TRANSFORMING SAFETY, SIMULATION, AND COLLABORATION IN THE NUCLEAR RESEARCH THROUGH IMMERSIVE VIRTUAL REALITY

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The integration of immersive virtual reality (IVR) into nuclear research represents a transformative shift in how complex nuclear systems are designed, analysed, and managed. IVR technologies, encompassing virtual reality (VR), augmented reality (AR), and mixed reality (MR), offer unparalleled opportunities to simulate high-risk nuclear environments, train personnel, and optimise operational protocols in a safe, cost-effective manner. This research explores the applications, benefits, and challenges of IVR in nuclear research, emphasising its role in advancing safety, precision, and innovation within the field. One of the most critical applications of IVR lies in nuclear facility design and simulation. By creating photorealistic, interactive 3D models of reactors, fuel cycles, and waste management systems, researchers can test hypothetical scenarios, identify design flaws, and validate safety measures without exposing personnel to radiation hazards. Such simulations reduce reliance on physical prototypes, accelerating development timelines and minimising costs. In radiation safety training, IVR has emerged as a game-changer, offering immersive modules that replicate emergency scenarios, such as reactor malfunctions or containment breaches. Trainees can practise evacuation procedures, radiation shielding, and equipment handling in hyper-realistic environments, enhancing preparedness while eliminating exposure risks. Studies indicate that IVR-trained personnel demonstrate higher retention rates and decision-making accuracy compared to traditional methods. IVR also plays a pivotal role in decommissioning and waste management. IVR facilitates remote collaboration, enabling global experts to interact with shared virtual models, annotate designs, and troubleshoot challenges in real time—a critical advantage in a field often constrained by geopolitical and accessibility barriers. The adoption of IVR in nuclear research faces challenges. Data security concerns arise, as IVR systems handling sensitive nuclear data must adhere to stringent cybersecurity protocols. The fidelity of simulations depends on accurate integration of real-world data, necessitating robust partnerships between IVR developers and nuclear scientists. Advancements in AI-driven predictive modeling and real-time data analytics are poised to enhance IVR's capabilities. The fusion of IVR with digital twins and machine learning could enable autonomous scenario generation, predictive maintenance, and adaptive training programmes. As these technologies mature, IVR will likely become a cornerstone of nuclear research, fostering safer, more efficient, and collaborative approaches to managing one of humanity's most complex energy frontiers. This research underscores the necessity of interdisciplinary collaboration and sustained investment to unlock IVR's full potential in addressing the grand challenges of nuclear science and engineering.

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