sensor data monitoring. These functionalities provide a foundation for maintaining verifiable records and improving the visibility of waste management activities. Although the current evaluation demonstrates the system's functional capabilities, further comparative testing is required to quantify improvements in data integrity, traceability, and operational efficiency over conventional approaches. This project contributes to ongoing efforts toward safer and more sustainable nuclear waste management by presenting a potential solution that can be further evaluated and adapted for other hazardous material management applications.
Keywords: *Blockchain, Nuclear waste, Smart contracts, Data integrity, Environmental sustainability.*

1. Introduction
Many countries across the world, including India, rely heavily on nuclear power as a clean and efficient source of energy (Pathak et al., 2022; Selvam et al., 2025). However, the management of nuclear waste generated from nuclear power plants remains a critical and complex challenge. Nuclear waste is highly radioactive, hazardous, and long-lasting, requiring strict handling, transportation, storage, and disposal protocols. Any lapse in the nuclear waste supply chain can lead to severe environmental contamination, health risks, and large-scale disasters. Despite the existence of regulatory frameworks, the current nuclear waste management process is largely fragmented, semi-manual, and lacks real-time transparency, making it vulnerable to human error, data manipulation, and security breaches (Beckmerhagen et al., 2003; Pathak et al., 2022). Recent global and national reports highlight growing concerns regarding nuclear waste handling. According to international nuclear safety agencies, improper tracking, undocumented transfers, and delayed status updates of radioactive waste have contributed to safety violations and regulatory non-compliance. In developing nations, challenges such as outdated infrastructure, limited digital monitoring, and lack of secure data sharing further aggravate the problem. The absence of a unified, tamper-proof system makes it difficult for authorities to verify the authenticity of waste records, monitor transportation conditions, and ensure accountability at each stage of the supply chain (Lee et al., 2023; Yessenbayev et al., 2024). The nuclear waste supply chain involves multiple stakeholders, including nuclear power plants, transport agencies, storage facilities, disposal sites,

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and regulatory bodies. Each stage generates critical data related to waste type, radiation level, location, handling status, and safety approvals. When this information is stored in centralized or manual systems, it becomes prone to data loss, unauthorized modification, and cyberattacks. Such vulnerabilities pose serious risks, as inaccurate or manipulated data can result in improper handling of radioactive materials, threatening both public safety and the environment (Rachuri et al., 2008).

This gap can be effectively addressed by introducing a secure, transparent, and automated digital system that ensures end-to-end traceability of nuclear waste. Emerging technologies such as Blockchain, IoT sensors, and smart contracts offer a transformative solution to these challenges. Blockchain technology enables immutable and tamper-proof record keeping, ensuring that every transaction or status update related to nuclear waste is permanently recorded and verifiable. IoT-based sensors can continuously monitor parameters such as radiation levels, temperature, and location during transportation and storage, providing real-time data to stakeholders. Smart contracts can automate approval workflows, ensuring that waste movement or storage occurs only after regulatory compliance is verified (Lee et al., 2023; Yessenbayev et al., 2024). [1]

The proposed Nuclear Waste Supply Chain Management System aims to leverage blockchain technology, IoT integration, and secure web applications to create a reliable and transparent management platform. The system is designed to:

1. Track nuclear waste from generation to final disposal with complete traceability.
2. Ensure data integrity and prevent unauthorized modification using blockchain.
3. Enable real-time [2] monitoring of waste conditions through sensor integration.
4. Automate regulatory approvals and compliance checks using smart contracts.
5. Improve accountability among all stakeholders involved in the supply chain.

The platform also allows administrators and government agencies to audit records efficiently, detect anomalies early, and respond swiftly to potential threats. Our project utilizes modern web technologies and blockchain infrastructure to develop a scalable, secure, and user-friendly system suitable for real-world deployment. This proactive and technology-driven approach represents a significant step toward safer nuclear energy practices. By strengthening the nuclear waste supply chain, the proposed system contributes to environmental protection, public safety, and sustainable energy development, ensuring that the benefits of nuclear power do not come at the cost of long-term ecological or human harm. As shown in Figure 1 System Architecture.

2. System Architecture

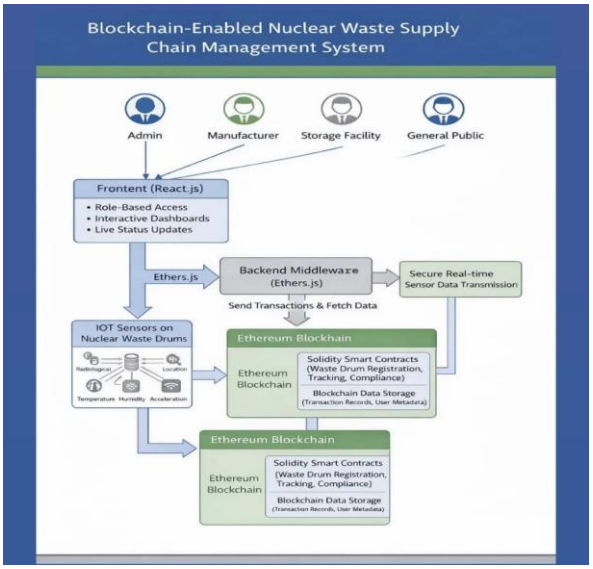


Figure 1 System Architecture

The proposed Nuclear Waste Supply Chain Management System is designed to support the tracking, monitoring, and record management of nuclear waste throughout its lifecycle. It combines blockchain technology, smart contracts, IoT-based monitoring, and a web-based interface to support traceability and information access among stakeholders. Previous [3 – 10] research has explored blockchain and IoT integration for nuclear waste management, as well as IoT-based tracking and condition monitoring of radioactive waste drums (Lee et al., 2023; Yessenbayev et al., 2024).

3. Methodology

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The methodology adopted for the Nuclear Waste Supply Chain Management System follows a systematic and modular approach to ensure secure monitoring, reliable data handling, and regulatory compliance. The proposed framework integrates hardware sensing, software processing, and automated alert mechanisms to achieve end-to-end traceability of nuclear waste (Lee et al., 2023; Yessenbayev et al., 2024).

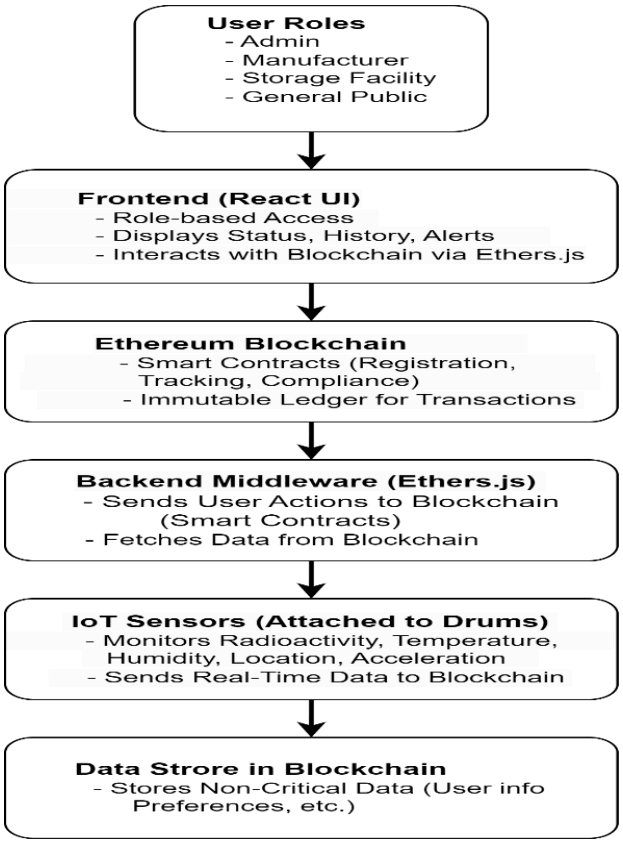


Figure 2 Flowchart of Blockchain Enabled System

The system architecture is designed to enable continuous and real-time supervision of nuclear waste containers throughout their lifecycle. It incorporates IoT-based sensing units, GPS tracking modules, and cloud infrastructure to monitor critical parameters such as radiation levels, temperature variations, and geographic location. This integrated design ensures seamless communication between [11] physical devices and digital platforms while supporting scalability and fault tolerance (Lee et al., 2023).



Figure 3 Home Page

The interface shown represents the homepage of the proposed Nuclear Waste Management system, designed to provide a simple and clear overview of nuclear waste tracking operations. It visually illustrates the movement, monitoring, and storage of nuclear waste across different locations, emphasizing end-to-end traceability within the supply chain. The interface integrates blockchain-based monitoring with a user-friendly web layout, enabling stakeholders to access real-time information securely and efficiently. This design enhances transparency, supports informed decision-making, and improves overall system usability in nuclear waste management operations. The Nuclear Waste Supply Chain Management System is developed using blockchain-based tools to ensure secure and reliable system operations. The Ethereum platform is used as the underlying blockchain network to maintain decentralized and tamper-proof records of nuclear waste activities. Smart contracts are integrated to automatically enforce safety rules and regulatory approvals, minimizing manual involvement and improving operational accuracy. MetaMask serves as a secure digital wallet that enables authenticated users to interact with the blockchain and authorize transactions safely. During development and testing, Ganache is used to simulate the Ethereum environment locally, allowing smart contracts to be tested and refined before real-world deployment. To enhance operational safety, the system includes an automated alert mechanism that continuously evaluates incoming sensor data against predefined safety thresholds. Alerts are generated in the event

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of abnormal radiation readings, temperature anomalies, or route deviations, enabling prompt corrective action[12 – 15].

4. Results And Discussion

4.1.Results

The proposed Nuclear Waste Supply Chain Management System was tested under simulated operational conditions to evaluate its effectiveness in ensuring secure tracking and monitoring of nuclear waste. The results show that the use of blockchain technology provided strong data integrity and end-to-end traceability across all stages of the waste lifecycle. Each operational update was permanently recorded, making the records tamper-resistant and easily verifiable by authorized stakeholders. In addition, the integration of real-time monitoring enabled continuous observation of critical parameters such as radiation levels, temperature, and location, allowing the system to detect abnormal conditions promptly and support timely preventive actions. As shown in Table 1 Real Time Monitoring Data of Nuclear Drums.

Table 1 Real Time Monitoring Data of Nuclear Drums

Drum ID	*Waste Type*	*Radio-activity (mSv/h)*	*Temp (°C)*	*Humi-dity (%)*	*Status*
DR-101	Spent Fuel	78.6	28.4	72.5	Verified
DR-102	Chemical Waste	55.1	32.0	65.8	Verified
DR-103	Low-Level Waste	34.8	40.6	64.1	Verified
DR-104	Mixed Waste	22.3	20.5	38.6	Verified

Table 1 presents the simulated radioactivity, temperature, and humidity readings for four nuclear waste drums, identified as DR-101, DR-102, DR-103, and DR-104. The recorded radioactivity values decrease from 78.6 mSv/h for DR-101 to 22.3 mSv/h for DR-104. Temperature values range from 20.5°C to 40.6°C, with DR-103 showing the highest recorded temperature. Humidity ranges from 38.6% to 72.5%, with DR-101 showing the highest value and DR-104 the lowest.

4.2.Discussion

The simulation confirms that the proposed system ensures secure, tamper-resistant tracking of nuclear waste through blockchain integration and real-time monitoring. Continuous observation of radiation and environmental parameters enables early anomaly detection, supporting safe and transparent waste management [16].

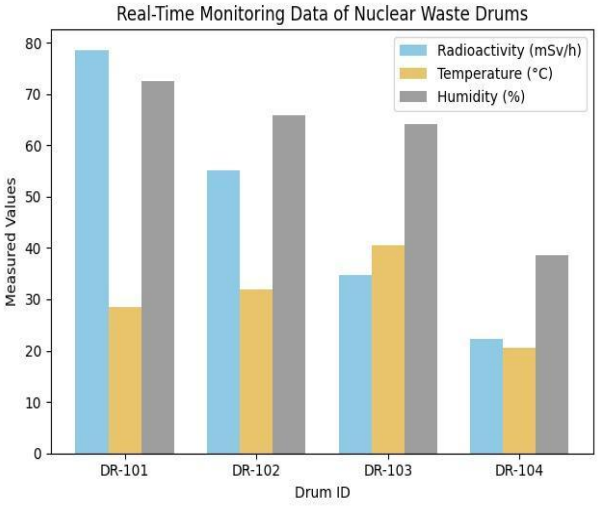


Figure 4 Real Time Monitoring Data Chart of Nuclear Drums

The chart presents real-time sensor data for four nuclear waste drums, comparing radioactivity, temperature, and humidity levels. DR-101 shows the highest radioactivity and humidity, indicating a higher safety risk and the need for closer monitoring. DR-103 records the highest temperature, highlighting possible environmental or storage-related variations. In contrast, DR-104 maintains relatively lower values across all parameters, suggesting more stable storage conditions. Overall, the visualization demonstrates how continuous sensor monitoring helps identify variations in safety conditions and supports effective management of nuclear waste storage.

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Figure 4 visualizes the recorded parameters across the four drums, while Figure 5 compares their variations. These visualizations help identify differences in the simulated readings and illustrate how sensor data can be presented for monitoring purposes. The readings represent the values used in this evaluation and should not be interpreted as evidence of actual storage conditions or a validated assessment of radiological risk.

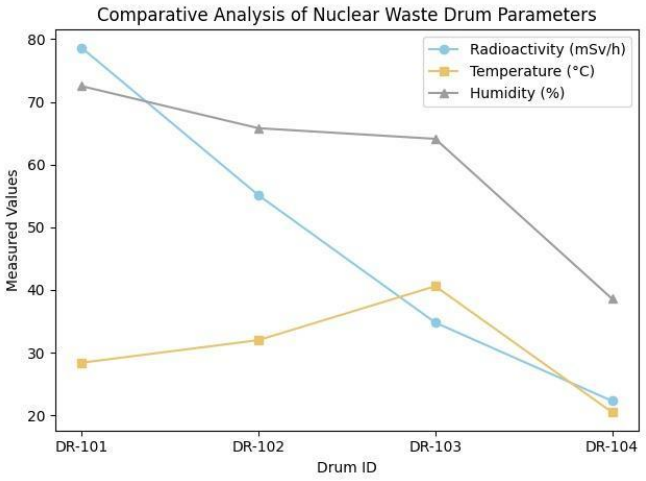


Figure 5 Comparative Analysis of Nuclear Waste Drum Parameters

The line chart compares radioactivity, temperature, and humidity levels across nuclear waste drums DR-101 to DR-104. Radioactivity shows a steady decline from DR-101 to DR-104, indicating decreasing radiological risk across the drums. Temperature increases up to DR-103 before dropping sharply at DR-104, reflecting variations in storage or environmental conditions. Humidity follows a similar downward trend, with a significant reduction at DR-104, suggesting improved storage stability. Overall, the chart highlights how comparative analysis of sensor data helps identify safety trends and supports informed monitoring decisions. The discussion of these results highlights the practical advantages of adopting a decentralized and automated approach for nuclear waste management. Smart contract-based automation reduced reliance on manual approvals and ensured consistent enforcement of safety and regulatory rules. The alert mechanism further enhanced operational safety by providing immediate notifications during anomaly detection. Compared to traditional centralized systems, the proposed solution improves transparency, accountability, and reliability while reducing human error. Overall, the findings confirm that the system is technically feasible and capable of strengthening nuclear waste safety practices, with potential for future expansion and real-world deployment.

Conclusion

This research presented a blockchain-based Nuclear Waste Supply Chain Management System aimed at improving the safety, transparency, and reliability of nuclear waste handling operations. By integrating blockchain technology with real-time monitoring and automated control mechanisms, the proposed system addresses key limitations of traditional nuclear waste management practices, such as fragmented record-keeping, lack of traceability, and dependency on manual processes (Lee et al., 2023; Yessenbayev et al., 2024). Overall, the proposed approach offers a practical and scalable solution for strengthening nuclear waste governance and regulatory compliance. The use of smart contracts ensures consistent enforcement of safety rules, while decentralized data storage enhances trust among stakeholders. By reducing operational risks and human errors, the system contributes to safer nuclear energy practices and long-term environmental protection. Future enhancements may focus on large-scale deployment, integration with national regulatory frameworks, and performance optimization to support real-world nuclear waste management scenarios.

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References

[1]. Beckmerhagen, I. A., Berg, H. P., Karapetrovic, S. V., & Willborn, W. O.

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(2003). Integration of Management Systems: Focus on Safety in the Nuclear Industry. International Journal of Quality & Reliability Management, 20(2), 210-228. doi: 10.1108/02656710310456626.

[2]. Ahmad, M. I., Ab. Rahim, M. H., Nordin, R., Mohamed, F., Abu-Samah, A., & Abdullah, N. F. (2021). Ionizing Radiation Monitoring Technology at the Verge of Internet of Things. Sensors, 21(22), Article 7629. doi: 10.3390/s21227629.

[3]. Chang, S. E., & Chen, Y. (2020). When Blockchain Meets Supply Chain: A Systematic Literature Review on Current Development and Potential Applications. IEEE Access, 8, 62478-62494. doi: 10.1109/ACCESS.2020.2983601.

[4]. Devarajan, Y., & Thiagarajan, C. (2025). Innovative Materials for Enhancing Safety, Efficiency, and Sustainability in Nuclear Waste Management. Kerntechnik, 90(3), 261-274. doi: 10.1515/kern-2025-0009.

[5]. Ecemis, I. N., Ekinci, F., Acici, K., Guzel, M. S., Medeni, I. T., & Asuroglu, T. (2024). Exploring Blockchain for Nuclear Material Tracking: A Scoping Review and Innovative Model Proposal. Energies, 17(12), Article 3028. doi: 10.3390/en17123028.

[6]. Fernández-Caramés, T. M., & Fraga-Lamas, P. (2018). A Review on the Use of Blockchain for the Internet of Things. IEEE Access, 6, 32979-33001. doi: 10.1109/ACCESS.2018.2842685.

[7]. Lee, J.-W., Kim, T.-J., & Lee, H.-K. (2023). Design of an IoT-Based Indoor Tracking and Condition Monitoring System for the Safe and Transparent Management of Drums Storing Low- and Intermediate-Level Radioactive Waste. Journal of the Air & Waste Management Association, 73(2), 133-145. doi: 10.1080/10962247.2022.2149636.

[8]. Longo, F., Nicoletti, L., Padovano, A., d'Atri, G., & Forte, M. (2019). Blockchain-Enabled Supply Chain: An Experimental Study. Computers & Industrial Engineering, 136, 57-69. doi: 10.1016/j.cie.2019.07.026.

[9]. Pathak, B. C., Kaushik, C. P., Vyas, K. N., & Grover, R. B. (2022). The Status of Nuclear Power Development in India. Current Science, 123(3), 281-292. doi: 10.18520/cs/v123/i3/281-292.

[10]. Pournader, M., Shi, Y., Seuring, S., & Koh, S. C. L. (2020). Blockchain Applications in Supply Chains, Transport and Logistics: A Systematic Review of the Literature. International Journal of Production Research, 58(7), 2063-2081. doi: 10.1080/00207543.2019.1650976.

[11]. Rachuri, S., Subrahmanian, E., Bouras, A., Fenves, S. J., Foufou, S., & Sriram, R. D. (2008). Information Sharing and Exchange in the Context of Product Lifecycle Management: Role of Standards. Computer-Aided Design, 40(7), 789-800. doi: 10.1016/j.cad.2007.06.012.

[12]. Romoli, M., Di Giovanni, M., Di Meo, P., Pandalone, A., Principe, C., Sabbarese, C., D'Onofrio, A., Prchal, K., Záruba, J., & Finocchiaro, P. (2024). A Wireless Gamma-Ray Monitoring System for Cemented Radwaste Drums. Sensors, 24(7), Article 2332. doi: 10.3390/s24072332.

[13]. Selvam, D. C., Devarajan, Y., & Raja, T. (2025). Exploring the Potential of Artificial Intelligence in Nuclear Waste Management: Applications, Challenges, and Future Directions. Nuclear Engineering and Design, 431, Article 113719. doi: 10.1016/j.nucengdes.2024.113719.

[14]. Ullo, S. L., & Sinha, G. R. (2020). Advances in Smart Environment Monitoring Systems Using IoT and Sensors. Sensors, 20(11), Article 3113. doi: 10.3390/s20113113.

[15]. Wang, Y., Chen, C. H., & Zghari-Sales, A. (2021). Designing a Blockchain Enabled Supply Chain. International Journal of Production Research, 59(5), 1450-1475.

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October 2026
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doi: 10.1080/00207543.2020.1824086.

[16]. Yessenbayev, O., Nguyen, D. C. D., Jeong, T., Kang, K. J., Kim, H. R., Ko, J., Park, J.-Y., Roh, M.-S., & Comuzzi, M. (2024). Combining Blockchain and IoT for Safe and Transparent Nuclear Waste Management: A Prototype Implementation. Journal of Industrial Information Integration, 39, Article 100596. doi: 10.1016/j.jii.2024.100596.