**Workshop on Human Factors Considerations for Remote Operation of Nuclear Facilities**
**January 31 – February 1, 2024**
**Rockville, MD**
**Public Meeting Summary**

Workshop Agenda: ML24025A134
Public Meeting Notice: ML24030A060

On January 31 and February 1, 2024, the U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research (RES) hosted a workshop to explore the human role in remotely operating advanced nuclear reactors. The workshop was conducted as part of a research project with the Department of Energy's Idaho National Laboratory (INL) to develop the technical basis for guidance supporting human factors reviews of advanced reactor license applications that include novel concepts, such as remote and highly automated operations.

The public workshop was hosted as a hybrid meeting, with in-person attendees at NRC headquarters and virtual attendees joining via Microsoft Teams. There were approximately 60 in-person participants and over 230 virtual participants. The workshop included NRC staff, advanced reactor vendors, current reactor licensees, researchers, industry consultants, and international regulators (see Table 1 for a list of participating organizations).

The goals of the workshop were to 1) understand concepts of operations the nuclear industry is considering that may include elements of remote operation, and 2) gain insights regarding how well-suited NRC's current guidance is for the human factors review of these concepts. The topics explored included:

- the potential role of plant personnel in facility operation and maintenance
- technologies and methods for enabling remote operations (e.g., automation, passive safety systems, design simplicity)
- the design of local and remote monitoring and control interfaces and facilities
- multi-unit monitoring and control
- communications between reactor facilities and remote operations facilities
- personnel training
- local and remote staffing models

Additional information about the focus of the workshop can be found in the background document shared with attendees prior to the workshop, available in the NRC's Agencywide Document and Management System (ADAMS) at ML24025A139.

The workshop provided an opportunity for advanced reactor developers and others involved in the development and deployment of advanced reactor technologies to engage early with the NRC and help ensure the NRC staff has the guidance necessary for effective and timely reviews of future license applications.

**Workshop Day 1**

***Opening and Introductions***
Mr. Raymond Furstenau, Acting NRC Executive Director for Operations, opened the workshop and welcomed participants, remarking on the importance of early engagements to help the NRC prepare for the future.

The workshop organizers, Dr. Niav Hughes Green and Dr. Stephanie Morrow, human factors psychologists in RES, provided introductions and an overview of the workshop agenda and goals.

***Overview of NRC Ongoing Regulatory Development Areas***
Dr. David Desaulniers, Senior Technical Advisor for Human Factors and Human Performance Evaluation in NRC's Office of Nuclear Reactor Regulation (NRR) presented on the development of ground rules for the regulatory feasibility of remote operations. Presentation: ML24030A001 (see pages 8-22)

Dr. Tom Ulrich, Human Factors Scientist at INL, followed with perspectives on the ground rules through human factors lens. Presentation: ML24030A001 (see pages 23-29)

Dr. Desaulniers and Theresa Buchanan, Senior Reactor Engineer for operator licensing in NRR, provided an overview of relevant parts of the NRC's proposed part 53 rulemaking. Presentation: ML24030A001 (see pages 30-46)

Dr. Desaulniers then closed the first session with key questions of interest to set the context for the workshop. Presentation: ML24030A001 (see pages 47-56)

***Session 1: Industry Presentations on Remote Operation Concepts***
Nuria Bernal Cortés, Human Factors Engineering Senior Engineer for Westinghouse eVinci provided a presentation on Human Factors Engineering (HFE) considerations for microreactors. She also identified areas to consider as gaps in various NRC HFE guidance documents. Presentation: ML24053A206

Chanson Yang, Systems Engineer, and Roger Chin, Software Architect for Radiant Nuclear, provided a presentation on the concept of remote operations for the Kaleidos portable microreactor that could be used to replace diesel generators. Their concept includes units that would be factory operated and monitored remotely from an operations center using automated and passive safety mechanisms and continuous data review and analysis using machine learning. Presentation: ML24053A204

Christopher Poresky, Manager of Cyber-Physical Systems for Kairos, provided an overview of their iterative design and operations for their fluoride salt-cooled high temperature reactor (FHR) that utilizes successive large-scale integrated demonstrations and focuses on safety outcomes. Learnings gained from their iterative design process included evolving the remote support room to a remote control room in which the shifts would be augmented with remote observers. He also addressed concepts where remote operations could be both part of routine responsibilities and a means to support operations during a local control room evacuation. Presentation: ML24053A202

***Session 2: Industry Presentations on Remote Operations Concepts***
Annie Paskavitch, General Manager Central Operations for NextEra, provided a presentation on NextEra's experiences with remote operation and monitoring of their fleet of renewable and fossil fuel control centers. Presentation: ML24053A203

Dan Laughman, Senior Engineer of Human Factors Engineering for General Electric (GE) Vernova provided perspectives on topics that should be considered in determining the feasibility of remote operations. He discussed the importance of standardization, including international standardization, and establishing clarity in what constitutes remote operation. Another consideration he identified was the level of connectedness between the remotely operated control room and the reactor, such as whether connections are hard-wired or through the internet. Presentation: ML24053A200

DJ Hanson, Chief Operating Officer for Flibe Energy, provided an overview of Flibe Energy's focus on fluid-fueled molten-salt reactor development. He emphasized the importance of learning from the experiences of other industries as the risk of failure in the nuclear industry bears high consequences. He cautioned about the challenges of employing remote operations without on-site operating experience, noting that one cannot easily account for the quality of information and calibration of risk that occurs for an operator employing all their senses in the plant itself. Presentation: ML24053A208

***Public Comment***
The end of day 1 of the workshop included a public comment period for the NRC staff to address comments or questions from members of the public in attendance.

**Workshop Day 2**

***Stakeholder Presentations***
Richard Paese, Digital Instrumentation and Control and Human Factors Engineering Consultant for Sargent and Lundy presented on lessons from NASA's experience in remote manned spaceflight operations. He noted many similarities in operational philosophies between the nuclear industry and manned spaceflight that could be leveraged for benchmarking. Presentation: ML24053A205

Cristina Corrales, Principal Technical Leader of Nuclear Instrumentation and Control for the Electric Power Research Institute (EPRI) provided an overview of EPRI's human factors analysis methodology as a means of enabling remote operations. She described how the EPRI methodology integrates human factors and human reliability considerations into overall systems engineering activities to address safety, reliability, cybersecurity, and other key topics. Presentation: ML24053A207

Dr. Per Øivind Braarud, Senior Scientist at the Institute for Energy Technology (IFE), Halden Human-Technology-Organization project (Halden), provided a presentation on lessons from experiences with remote operation in other industries, including petroleum, maritime, and aviation. He also presented on research insights from studies in the Halden small modular reactor simulator. Daniel Odéen from IFE provided additional information on the Halden project facilities and capabilities to support future research on remote operations and other advanced reactor topics. Presentation: ML24053A201

***NRC Human Factors Reviews: Current Practices and Preparing for the Future***
Dr. Brian Green, Senior Technical Advisor for Human Factors in NRR, presented on the NRC's technical review process, specifically the scope of human factors reviews within that process. He discussed the

importance of understanding the various licensing processes available and the guidance associated with each. He also emphasized that pre-application activities, although optional, are highly recommended to identify challenging issues associated with design features, schedules, and regulatory challenges to resolve them efficiently. Presentation: ML24030A001 (see pages 66-76)

***Development of Scalable Human Factors Engineering Review Plans for Advanced Reactors***

Dr. David Desaulniers presented on the development of the draft Interim Staff Guidance, "Development of Scalable Human Factors Engineering" (DRO-ISG-2023-03). He described the draft guidance as a means to scale human factors reviews for advanced reactors. Scaled reviews would be risk-informed and focus on areas where human factors engineering is necessary to support important human actions. The intent is for human factors reviews to be application-specific considering the characteristics of the facility design and its operation. Presentation: ML24030A001 (see pages 77-100)

***Summary of Range of Concepts of Operations Discussed on Day 1***

Casey Kovesdi, Human Factors Scientist at INL, shared insights from the range of concepts of operations discussed during day 1 of the workshop. He noted that many different strategies were being considered within various advanced reactor designs. Some developers were not considering remote operation as part of their design whereas others intended to use automation and passive safety features to enable remote monitoring and control in various phases of operation. In between, there were some designs that planned to only employ remote monitoring while others planned to consider remote operation in subsequent designs. He noted that different strategies would impact the roles and responsibilities of personnel and automation, the staffing and qualifications of personnel, and the management of functions during normal operations, emergency response, and maintenance and testing activities.

***Breakout Discussions of Concepts of Operations for Remote Operation***

In-person attendees participated in interactive, small group breakout discussions to further explore the human-system interactions in remote concepts of operation, including areas that might be challenging or have unique implications for human performance. Group discussions were organized around the seven elements of a concept of operations, as identified in § 53.730(c) of the draft proposed Part 53 rulemaking. The seven elements are:

1. Plant Mission/Goals
2. Roles and Responsibilities of Personnel and Automation
3. Staffing, Qualifications, and Training
4. Management of Normal Operations
5. Management of Off-Normal Conditions and Emergencies
6. Management of Maintenance and Modifications
7. Management of Tests, Inspections, and Surveillances

Each group discussion focused on one or two elements of a concept of operations (as described above). A representative from the NRC and from INL served as the discussion hosts within each group. Participants rotated to three different discussion groups during the discussion period to promote interaction and diversity of views in the dialogue.

***Summary of Breakout Discussions & Key Takeaways***

The NRC and INL hosts for each breakout group reported on the key takeaways from the discussion of their respective concept of operations element.

Dr. Brian Green (NRC) and Rachael Hill (INL) hosted a discussion group focused on two elements: 1) plant mission and goals, and 2) roles and responsibilities of personnel and automation. The discussion on plant mission and goals included topics such as:

- Implications of new missions and interdependencies that may exist when reactors have multiple missions (e.g., supplying electric power and hydrogen production or plant desalinization).
- Importance of considering different jurisdictions (e.g., a plant in Alaska controlled from Nebraska) and proximity of dispatchable resources, including the time required for personnel or other resources to reach a site.
- Skillset of operators, including consideration that remote and on-site operators may have different levels of qualification.
- Considering more extreme environmental conditions (based on siting) and technology specific hazards (e.g., corrosive chemicals) that could present hazards to site staff.
- Questions about the level of information an operator would need in highly automated or self-reliant facilities, including data reliability and cyber security.

Insights from the discussion on the roles and responsibilities of personnel and automation included:

- The potential need for new guidance on function allocation to address new technologies and provide guidance to support inherent safety systems.
- Need to determine appropriate approaches for keeping the human in the loop, especially for designs that may have minimal interactions with operators.
- Need to identify skills needed by various qualification levels of offsite operators.
- The potential role for digital twins to support offsite operators.

Theresa Buchanan (NRC) and Zachary Spielman (INL) hosted a discussion group focused on staffing, qualifications, and training. Their group began with a discussion of the generally licensed reactor operator, and how remote operations might be easier to implement in a self-reliant mitigation facility (see pages 38-40 of ML24030A001 for discussion of these terms). The group also discussed how current reactor operators are somewhat remote in that they push buttons that trigger electrical signals from a main control room, as opposed to physically operating valve handwheels or using pulleys to pull control rods. At a general level, the interactions between main control room operators and field operators in current nuclear plants would be similar in a remote concept that also employed some contingent of local staffing. Without use of local operators, there would need to be some use of instrumentation and other enhanced monitoring capabilities, and then more data available to remote operators. The group talked about potential changes in number of staff needed to remotely operate a reactor, the potential for operators to take on more than one role, and the associated impacts to operator training.

Stephen Fleger (NRC) and Casey Kovesdi (INL) hosted a discussion group on the management of normal operations. Their group began discussions around normal operations in a highly automated reactor design. Normal operations would have layers of automation, active controls, and passive features. In this concept there would not be time-critical actions that operators would need to perform. Operators would be located primarily at an offsite control center with the primary function of supporting monitoring and dispatching local staff, such as security personnel. In these highly automated concepts, credited operator actions may not be needed for normal operations. The group also discussed other implications of higher levels of automation, such as impacts on workload, situation awareness, response time, and vigilance. This led to discussion of the importance of early validation, including a phased or staged approach to validation. An important topic to address would be measures for validation. Lastly,

in the context of normal operations, training was raised an important topic, as it could be fundamentally different from the training approach for large light-water reactors.

Dr. Niav Hughes Green (NRC) and Dr. Ronald Boring (INL) hosted a discussion group on the management of off-normal conditions and emergencies. Their group began with a discussion of reactor design concepts that only intended to use remote monitoring, rather than remote operations, and therefore, personnel would be dispatched locally in off-normal conditions and emergencies. The communication network used for monitoring would be very important to ensure redundancy and defense in depth through a variety of mitigating strategies. Some human performance implications identified were related to trusting incoming data and data integrity. The group identified situations with degraded communication, and where the ability to remotely monitor is lost, as areas in need of further research and guidance. The level of human intervention needed when remote monitoring is degraded or lost may also depend on the plant design, especially when designs may have greater reliance on inherent and passive safety features and automation. The conversation then moved into a discussion of what is meant by consequences for non-normal events and how they might be measured. If consequences are measured in terms of impact to the local population, there might be a very low consequence to emergency situations when reactors are sited in remote areas with a very low population. Other types of consequences that may need to be considered are the environmental impact or the economics of shutting down the reactor. Additionally, consideration may need to be given to the changing role of the regulator in cases where radiological release is no longer the primary consequence of concern.

Dr. Amy D'Agostino (NRC) and Dr. Tina Miyake (INL) hosted a discussion group on the management of maintenance and modifications and management of tests, inspections, and surveillances. Their group discussed how the reactor design would dictate the role of the humans including maintenance. New design aspects, like use of different materials or fuels (e.g., molten salt) could introduce new safety hazards that affect how maintenance is performed. Maintenance activities would also be dependent on the lifecycle of the reactor, the extent to which inherent safety characteristics or passive safety features are employed, where maintenance would be expected to be performed (e.g., on or off site), and the level of automation incorporated into the design. The group also discussed how training would depend on personnel's ability to access the plant, and if access is limited then personnel would need better training tools (e.g., high fidelity mock-ups, simulators, or even digital twins). Also, new designs and multi-unit designs may make use of more shared maintenance resources. Another topic raised during the discussion was the potential for the human role to change in terms of "level of abstraction" with regard to maintenance – rather than a human with a screwdriver performing maintenance directly on a piece of equipment, it may be a human controlling a device that is "turning the screwdriver" or a human monitoring data from an automatic device performing a repair. It's also likely that maintenance would involve more software than hardware modifications, which would also have regulatory implications for how modifications are handled.

***Public Comment & Closing***

The end of day 2 of the workshop included a public comment period and closing remarks. The workshop organizers, Dr. Niav Hughes Green and Dr. Stephanie Morrow, closed the workshop by thanking workshop participants for their active participation and early engagement on the topic of human factors and remote operations. They stated that, as next steps, NRC and INL staff would consolidate information from the workshop to help identify and prioritize human factors research and guidance development that may be needed by the NRC to support future advanced reactor licensing reviews.

**Table 1. Participating Organizations in the January 31 – February 1, 2024, Workshop on Human Factors Considerations for Remote Operation of Nuclear Facilities**

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| 1. Aalo Atomics |
| 2. Atomic Alchemy |
| 3. ARC Clean Technology |
| 4. Boston Atomics |
| 5. Brookhaven National Laboratory |
| 6. BWX Technologies, Inc |
| 7. Canadian Nuclear Safety Commission (CNSC) |
| 8. Curtiss-Wright |
| 9. Dominion Energy |
| 10. Electric Power Research Institute (EPRI)* |
| 11. Flibe Energy, Inc* |
| 12. Florida Institute of Technology |
| 13. Framatome, Inc |
| 14. General Electric Vernova* |
| 15. Global First Power |
| 16. Holtec |
| 17. Idaho National Laboratory* |
| 18. Information Systems Laboratories (ISL) |
| 19. Institute for Energy Technology (Halden Human-Technology-Organization project)* |
| 20. Kairos* |
| 21. McMaster University |
| 22. NextEra Energy* |
| 23. Nuclear Energy Institute (NEI) |
| 24. Nuclear Promise X |
| 25. Nuclear ROSE Consulting, LLC |
| 26. NuScale Power, LLC |
| 27. Oklo |
| 28. Paragon Energy Solutions |
| 29. Radiant Nuclear* |
| 30. Reploy Power |
| 31. Sargent & Lundy* |
| 32. System Applications and Products (SAP) |
| 33. Tecnatom |
| 34. TerraPower |
| 35. UK Office for Nuclear Regulation (ONR) |
| 36. Ultra Safe Nuclear Corporation |
| 37. United Engineers & Constructors |
| 38. University of Central Florida |
| 39. University of Toronto |
| 40. U.S. NRC* |
| 41. Westinghouse* |
| 42. X-energy |

*(Listed in alphabetical order. * Indicates workshop presenter.)*