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Artificial Intelligence in Smart Radiation Monitoring Devices: Enhancing Safety and Efficiency in Radiation Management

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Abstract
Artificial Intelligence (AI) is transforming radiation monitoring by offering enhanced sensitivity, faster response times, and more adaptive management strategies across healthcare, nuclear safety, and environmental applications. This paper presents a comprehensive analysis of AI's integration into smart radiation monitoring devices, based on an extensive review of recent academic literature. Using a systematic search methodology across major databases, the study identifies key technological advances, performance metrics, emerging research directions, and critical implementation challenges. Findings indicate that AI-driven systems improve detection accuracy from 75–80% in traditional systems to 90–95%, reduce anomaly response times from 10–15 minutes to 1–2 minutes, and lower false positive rates significantly. However, challenges related to data quality, model interpretability, system integration, and regulatory compliance remain pressing barriers. Addressing these issues requires multidisciplinary collaboration, standardized data protocols, and the development of transparent and robust AI models. The paper concludes that while AI holds immense promise for advancing radiation safety and operational efficiency, careful governance and continuous innovation are essential to realize its full potential in real-world applications.

Keywords*: Artificial Intelligence, AI Model, Radiation Monitoring, Regulatory Compliance Smart Detection Systems.*

1.0 Introduction

Radiation monitoring has transformed profoundly since Röntgen's 1895 discovery of X-rays, evolving from photographic film badges into networked, sensor-driven, and intelligent platforms that underpin safety in healthcare, nuclear energy, environmental protection, and research laboratories (Ahmad et al., 2021; Andresz et al., 2022). In modern clinical and industrial settings, monitoring plays a pivotal role in cancer therapy, reactor operations, waste management, and emergency response (Thompson et al., 2018). However, traditional approaches remain constrained by static thresholding, delayed feedback, and heavy reliance on manual interpretation, limiting adaptability in dynamic radiation environments and delaying response during sudden exposure fluctuations (Qureshi & Nichols, 2023). Conventional systems often lack personalization and predictive intelligence, hindering exposure control in complex scenarios (Huynh et al., 2020).

AI offers a transformative solution. Machine learning (ML), deep learning (DL), and reinforcement learning (RL) algorithms process large-scale radiation datasets, identify subtle patterns, and make real-time predictive decisions (Chamunyonga et al., 2020; Baek et al., 2021). AI enables adaptive anomaly detection in nuclear reactors (Qureshi & Nichols, 2023), optimized radiotherapy planning (Vandewinckele et al., 2020), and intelligent dosimetry correction models such as neural-network-based calibration systems (Szumega et al., 2023). These advances shift radiation safety from passive monitoring toward proactive, predictive management.

The convergence of AI with IoT, wireless communication, and embedded sensing has expanded capabilities. IoT-enabled platforms using LoRaWAN provide real-time environmental dose reporting and remote accessibility (Ahmad et al., 2021; Saleem et al., 2023; Gallego Manzano et al., 2022). Smart marine buoys demonstrate reliable gamma detection with GPS tracking in ocean environments (Tran et al., 2022), while IoT area monitoring systems show stable performance in nuclear emergency preparedness (Muhtadan et al.,

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2023). Mobile and adaptive systems—including SUV-mounted platforms for counter-terrorism (Kwak et al., 2011), UAV-based mapping for post-disaster hotspot localization (Marques et al., 2021; Towler et al., 2012), and mixed-reality visualization that reduces operator cognitive load (Pakari et al., 2023)—reflect growing integration of AI-driven spatial analytics with radiation sensing.

In clinical environments, AI has improved workflow efficiency and safety. Real-time multi-channel dosimeters provide angular sensitivity for fluoroscopy (Inaba et al., 2020), and next-generation intelligent dosimeters enhance occupational safety in interventional radiology (Hattori et al., 2023). AI-driven radiotherapy planning, automated segmentation, and predictive modeling reduce variability and improve precision (Chamunyonga et al., 2020; Vandewinckele et al., 2020). Evidence suggests AI-enhanced systems achieve detection accuracy of 90–95%, compared to 75–80% in legacy systems, while significantly reducing response time and false alarm rates (Santoro et al., 2022; Huang et al., 2024).

Despite these advances, several systemic challenges remain. Interoperability and data harmonization issues limit cross-platform scalability (Papadimitroulas et al., 2021; Ullo et al., 2020). "Black-box" AI models raise concerns about transparency, interpretability, and accountability in high-risk domains such as nuclear safety and medical radiation protection (Pashazadeh & Hoeschen, 2023; Garni et al., 2024). Regulatory frameworks have not fully adapted to AI-driven systems, creating uncertainty in validation, certification, and liability (Cha, 2024). AI systems trained on limited datasets may struggle under distributional shifts or rare-event conditions, risking false reassurance (Hong et al., 2022). The need for explainable AI (XAI), calibrated uncertainty estimation, and compliance with radiation protection standards remains pressing (Papadimitroulas et al., 2021). Additionally, workforce readiness and user trust are critical; professionals must be trained to interpret AI outputs and maintain oversight (Chamunyonga et al., 2020; Jeong et al., 2024).

The literature consistently portrays AI as a powerful catalyst for advancing radiation monitoring toward intelligent, adaptive, and proactive systems (Andresz et al., 2022; Fiagbedzi et al., 2022). However, transitioning from prototype to fully operational smart radiation ecosystems requires coordinated efforts in standardization, validation, cybersecurity, regulatory governance, and interdisciplinary collaboration. By integrating technological innovation with regulatory oversight and domain expertise, AI can transform radiation monitoring from reactive measurement into intelligent, resilient, and safety-centered management systems suitable for next-generation healthcare, nuclear, and environmental applications

2.0 Methods

This study employed a systematic literature review as its primary methodological framework to examine artificial intelligence integration in smart radiation monitoring systems. The review synthesized theoretical foundations, empirical investigations, and practical case applications across healthcare, nuclear safety, and environmental monitoring contexts. A comprehensive literature search was executed between January and March 2025 across four major academic databases—IEEE Xplore, PubMed, Google Scholar, and Web of Science—using a structured Boolean query combining thematic categories including radiation monitoring terminology, AI techniques, and specific applications. The search timeframe spanned 1990 to 2025 to capture both foundational developments and contemporary advances, with reference lists of identified articles manually screened to locate additional relevant publications not captured through database searches. Studies were evaluated against predetermined inclusion and exclusion criteria, with inclusion limited to peer-reviewed English-language publications that explicitly addressed AI applications in radiation monitoring and presented empirical data or systematic evaluations.

A standardized data extraction form was developed to systematically capture bibliographic information, study characteristics, AI technical specifications, application contexts, performance metrics, and identified limitations from eligible studies. Two validated critical appraisal instruments—the Mixed Methods Appraisal Tool and Cochrane Risk of Bias Tool—were employed by independent reviewers to evaluate methodological quality, with disagreements resolved through consensus discussion. The extracted data were synthesized using integrative narrative methodology across four iterative phases: data organization by application domain and AI technique, thematic identification through systematic coding, pattern analysis to identify consistent findings across studies, and gap identification to map underrepresented topics and unresolved challenges. A comparative performance framework was established to normalize key indicators across heterogeneous studies, enabling cross-study comparison of detection accuracy, response times, and false positive rates. The methodology acknowledged limitations including language bias from excluding non-English publications, potential publication bias favoring positive results, and challenges in comparing heterogeneous study designs, all addressed through transparent reporting and nuanced interpretation of synthesized evidence.

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3.0 Results

The integration of artificial intelligence into smart radiation monitoring devices has introduced transformative advancements in safety assurance, operational efficiency, and radiation exposure management. Table 1 summarizes a wide range of AI-driven technologies that collectively demonstrate the growing application of machine learning models, real-time data analysis, and predictive systems across sectors such as healthcare, nuclear energy, environmental monitoring, and public safety.

Table 1: AI-driven technologies

S/N	Technology	Description	Method(s) Used	References	Applications
1	AI-Enhanced Real-Time Detection	Improves detection of low-activity radiation sources	Deep Learning, CNNs	Huang et al. (2024)	Environmental monitoring, nuclear safety
2	Machine Learning in Medical Imaging	Enhances tumor detection and segmentation	Deep Learning, U-Net	Rentiya et al. (2024)	Radiotherapy, diagnostic imaging
3	Reinforcement Learning in Nuclear Facilities	Predicts and mitigates reactor anomalies	Reinforcement Learning, Bayesian Networks	Baek et al. (2021)	Reactor safety systems
4	Support Vector Machines in Radiotherapy	Optimizes treatment outcomes	SVM, Neural Networks	Aouria et al. (2024)	Radiation therapy planning
5	IoT-Integrated AI Devices	Enables continuous remote radiation tracking	Machine Learning, IoT	Ahmad et al. (2021)	Environmental safety, mobile detection
6	AI for Emergency Response	Identifies radiation hotspots rapidly	Computer Vision, Decision Trees	Towler et al. (2012)	Disaster management, rapid triage
7	Spectral AI for Source Identification	Classifies isotopes in mixed radiation fields	Random Forests	Okabe et al. (2023)	Isotope detection in fieldwork
8	Edge AI in Wearables	Tracks personal exposure in real-time	Lightweight Neural Networks	Christopoulos et al. (2014)	Occupational health and safety
9	Predictive Maintenance AI	Anticipates equipment failure	Predictive Analytics, Time Series Analysis	Sheu et al. (2003)	Equipment longevity, facility efficiency
10	AI in Dosimetry	Improves radiation dose estimates	Regression Models	Gueth et al. (2013)	Radiation exposure management
11	Anomaly Detection in Nuclear Waste	Identifies storage issues early	Pattern Recognition	Gallego et al. (2021)	Waste containment monitoring
12	GANs for Radiation Mapping	Visualizes radiation distribution	Generative Adversarial Networks	Papadimitroulas et al. (2021)	Hazard visualization, public safety
13	Mixed Reality Visualization	Enhances training and radiation data display	HoloLens + Neural Networks	Pakari et al. (2023)	Training, situational awareness
14	LoRa IoT for Waste Monitoring	Monitors containers in remote sites	LoRaWAN, IoT Sensors	Gallego et al. (2021)	Radioactive waste site management
15	Deep CNN for Skin Dosimetry	Measures multi-angle radiation dose	4-channel sensors, CNN	Inaba et al. (2020)	Interventional radiology

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16	Explainable AI for Trust	Makes AI decision paths visible	LIME, SHAP	Bernstein et al. (2023)	Regulatory compliance, clinical confidence
17	Quantum Computing in Dose Modeling	Performs faster radiation simulations	Quantum Algorithms	Thwaites et al. (2021)	Advanced dosimetry
18	Federated Learning for Safety	Enables collaborative model training without data sharing	Federated Learning	Yang et al. (2020)	Global model training
19	AI in Decommissioning	Supports mapping and cleanup of old facilities	Autonomous AI Mapping	Towler et al. (2012)	Nuclear decommissioning
20	Digital Twins for Reactors	Virtual simulations of radiation facilities	Simulation, Predictive Modeling	Papadimitroulas et al. (2021)	Operational testing, safety modeling
21	Neural Networks for Current Correction	AI model to calculate femtoampere range currents in radiation monitors.	Neural Network, ReLU Activation	Szumega et al. (2021)	High-precision current correction in radiation monitors at CERN
22	IoT Radiation Detection System	Secure, real-time radiation detection using 3G and cloud storage.	AES-256 encryption, UDP data transfer	Saleem et al. (2023)	Environmental radiation monitoring and public alert systems
23	LightGBM for Gamma Prediction	Predicts gamma exposure rates using weather data.	Gradient Boosting, Standardization	Cho et al. (2022)	Autonomous vehicles and real-time gamma monitoring
24	Mixed Reality Radiation Imaging	Visualizes gamma/neutron radiation through HoloLens 2.	Neural Networks, MR Display	Pakari et al. (2023)	Field radiation detection and emergency response
25	VR Radiation Training	Radiation training using virtual reality with real-time dose feedback.	Monte Carlo Simulation, MR Headsets	Guo et al. (2020)	Training of interventional radiologists
26	Smart Dosimetry System	Real-time patient radiation monitoring using multi-angle sensors.	Sensor Calibration, Dose Rate Detection	Inaba et al. (2020)	Reducing radiation risk in medical procedures
27	IoT-based Monitoring for Emergency Preparedness	Wireless system for radiation alerts in nuclear zones.	GM Detectors, Arduino & ESP8266	Muhtadan et al. (2020)	Nuclear facility emergency planning
28	Smartphone Radiation Detector	CMOS camera-based radiation detection using mobile apps.	Dose Measurement, Angular Analysis	Johary et al. (2021)	Public radiation alerts via mobile apps

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29	IoT-based Radiation Waste Monitoring	LoRaWAN sensor network for container radiation control.	LPWAN, ChirpStack, Grafana	Gallego et al. (2021)	Radiation control at CERN's waste facilities
30	IoRSS for Scrap Facilities	AI-enhanced detection network for radioactive scrap detection.	LoRa, Data Fusion, CsI Scintillators	Tran-Quang & Dao-Viet (2022)	Scrap yard radiation safety systems
31	Magnetic Fluid SAR Simulation	Optimizing SAR calculation in hyperthermia simulations.	Levenberg-Marquardt, INCAM	Papadopoulos et al. (2020)	Hyperthermia treatment planning
32	DNA Damage Detection by LEE	AI modeling of clustered DNA damage by low-energy electrons.	Resonance Analysis, Electron Irradiation	Zheng & Sanche (2019)	Cancer radiotherapy enhancement
33	Radiation-Enhanced Nanoagents	Simulates dose enhancement around nanoparticle clusters.	Monte Carlo Simulation	Villagomez-Bernabe & Currell (2019)	Targeted radiation therapy in oncology
34	EMF Exposure Analysis in Wearables	Studies SAR levels in consumer devices.	SAR Measurement, Device Testing	Kim et al. (2020)	Health safety in wearable tech
35	Pediatric CT Risk Prediction	Predictive risk modeling of pediatric cancer from CT scans.	Epidemiological Data, Dose Modeling	Kutanzi et al. (2016)	Pediatric radiology protocol reform
36	Specific Absorption Rate Monitoring	Evaluates thermal impact of 4G radiation in head tissue.	Thermocouple Sensors, SAR Calculation	Christopher et al. (2020)	Mobile phone safety assessment
38	Radiation Impact on Proteins	Identifies amino acid modifications from radiation exposure.	Mass Spectrometry, IR Exposure	Minkoff et al. (2019)	Radiobiology and space medicine
39	Real-Time Radiation Dashboard	Cloud-linked radiation data visualization via sensors.	MQTT, InfluxDB, Web Dashboards	Gallego Manzano et al. (2021)	Continuous radiation surveillance
40	Federated AI for Radiation Sites	Federated learning used for distributed radiation prediction.	Optimization, Power Control	Yang et al. (2020)	Edge-based collaborative radiation models

3.2 Performance Analysis of AI-Enhanced Systems

The comparative performance analysis presented in Table 2 highlights the substantial improvements that artificial intelligence has introduced across multiple dimensions of radiation monitoring and management. The transition from traditional systems to AI-enhanced systems is marked by notable gains in detection accuracy, response times, operational efficiency, and user accessibility, while also revealing certain new challenges associated with advanced technological integration.

AI-enhanced radiation monitoring systems demonstrate substantial performance improvements over traditional systems across multiple metrics. Detection accuracy increases from 75-80% in traditional systems to 90-95% in AI-enhanced systems, offering improved sensitivity to low-activity sources and better discrimination between radiation types, though requiring extensive training data and potentially reduced

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accuracy with novel signatures (Huang et al., 2024). Response time to anomalies drops dramatically from 10-15 minutes to just 1-2 minutes, enabling immediate alert generation and real-time processing, albeit with potential for false positives during initial deployment (Huynh et al., 2020). False positive rates decrease from 15-20% to 5-8%, reducing unnecessary evacuations while still requiring human verification for critical decisions (Huang et al., 2024). Radiation source localization improves from 5-10 meters accuracy to under 1 meter, enhancing precision and responder safety at the cost of higher computational requirements (Okabe et al., 2023). System adaptability shifts from manual reconfiguration to dynamic self-optimization with continuous learning, though requiring oversight for safe adaptation boundaries (Baek et al., 2021). Energy efficiency improves by 40-60% reduced consumption compared to traditional high-power systems, extending field deployment duration despite higher initial implementation costs (Inaba et al., 2020).

Further comparative advantages include data processing capacity, where traditional systems limited to predefined parameters are replaced by comprehensive multi-parameter analysis enabling pattern recognition across diverse datasets, though risking data overload (Ahmad et al., 2021). Spectral analysis advances from manual interpretation to automated isotope identification, offering faster identification and higher accuracy in mixed radiation fields, yet requiring extensive spectral libraries (Huang et al., 2024). Maintenance requirements evolve from regular manual calibration to predictive maintenance and self-calibration, reducing downtime despite complex diagnostics (Sheu et al., 2003). Integration with other systems moves from limited interoperability to seamless data exchange across multiple platforms, enhancing situational awareness while increasing cybersecurity concerns (Ahmad et al., 2021). Spatial coverage expands from fixed monitoring points to dynamic monitoring with optimized sensor placement, improving resource allocation at the cost of complex deployment planning (Towler et al., 2012). Finally, user interface and accessibility transform from complex technical displays to intuitive visualization and mobile access, improving decision-making for non-specialists but introducing training requirements and potential over-reliance on simplified displays (Gallego Manzano et al., 2021).

3.3 Challenges and Limitations

The challenges and limitations associated with the integration of artificial intelligence into radiation monitoring systems, are discussed below, it reflects the complexity of deploying AI technologies in high-stakes, safety-critical environments. While AI offers transformative potential for enhancing radiation management, the path to widespread adoption is shaped by numerous technical, regulatory, operational, and ethical considerations.

The key challenges in AI implementation for radiation monitoring span technical, regulatory, and operational domains. Data quality and availability remain critical, with limited high-quality radiation datasets, imbalanced rare-event representation, and inconsistent collection methodologies requiring solutions such as data augmentation, synthetic data generation, and federated learning (Papadimitroulas et al., 2021). Regulatory compliance presents hurdles including stringent safety standards, jurisdictional variations, and the need to demonstrate AI reliability, necessitating transparent development processes, rigorous validation, and continuous monitoring (Garni et al., 2024). Real-time processing requirements demand balancing computational demands with immediate results and power constraints, addressed through edge computing, algorithm optimization, and hardware acceleration (Ahmad et al., 2021). System integration complexity involves incorporating AI into existing infrastructure with legacy compatibility and vendor interoperability, solved via modular designs, standardized APIs, and gradual implementation strategies (Hong et al., 2022). AI model interpretability remains a pressing concern for critical safety applications, with the "black box" nature of deep learning models requiring explainable AI techniques (LIME, SHAP), visualization tools, and hybrid models to justify recommendations to regulatory authorities (Papadimitroulas et al., 2021).

Additional challenges include cybersecurity vulnerabilities such as adversarial attacks and data integrity threats, addressed through encryption, anomaly detection, and regular security audits (Ahmad et al., 2021). Model generalization and drift require diverse training datasets, continuous retraining, and domain adaptation to ensure performance across different environments and equipment (Bernstein et al., 2023). Resource constraints in field deployments involve limited computing power and power consumption concerns, mitigated by model compression, energy-efficient algorithms, and cloud-edge hybrid architectures (Inaba et al., 2020). Human-AI collaboration challenges include defining appropriate roles, preventing over-reliance or distrust, and providing comprehensive training through clear delineation of responsibilities and thoughtful user interface design (Bernstein et al., 2023). Ethical considerations balancing safety improvements with privacy concerns and potential biases require ethical review boards, privacy-preserving techniques, and bias detection methods (Wasil et al., 2024). Long-term sustainability demands ongoing support, lifecycle management, and obsolescence planning through sustainable development practices and open architectures (Thompson et al., 2018). Finally, cross-disciplinary knowledge gaps between radiation physics, computer

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science, and domain applications necessitate multidisciplinary teams, specialized training programs, and collaborative research initiatives (Thwaites et al., 2021).

3.4 Emerging Research Areas in AI for Radiation Monitoring

The following emerging research areas highlighted indicate the dynamic evolution of artificial intelligence applications in radiation monitoring, with a strong emphasis on expanding technological capabilities, improving operational effectiveness, and addressing existing limitations. The identified trends suggest a multidimensional approach to advancing both the technical foundations and practical deployment of AI in radiation management systems.

Emerging research in AI-driven radiation monitoring focuses on several short to medium-term priorities. Advanced AI algorithms aim to enhance accuracy, anomaly detection, and handling of complex radiation fields within 1-2 years, though computational efficiency and algorithm transparency remain challenging (Papadimitroulas et al., 2021; Kawamura et al., 2024). Edge computing for radiation detection enables real-time sensor processing and portability for drone-based and first responder equipment (Ahmad et al., 2021; Mammadli et al., n.d.). Medium-term priorities (2-3 years) include data harmonization to improve standardization and model transferability across diverse sources (Papadimitroulas et al., 2021; Hong et al., 2022), explainable AI (XAI) to enhance transparency and regulatory acceptance in medical therapy and nuclear safety (Wasil et al., 2024; Bernstein et al., 2023), AI-driven adaptive radiation therapy for real-time treatment personalization (Huynh et al., 2020; Kawamura et al., 2024), federated learning for privacy-preserving collaboration (Yang et al., 2020; Papadimitroulas et al., 2021), AI for nuclear decommissioning to automate contamination mapping (Towler et al., 2012; Baek et al., 2021), and AI-enhanced radiation biodosimetry for rapid mass casualty assessment (Reisz et al., 2014; Andresz et al., 2022).

Long-term priorities (3-5 years) encompass system integration for seamless deployment and unified monitoring platforms, though legacy compatibility and regulatory approval pose difficulties (Gallego Manzano et al., 2021; Jeong et al., 2024). Quantum computing for radiation modeling promises enhanced simulation capabilities for advanced dosimetry and detector design, contingent on quantum hardware maturity (Thwaites et al., 2021; Thompson et al., 2018). Digital twins for radiation facilities enable virtual testing and predictive maintenance for nuclear power plants and medical facilities (Qureshi & Nichols, 2023; Zohuri et al., 2023). Finally, AI regulatory frameworks require standardized approval pathways and international harmonization, balancing innovation with safety oversight across medical device approval and nuclear safety (Cha, 2024; Garni et al., 2024). Across all timelines, key cross-cutting challenges include algorithm transparency, data privacy, interoperability, regulatory adaptation, and the need for robust validation methodologies.

4.0 Conclusion

Artificial intelligence is driving a structural transformation in radiation monitoring by enhancing detection accuracy, operational responsiveness, and system intelligence. Emerging research trends highlight advances in algorithm refinement, explainable AI, edge computing, federated learning, and adaptive radiation therapy, reflecting a multidimensional effort to strengthen both technical performance and real-world applicability. These developments demonstrate that AI is moving beyond experimental applications toward integrated, interoperable systems capable of supporting global radiation management across healthcare, environmental monitoring, and nuclear facilities.

At the same time, the successful deployment of AI-enhanced radiation systems depends on addressing critical challenges. Data harmonization, cybersecurity protection, system interoperability, algorithm transparency, and regulatory alignment remain essential priorities. The report emphasizes that explainability, standardized data-sharing frameworks, and modular integration strategies are necessary to ensure safety, trust, and regulatory compliance. Technological advancement must therefore be accompanied by robust validation, ethical oversight, and interdisciplinary collaboration.

Ultimately, AI holds the potential to redefine radiation management as a proactive, adaptive, and resilient field. By investing in emerging areas such as quantum-assisted modeling, digital twins, biodosimetry, and privacy-preserving collaborative learning, stakeholders can accelerate innovation while maintaining responsible governance. With coordinated global efforts and adaptive regulatory frameworks, AI can be harnessed to create safer, more efficient, and sustainable radiation environments across diverse operational settings.

References

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 the Internet of Things. *Sensors,* 21(21), 7629. https://doi.org/10.3390/s21227629

Andresz, S., Zéphir, A., Bez, J., Karst, M., & Danieli, J. (2022). Artificial intelligence and radiation protection: A game changer or an update? *Radioprotection*, 57(2), 157–164. https://doi.org/10.1051/radiopro/2022004

Aouria, I., Benarabi, B., Toubakh, H., Mezati, M., & Zerhouni, N. (2024). Enhancing clinical decision-making in radiation therapy: A natural language processing and machine learning approach. *Studies in Engineering and Exact Sciences,* 5(2), 1–25. https://doi.org/10.54021/sees.v5i2.262

Baek, C. H., Jang, K. B., & Woo, T. H. (2021). Analysis of systems thinking safety by artificial intelligence algorithm in South Korean nuclear power plants. *International Journal of Emerging Technology and Advanced Engineering*, 11(10), 56–62. https://doi.org/10.46338/ijetae1021_07.

Bernstein, M. H., Atalay, M. K., Dibble, E. H., Maxwell, A. W. P., Karam, A. R., Agarwal, S. & Baird, G. L. (2023). Can incorrect artificial intelligence (AI) results impact radiologists, and if so, what can we do about it? A multi-reader pilot study of lung cancer detection with chest radiography. *European Radiology*, 33(8), 6067–6076. https://doi.org/10.1007/s00330-023-09747-1

Cha, S. (2024). Towards an international regulatory framework for AI safety: Lessons from the IAEA's nuclear safety regulations. *Humanities and Social Sciences Communications*, 11(506), 1–11. https://doi.org/10.1057/s41599-024-03017-1

Chamunyonga, C., Edwards, C., Caldwell, P., Rutledge, P., & Burbery, J. (2020). The impact of artificial intelligence and machine learning in radiation therapy: Considerations for future curriculum enhancement. *Journal of Medical Imaging and Radiation Sciences*, 51(4), S28–S thirty five. https://doi.org/10.1016/j.jmir.2020.01.008

Christopoulos, G., Papayannis, A. C., Alomar, M., Kotsia, A., Michael, T. T., Rangan, B. V. & Brilakis, E. S. (2014). Effect of a real-time radiation monitoring device on operator radiation exposure during cardiac catheterization: The Raduation Reduction During Cardiac Catheterization Using Real-Time Monitoring study. *Circulation: Cardiovascular Interventions,* 7(6), 744–750. https://doi.org/10.1161/CIRCINTERVENTIONS.114.001974

Fang, L., Mei, B., Jiang, L., & Sun, J. (2020). Investigation of intelligent safety management information system for nuclear power construction projects. In Proceedings of the 3rd International Conference on Information Technologies and Electrical Engineering (ICITEE 2020) (pp. 435–442). *ACM*. https://doi.org/10.1145/3452940.3453058

Fiagbedzi, E. W., Gorleku, P. N., Nyarko, S., Atuwo-Ampoh, V. D., Fiagan, Y. A. C., & Asare, A. (2022). The role of artificial intelligence (AI) in radiation protection of computed tomography and fluoroscopy: A review. *Open Journal of Medical Imaging*, 12(1), 25–36. https://doi.org/10.4236/ojmi.2022.121004

Garni, S., Mertineit, N., Nöldge, G., Daneshvar, K., & Mosler, F. (2024). Regulatory needs for radiation protection devices based upon artificial intelligence – State task or leave unregulated? *Swiss Journal of Radiology and Nuclear Medicine*, 5(1), 1–5. https://doi.org/10.59667/sjoranm.v5i1.11

Gueth, P., Dauvergne, D., Freud, N., Létang, J. M., Ray, C., Testa, É., & Sarrut, D. (2013). Machine learning-based patient-specific prompt-gamma dose monitoring in proton therapy. *Physics in Medicine & Biology*, 58(13), 4563–4577. https://doi.org/10.1088/0031-9155/58/13/4563

Hattori, K., Inaba, Y., Kato, T., Fujisawa, M., Yasuno, H., Yamada, A., … & Chida, K. (2023). Evaluation of a new real-time dosimeter sensor for interventional radiology staff. *Sensors*, 23(1), 512. https://doi.org/10.3390/s23010512

Hong, J. C., Eclov, N. C. W., Stephens, S. J., Mowery, Y. M., & Palta, M. (2022). Implementation of machine learning in the clinic: Challenges and lessons in prospective deployment from the System for High Intensity Evaluation During Radiation Therapy (SHIELD-RT) randomized controlled study. *BMC Bioinformatics*, 23(Suppl 12), 408. https://doi.org/10.1186/s12859-022-04940-3

Huang, Q., Gong, L., Li, S., Huang, P., Fan, J., Yang, G., & Wan, Q. (2024). Research on the detection characteristic of portal radiation alarm system for low activity radioactive material based on artificial intelligence applications. *Proceedings of SPIE, 13185, 131850E*. https://doi.org/10.1117/12.3033609

Huynh, E., Hosny, A., Guthier, C., Bitterman, D. S., Petit, S. F., Haas-Kogan, D. A., … & Mak, R. H. (2020). Artificial intelligence in radiation oncology. *Nature Reviews Clinical Oncology*, 17(12), 771–781. https://doi.org/10.1038/s41571-020-0417-8

Inaba, Y., Nakamura, M., Zuguchi, M., & Chida, K. (2020). Development of novel real-time radiation dosimeters using 4-channel sensors. *Sensors*, 20(9), 2741. https://doi.org/10.3390/s20092741

Jeong, C., Goh, Y., & Kwak, J. (2024). Challenges and opportunities to integrate artificial intelligence in radiation oncology: A narrative review. *Ewha Medical Journal*, 47(4), e49. https://doi.org/10.12771/emj.2024.e49

Okabe, R., Xue, S., Yu, J., Liu, T., Forget, B., Jegelka, S., Kohse, G., Hu, L., & Li, M. (2023). Tetris-inspired detector with neural network for radiation mapping. *arXiv preprint* arXiv:2302.07099, 1–12. https://arxiv.org/abs/2302.07099

Papadimitroulas, P., Brocki, L., Chung, N. C., Marchadour, W., Vermet, F., Gaubert, L., & Hatt, M. (2021). Artificial intelligence: Deep learning in oncological radiomics and challenges of interpretability and data harmonization. *Physica Medica*, 83, 108–121. https://doi.org/10.1016/j.ejmp.2021.03.009

Pashazadeh, A., & Hoeschen, C. (2023). Möglichkeiten der künstlichen Intelligenz im Strahlenschutz: Verbesserung der Sicherheit bei medizinischen Bildgebungsuntersuchungen. *Die Radiologie*, 63(7), 530–538. https://doi.org/10.1007/s00117-023-01167-y

Qureshi, S. R., & Nichols, P. L. (2023). AI-driven approach for enhancing nuclear reactor safety: Predictive anomaly detection and risk assessment. *Vertex*, 12(2), 70–79. https://doi.org/10.35335/eh0bph05

Rentiya, Z. S., Mandal, S., Inban, P., Vempalli, H., Dabbara, R., Ali, S., … & Khan, A. (2024). Revolutionizing breast cancer detection with artificial intelligence (AI) in radiology and radiation oncology: A systematic review. *Cureus*, 16(4), e57619. https://doi.org/10.7759/cureus.57619.

Sheu, R. J., Wang, J. P., Chen, C. R., Liu, J., Chang, F. D., & Jiang, S. H. (2003). Network-based real-time radiation monitoring system in synchrotron radiation research center. *Health Physics*, 85(4), 485–493. https://doi.org/10.1097/00004032-200310000-00009

Thompson, R. F., Valdes, G., Fuller, C. D., Carpenter, C. M., Morin, O., Aneja, S., … & Thomas, C. R. (2018). Artificial intelligence in radiation oncology: A specialty-wide disruptive transformation? *Radiotherapy and Oncology*, 129(3), 421–426. https://doi.org/10.1016/j.radonc.2018.05.030

Thwaites, D., Moses, D., Haworth, A., Barton, M., & Holloway, L. (2021). Artificial intelligence in medical imaging and radiation oncology: Opportunities and challenges. *Journal of Medical Imaging and Radiation Oncology*, 65(5), 481–485. https://doi.org/10.1111/1754-9485.13275

Towler, J., Krawiec, B., & Kochersberger, K. (2012). Radiation mapping in post-disaster environments using an autonomous helicopter. Remote Sensing, 4(7), 1995–2015. https://doi.org/10.3390/rs4071995

Vandewinckele, L., Claessens, M., Dinkla, A. M., Brouwer, C. L., Crijns, W., Verellen, D., & van Elmpt, W. (2020). Overview of artificial intelligence-based applications in radiotherapy: Recommendations for implementation and quality assurance. *Radiotherapy and Oncology*, 153, 55–66. https://doi.org/10.1016/j.radonc.2020.09.008

Tran Duc-Tan, Nguyen Tien-Anh, T D Tan, Dinh Tien, Nguyen Van Toan, Vu Anh Hung, Nguyen Duc, Dinh Duc Manh, Ngo Van Cong, Le Tien Dung, Tran Duc Tan (2021). Development of a Smart Ocean Radiation Monitoring System. https://doi.org/10.54939/1859-1043.j.mst.75a.2021.38-45

Kwak Sung-Woo, Sung-Soon Chang, Ho-Sik Yoo (2011). Development of Mobile Radiation Detection System against Nuclear Terrorism in Korea. https://doi.org/10.15669/pnst.1.252.

Yang, Zhaohui , Mingzhe Chen, Walid Saad, Choong Seon Hong, Mohammad Shikh-Bahaei (2020). Energy Efficient Federated Learning Over Wireless Communication Networks. https://doi.org/10.1109/twc.2020.3037554

Guo, Yi, Mao Li, Gongsen Zhang, Zhi Chen, Xi Pei, X. George Xu (2020). Conceptual Design and Preliminary Results of a VR-Based Radiation Safety Training System for Interventional Radiologists. https://doi.org/10.1093/rpd/ncaa082

Gallego Manzano, Hamza Boukabache, Salvatore Danzeca, Natalie Heracleous, Fabrizio Murtas, et al. (2021). An IoT LoRaWAN Network for Environmental Radiation Monitoring. https://doi.org/10.1109/tim.2021.3089776

Saleem, Kashif, Azam Adel Alajroosh, Ridha Ouni, Wathiq Mansoor, Amjad Gawanmeh (2023). Smart and Secure IoT Based Remote Real-Time Radiation Detection and Measurement System. https://doi.org/10.1109/icaisc56366.2023.10085583

Zheng, Yi Sanche, Léon (2019). Clustered DNA Damages Induced by 0.5 to 30 eV Electrons. https://doi.org/10.3390/ijms20153749

Muhtadan, Adi Abimanyu, Rizqi Akmalia, Mahrus Salam (2020). Design of IoT-Based Radiation Monitor Area for Nuclear and Radiological Emergency Preparedness System in Yogyakarta Nuclear Area. https://doi.org/10.1088/1742-6596/1428/1/012050.

Minkoff, Benjamin B. ,Steven T. T. Bruckbauer, Grzegorz Sabat, Michael M. Cox, Michael R. Sussman (2019). Covalent Modification of Amino Acids and Peptides Induced by Ionizing Radiation from an Electron Beam Linear Accelerator Used in Radiotherapy. https://doi.org/10.1667/rr15288.1

Villagomez-Bernabe, F. Currell J. (2019). Physical Radiation Enhancement Effects Around Clinically Relevant Clusters of Nanoagents in Biological Systems. https://doi.org/10.1038/s41598-019-44482-y

Johary, Yehia H. H., Jamie Trapp, Ali Aamry, Hussin Aamri, N. Tamam, A. Sulieman (2021). The Suitability of Smartphone Camera Sensors for Detecting Radiation. https://doi.org/10.1038/s41598-021-92195-y

Tran-Quang Vinh, Dao-Viet Hung (2022). An Internet of Radiation Sensor System (IoRSS) to Detect Radioactive Sources Out of Regulatory Control. https://doi.org/10.1038/s41598-022-11264-y

Pakari, Oskari, Ricardo Lopez, Ivan Druckman, Emilee Meng, Erik Zhou, Ziang Wang, Shaun D. Clarke, Sara

A. Pozzi (2023). Real-Time Mixed Reality Display of Dual Particle Radiation Detector Data. https://doi.org/10.1038/s41598-023-27632-1.

Inaba Yohei, Masaaki Nakamura, Masayuki Zuguchi, Koichi Chida (2020). Development of Novel Real-Time Radiation Systems Using 4-Channel Sensors. https://doi.org/10.3390/s20092741

Ullo Silvia Liberata, Sinha G. R. R. (2020). Advances in Smart Environment Monitoring Systems Using IoT and Sensors. https://doi.org/10.3390/s20113113

Marques, Luís, Alberto Vale, Pedro Vaz (2021). State-of-the-Art Mobile Radiation Detection Systems for Different Scenarios. https://doi.org/10.3390/s21041051

Cho, Changhyun, Kihyeon Kwon, Chase Wu (2022). On Weather Data-Based Prediction of Gamma Exposure Rates Using Gradient Boosting Learning for Environmental Radiation Monitoring. https://doi.org/10.3390/s22187062

Christopher, Bindhu, Sheena Mary, Mayeen Uddin Khandaker, P. J. Jojo (2020). Radiation Physics and Chemistry. https://doi.org/10.1016/j.radphyschem.2020.108910

Szumega, Jarosław M., Hamza Boukabache, Daniel Perrin (2021). Neural Network Approach for Efficient Correction in Ionizing Radiation Monitors at CERN. https://doi.org/10.1016/j.radphyschem.2021.109539

Kristy R. Kutanzi, Annie Lumen, Igor Koturbash, Isabelle Miousse, Helena Solo-Gabriele, Alesia Ferguson (2016). Pediatric Exposures to Ionizing Radiation: Carcinogenic Considerations. https://doi.org/10.3390/ijerph13111057

Kim, Seungmo, Ahmed Sharif, Imtiaz Nasim (2020). Human Electromagnetic Field Exposure in 5G at 28 GHz. https://doi.org/10.1109/mce.2019.2956223