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Rethinking operations

through digital control room design

The NuScale control room simulator has been used to showcase the plant's design, prototype new displays, and test the operator and supervisor procedures in a fully digital control room. (Photos: NuScale Power)

By Ryan Flamand

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Since the inception of commercial nuclear power in the United States, every control room in every nuclear plant has looked essentially the same. You will see fixed alarm tiles, red and green lights, rows of switches, and analog meters. Until about a decade ago, you would even have seen paper charts (now replaced by digital versions of those same charts). Licensed operators have shown through a proven operating history that this control room design is safe and effective. Genius definitely went into the complexity of circuits and placement of switches and indications in the design, but things have come a long way over the years, and new technology, updated plant designs, and the need to improve efficiency and maintain reliability have impacted staffing and the role of operators. A control room update is long overdue. So, what lies ahead for the future of nuclear control room design? What possibilities exist for the next generation of plants?

My own career in nuclear, like many others, started by standing in front of a Navy recruiter and thinking the word "nuclear" sounded cool. After my time in the Navy as a reactor operator, I worked at the Palisades nuclear power plant in Covert, Mich., first as a nonlicensed operator, then a reactor operator, and then finally as senior reactor operator. In 2014, I had the opportunity to come work for NuScale Power, a company focused on providing scalable advanced nuclear technology. In my current role, I assist with the physical design of the plant and control room and I get to rethink how future operators can use new features to operate the plants of tomorrow.

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Optimized by design

The goal of NuScale's simulator design team, which I supervise, is to create and maintain a complete, simulated control room modeled to exactly match the plant design. This allows us to rapidly prototype new displays, controls, and indications to optimize the ease of operation of the plant. The NuScale simulator has been used as a platform to check the integration of the full design and as a test facility for staffing; it also acts to tangibly show how plant design works.

To optimize control room design, NuScale created a control room human factors design team with several former licensed operators from a wide variety of plants. Combining that knowledge and studying operating experiences outside of the nuclear industry allowed the benefit of various perspectives on different types of challenges.

For example, NuScale operates 12 reactors from a single control room, rather than the traditional 1:1 operator-to-reactor ratio. It was important to examine industries that had to manage multiple important items with minimal staff. Air traffic control and neonatal intensive care unit management were two examples of other industries that manage multiple precious pieces of information and prioritize the most critical aspects. We also benchmarked the Bruce nuclear generating station in Ontario as a plant that operates multiple power reactors from a single control room. These examples share the same basic concept: one person is designated to monitor things and usually can act in short bursts to stabilize a situation, while other operators handle detailed and follow-up issues.

The biggest change coming with new control room designs is actually part of new plant designs. Many new reactors are relying on passive safety systems and use proven physical characteristics, such as natural circulation, to remove decay heat. This helps with the inherent safety of the plant and simplifies the controls necessary in the control room. In some cases, the safety-related need for these controls is even eliminated. For example, NuScale relies on a hardware-based, safety-related, module protection system separate from the control system. It continuously monitors all necessary plant parameters and will automatically place the plant in a safe condition as required, regardless of any signal from the nonsafety control system.

The nuclear industry adopts new practices and control room upgrades only after careful consideration and with a great deal of oversight. As a result, nuclear may be the last of the big industries to fully join the digital revolution. With the NuScale standard design approval certified in 2022, we will have the first fully digital commercial nuclear power operations control room.

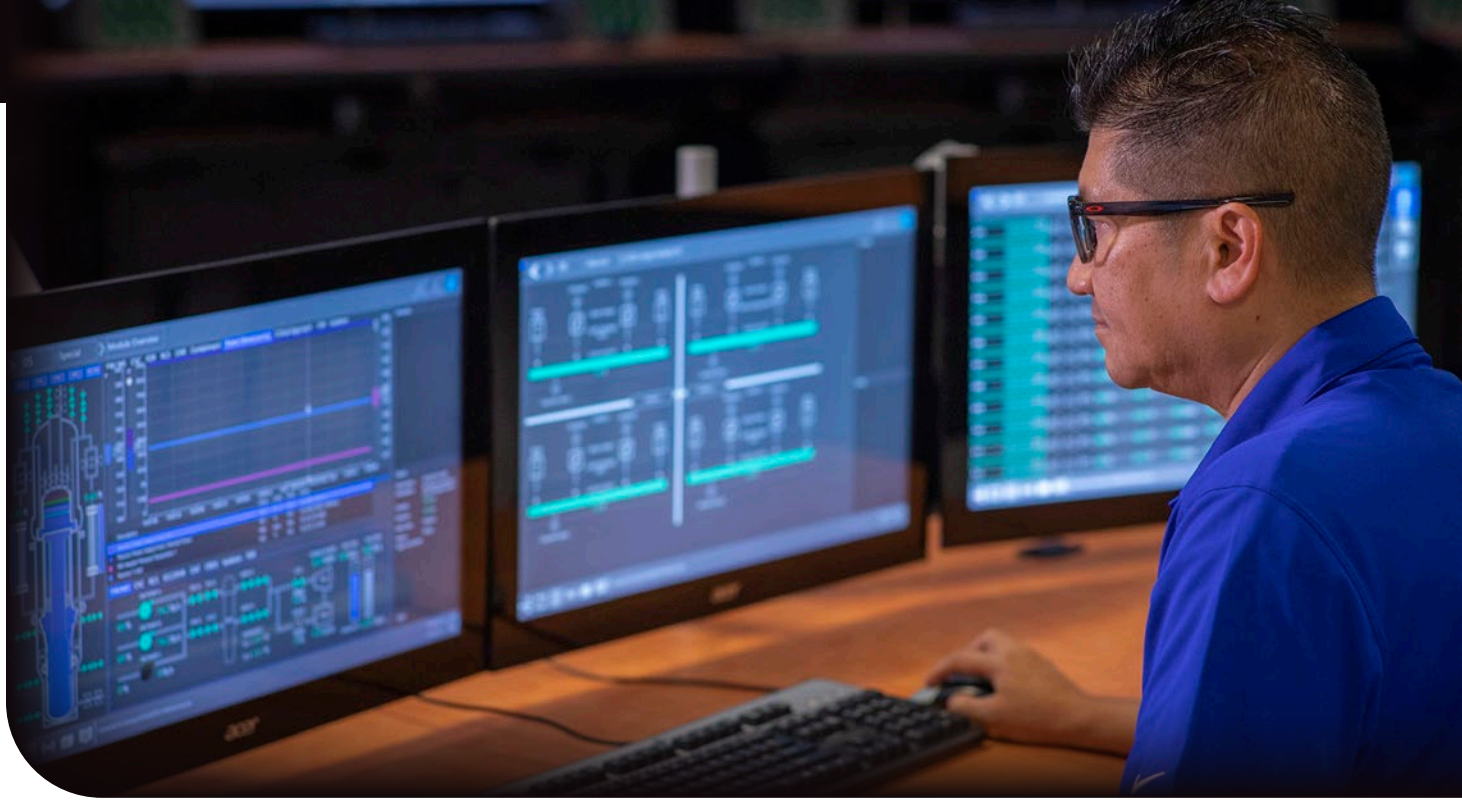
Information management

In the NuScale control room, operators perform most day-to-day activities using a nonsafety digital control system. A fully digital control room creates the opportunity for even more information to be at the fingertips of the crew.

Moving to this fully digital control room can create the challenge of information overload. It is important to find the right balance to provide information to operators in a meaningful way without taxing them. With a traditional alarm tile arrangement, the number of alarms may be large, but it remains finite. Pattern recognition aids operators in evaluating plant status. (Many licensed operators may remember their license class instructors sneaking in an extra alarm during training to see if they were paying attention.) In a digital control room, however, there could be hundreds of alarms for a single system, which can potentially overload operators. NuScale uses three main approaches to help prioritize alarms and focus the operator on the important tasks:

1. **Alarms tied to plant status.** For example, a pump that is off no longer needs a low discharge pressure or pump trip alarm to be active.
2. **Alarms with logic.** That is, with the alarm logic in code and not circuitry, the use of IF/THEN statements can help ensure alarms only actuate when action is needed.
3. **Alarms tiered into alarms, cautions, and notices such that only signals that require operator action are truly classified as alarms.** For example, a pump trip with a standby pump that automatically starts and maintains proper flow would be lowered in priority to a caution. In that same scenario, if the standby pump also failed to start and operator action was needed, it would be indicated as an alarm. Notices, the lowest tier, provide normal system status updates, much like getting an email from the control system.

Because the NuScale control room monitors multiple reactors, in the design we focused on removing potential human error traps associated with operating multiple units and linked alarm response procedures directly to the alarm indication. This linkage allows operators to easily and quickly navigate from the alarm directly to the response procedure for the correct unit. Not only does this eliminate the need for alarm response binders all over the control room, it also greatly eases the operator burden of finding the correct procedure when responding to an alarm condition.



Complementing human performance

Along with digital operating systems, the use of digital procedures is another area where the industry is looking to make gains in human performance. NuScale has included procedures directly into the control interface for a seamless transition from procedure use to equipment operation. Embedded electronic procedures allow for helpful operational features to be included directly within the procedure text, such as live parameter updates, live status of equipment, and even recommendations based on plant conditions.

Human performance tools such as place keeping can be incorporated directly, and the status of any step is available to any crew member from any workstation. Gone are the days of the control room supervisor hovering over the shoulder of a reactor operator to effectively supervise step compliance. Completed procedure steps can be electronically signed off on by the operator performing the action. Operators can even assign individual procedure steps to specific operators to help coordinate complex evolutions when multiple individuals are involved. For instance, during a pre-job brief, the control room supervisor could assign procedure steps to a specific operator. The assigned operator would then get a notice or system email informing them of the assigned procedure or steps.

Computers are great at continuously monitoring parameters (and they don't get bored or distracted), whereas humans are great at processing information and making decisions. NuScale wanted to take advantage of these traits in the design and monitoring of critical safety functions. A continuous safety function monitoring system alerts the operator if any off-normal condition is detected. This system moves the operator into a supervisory and understanding role and less of a direct monitoring role.

Three critical safety functions are continuously monitored at NuScale plants to ensure the safety of each reactor: containment isolation, reactivity control, and core heat removal. These functions ensure that the reactor coolant system inventory is retained, the reactor is shut down when required, and decay heat is removed either through normal means or by the safety systems. Emergency procedures ensure these three safety functions are always met. For the NuScale design, there are no credited operator actions during any design-basis event. In the very remote chance of a beyond-design-basis event, the system would alert the operator of a potential challenge to a safety function and provide the exact emergency procedure steps to the operator on the affected unit. The emergency procedures use a symptom-based approach, rather than a diagnosis-based approach, which lowers the burden on the crew to ensure a correct diagnosis to successfully mitigate any condition.

Many human performance error-reduction tools used in the industry have been incorporated directly into the digital control interface design. Most of these should sound familiar:

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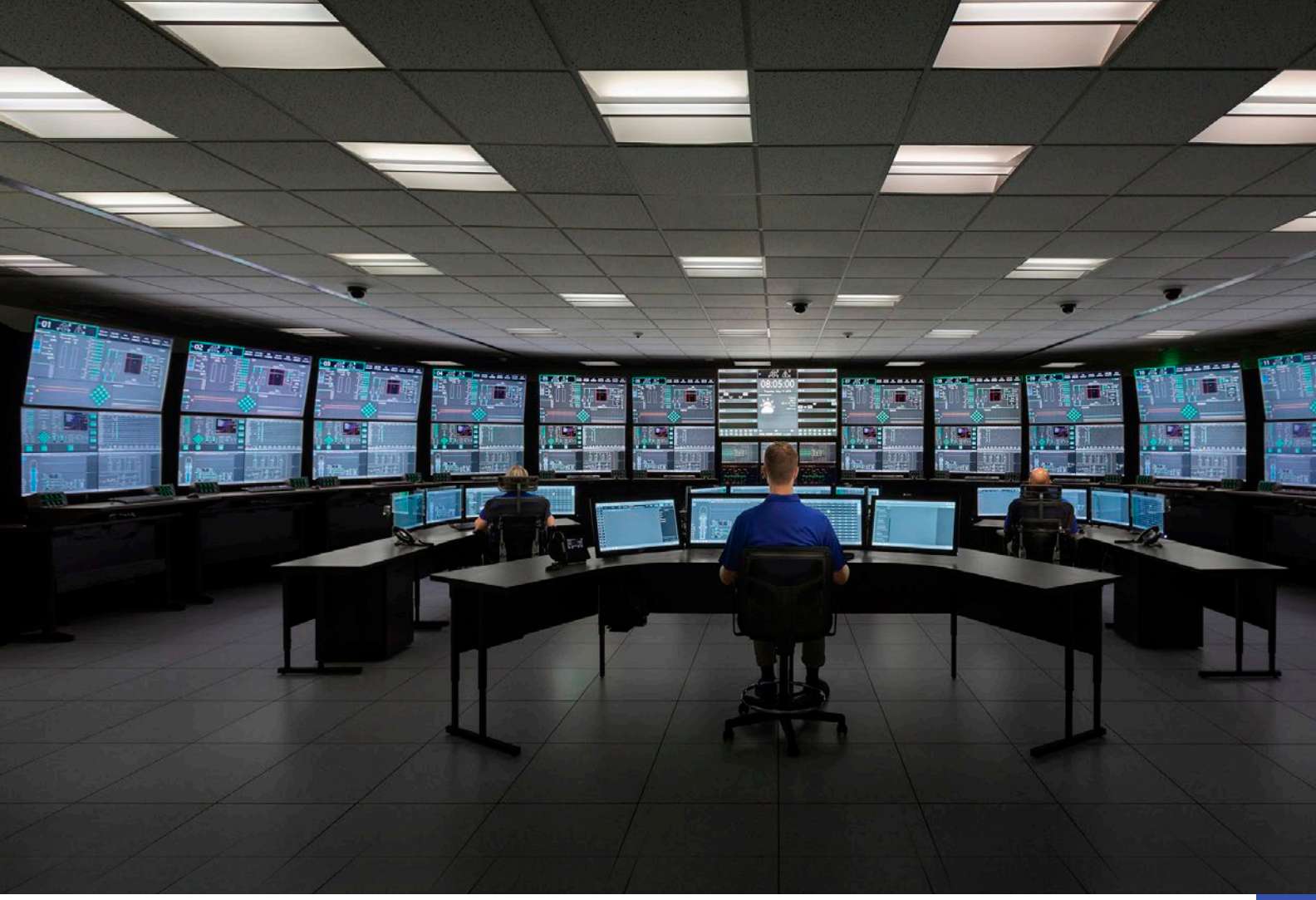


■ **Three-way communication.** An effective tool used to ensure that directions have been received and are understood. The NuScale interface provides a repeat-back summary of issued commands, so the operator can acknowledge or cancel prior to starting an evolution.

■ **Place keeping.** All digital procedures contain place keeping. Options to check a step as complete, in progress, or not applicable are available. Completed steps receive a date/time stamp and digital initial of the performer. Individual steps can be directly assigned to operators such that a team can work together on the same procedure.

■ **Right action/unit.** The NuScale control room can control up to 12 small modular reactors. To remove the potential for actions to be performed on the wrong unit, procedures are directly linked to icons (i.e., alarms or safety function indications) such that clicking on the icon opens the procedure for the affected unit.

■ **Peer checking.** NuScale considers the control system an agent of the control room. The control system can recommend or request permission from the operator to perform an action, then the operator can review and approve the recommendation, acting as the peer checker for the control system. For example, the control system will inform the operator that a dilution of a certain quantity is recommended to maintain average coolant temperature. The operator can review and approve the dilution evolution (i.e., act as the peer check of the dilution event). Peers are also employed in the more traditional sense for operator-initiated actions.

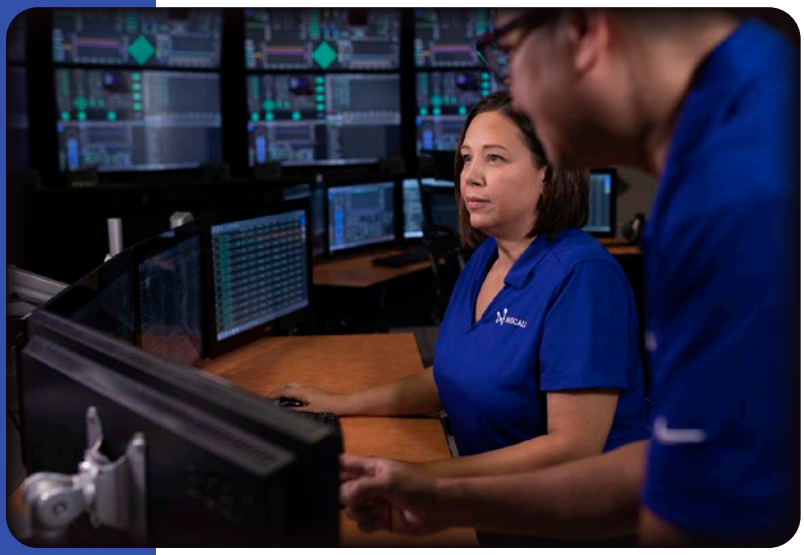
■ **Use of backup indications.** One of the highest workload tasks of operation is communication between the control room supervisor and reactor operators. By providing information directly to the control room supervisor workstation, the team can focus on assignment and review of actions and not on reader/doer direction of procedure steps.

■ **Roles and responsibilities.** The crew needs to be aware of the ownership for each unit. This is especially important with multiple units being operated from the same control room. For the NuScale conduct of operations, one operator monitors all units. This is similar to the at-the-controls concept currently adopted by the industry. When an operator transitions from monitoring to actively controlling a unit for an evolution or response, an icon is shown throughout the control room as a visual cue of which operator has ownership of which unit.

Roles remodeled

The job description of the operator has changed with the use of technology and higher levels of automation. Reactor operators initiate and approve control system sequences and respond to exceptions from normal operation, rather than performing individual actions as independent tasks. Since procedure status is available at every workstation, there is no longer a need for the "reader/doer" method of the supervisor directing individual steps. Control room supervisors are responsible for overall direction and task assignment to reactor operators rather than directing individual procedure steps. In addition, the control room supervisor acts as resource manager much like an air traffic controller, assigning reactor operators to issues as needed and prioritizing responses to situations whether they are normal or emergencies.

The quasi-oversight position of shift technical advisor (STA), created in the wake of the Three Mile Island accident, was intended to provide to the operating crew the additional resource of engineering experience. The original regulation mandating the STA position provided a path to eventually eliminate the position once operator training was improved and the controls of the facility had been upgraded to "state of the art"—goals that have now been achieved. NuScale training for operators includes engineering fundamentals, as is the standard in the nuclear industry. The plant design doesn't require operator actions for accidents within the design basis, and the human-system interface has been demonstrated to provide operators with intuitive cues to identify beyond-design-basis events. For the first time in 40 years, these upgrades in design allowed NuScale to demonstrate that a minimum crew of three licensed operators could operate the plant safely and eliminate the STA requirement.



Future focus

As we think about the future of these new reactor and control room designs, we realize that the middle and high school students of today will be the trained licensed operators of tomorrow. The use of web browser–themed navigation, intuitive icons, and control methods commonly used on phones, computers, and game consoles will allow the interface to be familiar and intuitive to new users. One of the most satisfying parts of the job is to see how even untrained individuals who visit the simulated control room can pick up on how to operate or respond to events with only minutes of basic instruction. A virtual tour of the control room simulator is available on YouTube (youtu.be/brr5j50umYA).

Overall, an effective control room design team maintains a questioning attitude on how to reduce or eliminate errors, provide needed information to the operations team, reduce administrative workload, and allow operators to focus directly on the safe operation of the facility. As a team, our end goal is to ensure we use new technology and tools to help operators continue a tradition of error-free operations, and always keeping nuclear safety at the forefront of any design decision.

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