Advances in Human Factors Engineering for Enhancing the Operational Safety of Nuclear Power Plants

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1. Introduction

This work explores recent advancements in human factors engineering and its application to enhance operational safety in nuclear power plants. With the continued importance of nuclear power in meeting global energy needs, ensuring the safe and efficient operation of these facilities is paramount. Human factors engineering aims to optimize the interaction between humans, technology, and organizational systems to reduce the risk of human error and improve overall safety. The paper begins by emphasizing the significance of human-system interaction design in nuclear power plants. Human error is a significant factor in system failures within large and complex interactive systems. Nuclear power plants have experienced safety-related incidents where human error played a substantial role. However, it has also been observed that human intervention can be highly effective when there is a comprehensive understanding of the plant's situation. Therefore, the interface between humans and machines is crucial not only for preventing human errors but also for assisting operators in handling unforeseen events. Reliability can be defined both qualitatively and quantitatively. Qualitatively, it involves striving for successful human performance in activities that contribute to system reliability and availability. Quantitatively, it refers to failure rates or error probabilities, which can be utilized in probabilistic safety assessments (PSAs). The work focuses on human factors and safety culture in nuclear power plants, with a focus on the role of organisational and individual performance.

2. Objectives

The objectives of the work may include:

- Explore the latest advancements in human factors engineering (HFE) for improving operational safety in nuclear power plants
- Analyze case studies and best practices
- Assess the impact of HFE on human performance and error prevention
- Examine the integration of HFE into nuclear power plant design and operation
- Identify challenges and future directions for HFE in nuclear power plants

3. Human factors in nuclear power plants

Post-analysis of major nuclear industry catastrophes, including Three Mile Island and Chernobyl, has demonstrated that the origins of such incidents involving technologically sophisticated systems extend beyond mere technical aspects. Instead, factors that may appear intangible, such as human factors, significantly contribute to their development. Human factors encompass the interplay between individuals, machines, and their environment, influencing performance, safety, and well-being. Within the context of nuclear power plants, human factors are crucial in ensuring safe and efficient operations.

Human factors issues have been identified as a major contributor to safety incidents in the nuclear industry. These issues arise from some interactions and can have significant consequences on safety, Figure 1.

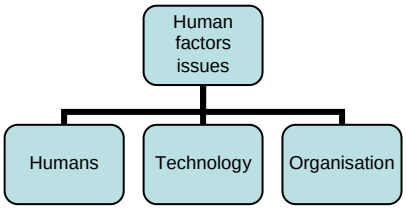

Figure 1: Main human factors issues representation

One of the most significant human factors issues in nuclear power plants is human error. **Human error** can result from a range of factors including lack of training, communication breakdowns, and inadequate procedures. The impact of human error can range from minor incidents to catastrophic accidents such as Chernobyl and Three Mile Island. Human error can also have a significant impact on safety culture by eroding trust in the system and reducing the willingness of workers to report safety incidents. Dealing with human error, we must work to reduce and prevent it by using some strategies:

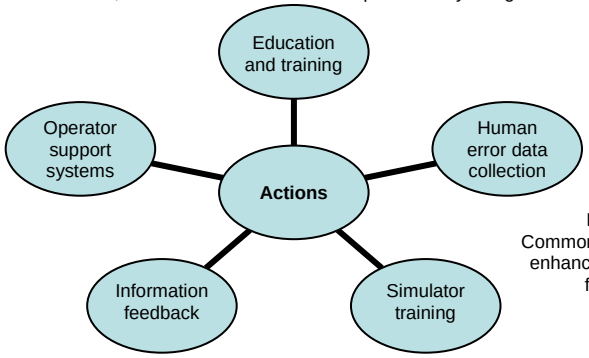

Fig. 2 Common strategies to enhance the human factors

When applying any of the strategies to enhance human factors in nuclear power plants, **nuclear knowledge management** (NKM) is supposed to be developed. Nuclear knowledge management practices enhance and support traditional business functions and goals such as human resource management, training, planning, operations, maintenance, projects, innovation, performance and risk management, information management, process management, organizational learning, and information.

4. Challenges

Human Robot Interaction (HRI):

In the nuclear industry it is still common to rely on teleoperated robots. Tele-operation however can be strenuous and demanding on operating personnel and productivity can be low without advanced HRI interfaces. Today, the world is moving towards **Industry 4.0**. With that vision, this part introduces the concept of Remotely Instructed Robots (RIRs), which are reliable yet rely on human intelligence. RIRs can accept high and low level instructions from the operator and execute tasks based on operators' descriptions and at a variety of complexity levels. The work outlines an agent model of RIRs and furthermore, presents how it could be implemented inside nuclear gloveboxes to achieve novel human robot interaction.

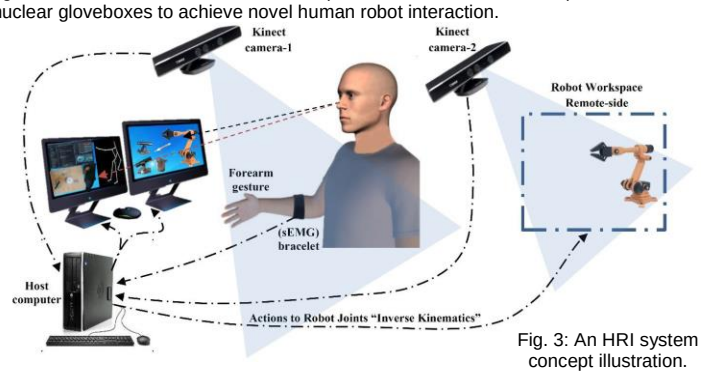

Fig. 3: An HRI system concept illustration.

Artificial Intelligence (AI):

It's important to note that the implementation of AI in nuclear power plants requires careful consideration of safety, reliability, and regulatory requirements. Additionally, human oversight and collaboration remain essential to ensure the effective integration of AI technologies with human operators in nuclear power plant environments. Here are some ways AI can be applied in these areas:

1. Data Collection
   - Sensor Data Analysis
   - Natural Language Processing (NLP)
2. Training and Education:
   - Intelligent Tutoring Systems
   - Virtual Reality (VR) and Augmented Reality (AR)
3. Simulators and Scenario Modelling
   - AI-generated Scenarios
   - Intelligent Simulation Control
4. Cognitive Workload Monitoring
5. Decision Support Systems

Fig. 4: Example of data analysis representation

Fig. 5: Training by Virtual Reality (VR) and Augmented Reality (AR) technologies

5. Conclusions and Future Work

The research highlights the importance of human factors engineering in enhancing operational safety in nuclear power plants through advancements in techniques, methodologies, and technologies, including AI integration, data-driven approaches, advanced training methods, and simulation tools, while addressing challenges such as data collection, AI reliability, bias, and human-AI collaboration, and identifies future research areas such as AI exploration, long-term evaluation, collaboration, human-AI interaction, and continuous training for sustained improvement in operational safety.