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Exploring the Intersection of AI and Visualization in the Nuclear Industry

November 2024

Rajiv Khadka

Changing the World's Energy Future

Idaho National Laboratory

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Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy

Idaho National Laboratory

About me

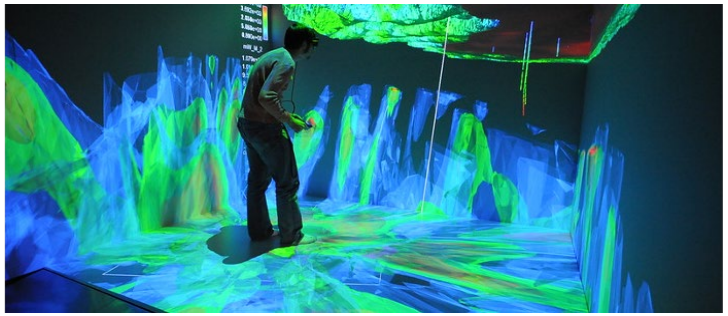
- Rajiv Khadka
  - Visualization Researcher, Applied Visualization Laboratory
  - Joint Appointment, Idaho State University

- Conducting research in:
  - Virtual Reality/Augmented Reality, 3D User Interfaces, HCI
  - Immersive Data Visualization
  - Immersive Analytics (3D), Digital Twins

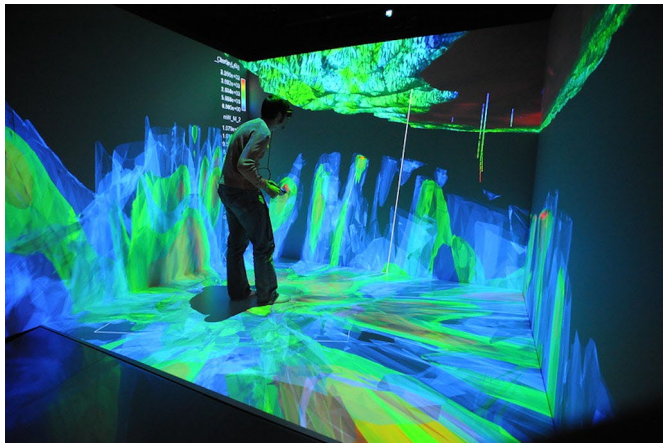
Applied Visualization Laboratory (AVL)

Applied Visualization Laboratory (AVL)

- Established in 2009
- Center for Advanced Energy Studies (CAES)
- Contains state-of-the-art visualization technologies (2D to 3D)

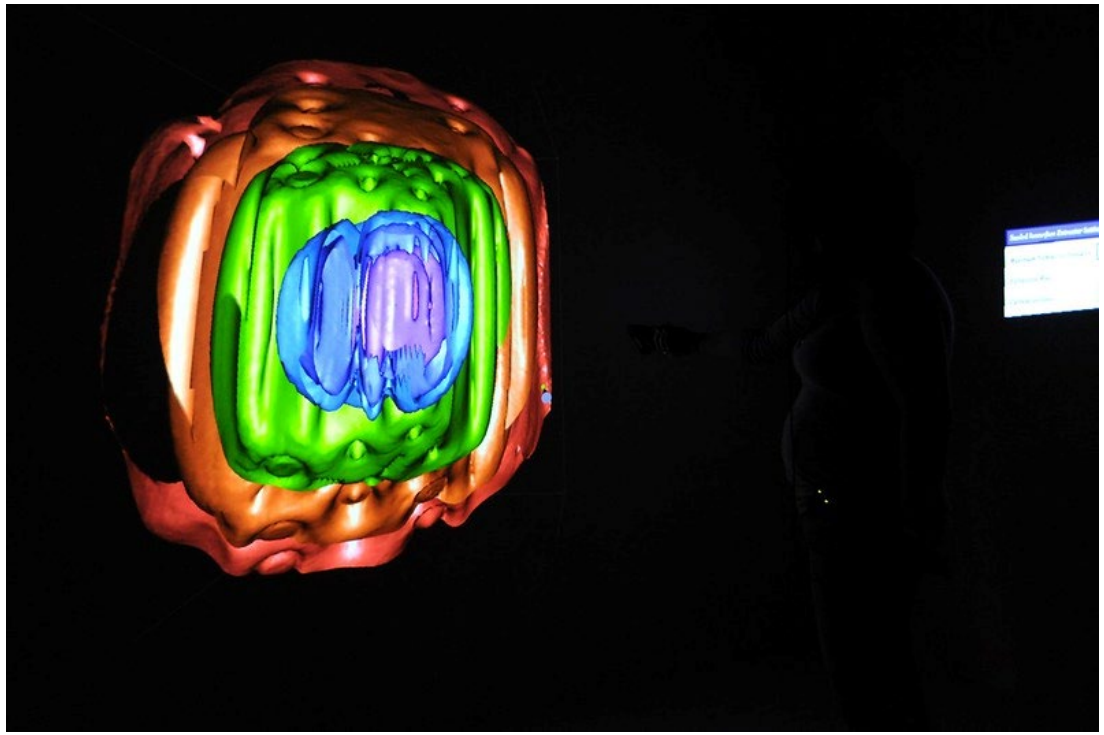


Applied Visualization Laboratory (AVL)



AVL Portfolio

Scientific Visualization

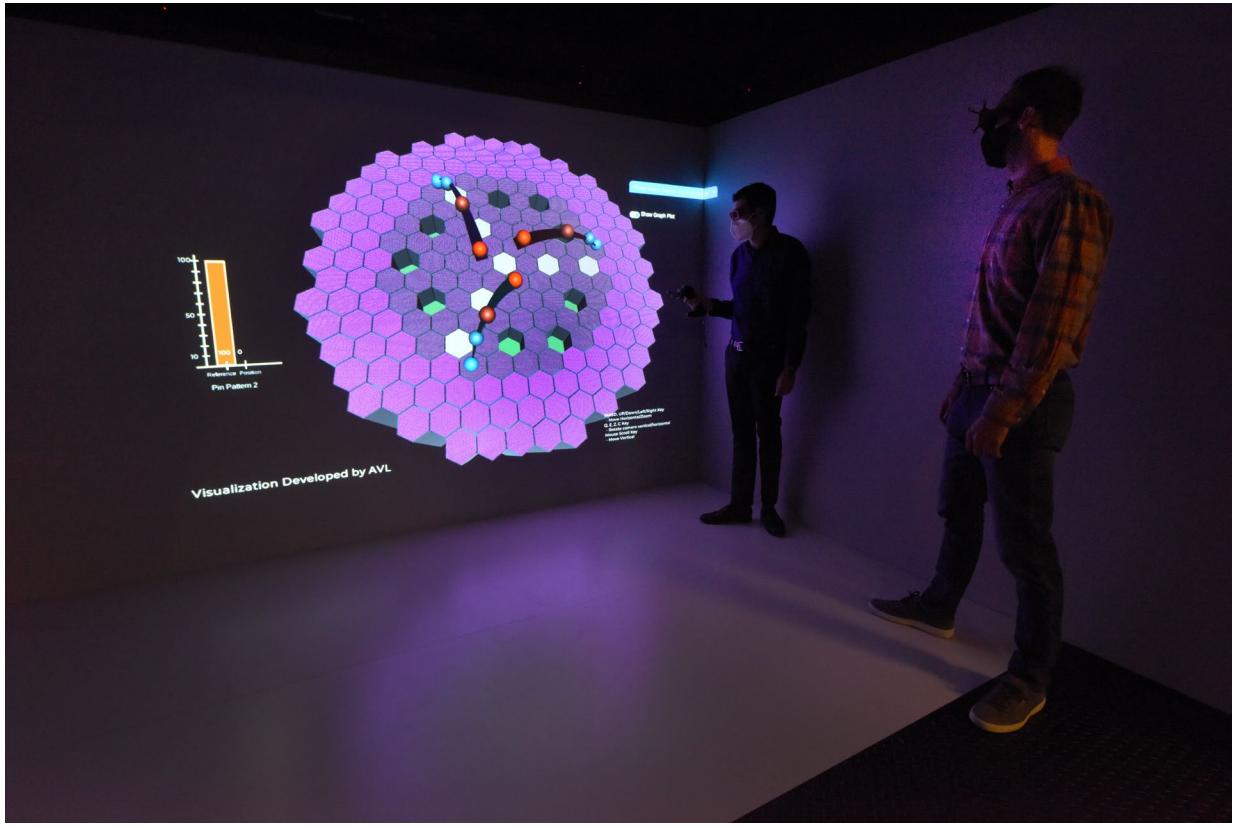


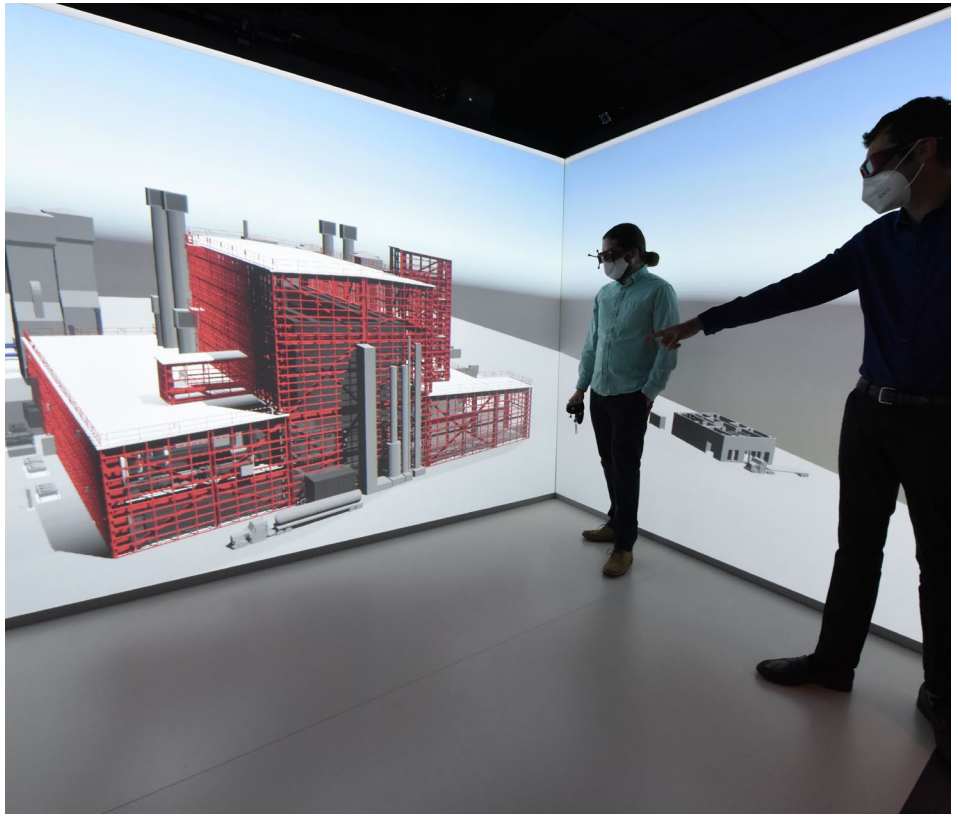
Neutron flux levels generated in the core of INL's Advanced Test Reactor during operation. Neutron levels are highest in the blue and purple areas, and lower in the orange and red areas.

Engineering Prototype & Designs

Virtual Prototype of Mobile Hot Cell (left), radiation modeling of the environment (middle) and inner components (right)

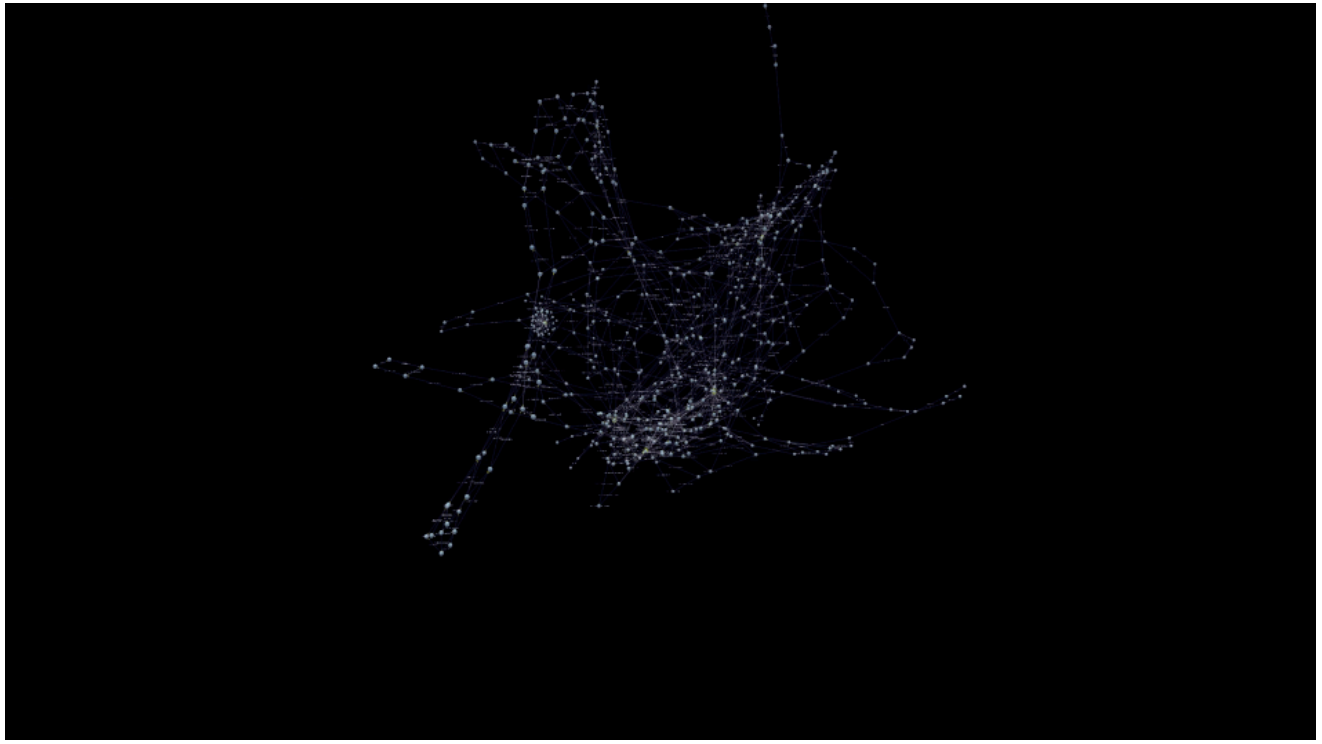
Digital Twins – Design and Planning

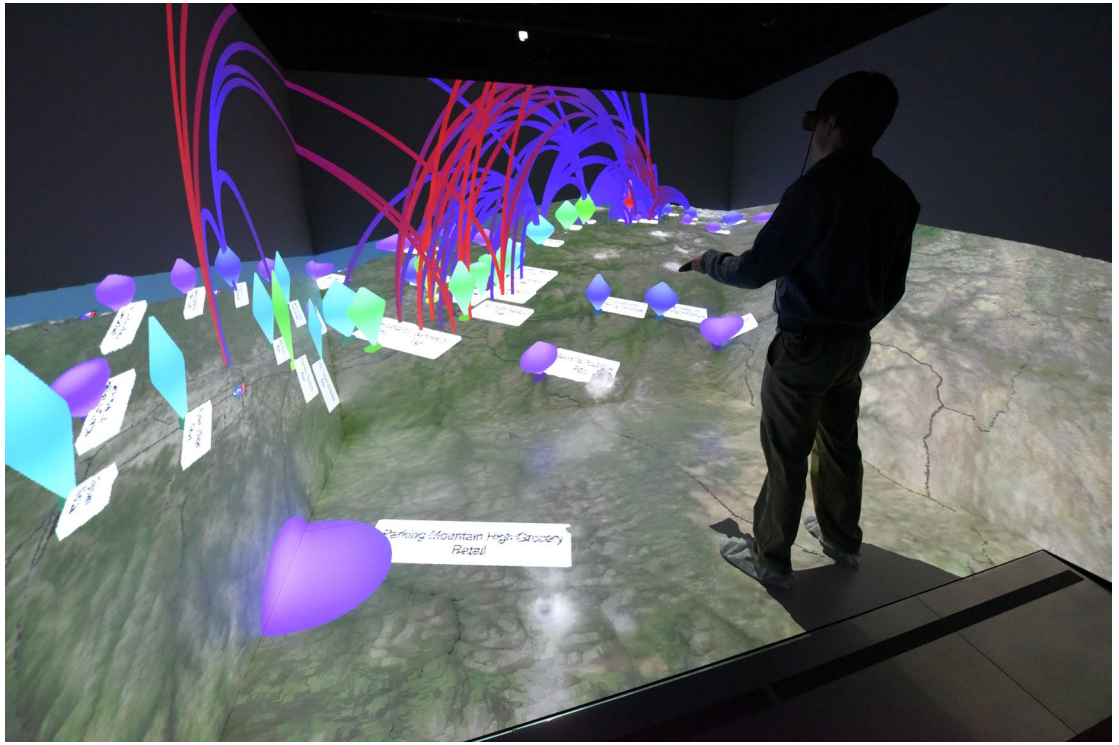




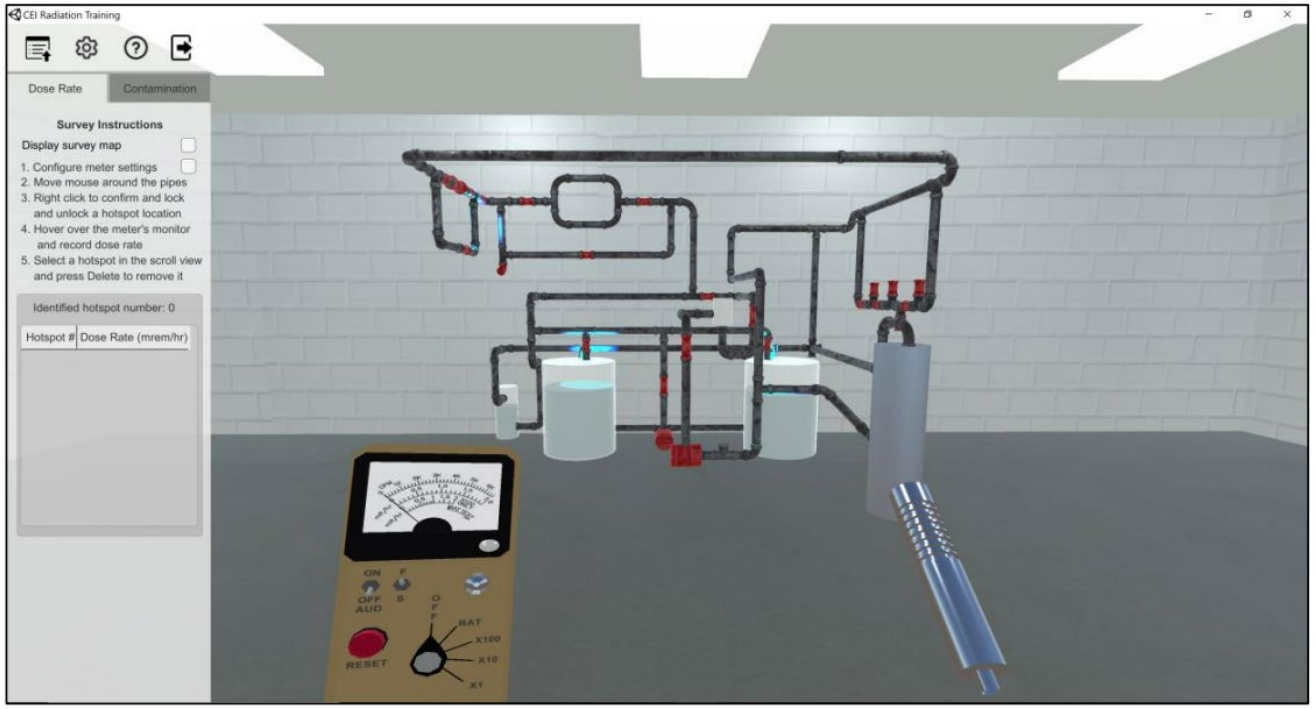
Human Factors and Ergonomics

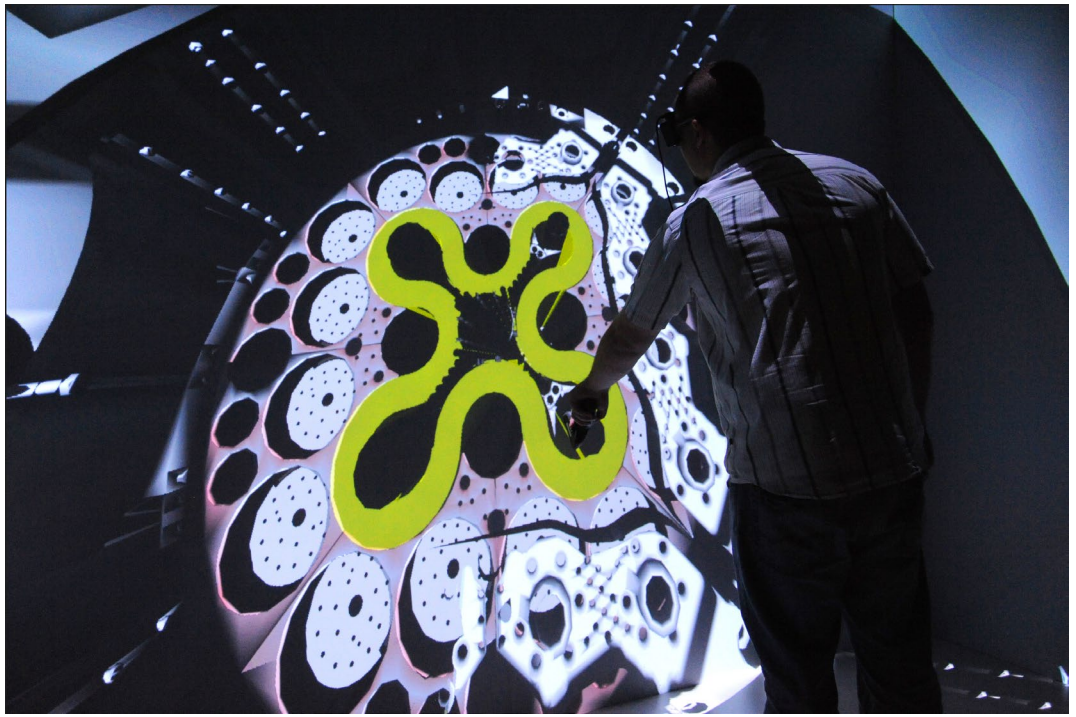
Immersive Analytics





Training and Simulation

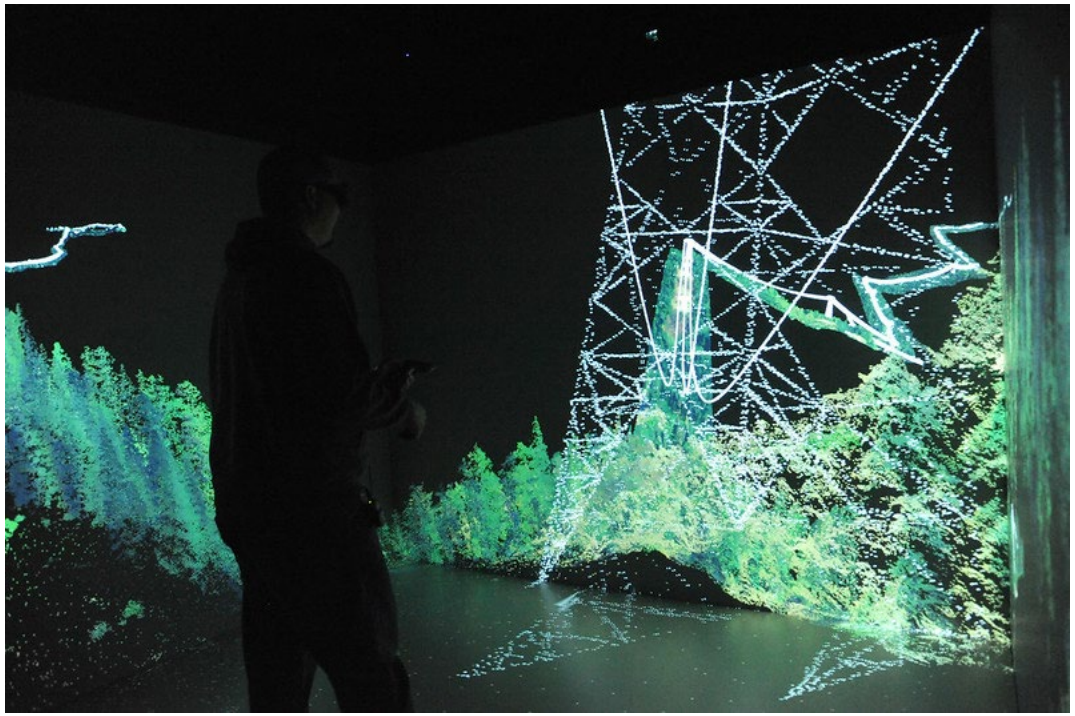




A user using CAVE to interact with ATR core to understand its design and operations.

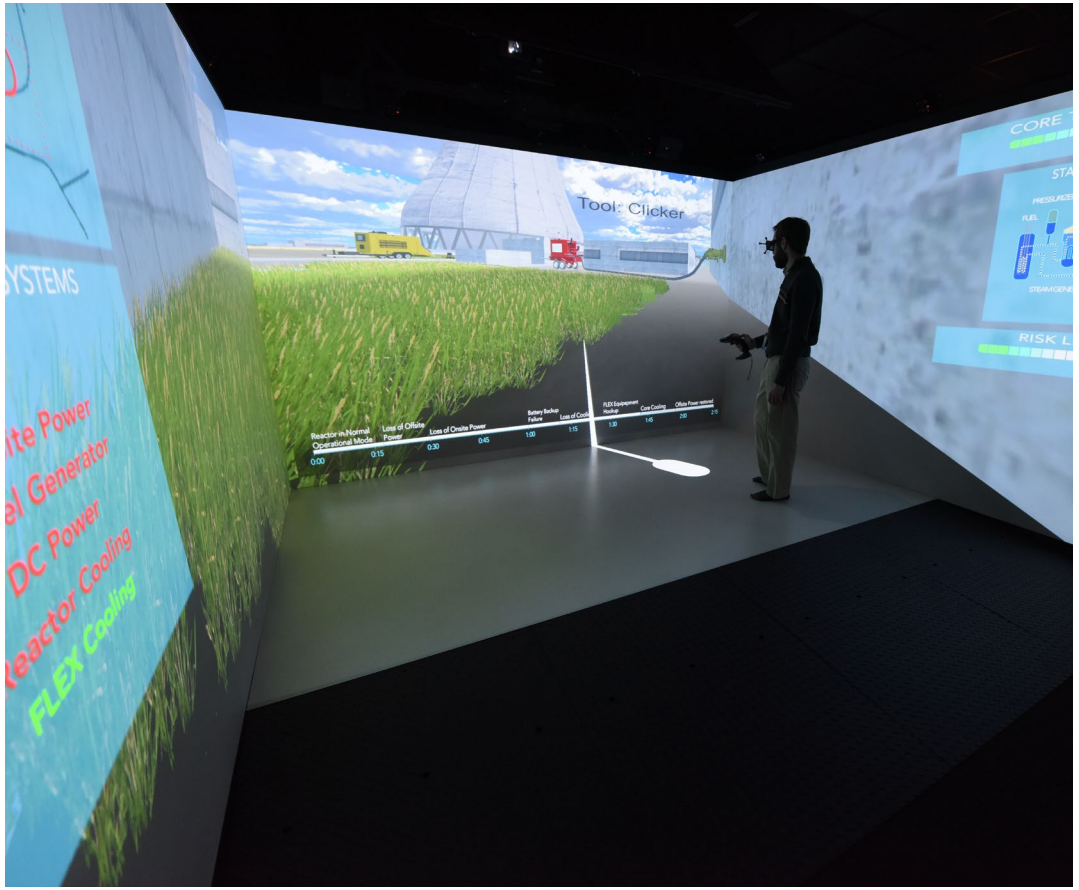
https://www.ornl.gov/organization-news/transforming-how-workers-see-radiation-augmented-reality-technology

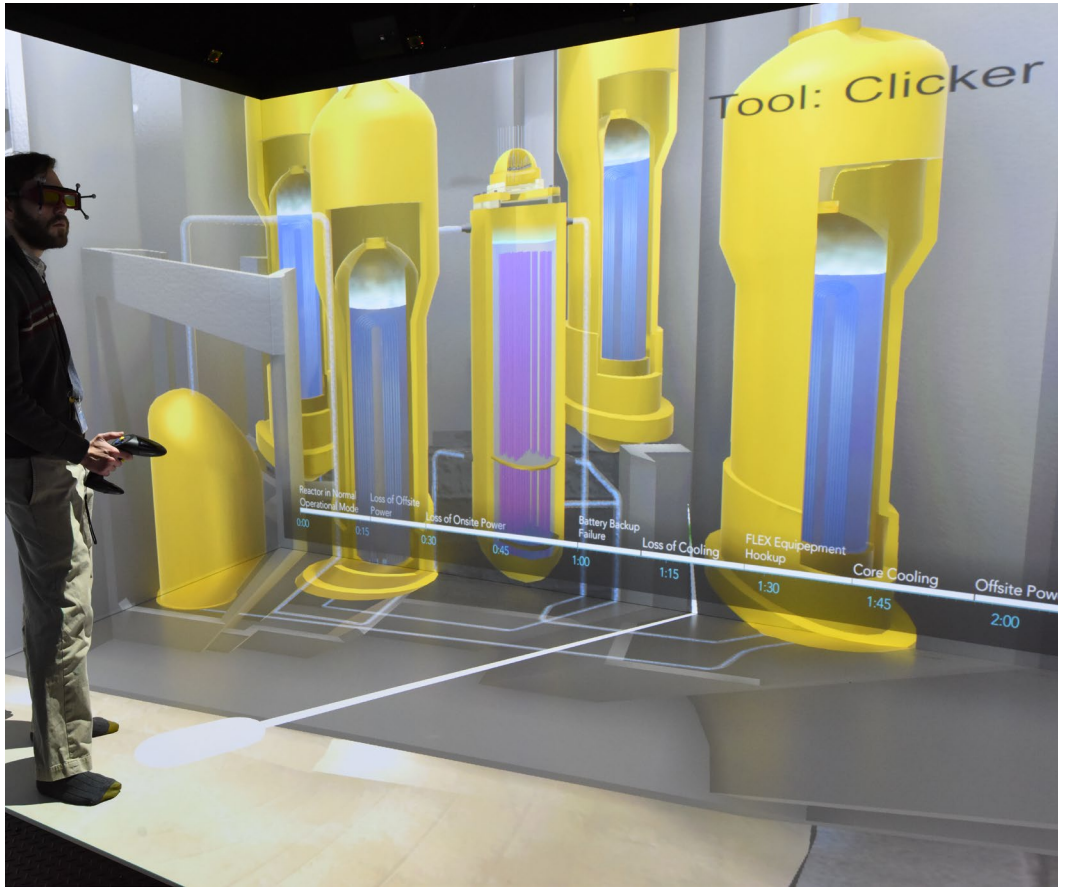
Lidar Visualization



Utility companies can upload LiDAR data to the CAVE to analyze real or planned power line corridors.

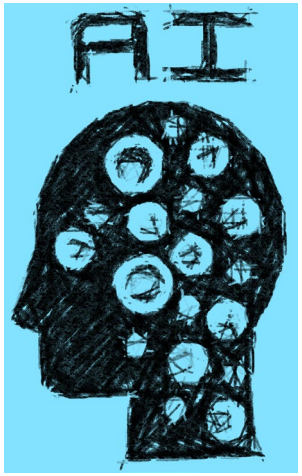
Maintenance and Inspections

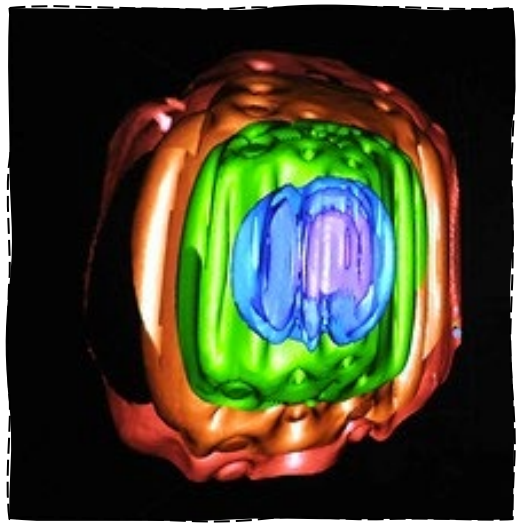




Artificial Intelligence and Visualization

Introduction





Introduction: Importance of AI and Visualization

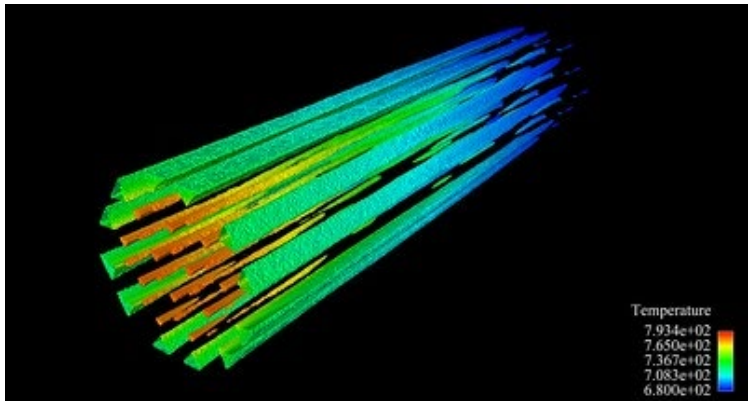
- Complexity of Nuclear Systems
  - Nuclear operations involve intricate processes and safety measures.
  - High-stakes decision-making requires advanced analytical tools.
- AI's Role
  - Enhances predictive capabilities and operational efficiency.
  - Supports real-time decision-making and risk management
- Visualization's Role
  - Transforms complex data into actionable insights.
  - Simplifies understanding of reactor status and risks.
- Synergy of AI and Visualization
  - Together, they improve safety, efficiency, and operational transparency.

State of the Art: AI Applications in Nuclear Energy

- Predictive Maintenance
- Anomaly Detection
- Operational Optimization
- Decision Support Systems
- Data Analysis for Research

State of the Art: Visualization in Nuclear Operations

- 3D Modeling of Reactors
- Real-Time Data Visualization
- Virtual Reality Training
- Risk Visualization
- User-Centric Dashboards



AI & Visualization Intersection

AI and Visualization for Safety Enhancements

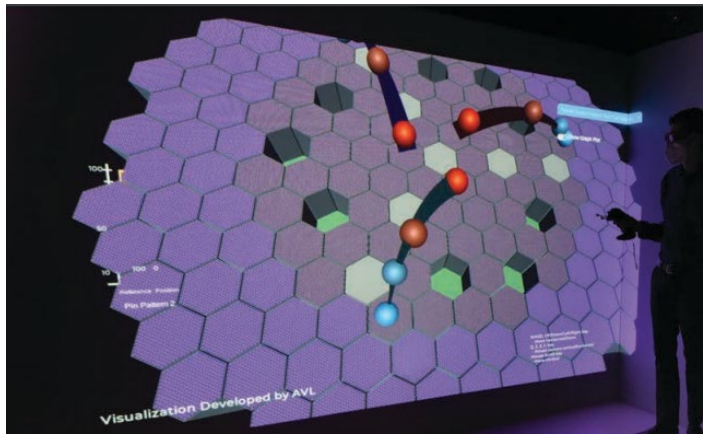
- Real-Time Monitoring Systems
- Automated Fault Detection
- Risk Prediction Models
- Emergency Response Simulations
- Decision Support for Safety Protocols

AI and Visualization for Enhancing Human-Machine Interaction

- Operator Interfaces
- AI-Driven Recommendations
- Balancing Automation and Oversight
- Adaptive Learning Systems
- Continuous Improvement

AI and Visualization for Digital Twins in Nuclear Operations

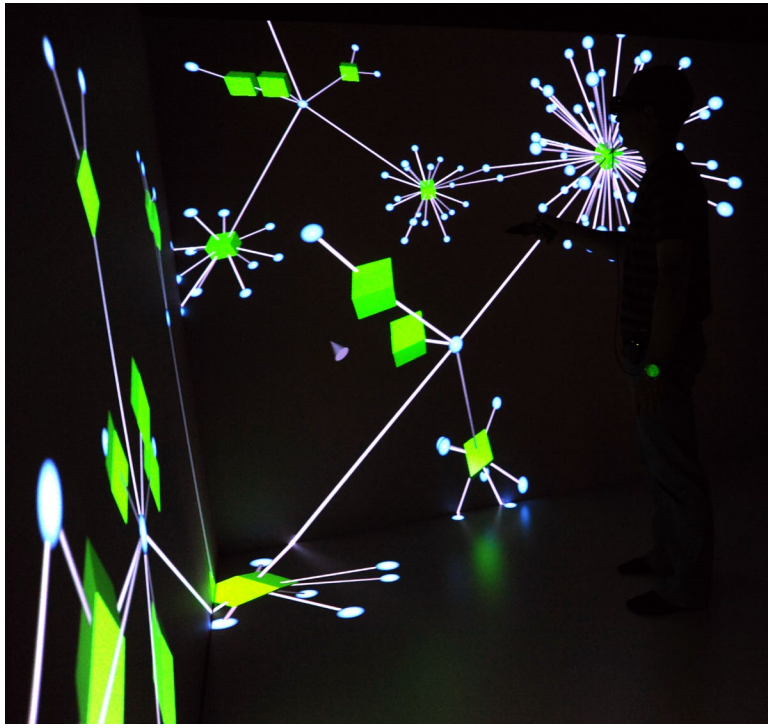
- Definition of Digital Twins
  - Virtual replicas of physical reactors that simulate real-time data.
  - Provides comprehensive insights into reactor operations.
- AI Integration
  - AI enhances digital twin accuracy with continuous data updates.
  - Predicts operational outcomes based on various scenarios.
- Visualization Benefits
  - Visual representations help operators understand complex data.
  - Interactive simulations allow for scenario testing and analysis.
- Operational Insights
  - Identifies inefficiencies and optimization opportunities in real-time.
  - Supports data-driven decision-making and operational planning.
- Future Potential
  - Expansion of digital twins to cover entire nuclear facilities.
  - AI-driven automation could enhance overall plant efficiency.



Challenges

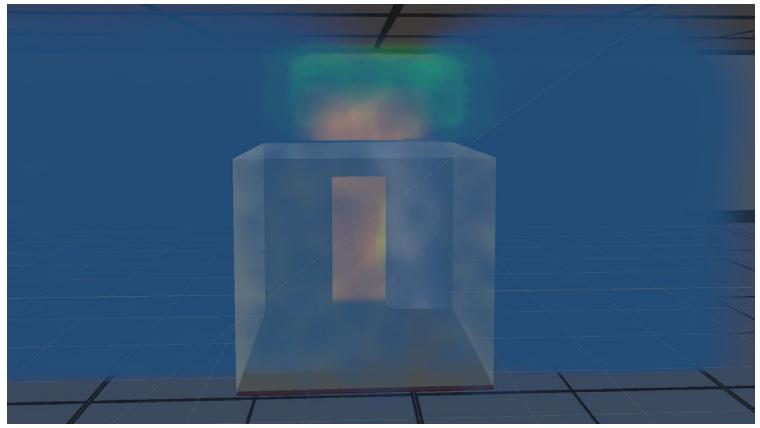
Challenges: Data Quality and Availability

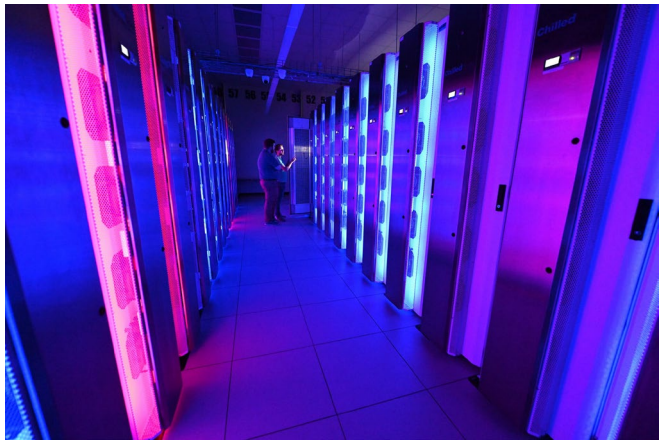
- Data Scarcity
- Data Integration Issues
- Data Privacy and Security
- Real-Time Data Needs
- Addressing Data Gaps



Challenges: Explainability and Trust in AI

- Black Box Nature of AI
- Need for Explainable AI
- Visualization as a Solution
- Human Oversight Requirements
- Opportunities for Improvement





Challenges: Regulatory Hurdles

- Stringent Safety Regulations
- Validation of AI Models
- Regulatory Approval Processes
- Lack of Standardization
- International Compliance

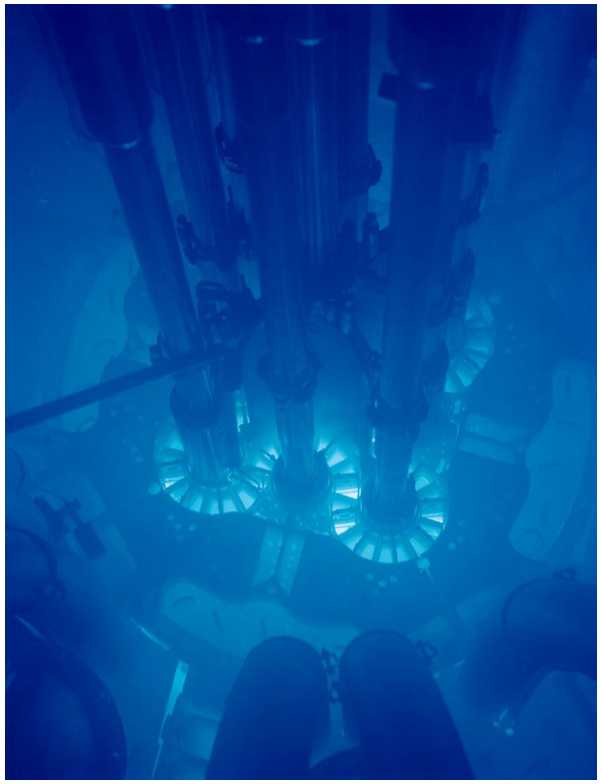
Opportunities

Opportunities: AI for Enhanced Risk Assessment

- AI Risk Models
- Visualization of Risk
- Emergency Preparedness
- Incorporating Historical Data
- Improved Decision-Making

Opportunities: AI in Nuclear Design and Innovation

- AI for Reactor Design Optimization
- Visualization of Design Iterations
- Collaborative Design Tools
- Research and Development Opportunities
- Future-Ready Designs



Opportunities: Immersive Training for Nuclear Workforce

- AI-Driven Training Programs
- Virtual and Augmented Reality Applications
- Continuous Learning Frameworks
- Assessment and Feedback Mechanisms
- Future Training Innovations

Conclusion: Transforming the Nuclear Industry

- AI and Visualization as Catalysts
  - Together, they revolutionize nuclear operations and safety.
  - Enhances efficiency and decision-making capabilities.
- Vision for the Future
  - Advancements in AI and visualization can unlock new potentials.
  - Commitment to safety and sustainability will drive the industry forward.
- Final Thoughts
  - The nuclear industry is poised for a technological revolution.
  - Leveraging AI and visualization will lead to enhanced safety and efficiency.

Thank You

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