Digital Procedure Systems for Nuclear Reactors—Human Factors and Organizational Considerations Beyond Main Control Room Operations

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Abstract: Digital procedure systems are often introduced as operator-support technologies: they can present procedure steps, track placekeeping, display plant values, record user actions, and support branching logic during task execution. However, the transition from paper procedures to digital procedures also changes the organizational work required to author, approve, issue, execute, and preserve procedures as controlled records. This paper examines those organizational and human-factors issues through a proof-of-concept digital procedure deployment for the National Reactor Innovation Center's Demonstration of Microreactor Experiments (DOME) operations at Idaho National Laboratory. The project used interview-based discussions with procedure writers, operations personnel, information-technology architects, records stakeholders, and a digital procedure system vendor to identify adoption requirements and implementation constraints. The resulting prototype effort produced three converted digital procedures, a reusable procedure template within the procedure authoring system, a draft writer's guide, device and authentication selection with rationale, and a static-output strategy for review and records management. The central finding is that digital procedure adoption should be treated as a socio-technical change to procedure governance, not only as an interface upgrade for operating crews.

Keywords: digital procedures, computerized operating procedure systems, human factors, document control, records management, DOME, microreactors

1. INTRODUCTION

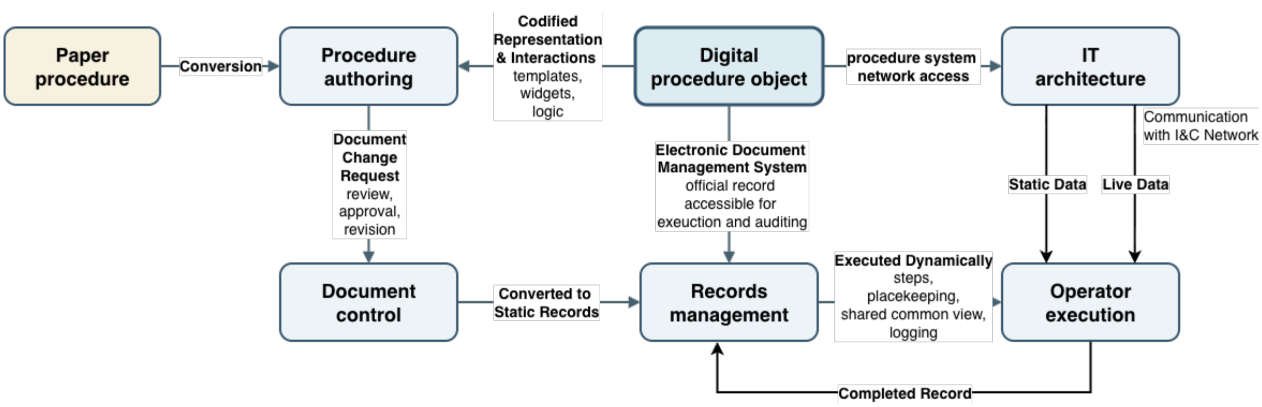
Plant procedures are the governing mechanism that translate design, safety, operating, and administrative requirements into work that operators and other personnel can perform at nuclear facilities. Historically, these procedures have been paper-based or document-centered: the approved static artifact is a controlled document, operators mark or sign steps as needed, and completed copies can be retained as records. Digital procedure systems change that pattern by introducing dynamic aspects. They can support procedure execution by presenting steps on a computer interface, maintaining placekeeping, logging user actions, checking conditions, displaying live values, and guiding transitions through procedure logic [1, 2].

The human-factors value of computerized operating procedure systems, henceforth referred to as digital procedures, has usually been framed around the control room or the operator work context. That framing is appropriate, but incomplete. A digital procedure is not simply a paper procedure executed from a digital display. Its behavior may depend on interface widgets, defined operator user roles, live data, branching paths, embedded calculations, and system-generated record logging. As a result, the procedure that an operator experiences is partly a document, partly an interface, and partly an executable workflow. The transition therefore affects more than operator usability. It also affects procedure authorship, document control, review and approval, cybersecurity, records management, and the organizational handoffs through which procedures become official work controls [1, 3, 4].

This paper focuses on those broader organizational and human-factors considerations. It uses a proof-of-concept digital procedure system deployment for the National Reactor Innovation Center's Demonstration of Microreactor Experiments (DOME) as the motivating use case. DOME is an advanced-reactor test bed at Idaho National Laboratory intended to support fueled microreactor demonstrations up to 20 MWth [5,6]. Because DOME combines evolving facility operations, formal conduct-of-operations expectations, controlled procedures, records obligations, and digital infrastructure decisions, it provides a useful setting for examining what must be resolved to deploy a digital procedure system in a realistic nuclear reactor operations context as only one U.S. commercial nuclear power plant uses a digital procedure (cite).

The contribution of this paper is a structured account of the adoption issues and resolutions that emerged when converting existing paper procedures into digital procedures and considering their deployment in a nuclear reactor facility context. The analysis emphasizes that successful adoption depends on aligning operator usability with the work of procedure writers, document custodians, information-technology architects, cybersecurity stakeholders, and records managers. There is likely a tradeoff in that smoother more efficient operations through digital procedures requires a greater burden on the development and management of those procedures. In that sense, digital procedure adoption is an organizational design problem as much as a human-system interface problem [7–9].

Figure 1: Organizational and Human-Factors Scope of Digital Procedure Adoption



2. BACKGROUND: PROCEDURES, HUMAN FACTORS, AND DOCUMENT CONTROL

Procedures support disciplined operations by guiding personnel through monitoring, decision-making, equipment manipulation, testing, maintenance, turnovers, and controlled work. In the nuclear domain, procedures are part of the broader system used to manage human performance and maintain facility safety. DOE conduct-of-operations guidance treats formal documentation, practices, and actions as mechanisms for structured operation and for reducing the likelihood or consequence of human fallibility and organizational failures [3]. Similarly, NRC computer-based procedure guidance characterizes plant procedures as instructions that guide operators in monitoring, decision-making, and controlling nuclear power plants [1].

Procedure quality matters because the procedure is often the immediate representation of approved work. Technical procedure writer guidance emphasizes that procedures should be accurate, complete, clear, consistent, and usable, and that writing practices should reduce ambiguity, confusion, rework, and error [10,11]. These expectations do not disappear when procedures become digital. Instead, they become more demanding. Digital procedures must preserve the procedural intent embedded in the approved paper record while also making explicit the execution behavior that the software will present to users. Step sequence, prerequisites, cautions, notes, conditions, contingencies, branching paths, user acknowledgments, and records of completion all become part of the human-system design.

Human-factors review guidance is relevant because digital procedures are human-system interfaces. NUREG-0700 includes guidance for evaluating interface characteristics, and NUREG-0711 frames HFE review as a top-down process that connects plant goals, functions, tasks, interfaces, procedures, training, verification, validation, and implementation [8,9]. For digital procedure systems, this connection is especially important. The procedure interface can shape what information is visible, how users know where they are, how they move between steps, how conditions are evaluated, and how procedural status is recorded.

At the same time, procedures are controlled documents. Under 10 C.F.R. Part 50, Appendix B, document control measures must control the issuance of instructions, procedures, drawings, and changes, including review, approval, distribution, and use at the location where the prescribed activity is performed [4]. DOE conduct-of-operations requirements also address technical procedure content, change processes, revisions, and the need for configuration control [3]. These requirements make digital adoption a governance issue. The approved procedure is no longer just a visible page; it may include source data, interaction rules, embedded logic, software rendering behavior, and execution records.

Records management is the companion problem. Executed procedures, approvals, checkoffs, signatures, changes, and revision histories may become official records that must remain retrievable and interpretable outside the immediate moment of use. Federal records management requirements and NARA electronic-records guidance emphasize that records must be managed across media and that electronic records require sufficient metadata to support preservation, transfer, retrieval, and use [12,13]. For digital procedures, this raises a practical question: what is the record of a dynamic procedure? The answer cannot be assumed to be the runtime file alone, because reviewers and auditors may need a static, readable representation of the procedure content, execution path, changes, and completed actions.

3. DIGITAL PROCEDURE ADOPTION CHALLENGES

The first adoption challenge is the transition from static procedure text to dynamic procedure behavior. In a paper procedure, the approved artifact exposes most of its content directly. A reviewer can read the step sequence, cautions, notes, prerequisites, signatures, and branching instructions. In a digital procedure system, some of that content may be visible only through interaction. Branching logic, conditional displays, live-value checks, embedded calculations, role-based actions, required acknowledgments, and automated logging may be distributed across the digital procedure file and the procedure-system runtime. This can improve operator support, but it also complicates review and control [1,2,14].

The second challenge is the changing role of the procedure writer. For paper procedures, writers specify the text and structure that operators will follow. For digital procedures, writers also shape how the procedure behaves. They must decide which widgets are permitted, where user input is required, how branching should be represented, which fields are logged, when a step requires acknowledgment, and how the system should render procedure status. This turns procedure writing into a form of interaction design. The writer remains responsible for clarity and accuracy, but now must also understand how interface behavior affects operator interpretation and task flow [1, 2, 11].

Templates and reusable functional blocks add another layer of governance. Historically, procedures have often been controlled as whole documents. Digital systems make it attractive to define smaller reusable sequences, standard widgets, or procedure skeletons. Reuse can reduce duplication and promote consistency, but it also creates ownership and configuration-control questions. If a reusable block changes, which procedures are affected? Who reviews the change? How is the change represented in the document-change process? How do reviewers distinguish a text edit from a logic edit? These questions show why templates should be treated as controlled procedure infrastructure rather than merely authoring conveniences [3, 4, 10].

The third challenge is cybersecurity and network placement. Digital procedure systems can range from stand-alone presentation tools to systems that integrate live plant data or support more advanced operator guidance. Live-data integration can improve procedure execution by reducing manual transcription and making plant state more visible, but it also creates an interface between business information systems, procedure-authoring tools, operator workstations, and potentially operational technology networks. NRC cyber guidance and NIST operational-technology security guidance both emphasize the need to protect digital systems and networks that support safety, security, and operational functions [15–17]. For procedure deployment, the architecture must therefore distinguish authoring, approval, execution, records export, and plant-data access.

The fourth challenge is static representation. A controlled digital procedure needs an executable source that the system can run, but document control and records review often require a static representation that can be read, compared, approved, and archived. Static output is especially important for change review. A reviewer should be able to see not only that the words of a step changed, but also that branching conditions, required user actions, logged fields, or display behavior changed. Without such a representation, the official review may depend on access to the procedure software and on a reviewer manually exercising possible paths. That approach is fragile for approval, audit, and long-term records management [3, 12, 13].

4. USE CASE: DOME DIGITAL PROCEDURE PROTOTYPE

The use case for this work is a proof-of-concept digital procedure system deployment for NRIC's DOME facility. DOME is a DOE and NRIC test bed located at Idaho National Laboratory that reuses the containment structure of the former Experimental Breeder Reactor-II to support fueled microreactor experiments. DOE describes DOME as a test bed for reactor experiments up to 20 MWth, intended to help developers generate data for design verification, safety analysis, and licensing activities [5]. NRIC describes the facility as including a containment building, control room area, yard, utilities, electrical and instrumentation penetrations, ventilation, and supporting infrastructure for reactor demonstrations [6, 18].

DOME is an instructive setting because its operational environment is both formal and evolving. As an advanced-reactor demonstration facility, it must support new reactor technologies and changing test campaigns. At the same time, facility work must be governed through approved procedures, conduct-of-operations expectations, document control, cybersecurity constraints, and records management. This combination creates a practical adoption question: how can a digital procedure system be introduced in a way that helps operators without bypassing the organizational systems that make procedures official?

The project goal was to develop requirements and evaluate implementation options for a prototype digital procedure system deployment. The scope included converting three existing paper procedures into digital procedures, creating a reusable procedure template, drafting a writer's guide, evaluating execution-device options, considering authentication and user-role needs, and identifying a pathway for closing out executed procedures as records. The prototype was not intended to validate operator performance or qualify a production system. It was intended to reveal the organizational and human-factors requirements that would need to be resolved before broader deployment.

Several design questions structured the effort. First, how should existing paper procedures be translated into a compatible and usable digital format while preserving procedural intent? Second, what execution device would fit the control-room task environment: a thin client, a two-in-one laptop, or a ruggedized laptop? Third, how should user identity, operator assent, checkoffs, signatures, timestamps, and role-based permissions be represented? Fourth, how should executed procedures be closed out and filed in the electronic document or records management system? Fifth, how should digital procedures enter the existing document-change request process, especially when dynamic behavior is not fully visible in a conventional paper printout [3, 4, 12]?

5. METHODOLOGY

The project used semi-structured, interview-based discussions and iterative artifact review. Participants and stakeholders included the digital procedure system vendor, procedure writers, operations personnel, information-technology architects, cybersecurity-aware infrastructure stakeholders, and records or document-management personnel. This approach was appropriate for a proof-of-concept effort because many adoption constraints were embedded in organizational practice rather than in the software alone. The method therefore emphasized eliciting requirements, identifying handoffs, and testing whether prototype artifacts could fit existing work processes [9, 11].

Discussions with the vendor focused on platform capabilities and limitations. Topics included procedure authoring, step structure, available interaction elements, role definitions, execution logging, static export, change tracking, and the subset of features appropriate for an initial deployment. The aim was not to use every available function, but to constrain the system to a controlled feature set that procedure writers and reviewers could understand. This constraint is important because an unconstrained digital procedure system can create variability in operator experience and make review more difficult [1, 2].

Work with procedure writers focused on converting selected paper procedures and developing authoring controls. The conversion effort identified where existing procedure text could map directly to digital steps and where additional decisions were required about branching, step completion, user input, display format, and logged information. The writer's guide was developed as a way to standardize those decisions. It defined the procedure skeleton, approved interaction elements, expected use of widgets, and conventions for producing a final digital procedure that would remain readable and reviewable [10, 11].

Work with operations personnel focused on task context and usability. Operators and operations staff provided insight into the physical control-room environment, expected procedure use, device placement, available workspace, and the practical difference between using a fixed workstation, a shared device, or an individual portable device. These discussions were necessary because the usability of a digital procedure system depends not only on the screen design, but also on where the device sits, how the operator moves, how much space is available, and whether the system interrupts or supports the operator's normal work pattern [7, 8].

Work with IT and records stakeholders focused on deployment architecture. Topics included whether operators could access the business network, whether procedure execution could occur on existing control-room devices, how authoring and execution environments should be separated, how credentials and roles should be managed, whether live plant data would require control-network integration, how executed procedures would be exported, and how static outputs would support review and records. These discussions connected procedure usability to cybersecurity and records obligations [13, 15, 16].

6. RESULTS

The first result was a clearer understanding of deployment constraints. Operators had access to the business network, which made multiple execution-device options technically possible. However, the physical control-room environment limited the practicality of some devices. A large or cumbersome device could satisfy software requirements while still imposing unacceptable workspace and handling burdens. This reinforced a basic human-factors point: device selection should be evaluated in the actual work setting, not only against software compatibility or procurement availability [8].

The second result was the creation of three prototype digital procedures from existing paper procedures. The conversion process demonstrated that basic step content could be migrated into the vendor-provided software, but also showed that procedure conversion is not a simple transcription task. Even when the paper procedure is clear, digital implementation requires choices about step grouping, branching, user acknowledgments, expected input, display behavior, and how much procedural context should remain visible. The prototypes therefore served as both candidate operational artifacts and discovery tools for authoring requirements [10, 11].

The third result was a reusable procedure skeleton and draft writer's guide. The skeleton provided a common structure for future procedure authors, while the writer's guide constrained how digital features should be used. This was important because digital procedure systems can provide many possible interaction elements, not all of which are appropriate for controlled procedure execution. By defining approved widgets and conventions, the project reduced variability and gave reviewers a basis for evaluating whether a digital procedure followed expected practice [1, 2, 8].

The fourth result was a records-management strategy centered on static PDF output. Stakeholders identified that procedure review, change tracking, approval, and executed-procedure filing could not depend solely on the digital procedure runtime environment. A static representation was needed so that reviewers could see the procedure content and changes in a format compatible with existing document-control practices. Static output was also needed for executed procedure records, where timestamps, user actions, checkoffs, and completed paths may need to be preserved for later retrieval and audit [4, 12, 13].

The fifth result was the identification of a document-change challenge specific to dynamic procedure logic. Existing document-change processes are generally well suited to reviewing visible changes in controlled documents. Digital procedures introduce changes that may not be visible as ordinary text edits. A change to branching logic, required input, user-role permissions, or logging behavior can alter procedure execution even if the displayed words remain similar. Therefore, the document-change process must be able to expose both text changes and logic changes in a form that reviewers can understand [3, 4, 13].

7. DISCUSSION

The prototype suggests that digital procedure adoption should be treated as a socio-technical change to procedure governance. Operator-facing usability remains essential, but it is only one part of the adoption problem. The procedure must be authored, reviewed, approved, issued, executed, changed, and archived. Each of those activities has stakeholders, tools, and expectations that may be affected by the move from paper to digital procedure objects. A deployment that focuses only on the operator interface risks leaving unresolved the organizational work that makes procedures trustworthy and official [3, 9, 16].

The procedure-writer role is especially important. In a digital procedure system, writers become designers of interaction paths. They determine how the operator moves through the procedure, what information is collected, what is logged, when branching occurs, and how completion is represented. This does not mean that procedure writers must become software engineers. It does mean that the organization must provide a writer's guide, templates, review criteria, and training that treat digital behavior as part of procedure quality. Otherwise, procedure usability may vary from author to author, and reviewers may struggle to determine whether the digital implementation matches the approved intent [2, 8, 11].

The document-control implication is that an approved digital procedure needs both an executable source of truth and an auditable representation. The executable source is needed for operation. The auditable representation is needed for review, approval, change comparison, records management, and long-term retrievability. These two artifacts must be synchronized and governed. If the static representation omits logic that affects execution, reviewers may approve an incomplete picture of the procedure. If the executable source can change without producing a reviewable record, document control is weakened. The adoption process must therefore define what counts as the official procedure package [4, 12, 13].

The cybersecurity implication is that added functionality changes deployment architecture. A digital procedure system used only for static display has different risk characteristics than a system that receives live plant data, writes execution records, or bridges authoring and execution environments. Live data can reduce manual workload and support operator awareness, but it may also create dependencies on networks, credentials, data integrity, and operational-technology boundaries. Architecture decisions should therefore be made before the organization commits to a feature set, because the desired level of automation may determine where the system can reside and how it must be protected [15–17].

The study has several limits. It was a proof-of-concept deployment analysis rather than a validated operator-performance study. It did not conduct full-scale verification and validation, complete cybersecurity assessment, or long-term records-retention testing. It also examined a limited number of converted procedures. The findings should therefore be interpreted as adoption requirements and design considerations, not as evidence that a particular digital procedure system improves operations. Future work should evaluate operator performance, procedure-writer workload, reviewer effectiveness, and records integration using more complete operational scenarios [1, 9].

8. CONCLUSIONS

Digital procedure systems offer meaningful opportunities for nuclear reactor facilities. They can support operators through placekeeping, guided execution, live values, branching logic, logging, and more consistent presentation of procedural content. However, the adoption of digital procedures also changes the organizational work surrounding procedures. Procedure writers must specify interaction behavior, document-control reviewers must evaluate dynamic logic, IT architects must define deployment boundaries, cybersecurity stakeholders must address network and credential implications, and records managers must preserve executed and approved procedure artifacts in retrievable form.

The DOME proof-of-concept effort produced practical adoption artifacts: three converted prototype procedures, a reusable procedure template, a draft writer's guide, device and authentication considerations, and a static-output approach for review and records. More importantly, it showed that these artifacts are interconnected. A writer's guide affects review; review affects records; records affect static export; static export affects what logic must be visible; and live-data aspirations affect cybersecurity and architecture.

The central conclusion is that successful digital procedure adoption requires alignment between operator usability and procedure governance. A digital procedure system should not be evaluated only by whether operators can execute a procedure on a screen. It should also be evaluated by whether the organization can author, approve, issue, execute, revise, audit, and preserve that procedure with the same or greater confidence than the paper-based process it replaces [1, 3, 16]. This digital procedure adoption stops short of soft controls which are embedded controls within the procedure itself. The findings of this current effort have particular implications for soft controls as these blur the line between the instrumentation and control system and procedures. As evidenced here, dynamic elements impose additional challenges for procedure writers, however controls would likely involve control system engineers as well which is an additional level of complexity and must be solved for more advanced procedure system deployments. Sans controls, the next steps for this research and development include operator-use evaluation, writer-workflow validation, integration testing with document and records systems, refinement of change-control review for dynamic logic, and cybersecurity assessment for live-data integration [8, 9, 15].

DISCLAIMER

REFERENCES

[1] John M. O'Hara, John C. Higgins, William F. Stubler, and John Kramer. Computer-based procedure systems: Technical basis and human factors review guidance. Technical Report NUREG/CR-6634, U.S. Nuclear Regulatory Commission, March 2000.

[2] IEEE Standards Association. IEEE Approved Draft Recommended Practice for Human Factors Applications of Computerized Operating Procedure Systems (COPS) at Nuclear Power Generating Stations and Other Nuclear Facilities, 2026.

[3] U.S. Department of Energy. *Conduct of Operations*. U.S. Department of Energy, August 2025.

[4] U.S. Nuclear Regulatory Commission. Appendix b to part 50: Quality assurance criteria for nuclear power plants and fuel reprocessing plants. 10 C.F.R. Part 50, Appendix B, 2026.

[5] U.S. Department of Energy. Demonstration of microreactor experiments (dome), 2026. Web page.

[6] National Reactor Innovation Center. The nric-dome test bed. Technical Report 20-50250-07 R7, National Reactor Innovation Center, 2025.

[7] U.S. Nuclear Regulatory Commission. Human factors, 2026. Web page.

[8] John M. O'Hara and Stephen Fleger. Human-system interface design review guidelines. Technical Report NUREG-0700, Revision 3, U.S. Nuclear Regulatory Commission, July 2020.

[9] John M. O'Hara, John C. Higgins, Stephen A. Fleger, and Paul A. Pieringer. Human factors engineering program review model. Technical Report NUREG-0711, Revision 3, U.S. Nuclear Regulatory Commission, November 2012.

[10] USDOE Assistant Secretary for Nuclear Energy. Writer's guide for technical procedures. Technical report, U.S. Department of Energy, September 1991.

[11] Megan Greenwald-Yarnell, Walter Edgar Gilmore, and Paul Cameron Schutte. Technical procedures writer's guide. Technical Report SAND-2021-0153, Sandia National Laboratories, 2021.

[12] National Archives and Records Administration. Records management. 36 C.F.R. Chapter XII, Subchapter B, 2026.

[13] National Archives and Records Administration. Metadata requirements for permanent electronic records, 2024. Web page.

[14] Westinghouse Electric Company. Computerized procedures system, 2026. Product data sheet.

[15] U.S. Nuclear Regulatory Commission. Cybersecurity, 2026. Web page.

[16] Keith Stouffer, Michael Pease, CheeYee Tang, Timothy Zimmerman, Victoria Yan Pillitteri, Suzanne Lightman, Adam Hahn, Stephanie Saravia, Aslam Sherule, and Michael Thompson. Guide to operational technology (ot) security. Technical Report NIST Special Publication 800-82 Revision 3, National Institute of Standards and Technology, 2023.

[17] C. Chenoweth, J. Green, T. Shaw, M. Shinn, and G. Simonds. The u.s. nuclear regulatory commission's cyber security regulatory framework for nuclear power reactors. Technical Report NUREG/CR-7141, U.S. Nuclear Regulatory Commission, November 2014.

[18] National Reactor Innovation Center. Dome: Demonstration of microreactor experiments, 2026. Web page.