Nuclear Power Plant Maintenance Improvement via Implementation of Wearable Technology

Thesis

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By

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Abstract

The recent commercialization of wearable technology presents an opportunity for nuclear power plant maintenance workers to increase their performance by becoming more aware of their situation and increasing the tools at hand to perform the maintenance. A wearable technology, such as Google Glass (GG), gives the wearer a small screen in front of the user’s eye, which is a potentially useful medium through which to convey information about radiation fields and maintenance procedures. If used to its full potential, the technology can be used to monitor worker progress in real time, guide to divert potential errors, and give the worker performance feedback, all of which may be invaluable during time-sensitive activities in the plant.

A GG program has been created which allows a utility worker to see the procedure in a small screen worn on his or her head. The worker follows the procedure and enters decisions made and situations encountered during the procedure. The program tracks these decisions and checks them against the preprogrammed valid solutions. Should an error occur, the worker is immediately notified that an invalid set of solutions has occurred. Such an error may present itself in the form of a valve out of position, a tag not cleared on an associated system, or a step inadvertently being marked as “Not Applicable.” In addition, another GG program was created to record and relay data from a Bluetooth-enabled radiation dosimetry device and conveys this information to the
worker in a small box on the screen. This alternative form of conveying dosimetry
information presents the information in a more accessible way: on a screen in the
worker’s field of view rather than on a pocket dosimeter which, requires a button to be
pressed to convey the information.
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Chapter 1: Introduction

While the nuclear field is generally technologically advanced, nuclear power plant workers are constrained by a general lack of modern technology at their disposal for maintenance purposes. Although new technologies are available, nuclear power plant workers frequently are limited to the tools that have been made available to them for many years because of the extensive operating experience available for these more conventional and robust tools. Chiefly amongst these established technologies is Paper Based Procedures (PBP). Nuclear utility maintenance personnel frequently perform maintenance tasks with PBPs and equipment that is over 30 years old, calling upon experience and training for guidance with few instances of automated oversight. The extensive reliance on operator judgement, experience, and training while performing tasks with PBPs leaves open the possibility of making errors while performing maintenance tasks. The practices, methodologies, and findings relevant to maintenance in the commercial nuclear power industry is the chief focus on Chapter 3. Relevant findings PBPs is covered primarily in Chapter 2.

In the nuclear industry, the maintenance complexity is compounded by the presence of radiation. This makes it all the more important that the maintenance be done quickly and with knowledge of the radiation intensity, which changes with position and time. If the radiation field strength can be conveyed to the worker in real time, the worker can change
position to perform the maintenance in a new position that may be less severe. Radiation field strengths are spot measured on a routine basis; however, these surveys are do not relay information for all points in space nor can these surveys be done instantaneously to reflect the current state. It is generally accepted in the nuclear industry that awareness is fundamental to combating high cumulative dose and adhering to the As Low As Reasonably Achievable (ALARA) principles, which is challenging using the methods employed currently. A full summary of the applicable aspects of conducting work in radiation fields, as laid out by the Department of Energy, is detailed in Chapter 3.

While Computer Based Procedures (CBPs) have been a matter of discussion for over 30 years [1], nuclear utility companies have been hesitant to be the first to implement CBPs at nuclear power plants for work in the control room or in the field due to potential regulatory issues that may need to be addressed. As stated in [1] “One of the reasons for the delay in implementing CBPs may be the fact that there is insufficient information regarding the effect of CBPs on human performance of procedural tasks.” More recently, CBPs have been experimented with for simple maintenance tasks as a sort of pilot program with assistance from Duke Energy and the Idaho National Laboratory [1]. The success of the prototype used at Duke Energy in 2012 opens the floor to the decision of which platforms may be beneficial to be the medium on which these CBPs may be carried. The relevant findings of CBPs and the summary by the research team at Idaho National Laboratory are summarized in Chapter 2.

Nuclear power plant maintenance carries a small degree of risk of human error as well as harmful radiation exposure, both of which should be minimized by every practical means
as made evident in the mission statement of the Electrical Power Research Institute (EPRI) [10] and the industry standard of practicing ALARA. If a CBP is coupled with a piece of hardware which successfully improves worker performance, this could benefit the nuclear industry by reducing radiation dose to plant workers and reduce the risk of operator errors during nuclear maintenance tasks. Components of human error with respect to nuclear maintenance applications are summarized in Section 2.3. These components were identified by the Department of Energy (DOE) with credited assistance to the Institute of Nuclear Power Operations (INPO) [2].

It is the intent of this research to investigate if the use of wearable devices with head-mounted displays have the potential to reduce errors and reinforce ALARA within the specific field of industry and are a suitable medium on which to implement CBPs.

This objective was achieved using a GG wearable device and installing a custom GG program designed to step a user through a maintenance procedure. By completing a simulation of the task as described in Chapter 4, it is demonstrated that a user could perform the task and the hardware offered numerous features as identified to be desirable for implementation into a CBP [1].
Chapter 2: Related Literature and Theoretical Focus

To better understand the potential to successfully implement GG into the nuclear maintenance field, three subjects were explored: the implementation of GG in the medical field, the potentially beneficial characteristics of Computer Based Procedures, and a brief summary of common human performance modes which are possibly correlated to errors at nuclear power plants.

2.1: Example of Implementation of GG in the Medical Field

Identified by INPO as a high performance industry [2], the medical field is an area of keen interest to this project. Because both nuclear and medical fields are considered high performance industries, it is potentially possible to learn from the experiences of the medical field where it was attempted to implement GG into certain tasks. To that extend, an article published in 2014 [3] was examined. The main areas of focus in the study were ergonomics, battery life, audiovisual quality, functionality, connectivity, applications, acceptance, and data privacy issues. Many of these individual topics are not of primary interest in the nuclear field; however, there are parallels. Data privacy may not be an issue, but data security is a similar concern. Other topics discussed have more direct relevance; chief among which is the report regarding ergonomics as reported by the doctors performing surgery in a potentially dangerous situation. Although the study
mentioned in this example was the first of its kind, according to authors in the article, it is not an isolated case regarding the development of software for GG for the medical research industry (and by extension, for a high performance industry.) The GG Developer Kit website [4] indicates that “Advanced Medical Applications” offers specialized medical field solutions via telemedicine and live-surgery demonstrations using GG solutions which connects doctors and patients to other doctors with the aid of GG. There are multiple other companies (Advanced Medical Applications, APX Labs, and Augmedix for example) which offer GG solutions to industries which stand to benefit from their technology, many of which are centered on the healthcare industry [4]. In these respects, it seems feasible to search for ways GG may be used in commercial nuclear utilities.

One potential issue associated with the use of GG in the nuclear industry is data security. As stated in [3], permission was obtained from the patients and caregivers to avoid privacy issues. Additionally, wireless connectivity was temporarily deactivated to avoid upload to an external unsecured server. A similar method could be used at nuclear power plants in that the facility may or may not choose to implement Wi-Fi or other wireless connectivity options. Ultimately, GG only has local wireless connectivity and will not directly connect to a cell phone tower. Temporary deactivation may not be necessary in all cases if security can be adequately resolved from a software standpoint.

Regarding ergonomics and practicality, a potential concern is obstructing the view of the operator. This concern is applicable to the nuclear power industry as well. Authors of the [3] study indicate that researchers have tested the ergonomics of the position of the
display and reported on the findings both in terms of how simple the display was to read as well as whether or not the screen is in the way or distracting. The results are best summarized as “The test person found the view to be unobstructed by the head-mounted prism display…” [3] The screen not being in the way is of high importance for a practicality standpoint but leads to the consideration that the screen may be too difficult to read. This was resolved in the next test where GG was worn as it was in the previous test. Seeing the screen was described as being achievable “…without much effort…” [3]. However, it was indicated in [3] that the head tilt-activation was not responsive 100% of the time and sometimes required a second head tilt to activate. Normally, the two primary methods to activate the device are to tilt the head back 20-30 degrees or to make use of the touchpad (less ideal if hands are occupied.) Additionally, the implementation of the optional polycarbonate lenses were seen as useful in the operating room as they “provided good splatter eye protection” [3], a feature which may have a parallel application in a radiation work environment where eye protection is required to be worn.

Furthermore, the operators described the input controls as “intuitive and easy” [3] which is an important consideration from a practical standpoint. In these respects, it is assumed that worker comfort and attention are desired to be maximized while minimizing distractions for applications in the nuclear field as well.

The device used in the medical study [3] for audio was the built in bone-conduction speaker, which vibrates while touching behind the ear to convey sound. The doctors conducting the field research in this study were using the bone-conductive speaker and found it hard to hear in most situations. The GG device now has the option for an actual
speaker which mounds in the ear as a normal headphone and connects to the GG device via the mini USB. The video quality is a topic more within the scope of this project. The medical researchers described the video and audio quality as “…high, and definitively sufficient to document all clinically relevant findings” [3] and it should also be mentioned that GG takes 5 Megapixel photos. The recording features are considered of high importance in the nuclear field application as this can be a source of documentation. Regarding the screen resolution, experimenters summarized it as “easily seen with the right eye and seemed to have adequate resolution to pick up pertinent details in most circumstances” [3]. Actual specifications regarding the GG device are fully described in Chapter 4, including some similarities between the GG features and CBPs.

The battery life was not always found to be as long as desired, lasting only for a few hours depending on operator use. However, this setback can be avoided by making use of an external battery, which could be placed in a helmet that is conveniently worn in industrial settings typical of nuclear power plants.

2.2: An Exploration of Computer Based Procedures

As nuclear technology is relatively old and commercial power plants have existed for over half a century, the first nuclear power plants made use of PBPs to guide workers through maintenance procedures. These unpowered, unconnected sheets of paper still remain in existence and are popularly used for nuclear power plant maintenance performance. An alternative to PBPs are CBPs. The concept was introduced to the nuclear industry in the mid 1980’s (as stated in [1] and [2]) and was planned at one time
to be used in several nuclear power plants; however, a lack of expediency seemed to be tied to the lack of Operator Experience (OE) with implementing and using a CBP program [1]. Because information is shared in the nuclear industry through organizations such as EPRI and INPO for mutual benefit, companies have been hesitant to be among the first to implement the new procedure method [1]. Researchers at INL in collaboration with Duke Energy identified the main necessities of a CBP program and how it would be different from the PBPs [1]. The main drawbacks to PBPs were identified by the team were the following:

1. Must be written to account for large degree of variations in plant conditions;
2. It is challenging to manage multiple procedures;
3. Manual Place-Keeping is time consuming, mentally demanding, and increases likelihood of errors.

With the drawbacks to PBPs identified and categorized, the team set a goal for what a CPB would have to implement: configuration and control of procedures, context sensitivity of procedures, procedure tracking, and human performance improvement (HPI) [1]. The team gathered this information from multiple and various sources within the nuclear utility. The desires of a CBP were finally formalized into several categories [1]:

1. CBPs should ease the burden of Place-Keeping for the operator. The procedure should highlight the current step, should keep track of completed steps, and keep track of where in the procedure the operator currently is.
2. CBPs should make clear differentiations between steps which require the performance of an action and steps which only require the gathering of information.

3. CBPs should make the operator aware of situations in which the operator will need to read ahead in the procedure before performing the step; additionally, the procedure should alert the operator to relevant changes in plant condition when such a CBP has access to real-time plant data.

4. CBPs should employ some method of automatic Correct Component Verification, possibly though the use of barcode recognition.

5. CBPs should make the expected initial conditions more clear for the operator.

6. CBPs should make it easier for the operator to correctly assess proper equipment response.

7. CBP should include functions which improve communication by enabling the operator to share text, picture, or video information.

The INL/Duke Energy team created a CBP which incorporated context sensitivity and simplified step logic. “Context-sensitivity basically means that the CBP only presents steps that are relevant to the current conditions” [1]. In the prototype CBP created in this study, the display would only show the steps which were pertinent to the user based on adapting plant conditions. Having a simplified version of the procedure which only consisted of instructions based on relevant information can greatly reduce the amount of information in the procedure which the user is behaviorally encouraged to ignore. In other words, the CBP only displayed relevant information rather than a complex statement which required the user to decipher the instruction and perform an action which
was subject to the user interpretation of what was instructed. As described later in this chapter, introducing judgement decisions into a long procedural-based process can expand the likelihood of error and the presence of such a long complicated instruction would be an Error Precursor. Essentially, an exhausted worker who is asked to make a judgement as to whether or not a certain task must be performed based on non-straight-forward or outdated information is a nested error which can increase error likelihood. It would be preferable that the procedure only display information which is relevant to the situation in question and does not preemptively introduce the Error Precursor. The “Simplified Step Logic” incorporated by the team was implemented by rephrasing complicated plant conditions into the CBP by reducing these circumstances into IF/THEN logic by stating applicable questions regarding the relevant plant conditions followed by condition-relevant instructions rather than expressing all possible conditions the plant could be in which could be applicable as a broad statement [5]. By asking logic questions and tailoring the phrasing of the instruction accordingly, it was found out that long and complicated steps can be greatly reduced in length and simplified. Reducing length and complexity can theoretically help reduce risk and simplify the operator’s task, as identified later in this chapter. The procedure created within the context of this thesis was designed to fulfill a similar objective by discretizing the steps into smaller steps with the operator making swipe gestures to input relevant information and allowing the procedure to generate the relevant instruction as a consequence of the straight-forward binary output questions. More details regarding the test setup are explored in Chapter 4.
Identified as a drawback of PBPs, *Place-Keeping* is both mentally and physically cumbersome; however, this drawback is removed in the case of implementing a CBP as stated by the INL researchers, “*Place-Keeping* is automatically conducted by the CBP system [5].” Essentially, the procedure only allows for the display of one step at any given time. Completing a step automatically begins the display of the next step after checking the initial step as complete. This can be most beneficial when performing long tasks involving multiple sections and subsections. The performance of automatic *Place-Keeping* in combination with the simplified logic steps presents an opportunity to greatly reduce the chance of human error induced by reading a PBP. The details and correlations in regards to human error are discussed at a later point in this chapter.

The CBP report also mentioned the desire to implement a barcode reading system:

“Automated Correct component verification is achieved by utilizing equipment barcodes and matching the equipment information to a database on the device” [5]. The benefit to this would be the addition of an automated logic check which can act as a means of “peer check” to assist in the prevention of direct opportunity for human error. The more apparent benefit of a CBP is the opportunity to implement these automated checks and to make full use of the hardware commonly available on commercially available electronics. The concept of Optical Character Recognition, barcode readers, and QR code readers as a whole have already been validated [6] in independent applications as a means to reduce human error and subsequently are expected to be assisting desirable features for applications within the context of this thesis. Such assistive actions were not incorporated into the GG program developed in this study; however, remains a desirable option for
consideration in future work whose implementations are expected to be relatively straightforward (see Chapter 6).

2.3: A Brief Overview of Human Performance Errors and Failure Modes

The focus of this research is not to fully detail the factors and contributors to affect human performance nor is it an attempt to make a case that human performance is demonstrably improved by the implementations of GG as a hardware medium for a CBP. The research is expected to provide context for the decisions made for the implementation of the product into the realm of commercial nuclear power. Because the majority of the focus of this research was placed on human action in performing a task and 80% of undesirable events (or Events for short) are caused by human error [2] in the commercial nuclear industry as illustrated by Fig. 1, a discussion regarding human performance is warranted.
A DOE study [2] states that performance is the summation of behavior and results. Accordingly, performance can be influenced by altering either. Obtaining both desired behavior and results relies on safeguards against residual errors to prevent Events, the components of which are described below in Section 2.3.1. The additional topics explored in Sections 2.3.1 through 2.3.4 include an analysis of undesirable events prevalent at nuclear power plants (Section 2.3.1), one significant contributor to human performance errors (Section 2.3.2), and two specific performance modes in which workers operate in while performing maintenance tasks (Sections 2.3.3 and Sections 2.3.4, respectively).

2.3.1: A Brief Overview of Undesirable Events at Nuclear Power Plants
“Events” are considered to be “an unwanted, undesirable change in the state of facility structures, systems, or components or human/organizational conditions (health, behavior, administrative controls, environments, etc.) that exceeds established significance criteria” [2]. Essentially, what the DOE refers to is for Events to be reduced in key facilities by the judicious mitigation of error precursors, flawed controls, and organizational weaknesses, as illustrated in Fig. 2.

Figure 2: Anatomy of an Event (Adapted from [2])
The anatomy of an event is comprised of latent organizational weaknesses, flawed controls, error precursors, initiating action, and events. These can be referred to as Figs. 2(a) through 2(e), respectively. An Initiating Action, Fig. 2(d), is “an action by an individual, either correct, in error, or in violation, that results in a facility event” [2]. Notable from the definition, the initiating event is not always necessarily made in error, but may only be the execution of the errors put in place by precursors or flawed controls. Flawed Controls, Fig. 2(b), are “defects that, under the right circumstances, may inhibit the ability of defensive measures to protect facility equipment or people against hazards or fail to prevent the occurrence of active errors” [2], such as a warning sign not being placed properly or work control not being strictly enforced. These errors alone would not create an event without an initiating action but do set the stage for initiating action. Error Precursors may also preclude initiating actions and are generally characterized as events which are beyond the “capabilities of the individual or when work conditions aggravate the limitations of human nature” [2]. Latent Organizational Weaknesses, Fig. 2(a), are described as the flawed management controlled processes regarding items such as work control or training. Notably, it is said that these include “system-level weaknesses that may exist in procedure development and review” [2]. The implications of system-level weaknesses are that procedures may be a part of the latent organizational weaknesses and may contribute to Events. Procedures that are either written in error or set into motion a sequence of actions which fail to prevent an undesirable action may in fact be latent organizational weakness if such an event could have been prevented. As described later
in Section 3.5.2, EPRI seeks to continuously improve procedures in order to reduce the chances for errors, suggesting that procedures left unimproved may be an error precursor.

As has been described in this section, procedures may contribute to the initiation of Events through latent organizational weaknesses, but improving the procedures might not completely reduce error: “Even if opportunities to err are systematically identified and prevented, people may still err in unanticipated and creative ways. Consequently, additional means are necessary to protect against errors that are not prevented or anticipated” [2]. Accordingly, emphasis can be placed on reducing the error sources, 80 percent of which are human in origin [2], which could be in the form of autonomous oversight. Regardless of the means which are identified to reduce the error, it is considered effective to focus on the actual work execution; because the execution is performed in accordance with the procedures, procedures are the focus of the solution for this research.

2.3.2: Task Demand

Task Demand is a “Specific mental, physical, and team requirement to perform an activity that may either exceed the capabilities or challenge the limitations of human nature of the individual assigned to the task [2].” Some examples of this include both the task difficulty and complexity. The Error Precursor category of “Work Environment” includes awkward equipment layout, complex tagout procedures, and distractions [2]. As the nature of the work in nuclear power plants is inherently complex in addition to the numerous peripheral tasks and the attitude that no job is routine, all work at nuclear
power plants can fall into the DOE definition of an Error Precursor as work at nuclear power plants is considered to be inherently complex. Attachment A of the DOE human performance handbook also includes “Confusing procedures/Vague guidance” and “Excessive communication requirements” [2] as error precursors. Therefore, the case is made explicitly that the maintenance in question is inherently complex and that complex work can be an error precursor. Reference [2] goes on to discuss the contributions to the errors frequently made within the context of maintenance at nuclear power plants.

Procedural compliance seems to be key to error prevention. As described by DOE, “Procedures provide individuals with the means of avoiding or detecting mistakes” [2] and yet, as described previously, workers at nuclear power plants still are responsible for approximately 80% of mistakes. To further understand the sources of these errors, the sources of errors are analyzed by the mode in which the operator performs the task.

According to a study by the nuclear power industry, under ideal conditions, error frequency is less than 1 in 10,000 [7]. Recognizing the sources of these errors is of critical importance and can be studied based on the skillsets required while making these errors. Of particular interest are the skill-based performance mode and rule-based performance mode.

2.3.3: Overview of Skill-Based Performance Mode

Skill-based performance involves physical actions which are highly practiced. According to the DOE, 25% of all errors in the nuclear power industry are attributed to Skill-Based Performance [2]. As phrased in [2], “Such actions are usually executed from memory without significant conscious thought or attention… Behavior is governed by
preprogrammed instructions developed by either raining or experience and is less
dependent upon external conditions [2].” In other words, these are the physical actions
performed by people without much conscious thought. Examples include everything from
mowing the lawn to analyzing chemical composition of a routine sample [2]. It is of
interest that these actions also include hanging a tag, opening a valve, taking logs, and
replacing parts during maintenance, as these are tasks performed during nuclear power
plant maintenance operations. Still, while 25 % of errors are attributable to skill-based
errors in the nuclear power industry, “roughly 90 percent of a person’s daily activities are
spend in the skill-based performance mode.” Taken as a whole, Skill-Based Performance
errors attribute to only 25 percent of all errors even while this state of mind accounts for
90 percent of daily activities [2]. The Skill-Based Performance mode is discussed here
although it is not seen as a primary target for improvement via the GG CBP initiative.
The errors that are given as examples of this error mode are not highly procedure-driven
as the actual error source. These error examples include actions such as intentionally
turning on a machine after replacing a light on the front panel, which may be analogous
to an action such as cleaning a microwave then turning the microwave on after closing
the door. These errors seem to be executed as a consequence of operator “muscle
memory” and are not pursued by this research as a possible source of error reduction
because the errors themselves don’t seem to be highly procedurally focused; procedure
improvements directed to reduce human error opportunity is the focus of this research.

2.3.4: Overview of Rule-Based Performance Mode
Rule-based performance involves the application of either memorized or written rules. It is commonly employed when a work situation changes and the previous activity will no longer adequately guide one’s actions. In the rule-based performance method, a worker will apply IF/THEN logic in such a way that “prepackaged units of behavior” are applied and then the worker “may then use conscious thinking to verify whether or not the solution is appropriate” [2]. Using emergency operating procedures is an example of a rule-based activity. The common error mode of rule-based performance is misinterpretation. “Errors involve deviating from an approved procedure, applying the wrong response to a work situation, or applying the correct procedure to the wrong situation” [2]. In the nuclear power industry, these opportunities for error are also present. Deviating from an approved procedure may occur in the presence of complicated procedure references and logic statements. Applying the wrong response to a work situation may occur after a changing work situation. Applying the correct procedure to the wrong situation may also occur in the situation of a changing work situation. [2] states that “with less familiarity for the activity, the chance for error increases to roughly 1 in 1,000” which is still 99.9 percent reliable; although it tends to account for a larger percentage of the errors committed in the nuclear power industry. According to the nuclear power industry, “studies have shown that roughly 60 percent of all errors are rule-based [2]”. The listed methods to prevent rule-based errors are: “Task Preview, Procedure Adherence, Pre-Job Briefing, Questioning Attitude, Peer-Checking and Concurrent and Independent Verification among others.” The medium in which this HPI tool is implemented is by meticulous training and, in some companies, requiring
employees to carry a copy of the human performance handbook [8] on their person at all times in industrial environments. Implementing this DOE HPI handbook into an electronic version would be one of the primary focuses of the implementation of a GG based CBP. The usage of the human performance book [8] can be highly contextual as the handbook appears to cover such a wide range of topics from emergency exit accessibility to safety precautions. Implementing a CBP allows for the selection of certain portions of the relevant text to be placed into the procedure and activated with logic cues.

Some of the HPI tools (Self-Checking and Effective Communication) listed in [2] are described in [8]. The full exhaustive list for the individual includes [8]:

1. **Task preview**: Before starting work, individuals review the procedures and other documents to familiarize themselves with the scope of work.
2. **Job-Site Review**: Workers familiarize themselves with the jobsite prior to initiating work to boost Questioning Attitude and situational awareness
3. **Questioning Attitude** (at activity level and work planning and preparation level)
4. **Pause when Unsure**
5. **Self-Checking**: Generally performed by stopping, thinking prior to performing an action and then reviewing to ensure the outcome was consistent with expectations.
6. **Procedure Use and Adherence**
7. **Validate Assumptions**
8. **Signature**
9. **Effective Communication**
10. *Place-Keeping.* Marking a procedure as steps are performed to help avoid performing steps out of order or omitting steps.

For work-teams, additional methods include [8]:

1. *Pre-Job Briefing:* A meeting of individual performers and supervisors before performing a task.

2. **Checking and Verification Practices**

3. *Peer-Checking:* A series of actions performed by two individuals where the second individual performs a second check to verify the proper action is to take place.

4. **Concurrent and Independent Verification**

5. *Peer Review:* A series of actions performed by a second individual where the second individual is equally responsible for correct performance.

6. *Flagging:* physically distinguishing a single component when such a component is in the vicinity of similar-looking components so as to not perform undesired action on the wrong component.

7. *Turnover:* When a task is to be completed by a second shift, the two workers or work teams meet and discuss the full state of work completed.

8. **Post-Job Review**

The presence of these human performance tools emphasizes the key point which is that the nuclear utilities and affiliates have developed numerous procedures for methods to
prevent Rule-Based performance errors. The primary cause of the errors is not explicitly stated in [2]; however, it is accompanied by a misinterpretation of the procedure.

Several suggestions have been made by utility workers regarding how procedures can be improved by making them easier to understand (as stated in Section 2.2 with regard to CBPs making the procedures easier to interpret and Section 2.3.2 with regard to confusing/complex procedures being an Error Precursor). The previous solution provided by the DOE has been to implement new separate procedures for the use of human performance tools, which are broad and not directly tied into the individual procedure. The GG CBP presented in this thesis attempts to tie the improvements of the CBP into a hardware medium which facilitates these improvements (see Chapter 4). It is expected that the implementation of these tools into one electronic device would consolidate multiple procedures into one source, possibly with the added benefit of being in a more applicable, and therefore consequential, position. Not all of the human performance tools (Self-Checking, Pause When Unsure, Questioning Attitude) have immediate applicability to the implementation of GG in nuclear power plants; however, several of the items (Procedure Use and Adherence, Place-Keeping) do appear in the procedure version seen in GG-based CBP in an attempt to seamlessly implement them into the overall maintenance process.
Chapter 3: Presentation of the Background for Target Application

The focus of this chapter is to explain the work environment at nuclear power plants, mostly by explaining two of the most prevalent considerations to occupying a power plant: (Section 3.1) maintain ALARA and comply verbatim with approved written procedures (Section 3.2).

3.1: Implications of Performing Work in a Radiation Environment

Maintenance tasks in a nuclear power plant frequently take place in radiological areas. For the most part, it is unavoidable to accrue some degree of radiation dose while performing this such maintenance. However, the cumulative dose can be reduced by knowing what the dose rates are in a given position and altering position accordingly, as indicated by the DOE [3]. It is stated in [3] that awareness of radiation field strength as a function of location is a prerequisite to entering a radiation area. This is typically done by reviewing Survey Maps, which are documents where measured radiation strength is recorded as a function of position. The radiation areas are surveyed regularly; however, these can be inaccurate for two reasons: i) the surveys don’t measure or record every location and the readings can become outdated due to the removal of shielding, or, ii) the replacement of radioactive material. No matter how carefully a survey map is scrutinized,
it is possible for significantly higher dose rates to be present in the areas between recorded survey points without the worker’s knowledge.

There are, however, other methods of determining radiation intensity in the field and in real time. The radiation field strength is also measured by the worker’s Electronic Pocket Dosimeter (EPD), which is typically worn on the chest and can display the dose rate if the worker presses a button on the EPD and inspects the viewing screen. The disadvantage to this is that it requires the worker to be in a radiation field to determine the field strength; therefore, this is not used as a primary method to determine radiation field strength. The current maintenance practices require a worker to read a Survey Map [9] as a primary preventative measure (which may be incomplete, as discussed above,) enter the radiation field to perform the maintenance, and periodically check the EPD as a cautionary measure. The actual dose rate is not made evident to the worker unless the said worker inspects the EPD and presses a button to temporarily view the dose rate. The process also requires the worker to be mindful during a distracting maintenance procedure, raising the potential to forget to manually check the EPD. It is currently required for the worker to inspect the EPD for cumulative dose no less often than every fifteen minutes, as described in the DOE handbook for Radiological Worker Training [9].

3.2: The ALARA Policy

There are many consequences of the DOE ALARA policy; as such, it is stated below:
“ALARA is an approach to radiation safety that strives to manage and control doses (both individual and collective) to the work force and the general public to as low as is reasonable taking into account social, technical, economic, practical, and public policy considerations.” [9]

This policy is based on the understanding that some degree of risk exists in proportion with radiation dose, however slight. ALARA concept is firmly rooted in all activities that takes place within the nuclear power industry. In the words of the DOE: “The ALARA concept is an integral part of all site activities that involve the use of sources of ionizing radiation [9].” As such, it plays an integral role of nuclear power plant maintenance and its policies and practices are in affect during any maintenance that may occur in an ionizing radiation environment. The responsibility for maintaining ALARA is shared amongst all employees, including the workers at the individual level but extends to all individuals in one way or another. As stated in [9], “ALARA is the responsibility of all employees”. Consequentially, it is also the responsibility of the management personnel to ensure proper tools are provided for the workers to execute the task of avoiding exposure to ionizing radiation which requires awareness of the ionization field strength as a function of location. Again it is stated in [9] that “Each radiological worker is expected to demonstrate responsibility and accountability. This is accomplished through an informed, disciplined, and cautious attitude toward radiation and radioactivity.” It is also stated in [9]: “Engineering controls should be the primary method to control exposure [9].”

Although there are numerous methods by which to control exposure (glove bags, survey maps, temporary shielding, etc.) engineered solutions are the primary solution. An
apparatus using modern technology (such as GG) rather than depending on traditional methods such as radiation survey maps and discretized postings to maintain ALARA is expected to be an improved means to control exposure.

Discussed in Section 3.2, the procedures described here compound with additional procedures to create a substantial amount of considerations for a worker to keep in mind during maintenance. Compounding all procedures technically applicable in combination with the task to be very mindful of position at all times and other consequences of working in a radiation environment results in the possibility for distraction and confusion in the presence of possibly contradicting tasks at various levels of importance.

Essentially, working in a radiation field introduces, amongst other things, the emphasis on performing a job quickly and expeditiously, which may not always align with the possible need of taking more time to adapt to changing situations, seek clarification, or run through an exhaustive checklist of everything that the worker should be mindful of at all times. The added complexity of performing work in a radiation environment and also in a work culture that seeks to minimize worker dose as well as minimize human errors should be considered when seeking to understand how certain seemingly careless errors may occur. This is another reason for the research conducted within the scope of the GG CBP project: consolidated procedures and tasks, as previously described, reduces the complexity of procedure tasks, which was identified by the INL and Duke Energy teams to be desirable features of a CBP.
3.3: Methods to Maintain ALARA

As defined by [3] the actual methods by which workers prevent excessively high doses are split into three primary relevant types summarized by the mantra “Time, Distance, Shielding.” The first two are the primary focus of this research.

3.3.1: Time

According to [3], time required to complete a task within the presence of radiation source can be reduced by the following practices:

1. Plan and discuss the task thoroughly prior to entering the area. Use only the number of workers actually required to do the job.
2. Have all necessary tools present before entering the area.
3. Use mock-ups and practice runs that duplicate the work conditions.
4. Take the most direct route to the job site if possible and practical.
5. Never loiter in an area controlled for radiological purposes.
6. Work efficiently and swiftly.
7. Do the job right the first time.
8. Perform as much work outside the area as possible. When practical, remove parts or components to areas with lower dose rates to perform work.
9. Do not exceed any stay times. In some cases, the Radiological Control Organization may limit the amount of time a worker may stay in an area due to various reasons. This is known as “stay time.” If you have been assigned a stay time, do not exceed this time.
Execution of these practices are immediately improved upon by the use of GG as a tool. Although the use of GG does not directly impact the act of planning or discussing the task thoroughly, the use of the Human Performance Tool (as discussed in Section 2.3.4) is facilitated by incorporating the tool (such as Place Keeping or Procedural Use and Adherence) into the procedure. Additionally, the potential implementation of a QR code reader would ensure the proper tools would be on hand prior to beginning the procedure. This can be done by marking the tools with a QR code and scanning them with the GG camera. GG is expected to quicken and improve the reliability of the correct completion of tasks performed under its use; therefore, it would be expected to contribute to Item (g) above, i.e. “Do the job right the first time”. Should GG prove to increase the reliability of the task performed, there could be an indirect benefit to minimizing exposure as a whole. The goal of using GG is also tied to keeping the worker more aware of Stay Times (Item (i) above) and thus a decrease in overstay may be observed in the overall implementation.

3.3.2: Distance
Exposure rate is related to source strength by an inverse square distance relationship. By increasing distance from a radiation source, dose rate decreases. Numerous recommendations are made for how to increase distance from radiation sources:

According the Department of Energy Radiation Worker Handbook: [9]

“Stay as far away from radiation sources as practical given the task assignment.” For point sources (such as valves and hot spots), the dose rate follows a principle called inverse square law. This law states that if you double the distance, the dose rate falls to \( \frac{1}{4} \)
of the original dose rate. If you triple the distance, the dose rate falls to $1/9$ of the original dose rate. More generally:

$$DR_A = DR_B \left[ \frac{\text{Dis} \tan \theta_A^2}{\text{Dis} \tan \theta_B^2} \right]$$

(Equation 1)

The following three practices are stated in [9] as key techniques to decreasing dose rate by increasing distance:

1. Be familiar with radiological conditions in the area.
2. During work delays, move to lower dose rate areas.
3. Use remote handling devices when possible.

Technique 1 gives a clear explanation for the advantage of maximizing distance; with an inverse square relationship between source strength and exposure, the actual sensitivity is high, making distance a large factor in minimizing dose. It is inferred that increasing familiarity with the radiological conditions in the area indirectly decreases dose rate by encouraging the worker to move to a lower dose area. Regardless of whether or not there is a direct benefit to being aware, awareness is nonetheless recognized as a primary practice for the workers. One of the proposed uses of GG is to increase the workers awareness of the radiation fields. As described in Chapter 5 and supported in Section 2.1, GG can be an effective tool for increasing worker awareness by displaying certain information on its screen in a conspicuous yet unobtrusive way.
Technique 2 has high implications for the behaviors of radiation workers in all work in areas potentially involving a detectable radiation field above background. It is very difficult to be intimately familiar with the radiation field strength in all areas in which work may be performed. This is generally achieved by use of survey maps, described shortly. Survey Maps are convey information as a printed medium. GG can display the same information on the screen.

Technique 3 refers to the use of robotics or extender mechanisms (reach-rods) to increase distance and is not believed to be immediately applicable to the GG use at this time.

3.3.3: Shielding

Shielding is important [9] but not primarily related to the potential benefits of using the heads up display proposed in this thesis, except for temporary shielding. A piece of temporary shielding may be installed in an area while a worker is performing a task in an area and the same worker may be involved in another task in a similar area after the temporary shielding has been removed. In the inverse, a worker may decide the best place to stand may be in one area when there is no temporary shielding installed but the same area may not be accurate memorized once temporary shielding is installed. Because ALARA emphasizes keeping dose as low as reasonably achievable, both of these situations would be unacceptable and workers are expected to keep an updated knowledge of recorded radiation field strengths. This can be challenging under changing situations. The implementation of a heads-up-display coupled with a CBP addresses the issue of passive administrative controls such as an outdated radiation survey. The primary
objective of the use of GG addresses the implementation of a CBP, which can be updated more readily than a PBP.

3.4: Available Tools for Maintaining ALARA

There are numerous tools currently in place designed to assist workers in efforts to avoid radiation exposure. The tools to be addressed in this research paper are the EPD, radiation worker permits (RWPs), and Survey Maps (Sections 3.4.1, 3.4.2, and 3.4.3 respectively).

3.4.1: Electronic Pocket Dosimeter (EPD)

There are currently information sources for radiation exposure which give more real-time feedback than the traditional Thermoluminescent Dosimeter (TLD). The (EPD) is a device which is typically worn on the chest region and displays cumulative dose as well as dose rate for a short period of time if a button is pressed. When entering a radiation area, an EPD is required to be worn by the worker and monitored periodically. As described in [3], “A personnel dosimeter is a device used to measure radiation dose. Different types of external dosimeter may be used. Radiological Control personnel determine which type(s) are needed [9]”. The use of an EPD has several inherent drawbacks.

1. Reading the EPD is not a method to predict dose.
2. The EPD is not always convenient to read.

Provisions are also included for what to do in the case of a lost EPD or if one reads off scale or is damaged. In such a case, the worker is required to place work in a safe condition, alert others, exit the area, and notify a radiological control personnel. Because
the EPD is only required to be checked every 15 minutes, there exists a possibility that the worker may not be aware of their dose rate for a fifteen minute period, assuming the worker is checking the EPD reading at regular required intervals. The implementation of a head-mounted display such as GG could reduce the likelihood of such an event transpiring or mitigate the consequences. The assumption is made here that the worker is more aware of a device mounted to the face than one that is clipped to the front of a shirt. By displaying the information on a screen which is in the user’s field of view, the worker can be made aware of radiation dose rates in real time rather than periodically checking the cumulative dose for the job, which is the status quo. Becoming more aware of the dose rate can prompt the worker to move to a position which may have a lower dose rate and result in a lower cumulative dose for the entire job. Additionally, because cumulative dose only actually needs to be checked every 15 minutes, the dose rate can be shown in real time with cumulative dose only being displayed at a preselected frequency, which could reduce the instances of the worker forgetting to check the EPD manually. The GG software can also be modified to display dose rate only when the sensor also detects a given degree of motion, suggesting movement. This is not to the detriment of maintenance procedure awareness, as the dose information can be overlaid with the procedure information. Additionally, by relaying the information to a device which tracks performance of a maintenance task, the data can be recorded and tabulated according to task. Later, this data can be reviewed to find dose rate spikes which may occur between survey points. This information can be used to understand other jobs that would be performed in the
area. Currently, survey map data does not contain shared information from prior tasks; therefore, knowledge of the dose rate profile from a task does not get documented for further exploration.

3.4.2: Radiation Worker Permit

All work done in radiation areas are conducted under the guidelines of an (RWP). RWPs are sources of a wide range of information including [3]:

1. Description of work
2. Work area radiological conditions
3. Dosimetry requirements
4. Pre-job briefing requirements
5. Required level of training for entry protective clothing/equipment requirements
6. Radiological Control coverage requirements and stay time controls, as applicable.
   This refers to having a representative from the Radiological Controls department present for the duration of the work.
7. Limiting radiological conditions that may void the permit.
8. Special dose or contamination reduction requirements.
9. Special personnel frisking requirements.
10. Technical work documents to be used, as applicable.
11. Date of issue and expiration.
12. Authorizing signatures and unique identifying designation or number.
There are multiple items listed on the RWP which may be difficult for the worker to entirely memorize and verify manually. As discussed previously in Section 2.2, the implementation of a CBP in this area makes it possible to greatly reduce the complexity of the task of memorizing the individual tasks and verifying the information contained therein is relevant to and in compliance with the given situation. By digitizing the RWP, it can be integrated into the CBP, reducing complexity as discussed in Chapter 2.

In addition to the information found on the RWP, the worker has the responsibility to [9] read and comply with the RWP requirements, acknowledge that they have read the RWP and intend to comply with it, and notify Radiological Controls of discrepancies in the RWP. These items can also be greatly consolidated by the use of CBP.

3.4.3: Dose Survey Maps

Dose survey maps are another key to maintaining ALARA. However, there is not a great deal of specific information found in the available sources which explicitly discuss their periodicity of update or standard practices for reading or creating them. Therefore, they are not discussed here in great detail. They are, however, mentioned extensively in [9] to be a primary source for obtaining information regarding background radiation. This information can be updated and shared via wireless communication and updated in the CBP via wearable heads-up-display.

3.5: Nuclear Power Plant Maintenance Introduction

Traditionally, maintenance at nuclear power plants has been performed by following printed versions of maintenance procedures. The medium on which the procedure is
printed does not give any feedback to the worker and successful completion relies on the worker exercising judgement and knowledge of plant conditions before initiation of the maintenance, as described in Chapter 2. This operation typically is successful at nuclear power plants due to the rigorous training program, planning of the task, and oversight by senior members of energy utility. However, the process is very dependent on every member involved paying close attention to the task and not making any procedural errors during the task. It is a missed opportunity, therefore, that the procedure that guides the operation to safe completion not actually be able to enforce its proper execution in real-time. It is the stance of the EPRI Nuclear Maintenance Applications Center (NMAC) that “Maintenance practices must be continuously reviewed and updated based on industry operating experience and emerging issues [10].”) Because the NMAC decrees that maintenance practices should be continuously improved, it is contrary to this stance that maintenance practices not incorporate CBPs if given a practical medium on which to implement them. It is again mentioned that the concept of CBPs were originally considered for nuclear utility applications over 30 years ago, as discussed in Chapter 2. Should a procedure along with all of its implicit logic checks be encoded into a computer program and the program be executed in real time with the procedure, warnings and other information could be conveyed to the user in time for mistakes to be corrected or to prevent the errors from being compounded by subsequent missteps. The information could be relayed to the user by showing a warning message on the screen where the procedure typically is. This feature is made possible with the current GG technology commercially available at this time.
In addition to the procedure providing logic checks on the information entered, other pertinent information could be relayed to the user. If a piece of hardware was outfitted with sensors that could determine what components are in the field of vision being worked on, the program could verify that this is the proper component referred to in the procedure. This could prevent work from being done on a component which is not cleared for maintenance but could be mistaken for another component by mistakenly misreading the label plate. This type of error can happen in cases where there are multiple similar components near one another which look the same (like in a cabinet or switchboard) or in cases with multiple identical system trains. While a person can easily confuse one component for another and at some point perform a task on the device which should not be manipulated, a device such as GG can use a barcode reader to recognize components should they be labeled with a barcode. In such a case, the program would alert the user that the wrong component is about to be worked on. The GG technology commercially available at this time is fully capable of performing such identification and logic checks. The remainder of this chapter will discuss the extent to which additional procedures are required to be utilized for situation-specific work as well as highlight some of the implications GG may have in regards to satisfying objectives outlines by EPRI and INPO.

3.5.1: Scope of Peripheral Safety-Related Procedures

Maintenance work at nuclear power plants can be complicated. The DOE guide to good worker training practices [11] implements guidelines for the proper training to be performed in the presence of numerous maintenance complexities such as:
1. The Lock and Tag program: This refers to the sequence of events necessary to ensure a system is isolated and remains isolated from a worker during maintenance or temporary condition of operation.

2. Industrial safety hazards

3. Chemicals, gases, and solvents

4. Electrical safety

5. Working from heights

6. Working in confined spaces

7. Personnel protective equipment

All of these categories have the implication of further details which have their own procedures and compounded layers of complexity. Not only do the workers need to be aware of the additional hazards which may apply for a given situation, but the worker also needs to be aware of which procedures may apply and be aware of whether or not their qualifications for the individual category are verified to be updated. Maintenance may be performed in an area which was technically defined as “Working from Heights” by a changing situation, such as the removal of scaffolding in the area, without the workers knowledge. The worker would then need be procedurally required to verify their training is up to date. This is a manual procedure which may go unnoticed; however, if the worker were to implement a CBP implemented by a wearable device, the opportunity for human error is reduced in this situation.

Performing maintenance improperly can bring down protective systems and adversely influence the overall system at nuclear power plants. For this reason, the DOE has
implemented the Guide to Good Practices for Training and Qualification of Maintenance Personnel [11]. This guide calls out the need for improving maintenance in nuclear power plants: “This need was based on the increasing emphasis on properly conducting maintenance activities in the nuclear industry” [11]. The implications of performing maintenance at nuclear power plants are inherently significant as doing so challenges the personal safety of the personnel performing maintenance as well as possibly challenge plant safety systems and threaten the economic stability of the nuclear utility due to the lost generation costs should the plant be inadvertently shutdown. It is critical, therefore, that maintenance conducted at nuclear power plants not endanger the worker or challenge plant safety system. As described in Chapter 4 and Chapter 2, GG has the capabilities to improve performance by reducing human decision consequences as well as prevent possible errors by adapting the procedure to changing conditions, making the procedure steps more applicable and less subject to being dismissed as “Not Applicable.” Additionally, because there are connectivity options with GG, plant conditions can be relayed to the worker in real time should connectivity means be implemented at the power plant facilities. Connectivity is a subject to which EPRI calls specific attention.

3.5.2: Significant Findings from EPRI and Further Considerations to INPO

The EPRI NMAC has both long term and short term improvement initiatives. Nuclear maintenance falls into the short term improvements category. According to EPRI “maintenance practices must be continuously reviewed and updated based on industry operating experience and emerging issues. The NMAC conducts research to identify maintenance advances with the potential to produce substantial plant performance
improvements.” [10]. This statement suggests that the approach described as a part of this research may be of interest to utilities, as it is directly applicable to plant process improvements. Of particular interest is the statement EPRI has made regarding real-time information availability: “Bringing essential information to the point of decision-making can drive safe and reliable plant and fleet performance. Access to equipment information and personnel knowledgeable in operations and maintenance practices can provide useful perspective and input [10].” This statement emphasizes the benefit of equipping maintenance workers with real-time information updates which to improve performance. Improving reliability is a key goal of EPRI which can be performed with improved availability of information. Therefore, as suggested by EPRI, should a system be found which incorporates connectivity and can implement it into the maintenance execution, performance and reliability can be improved. As described in Chapter 4, GG has connectivity functionalities which could be implemented should the power plants facilitate such communication. This is a key point of focus in this research. Better communication can be useful in the performance of maintenance.

EPRI is not the only authority within nuclear maintenance research. INPO is an organization which exists to share information among nuclear power plants and independently monitor and evaluate the conditions of nuclear utilities in order for the industry to exercise a degree of self-regulation at standards which are above and beyond the federal requirements. For this purpose, INPO conducts regular evaluations to assess the conditions of equipment and human performance which can be further benefited by increased monitoring via remote monitoring equipment. This can be accomplished by
implementing the GG equipment because it is equipped with a camera and could record the maintenance activity. Recording maintenance activities does not only serve the goals of INPO. Recording maintenance activities directly at the source has the implication of having video evidence for convenient use should mistakes be made and data be needed by the plant problem solving teams.

3.5.3: Additional Situation-Specific Maintenance Complexities

The maintenance performed at nuclear power plants is inherently complex and requires a great degree of attention and procedural compliance. Ordinary maintenance tasks can be compounded in complexity when other factors are introduced such as: Foreign Material Exclusion precautions (Section 3.4.2.1), Electrical Safety Precautions (Section 3.4.2.2), and Radiological Controls (Section 3.4.2.3). In considering these other equally important aspects that heavily influence nuclear power plant maintenance, the opportunities for consolidated and simplified procedures becomes all the more clear. These topics are only some of the examples of maintenance complexities and are briefly described in the rest of this section.

3.5.3.1: Foreign Material Exclusion

According to the EPRI, [12] “The entry of foreign material (FM) into primary or secondary plant systems, equipment, and components can cause equipment degradation or inoperability, lost generation, and it can also increase operations and maintenance (O&M) costs and adversely impact personnel safety.” To combat the detrimental effects of FM into vital plant systems, EPRI has conducted research and published a 190 page
report detailing how to design and implement an FME (Foreign Material Exclusion) program (specifically, at a fossil plant in the case of the abstract quotation above) which adds to the complexity of performing maintenance. The FME program primarily takes the form of extra steps taken before and after the maintenance is performed in order to ensure the FM is not introduced into the system and then verify it did not get introduced [13]. The additional complexities presented by the addition of FM controls can increase human error rate due to the higher complexity of the task and associated mental burden, as described in Chapter 2. The implementation of a wearable head mounted device such as GG does not add to the complexity of the FM protocol because it takes the same place as safety glasses and is tethered to the worker body just as in the current case of safety glasses and lanyard. GG versions have been released which allow for the addition of specialty lenses, typically for visual correction purposes, which can be safety rated.

3.5.3.2: Energized Equipment

The dangers associated with working on equipment which may be electrically energized adds another layer of complexity and administrative controls. Because the dangers of working on high energy systems is apparent, the DOE has implemented far reaching controls which govern the maintenance practices of any system normally energized to greater than 50 Volts [14]. There are numerous consequences of the administrative controls placed over work done on electrical equipment (such as the need for CPR qualification of electrical safety workers.) Adding to the complexity of establishing proper electrical safety procedures, there are numerous standards organizations which have claim to electrical safety work [14] including: DOE order 10 CFR 851, Institute of
Electrical and Electronics Engineers, International Society of Automation, National Electrical Manufacturers Association, American National Standards Institute, American Society of Testing and Materials, National Fire Protection Association, etc., all of which the DOE electrical safety handbook forces compliance and are subject at nuclear power plants. Although the worker’s task is less exhaustive in scope than the burdens upon the administration, the worker’s task still becomes considerably more complex when electrical safety standards are involved. The worker needs to take several steps to eliminate the dangers of electrical shock [14]. The worker must: inspect the work area for unaccounted for electrical hazards, use appropriate equipment to test to make sure the equipment is deenergized, and wear appropriate Personal Protective Equipment. Each of these steps has multiple implications: personal equipment must be certified to be in proper working order as well as meet the level of controls for the specific task; also, the tools used to determine the equipment is energized must be certified to be in working order and used appropriately. Each of these things adds additional steps to the procedure (there are independent procedures for all of these tasks) and the opportunity for error is compounded. Personal qualifications also must be checked to be certain that the worker’s certifications for every related task has been completed and is updated. As mentioned previously, a worker may be certified to perform every step of the maintenance but may have forgotten to check for an updated Cardiopulmonary Resuscitation (CPR) certification. The list is exhaustive. If a maintenance task is detailed on a CBP, verification of all worker credentials and equipment verification can be performed automatically without the distraction to the worker or the opportunity for introducing
human error into the validation steps. These steps are currently performed manually.

There exists an opportunity for human error in both the manual checking of valid credentials as well as in deciding which special credentials are required for a given task.

3.5.3.3: Radiological Controls

Radiological Controls implications are exhaustive and have been discussed in detail previously in Section 3.2.
Chapter 4: Proposed Method

While the focus of this research is regarding the implementation of a heads up display in general as a medium in which to use a CBP, the specific device chosen for testing purposes was the wearable device designed by Google X, GG. This product was made available for developers in early 2013, made available for the public in early 2014, and subsequently dropped from production in early 2015. Although the product received criticism, the product has been applied for commercial purposes by such industries as medicine [4]. The viability of GG in commercial industries, specifically in HPIs as describes in Chapter 2, suggests it may be used in the nuclear industry, which has been identified by some to need updated CBP, as suggested in Chapter 2.

This chapter will describe the hardware (Section 4.1) and firmware (Section 4.2) associated with GG before describing the procedure and the features adapted into a CBP (Section 4.3).

4.1: Google Glass Hardware

The GG, as seen in Fig. 3 [4], has a number of sensors and transducers including: accelerometer, gyroscope, camera, microphone, ambient light sensor, and magnetometer; GG also has a bone conduction transducer for sound and a prism projector display in front of the right eye. An in-ear speaker has also been made available with the device
which is to be plugged into the device’s mini-USB port. The device has Wi-Fi and Bluetooth Connectivity. Interaction for normal operation can be performed by the touchpad on the side of the device or via voice commands. The Glass touchpad allows for detection of swipes made in the up, down, forward, and backwards direction as well as rapid successions of swipes and multi-fingered swipes. With these sensors and actuators, a number of parameters can be derived and a wide range of applications have been developed.
4.2: Google Glass Firmware and Graphical User Interface

GG programs can be created with a variety of software including Google’s own Glass Development Kit and newer versions of Android Studio. The Timeline is the main hub for the user experience, as seen in Figure 4. It provides a way to present live cards and
static cards, voice commands, and a launching platform for Glass applications. It is organized with the Home screen at the center with past (a means to present static cards) to the right and present/future to the left of the Home screen. Live cards are a means to alert the user to information they may be periodically interested in while performing other tasks, “Live cards are great for when users are actively engaged in a task, but want to periodically check GG for supplemental information. For example, checking their time on a run every few minutes or controlling a music player when they want to skip or pause a song. [4]” Live cards do not remain active in the timeline but to exist there for as long as they are used. Much like a navigation application on a cell phone that is periodically consulted, these kinds of cards are used as an activity which is periodically referenced. Live Cards also have access to sensor data and can be used to create animations. Static Cards, on the other hand, display information such as text and images. Static cards can be configured to display new or old information on a recurring basis. Such tiles can include non-interactive postings such as: Best business practices, safety message of the day, 2 min drills, etc. More complicated activities can be built in Immersions, which run outside of the Timeline. An Immersion in the basis in which interactive programs must be based, such as the one used for this research.
4.3: Google Glass Program Purpose Explanation

Combined with the hardware, GG software has the fundamental building blocks available to create a program which can be used by nuclear power plant workers with the intent to improve performance. To this extend, a program was developed which implemented a CBP to be executed via GG. The program emulates a procedure wherein a maintenance technician performs all checks necessary to perform maintenance on a pump and subsequently performs the maintenance and is summarized by the logic flow diagram in Fig. 5. The program shows one step at a time (as each step should be performed as an independent action) and the operator swipes the pad to move to the next step. Some steps require certain variables to be true in order for the logic to be satisfied and the procedure continued. In these cases, the tile screen prompts the user to swipe in a certain direction to indicate a certain status, as interpreted by the trained operator. Because the program implements logic steps prompted by operator input, certain portions of the procedure are omitted which are not applicable rather than relying on the maintenance worker to decide which steps may be marked as “N/A.” This avoids an identified common source for...
operator error as referenced in Chapter 3. The setup also only allows users to view one
step at a time, which eliminates the possibility for a worker to accidentally read a step out
of place and perform that action out of sequence, inadvertently violating the very
procedure said worker was following. The function of this was also evaluated in the test,
as examined in Chapter 5.

4.4: Procedure Adapted for Test and Implemented Features
The procedure adapted into a CBP is intended for maintenance on a pump at a nuclear
power plant. The details of the procedure have been simplified to anonymize the plant
from which it came. References and components mentioned in the procedure are
replacement names for those listed in the actual procedure. The task numbers that appear
multiple times have been split into several cards as permitted by the task. For example,
the procedure has three sub-tasks to the second task in the procedure (2a, 2b, and 2c)
which have been consolidated into one step (Task 2a of Fig. 6) on the GG program in the
interest of grouping similar steps (precautions do not need to be performed in a specific
order). Meanwhile, Task 2b in Fig. 6 was added as additional precautionary information
specific to the GG procedure. The purpose of Task 2b in Fig. 9 is to show the worker a
picture of the component to be worked on. In the program, the decision blocks to follow
an alternative procedure path create a subsequent set of slides which are added to the card
lineup. It also changes the options allowed in future decision blocks so as to not allow the
operator to decide to remove pressure-retaining parts if the decision has already been
made to replace the pump in Task (6). The procedure begins below.
1. *Conduct a Pre-job Brief.* The Pre-job Brief is one of the human performance tools routinely incorporated into procedures in nuclear power plant maintenance as discussed in Section 2.3.4.

2. *Precautions/Notes.* This step has been entirely incorporated into Task 2a in Fig. 5. Task 2b is a picture showing an example of the pump on which to perform the maintenance.
   a. *Follow Heavy Load Precautions.* Components above a certain weight limit are required to be handled under more restrictive conditions to reduce the possibility of personal injury.
   b. *Follow ASME parts specification.* ASME has specific criteria for certain components being implemented in nuclear power plants.
   c. *Removal of pressure boundaries warrants inspection.* This is a precaution brought up in the procedure at this point.

3. *Prefabrication (Contingency).* In the interest of saving time at the worksite and possibly reducing exposure to radiation, it may be desirable to complete portions of the maintenance in a more advantageous location and then presage a partially assembled component in the vicinity of the worksite.
   a. Assembly of rotating assembly may be performed.
   b. Prestage assembly at job site.

4. *Erect scaffolding.*
5. *Issue Clearance.* “Clearance” refers to being given permission to start the following subsequent tasks, which are more invasive to the system. This is done through the tag out system (hanging danger and caution tags).

![GG Logic Flow Diagram Tasks 1 Through 5](image)

The next task (Task 6) of Fig. 6 asks if it is desired to replace the pump. Should replacement of the pump be necessary, this procedurally prohibits the operator from replacing pressure retaining parts later in the procedure (in Task 11). In the program, this is administered by asking the user if it is desired to replace the pump. If the user selects that the replacement is necessary, the steps are made available to perform this action. Should the user swipe forward, the subcategories of Task 6 are skipped and Task 7 is brought up next in the procedure. Should the worker decide to replace the pump, the program will loop back to the original question after completing Task 6(g). In this
situation, the program will not advance forward if the user again makes the choice to replace the pump, as it has already been replaced.

6. **Replace Pump (Contingency).** The details of the pump replacement procedure are skipped by the program if replacement is not necessary.
   
a. *Disconnect pump from motor*
   
b. *Disconnect suction and discharge piping*
   
c. *Drain oil*
   
d. *Remove pump from base fasteners (Warning: heavy load).* This step comes with an additional reminder to follow the heavy load precautions referenced previously in step 2a.
   
e. *Transport pump IAW equipment removal scheme.*
   
f. *Lift pump from baseplate.*
   
g. *Transport pump IAW equipment removal scheme.*
   
h. *Install new pump.*
   
i. *Make up suction and discharge flanges. Torque fasteners and enter data.*
   
j. *Clean and install oiler piping.*
   
k. *Torque motor to baseplate fasteners to torque value specified.*
   
l. *Sign Off.*

7. **Disassemble Pump. Uncouple and disable the installed Unit 1.**
   
a. *Clean lower casing half internals. Note: Soft centers with pullers are necessary to prevent damage to shaft when removing bearings.*
   
b. *Remove thrust bearing retaining Ring 1.*
c. **Remove Bearing from pump shaft with use of Tool 1.**

d. **Perform sanity check of replacement flingers and lip seals to make sure they are correct, and discard the existing flingers and lips seals.**

e. **Clean/inspect inboard and outboard bearing brackets and store for Re-Use.**

f. **Sign**

8. **Clean and inspect assembly**

9. **Based on the current work status a formal decision can now be made as far as the need of ASME replacement parts. A repair replacement plan must be instituted when new ASME parts are to be installed. The plan must be completed prior to installation of new ASME materials and shall be included in the order.**

10. **ASME replacement parts verification.**

   a. **Document replacement of any parts. Document replacement of any pressure containing parts.**

   b. **Record serial number of part being rebuilt.**

   c. **Sign.**

   d. **Document replacement of any replacement parts. Document replacement of any pressure containing parts.**

   e. **Verify serial number matches expected.**
The next task in the procedure relates to the replacement of pressure-retaining parts. If the pump was replaced previously in Task 6, the user is unable to access the parts of this procedure which would instruct on the removal of pressure-retaining parts. If the pump was not replaced, the user has access and if the operator taps the GG pad in the next step, the user will be given such instruction. Otherwise, the user is taken directly to Task 12.

11. Reassemble Pump. *If pump has already been replaced, it is not within the scope to replace pressure-retaining parts. Obtain permission prior to replacing such parts if scope of work changes after initiation of procedure. If it is not desired to replace*
pressure-retaining parts, proceed to Task 12. If it is desired to replace pressure retaining parts:

a. At a minimum, replace both bearing, both shaft seals, both mechanical seals, bearing lops seals, and casing gasket.

b. Record pressure boundary replacement parts.

c. Sign.

12. Housekeeping.

a. Inspection completed and work areas returned to standards.

b. Sign.

13. Remove clearance. This refers to removing any associated Tag-outs.

14. Test 1

a. Verify pump operates properly during performance of first operability test.

b. Collect pump performance data.

c. Verify no process leakage.

d. Verify no leakage from casing and mechanical joints.


17. Test 4. Obtain vibration data.

18. Remove Scaffolding.


a. Inspection completed and work areas returned to standards.

b. Sign.
The user is made aware of the prompts within the program through displaying the text on the screen. Three example cases are shown in Fig. 8, Fig. 9, and Fig. 10. These figures are adapted from the screen shown on the GG program. The actual display appears to the user as a black background with white text. The figures have been manually adapted for display in this thesis and appendix. All other display screens and the program code are included in the appendix. Figure 8 shows a simple text screen which instruct the worker to perform a certain action, which coincides with the text in the procedure. Figure 8 specifically refers to Task (2) listed in the procedure section and Task 2(a) in the Logic Flow Diagram of Fig. 5.
Precautions/Notes
- Follow Heavy Load Precautions
- Follow ASME parts specifications
- Removal of Pressure boundaries
Warrants inspection

Figure 8: Visualization of Screen Task (2a)

Figure 9 shows Task 2(b) in the Logic Flow Diagram of Fig. 5. This was added to the initial procedure as a subsequent notification to Step (2). It shows a picture of what would be the pump to be worked on in the procedure. It is added with the intent to make the operator more aware of the equipment on which to be worked and is added in direct response to Item (e) on the list of things a CBP should include, listed in Section 2.2.
Figure 9 shows the method by which the GG program gathers information for making decisions. To prevent the operator from being able to read steps out of order, the GG program shows a slide with a question on it. The user can answer the question by swiping forward or tapping. By using this method, the user does not make inferences about what steps in the procedure are done later in the procedure. Unnecessary steps are not shown to the user. The user is only made aware of one step at a time and incorporates Item (c) on the list of features listed in Section 2.2 by doing so.
In features demonstrated above, there was also a function generated which allows the user to see a visual representation of dose rate. This feature shows a screen which shows a bar on the bottom of the screen, indicative of the fraction of total allowed dose the operator is currently receiving. This was implemented for display purposes only and does not incorporate external connectivity. The purpose was to give the user a visual representation of dose rate which is visible on the GG screen rather than on an EPD. Future work will include applying external connectivity to the GG to allow an interface between an EPD and the GG. What is seen by the user while running the program is shown below in Fig. 11.
Measuring Radiation Level

Figure 11: Dose Rate Meter on GG
In the test described in Section 4.3, the procedure was followed through to completion on a mock-up piece of equipment. Of the features identified by the original INL and Duke Energy team in Section 2.2 to be desirable, the program specifically addresses all except for Item (d): “CBPs should employ some method of automatic Correct Component Verification, possibly though the use of barcode recognition” and Item (f), implementation of a video-enacted response. The implementation of the barcode reader can be implemented in future revisions of the program and does not present a substantial barrier to success because there are numerous barcode reader programs available for GG. The feature was not implemented in the current version for timing considerations; however, there are numerous application program interfaces (APIs) which implement either QR code or Barcode readers which have been implemented in commercially available GG applications, which suggests it is technically feasible for implementation into a program used for the purpose of verifying proper equipment is interfaced with. Implementing an automatic reader of this nature would allow for automatic state recognition rather than asking the operator for input (a method which is subject to the same errors as current practices.) The activation of a video which demonstrates the proper operation of a piece of equipment could possibly be beneficial in the more convoluted procedures, but was not implemented for this task. By only showing certain portions of
the procedure at a time, the program performs the case sensitivity function. Because the program maintains a logic checklist of tasks performed and only allows the operator to follow the flowpath described in Fig. 5, the program allows for automatic place keeping. Both of these functions serve the purpose of discretizing the procedure and preventing the operator from performing steps out of sequence. Video additions were also fully capable [4] within the context of standard GG functions, but were not implemented into the tested GG procedure. Insertion of such a video is a matter of future work. Automatic place keeping is a key benefit of implementation of the program in present form. The advantage of this was validated, as predicted, because the wearer is only able to see certain instructions at any given time, eliminating the possibility of “getting lost in the procedure” and taking an action out of sequence. Pictures were inserted into the procedure as a means to assist the reader in understanding the initial conditions of the component in question. This feature was identified as one of the improvement points that a CBP could offer over a PBP. GG has the hardware and standard software to take pictures as well as display images for the convenience of the operator. This feature was successfully implemented into the procedure and the operator reported it the image to be more descriptive and beneficial than a written description. The radiation dose rate program feature enabled the worker to have a real-time readout of radiation dose rate on the GG screen. The worker reported that this was not obstructive but did offer an easy to read dose rate display without being distracting.
Chapter 6: Conclusion and Future Work

The purpose of the research and prototype was to demonstrate the practicality of implementing GG as a CBP. For that reason, the functionality of certain features within the context of the identified CBP desirable features were not implemented in this prototype if their benefit was either indisputable or already proven to be functional in other programs. The Barcode Reader would significantly decrease the human involvement (and conceivably reduce opportunity for human error) as well as add a higher degree of automation to the GG program. Video insertion would also satisfy another desired trait of a CBP.
References


Appendix A: All GG Displays
Prejob Brief
Introduction

Precautions/Notes
- Follow Heavy Load Precautions
- Follow ASME parts specifications
- Removal of Pressure boundaries
Warrants inspection

Prefabrication
- Assembly of rotating assembly may be performed [IAW Reference 5]
- Prestage assembly at job site
Erect Scaffolding

Issue Clearance

Replace Pump?
Tap for YES, Slide forward for NO

Replace Pump Necessary
Replace Pump:
- Disconnect pump from motor
- Disconnect suction and discharge piping
- Drain Oil

Replace Pump Cont.:
- Remove pump from base fasteners
  (WARNING: Heavy LOAD)
- Transport pump for removal

Replace Pump Cont.:
- Lift pump from baseplate
- Transport pump IAW equipment removal scheme
- Install new pump

Replace Pump Cont.:
- Make up suction and discharge flanges. Torque fasteners [IAW REFERENCE 1] and enter data.
Replace Pump Cont.:
-Clean and install Oiler Piping [IAW REFERENCE 2]

Replace Pump Cont.:
-Torque pump mounting fasteners [IAW REFERENCE 1] to torque value in REFERENCE 3 and enter data.

Replace Pump Cont.:
-Align pump to motor GMI-0037 (5.4.48 through 5.4.50)

Disassemble Pump
-Uncouple and disassemble the Installed unit [COMPONENT 1]
Disassemble Pump Cont:
- Clean lower casing half internals
- Note: soft centers with pullers are necessary to prevent damage to shaft when removing bearings.

Disassemble Pump Cont:
- Remove thrust bering retaining ring [ITEM NUMBER 1]

Disassemble Pump Cont:
- Remove Bearing [ITEM NUMBER 2 & 3] from pump shaft with use of bearing pullers [Tool 1]

Disassemble Pump Cont:
- Perform sanity check of replacement flingers and lip seals to make sure they are correctly, and discard the existing flingers and lips seals
Disassemble Pump Cont:
- Clean/inspect inboard and outboard Bearing brackets and store for Re-Use
- Sign Off

Inspect and Clean
- Clean and Inspect IAW Reference 6

Repair/Replacement Plan
- Based on the current work status a formal decision can now be made as far as the need of ASME replacement parts.

Repair Parts Required?
- If so, fill out RPP form
ASME Parts Verification
- Verify Pressure retaining parts are to be documented
- Record S/N of pump being rebuilt
- Sign off

ASME Parts Verification (Cont.)
- Document replacement of any parts
- Document replacement of any Pressure containing parts

ASME Parts Verification (cont.)
- Record SN of pump being rebuilt
- Verify pump S/N matches expected

Is it desired at this point to replace pressure retaining parts?

Tap for YES, Slide forward for NO
Replace Parts:
- At a minimum, replace both bearing, both shaft seals, both mechanical seals, bearing lips seals and casing Gasket.

Replace Parts (cont.):
- Record Pressure Boundary Replacement Parts
- Sign off

Housekeeping
- Housekeeping inspection complete and work areas returned to standards
- Sign off

Remove Clearance
Test 1
- Verify pump operates properly during Performance of Reference 7
- Collect Pump Performance Data

Test 1 (cont.)
- Verify no process leakage
- Verify no leakage from casing
  And mechanical joints

Test 2
- Test Supports operation in Performance of Reference 8

Test 3
- Measure and record running current IAW Reference 9
Test 4
- Obtain vibration data per Reference 10

Remove Scaffolding

Operational Acceptance of Housekeeping
Appendix B: All GG Code
package com.google.android.glass.sample.apidemo.card;
import android.app.Activity;
import android.content.Context;
import android.media.AudioManager;
import android.os.Bundle;
import android.view.View;
import android.view.WindowManager;
import android.widget.AdapterView;
import com.google.android.glass.app.Card;
import com.google.android.glass.media.Sounds;
import com.google.android.glass.sample.apidemo.R;
import com.google.android.glass.widget.CardBuilder;
import com.google.android.glass.widget.CardScrollView;
import java.util.ArrayList;
import java.util.List;
import java.util.Random;
/**
 * Creates a card scroll view with various examples of its API.
 *
 * Planning:
 * Each set of static cards will be deployed, then when a "yes or no" question is asked, new
 * cards will be deployed based on the answer to the question.
 *
 * Problems:
 * Each Prompt can only be answered once. What happens if they answer incorrectly?
 * Sub-Q: Is this production-ready software or just prototype?
 * Sub-A: For now, lets assume its just a prototype. Therefore, we will just gen. the new cards
 * and not delete any other cards, and every time the q is answered the new cards will be added.
 *
 * Card pos. cannot be assumed since cards will be adding and deleting dynamically
 */
public final class AdamProcedureCards extends Activity {

    private enum Action {
        GO_TO_BEGINNING, GO_TO_END, DELETE_THIS_CARD, NONE, ADD_SLIDES_1, ADD_SLIDES_2;
    }
}
private ArrayList<String> mTextSteps = new ArrayList<String>();
/**
 * Custom Card Adapter that handles WCards
 */
private final class WCardAdapter extends CardAdapter {
    private final List<Action> mActions;
    public WCardAdapter() {
        super(new ArrayList<CardBuilder>());
        mActions = new ArrayList<Action>();
    }
    public void insertCard(int position, CardBuilder card, Action action) {
        super.insertCard(position, card);
        mActions.add(position, action);
    }
    /* If no position is specified, insert at last index */
    public void insertCard(CardBuilder card, Action action) {
        int position = mActions.size();
        super.insertCard(position, card);
        mActions.add(position, action);
    }
    @Override
    public CardBuilder deleteCard(int position) {
        mActions.remove(position);
        return (CardBuilder) super.deleteCard(position);
    }
    public Action getAction(int position) {
        return mActions.get(position);
    }
}
private CardScrollView mCardScroller;
private WCardAdapter mAdapter;
@Override
protected void onCreate(Bundle bundle) {
    super.onCreate(bundle);
    mCardScroller = new CardScrollView(this);
    setupAdapter();
    setupClickListener();
    setContentView(mCardScroller);
    getWindow().addFlags(WindowManager.LayoutParams.FLAG_KEEP_SCREEN_ON);
}
/**
 * Sets up adapter.
 */
private void setupAdapter() {
    mAdapter = new WCardAdapter();
    CardBuilder step1 = new CardBuilder(this, CardBuilder.Layout.TEXT)
        .setText("Prejob Brief Introduction");
    mAdapter.insertCard(step1, Action.NONE);
    CardBuilder step2 = new CardBuilder(this, CardBuilder.Layout.TEXT)
        .setText("Precautions/Notes
- Follow Heavy Load Precautions
- Follow ASME parts specifications
" +
        "")
        .setText("Precautions/Notes
- Follow Heavy Load Precautions
- Follow ASME parts specifications
" +
        "")
        .setText("Precautions/Notes
- Follow Heavy Load Precautions
- Follow ASME parts specifications
" +
        "");
        }
"- Removal of Pressure boundaries warrants inspection
mAdapter.insertCard(step2, Action.NONE);
CardBuilder step2a = new CardBuilder(this, CardBuilder.Layout.TEXT)
    .setText("Precautions/Notes")
    .addImage(R.drawable.pump);
mAdapter.insertCard(step2a, Action.NONE);
CardBuilder step3 = new CardBuilder(this, CardBuilder.Layout.TEXT)
    .setText("Prefabrication
- Assembly of rotating assembly may be performed [IAW Reference 5]
- Prestage assembly at job site")
mAdapter.insertCard(step3, Action.NONE);
CardBuilder step4 = new CardBuilder(this, CardBuilder.Layout.TEXT)
    .setText("Erect Scaffolding")
mAdapter.insertCard(step4, Action.NONE);
CardBuilder step5 = new CardBuilder(this, CardBuilder.Layout.TEXT)
    .setText("Issue Clearance")
mAdapter.insertCard(step5, Action.NONE);
CardBuilder step6 = new CardBuilder(this, CardBuilder.Layout.TEXT)
    .setText("Replace Pump?")
    .setFootnote("Tap for YES, Slide forward for NO")
mAdapter.insertCard(step6, Action.ADD_SLIDES_1);
/* Continue on with Slide 16 */
CardBuilder step16 = new CardBuilder(this, CardBuilder.Layout.TEXT)
    .setText("Disassemble Pump
- Uncouple and disassemble the installed unit [COMPONENT 1]")
mAdapter.insertCard(step16, Action.NONE);
CardBuilder step17 = new CardBuilder(this, CardBuilder.Layout.TEXT)
    .setText("Disassemble Pump Cont:
- Clean lower casing half internals
- Note: soft centers with pullers are necessary to prevent damage to shaft when removing bearings.")
mAdapter.insertCard(step17, Action.NONE);
CardBuilder step18 = new CardBuilder(this, CardBuilder.Layout.TEXT)
    .setText("Disassemble Pump Cont:
- Remove thrust bearing retaining ring [ITEM NUMBER 1]")
mAdapter.insertCard(step18, Action.NONE);
CardBuilder step18a = new CardBuilder(this, CardBuilder.Layout.TEXT)
    .setText("Disassemble Pump Cont:
- Remove Bearing [ITEM NUMBER 2 & 3] from pump shaft with use of bearing pullers [Tool 1]")
mAdapter.insertCard(step18a, Action.NONE);
CardBuilder step19 = new CardBuilder(this, CardBuilder.Layout.TEXT)
    .setText("Disassemble Pump Cont:
- Perform sanity check of replacement flingers and lip seals to make sure they are correctly, and discard the existing flingers and lips seals")
mAdapter.insertCard(step19, Action.NONE);
CardBuilder step20 = new CardBuilder(this, CardBuilder.Layout.TEXT)
    .setText("Disassemble Pump Cont:
- Clean/inspect inboard and outboard bearing brackets and store for Re-Use
- Sign Off")
mAdapter.insertCard(step20, Action.NONE);
CardBuilder step21 = new CardBuilder(this, CardBuilder.Layout.TEXT)
    .setText("Inspect and Clean")
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" - Clean and Inspect IAW Reference 6");
CardBuilder step21 = new CardBuilder(this, CardBuilder.Layout.TEXT)
   .setText(" - Based on the current work status a formal decision can now be made as far as the need of asme replacement parts.");
mAdapter.insertCard(step21, Action.NONE);
CardBuilder step22 = new CardBuilder(this, CardBuilder.Layout.TEXT)
   .setText(" - Repair/Replacement Plan
   
   - Based on the current work status a formal decision can now be made as far as the need of asme replacement parts.");
mAdapter.insertCard(step22, Action.NONE);
CardBuilder step23 = new CardBuilder(this, CardBuilder.Layout.TEXT)
   .setText(" - Repair Parts Required?
   
   - If so, fill out RPP form");
mAdapter.insertCard(step23, Action.NONE);
CardBuilder step24 = new CardBuilder(this, CardBuilder.Layout.TEXT)
   .setText(" - ASME Parts Verification
      
      - Verify Pressure retaining parts are to be documented
      - Record S/N of pump being rebuilt
      - Sign off");
mAdapter.insertCard(step24, Action.NONE);
CardBuilder step25 = new CardBuilder(this, CardBuilder.Layout.TEXT)
   .setText(" - ASME Parts Verification (cont.)
      
      - Document replacement of any parts
      - Document replacement of any pressure containing parts
");
mAdapter.insertCard(step25, Action.NONE);
CardBuilder step26 = new CardBuilder(this, CardBuilder.Layout.TEXT)
   .setText(" - ASME Parts Verification (cont.)
      
      - Record SN of pump being rebuilt
      - Verify pump S/N matches expected
");
mAdapter.insertCard(step26, Action.NONE);
CardBuilder step27 = new CardBuilder(this, CardBuilder.Layout.TEXT)
   .setText("Is it desired at this point to replace pressure retaining parts?")
   .setFootnote("Tap for YES, Slide forward for NO");
mAdapter.insertCard(step27, Action.ADD_SLIDES_2);
/* Continue on with Slide 30 */
CardBuilder step30 = new CardBuilder(this, CardBuilder.Layout.TEXT)
   .setText(" - Housekeeping inspection complete and work areas returned to standards
      - Sign off");
mAdapter.insertCard(step30, Action.NONE);
CardBuilder step31 = new CardBuilder(this, CardBuilder.Layout.TEXT)
   .setText("Remove Clearance");
mAdapter.insertCard(step31, Action.NONE);
CardBuilder step32 = new CardBuilder(this, CardBuilder.Layout.TEXT)
   .setText(" - Test 1
      
      - Verify pump operates properly during performance of Reference 7
      - Collect Pump Performance Data");
mAdapter.insertCard(step32, Action.NONE);
CardBuilder step33 = new CardBuilder(this, CardBuilder.Layout.TEXT)
   .setText(" - Test 1 (cont.)
      
      - Verify no process leakage
      - Verify no leakage from casing and mechanical joints");
mAdapter.insertCard(step33, Action.NONE);
CardBuilder step34 = new CardBuilder(this, CardBuilder.Layout.TEXT)
   .setText(" - Test 2
      

"- Test Supports operation in performance of Reference 8");
ListAdapter.insertCard(step34, Action.NONE);
CardBuilder step35 = new CardBuilder(this, CardBuilder.Layout.TEXT)
  .setText("Test 3
  - Measure and record running current IAW Reference 9");
ListAdapter.insertCard(step35, Action.NONE);
CardBuilder step36 = new CardBuilder(this, CardBuilder.Layout.TEXT)
  .setText("Test 4
  - Obtain vibration data per Reference 10.");
ListAdapter.insertCard(step36, Action.NONE);
CardBuilder step37 = new CardBuilder(this, CardBuilder.Layout.TEXT)
  .setText("Remove Scaffolding");
ListAdapter.insertCard(step37, Action.NONE);
CardBuilder step38 = new CardBuilder(this, CardBuilder.Layout.TEXT)
  .setText("Operational Acceptance of Housekeeping");
ListAdapter.insertCard(step38, Action.NONE);
// Setting adapter notifies the card scroller of new content.
ListAdapter.setAdapter(mAdapter);
}
/**
 * Sets up click listener.
 */
private void setupClickListener()
{

ListAdapter.setOnItemClickListener(new AdapterView.OnItemClickListener()
{
  @Override
  public void onItemClick(AdapterView<?> parent, View view, int position, long id)
  {
    AudioManager am = (AudioManager) getSystemService(Context.AUDIO_SERVICE);
    switch (ListAdapter.getAction(position))
    {
      case GO_TO_BEGINNING:
        am.playSoundEffect(Sounds.TAP);
        navigateToCard(0);
        break;
      case GO_TO_END:
        am.playSoundEffect(Sounds.TAP);
        navigateToCard(ListAdapter.getCount());
        break;
      case DELETE_THIS_CARD:
        am.playSoundEffect(Sounds.TAP);
        deleteCardWithAnimation(position);
        break;
      case ADD_SLIDES_1:
        CardBuilder step7 = new CardBuilder(ListAdapter.getContext(),
          CardBuilder.Layout.TEXT)
          .setText("Replace Pump Necessary");
        CardBuilder step8 = new CardBuilder(ListAdapter.getContext(),
          CardBuilder.Layout.TEXT)
          .setText("Replace Pump:
            - Disconnect pump from motor
            - Disconnect suction and discharge piping
            - Drain Oil
            ");
        CardBuilder step9 = new CardBuilder(ListAdapter.getContext(),
          CardBuilder.Layout.TEXT)
          // Setting adapter notifies the card scroller of new content.
         ListAdapter.setAdapter(ListAdapter);
    }
    } //**
    * Sets up click listener.
    */
  private void setupClickListener()
  {
    ListAdapter.setOnItemClickListener(new AdapterView.OnItemClickListener()
    {
      @Override
      public void onItemClick(AdapterView<?> parent, View view, int position, long id)
      {
        AudioManager am = (AudioManager) getSystemService(Context.AUDIO_SERVICE);
        switch (ListAdapter.getAction(position))
        {
          case GO_TO_BEGINNING:
            am.playSoundEffect(Sounds.TAP);
            navigateToCard(0);
            break;
          case GO_TO_END:
            am.playSoundEffect(Sounds.TAP);
            navigateToCard(ListAdapter.getCount());
            break;
          case DELETE_THIS_CARD:
            am.playSoundEffect(Sounds.TAP);
            deleteCardWithAnimation(position);
            break;
          case ADD_SLIDES_1:
            CardBuilder step7 = new CardBuilder(ListAdapter.getContext(),
              CardBuilder.Layout.TEXT)
              .setText("Replace Pump Necessary");
            CardBuilder step8 = new CardBuilder(ListAdapter.getContext(),
              CardBuilder.Layout.TEXT)
              .setText("Replace Pump:
                - Disconnect pump from motor
                - Disconnect suction and discharge piping
                - Drain Oil
                ");
            CardBuilder step9 = new CardBuilder(ListAdapter.getContext(),
              CardBuilder.Layout.TEXT)
Replace Pump Cont.:
- Remove pump from base fasteners (WARNING: HEAVY LOAD)
- Transport pump for removal

CardBuilder step10 = new CardBuilder(mCardScroller.getContext(), CardBuilder.Layout.TEXT)
    .setText("Replace Pump Cont.:
- Lift pump from baseplate
- Transport pump IAW equipment removal scheme
- Install new pump

CardBuilder step11 = new CardBuilder(mCardScroller.getContext(), CardBuilder.Layout.TEXT)
    .setText("Replace Pump Cont.:
- Make up suction and discharge flanges. Torque fasteners [IAW REFERENCE 1] and enter data.

CardBuilder step12 = new CardBuilder(mCardScroller.getContext(), CardBuilder.Layout.TEXT)
    .setText("Replace Pump Cont.:
- Clean and install Oiler Piping [IAW REFERENCE 2]

CardBuilder step13 = new CardBuilder(mCardScroller.getContext(), CardBuilder.Layout.TEXT)
    .setText("Replace Pump Cont.:
- Torque pump mounting fasteners [IAW Reference 1] to torque value in Reference 3 and enter data.

CardBuilder step14 = new CardBuilder(mCardScroller.getContext(), CardBuilder.Layout.TEXT)
    .setText("Replace Pump Cont.:
- Align pump to motor GMI-0037 (5.4.48 through 5.4.50)

CardBuilder step15 = new CardBuilder(mCardScroller.getContext(), CardBuilder.Layout.TEXT)
    .setText("Replace Pump Cont.:
- Torque motor to baseplate fasteners IAW Reference 1 to torque value in REFERENCE 3. IAW REFERENCE 4
- Sign Off")

insertNewCardWithoutAnimation(6, step15, Action.NONE);
insertNewCardWithoutAnimation(6, step14, Action.NONE);
insertNewCardWithoutAnimation(6, step13, Action.NONE);
insertNewCardWithoutAnimation(6, step12, Action.NONE);
insertNewCardWithoutAnimation(6, step11, Action.NONE);
insertNewCardWithoutAnimation(6, step10, Action.NONE);
insertNewCardWithoutAnimation(6, step9, Action.NONE);
insertNewCardWithoutAnimation(6, step8, Action.NONE);
insertNewCardWithAnimation(6, step7, Action.NONE);
break;

Replace Parts:
- At a minimum, replace both bearing, both shaft seals, both mechanical seals, bearing lips seals and casing Gasket.

CardBuilder step28 = new CardBuilder(mCardScroller.getContext(), CardBuilder.Layout.TEXT)
    .setText("Replace Parts (cont.):
- Record Pressure Boundary Replacement Parts")

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"- Sign off";
insertNewCardWithoutAnimation(mCardScroller.getSelectedItemPosition() + 1, step29, Action.NONE);
insertNewCardWithAnimation(mCardScroller.getSelectedItemPosition() + 1, step28, Action.NONE);
default:
am.playSoundEffect(Sounds.DISALLOWED);
break;
}
});
/**
* Deletes a card at the given position using proper insertion animation
* (the card scroller will animate the old card from view).
*/
private CardBuilder deleteCardWithAnimation(int position) {
    // Delete card in the adapter, but don't call notifyDataSetChanged() yet.
    // Instead, request proper animation for deleted card from card scroller,
    // which will notify the adapter at the right time during the animation.
    CardBuilder deletedCard = mAdapter.deleteCard(position);
    mCardScroller.animate(position, CardScrollView.Animation.DELETION);
    return deletedCard;
}
/** Navigates to card at given position. */
private void navigateToCard(int position) {
    mCardScroller.animate(position, CardScrollView.Animation.NAVIGATION);
}
/**
* Inserts a new card at the given position using proper insertion animation
* (the card scroller will animate to the new card).
*/
private void insertNewCardWithAnimation(int position, CardBuilder card, Action action) {
    // Insert new card in the adapter, but don't call notifyDataSetChanged() yet.
    // Instead, request proper animation to inserted card from card scroller,
    // which will notify the adapter at the right time during the animation.
    mAdapter.insertCard(position, card);
    mCardScroller.animate(position, CardScrollView.Animation.INSERTION);
}
private void insertNewCardWithoutAnimation(int position, CardBuilder card, Action action) {
    // Insert new card in the adapter, but don't call notifyDataSetChanged() yet.
    // Instead, request proper animation to inserted card from card scroller,
    // which will notify the adapter at the right time during the animation.
    mAdapter.insertCard(position, card);
}
@Override
protected void onResume() {
    super.onResume();
    mCardScroller.activate();
}
@Override
protected void onPause() {
    mCardScroller.deactivate();
}
super.onPause();

*/

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 */

package com.google.android.glass.sample.apidemo;
import com.google.android.glass.media.Sounds;
import com.google.android.glass.sample.apidemo.card.AdamProcedureCards;
import com.google.android.glass.sample.apidemo.card.CardAdapter;
import com.google.android.glass.sample.apidemo.card.CardBuilderActivity;
import com.google.android.glass.sample.apidemo.card.CardScrollViewActivity;
import com.google.android.glass.sample.apidemo.card.EmbeddedCardLayoutActivity;
import com.google.android.glass.sample.apidemo.opengl.OpenGlService;
import com.google.android.glass.sample.apidemo.theming.TextAppearanceActivity;
import com.google.android.glass.sample.apidemo.touchpad.SelectGestureDemoActivity;
import com.google.android.glass.widget.CardBuilder;
import com.google.android.glass.widget.CardScrollAdapter;
import android.app.Activity;
import android.content.Context;
import android.content.Intent;
import android.media.AudioManager;
import android.os.Bundle;
import android.util.Log;
import android.view.View;
import android.widget.AdapterView;
import java.util.ArrayList;
import java.util.List;

/**
 * Creates a card scroll view with examples of different GDK APIs.
 *
 * <ol>
 * <li> Procedure 1
 * <li> Procedure 2
 * </ol>
 */

public class ApiDemoActivity extends Activity {
    private static final String TAG = ApiDemoActivity.class.getSimpleName();

    super.onPause();

    }
// Index of api demo cards.
// Visible for testing.
static final int PROCEDURE_1 = 0;
static final int PROCEDURE_2 = 1;
private CardScrollAdapter mAdapter;
private CardScrollView mCardScroller;
// Visible for testing.
CardScrollView getScroller() {
    return mCardScroller;
}
@Override
protected void onCreate(Bundle bundle) {
    super.onCreate(bundle);
    mAdapter = new CardAdapter(createCards(this));
    mCardScroller = new CardScrollView(this);
    mCardScroller.setAdapter(mAdapter);
    setContentView(mCardScroller);
    setCardScrollListener();
}

private List<CardBuilder> createCards(Context context) {
    ArrayList<CardBuilder> cards = new ArrayList<CardBuilder>();
    cards.add(PROCEDURE_1, new CardBuilder(context, CardBuilder.Layout.TEXT)
        .setText(R.string.procedure_1)
        .addImage(R.drawable.atom)
        .showStackIndicator(true));
    cards.add(PROCEDURE_2, new CardBuilder(context, CardBuilder.Layout.TEXT)
        .setText("View Rad. Meter")
        .addImage(R.drawable.stacks)
        .showStackIndicator(true));
    return cards;
}

@Override
protected void onResume() {
    super.onResume();
    mCardScroller.activate();
}

@Override
protected void onPause() {
    mCardScroller.deactivate();
    super.onPause();
}

private void setCardScrollListener() {
    mCardScroller.setOnItemClickListener(new AdapterView.OnItemClickListener() {
        @Override
        public void onItemClick(AdapterView<?> parent, View view, int position, long id) {
            Log.d(TAG, "Clicked view at position " + position + ", row-id " + id);  
            int soundEffect = Sounds.TAP;
        }
    });
}

/**
 * Create list of API demo cards.
 */
private List<CardBuilder> createCards(Context context) {
    ArrayList<CardBuilder> cards = new ArrayList<CardBuilder>();
    cards.add(PROCEDURE_1, new CardBuilder(context, CardBuilder.Layout.TEXT)
        .setText(R.string.procedure_1)
        .addImage(R.drawable.atom)
        .showStackIndicator(true));
    cards.add(PROCEDURE_2, new CardBuilder(context, CardBuilder.Layout.TEXT)
        .setText("View Rad. Meter")
        .addImage(R.drawable.stacks)
        .showStackIndicator(true));
    return cards;
}

@Override
protected void onResume() {
    super.onResume();
    mCardScroller.activate();
}

@Override
protected void onPause() {
    mCardScroller.deactivate();
    super.onPause();
}

/**
 * Different type of activities can be shown, when tapped on a card.
 */
private void setCardScrollListener() {
    mCardScroller.setOnItemClickListener(new AdapterView.OnItemClickListener() {
        @Override
        public void onItemClick(AdapterView<?> parent, View view, int position, long id) {
            Log.d(TAG, "Clicked view at position " + position + ", row-id " + id);  
            int soundEffect = Sounds.TAP;
        }
    });
}
switch (position) {
    case PROCEDURE_1:
        startActivity(new Intent(ApiDemoActivity.this, AdamProcedureCards.class));
        break;
    case PROCEDURE_2:
        //startActivity(new Intent(  
        //        ApiDemoActivity.this, EmbeddedCardLayoutActivity.class));
        startActivity(new Intent(ApiDemoActivity.this, SliderActivity.class));
        break;
    default:
        soundEffect = Sounds.ERROR;
        Log.d(TAG, "Don't show anything");
    }
    // Play sound.
    AudioManager am = (AudioManager) getSystemService(Context.AUDIO_SERVICE);
    am.playSoundEffect(soundEffect);
    }
    }
}/*
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 * limitations under the License.
 */

package com.google.android.glass.sample.apidemo.card;
import com.google.android.google.glass.widget.CardBuilder;
import com.google.android.glass.widget.CardScrollAdapter;
import android.view.View;
import android.view.ViewGroup;
import android.widget.AdapterView;
import java.util.List;

/**
 * Adapter class that handles list of cards.
 */
public class CardAdapter extends CardScrollAdapter {
    final List<CardBuilder> mCards;
    public CardAdapter(List<CardBuilder> cards) {
        mCards = cards;
    }
    @Override
    public int getCount() {
        return mCards.size();
    }
}
return mCards.size();
}
@Override
public Object getItem(int position) {
    return mCards.get(position);
}
@Override
public View getView(int position, View convertView, ViewGroup parent) {
    return mCards.get(position).getView(convertView, parent);
}
@Override
public int getViewTypeCount() {
    return CardBuilder.getViewTypeCount();
}
@Override
public int getItemViewType(int position){
    return mCards.get(position).getItemViewType();
}
public Object deleteCard(int position) {return mCards.remove(position);}
public void insertCard(int position, CardBuilder card){mCards.add(position, card);}
public void insertCard(CardBuilder card){mCards.add(card);}
@Override
public int getPosition(Object item) {
    for (int i = 0; i < mCards.size(); i++) {
        if (getItem(i).equals(item)) {
            return i;
        }
    }
    return AdapterView.INVALID_POSITION;
}

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-->
<trigger keyword="@string/voice_trigger"/>