

Priorities and Considerations in Advancing the Training of Nuclear Reactor Operators through Mixed Reality

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INTRODUCTION

Nuclear reactor safety is unique in that even after an incident is identified and the reactor shut down, the possibility of damage to people and environment does not stop: there is a long tail to the incident due to decay heat and potential for radiation leakage, which must also be contained properly, as exemplified in Fukushima where most radiation releases happened after initial earthquake and plant shut-down.

Nuclear reactors generate close to 20% of the energy required by our nation. There is increasing interest in nuclear power as a low emissions alternative to fossil fuel-based power. Investments in the next generation of nuclear power plants include many nuclear startups such as NuScale and high-profile investments by Bill Gates' Terra Power.

Nuclear reactor operators are critical personnel who operate nuclear reactors, monitor the health of the operation, and are the first line of defense in case of an incident. Though the Nuclear Regulatory Commission creates and maintains standards and procedures for nuclear safety, their programmatic mandate involves are focused on existing technology, in the form of commercial nuclear power plants and other uses of nuclear materials through licensing, inspection and enforcement activities. This report summarizes the collected thoughts and insights from a diverse working group on the intersection of next generation technology with the training of future nuclear reactor operators.

Working Group Details

The working group, hosted by the University of Florida, brought together stakeholders in the nuclear industry with academic researchers drawn from diverse fields including virtual and augmented reality, educational technology, and nuclear engineering. The working group meeting, held on a March afternoon over video conference, involved warm-up introductions, invited presentations, a breakout group discussion, and a closing session. All discussions were done under Chatham House rules: "When a meeting, or part thereof, is held under the Chatham House Rule, participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed."

The focus of the discussion was the anticipated needs and requirements for training future nuclear reactor

operators. The attendees were divided into two breakout rooms, allowing for a mix of areas of expertise in each room. Each breakout room was given the following prompts to seed the discussion, after which the discussion was allowed to move freely. An undergraduate research assistant served as a scribe for each breakout room. The prompts included: Sketch out the concept for what a future training will look like. Where will the training be done? What are the costs? Who will create the training materials? What will the trainee do? What are outcomes of a successful training?

Named Attendees

Eakta Jain, Assistant Professor, Computer & Information Science & Engineering, University of Florida

Andreas Enqvist, Associate Professor, Director Nuclear Engineering Program, University of Florida

Tim Tovar: NuScale, Director, Plant Operations

Doug Bowman: NuScale, Supervisor, Plant Operations

Patrick Leary: NuScale, Senior Reactor Operator

Hyo Kang: UF, Assistant Professor, Digital Arts and Sciences

Richard Hayes: Research Scientist/Criminologist, Herbert Wertheim College of Engineering, FLEX Station, Director, Loss Prevention Research Council

DESIGN SPACE

Nuclear power plants are large facilities that normally employ up to 1000- skilled workers in various capacities from technicians such as electricians, welders and pipefitters and plumbers to highly trained critical personnel for control room operations. Nuclear reactor operators monitor operations from the control room and they are responsible the health of the plant. They are typically the first to detect and respond to incidents. The work requires concentration, high attention to detail, and continuous monitoring of gauges and indicators through a combination of rotating checklists and tests. The median annual wage for power plant operators in 2020 was \$89,090 [1]. Stress and burnout rate have historically been high due to long hours and the rotating shift work related nature of the work.

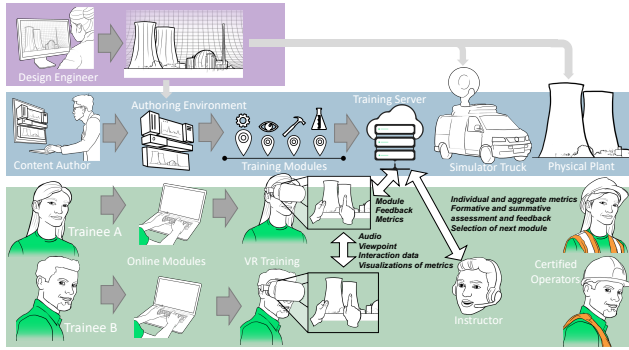


Fig. 1. Envisioned training ecosystem for future nuclear reactor operators.

The future aspects of the work have three changing components:

- Future Worker
- Future Training
- Future Technology

Future Worker

The future worker, referred to in Figure 1 as “Operator Trainee” is expected to be one of the following types of workers: a) A new worker entering the workforce for the first time: b) A person already in the work force but now moving from a different area of nuclear engineering to the area of work involving power plant operations. c) A person already in the work force but in a different context, for example, moving from a coal plant to a nuclear plant. d) Workers may be shared across different facilities.

Future Training

Future Training of nuclear reactor operators is expected to occur in distinct stages and styles which range from remote, online training, to virtual and physical simulations, and on-site training in the plant itself. The design space created by the ecosystem envisioned in Fig. 1 includes aspects such as:

- Role of remote training
- Team training versus individual training
- Asynchronous versus synchronous training
- Shared workers
- Job modification-training

All related to what outcomes are intended, it is for purpose of “Just-In-Time” training, safety mindset retention, or equipment design change training as examples.

Future Technology

There is a confluence of several different technologies in the nuclear context that will create novel opportunities and

challenges for reactor operator training as new plant designs are deployed:

- Digital engineering
- Training environment
- Intelligence (AI)
- Data sharing

OPPORTUNITIES & CHALLENGES

The envisioned ecosystem and the design space around it offers both opportunities and challenges. Table I illustrates the strengths, weaknesses, opportunities and threats in a SWOT analysis.

TABLE I. SWOT analysis for virtual reality based nuclear reactor operator training.

Strengths: Cost Future ubiquity of VR technology Remote training and broader recruitment base enabled Enable safe pandemic/lockdown training	Weakness: Loss of immersion vs. reality Cannot train for non-codes scenarios Lack of proper physical response (XR option?)
Opportunity: New plant pre-certification/approvals Plant modification training/certification before outage/modification	Threat: Cyber security: • VR access by unauthorized person • Mapping technology Espionage – streamed data, competitors, adversaries

SWOT Breakdown

Below follows a brief discussion on each aspect mentioned in Table I.

Cost

All simulators allow trainees to practice action and consequence. VR is cheaper than physical simulators, which are currently used for training in nuclear operations. These simulators are often-time plant specific to accommodate for the large amount of variety and technological differentiation between separate nuclear plants. The physical simulators are excellent for team-based training but lack the versatility with associated with Integrated State Awareness where each reactor component has its own digital twin, or augmented digital twins that can assist with decision-making and feedback through AI.

Ubiquity

Virtual reality-based training is rapidly being adopted across a spectrum of industries [2]. This adoption creates an ancillary ecosystem of content developers, authoring systems, hardware and platform support, as well as familiarity amongst the public.

Broader recruitment base

Opportunities to perform the first few stages of training remotely will increase the recruitment base for reactor operator trainees. For example, a diverse geographical area can be reached. Once the trainees pass the initial plant ops training, they can check out VR based training equipment and complete the second level of training in their home towns. This again reduces costs from the perspective of both the trainer and the trainee and enables a wider pool of participants at this stage. Artificial intelligence-based feedback at the training stage additionally enables fewer instructors to keep track of (supervise? oversee?) more trainees, once again allowing for a wider participant pool at the outset.

Safe pandemic/lockdown training

Remote training can continue even in the case of lockdown or limited mobility as experienced during the coronavirus pandemic.

New plant pre-certifications and modification training

The training ecosystem envisioned here creates a talent vetting pipeline that will allow for operators to achieve greater readiness by the time a new plant is ready for operation. When a plant needs modifications, for example for upgrades to a subsystem, virtual reality-based training may be done using the digital twin ahead of the outage.

Loss of immersion vs reality (transference?)

The extent to which virtual reality-based training transfers to real life will prompt the adoption of this technology in the training pipeline. While VR-based training is unlikely to replace in-situ training exercises, it can be expected to provide a greater level of readiness going into the in-situ stage relative to traditional lecture-based training. This weakness could be mitigated by late-stage training on mixed reality options and physical simulators such as simulator on a truck.

Non-coded scenarios

By very definition, training modules are created around situations the trainers can plausibly imagine. To that extent, whether the training is performed in the traditional lecture-

based format, or via immersive virtual reality, it remains limited by the codes.

Lack of proper physical response

In a complete nuclear operator training environment VR would likely be paired with other novel evolutions of existing nuclear operator training modes. Specifically, the physical response and muscle memory training is better addressed by a mobile control-room simulator with physical instrumentation, that fulfils this specific training goal, in a wider training pipeline.

Security

Remote training equipment is susceptible to threats such as an unauthorized person gaining access to the training module and leaking information such as plant layouts. Another threat to the integrity of the training and certification is that a proxy takes the training in place of the trainee and helps them pass the initial stages. These threats could be alleviated with strong authentication techniques that use a combination of password protection and biometric identification for both one-time and on-the-fly user authentication. Virtual reality-based training is also susceptible to attacks on the streaming data because high-quality data needs to be exchanged between the trainee's devices and between them and the training server and the instructor. Cybersecurity considerations would need to be resolved concurrently with training paradigms for virtual training to be widely adopted.

CONCLUSIONS

While direct experience in the lab may be considered the highest fidelity training environment, there is a rich history of providing trainees with simulated environments to practice in. Simulated environments allow trainees unlimited hours of training at their convenience (in contrast to a lab or working facility) and thus have the advantage of reducing the time and cost of training. The discussions during the working group meeting elucidated a design space as well as considerations.

REFERENCES

1. <https://www.bls.gov/ooh/production/power-plant-operators-distributors-and-dispatchers.htm> [Accessed: May-2021]
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