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Light Water Reactor Sustainability Program

Computer-Based Procedures for Field Activities: Results from Three Evaluations at Nuclear Power Plants

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EXECUTIVE SUMMARY

The Computer-Based Procedure (CBP) research effort is a part of the Light-Water Reactor Sustainability (LWRS) Program, which is a research and development (R&D) program sponsored by Department of Energy (DOE) and performed in close collaboration with industry R&D programs that provides the technical foundations for licensing and managing the long-term, safe, and economical operation of current nuclear power plants. One of the primary missions of the LWRS program is to help the U.S. nuclear industry adopt new technologies and engineering solutions that facilitate the continued safe operation of the plants and extension of the current operating licenses.

One area that could yield tremendous savings in increased efficiency and safety is in improving procedure use. Nearly all activities in the nuclear power industry are guided by procedures, which today are printed and executed on paper. This paper-based procedure process has proven to ensure safety; however, there are improvements to be gained. Due to its inherent dynamic nature, a CBP provides the opportunity to incorporate context driven job aids, such as drawings, photos, and just-in-time training. Compared to the static state of paper-based procedures (PBPs), the presentation of information in CBPs can be much more flexible and tailored to the task, actual plant condition, and operation mode. The dynamic presentation of the procedure will guide the user down the path of relevant steps, thus minimizing time spent by the field worker to evaluate plant conditions and decisions related to the applicability of each step. This dynamic presentation of the procedure also minimizes the risk of conducting steps out of order and/or incorrectly assessed applicability of steps.

Previously, the INL research team conducted two evaluation studies in controlled laboratory settings where the usability of CBP system prototype was evaluation. The studies conclude that a well-designed CBP can prevent errors and hence improve human performance. However, it may initially take more time to conduct the task with a CBP system compared with the current paper-based work process.

A third laboratory evaluation study was conducted in the I&C Laboratory at the Arizona Public Service Palo Verde Nuclear Generating Station (PVNGS) in February, 2014 to incorporate improvements to the CBP system and to expand the functionality to prepare for demonstrating the system with real-world procedures. The CBP system was revised to incorporate automated calculations, continuous action steps, and links to supplemental information. Fourteen operators and technicians participated in the study. Each participant carried out

the procedure twice; once with the CBP and once with a traditional PBP. The results from the study yielded that the participants committed 95 errors when using the PBP and 48 when using the CBP version of the same procedure. The most common error committed in both the PBP and CBP conditions was a failure to conduct proper correct component verification and the second most common error was in executing a calculation of the volume required to fill a tank. In addition, the results showed that it did not take more time to execute the procedure using the CBP compared to the PBP, which indicates that the potential tradeoff between reduced errors and a longer time to execute the procedure might not be inevitable. It might be possible to reduce errors without increasing procedure execution time with a CBP system.

In order to fully test the degree to which CBPs can reduce errors and increase efficiency, research needs to be conducted over longer period of time and in a more realistic setting than in laboratories and training facilities. The laboratory evaluation studies were successful in evaluating the usability of the CBP system and its potential impact on human performance. However, the studies were limited in scope and the participants only went through the task once with the CBP system. This does not provide sufficient information to conclude if the CBP system actually will have a positive impact on human performance and safety in the plant. Therefore, the researchers planned field evaluations of the CBP system, which would use real plant procedures and occur over several months.

A pilot field evaluation study was conducted at Duke Energy's Catawba Nuclear Station (CNS) between April and June, 2014. The main objectives of the pilot field study were to evaluate the feasibility of using a CBP system in the actual plant during everyday operations, evaluate the usability of the revised CBP system, and to gather insights about how to best conduct a field evaluation study (i.e., lessons learned about what went well in the method used and what needs to be tweaked or approached slightly different in the future). The result from the study indicates that all of the AOs who used the CBP preferred it to the PBP. The CBP did not slow down the execution of the task. The AOs rated the CBP as highly usable at an average of 9.67 on a 10 point scale. They also indicated that there was no situation in which the CBP caused errors or error-likely situations. Instead, there was at least one instance in which the CBP may have increased efficiency compared to the PBP. Lessons learned from the pilot study include the importance of becoming familiar with the users and task early in the design phase of the CBP version and to plan for sufficient time for the users to become familiar with the CBP system and slightly modified work flow before any major disturbances such as an outage occurs.

A second field evaluation study was initiated at PVNGS in early September, 2014. The research team decided to base the study on a preventive maintenance work order as a step to incorporate more aspects of the work package process used in the nuclear power industry. The study is still in progress; however, some initial findings have already been identified. For example, the maintenance technicians identified instances in the work order where the system could provide even more distinct cues and information. In addition, the research team identified a couple of lessons learned while they conducted a pre-validation activity before initiating the field study. One example of these lessons learned is the importance to select a work instruction that is executed in a location where visitors such as the research team can access in some manner. In order to design a

CBP that will help improve human performance it is of great value to be able to observe the field workers as they execute the task with their current paper-based process.

In order for CBP systems to be of interest to the nuclear industry, they need to encompass more than just procedures for field workers. The system needs to be able to handle all types of instructions, checklists, procedures, work orders and other documents used in the plant. The vision is to have all the different organizations within the plant use the same system. The version of the CBP system to be used in the second field test will take steps toward the vision of incorporating all elements needed in a work package. Moving forward, the research team will conduct additional field validation studies to ensure that as many different types of instructions and procedures as possible are covered by the research. This is of great importance in order to develop a design guidance that is applicable across the nuclear power industry. In addition, the researchers will investigate how to best design, from a human factors perspective, additional parts of the work package process to eventually transform the current CBP system prototype into an Automated Work Package system.

The research team is currently in the planning stage with two other utilities that have expressed their interest in hosting field test activities. For each field test planned and conducted, the CBP system will be revised to include additional functionality needed to bring it closer to handle all aspects of a work package, i.e., the full process from initiating work request, planning, execution, and archiving.

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ACRONYMS

AO	auxiliary operators
CBP	computer-based procedures
CBWO	computer-based work order
CCV	correct component verification
CNS	Catawba Nuclear Station
DOE	Department of Energy
HVAC	heating, venting, and air conditioning
I&C	instrumentation and controls
INL	Idaho National Laboratory
PBP	paper-based procedures
PVNGS	Palo Verde Nuclear Generating Station

1. INTRODUCTION

1.1 General LWRS and CBP background

Nearly all activities that involve human interaction with the systems of a nuclear power plants are guided by procedures. The paper-based procedures (PBPs) currently used by industry have a demonstrated history of ensuring safety; however, improving procedure use could yield tremendous savings in increased efficiency and safety. One potential way to improve procedure-based activities is through the use of computer-based procedures (CBPs).

Computer-based procedures provide the opportunity to incorporate context driven job aids, such as drawings, photos, and just-in-time training into the CBP system. One obvious advantage of this capability is reducing the time spent tracking down applicable documentation. Additionally, human performance tools can be integrated in the CBP system to help the worker focus on the task rather than the tools. Some tools can be completely incorporated into the CBP system, such as pre-job briefs, placekeeping, correct component verification, and peer checks. Other tools can be partly integrated in a fashion that reduces the time and labor required, such as concurrent and independent verification.

Another benefit of CBPs compared to PBPs is dynamic procedure presentation. PBPs are static documents which limits the degree to which the information presented can be tailored to the task and conditions when the procedure is executed. The CBP system could be configured to display only the relevant steps based on operating mode, plant status, and the task at hand. A dynamic presentation of the procedure (also known as context-sensitive procedures) will guide the user down the path of relevant steps based on the current conditions. This feature will reduce the user's workload and inherently reduce the risk of incorrectly marking a step as not applicable and the risk of incorrectly performing a step that should be marked as not applicable.

As part of the Department of Energy's (DOE) Light Water Reactors Sustainability Program, researchers at Idaho National Laboratory (INL) along with partners from the nuclear industry have been investigating the design requirements for computer-based work instructions (including operations procedures, work orders, maintenance procedures, etc.) to increase efficiency, safety, and cost competitiveness of existing light water reactors. This report addresses the DOE milestone M3LW-14IN0603092 - Complete report on results of the computer based procedures validation study with nuclear power plant personnel.

1.2 Previous Research Activities

The overarching focus of the research effort is to define how to design a CBP system that will increase efficiency while also improving human performance. This includes both identifying the underlying structure and content of the procedures as well identifying the appropriate user interface characteristics of the CBP.

As a first step, researchers conducted a qualitative study to investigate the current use of procedures in the nuclear power industry (Le Blanc, Oxstrand and Waicosky, 2012a; Oxstrand and Le Blanc, 2012). The purpose was to identify error-likely situations in procedure execution as well as potential improvements to the process through the use of technology. The researchers shadowed auxiliary operators as they conducted rounds, and conducted semi-structured interviews with operators and trainers. In addition, researchers mapped the flow of information in the procedure process to identify what information needs to be available in the computer-based procedure and who would need to have access to the information. The study identified which aspects of the existing paper-based process should be retained when designing a CBP system, e.g., providing an overview of the task and keeping the operator focused on the task at hand. Areas in which a CBP could improve upon the paper-based process were also identified, such as the processes for placekeeping and correct component verification.

Industry acceptance of advanced technology and CBP systems is vital in order to move the industry closer to fleet-wide deployment of such systems. One way to gain this acceptance is to put the technology in the hands of the end users. In the case of the CBP research, the end users are auxiliary operators, maintenance technicians, chemistry technicians, etc. Hence, it was important to engage end users early in the design process of the CBP system.

Based on the findings from the qualitative study, the researchers identified an initial set of design requirements (Le Blanc, Oxstrand & Waicosky, 2012b; Oxstrand and Le Blanc, 2012), which was used to design the first version of the CBP prototype system. Each revision of the prototype was evaluated through empirical research conducted in laboratory settings at the collaborating utilities. Four laboratory evaluation studies were conducted overall. Three were hosted by collaborating utilities and were conducted in their training facilities (flow loop, electrical laboratory, and instrument and control laboratory). One study was conducted during a Light Water Reactor Sustainability Utility Working Group meeting at INL. The study participants conducted scenarios using both a paper-based procedure and a computer-based version of the same procedure. The researchers compared the participants' performance using both types of procedures. The studies evaluated the CBP design from a human factors perspective, i.e., evaluated the usability of the design, the impact on human performance, and error reduction possibilities. The researchers gathered input on deviations from specified path, performance time, mental workload, and the general usability of device and interface (Oxstrand, Le Blanc, and Hays, 2012; Oxstrand, Le Blanc, and Bly, 2013).

The main objective of the evaluation studies was to collect feedback on the design of the user interface of the CBP as well as to identify the appropriate functionality of the CBP. The researchers incorporated suggestions from the users as well as insights gained from carefully observing the participants carry out the procedures using the CBP. In addition to gathering information about usability and functionality, the researchers aimed to evaluate the effect a CBP may have on performance and efficiency of the procedural task.

The results of the first two laboratory evaluation studies indicate that well-designed CBPs may reduce errors (Le Blanc & Oxstrand, 2013). The procedure used in the first study was incredibly simple, and none of the participants made an error in executing the procedure, making it impossible to compare performance between the CBP and PBP. The second evaluation study revealed that in a more complex procedure, the CBP could potentially reduce the number of errors. Participants committed a total of thirteen errors when using the PBP compared to a total of one error using the CBP.

The evaluation studies also indicated that it might take more time to execute the procedure using a CBP (Le Blanc & Oxstrand, 2013; Oxstrand, Le Blanc, and Bly, 2013). It took an average of two minutes longer to complete the procedure with the CBP in the first study, and an average of eight minutes longer to complete the procedure with the CBP in the second study. The researchers suggested that the longer time could be partially due to a lack of familiarity with the CBP. Participants had only ten minutes of training on how to use the CBP, but had been using PBPs for their entire careers as operators. However, researchers also acknowledged that there might be a legitimate tradeoff between reduced errors and longer completion time when using CBPs.

In order to fully test the degree to which CBPs can reduce errors and increase efficiency, research needs to be conducted over a longer period of time and in a more realistic setting. Researchers planned field evaluations of the CBP, which would use a real plant procedure and occur over several months. However, before conducting the pilot test of the field evaluation, the researchers conducted a final laboratory evaluation study to incorporate improvements to CBP and to expand the functionality to prepare for real-world procedures.

2. THIRD LABORATORY EVALUATION STUDY

Before conducting the field evaluation of the CBP system, researchers conducted a third laboratory evaluation study. The study was designed to test additional functionality of the CBP system in preparation for the pilot field evaluation study. The revised prototype incorporated automated calculations, continuous action steps (i.e., steps that apply across the entire procedure, or when certain conditions are present), and links to supplemental information. The evaluation study was conducted at a partnering utility in their Instrumentation and Controls (I&C) training laboratory. The team developed a procedure for Operation of the Flow Work Station. The procedure provides instructions for using the flow lab to fill a portable tank in the I&C Training Laboratory (See Appendix A). An operator performing the procedure in the I&C Laboratory with the CBP is depicted in Figure 1.

Figure 1. An operator executes the procedure with the CBP.

2.1 Method

Fourteen operators and technicians participated in the study. Each participant carried out the procedure twice; once with the CBP and once with a traditional PBP. The order was counterbalanced (i.e., every other participant started with the PBP). Two researchers were extensively trained to observe the execution of the procedure and record any errors that occurred. Two observers were used in this study to reduce the potential bias of a single observer. The following definitions and examples were used for coding errors:

- Correct component verification (CCV) error. This error was coded if the operator did not perform CCV prior to performing an action in the step. CCV is the process by which an operator verifies that he is operating on the equipment identified in the procedure step. Examples are, either failing to conduct observable CCV or scanning the bar code after performing the action (if and only if they didn't perform a manual verification with the CBP. If they did perform a manual verification, then it was coded as an inefficiency)
- Error of commission. This error was coded if an operator took an incorrect action. Examples are, turning the wrong valve, pushing the wrong button, operating the wrong equipment, operating the right equipment in the wrong way, calculation errors, and performing steps out of sequence

- Error of omission. This error was coded if an operator failed to take an action, including failing to make a verification (e.g., that an automatic valve opens or a tank fills).

All of the errors above were deemed to have potential negative consequences in real-world procedure execution, and were grouped simply as "errors." In addition to the errors listed above, the researchers recorded the occurrence of three other deviations that would not necessarily have direct consequences, but provide information about the use of the CBP (or PBP).

- Inefficiency (CBP error). This error was coded when an operator completed both manual CCV and scanned the barcode.
- Interface Error (CBP error). This error was coded of the operator made a using the CBP system (e.g., clicking the wrong button).
- Close Call. This error was coded if the operator almost made an error, but caught it before moving on (e.g., starting to move on before actually closing the valve, but catching the potential error).

The observers were provided with a score sheet that broke down the procedure into the sub-actions that were required to execute the procedure correctly. For example, to execute a single step, an operator must locate the equipment, perform place keeping, perform correct component verification (either manually or by scanning the barcode with the CBP), and execute the action in the step. If any of these sub actions was performed incorrectly, then the observer marked an error. The score sheet had a total of 38 observations per procedure execution. The observers were also instructed to note as much as they could about the situation when they marked an error so that discrepancies between the two observers could be resolved if necessary.

The two observers met after the study, and compared the observation score sheets. Any discrepancy between the two score sheets (e.g., one of the observers recorded an error, but the other did not), were resolved by a discussion and a forced consensus. A total of 51 observation discrepancies (out of 1064 observations) were resolved this way.

2.2 Results and Discussion

Participants committed an average of 7 errors when using the PBP, and an average of 4 errors when using the CBP. A paired sample t-test revealed a marginally significant effect of type of procedure (CBP or PBP) on average number of errors committed $t(13) = -1.49$, $p = .08$. A calculation of the total number of errors committed by all the participants revealed that overall participants committed 95 errors when using the PBP and 48 when using the CBP (see Figure 2 for an illustration).

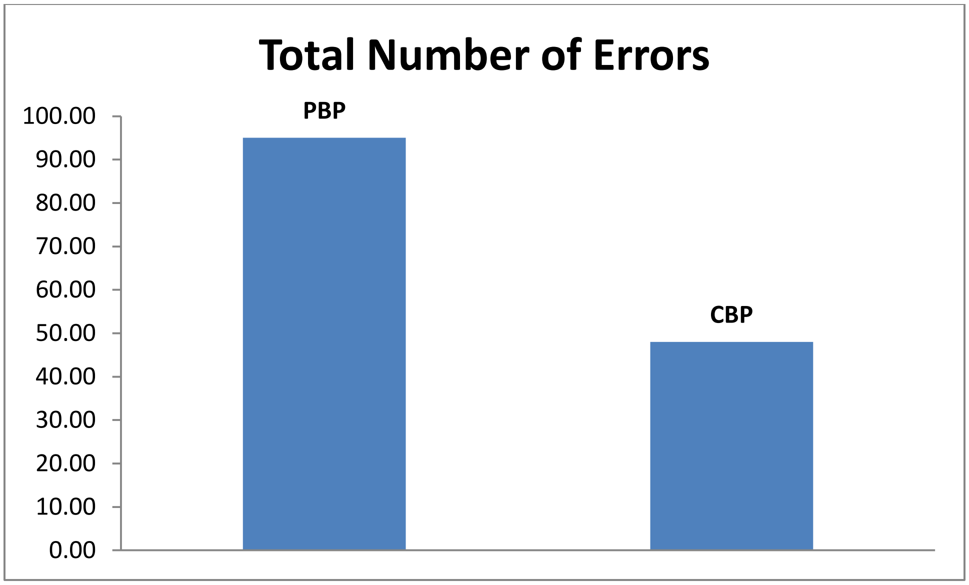

Figure 2. A comparison of the total number of errors in the PBP and CBP conditions.

The fact that participants committed almost half as many errors when using the CBP, indicates that it might be effective in reducing human errors. The following discussion of what types of errors occurred (and were prevented) may provide insight into how the CBP prevented errors.

The most common error committed in both the PBP and CBP conditions was a failure to conduct proper CCV. This action is considered an important human performance tool meant to prevent operators from operating on the wrong equipment (which is a common error). When using the PBP, operators were expected to read the equipment identification number aloud as it was matched between the procedure and the label on the equipment. If the operator did not do this, the step was marked with a CCV error. In the CBP condition, the operator was expected to scan the barcode on the equipment which would automatically match the ID to the one identified in the procedure. It is important to note that although the CCV was conducted through scanning the barcode with the CBP, it was still possible to execute the action in the step before the component had been verified. By design, the CBP continuously presented step text so that operators can look ahead and gain an overview. The unintended consequence is that even though the operator was prevented from moving on in the procedure before scanning the barcode, he could still read the step text and carry out the action. Many operators took an action before scanning the barcode, and ended up scanning the barcode before moving on to the next step, which is too late for proper CCV. The CCV errors were roughly equivalent in both conditions (26 in the PBP and 25 in the CBP). Future work should investigate how to ensure operators conduct CCV before taking an action without preventing desirable behaviors like looking ahead. If the CBP can make it impossible to conduct an action before conducting CCV, it could have a positive impact on procedure performance.

The second most common error was in executing a calculation of the volume required to fill a tank. Performers used the wrong formula for the instrument they were using (there were two choices in the procedure for which instrument to use), did the math wrong, or made rounding errors (rounding errors were noted but not counted in the error counts reported above). When using the PBP, this error was typically caught during a second party verification and did not ultimately have a direct consequence on the procedure execution. However, it is important to note the second party verification was conducted by a researcher. The researcher knew what the value should be, and was looking carefully for the calculation error. In an actual plant, a peer-checker is less likely to catch a calculation error because they typically expect that their peer performed it correctly. The CBP automatically calculated the value based on a single input, completely preventing this type of error. Further, the CBP eliminated the need for a second party verification, increasing efficiency of the process. The resulting value was also carried forward into a step in a later section that used the value, eliminating the need to look back. Two participants made errors due to misreading the earlier value or forgetting the value after they turned the page when using the PBP.

The researchers also recorded the amount of time it took to execute the procedure using the CBP and the PBP. Figure 3 shows that the average time it took the participants to execute the scenario was roughly equal (963 seconds in the CBP condition versus 964 seconds in the PBP condition). This is the first CBP study conducted by INL researchers to find that it does not take longer to execute the procedure using the CBP. This indicates that although previous work has identified a potential tradeoff between reduced errors and a longer time to execute the procedure, it might not be inevitable.

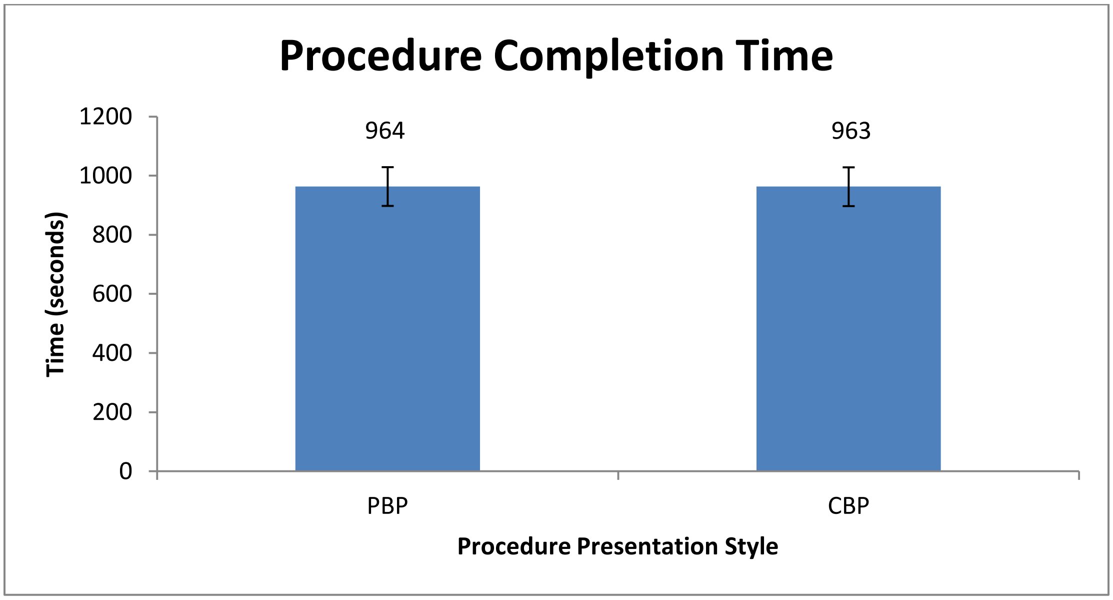

Figure 3. A comparison of completion time when executing the procedure with the PBP versus the CBP. Error bars represent standard error of the mean.

The results from the second study indicate that the CBP can reduce the number of errors committed during procedure execution without increasing the time it takes to conduct the procedure. These results bring the CBP team closer to the objective of increasing performance and efficiency using CBPs.

3. LIMITATIONS OF THE LABORATORY EVALUATION STUDIES

The laboratory studies facilitated the iterative design, test, and redesign of the CBP prototypes and revealed many ways in which the use of the CBP could be improved. However, there are many limitations in the laboratory evaluation studies that need to be addressed before recommendations for CBPs can be developed for real-world applications.

The first limitation is that the procedures used in these studies were either procedures used for training or procedures designed specifically for the study. While this helped researchers to meet the specific objectives of the evaluation studies, it did not allow us to design or test for a comprehensive set of procedure elements. For example, some procedures have complex branching and looping (i.e., sets of steps are executed again until a certain condition is met), and the simple procedures used in the studies did not include that level of complexity. Further, the evaluation study procedures needed to be relatively short in duration (~20 minutes) to allow operators to participate in the 1-hour they were allotted by their supervisors. This meant that the procedure had to be short and relatively simple to execute. This also limited the capability to test the breadth of procedure elements that users might find in a real-world procedure.

Another limitation is that participants were recruited from staff at the partnering utilities. In most cases, the participants could only be spared for an hour, limiting the amount of time available for training and familiarization with the CBP.

The final, and most important, limitation is that participant's had very limited interaction with the CBP. They were trained for ~10 minutes on how to use the device before they conducted the scenario. Participants only used the device once for the CBP scenario. In summary the results of the laboratory studies are based on the use of the CBP as an unfamiliar tool to novice users. Researchers might be able to demonstrate enhancements to performance and timing better if users were more trained, and had more than one opportunity to use the CBP.

Moving forward, the INL CBP research team is conducting several activities to test and evaluate the feasibility of using a CBP system in nuclear power plants, i.e., outside a controlled laboratory setting. The question that needs to be answered is: "will the CBP system and use of related technology improve human performance and help maintain plant status control?" To answer this question a series of activities will be conducted where the CBP system will be used for normal operation activities in the nuclear power plant. At this point, one field evaluation has been completed and a second one has just started. Both of these activities are described in detail in this report. Several similar activities are planned for FY15 and the results from these will be documented in later reports.

4. FIELD EVALUATION STUDIES

The laboratory evaluation studies were all conducted in controlled settings. They were all successful in evaluating the usability of the CBP system and its potential impact on human performance. However, the studies were limited in scope and the participants only went through the task once with the CBP system. This does not provide sufficient information to conclude if the CBP system actually will have a positive impact on human performance and safety in the plant. In order to get this type of feedback, the CBP system has to be used in the context of the real world. There are issues specific to everyday use of the CBP system in a nuclear power plant that need to be identified and addressed to ensure that the implementation of a CBP system both adequately removes current error traps and does not introduce new ones. The only way to identify these potential issues is to put the CBP system in the hands of the end users (e.g., Auxiliary Operators, Maintenance Technicians, etc.) and to have them use the system for tasks they conduct on a regular basis.

4.1 Pilot Field Evaluation Study

A pilot field evaluation study was conducted at Duke Energy's Catawba Nuclear Station (CNS) between April and June, 2014. The main objectives of the pilot field study were to evaluate the feasibility of using a CBP system in the actual plant during everyday operations, evaluate the usability of the revised CBP system, and to gather insights about how to best conduct a field evaluation study (i.e., lessons learned about what went well in the method used and what needs to be tweaked or approached slightly different in the future).

As mentioned earlier, the focus of the research effort is to use technology to improve human performance and help maintain plant status control. An example of how technology is used for this purpose is the use of barcodes for CCV, which in this report is called digital CCV. Due to having barcodes throughout the plant, Catawba is a perfect candidate to evaluate the potential error reduction when using technology compared to the current practice of paper-based processes and procedures.

4.1.1 Procedure

The procedure used for the pilot field study was selected based on a list of requirements the research team and the plant agreed were essential to add as much value as possible to the study. Examples of requirements are:

- The procedure does not use safety related equipment,
- The procedure is not conducted in a radioactive area,
- The procedure includes branching between enclosures or sections, and
- The procedure is conducted at least once per week.

Based on these requirements, the team decided to use an Instrument Air System procedure. Four enclosures (i.e., sections) of the procedure were selected. Three of these were functional tests for each of the three backup air compressors. One of these three functional tests requires an additional enclosure to be used to control the moisture drainage from the air compressor during the functional test. The procedure for the Instrument Air System, including the functional tests of the backup air compressors, is conducted by auxiliary operators (AOs).

During the development of the CBP prototype, each procedure that is converted into the CBP format is carefully analyzed, and the logical flow of the procedure steps are illustrated. This is especially important for procedures with branching or complex conditional steps (such as “when then” steps or “if at any time” steps). Figure 4 illustrates examples of how the team mapped out the logical flow before building the CBP version of the procedure. The logical flow is then reviewed by the collaborators at the plant to ensure that the computer-based version of the procedure matches the logic of the paper-based version. The work flow of carrying out the task with the CBP system should match the work flow of the existing procedure, except where the existing workflow is a direct result of the paper based process. This comparison step of the two versions of the procedure ensures that although the researchers are modifying the way the information is presented in the CBP, they are not changing the logic, intent, or use of the procedure.

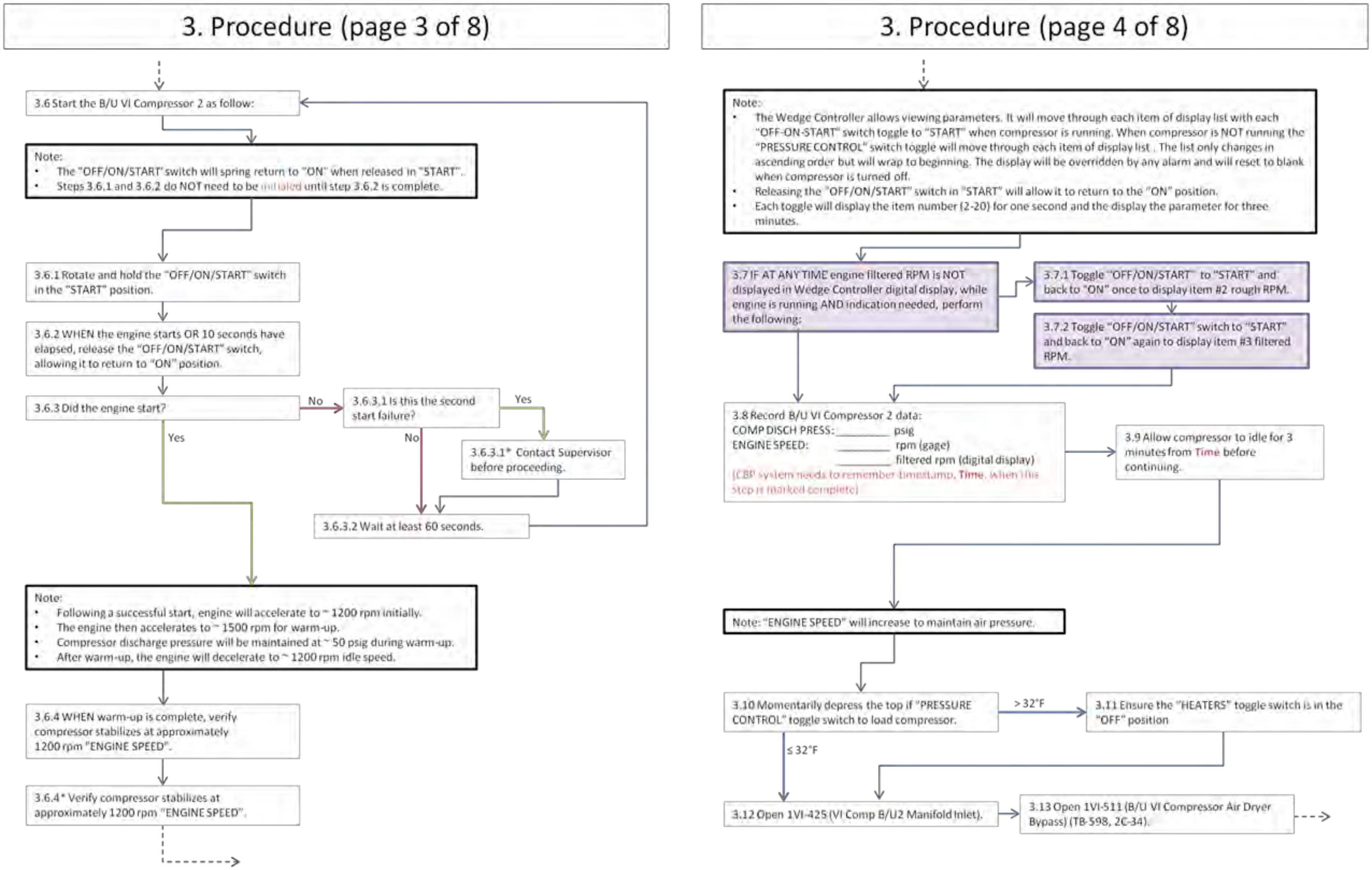

Figure 4. Examples of the mapping of procedure flow.

4.1.2 New functionality

The procedure selected for the pilot field evaluation was more complex than any of the procedures used in the previous laboratory studies. Therefore, new functionality needed to be built into the CBP prototype before the evaluation study could be conducted. The new functionality added includes:

- handling of continuous action steps,
- handling of contingencies,
- ability to check revision of procedure before starting the activity,
- creation of a printable copy of the procedure as executed for archiving purposes,
- ability to review decisions and data input in previous steps,
- improved ability to edit previous steps, and
- improved data structure to handle the new functionality.

4.1.3 Pre-validation of the selected procedure

The INL research team visited CNS the first week of April, 2014. The goals of the visit were to validate the computer-based version of the procedure, gather feedback from plant staff, make revisions to the computer-based procedure system if needed, provide training to the AOs, and observe the first time the CBP system was used during a functional test in the plant. During that week the team had the opportunity to meet and brief multiple employees from both Duke Energy Corporate and CNS. During these conversations the team was able to gather valuable information that was of great benefit to both improving the CBP system for the pilot field evaluation study and for moving the overall CBP research forward.

The team had the opportunity to speak to the Catawba site vice president, the Catawba plant manager, the general office operations support, the IT application development and deployment manager, the senior IT business analyst fleet nuclear operations, an operations instructor, a shift manager, two operations shift supervisors, three procedure writers, the organizational effectiveness manager, the emergency planning manager, and three senior reactor operators. AOs from two shifts provided a large amount of feedback on the design and usability of the CBP system as well.

Over the course of the week, the five procedure validation activities (i.e., walkdowns at the job site) were performed. These were performed by three AOs, a procedure writer, and an operations instructor. Figure 5 shows two AOs conducting one of the walkdowns by the back-up air compressors. In the figure, one of the AOs conducts a digital CCV of a valve.

The INL researchers observed and took notes during the walkdowns and the participants were debriefed afterwards. The objectives of the validation activities were to validate the procedure flow, i.e., to ensure that it did not deviate from the controlling procedure, and to identify any areas for improvements. During the walkdowns the participants made a direct comparison between the CBP with the PBP. Identified items for improvement to the CBP system were:

- It has to be easier to differentiate between the active/current step, previous steps, and steps to be performed. There was not enough contrast or difference between active step, previous steps, and future steps in the procedure made it difficult to use the CBP system outside in bright sunlight.
- The user must get stronger visible feedback when conducting CCV on incorrect components.
- The user must get stronger visible feedback when transferring between enclosures.

- The user must be able to revise a step while conducting it and it must be possible to go back and revalidate a component (using digital CCV) if needed.
- The system should ask the user if all active enclosures should be closed out before exiting the procedure.
- It would be useful to have a reminder of what component to verify when conducting a digital CCV.
- The issue a backup solution must be properly addressed.

Figure 5. Two AOs at Catawba Conducts a Walkdown of The CBP at The Actual Job Site During The Pre-Validation Activity.

All but the last item were addressed and resolved by the research team during the week. The two AOs who conducted the first functional test using the CBP system had reviewed and approved the changes the day before the functional test.

The issue of backup solution has been revisited multiple times by both CBP researchers and vendors. However, there is not yet one widely accepted and verified solution. The long-term solutions discussed require either a plant-wide wifi infrastructure or a memory card in the device that the CBP system continuously writes to. When a backup is needed the memory card would be transferred to another device. The short-term backup solution is to have the AOs keep a paper copy of the procedure with them out in the field.

4.1.4 Method

Participants

The participants in the pilot evaluation study included the AOs tasked to conduct the functional test of the back-up air compressor each week during the duration of the study. The task was carried out by two AOs at the time and the duration of the study was initially planned to be 9 weeks, hence 18 AOs were lined up to participate in the study. However, due to the nature of how the plant plans its work there was no way for the research team to identify exactly who the participants would be before the study was conducted.

Survey

The participants were asked to fill out a brief web-based survey after completing the task using the CBP system. The questions targeted the experience of conducting the task with the CBP system compared to the traditional paper-based process. The goal of the survey was to assess the usability of the CBP system and device. The survey was also developed to gain more detailed feedback on the design of the user interface and the overall experience using the CBP. The survey was designed to be short and simple so that it wouldn't add much additional burden to technicians to increase the likelihood that they would take the time to respond. The wording of the survey questions was reviewed by plant personnel to ensure that operators would feel comfortable answering the questions candidly. The full survey is in Appendix B, however some examples of questions are listed below.

- Did the CBP lead you down a path where you conducted an error (e.g., mistake, near-miss, deviation, etc.)?
- Did the CBP stop you from committing an error (e.g., mistake, near-miss, deviation, etc.)?
- Did the CBP cause any confusion or behave in a way that was unexpected while you executed the procedure?
- After executing the procedure with the CBP, do you prefer using paper or the CBP?

Study Protocol

During the pre-validation activity the research team provided training on the CBP system to the AOs they interacted with. These AOs were instructed to train their peers on the CBP system.

At the day of the functional test the participants assigned to the task started out with a pre-job brief with their supervisor that included a review of the procedure, a discussion of the conditions that would be encountered at the job site, as well as a discussion of the potential safety issues associated with the task. The pre-job brief served as the pre-job brief for both versions of the procedure (PBP and CBP) and was executed with the PBP. After the pre-job brief the participants filled out an informed consent form. The form was provided as a link on their work desktop. The link took them to a web-based version of the informed consent form. The research team provided a job aid, which included a short description of the expected work process (from the consent form to printing a copy of the executed procedure) as well as a brief overview of the functionality of the CBP system. The job aid was printed on a piece of paper that was laminated and located by their work computer. A copy of the job aid can be found in Appendix C. The participants reviewed the job aid before walking to the job site. At the job site the CBP system was used in conjunction with the PBP during the execution of the task. One of the AOs conducted the task with the PBP while the second AO followed along and simulated conducting the task while using the CBP system. When the task was complete the AOs returned to the office and printed out a paper-copy from the CBP system. This paper-copy showed who conducted the procedure, what steps were conducted, what steps were marked as not applicable, time and date stamps, etc. In other words, the printed version contained all the information the PBP did after the completion of the task. Before continuing with other tasks both AOs filled out the web-based questionnaire.

The researchers observed the first time the participants conducted the task with the CBP system. However, since the researchers would not be able to be at the plant during the remaining duration of the field evaluation one of the operations instructors who has been the main point of contact for the research effort agreed to be at the job site when the task was executed to help address any questions regarding the CBP system that the AOs might have.

4.1.5 Results

A total of three AOs participated in the pilot field evaluation and were able to experience using the CBP system while following along with the task. According to the responses to the survey all of the AOs who used the CBP said they preferred it to the PBP. The AOs rated the CBP as highly usable at an average of 9.67 on a 10 point scale. They also indicated that there was no situation in which the CBP caused errors or error-likely situations.

The pilot field evaluation also revealed at least one instance in which the CBP may have increased efficiency compared to the PBP. During the task, the pressure needed for automatic operation of the drainage tank was not obtained. The AOs had to manually drain the tank. This task required branching to a separate enclosure and carrying out a sequence of complex conditional steps. This requires a fair amount of flipping back and forth in the PBP. The AO using CBP system commented that the CBP system handled the situation perfectly. All the steps needed were presented in order and at the right time based on the AO's input to the system. Because the conditional logic was presented in a simplified manner, there was no need to go back and forth in the procedure to find correct enclosures and steps.

Based on the observations and debrief conducted with the AOs, it was concluded that the CBP system was not slowing them down at all. The AOs were very pleased with how much faster the CBP system was when transferring back and forth between enclosures (i.e., procedure sections) compared to doing the same with the paper procedure. After compiling all the feedback it can be concluded that the most appreciated features were the inclusions of photos, documents, and calculations, the digital correct component verification, and the automatic placekeeping. The feedback is summarized below.

Photos, documentation, and calculations

Relevant photos, figures, and other additional information and documentation were easily accessible from the procedure step. The AOs made comments such as; "I wish I had this when I was new! Instead I spent a lot of time trying to locate components in the plant" and "This would be very useful during outage or anytime you're scheduled to do a job you only do once in a while." The AOs also stated that the photos are not only useful when locating the component, but also during the process of validating the correct component. The use of the photos as a tool to locate the correct component was observed during the study.

The AOs also expressed that it was very nice to have easy access to all relevant documentations, such as drawings, figures, and just-in-time training directly from the applicable step, note, caution, or warning.

Another highly liked functionality was the ease of operator burden related to calculations. As discussed earlier, one of the most common errors in the third evaluation study was calculation errors. That study found that the CBP system was effective in preventing this type of error. The version of the CBP system used in the pilot field evaluation study conducted all calculations needed in the procedure based on input from the AO. The AO had the option to review the calculation and change the input in case the calculation did not match the expected outcome. Figure 6 is a screenshot from the CBP showing a calculation step. In this example the current fuel level, as recorded in the previous step, is 5 inches. The system uses this input to calculate how many gallons need to be added to restore the fuel level. In the case of the example 0.0 gallons need to be added since the fuel tank already is at its max level.

Figure 6. Screenshot Showing a Calculation Step.

Digital CCV

The use of barcodes to verify correct component was generally viewed as an effective implementation of the human performance tool. Some concerns regarding the time spent on barcode scanning were expressed. During the pre-validation activity one AO cautioned the researchers about using barcode scanning as a tool for digital CCV. The AO expressed concern that the digital CCV would slow down the task execution and might become a general annoyance. The same AO later expressed how easy it was to use the barcode scanning to conduct CCV. The second time he used the CBP system he had no issues at all and was able to efficiently scan the barcodes. The revision to the barcode scanning process made based on feedback from the AOs (e.g., presenting the component nomenclature in the scan mode) actually stopped the AOs from attempting to conduct a CCV on an incorrect component. Figure 7 illustrates the use of the digital CCV.

Figure 7. An AO Conducts a Digital CCV Using the CBP System.

It was also noted that scanning of barcodes located in darker places at the plant worked great when using the hardware flash. Figure 8 shows an AO using the flash while conducting a digital CCV inside the plant.

Figure 8. A Demonstration of Using The Flash in a Darker Location in The Plant.

Automatic placekeeping

The CBP system automatically takes the user to the next applicable step. This step is the only one that is active and lets the user take action. Hence, the system effectively reduces the risk of unintentionally conducting steps out of order as well as the need to flip through pages to find the next applicable step. The AOs liked the ease of moving between and within enclosures when having to transfer to other enclosures and/or conducting continuous action steps. AOs commented that the CBP system made the transitions much faster and smoother than when using the PBPs. An example of how the active step is clearly marked with a blue border and how the CBP provides cues to what the user should do next is shown in Figure 9. The future steps are visible to provide information of upcoming activities, but grayed out to reduce the risk of conducting the incorrect step. In Figure 6 above one can see how a completed step is presented to the user. The conducted step is grayed out, marked with a check mark, and all values recorded or decisions made in the step will be visible even after the completion of the step.

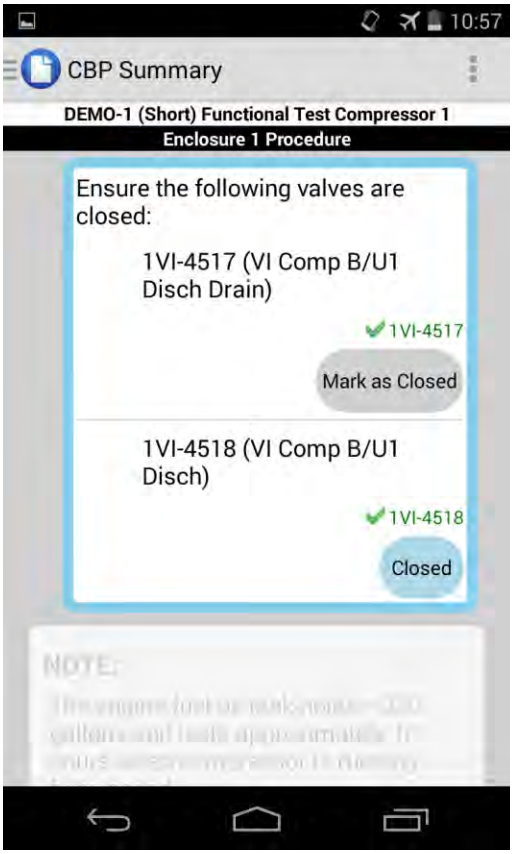

Figure 9. Screenshot for the CBP Depicting Placekeeping.

4.1.6 Lessons learned

One of the objectives of the pilot field evaluation study was to gather insights or lessons learned about how to best plan and conduct a field evaluation study, i.e., what are major dos and don'ts that need to be considered in order to successfully carry out a study during normal operations at the plant, without the INL researchers participation and direct oversight, and over an extended time period. The main identified lessons learned are:

Get to know task as early as possible

Conduct a plant visit early in the design process. It is very useful and cost effective to conduct walkdowns of the task before designing the flow of the CBP. There is a lot of information that can be shared over the phone and via emails, but the small (and often important) details are only identified when the actual task execution is observed.

Involve the actual users early

Get to know the field workers that will be using the CBP system early on. It is important to gain these people's trust as well as their understanding of the research activity. These people will be the advocates for the CBP system and they are essential players to keep the study going even after the researchers have handed off the CBP system to the plant.

If possible, use task where CBP can be used as the primary procedure.

There is a minimal chance that the utility will allow the use of a prototype CBP system as the main controlling document or procedure. Hence, the field workers will most likely have to conduct the task with both the CBP system and the original PBP. However, there are different ways to approach this issue. The least favorable solution is to lead with the PBP and shadow with the CBP. It is more favorable to lead with the CBP and shadow with the PBP.

Make sure both the procedure manager and the operations/maintenance/chemistry/etc. manager are on board before pursuing a field evaluation study.

It is important to make sure that the manager of the field worker organization that will be using the CBP system is aware of and has approved the activity. This manager has the power to decide if the staff has time and availability to support the research. It is also important to involve the procedure manager since this person usually knows the ins and outs of rules and regulations applicable to the procedure. The procedure manager is also essential in deciding what approach to take related to using the CBP system or the PBP to conduct the task.

Plan for sufficient familiarization time

In order to maximize the chance that the CBP system is used even under more stressful work conditions such as an outage, make sure to kick-off the field evaluation study with plenty of time for the field workers to become familiar with the system and the modified way of conducting the task (i.e., conducting it with both PBP and CBP) before any planned outage.

4.2 Field Evaluation at APS Palo Verde Nuclear Generating Station

The ultimate goal of the CBP research is to define requirements for computer-based work instructions. Previous work has focused on mobile applications for operations procedures. In the second field evaluation study the scope has been expanded to work orders. This field evaluation study is hosted by Arizona Public Service and conducted at the Palo Verde Nuclear Generating Station (PVNGS).

4.2.1 Work order selection

For this study, the researchers were careful to select a procedure that could be executed using the CBP rather than requiring an additional operator to shadow an operator executing the task using a PBP. Staff at the collaborating utility selected a heating, venting, and air conditioning (HVAC) Preventative maintenance work order to use for this field evaluation. The work order provides instructions for taking weekly readings from the plant's four HVAC chillers (and related equipment) and for handling out-of-range readings.

This task is ideal for this study because it is executed weekly for each of the three units. This will facilitate the collection of a large amount of feedback and performance data for the period of time selected for the study. The researchers mapped out the logical flow of the work, as illustrated in Figure 10. The logical flow is then reviewed by the collaborators at the plant to ensure that the computer-based version of the procedure matches the logic of the paper-based version.

Further, the original work order instructions contain redundant information, require multiple recordings of values and calculations, and there is no electronic record of the recorded values or the conducted procedures. Converting this work order and procedure to the CBP system will demonstrate the benefits of an electronic work order/procedure system while the plant staff is actually using it in their own plant. The revised version of the CBP system will be referred to as the Computer-Based Work Order (CBWO) system from here on.

Another way in which this procedure is ideal to demonstrate increased efficiency of computer-based work instructions is that when prompted to find the last logged value of a component the technician has to go through the binder with the previously conducted procedures to find the value. The CBWO system will store logged values in a database and automatically import these values when the task is conducted. In addition, the recorded values are currently reported to the engineer on paper. The engineer has to transfer the values to electronic format in order to log trends. This process includes multiple opportunities for human error and is inefficient and time-consuming. The CBWO system will export the recorded values to an electronic format that can easily be shared with the engineer.

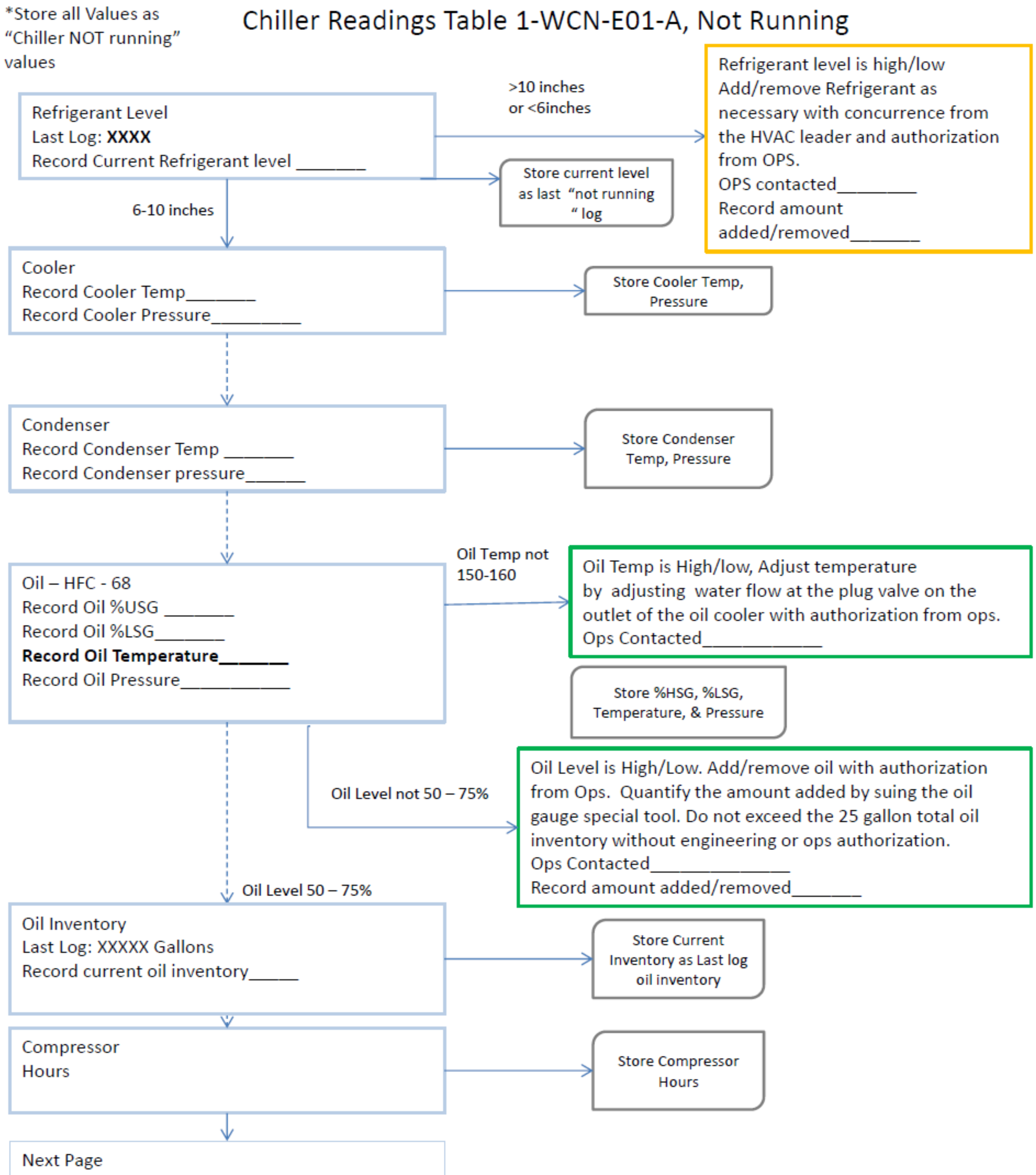

Figure 10. Illustration of logical flow of Work Order.

4.2.2 New functionality

The work order included several elements found in previous procedures used in the CBP prototype including conditional instructions and multiple calculations. The initial impression of the work order was that it was just simple instructions for taking readings, however early discussion with plant personnel revealed that major changes would have to be made to the current CBP system to enable multiple users, logical incorporation of automatic job aids, intuitive design and presentation of the table used to record values, and the export of recorded values to be shared with the engineer. The added functionality to the prototype includes the ability to:

- Store readings data for trending
- Import previous readings into current work order
- Export data to be used for trending
- Take notes while executing the work order
- Match readings data to acceptable ranges, alert users to out-of-range conditions, and provide a list of actions for out-of-range readings
- Enable sections of steps to be performed in any sequence as the task allows
- Execute the work order across multiple days and with multiple users
- Activate conditional steps based on multiple conditions
- Handle new functionality by utilizing an improved data structure

4.2.3 Pre-validation of the selected procedure

The research team visited PVNGS the second week of September, 2014. The goals of the visit were to validate the computer-based version of the work order, gather feedback from plant staff, make revisions to the computer-based work order system if needed, and provide training to the HVAC technicians.

During that week the research team had the opportunity to meet and brief multiple employees from the plant including two senior HVAC technicians, the HVAC planner, and a procedure writer. During these conversations the team was able to gather valuable information that was to great benefit to both improving the CBP system for the pilot field evaluation study and for moving the overall CBP research forward.

4.2.4 Method

Participants

The participants in the APS evaluation study will include HVAC technicians tasked to take the chiller readings each week during the duration of the study. The task will be carried out for each of the three units at the plant. The duration of the study is initially planned to be 26 weeks long. It is expected that the study will result in data for 78 uses of the CBWO system, however it is likely that several participants will conduct the task multiple times (resulting in fewer than 78 participants).

Survey

The participants will be asked to fill out a brief web-based survey after completing the task using the CBWO system. The questions target the experience of conducting the task with the CBWO system compared to the traditional paper-based process. The goal of the survey was to assess the usability of the CBWO system and device. The survey was also developed to gain more detailed feedback on the design of the user interface and the overall experience using the CBWO. The survey was designed to be short and simple so that it wouldn’t add much additional burden to technicians to increase the likelihood that they would take the time to respond. The wording of the survey questions was reviewed by plant personnel to ensure that operators would feel comfortable answering the questions candidly. The full survey is in Appendix D, however some examples of questions are listed below.

- Did the CBWO lead you down a path where you committed an error (e.g., mistake, near-miss, deviation, etc.)?
- Did the CBWO stop you from committing an error (e.g., mistake, near-miss, deviation, etc.)?
- Did the CBWO cause any confusion or behave in a way that was unexpected while you executed the procedure?
- After executing the procedure with the CBWO, do you prefer using paper or the CBWO?

4.2.5 Results

This study is in progress, so there a no official results. However, the following user interface issues were identified and addressed during the pre-validation activity:

The technicians at PVNGS desired more contrast on the no-active steps so they could be more readable. The future steps need to be more readable. The researchers set the text color to darker grey to provide additional contrast.

The technicians noted that the sub-steps in the instruction list should say “In Progress” if some readings have been made, see Figure 11 for an illustration. They indicated that there has to be a way to know what sub-steps are not started, in progress, and completed. The sub-step should say "reading started" and preferably have a warning triangle to indicate the readings are in progress.

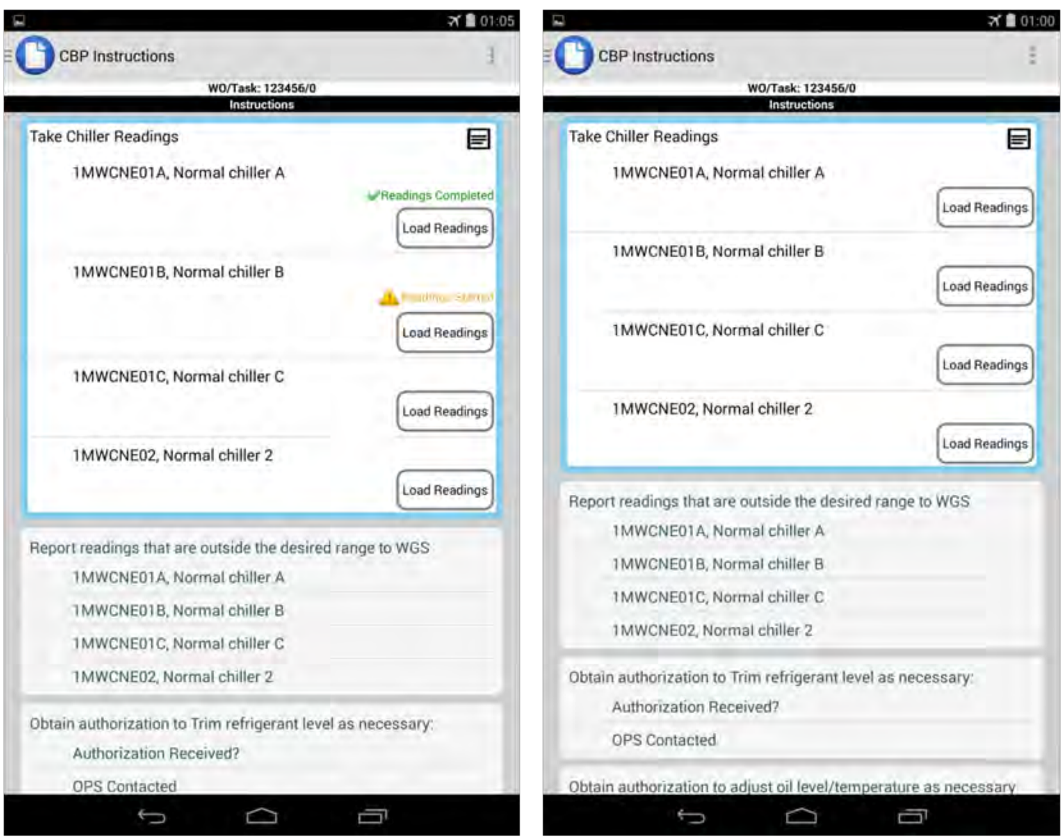

Figure 11. Changes made to the instructions list to indicate in progress and completed readings.

Although many of the desired actions are triggered by out-of-range readings, the task requires that technicians be able to override those actions by either not executing them or by taking different actions as required. Therefore, the technicians noted that the action to be taken should be recorded in the pop-up display that summarizes the out-of-range (i.e., abnormal) readings. An example of the popup for out-of-range readings can be seen in Figure 12.

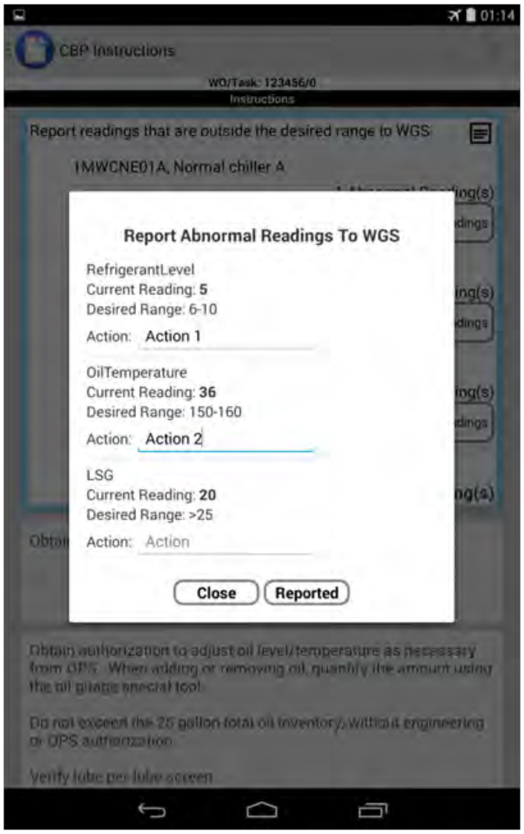

Figure 12. Example of Popup for out-of-range readings.

4.2.6 Lessons learned

Although this study is still in progress, the researchers have a short list of lessons learned from the process of developing the computer-based version of the work order and conducting the pre-validation activity.

Procedure selection should allow for researcher observation

Researchers were careful to avoid the undesirable situation in which the procedure had to be executed with the PBP, and shadowed with the CBP. However, the task selected for this study is executed in a radiological area, which prohibited the researchers from observing a walkdown of the task. This limited the degree to which researchers could identify inconsistencies in the task flow and the CBP flow during the plant visit and validation. It also limited the degree to which researchers could identify user interface issues that needed to be resolved prior to leaving the CBP system in the plant's custody. The next field evaluation study will be carried out using a plant procedure that both can be used as the primary procedure for the task and can be observed by researchers.

"Skill of the craft"

The work order selected requires a large amount of "skill of the craft" knowledge to execute the task. The conditions that require action, and some of the actions, are not fully specified in the procedure instructions. Plants will need to decide how much "skill of the craft" information should be proceduralized, and how much should simply be provided as additional information in the CBWO. In other words, plants can modify existing procedures to provide more detailed instructions for how to carry out these tasks, or they can simply provide additional information that is available if the technician needs it. This determination will require a comprehensive review of the work instructions prior to converting them to CBPs.

Tasks that require autonomy are more complex to "computerize" than strictly sequential tasks

In addition to requiring a fair amount of "skill of the craft" knowledge, the selected task was such that the technician could take a variety of legitimate paths through the procedure. For example, the chiller readings could be taken in any order. Similarly, the criteria for deciding what actions should be taken are not entirely deterministic (i.e., factors not explicitly specified in the work order could influence decision-making). Therefore, it is more difficult to provide context-sensitive instructions to technicians than with a procedure that must be followed step-by-step. An illustration of this issue is the fact that a technician may postpone an action that is triggered by an out-of-range reading due to higher priority work, conflicts with ongoing work, or conflicts with current conditions. The full scope of these possible situations is too complex to incorporate into the CBWO, so the process has to rely on the technician's (and in some cases, his supervisor's) judgment. Utilities and procedure writers need to carefully consider what level of support they want to provide their field workers. If utilities decide they want their operators to follow this type of work instruction more closely, then they will need to restructure and rewrite many of the instructions to offer a greater level of support.

5. GENERAL DISCUSSION AND CONCLUSIONS

The three activities described in this report have brought the CBP (including the CBWO version) several steps further in identifying design requirements for computer-based work instructions. The laboratory evaluation study allowed the researchers to demonstrate and test advanced functionality for the CBP system such as handling continuous action steps, automated calculations and further testing the dynamic context-sensitive presentation with the CBP prototype. The two field evaluation studies have enabled the researchers to identify and resolve a wide variety of issues related to using real-world work instructions that are more complex compared to the procedures used for the laboratory studies. The second field evaluation at PVNGS has informed the development of an underlying data structure for computer-based work instructions that can apply to both operations procedures and work orders. Future efforts will expand the scope of the data structure to include all types of work instructions used by field workers in nuclear power plants.

Previous work has indicated that CBPs might be effective in reducing the number of errors operators commit (Le Blanc & Oxstrand, 2013). The third laboratory evaluation study has provided further evidence that CBP may reduce errors by demonstrating that overall, operators conducted half as many errors when using the CBP as with a PBP. The study also provided the first evidence that field procedures can enhance performance without increasing the amount of time it takes to execute the procedure.

The field evaluations demonstrated that the CBP system can be used in a real-world context with real-world procedures. The field evaluations have also demonstrated that the CBP concepts for operations procedures can be translated (with some adjustment) to work orders.

6. PATH FORWARD

The research team will continue to conduct field evaluations with the objective of eventually demonstrating concepts for automated work packages. In order for the CBP system to be of interest to the nuclear industry, it needs to encompass more than just procedures for field workers. The system needs to be able to handle all types of instructions, checklists, procedures, work orders and other documents used in the plant. The vision is to have all the different organizations within the plant use the same system. The CBWO system to be used in the PVNGS field evaluation study took several steps toward the vision of incorporating all elements needed in a work package. For example, the preventive HVAC maintenance work order used in the field evaluation study is most commonly conducted by multiple technicians over the duration of a couple of days. The functionality to handle was incorporated in CBWO system. However, there are still many remaining aspects of a CBWO system that need to be investigated before a comprehensive design guidance can be developed.

Future efforts will incorporate CBPs for field organizations across the plant, i.e., users other than AOs and HVAC maintenance technicians. It is important to investigate a broad variety of instructions and procedures to ensure the design guidance covers both normal operation and as many special cases as possible. This will increase the applicability of the design guidance across the nuclear power industry.

The research effort will also expand the scope to look at the overall process, not just procedures or the work instructions. For example, future efforts will look at integrating planning, pre-job-briefs, and other activities that are part of the procedure process. Finally, the team will investigate ways to ease the transition to CBPs by identifying tools to convert paper procedures into CBPs.

The research team is currently in the planning stage with two other utilities that have expressed their interest in hosting field test activities. For each field test planned and conducted, the CBP system will be revised to include additional functionality needed to bring it closer to handle all aspects of a work package, i.e., the full process from initiating work request, planning, execution, and archiving.

7. REFERENCES

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APPENDIX A:
Procedure Used In Laboratory Evaluation Study

1.0 PURPOSE AND SCOPE

1.1 Purpose

1.1.1 This procedure provides instructions for using the flow lab to fill the portable tank in the I&C Training Lab.

1.2 Scope

1.2.1 This procedure uses the Flow Station in the I&C Training Lab to fill a level tank.

End of Section 1.0

2.0 RESPONSIBILITIES

2.1 I&C Department Responsibilities

2.1.1 The I&C Department is responsible for performing this procedure.

End of Section 2.0

3.0 PRECAUTIONS AND LIMITATIONS

3.1 Precautions

3.1.1 There may be electrical hazards in the vicinity of the work area. Use caution and proper PPE around exposed energized equipment.

3.1.2 Problems such as high pressure, overflow, etc., are mitigated by pressing the “Emergency Stop” button on the Flow Work Station.

3.2 Limitations

3.2.1 The T01A Level Tank is considered filled at 20 inches (19.2 - 20.8 inches) on the sight guage or 100% (96% - 104%) on the ultrasonic instrument.

End of Section 3.0

4.0 DEFINITIONS

4.1 None

End of Section 4.0

5.0 PREREQUISITES AND INITIAL CONDITIONS

5.1 Prerequisites

5.1.1 None

5.2 Initial Conditions

5.2.1 None

End of Section 5.0

6.0 INSTRUCTIONS

6.1 Determining Volume Required to Fill Level Tank

___ 6.1.1 **IF** the lab is NOT energized,
THEN energize the lab by pushing "AC MAINS" on the Patch Panel.

6.1.1.1 REFER TO the image of the Patch Panel in Section A.2 of Appendix A - Supplemental Information, as applicable.

___ 6.1.2 Determine the target volume to fill T01A Level Tank using ONE of the following:

___ 6.1.2.1 Ultrasonic Instrument

___ a. Record the current level of T01A Level Tank in Table 1.

___ b. Calculate the gallons required to fill the tank rounded to the nearest 0.1 gallon.

Table 1:

Level of Tank when filled	-	Current Level from Step 6.1.2.1a.	=	Volume Needed	x	Conversion factor to gallons	Target Volume to fill tank (round to 0.1 gallons)
100%	-	_______ %	=	_______ %	x	0.041gal/%	_________ gal

___ 6.1.2.2 Sight Guage

___ a. Record the current level of T01A Level Tank in Table 2.

___ b. Calculate the gallons required to fill the tank rounded to the nearest 0.1 gallon.

Table 2:

Level of Tank when filled	-	Current Level from Step 6.1.2.2a.	=	Volume Needed	x	Conversion factor to gallons	Target Volume to fill tank (round to 0.1 gallons)
20 in	-	_______ in	=	_______in	x	0.205 gal/in	_________ gal

___ 6.1.3 Ensure that a Second Party Verification of the volume calculation is performed.

Second Party Verification performed by: ________________________ Date/Time: ________/________

End of Section 6.1

6.2 Lab Lineup

___ 6.2.1 Ensure FCEDS13, Flow Station Pump Switch, is in the OFF position and the associated red "Pump Run" light is NOT illuminated.

6.2.1.1 REFER TO the image of the Flow Work Station, in Section A.1 of Appendix A - Supplemental Information, as applicable.

___ 6.2.2 Ensure the following valves are closed.

- ___ V1, Pump Outlet Isolation Valve
- ___ V2, Upper Flow Station Reservoir Inlet Valve
- ___ V3, Upper Flow Station Reservoir Outlet Valve
- ___ V7, Flow Control Valve Inlet Isolation Valve

___ 6.2.3 Ensure the following valves are open:

- ___ V4, Flow Transmitter Isolation Valve
- ___ V6, Rotameter Outlet Isolation Valve

___ 6.2.4 Ensure air is applied by pushing "AIR SUPPLY" on the Patch Panel.

6.2.4.1 REFER TO the image of the Patch Panel in Section A.2 of Appendix A - Supplemental Information, as applicable.

___ 6.2.5 **IF** the flow controller on Panel B is NOT in automatic as indicated by the illuminated letter "A" on Panel B,
THEN press the "A/M" button until in automatic.

6.2.5.1 REFER TO the image of the Flow Meter in Section A.3 of Appendix A - Supplemental Information, as applicable.

___ 6.2.6 **IF** any active alarms are present on FSFQIS1, Batch Controller, as indicated by a black bar across the top,
THEN ensure the alarm is acknowledged and reset.

6.2.6.1 REFER TO the image of FSFQIS1, Batch Controller, in Section A.4 of Appendix A - Supplemental Information, as applicable.

___ 6.2.7 Turn FCEDS13, Flow Station Pump Switch, to the ON position.

___ 6.2.8 Perform the following to start the pump:

___ 6.2.8.1 Press the pump start button.

___ 6.2.8.2 Verify the pump starts as indicated by the illumination of the red "Pump Run" light.

___ 6.2.9 Open slowly V1, Pump Outlet Isolation Valve.

End of Section 6.2

6.3 Batching Operations

___ 6.3.1 Ensure the default screen with the "Actual" and "Target" values is selected on FSFQIS1, Batch Controller.

___ 6.3.1.1 REFER TO Section A.4 of Appendix A - Supplemental Information, as applicable for more detailed information for operating FSFQIS1, Batch Controller.

___ 6.3.2 Enter the target volume obtained in Step 6.1.2 into FSFQIS1, Batch Controller, as the "Target" value.

NOTE

The cursor can be moved to the left or right to change the numbers individually on FSFQIS1, Batch Controller.

___ 6.3.3 **WHEN** the target value has been entered,
THEN press "End" and "Reset."

___ 6.3.4 Perform the following steps at the same time:

___ 6.3.4.1 Press the start button on FSFQIS1, Batch Controller.

___ 6.3.4.2 Verify FSNFV1, Flow Control Valve, modulates open.

___ 6.3.4.3 Verify that the level in T01A Level Tank increases to 96 -104% on the Ultrasonic Instrument or 19.2 - 20.8 inches on the sight guage.

___ 6.3.5 **WHEN** the desired total volume is obtained on FSFQIS1, Batch Controller,
THEN perform the following:

___ 6.3.5.1 Verify FSNFV1, Flow Control Valve, closes.

___ 6.3.5.2 Verify the "Actual" value on the screen stops increasing.

___ 6.3.6 **IF** the verification in Step 6.3.5 fails,
THEN perform the following:

___ 6.3.6.1 Close V1, Pump Outlet Isolation Valve.

___ 6.3.6.2 Turn switch FCEDS13, Flow Station Pump Switch, to the OFF position.

___ 6.3.6.3 GO TO Section 8.0, Contingencies,

___ 6.3.7 **IF** the desired tank level is NOT achieved,
THEN perform Section 6.1, Determining Volume Required to Fill Level Tank and Section 6.3, Batching Operations.

___ 6.3.8 **IF** the desired tank level is achieved,
THEN GO TO Section 7.0, Restoration.

End of Section 6.3

End of Section 6.0

7.0 RESTORATION

___ 7.1 Close ALL of the following valves:

- ____ V1, Pump Outlet Isolation Valve
- ____ V4, Flow Transmitter Isolation Valve
- ____ V6, Rotameter Outlet Isolation Valve

___ 7.2 Ensure ALL of the following valves are closed:

- ____ V2, Upper Flow Station Reservoir Inlet Valve
- ____ V3, Upper Flow Station Reservoir Outlet Valve
- ____ V7, Flow Control Valve Inlet Isolation Valve

___ 7.3 Turn FCEDS13, Flow Station Pump Switch, to the OFF position.

___ 7.4 Ensure the red "Pump Run" light extinguishes.

___ 7.5 Notify Operations of completion of this evolution.

End of Section 7.0

8.0 CONTINGENCIES

___ 8.1 **IF** the batch control loop fails,
THEN initiate a PVAR to troubleshoot.

___ 8.2 **IF** any unexpected conditions is identified during the performance of this procedure,
THEN notify Operations and/or the Team Leader.

End of Section 8.0

9.0 REFERENCES

9.1 Implementing References

9.1.1 None

9.2 Developmental References

9.2.1 Developmental References are listed in the Basis Document.

ⓘ

End of Section 9.0

APPENDIX B:
Survey Used In Pilot Field Evaluation Study

INL CBP Post Procedure Survey

Please answer the following questions based on your experience using the CBP. Please answer as though you had actually conducted the task (rather than simulating it).

* Required

1. **Which procedure did you conduct today? ***
   Mark only one oval.
   - ( ) 4.11 Functional Test of B/U VI Compressor 1
   - ( ) 4.21 Functional Test of B/U VI Compressor 2
   - ( ) 4.23 Functional Test of B/U VI Compressor 3

2. **Please provide your first, middle, and last initials in the space below ***

   ____

3. **Did the CBP lead you down a path where you conducted an error (e.g., mistake, near-miss, deviation, etc.)?**
   Please answer the following questions based on your experience using the CBP. Please answer as though you had actually conducted the task (rather than simulating it).
   Mark only one oval.
   - ( ) Yes *Skip to question 4.*
   - ( ) No *Skip to question 5.*

4. **Please briefly describe the situation in which the CBP lead you down a path where you conducted an error (e.g., mistake, near-miss, deviation, etc.).**

   ____
   ____
   ____
   ____
   ____

5. **Did the CBP stop you from conducting an error (e.g., mistake, near-miss, deviation, etc.)?**
   Mark only one oval.
   - ( ) Yes *Skip to question 6.*
   - ( ) No *Skip to question 7.*

6. **Please briefly describe the situation in which the CBP stopped you from conducting an error (e.g., mistake, near-miss, deviation, etc.)?**

____
____
____
____
____

7. **Did the CBP cause any confusion or behave in a way that was unexpected while you executed the procedure?**
Mark only one oval.

( ) Yes *Skip to question 8.*
( ) No *Skip to question 9.*

8. **Please briefly describe the situation in which the CBP caused confusion or behaved in a way that was unexpected while you executed the procedure?**

____
____
____
____
____

9. **After executing the procedure with the CBP, do you prefer using paper or the CBP?**
Mark only one oval.

( ) Computer-Based Procedure *Skip to question 10.*
( ) Paper-Based Procedure *Skip to question 11.*

10. **Please briefly explain why you prefer the CBP.**

____
____
____
____
____

Skip to question 12.

11. **Please briefly explain why you prefer the PBP.**

12. **Please Rate the usability of the CBP**
Consider how easy it was to navigate, how easy it was to learn, and how easy it was to use.
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Poor											Excellent

13. **Do you have anything you want to add?**
E.g., suggestions for improving the interface or issues that need to be addressed before a system like this could be implemented

APPENDIX C:
Job Aid Used In Pilot Field Evaluation Study

Job Aid

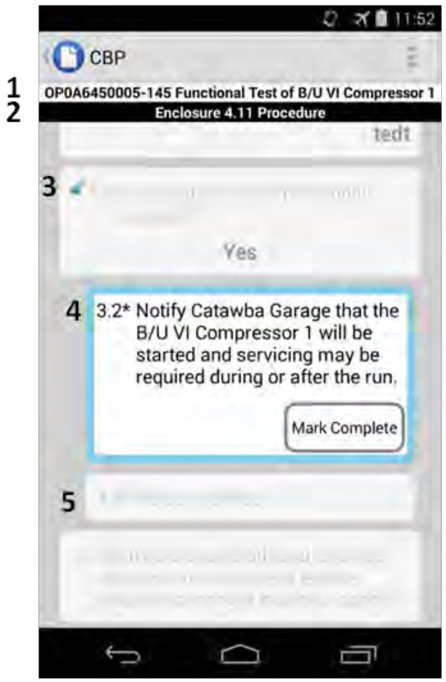
Thank you for taking part of this research study!
Idaho National Laboratory is conducting research on the design of computer –based procedures (CBPs). We are working with CNS to test a prototype CBP using a real-world procedure (so far our prototype has been demonstrated only in a laboratory setting). You will be using the prototype CBP in parallel with a fellow AO who is conducting the procedure using the traditional paper procedure.
The feedback you provide will help researchers design CBPs that improve efficiency, reduce errors, and hopefully make your job easier and more enjoyable.
Again, Thank You for your participation!

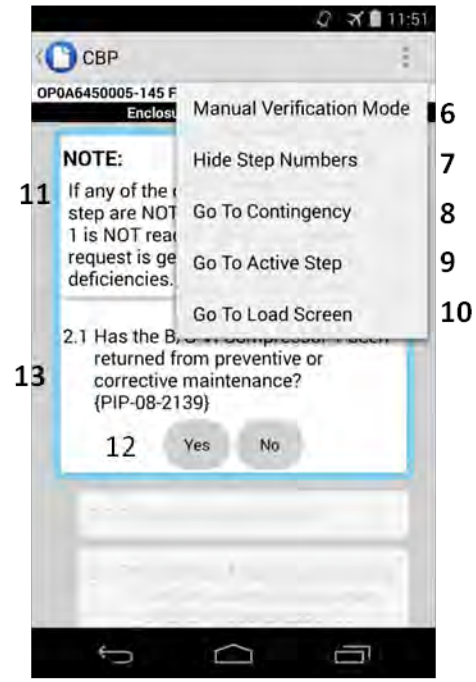
Instructions

1. Log in on the dedicated desktop (corner desktop)
2. Open up the folder named "CBP Desktop"
3. Open and complete the Informed Consent Form
4. Obtain a stylus and the handheld device and make sure it's charged
5. If needed, read the CBP_ Training document (located in the CBP Desktop folder) or look at the Quick Refresher sheet (on the back of this sheet)
6. Unlock the device by swiping your finger or stylus across the screen
7. Open the CBP application (on the handheld device), log in, and select the appropriate procedure
8. Conduct Pre-Job Brief
9. While procedure is conducted, follow along as though you were conducting the task
10. Log out of the procedure application when procedure is completed
11. If you would like to print a copy of the procedure you conducted:
    a. Plug the device into the desktop (using the dedicated USB cord),
    b. Open up the CBP Desktop application (located in the CBP folder)
    c. Select the procedure you conducted
    d. Generate and print the Word document
12. Put the device back and plug it in to the wall charger
13. **Important**: Fill out the brief survey. Your honest feedback is very valuable to the researchers. We need to know what you like and/or don't like in order to improve the design. The link to the survey is located in the CBP Desktop folder.

Thank you!

If you have any questions, please don't hesitate to contact us:
Tom Waicosky: Thomas.Waicosky@Duke-Energy.com
Johanna Oxstrand: Johanna.Oxstrand@inl.gov





1. Procedure title and revision
2. Enclosure
3. Conducted step - Click checkmark to edit
4. Active step
5. Future steps

Menu Items:

6. Toggle Manual and digital (barcode) mode for CCV
7. Hide/Show step numbers
8. List of contingency actions
9. Go back to the step to be performed (the currently active step)
10. Go to load screen to switch user or log out
11. Notes are presented together with the step
12. Conditional statements are phrased as questions
13. Click on the step text to view PIPs, NSWPs, etc.

Continuous Action Steps:

When a continuous action step is active the yellow triangle icon will appear. Click on the icon to view the list of active continuous action step . To get more information, click on the step in the list. You will be asked if you want to perform the step at this time or not.

APPENDIX D:
Survey Used In Field Evaluation Study

INL Computer-Based Work Order Post Task Survey

Please answer the following questions based on your experience using the Computer-Based Work Order (CBWO).

* Required

1. **Please enter the work order number for the task you executed using the CBWO** *

   ____

2. **Please provide your first, middle, and last initials in the space below** *

   ____

3. **Did the CBWO lead you down a path where you conducted an error (e.g., mistake, near-miss, deviation, etc.)?** *
   Please answer the following questions based on your experience using the CBWO.
   Mark only one oval.

   ◯ Yes *Skip to question 4.*
   ◯ No *Skip to question 5.*

4. **Please briefly describe the situation in which the CBWO lead you down a path where you conducted an error (e.g., mistake, near-miss, deviation, etc.).** *

   ____
   ____
   ____
   ____
   ____

5. **Did the CBWO prevent you from conducting an error (e.g., mistake, near-miss, deviation, etc.)?** *
   Mark only one oval.

   ◯ Yes *Skip to question 6.*
   ◯ No *Skip to question 7.*

6. **Please briefly describe the situation in which the CBWO stopped you from conducting an error (e.g., mistake, near-miss, deviation, etc.)?**

____
____
____
____
____

7. **Did the CBWO cause any confusion or behave in a way that was unexpected while you executed the procedure?** *
Mark only one oval.
   - ( ) Yes *Skip to question 8.*
   - ( ) No *Skip to question 9.*

8. **Please briefly describe the situation in which the CBWO caused confusion or behaved in a way that was unexpected while you executed the procedure?** *

____
____
____
____
____

9. **Do you think the CBWO system has the potential to improve the reliability of the equipment?** *
Mark only one oval.
   - ( ) yes
   - ( ) no

10. **Please briefly explain your response.** *

____
____
____
____
____

11. **After executing the procedure with the CBWO, do you prefer using paper or the CBWO? ***
    Mark only one oval.
    - ( ) Computer-Based Work Order *Skip to question 12.*
    - ( ) Paper-Based Work Order *Skip to question 13.*

12. **Please briefly explain why you prefer the CBWO. ***

    ____
    ____
    ____
    ____
    ____

Skip to question 14.

13. **Please briefly explain why you prefer the PBWO. ***

    ____
    ____
    ____
    ____
    ____

14. **Please Rate the usability of the CBWO ***
    Consider how easy it was to navigate, how easy it was to learn, and how easy it was to use.
    Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Poor	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	Excellent

15. **Do you have anything you want to add?**
    E.g., suggestions for improving the interface or issues that need to be addressed before a system like this could be implemented

    ____
    ____
    ____
    ____
    ____