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Nuclear Work Function Innovation Tool Set Development for Performance Improvement and Human Systems Integration

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Executive Summary

The nuclear energy industry in the United States is currently facing several major socioeconomic challenges to its continued existence. At present, nuclear energy in many markets is more expensive to produce than other forms of energy generation, largely due to its greater associated operations and maintenance (OM) costs. A major factor contributing to these costs is the significantly higher number of staff required to operate and maintain nuclear power plants than in other forms of energy generation. A second factor relates to the aging technology and related procedures still present in most nuclear power plants, a significant contributor to higher costs, staffing levels and associated workload.

In response, the industry is seeking to modernize many of its technical systems and procedures. Much of this work is focusing on control room design and operations. However, there are many potential opportunities for improvements in efficiency and performance of other plant functions as well, such as plant maintenance, managerial decision making, assurance activities and others. In the project described in this report, we worked with a nuclear utility partner to identify potential opportunities for modernization outside the control room.

The goal of the current research is to provide a scientifically valid and operationally useful conceptual structure within which to address the modernization and design challenges facing the industry. The concept of Integrated Operations for Nuclear (ION) is presented as one means of addressing this challenge. ION is a framework within which strategic and tactical approaches to nuclear power plant modernization are organized around the fundamental principle of integrating and jointly optimizing staffing, technology, and procedures in systems design, supported by a corresponding model of managerial governance. Based on similar, successful approaches in the North Sea oil and gas industry, ION is focused on the application of methods and tools proven to be useful in these and other settings to help guide nuclear energy modernization efforts.

This report also describes the application of a set of analytic and design tools derived from sociotechnical systems theory and previously applied in nuclear power plant control room and other complex system design settings. This theory holds that the performance of complex human-machine and human-computer systems, and their associated safety, is a function of interactions between human, organizational, and technical factors. It has led to the development and application of many tools for system design to address these issues, as summarized in a previous report (Dainoff et al., 2020). Building on a program of research at Idaho National Laboratory focused on development and application of these methods and tools, they were applied to the analysis and design of two separate modernization use cases within the utility partner's operations. The first, the Radiation Protection (RP) use case, was focused on identifying potential design approaches for improving efficiency and performance of maintenance-related RP tasks without loss of safety. The second, the Information Support (IS) use case focused on analysis and design of methods and tools to enhance efficiencies in managerial decision making and issue resolution, specifically regarding support of forcing function meetings such as management review meetings. While each case used different analytic and design tools to accomplish its objectives, they both shared a fundamental emphasis on user-centered design; an approach to systems design that emphasizes the essential requirement for user input at all stages of the system design and development process.

Each use case analysis and design effort resulted in the development of potential technical and associated procedural and governance designs to support modernization efforts. The RP use case resulted in the identification of three key areas of potential development, including increased use of wearable technologies, integration of robotic and drone systems, and more modernized methods of air sampling. After an analysis of available commercial-off-the-shelf systems considered to be potentially useful, a set of possible design approaches was presented to the utility partner. The IS use case resulted in the identification and development of a human-computer interface concept intended to support more efficient analysis and resolution of assurance gaps at management review meetings. This involved the conceptual design of the 'information object', a software architecture entity specialized for the automated gathering,

analysis, dissemination and tracking of data and information. It also involved the development of a corresponding, prototype information dashboard interface. Each of the two use cases resulted in candidate designs that are expected to have broader application outside their specific characteristics.

These results offer support for the ION concept in that they demonstrate that methods used in the successful design of other complex sociotechnical systems can also be successfully applied to support development of systems that enable safe and effective task performance by fewer individuals.

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ACRONYMS

AI	Artificial Intelligence
ALARA	As Low As Reasonably Achievable
CAP	corrective action program
CNO	Chief of Nuclear Operations
COTS	Commercial Off-the-Shelf
CSA	Control Structure Analysis
CTA	Cognitive Task Analysis
CWA	Cognitive Work Analysis
EPRI	Electric Power Research Institute
HA	human action
HED	Human Engineering Discrepancy
HFE	Human Factors Engineering
HSI	Human-System Interface
HTA	Hierarchical Task Analysis
INL	Idaho National Laboratory
INPO	Institute of Nuclear Power Operations
IO	Integrated Operations
ION	Integrated Operations for Nuclear
IP	Innovation Portal
IS	Information Support
ISV	Integrated System Validation
LWRS	Light Water Reactor Sustainability
ML	Machine Learning
MRM	management review meeting
NGT	nominal group technique
NPP	nuclear power plant
NPPI	Nuclear Plant Performance Indicator
NRC	US Nuclear Regulatory Commission
NUREG	US Nuclear Regulatory Commission Regulation
PIC	Plant Information Center
OER	Operating Experience Review
OM	Operations and Maintenance
OSHA	Occupational Safety and Health Administration
PTPG	Process, Technology, People and Governance
RP	Radiation Protection
RWP	Radiation Work Permit
SCS	safety control structure
SME	Subject Matter Expert
STAMP	Systems-Theoretic Accident Modeling and Processes

STPA	System Theoretic Process Analysis
TA	task analysis
US	use case
UCA	unsafe control action
UCD	User-Centered Design
UO	undesired outcomes
V&V	verification and validation
WDA	Work Domain Analysis
WRO	Work Reduction Opportunity

1.   INTRODUCTION

The U.S. nuclear power industry requires substantial business innovation to remain competitive in the electric market. Its operating costs are high compared to other energy suppliers mainly due to its reliance on analog systems rather than modern digital technologies. Innovative technologies can provide the means for transforming the nuclear power business operating model into one that is technically sound and cost competitive, extending the life of these clean-energy assets for decades to come. This is the fundamental objective of an initiative known as Integrated Operations for Nuclear (ION) under the Department of Energy's Light Water Sustainability Program.

This report describes recent research that addresses a critical dimension of nuclear power business innovation, i.e., that of ensuring the enabling technologies and process improvements are well-designed from a human factors standpoint. There are cases across industry where the human-computer interface of a promising technology was inadequate, resulting in deployment failure because it was too hard to use and resulted in excessive work burden. In other cases, inadequate attention was given to the procedural and personnel selection and training implications of new technologies and processes, resulting in a lack of operational coordination. In many cases, these innovations were abandoned because they did not deliver the expected benefits.

1.1   The Challenge of Large-Scale Innovation

Transformation implies a step-change in the business model of an enterprise as opposed to the incremental improvement of the current one. It is enabled by paradigm-shifting innovations, creating new and more efficient ways of working that achieve the requisite business outcomes. Many times, these innovations are synergistic and therefore the benefits are dependent on changes across related functional areas. This drives an enterprise to undertake a number of transformational improvements in parallel. While they can be sequenced in a manageable order to control the rate of change, the overall transformation must be achieved within a reasonable timeframe if it is to have an impact on the pressing competitive situation.

Well-designed technical and procedural innovations are essential to enabling quick worker adaptation to the new ways of working. Technologies must be intuitive, logical, and require a minimum of training and retained knowledge. Similarly, novel processes and procedures require effective coordination of personnel and technical resources in order to realize their potential benefits. Factors such as these determine how quickly the organization can undertake a series of innovation deployments that deliver the broader organizational benefits. The rate of assimilation of technology into the business operation model is therefore a function of how quickly the plant staff becomes proficient in their use.

Poorly designed human interfaces and/or work processes will always be disruptive to an enterprise, impeding productivity and quality, and absorbing an inordinate amount of management attention to resolve the resulting problems. At the same time, they will demoralize and disenfranchise the affected workers, who are often comfortable with the present way of doing business and skeptical of the change. In a transformation setting, to have this scale of human-readiness failure in multiple business processes at the same time would be overwhelming for any organization.

It is therefore imperative that a business model transformation methodology thoroughly address human factors considerations to avoid these kinds of problems and take advantage of opportunities provided by innovations based on new technologies and procedures. Better yet, the transformation methodology should be so effective in designing superior human-technology interfaces and associated processes and procedures that they instill worker confidence that the innovations offer substantial improvements over the present ways of working. This is a key objective of the ION methodology.

1.1.1   The Integrated Operations for Nuclear (ION) concept

ION is a business-driven approach to transforming the nuclear power plant operating model from one that is labor-centric (rising cost) to one that is technology-centric (declining cost), using a top-down/bottom-up process. First, a top-down process is used to determine a market-based maximum production cost, thus ensuring price competitiveness, and then a bottom-up process is used to apply technology-based innovations to plant activities, constraining them to the market-allowable cost for each functional area. The result is long-term technical and economic sustainability for a nuclear plant.

Within ION, the innovations and related enabling technologies are referred to as work reduction opportunities (WROs). The WROs describe the new ways of working, often in a paradigm-shifting way, that enable the work activities to be effectively accomplished within the cost constraints. For example, rather than having all needed expertise on site for time-sensitive operational problems, remote experts can provide close tactical support of field activities through virtual collaboration technologies. This avoids the expense of maintaining such expertise on site full time for the relatively few instances where it is time critical.

1.1.2   ION Emphasis on Optimized Human Factors

A defining feature of the ION methodology for WRO formulation is the synthesis of four essential elements: Process, Technology, People, and Governance, collectively referred to as "PTPG." Synthesis implies more than simply taking these factors taken into consideration, but that they are optimized with respect to each other to ensure their roles in the success of a WRO are properly balanced and well-integrated. We refer to this process as "joint optimization" (e.g., Dainoff et al, 2020).

Within the PTPG context, this project addresses the relationship of People to the Technology, Process, and Governance elements. More specifically, it addresses human factors, human reliability, and sociotechnical considerations to ensure that the roles allocated to humans within emerging innovations are appropriate and suited to their abilities and the requirements of their tasks. It further assures that the innovations and technologies are designed in a manner to support efficient human-system interaction, as well as considerations and constraints of process and governance. It encompasses normal operations in addition to dealing with off normal and hazardous situations.

Human factors engineering (HFE) is a discipline based on proven principles and analysis methodologies, many of which have previously been applied to the analysis and design of NPP control rooms (see Section 2.2.3). This science has been advanced over many decades of application and assessment of results. It has proven to be reliable in designing human-technology interfaces and effective in understanding the specific deficiencies when human-technology systems fail. The methods have further been extended from an initial focus on direct operational control settings to the broad aspects of complex business and technological processes.

Through the research of this project, ION is employing these human factors and sociotechnical methods to ensure that the desired operational and business outcomes are achieved in the transformation of the nuclear business operating model, and that they are not impeded by poor human interface design.

1.2   Scope of Report

The scope of this report is to describe research and results in the development of a tool set for nuclear work function innovation development for maximum performance improvement and human-system integration. This involves the integration of the tool set into both the ION methodology and its associated ION development application known as the Integrated Operations Capability Analysis Platform (ICAP).

The report describes specific approaches to sociotechnical system analysis and design and provides background into the tools and methodologies for this purpose. It also describes two use cases. The RP use case was specifically concerned with identifying potential technical and associated procedural innovations to support radiation protection tasks in an integrated operation setting. It develops and employs a graded

approach to the design and test of novel technologies and procedures that has potential extension far beyond the scope of the current work. The Information Support (IS) use case encompassed a broader and somewhat less well understood set of operational constraints than the RP use case. Simply put, it involved the analysis and preliminary design of new information technologies and associated procedures intended to enhance nuclear plant senior management communications and decision making, particularly regarding resolution of issues during managerial forcing function meetings. Finally, the report describes how the sociotechnical methods and tools are integrated into ICAP.

1.2.1   ION Methodology Integration

As previously described, ION involves a methodology in applying innovations to nuclear plant work functions to enable them to be performed within the constraints of a market-driven budget. The innovations are formulated into certain WROs, which are typically scalable and reusable in many related work settings. Some WROs do not represent particular human-technology interface concerns, such as when a work function is entirely automated, or when a work function is outsourced to a third party (who then becomes responsible for human interface concerns within their own operations).

However, more often than not, WROs have human-technology interface requirements that must be addressed to avoid safety and efficiency problems associated with human factors issues. The ION methodology integrates this consideration into the formulation of WROs and provides guidance for the application of the tool set in a graded manner to ensure effective human-technology integration across the enterprise. Thus, issues with human factors are considered alongside issues of technical and business functionality so that the optimum PTPG balance is achieved from the beginning.

1.2.2   ICAP Integration

ICAP, as the development platform for ION, likewise accommodates the information derived in applying the sociotechnical methods and tools to a WRO, such that they become part of the requirements specification for that WRO. ICAP does not provide a guided process for the application of these methods, in that they require a certain knowledge base and skill set to customize their use with respect to the particular aspects of a given work function. However, ICAP serves as the repository for information related to the human performance challenges, methods and tools applied, and the resultant sociotechnical requirements to be addressed along with the technical requirements of the WRO. It further incorporates this PTPG balance for the WRO into the larger context for the broad capabilities that define the transformed business operating model.

1.3   Potential Utility of Sociotechnical Methods and Tools

Sociotechnical analysis and design methods and tools are based on principles of user-centered design (UCD) that have proven to be useful in supporting modernization efforts in other complex, sociotechnical settings. These include other NPP applications related to control room design (see Section 2.2.3). UCD has numerous advantages over more traditional approaches in that involving representative users and stakeholders as much as possible throughout analysis and design processes greatly helps reduce the risk that the end-product, on which much has often been invested, will not be useful, safe or successful. UCD also greatly enhances user buy-in regarding the end products of design. Technical and/or procedural changes have a much greater chance of new and long-term acceptance when end-users know that they, or other individuals like them, had significant influence on the design (e.g., Lowdermilk, 2013)

Sociotechnical systems theory, described in more detail in Section 2, is concerned with examining the impact of social, organizational, and technical factors on the design and performance of complex systems, as well as the critical interactions between them. In promoting a view of system modernization focused on integrating (as opposed to inserting) technological, organizational and/or procedural innovations, the sociotechnical approach focuses on the development of systems and processes which can help achieve strategic performance, safety, and efficiency objectives

Sociotechnical approaches to systems analysis and design focus heavily on working across organizational boundaries. This is done to assure that sufficiently broad expertise is brought to bear on the design of systems that may have extensive organizational impact, and which would therefore benefit from equally extensive user and subject matter expert (SME) input. Additionally, sociotechnical approaches place great emphasis on minimizing organizational and associated technical siloes as a design outcome. This is particularly relevant to the ION concept and other modernization efforts based on reduced staffing and enhanced communication and collaboration.

The methods and tools used to conduct sociotechnical analyses and design have been successfully applied to numerous complex systems (see Section 2). Several modeling and simulation techniques have either been specifically developed to address potential sociotechnical influences on system operation (e.g., systems-theoretic accident modeling and processes (STAMP), agent-based modeling) while others are easily adapted to do so (e.g, discrete event modeling, system dynamic modeling). When done as part of design these models can 'exercise' the system of interest under a variety of potential design and application conditions, which greatly facilitates the identification of unintended, negative consequences of the design.

1.3.1 Objectives

As this project was focused on the application and refinement of sociotechnical methods and tools for systems design, the major objective was to determine the extent to which they could be successfully applied to a real-world NPP design problem. Given the needs and requirements of our utility industry partner, we were particularly interested in assessing the degree to which these methods could support successful modernization efforts not specifically related to control room design or activities.

As a result of a collaborative process between Idaho National Laboratory (INL) and the utility partner, described in more detail in Section 2, two use cases were selected for analysis and design. The first, analyzed current RP procedures and associated task performance requirements to identify potential modernization opportunities. These were primarily focused on the support of maintenance activities in workspaces in which exposure to excessive amounts of radiation is a potential risk. The analysis resulted in a set of recommended design approaches, based on the use of commercial-off-the-shelf (COTS) technologies, to potential technical and procedural improvements. This use case is described in detail in Section 4. The second use case, information support (IS), examined issues involved in plant management decision-making and issue-resolution, specifically of the type associated with forcing function meetings and, in particular, management review meetings (MRMs). This analysis resulted in the development of a prototype interface/dashboard design concept, built around the novel concept of the "information object". The IS use case is discussed in detail in Section 5.

1.3.1.1 *Objective One: Assess utility of sociotechnical methods and tools in a nuclear energy generation setting*

Sociotechnical tools and methods have been shown to be useful in supporting the design of systems of comparable complexity to NPPs, including NPP control rooms. Therefore, the principal objective of the current work was to determine the extent to which these methods and tools can support the design of effective, novel technologies and procedures for non-control room, NPP use cases and applications.

Assessing the utility of the methods and tools is limited, in the current work, to the early prototype design phase. The prototype designs and concepts that were produced are in early stages of design and thus far from complete. A more complete view of the quality of the eventual designs and the methods that supported their development will become clearer once usability, proof-of-concept and/or verification and validation tests are conducted in the following phases of this effort. In the current work our objective was to assess the utility of sociotechnical methods and tools in supporting the development of early prototype designs.

1.3.1.2 Objective Two: Develop Scalable Design Solutions Using Sociotechnical Methods and Tools

Another objective was to assess the extent to which sociotechnical methods and tools are able to support the development of design concepts whose potential applications extend beyond the specific limits of the two use cases selected. Each of the use cases focused on a specific functional area within broader areas of management decision-making (in the case of IS) and plant maintenance (in the case of RP). Therefore, the objective was to determine the degree to which the methods and tools contributed to the design of prototype designs whose specific applications within their use cases exhibited potential for broader use across related areas within the enterprise.

Successful scalability of design solutions is advantageous to an organization's expenditure of time and resources in modernization efforts. Developing designs whose attributes and performance characteristics afford broader application across related functional areas is a particularly efficient approach from a cost perspective, and it can also take advantage of the training and performance benefits "common look and feel" interfaces across related applications.

1.3.1.3 Objective Three: Assess Ability of Methods and Tools to Support Future Use by NPP Personnel

Analysis and design methods and tools that can be usefully employed by NPP personnel are also advantageous in that they can help an organization adopt its own in-house UCD capabilities as part of continuing modernization efforts. There are several benefits to this capability, chief among them being that in-house subject matter expertise in areas relevant to modernization efforts who are also trained in the use of sociotechnical methods and tools would be invaluable members of design teams. Additionally, an in-house capability of this type would enable organizations to perform their own human factors engineering (HFE) and UCD functions without having to rely solely on outside expertise.

1.3.1.4 Objective Four: Relate Findings to Development of Integrated Operations for Nuclear (ION)

Application of the methods and tools described herein and elsewhere (e.g., Dainoff et al 2020; Hettinger et al 2020) to the modernization of NPP plant design and function is a long-term objective of an ongoing program of research of which the current effort is a part. An important program element is examining the extent to which an integrated operations framework and, in particular, the ION model, can provide a logically and empirically coherent, functional framework for future modernization efforts. Therefore, an objective for the current work was to examine the extent to which the early design concepts developed for each use case, and the methods and tools used to develop them, might afford integrated operations across related applications.

1.4 Organization of the Report

The report is organized around the following major topics

- Section 2 provides an overview of basic concepts, methods and tools supporting sociotechnical approaches to systems design. Applications of sociotechnical approaches to nuclear control room design are discussed as a potential model for additional, non-control room use cases of the sort examined in the current work.

- Section 3 presents the process that was used to select the two use cases for study. This involved substantial interaction between researchers and utility partners to converge on two areas of plant modernization that could address near-term business needs with potential, future application to others. An overview of the use cases is also provided.

- Sections 4 and 5 present the analysis and design work that was conducted in support of the RP and IS use cases, respectively. The sociotechnical methods and tools that were used are described and resulting design recommendations are presented.

- Section 6 provides a discussion of the results. The potential implications of the results for the further refinement and application of the sociotechnical toolset to other NPP modernization and operational objectives are discussed. The implications of the results for further development and implementation of the ION concept are also discussed.

- Section 7 presents further discussion of the results with regard to the integration of the sociotechnical methods and toolsets into the development of INL's ION methodology (ICAP) and innovation portal (IP)

- Section 8 provides conclusions and recommendation for near-term and longer-term development of the design products that emerged from the analyses, as well as continued refinement and broader use of sociotechnical methods and tools.

2. BACKGROUND

2.1 Introduction

This section provides background on sociotechnical system analysis and design methods of the sort that were used in the current work. This includes a concise introduction to the fundamental concepts underlying sociotechnical systems theory, particularly as applied to the design of complex systems such as NPPs. More detailed discussions of the material described in this section can be found in two previous LWRS program reports (Dainoff et al, 2020; Hettinger et al 2020)

2.2 Relation to Prior Work

The analysis and design methods that were used in the current work are primarily derived from two major sources

- Sociotechnical systems theory and its various applications to the design of complex systems other than NPPs, and

- Research and design work conducted at EPRI and elsewhere in support of NPP control room design. The human-system analysis and design processes described in NUREG-0711 (Rev 3, 2012), formulated with the objective of supporting control room and plant design and modernization, were also very influential in the current work.

UCD is an overriding theme in nearly all this work. UCD is a broad approach to systems design that includes representative users and others (e.g., technical subject matter experts, system stakeholders) at all stages of the process. This includes the early stages of concept formation and initial design through final acceptance or verification testing. Ideally, these individuals become full-time members of the design team.

UCD's benefits include:

- Reducing long-term risk that technical and/or procedural innovations will fail to have their desired impact due to poor usability, an absence of important features and/or a failure to take full advantage of the innovation's capabilities, and

- Enhancing immediate and long-term user acceptance and buy-in.

Another common theme within UCD is an emphasis on periodic assessment of human-system performance throughout the design process. Ultimately, human-system performance assessment in the

execution of representative tasks is an important part of proof-of-concept and acceptance/verification testing.

2.2.1   Fundamental Concepts of Sociotechnical Approaches to Systems Design

A sociotechnical system is an integrated, dynamic network of humans and technology, typically focused on accomplishing one or more strategic objectives (e.g., safely and effectively operating and maintaining a nuclear plant, performing complex surgical procedures, managing an emergency response, etc.). Sociotechnical systems theory is an approach to analyzing and explaining existing system and sub-system behaviors, as well as designing new systems. It originated partly in response to an analysis of problems associated with the rapid introduction of novel technologies and procedures into the British coal mining industry in the 1950s. A subsequent drop in productivity and resistance from the miners, who were not involved in any way in the design of the innovations, rendered the innovations impractical and poorly usable until they could be modified to better suit the context and demands of the mining task. The problem, repeated in many other system design settings before and after, was that the designers had failed to take account of the way users might use the technology or respond to the new procedures and how they could thereby be more effectively integrated. Failure to include users in the design and periodic assessment of the innovation concepts resulted in a needless waste of time, money, and other resources, an unfortunate but common outcome. HFE emerged as a discipline over roughly the same period. Aviation accidents and related military human performance problems are generally recognized as the birth of HFE and later formal systems engineering.

Within sociotechnical systems theory, system outcomes (e.g., productivity, safety, efficiency, etc.) are seen as emergent properties of total system behavior, a concept derived from general systems theory (von Bertalanffy, 1968). In other words, system outcomes are considered to be a complex function of the combined pattern of *interactions* between humans and technical/procedural components of the system and not their combined (additive) *independent* effects. Therefore, the fundamental analysis and design problem from this perspective is to understand the nature of these interactions and their impact on system performance and, if possible, to improve them.

Sociotechnical methods and tools are derived from broader scientific and engineering aspects of the theory. In analyzing existing systems and supporting the design of new ones, these methods focus on assessing the interactions between human and technical components of a system from a holistic (i.e., system-wide) perspective. From a design perspective, the goal is to *jointly optimize* human and technical components of a system. An exclusive or excessive focus on one versus the other can result in an asymmetry between users and technical systems, leading to less-than-desired or poor outcomes.

The sociotechnical approach also includes considerations of factors related to future staffing levels, job and personnel requirements, and the development/identification of enabling technical, management, and procedural supports focused on the effective integration of people, technology, process, and governance (PTPG, Droivodsmo et al. 2014). The PTPG model has been effectively used to support advanced integrated operations concepts in North Sea oil extraction operations.

To reiterate, all sociotechnical approaches place central importance on UCD. Many of the methods and tools that exist within this framework were explicitly developed to support specific activities, such as knowledge elicitation, task analysis, system modeling, and function allocation, within an overall UCD framework. These approaches also share an emphasis on joint optimization of humans and other elements of the system, including technology and procedures.

2.2.2   Application of Sociotechnical Methods and Tools in Systems Design

Following its introduction in the 1950s, the sociotechnical approach did not begin to attract sustained interest again until the 1980s. This arose through growing concerns with the complexity of emerging systems, both across industry and within the defense sector, that were shared by users and designers alike. As a result, sociotechnical-based approaches began to emerge. These include normal accident theory

(Perrow, 1984), macro ergonomics (Hendrick and Kleiner 2002), cognitive systems engineering (Hollnagel and Woods 1983; Rasmussen, Pejtersen, and Goodstein 1994), human–systems integration (HSI) (Booher 2003; Pew and Mavor 2007), resilience engineering (Hollnagel, Woods, and Leveson 2006), and systems-theoretic accident and modeling processes (STAMP; Leveson 2012)

In recent years, organizations across the public and private sectors have been seeking methods to better integrate their technical and personnel resources to enhance efficiency and cost competitiveness. However, realizing these gains at the cost of associated loss in system or worker safety is never an acceptable trade. Therefore, enhancing system safety along with performance has also been a major goal of sociotechnical approaches. The theory and its associated applications arose to help organizations address these occasionally competing needs with its emphasis on joint optimization and addressing design requirements to support functional interactions among system components.

An example of recent applications of sociotechnical methods involves oil platform operations in the North Sea (e.g., Droivodsmo et al, 2014) using the PTPG framework described above. Oil producers, in this instance, are interested in centralizing various organizational functions (e.g., maintenance management, personnel, logistics, etc.) in one physical location, thereby reducing or eliminating the need for redundant personnel on the platforms. The design challenge, in this case, is to design a command-and-control system that satisfactorily supports the numerous interactions that are required for successful operation of the concept.

Finally, Leveson's STAMP model has gained wide acceptance in many areas of design. This model, which comprises separate risk and accident analysis tools, is primarily based on the notion of the 'safety control structure' (Leveson, 2012), a non-computer-based model of the interactions between human and technical components of a system. STAMP was used as one of several methods in the IS use case. To date, its domains of successful application include nuclear (e.g., Thomas et al, 2012), robotics (e.g., Almazehdeh et al, 2014), and transportation (e.g., Salmon et al, 2015).

2.2.3   Sociotechnical Methods and Tools for the Nuclear Industry

This section presents a summary of major themes from a prior report (Dainoff et al, 2020) prepared as part of the current research program. The intent of this report was to familiarize the nuclear energy community with sociotechnical concepts and methods, and to present an array of methods and tools for use in system analysis and design efforts. A central proposition in Dainoff et al, one directly related to the current effort, is that sociotechnical methods and tools that have been shown to be useful in the design of systems of comparable complexity to NPPs, and which have been adopted by broad communities of practice of engineers and designers, ought to translate well to issues regarding the latter.

The Dainoff et al. report provides detailed descriptions of these sociotechnical methods and tools, including cognitive work analysis (CWA), hierarchical task analysis (HTA), and system theoretic process analysis (STPA), the latter a risk analysis modeling tool contained within STAMP. These were used in the use case analyses and are described in detail in Sections 4 and 5. Dainoff et al also present a systematic approach to the effective integration of sociotechnical methods and tools across the span of system design, development, test, and deployment.

An additional consideration given to the selection of these methods and tools by Dainoff et al was the degree to which non-specialists, specifically, employees of the organization itself, could be expected to learn their use and application to support other, future modernization efforts. This would help to ensure that a UCD approach to design, featuring continuous learning about sociotechnical factors influencing human-system performance, becomes a durable part of the organization's modernization efforts and overall culture.

Dainoff et al provide a description of a broad set of analytic methods and tools that have been used in the design of sociotechnical systems of comparable complexity to NPPs. Their objective was to describe those tools that would best satisfy the criteria described above and to provide an overarching context for their use. The latter involves combination of bottom-up and top-down approaches to system design. From

a bottom-up perspective, understanding the nature of user needs (task requirement, information requirements, decision-making requirements etc.) can be addressed in conjunction with a top-down approach that examines such factors as capabilities of and assumptions about innovative technologies and procedures.

2.2.4   A Sample Plan for Applying Sociotechnical Methods in Systems Design

Building on the Dainoff et al (2020) report, Hettinger et al (2020) provided guidance on developing a plan for the application of sociotechnical tools and methods to NPP modernization efforts. The report presents a stepwise set of processes and objectives that are specifically intended to support the development, test, and implementation of modernized NPP technologies and procedures. The current project has provided an appropriately complex context within which to assess the value of such an approach and its associated methods and tools.

The plan drew from two primary sources: Dainoff et al's theoretical and methodological overview and the authors' prior experience with the design of similarly complex systems, including nuclear power plant control rooms, etc. It also drew heavily on the stepwise, user-centered procedure described in NUREG-0711. Its intent is to serve as guidance for those in the industry who wish to pursue a UCD approach to integration of new technologies into new or existing systems of their own. A series of stages in the design process are defined, along with the general goals of each. These include:

- The initial step in the process involves understanding the problem or opportunity to be addressed and organizing a multi-disciplinary design team to address it. Specially, it involves:

  o *Identifying modernization opportunity.* Several HFE methods exist that can facilitate the achievement of a group consensus. Selection of the modernization opportunity should consider associated sociotechnical issues, e.g., reduction in workforce size, increased reliance on automation, etc.

  o *Identifying system goals, constraints, and assumptions*. This involves identifying the system's planned functions within the broader organizational context, its anticipated benefits, constraints on its design and operation (budgetary, schedule, regulatory, etc.), and assumptions about the capabilities of novel technical, managerial, and procedural approaches central to its effective operation.

  o *Identifying issues for analysis.* This involves focusing on potential sociotechnical issues associated with the design. The objective is to identify those issues whose impacts on outcomes associated with system safety, performance, cost, efficiency, acceptance, etc. are likely to be greatest.

  o *Assembling a cross-functional analysis team.* The core of the analysis effort is the multidisciplinary, cross-functional team that guides and conducts it. At least one member of the team needs to have sociotechnical analysis expertise and the participation of representative users and technical SMEs is also critical

- The second step involves developing the analysis and design plan. Specifically:

  o *Develop analysis objectives.* Planning at this stage involves developing and communicating to stakeholders a description of the analytic objectives associated with each issue, particularly regarding the human-system integration and performance concerns to be addressed.

  o *Select analysis tools.* The core of this stage is the selection of appropriate analysis tools and methods. 'Appropriate,' within this context, refers to validated tools and methods (described in Dainoff et al. 2020) whose prior application in the analysis of comparable,

complex socio-technical systems has been shown to produce information of significant value to their design and use.

- o *Develop logistical plan.* Logistical planning involves identifying and securing required resources and developing an integrated, master schedule of analysis activities. It also involves the identification of critical dependencies in the plan, such as the availability of subject matter experts, whose schedules are typically busy and whose availability must be secured well in advance of when it is needed. Risks to plan execution and corresponding mitigation steps should also be documented.

- The third step involves conducting the analyses identified in the previous step and translating findings into design recommendations. Specific activities include:

  - o Applying the sociotechnical methods and tools identified in the planning phase to generate results applicable to the modernization effort, as identified in the first stage.

  - o Representing the findings by documenting, modeling, or otherwise describing their influence on key system performance parameters.

  - o Translating findings from the analysis and modeling into forms useful for design (e.g., system design specifications and requirement, training and personnel requirements, system prototype design and test results, etc.).

By design, Hettinger et al did not prescribe how and when specific analysis and design methods and tools should be used. For instance, although there were differences between the two use cases in this study in terms of the specific tools and methods that were used, each adhered to the general plan described above. We anticipate the lessons learned from the current work will result in modifications to the guidance provided in Hettinger et al.

2.3   Related Work in the Nuclear Industry

Human factors engineering, a major aspect of sociotechnical systems approaches, has a long and largely successful history in the nuclear industry. The analysis of human-system performance issues relevant to nuclear industry design topics has a history that goes back to approximately the time of the Three-Mile Island incident (e.g., Hagen & Mays, 1981; Hanes et al, 1982; Moray & Huey, 1988; Rasmussen & Pederson, 1984). Furthermore, our application of sociotechnical methods and tools to the nuclear industry is not entirely novel in that previous work, primarily conducted at the Electric Power Research Institute (EPRI), has successfully applied these methods and tools to NPP control room design. While the control room is in many ways a unique setting within the plant, it shares a fundamental characteristic with NPP business operations, plant maintenance, etc. Specifically, each can be viewed as an integrated human-technology system that serves a monitoring, decision-making, and command-and-control function.

For example, EPRI has employed an overarching UCD model to the development of numerous advanced systems supporting control room design. These include developing guidance for designing/selecting and implementing automation (EPRI, 2005), 2.5D and 3D visualization systems (EPRI, 2010), human-system interface design (EPRI, 2010), and computerized procedure systems. While a variety of analytic tools were used in each case, they all share the core characteristic of being guided by the criticality of including the user in all stages of design.

STAMP-related analyses of NPP systems are also beginning to appear in the scientific and engineering literature. For example, Shin et al (2021) used STAMP's STPA tool, used primarily for risk identification and amelioration during the design phase. In their case, the method was applied to an example case requiring reactor trip signal generation in the Advanced Power Reactor 1400 (APR-1400) and identified risks and potential modifications which the authors argue other risk analysis techniques

often cannot. Rejzek and Hilbes (2018) applied STPA to the design of NPP digital instrumentation and control systems. The authors concluded that STPA is a useful tool for design and, in some instances, verification in these cases because of its holistic, systems-based approach. In other words, STAMP and its associated tools do not focus solely on *component* reliability or performance, but on the nature and quality of the *interactions* between these components.

2.4   Implications for Development of ION Systems

Achieving the sorts of performance benefits and cost savings that an ION approach potentially affords requires an approach to systems design that views systems holistically, addressing the impact an innovation might have on a local sub-system and/or the system as a whole. The sociotechnical approach is specifically intended to address these needs in a manner that addresses the influence that innovations may have locally and globally throughout the larger system. Its distinguishing factor is exemplified by the difference between the terms 'innovation insertion' and 'innovation integration.' The former case refers to traditional approaches to the design of new systems and the upgrading or redesign of existing systems. That is, a new technology and/or procedure is identified that appears to hold promise for helping an organization achieve various performance objectives. These are often commercial-off-the-shelf (COTS) technologies, usually not specifically designed for or readily adaptable to the organization's characteristics and needs, resulting in an inability to achieve the anticipated performance or cost benefits. Simply put, it is often the case a technical or organizational 'solution' that works well in one setting does not transfer well to another. This is frequently due to failing to take a technology integration approach. Note that this discussion is not intended to disparage or preclude the use of COTS systems. However, when considering such systems, considerations about their ease of functional integration into the overall system should be considered.

As discussed above, other organizations (e.g., North Sea oil and gas operations) have found that adopting UCD approaches, with the appropriate sociotechnical methods and tools, are helping them achieve significant performance improvements and cost savings, without sacrificing safety. Others, described above, have found that incorporating sociotechnical analytic methods such as STAMP is also supporting these sorts of improvements, while also helping to identify and address the sort of unintended and frequently unforeseen consequences ("ripple effects") of introducing new technologies and procedures.

ION solutions will rely heavily on automation and, increasingly, artificial intelligence (AI) and machine learning (ML). As has now repeatedly been shown in the HFE literature, insufficient attention paid to the integration of humans and automation is fraught with risks if not properly addressed in the requirements definition and design phases of development. These same points hold for other advanced technologies such as robots and drones. While there is some useful information in the HFE literature on human-drone interaction (e.g.,Tezza et al, 2019), the area of human-robot interaction is just beginning to be explored (e.g., Mindell, 2015; Sheridan, 2016). Therefore, it is essential to pay attention to how these systems will be most effectively integrated within an ION approach.

2.5   Summary

The purpose of this section was to provide background information on the sociotechnical methods and tools used in the current work. This included discussions of several fundamental concepts, including the maxim that the goal of systems design is the joint optimization of people, technology, process, and governance in the achievement of more efficient operations that do not sacrifice safety, efficiency, or reliability. UCD was also discussed as a fundamental component of sociotechnical methods and tools. Simply put, including representative users and technical SMEs at all stages of system design from conceptualization and initial design through system verification and validation has been repeatedly shown to reduce the risk of poor usability and poor user-community acceptance upon system roll-out.

3. OVERVIEW OF USE CASES

This section provides a description of the process used for selecting the two cases examined in the current work, as well as an overview of the use cases themselves. The use cases were selected at the conclusion of a series of discussions between INL and the utility industry partner personnel. These discussions were structured according to methods derived from nominal group technique (NGT; Delbecq et al. 1986), an approach to knowledge elicitation and consensus building among key project stakeholders and subject matter experts (see also Dainoff et al, 2020). Specifically, NGT enables all key stakeholders' inputs to be presented and considered in the decision-making process. The latter is often accomplished through a group voting process, while in other contexts senior decision maker(s) weigh the inputs and make the associated decisions.

The two use cases selected. RP and IS, were chosen because of the perceived likelihood that cost-beneficial, near-term innovations were possible, and that they were potentially scalable to broader applications across the organization. In the case of RP, the specific use case focused on support of maintenance in areas with potential radiation and contaminant exposure, with potential broad application across most or all other plant activities. For IS, the specific use case focused on increasing the efficiency of forcing function meetings, specifically MRMs. The potentially broader application of innovations from this use case were seen as providing similar information support capabilities across the full plant management team.

The relevance of these use cases to the ION concept is also discussed. Primarily, they serve as highly representative test cases across two broadly different areas of NPP operations; plant maintenance and management information and decision-making support. The emphasis on development of reusable and scalable methods and products is also discussed.

3.1 Use Case Selection Process

The selection of the two use cases took place over the course of a series of several hour-long discussions between the INL research team and utility partner stakeholders, decision makers and subject matter experts. Among the factors that were considered in the selection process were the following:

- What areas of plant operation afford the best near-term potential for improvements in efficiency and performance without concomitant loss of safety?

- What types of technical and/or procedural innovations, broadly considered, might be beneficial to these areas?

- Potential cost-benefit tradeoffs were also considered but were not the subject of detailed analysis at this time. A key factor in the use case selection decision was to pick functional areas of plant operation, outside of the control room, with the greatest potential for cost reduction by means of reduced staffing requirements and increased technical capacities and efficiencies. A method for more detailed examination of human-system performance cost-benefit tradeoffs is provided in Appendix A.

- The feasibility of producing a prototype design and/or a set of design recommendations in the near-term that would also have potential for long-term scalability.

Each use case process involves (1) selecting and describing an existing job activity (e.g., procedure) with its functions and tasks, (2) analyzing the current procedure's functions and tasks to identify opportunities for introducing one or more technical or procedural innovations resulting in reduced costs, (3) designing and developing innovations (potentially using commercial off-the-shelf (COTS) devices, and (4) testing and implementing the innovations to replace existing systems.

The utility partner's management was ultimately responsible for selecting the use cases described in this report, while INL personnel participated in the discussions supporting the decision, per the NGT method referred to above. An overview of the process used is as follows.

- Senior utility partner management discussed the project and possible use cases with other members of utility management and senior professionals

- A list of possible use cases was prepared by the utility partner and provided to the INL team

- Possible use cases were reviewed by INL team members and identified several that could be expected to provide desired results of the type described above. Feedback was provided and discussed with the utility partner over the course of several discussions.

- Taking INL input into account, utility partner management then selected the radiation protection and information support use cases for study.

3.2   Use Case Summary Descriptions

Detailed descriptions of the RP and IS use cases are provided in Sections 4 and 5, respectively. This section provides additional information regarding the challenges and opportunities associated with each, along with their summary descriptions.

As noted above, each use case was seen as providing an opportunity to explore the development of useful technical and/or procedural innovations to assist the nuclear energy industry in its modernization efforts. Each was also seen as providing an opportunity to assess the utility of sociotechnical methods and tools in supporting their development. Therefore, each use case was deemed to be relevant to both the goals of the study and the requirements of the utility partner.

3.2.1   Radiological protection

The area of nuclear power plant maintenance covers many activities that, in combination, require significant numbers of specialized staff and other personnel resources (e.g., training, human resources). These resource expenditures present a significant challenge to the industry's need to modernize. Therefore, effective technical and procedural solutions that increase maintenance efficiencies without sacrificing safety are critical. Current developments in robotics, drones, wearable sensors and devices, AI and other technologies appear to hold significant promise for partially addressing the socioeconomic issues related to NPP maintenance staffing. Whether they can do so safely and effectively within the required context is a key analysis and design problem. The RP use case set out to examine these challenges and opportunities.

Prior to the start of the current work, the utility partner was already in the process of examining potential technical and procedural improvements to RP technologies and procedures. As part of the use case selection process, they expressed a desire to continue this development using sociotechnical methods and tools to assist analysis and design. RP represents an important subset of plant maintenance functions with critical safety and performance implications. It also affords an opportunity to extrapolate findings from its analysis and development to other areas of plant maintenance, given its many technical and procedural similarities with them.

Working with RP technical SMEs, this use case focused on tasks involved in functions such as performing radiation surveys, arranging workspaces to control exposures, and recording and documenting data and information. Detailed methods, results, and recommendations from this use case are provided in Section 4.

3.2.2   Information Support

NPP management decision-making covers a broad range of topics ranging from economics, personnel and staffing issues, project management, compliance, assurance, and others. The data and information

required to support this decision-making generally exist in disparate domains, potentially nested within relatively inaccessible organizational silos. In the absence of useful and reliable automated processes, the collection and analysis of this information requires significant staffing and associated time and workload.

The IS use case set out to examine whether emerging concepts from data and computer science, such information objects, in combination with an advanced information dashboard designed in collaboration with the utility partner's personnel, could support a more efficient decision-making process. It also explored the introduction of a procedural innovation, management by exception, as a further means of adding efficiencies to the process. Simply put, in an issue-resolution setting such as MRM and other forcing function meetings, management by exception means that those issues that can be resolved outside the formal meeting itself (i.e., using the dashboard to access desired information, communicate with others, etc.) should be resolved.

Working with the utility partner's management and technical SMEs, the IS use case pursued the design of a prototype information object-information dashboard concept. MRM was selected as context for the use case due to a perceived need for an effective near-term approach since MRMs are typically long in duration, not as efficiently focused on important issues as they could be, and difficult and time-consuming for many staff to prepare for. It has many opportunities for improvement, including the technical and procedural innovations examined in the IS use case. Detailed methods, results, and recommendations from this use case are provided in Section 5.

3.3   Relevance of Use Cases to ION Concept

One of the objectives of the current work was to examine sociotechnical methods and tools with regard to how effectively they might aid the development of related use cases and applications supporting effective integrated operations. Similar consideration was also given to the selection of the use cases. Specifically, the INL team internally concurred that each use case presented a valid context within which to assess the utility of the methods and tools. At the same time, the projected outcomes of each use case – the prototype designs and design recommendations – were considered to have potentially significant implications for further development of the ION concept.

Two of the key areas of human-system performance addressed in the current work that are relevant to ION are (1) the enhancement of collaboration among personnel and supporting technologies to improve processes, communications and decision making and (2) improved efficiencies in plant assurance functions. As described in the following section, each represents a domain of human-system performance with near-term and long-term relevance for two use cases to the further development of the ION concept.

3.3.1   Collaboration and Assurance Capabilities

To be useful, sociotechnical tools and methods must effectively support the design of systems that result in significantly improved efficiencies, safety, and overall performance of key functions. If realized, these systems could be operated with fewer personnel, many of whom would be performing supervisory or monitoring roles, overseeing automated processes, robotic systems, etc. performing tasks formerly performed manually. Effective collaboration between staff and the technologies with which they interact will be essential. The RP use case examined this issue by initially analyzing the radiation protection system as it currently operates with regard to surveying and monitoring workspaces. Using these results and in discussions with utility partner SMEs, many opportunities for improved collaboration were identified. Further analysis, as described in Section 4, resulted in several sets of design recommendations.

One of the functional areas accounting for high staffing levels and associated workload is assurance. The utility partner estimated that nearly 50% of its staff workload was involved with assurance activities in one form or another. Assurance-related activities include manual data collection, reduction, analysis and interpretation, documentation, action assignment and tracking, preparations for and conduct of forcing function meetings such as MRMs. The IS use case examined these issues by analyzing processes underlying current MRM preparation and conduct procedures. Working in conjunction with utility partner

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SMEs, the major portion of the work, as described in Section 5, focused on the development of an early (i.e., non-interactive) human-system interface.

3.3.2 Reusable and Scalable Methods and Products

Each use case afforded the opportunity to assess the ability of a sociotechnical approach to translate its methods and products into forms that are reusable and scalable across related applications. Specifically, each use case employed a variety of sociotechnical methods and tools which, it is hoped, would be able to be used by appropriately trained plant personnel in future modernization efforts. Enabling the effective use of these tools by non-HFE specialists would encourage their use across the organization while reducing expenditures on outside expertise.

The RP and IS uses cases, described in the next two sections, provided the opportunity to assess the extent to which a set of sociotechnically based, analytic tools can effectively support product design across two separate NPP applications. Similarly, they provide the opportunity to assess the extent to which the resultant products of the design effort are potentially useful across applications related to, but broader than each use case.

3.4 Summary

This section provided background on the use case selection process, including an overview of the use cases selected for analysis in the current work and a discussion of their relevance to the ION concept. The RP and IS use cases were each selected following a series of discussions between INL and utility partner personnel. These discussions were focused on identifying potential technical and/or procedure innovations that could significantly contribute to the industry's desire to move toward more efficient processes and procedures that do not sacrifice safety. Both use cases were seen as having potential near-term benefits to specific needs such as radiation protection and improving organizational performance around forcing function meetings such as MRMs. However, both were also seen as having broader potential application in the areas of overall plant maintenance and better management information support for decision making, respectively.

4. RADIATION PROTECTION USE CASE

This section provides a description of the RP use case. The utility partner had determined that RP provided opportunities to introduce innovation technologies, especially those involving automation. Also, the innovations identified for RP and the process created for developing and implementing innovations were considered to have application to other nuclear plant activities, such as maintenance, operations, and support.

Some of the opportunities to reduce costs in RP and other plant activities are shown below.

- Replacing human labor with automation and other technical innovations for functions and tasks now performed manually

- Permitting one worker at a remote location to supervise and, for example, perform verification (assurance) now performed by a second, on-site worker; sometimes perform plant tasks at any location in a plant (such as initiating an autonomous vehicle to perform tasks); the one worker located remotely may be able to monitor more than one job at a time and possibly further eliminate the need for a second worker at several locations

- Reducing time to perform tasks by changing work procedures and/or applying technology from the innovation

- Automatically capturing and processing data to provide useful information to workers quickly and without any or with minimum human involvement

- Improving human decision-making based on data provided by an innovation more frequently than possible manually (e.g., environmental, and other sampling by autonomous and semi-autonomous equipment, such as with an air sampling innovation mounted on a drone)

- Reducing human errors and thereby possibly eliminating or reducing rework, personnel injury, equipment damage, or other plant incidents (possibly due to completely or partially eliminating human tasks because of automation)

- Eliminating the need for reducing plant power output to permit workers to enter very high radiation areas, thereby eliminating loss of revenue and reducing radiation exposure, if present

- Reducing opportunities for accidents/incidents resulting in fewer safety incidents or reports to agencies (e.g., U.S. Nuclear Regulatory Commission (NRC), INPO) and the costs associated with such reports and resulting actions required by agencies.

- Reducing worker exposure to contaminants and irritants such as radiation, chemical spills, heat stress, etc., because an innovative technical system is able to perform the task (such as a robot performing a cleanup task)

- Reducing or eliminating time for workers to don and remove protective clothing which can result in slower task performance due to the constraints of the equipment

- Reducing task performance times that are on critical path during refueling or other outages permitting plant to get back online quicker providing increased revenue from selling electricity sooner and possibly reducing radiation exposure

The RP use case background, objectives, approach, results, potential innovations identified, conclusions, recommendations and lessons learned, and references are presented below.

4.1   Use Case Overview

RP functions and tasks are primarily concerned with maintaining safe barriers against risks of radiation exposure to plant personnel and the public. Additionally, RP Technicians oversee maintenance activities performed in areas with exposure risk, supporting these activities by performing initial and as-needed radiation surveys, occasionally repositioning workers and/or equipment in work spaces to minimize exposure risk, and other activities.

RP technicians rely on several key sources of information to perform their work. In addition to the sensors and other measurement equipment used in the field to measure radiation levels, they also rely on printed and/or computer-based work orders, on-line procedures manuals, etc. Measurements taken in the field are typically recorded with paper and pencil and are later manually entered into a computer. Required approvals for modified work orders or site surveys can involve lengthy delays in tracking down the appropriate approver. Remotely observing and communicating with maintenance personnel working in restricted spaces can be problematic because of constraints on camera capabilities and location. These and other aspects of RP job performance represent significant constraints on current task performance, as well as opportunities for improvement in overall system design and performance.

4.2   Objectives

The RP use case objectives are listed below.

- Develop an HFE-based demonstration plan employing sociotechnical methods and tools and implement the plan within the scope of the project

- Demonstration to involve developing an HFE-based process and identifying appropriate sociotechnical methods and tools to help demonstrate that it is possible to transform RP operations into a more technology-centric (ION) model

- Scope of project limited to (1) identifying potential RP innovations and presenting them to the utility partner for consideration, and (2) providing complete HFE process that extends through innovation implementation and operation even though later elements of process were not addressed due to being out of scope of the current work.

- Describe a process and sociotechnical methods and tools that are extendable to all plant jobs that could benefit from such an approach, and be applicable throughout the utility's nuclear plants and nuclear plants owned by others

- Identify and present to utility partner potential innovations that, in collaboration with the utility's current RP modernization efforts, will reduce operating costs while maintaining RP safety and reliability, and improving efficiency and effectiveness

The innovations identified in the use case, when implemented, are expected to support RP and other work in a nuclear power plant. For example, an innovation might provide the capability for one RP technician or other worker located remotely to observe, supervise, provide support, and/or verify that the person performing the work has performed it correctly (possibly eliminating the need for a second worker on site to verify the actions were taken correctly), perform tasks remotely using innovations such as a robot or drone with cameras and appropriate communication capability, etc. Another example is the use of a wearable device, such as smart glasses. These glasses could provide remote viewing capability by cameras, relay dose rate data, include two-way communication capability, display procedural information on the glasses, provide augmented reality capability permitting, for instance, the superimposition of a drawing of a device through the glasses, etc. The results may include reducing the number of staff required, permitting a remote expert anywhere in the world to apply his/her knowledge and skills in support of on-site staff, including a single worker, possibly permitting one remote worker to supervise more than one work site, reducing time to perform tasks, and/or reducing or eliminating exposure to environmental hazards such as radiation.

4.3   Method

Following identification of the RP use case (described in Section 3), the analysis adopted the following approach:

- Prepared HFE process and methods plan, primarily based on those described in Dainoff et al (2020), Hettinger et al (2020), NUREG-O711(Rev 3), Mil-Std-4685 (Rev A) and EPRI's Human Factors Guidance for Control Room and Digital Human-System Interface Design and Modification (EPRI, 2015)

- Performed initial operating experience review (OER) for the purposes of:
  - Reviewing utility corrective action program and INPO human engineering data base, and
  - Reviewing to identify any NPPs applying advanced technology related to the use case.

- Identified one RP procedure as the initial, primary focus of analysis and design. The utility partner selected FP-RP-NISP-10 Revision: 3 Radiological Job Coverage as the procedure of interest.

- Identified functions and tasks required by the procedure during two, one-hour working sessions with INL personnel and utility partner SMEs.

- A hierarchical task analysis was performed over the course of three, one-hour sessions with two utility partner SMEs as participants.

- Each task analysis result was examined by INL personnel and utility partner SMEs to identify potential innovations.

- 25 potential innovations identified and subsequently categorized as follows according to their perceived potential contribution to modernization efforts: A=High, B=Medium, and C=Low

- Applied graded approach to identify three groups of potential innovations with highest priority for study (Wearables, Robots and Drones, Air Sampling).

- INL team contacted, talked with, and obtained information and in some cases videos of possible innovations (products) that applied to the three groups of potential innovations.

- INL team developed HFE Innovation Development and Implementation Model and description (Appendix B) based on activities performed in this Use Case for future application.

- INL prepared draft final report incorporated into this report.

4.4   Results

The utility partner determined that a need exists to reduce costs significantly for its nuclear plants to remain competitive with alternative electricity generating sources. Some possible opportunities involving workers to reduce costs are listed in the introduction to Section 4 above.

Innovations need to be implemented in existing NPPs to accomplish these approaches. An innovation may be defined as a new product or device, process, procedure and/or service that when implemented improves efficiency and effectiveness, and reduces cost, while ensuring safety. Innovations are intended to support achievement of the potential opportunities listed above. Nuclear utilities also need a procedure to apply across nuclear plants to:

- Identify which functions and tasks required to perform plant work activities (e.g., maintenance, radiation protection, operations, engineering, support) offer opportunities for improvements in efficiency and effectiveness as part of cost reduction.

- Identify innovations that when implemented will result in achieving the required improvements and cost reductions.

A graded analysis and design process, presented in Appendix B was developed as part of this use case. It provides a model and set of procedures for identifying, selecting, developing, evaluating, and implementing innovations to improve performance and reduce costs in nuclear power plants. The need for such a model is presented in Section 4 of this report.

NRC NUREG-0711 (Rev 3, 2012) contains a program review model (Figure 1) consisting of four general activities and 12 elements. This model is used by NRC HFE personnel to review utility submittals involving operating and new plant control room and instrumentation designs requiring NRC approval. Some utilities and companies have applied the 0711 diagram to aid in creating control room and instrumentation design modifications. A major problem in attempting application of the 0711 model for creating new designs is that NUREG-0711 was not specifically developed to support identification of innovations that would result in reduced costs in the plant, but is instead intended to determine if a submitted design will result in safe operation
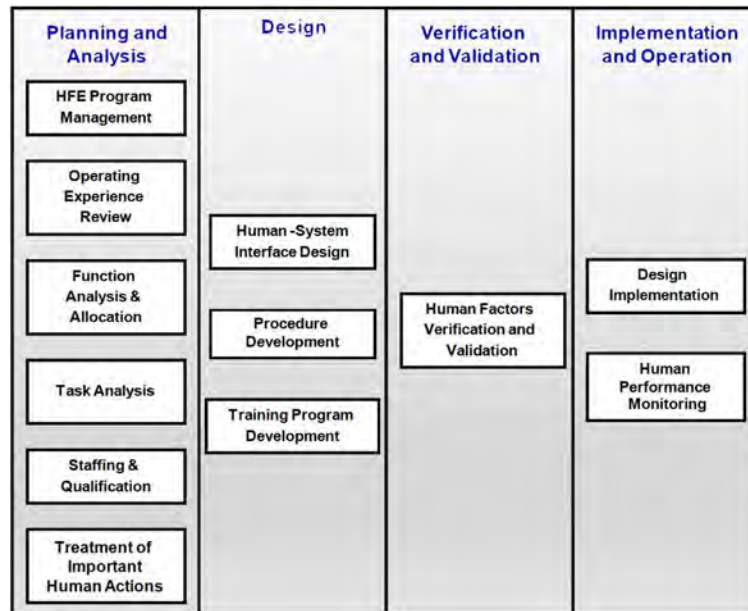
Figure 1. HFE program review model diagram with general activities shown as column headings and elements shown in boxes (NRC, 2012).

A process is needed that satisfies utility requirements for modernization. The diagram presented in Figure 2, and described in detail in Appendix B, resulted from the RP use case described in this report. It is intended to provide a utility with a process it can apply throughout its nuclear plants to identify the need for innovations in plant activities (e.g., Maintenance, Radiation Protection, Operations, Support), and select appropriate innovations for implementation.

This section contains a brief description of the process that was developed, the parts of it applied during the use case and the methods used. In addition, possible innovations were identified for consideration by the utility (see Element 8 in Figure 2).

Part of the process shown in Figure 2 was not completed in this use case. Elements 9-20 shown in boxes in Figure 2 were not performed. Element 2 in Figure 2 involved development of a HFE RP Use Case Plan. This Plan included creation of a process that would result in implementation and operation of innovations at the utility (Figure 2), but this specific use case concluded with the selection of possible innovations (Element 8).

A few comments are provided in the remainder of this section regarding General Activities D, E and F, and Elements 9-20. These comments are intended to provide input for preparation of a future HFE Use Case Plan for RP or other plant activities. This plan would provide guidance for work involved in completing General Activities and Elements shown in Figure 2 and not performed in the use case described in this report.
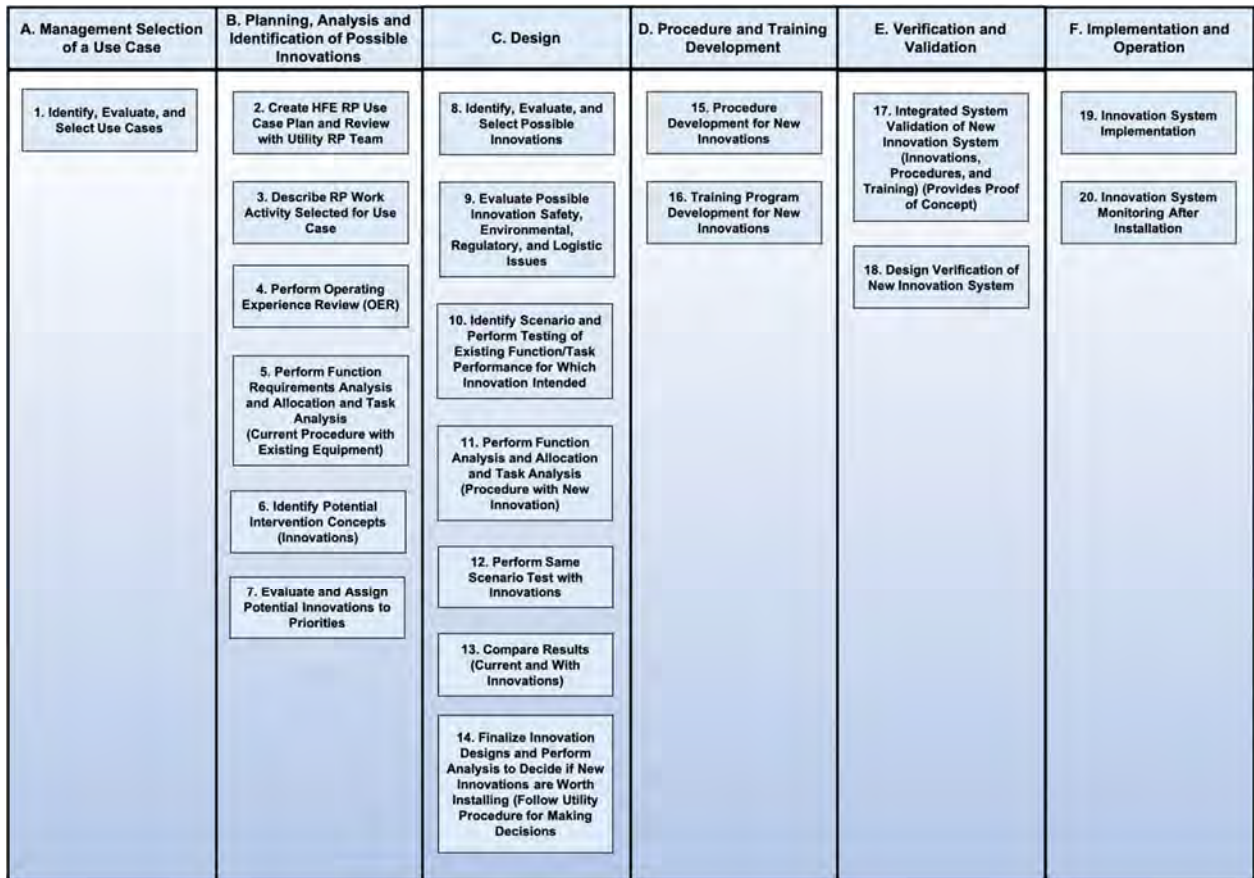
Figure 2. HFE innovation development and implementation model diagram with general activities shown as column headings and elements shown in boxes; developed and applied in radiation protection use case at a nuclear utility.

Task analysis results are shown in Table 1 for the Survey Work Area Function described in Section 5.4 of Radiological Job Coverage Procedure (FP-RP-NISP-10). Task analysis results for all Procedure functions (Sections 5.4 -5.8) are presented in Appendix B. The left three columns in Table 1 are copied from the Radiological Job Coverage Procedure. Entries in the sub-tasks column of Table 1 were provided from experience (memory) of SMEs during an initial task analysis session by means of standard, question-and-answer knowledge elicitation techniques.

Table 1. Task analysis results for survey work area function (current procedure with existing equipment).

Function Section 5.4	High-Level Tasks Section 5.4	Middle-Level Tasks Provided in Procedure for high-level tasks	Sub-Tasks Not included in Procedure but provided by SMEs
Section 5.4 Survey Work Area	Verify Conditions Are Consistent with RWP Bases	5.4.1 Perform work area radiation and contamination surveys as needed to ensure the radiological conditions during work activities are consistent with worker briefings and within the ranges specified by the RWP and, if applicable, the ALARA Plan.	Survey immediately prior to beginning work if radiological conditions are unknown or potentially unstable.
			Survey on a frequency as needed to validate conditions are stable; comply with survey frequencies in procedures, RWP, and ALARA Plans when a survey frequency is specified.
			Survey immediately if changes in conditions are suspected due to anomalies from worker activities or plant conditions, e.g., system breaches, leaks, unexpected alarms, etc.

Function Section 5.4	High-Level Tasks Section 5.4	Middle-Level Tasks Provided in Procedure for high-level tasks	Sub-Tasks Not included in Procedure but provided by SMEs
	Verify Conditions Are Consistent with RWP Bases	5.4.2 Obtain air samples per FP-RP- NISP-03, Radiological Air Sampling.	*per FP-RP-NISP-03*
	Verify Postings Correct for Work	5.4.3 Pre-post areas prior to performing work that is expected to increase radiation, contamination, and airborne concentrations in accordance with FP- RP-NISP-04, Radiological Posting and Labeling.	*in accordance with FP-RP-NISP-04*
	Inform Workers on Conditions & Expectations	5.4.4 Communicate survey results to workers	Areas where stay time should be minimized.
			Areas where dose rates are the lowest.
			Desired body positioning to minimize TEDE while working in areas with high contact radiation levels or elevated radiation levels.
			Steps or conditions when workers need to stop to allow additional surveys or protective actions before proceeding.
			Where contamination levels are high enough to challenge the effectiveness of workers' protective clothing and the precautions that need to be taken.
			Preventative actions and work practices to minimize the spread of contamination and prevent airborne radioactivity.

A determination was made that additional information concerning tasks and sub-task beyond that provided in Table 1 was required to help identify possible innovations. Ten additional types of information were identified, primarily though application of cognitive task analysis, and shown in the right-most columns of Table 2.

Table 2 is a copy of the hierarchical task analysis (HTA) data collection tool that was developed to support the remainder of the analysis. It contains the following:

- The left-top, labeled Sub-Task presents sub-task information and is included here to represent the linkage between Table 1 and Table 2 which, when combined, formed the complete HTA analysis spreadsheet.

- An example of an entry in Table 2 is as follows: Sub-Task shown in left column, "Information needed to perform Tasks/Sub-Tasks" is shown in next column to right (1. Understanding of work to be performed and required equipment to perform work (job coverage requirements), 2. Familiarity with work environment, 3. Radiation and contamination levels (historical and current), etc.).

Table 2. Additional information needed from task/ sub-task analysis to permit identification of potential innovations.

Sub-Tasks Required (Sub-Tasks that are not included in the procedure?)	Information Needed to Perform Tasks/ Sub-Tasks (What information is needed to monitor, make and implement decisions, and get relevant feedback?)	Sources of Information (Where is this information found?) (e.g., procedures, manuals, direct observation, displays, verbal communication, knowledgable source such as person, etc.) Is obtaining any information problematic?	Actions performed to complete Tasks/ Sub-Tasks (What needs to be done to complete the task?) (Voice commands, controls actions, monitoring, record data) (e.g., actions used to provide two way communication between RP tech and worker or others)	Tools/Devices used to perform Tasks/ Sub-Tasks Cameras, dosimeters, laptops, radios, and other resources used and to change field of view/obtain readings from sensors/access stored data/etc. Are any tools/devices problematic?
Survey immediately prior to beginning work if radiological conditions are unknown or potentially unstable.	1. Understanding of work to be performed, and required equipment to perform work (job coverage requirements) 2. Familiarity with work environment 3. Radiation and contamination levels (historical and current) 4. RWP and ALARA Plan

Need to know what kind of work is being planned, where in the space the work will be conducted, low-dose waiting areas, what activities are being conducted, can we relocate people or body position to minimize exposure, e.g., can a shield be used (manually placed).

RWP - type in all the info we want. Dose and dose rate set points.

Need a pre-job survey. Planning procedure helps us determine max dose rate. Getting to the point where it's beginning to be automated.

Data from pre-job survey is needed. Might have to send somebody to go do it. | 1. Radiation Work Permit (RWP) and ALARA Plan 2. Memory, PTZ cameras, debriefing 3a. (Historical) Recent surveys, RP logs, Condition Reports 3b. (Current) Dosimeters, (GEDDS?)

RWPs - Old work orders are accessed to obtain information specific to the job. Typing in key words heps to identify relevant work orders. They have a speech-to-text option for this as well. Need to understand what you're looking for - drill-downs are there.

Historical job files - hard copies of previous work orders. Maybe reference them once a month. if it's possible to find it on the computer, would rather do it that way.

"Most info I need is on the computer." | Perform radiation and contamination survey. Determine: [1] work area dose rates, [2] contamination levels for area and components, [3] dose radiation particles (DRPs), [4] alpha particles, [5] travel path to and from work location, and [6] 'movable boundaries.'

"If you didn't document it you didn't do it."

Verify that readings are being accurately recorded.

Red pen on a hard copy is how data are currently captured. Then manually entered into the computer.

"Definitely one of the more time-consuming aspects of the job." | 1. Radiation Work Permit (RWP) 2. ALARA Plan if applicable 3. PPE 4. Dosimeter 5. Radiation contamination monitor?

Hard-copy tablet for writing down readings, radiation survey instrument, contamination survey instrument, bag or sack to keep gloves smears, etc. PPE.

A lot of techs take pictures with their of problem area with their cell phones.

PTZ cameras. Other hand-held digital cameras. Comms devices |

Number and type of workers involved (e.g., RP techs, supervisors, and workers)	Key Interactions with Others With whom? About what? How accomplished? (remote, face-to-face, etc.) Bottlenecks?	Criticality of the Interactions for Task Completion and Personnel Safety (e.g., increased radiation condition that possibly causes need for immediate action, time running out to complete the job before dose rate exceeded)	Estimated time to perform activity Low, Medium, or High (Used to evaluate opportunities for new devices that will reduce time to perform activity)	Estimated total dose for activity Low, Medium, or High (Used to evaluate opportunities for new devices that will reduce total dose to perform activity)	Difficulties Performing Sub-Task (Additional potential bottlenecks that previously were not identified.)
Most jobs will only take one person unless you need someone to help build the survey.

Supervisor, who reviews and approves the survey.

Maintenance workers will sometimes be asked to come along and show how they intend to go about the work, positioning, etc. We will sometimes make recommendations to the maintenance workers about body positioning, work processes, worker selection, etc. - particularly for major evolutions. | One rad tech is in the room and another who is remote.

Rad tech obtains survey approval from supervisor.

"Sometimes there can be bottlenecks with maintenance but 90% of the time there aren't." | "If we don't get the survey we can't plan the work and if we can't plan the work then we'll be holding up important activities - so it's critical that we get the serves when we need them." | 10-15 minutes to physically do the survey, approx. 15-30 minutes to record the data. How are the data recorded?

If a prior record exists, then recording the data might only take about 5 minutes. | All three - routine jobs might only pick up zero, others might pick up 5 mrem or 50-100 mrem | Worker body positioning blocks camera and may contribute to unnecessary radiation dose.

Camera location

Communications equipment.

Superimpose smear locations on map

Documenting and recording data |

The next step in the process was to use the information gathered in Table 2 and, in conjunction with utility partner SMEs, identify possible innovations. Specifically, potential innovation capabilities and descriptions were prepared for the Tasks and Sub-Tasks in Sections 5.4-5.8. INL HFE personnel identified HFE criteria to consider while evaluating potential Innovation capabilities. The INL team and utility partner SMEs then completed the HFE Criteria columns shown in Appendix B. Finally, potential Innovation Concepts were identified.

The next step was to evaluate and assign potential innovations to the priorities. This step in the process involved evaluating and assigning a priority level to each potential innovation. This grading of the potential innovations was performed to limit the number of potential innovations given serious examination by the utility partner at this time. Priorities were assigned as follows:

- A: High priority, with expectation that implementation would result in significant cost reductions
- B: Medium priority, with expectation that implementation would result in important cost reductions but not as much as innovations prioritized as A
- C: Low priority, with expectation that implementation would result in some cost reductions but not as much as innovations assigned A or B

Priority determinations were made by the utility partner, including RP technicians, other work area personnel, utility personnel concerned with new technology selection, and management. Table 3 and the other information previously prepared by the INL/utility partner use case team was provided to utility personnel who discussed, evaluated, and assigned priorities to the 25 potential innovations. The far-right column in Table 3 provides prioritization results.

Table 3. Potential innovation prioritization results shown in right column.

Potential Innovation Capability	Description	Comments	Potential Innovation	Priority A - High B - Medium C - Low
Automated data entry	(e.g., source data automation, auto-population sensor, and other data)	Survey data (standing at certain point it would record data; auto-populate versus manual entry) May want to expand remote monitoring to capture data. There are some resources in the field now. Moving to next steps discussed before. Will be connected to wireless network.	GEDDS Lite (automatically take data and display on survey map) GPS mapping of room with grid locations (e.g., push button and dose is shown on map) MIRION.	B.
Electronic Forms and electronic transmittal	Replacing paper and need to hand carry hardcopy e.g., to obtain signature	With tablet in field already (half group), able to utilize electronic forms. Reduced risk of paper loss. Utilizing forms now for most part.	Tablet with capability to support filling out form.	C.
Real-time tracking and display of radiological data, worker position (e.g., GPS), dosimeter locations, etc., on a spatial (e.g., 3-D) map	e.g., Shown on display such as by virtual 3D model with visual indication of location shown together with other required information such as equipment location	3D mapping, GPS, triangulation would be a great feature to know exact location. Great if there was a remote alarm to tell someone where they can and cannot be.	Company came in previously for 3D mapping. MIRION is working on GPS for dosimetry (2-3 years ago). Haven't had recent conference.	B.
Manual performance of selected tasks performed by RP tech in radiological area, e.g., moving something	Remotely perform task using something like Da Vinci system used to support surgery			B Still requires the RP tech to drive the robot. Would only save the rap from the dose.
Automated scanning of paper-based information	e.g., scanning of form filled in automatically to eliminate need for manual data entry	ALARA files (paper records are historical) Have scanner now but it would take months to scan it all in.	Need something that is more efficient in scanning.	C have to be a machine that can do the scanning

Potential Innovation Capability	Description	Comments	Potential Innovation	Priority A - High B - Medium C - Low
Automated transmittal for survey approval	e.g., electronic communication to supervisor where signature is required	Refers to surveys that need to be approved. See row 2.		C it's something they go in and see everyday
Auto-flagging areas where surveys are needed	e.g., GEDDS Lite	VSDS scheduling software already installed and performs this. Works well. Sends message that shows what surveys are due by months/week. You enter freq. and survey.	Works well.	C. if not then it would be a B.
Ability for remote workers to perform their own smears	e.g., worker in radiologic area performs smear without RP Tech		No, but there was a NISP on self-coverage. But with unions decided not to implement.	C not a good idea at this time. The training performance does not work out.
Remote smears/ Automated smears (e.g., via robots)	RP Tech located at remote location controls device	Considerations with dose rates and SW reliability (Survivability)	Robot capable of doing smears and performing analysis. Drones?	B able to have the rp not receive the dose. The autonomous is the key part.
Cameras, remote dosimeters, with AI/ML or Robots or Drones	e.g., camera on stick (health physics) controlled by RP tech in work area or remotely		Not yet. Spot is the only one talked to recently. Robots/Drones (see comment about Survivability)	A having a robot that is outfitted with a camera. RP would be located in the RMS.
Remote air sampling	(e.g., with robots or drones)	If you had autonomous vehicle + robot/drone, wouldn't need driver. Could relay information in real-time.	Automatic on/off? See left column (autonomous vehicle + robot/drone)	B was also including a software interface that could be activated with a computer program.
Portable Access to data and spreadsheets, procedures, or anything needed to support task performance in real time	(e.g., laptops, tablets, glasses, etc.) accessed from any location	Half department has tablets See row 2. Tablets now are very good now.	Gestor-based control with glasses.	A. Currently have the tablets and laptops. Allowing them to view hands free will be helpful
Automated transport of sample to lab	(e.g., robots, drones, etc.) to move sample from place of origin to desired destination	See row 11.	Robots/drones.	B. Samples trash or anything and would fit in columns with the robots.
Automated/ electronic signage information selection at entrance to work area or elsewhere	(e.g., electronic displays with preplanned signage selected remotely with cameras to verify correct message shown)	Can't use electronic postage now (e.g., High Rad; NRC regulated, and some is through NISP. For informational it is acceptable (e.g., display dose in area).	Electronic signage;	C
Wearable technology for RP tech and worker	(e.g., cameras, dosimeters, position sensors)	Ability to change setpoints (can't right now). Some at other stations had concerns with wearables.	See comments above on wearables.	A. Related to number 12
Pre-scripted Briefings presented to workers	(e.g., videos) possibly with RP tech to answer questions		Videos	C their sister plant used this method and it went over well
Designated Briefing Room with equipment to support and speed up briefings	(e.g., brief workers in room with videos and other support -- currently done in trailer)	Currently designate a room (e.g., lunchroom). Have large screen TVs in room but not used for COVID. Skip		C have remodeled access control and a room can be

Potential Innovation Capability	Description	Comments	Potential Innovation	Priority A - High B - Medium C - Low
				used as a briefing room
Auto-calculations of data automatically collected or manually input	(e.g., trending)	Train data right, inform workers based on conditions. Currently manual.	Something that provides capability of informing workers using data. GEDDS Lite	B. have to find out from it where the data is stored and how long it is stored. Could be an A if they receive answers from their IT department.
Auto capture of dose and link to alarm setpoints	(e.g., reduce need for RP tech to continually monitor), alarms shown to RP tech and worker	Talked about giving percentage or graph. See something trend. Time based alarm (X number of minutes until you hit Y%).	RMS has a lot of functionality but does not lay out. Enhancement to SW? MIRION? Currently calculates stay time but does not update live time with lower and higher dose.	B if just rp can see it A if the worker in the field could receive the information
Auto notification of backup crew	(i.e., reduce time for backup crew to takeover job)		Automated identification and notification of backup crew.	C for RP A or B for other departments
Automated monitoring of workers' stay times	(e.g., RP tech can monitor more than one worker)	Currently used at plant		A for audible to the worker B or C if only to rp
Faster air sampling and analysis	(e.g., drone, robot, or fixed sensor)	Talked about adapting field common analysis or more localized gamma spec SW.	MIRION makes Spirrow ID (used for shipyards)	A. Because of their sister plant. Review if a way to speed this up.
Automated Visual Analysis of Camera Footage	(e.g., fast-time viewing of footage) When procedure requires review	Looking for boundary crossing, monitoring heavy lifts, RWP or high contaminated boundaries, workers touching faces. Good to know where in the time of the video that event occurred. Only can go x2 now in video.	Visual capture analysis technology (motion detection to stop fast-forwarding).	C they can set motion sensors in their software where it won't record all of the time
Handling of radioactive materials	(e.g., robots, drones, etc.)	See rows 11 and 13		B but if more automated would be an A same theme with root discussions.
Automated alarm presentation	(e.g., Alarming for dosimetry is not in place to measure extremity dose when required per Attachment 7 of procedure.)	See row 19		C.

4.4.1   Innovation Identification and Selection

The final step in the process involved the identification, evaluation and selection of possible innovations The purpose of this activity was to select and present information about possible innovations to the utility partner for its decision whether to proceed with further study or development.

The RP use case team decided to consider only potential innovations prioritized as A or B. It was determined that the amount of time and resources required to consider priority C innovations was beyond current scope. Potential innovations prioritized as C can be further evaluated in the future, if desired.

The utility identified three potential innovation categories of highest priority.

- Wearable Technology
- Robots and drones
- Air sampling

The utility partner provided the RP use case team with information about innovations fitting the categories previously identified. This included information about innovations currently under consideration and companies that might have devices of interest. The RP use case team contacted numerous companies, reviewed trade magazines and product brochures. Several videos were obtained showing potential innovations in action. A presentation was prepared and presented to a group of utility personnel providing a description of the entire RP use case project, including a section providing a description of commercially available innovations identified as part of this activity. Some of the results of the possible Innovation search are presented in the discussion of innovation categories shown below.

The RP use case team reviewed the priority A and B potential innovations listed in Table 3 and Table B-1 and assigned potential innovations to the three categories. The results are shown in Table 4 for the wearable technology category, Table 5 for robots and drones, and Table 6 for air sampling. Numbers in the left column of Table 4, Table 5, and Table 6 are the same as in the left column of Table B-1. The remaining columns in the three Tables contain the information for each potential Innovation from Table 3.

4.4.1.1 Wearable Technology

Wearable technology is also generally referred to as "wearables." It is a category of electronic and computer-based devices that serve work-related and job performance functions, and that can be worn as accessories, embedded in clothing, worn as glasses, etc. The devices are hands-free, powered by microprocessors and enhanced with the ability to send and receive data via the Internet or other communication means. Potential innovations considered to be wearable technology are shown in Table 4.

Table 4. Potential wearable technology innovation concepts that were used to search for possible innovations.

No.	Potential Innovation Capability	Description	Comments	Potential Innovation	Priority A - High B - Medium C - Low
12	Portable Access to data and spreadsheets, procedures, or anything needed to support task performance in real time	(e.g., laptops, tablets, glasses, etc.) accessed from any location	Options: Tablet or wearable	Y. Transitioning to the tablets for more hands free operations. Y. innovation team has brought them some Realware last year.	A. Currently have the tablets and laptops. Allowing them to view hands free will be helpful.
15	Wearable technology for RP tech and worker	(e.g., cameras, dosimeters, position sensors)	Options: Tablet or wearable	Y go pros they can use to capture but does not live stream. Y. Microsoft working on something for live stream and need real time live stream for the camera. Y. could change setpoints remotely	A. Related to number 12

There were two possible interventions identified. Video discussions were conducted with a representative of each possible innovation company and videos of some innovations in use were obtained. Some of the information and videos were presented to the final use case study meeting with the utility partner. Information and innovation videos are not included in this report. Capabilities and costs are changing rapidly, and the team did not request approval from the companies providing the information to include it in a generally available INL report.

4.4.1.2 Robots and Drones

Robots and drones are machines or devices (usually programmable by a computer) capable of carrying out a complex series of actions, sometimes automatically. A robot or drone can be guided by an external control device, or the control may be embedded within the device itself. Robots and drones are task-performing machines, designed with an emphasis on functionality. Some robots and drones are autonomous and following programming can sometimes operate autonomously and perform programmed tasks without human intervention. Semi-autonomous robots and drones, for example, can perform tasks autonomously once authorized by a human. The device may be authorized to move from point A to point B autonomously and then stop. The human can authorize the device to perform the next task, perhaps to perform a swab on a wall autonomously. A robot or drone also may be manually controllable, requiring a human operator to continuously control it. A robot performs its tasks while on a surface, such as a floor, while a drone, which may be designed like a helicopter or airplane, flies, and performs its tasks while hovering or moving. Robots and drones used in NPPs, and other industries usually have vision and communication capabilities, as well as collision avoidance capabilities to prevent injuries to humans and damage to equipment or itself. Some of these devices can be used beyond line of sight and in small areas.

Robots and drones typically are designed to carry loads that can support RP and other capabilities. For example, a robot or drone can carry an air sampling device and move it through the area where air samples need collecting. Robots and drones provided by different companies have different capabilities, and the one(s) selected should have the demonstrated capabilities to perform the tasks for which it was selected.

Potential robot and drone innovations are shown in Table 5. There were five possible interventions identified. Video discussions were conducted with a representative of each possible innovation company and videos of some innovations in use were obtained. Some of the information and videos were presented to the final use case study meeting with the utility partner. Information and videos about the possible innovations are not included in this report for the same reasons as presented in the wearable discussion above.

Table 5. Potential robots and drones innovation concepts that were used to search for possible innovations.

No.	Potential Innovation Capability	Description	Comments	Potential Innovation (Drones may also be considered)	Priority A - High B - Medium C - Low
4	Performance of tasks performed by RP tech in radiological area	Remotely perform task using robot	Options: RP tech drive the robot or autonomous	Robot controlled by RP tech from outside radiological area or autonomously	A if autonomous B if RP tech drives robot (would save the RP tech from dose
9	Collect smears remotely	Remotely perform task using robot	Options: RP tech drive the robot or autonomous	Robot controlled by RP tech from outside radiological area or autonomously	B if RP tech drives robot (would save the RP tech from dose) but autonomous preferred
10	Place, move and operate cameras, dosimeters, etc., from outside radiological area	Remotely perform task using robot	Options: RP tech drive the robot or autonomous	Robot controlled by RP tech from outside radiological area or autonomously	A if RP tech drives robot (would save the RP tech from dose) but prefer autonomous
13	Automated transfer of sample to laboratory	Move sample, trash, or many things from place of origin to desired destination	Options: RP tech drive the robot or autonomous	Robot controlled by RP tech from outside radiological area or autonomously	B if RP tech drives robot (would save the RP tech from dose) but autonomous preferred
24	Remote handling of radioactive materials	Remotely perform task using robot	Options: RP tech drive the robot or autonomous	Robot controlled by RP tech from outside radiological area or autonomously	A if autonomous B if RP drives robot (would save the RP tech from dose

4.4.1.3   Air Sampling

Air sampling involves the collection of samples of air to measure radioactivity or to detect the presence of radioactive material, particulate matter, or chemical pollutants in the air. The purpose of air sampling is to determine if measures to confine radioactive and other material are effective, to measure airborne radioactive or other material concentrations in the workplace, to estimate worker intakes, to determine posting requirements, to determine what protective equipment and measures are appropriate, and to warn of significantly elevated levels of airborne radioactive or other materials.

Potential air sampling innovations are shown in Table 6. There were two possible innovations identified. Video discussions were conducted with a representative of each possible innovation company and videos of some innovations in use were obtained. Some of the information and videos were presented to the final use case study meeting with the utility. Information and videos about the possible innovations are not included in this report for the same reasons as presented in the wearable discussion above.

Table 6. Potential Air Sampling Innovation Concepts that were used to Search for Possible Innovations.

No.	Potential Innovation Capability	Description	Comments	Potential Innovation	Priority A – High B - Medium C - Low
11	Remote air sampling	Remotely perform task using robot	Options: RP tech drive the robot or autonomous	Remotely perform task using robot	B was also including a software interface that could be activated with a computer program.
22	Faster air sampling and analysis	Reducing air sampling times using drone, robot, or fixed sensor technology	Options: RP tech drive the robot or autonomous	MIRION makes Spirrow ID (used for shipyards)	A. Because of their sister plant and goes back to CHP and does a review if a way to speed this up.

4.5   Recommendations

A series of recommendations were generated from the analyses described above, and these were presented to the utility partner upon conclusion of the effort. They are classified as either near-term or longer-term. Near-term recommendations are those which are potentially achievable given the current state of the requisite technology. Longer-term recommendations include those that will require further technology development and testing.

4.5.1   Near-Term Recommendations

The following near-term recommendations were made:

- Utility partner should review the potential innovations identified in this project and determine if they want to further investigate and determine if implementation of innovation(s) is desirable.

- Utility should decide if it wants to apply the remaining part of a UCD process not that were not completed (see Figure 2) in this project as part of deciding whether to implement an innovation.

- It is recommended that a utility consider application of the current work to a new plant activity (e.g., maintenance, operations, and support) or a different RP procedure to evaluate and validate the process. Evaluation of the results will provide a qualitative and quantitative assessment of the value of the process in reducing plant costs and improving efficiency, effectiveness, and overall plant performance.

- Utility should contact and possibly visit other plants that are now testing or applying innovations identified in this project.

4.5.2   Longer-Term Recommendations

The following longer-term recommendations were made:

- Utility should continue to monitor developments in AI, ML, and robotics (including drones). These technologies are maturing at a rapid rate and afford many potential advantages in terms of reducing costs while maintaining safety and performance at very high levels.

- Wearable technology, including wearable sensors, is another area of rapidly changing technology with many affordances for NPP operation. Utility should closely monitor technical developments in this area.

- Utility should train staff on use of analysis and design tools used in this work and described elsewhere (Dainoff et al, 2020; Hettinger et al, 2020) so they can be used to help effectively integrate future technical and organizational innovations.

4.6   Conclusions

Major conclusions from the RP use case effort are:

- The process and results from this use case are expected to be applicable and scalable to many other plant activities in addition to radiation protection. For example, maintenance procedures could be analyzed for jobs requiring two workers, such as performing inspections in a radiological area or verifying a manual repair task has been performed correctly. A program goal of reducing costs might be achieved by reducing the number of workers from two to one or zero. Function and task analyses could be performed, and possible innovations identified. A robot or drone innovation might be found for the inspection task, possibly eliminating the need for two workers and their exposure to radiation. An innovation based on wearable smart glasses with camera might be identified to permit verification that a repair task had been performed by the plant worker and verification performed by another worker at a remote location. The person located remotely may be able to perform verifications and other remote tasks at several locations during a work period thereby reducing number of workers at several sites to one rather than the two required before. Another example is the need to reduce time and costs to inspect possible leaks high in a building. Function and task analyses may show that to perform the inspection scaffolding needs to be erected and dismantled, shielding needs to be installed and removed, and a worker needs to climb and descend the scaffolding to perform the inspection. A drone may be identified as a possible innovation. If implemented and successful, the drone could reduce significantly both time to perform the inspection and labor costs.

- The design process described in Section 4.4 and Appendix B and illustrated in Figure 2, although not fully completed due to the limited scope of the use case, satisfactorily supported the development of innovative design concepts. This process has potential application across all areas of plant modernization involving human interaction with new technologies and processes.

- The use case analysis and design effort resulted in identification of several potential innovations (robots and drones, wearable technology and air sampling) that were presented to the utility for further action.

- A demonstration plan to apply a UCD/HFE process and methods to help determine if it is possible to transform RP operations into a more technology-centric, IO model was prepared and as much of it implemented successfully as possible within the scope of this project.

- The sociotechnical method and tools methods applied in this project were found to be effective.

5.   IONFORMATION SUPPORT USE CASE

5.1   Introduction

The second use case, the IS use case, focused on analysis and design activities geared toward developing technical and procedural innovations to support NPP management decision making. A 'management by exception' approach to issue resolution, such as those related to performance gaps that are typically addressed during management review meetings (MRMs) is proposed as a means of increasing efficiency of the issue-resolution process without sacrificing thoroughness of review.

To provide technical support for this novel approach, a prototype information dashboard is also proposed as a starting point for further development and test. Drawing on the proposed functionality of information objects, the dashboard supports automated data gathering and analysis, high-level issue summaries and resolution status with corresponding drill-down into more detailed information. The dashboard, available to management personnel on the organizational intranet on a 24/7 basis, will also support the ability to share, discuss and resolve issues outside of formal review meetings.

5.2   Use Case Overview

The specific use case selected to begin the process of developing potential technical and procedural innovations across the broader management domain involved forcing function meetings and, in particular, MRMs. Forcing function meetings, such as MRMs, are often very time-consuming for all involved. In addition to management participants, others within the organization devote significant amounts of time to gathering, analyzing, and preparing PowerPoint presentations to support them. The opportunities for efficiencies in this use are twofold: increased efficiency of data gathering, analysis and presentation through the automated capabilities of information objects, and increased efficiency of the meetings themselves by means of the management by exception approach supported by an advanced information dashboard concept.

As with the RP example, the IS use case seeks to improve the integration of organizational PTPG assets and capabilities. These include People (a new, management by exception approach) Technology (information objects and a 24/7 dashboard), Process (revised meeting procedures), and Governance (more efficient means of management oversight of critical organizational goals and objectives). A presumed outcome of this effort will be reduced length of MRMs.

5.3   Objectives

The objectives of the IS use case were as follows:

- Propose an information support system combined with governance modification (management by exception) to enable improving efficiency of forcing function meetings such as MRMs, particularly with respect to assurance capabilities. The goal is to support more efficient means of management oversight of critical organizational goals and objectives.

- The MRM information support will include development of an information object system for gap analysis and management. The information object for each gap will integrate relevant documentation related to management of that gap. The information object system will be made available 24/7 through a dashboard interface that will allow readily usable access to critical information needed to support gap management and decision making.

- The governance modification includes increasing efficiency by affording the possibility of limiting discussion of MRM agenda items using the *by exception* principle. In combination with

the information support system, this allows managers to preview key elements of gaps prior to meetings and select for review only those requiring high level management scrutiny at MRMs.

5.4   Method

The specific methods and procedures employed in this use case are systematically described and categorized below. However, the actual process of development was iterative, involving alternating between development of a prototype demonstration, interviews with SMEs, and follow-on analysis. However, as with the RP use case, the IS use case adopted a general UCD framework, implemented by means of several different sociotechnical tools and methods.

5.4.1   Conceptual Development of the Information Object Concept

In analyzing forcing function meetings such as MRMs, and other data review activities, consideration was given to identifying potential functional requirements of the information object concept (see Figure 3). These included:

- It must be a self-contained information structure (perhaps a tree structure or a relational database structure) with the ability to gather, analyze and summarize data from across the full, required breadth of organizational databases.

- It must have interactive display capability, such as pre-defined, human-factored graphics. The displays could have multiple options (data, graphs, etc.), support quick and shared understanding, allow drill-down into the underlying data, and provide links to related documents.

- In addition to manual creation, it must have some degree of capability of auto-populating data using a variety of techniques (data base queries, Excel-level analysis and graphics, AI/ML, etc.)

- The structure must have a dispositioning element to it in standard form – issue, drivers, actions, reference documents. Management staff could indicate concurrence with the dispositioning of the item in a graded manner – concurrence with comments, non-concurrence, etc.

- The structure must be self-maintaining.
  .
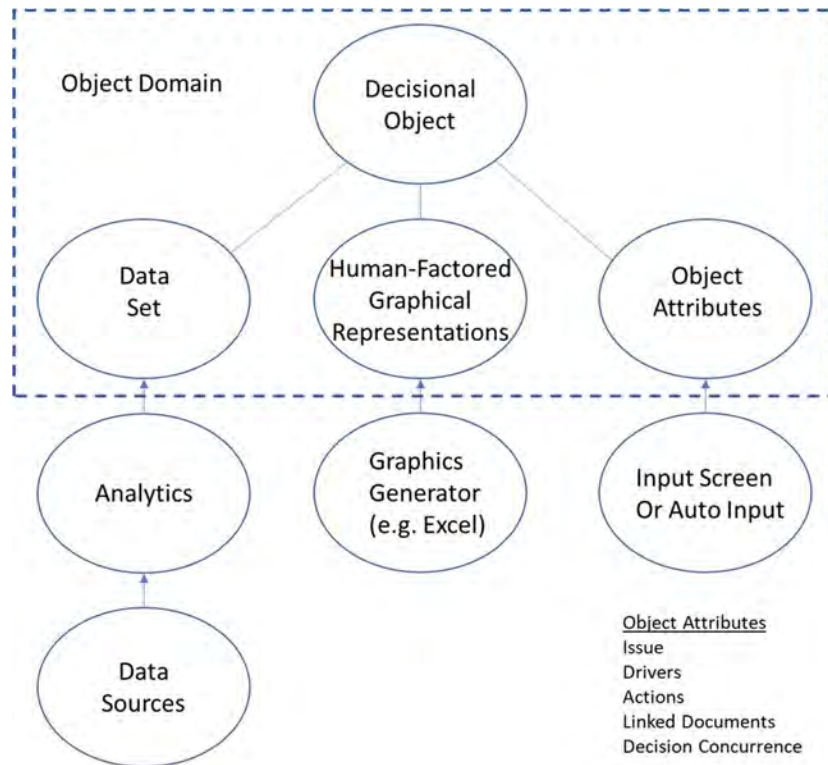
Figure 3. Information object domains and attributes.

A second early activity involved identifying the types of information objects that would be required to support the IS concept – decisional, informational (shared understanding), recognition, directive, etc. A review of a recent MRM information package, along with other related sources, were used to classify each type of information presented into one of the information object types. That information was used to help determine the potential structure and content for each type of information object. Creating a dashboard would then be a matter of pulling in the reusable information objects that are needed. Information items would be accessible through the NPP business network. They could be reviewed individually, aggregated in any way that serves a business purpose, and used in MRMs.

Forcing function meetings in general, and MRMs in particular, could be greatly streamlined by reviewing information objects by exception. In this case "exception" does not mean that the information fails performance expectations, but that a management member objects to the disposition of the item as contained in the information object. In other words, the person registers non-concurrence with how the item was resolved. More specifically, this would mean that the person had looked at the information item prior to the meeting and, if applicable, had looked at the performance shortfall – drivers – actions, and registered non-concurrence, with the justification residing in the information object itself. Only these items would be reviewed in the MRM. This format would provide an evolutionary path away from formal forcing function meetings to where the organization *asynchronously* reviews items at the appropriate level of management and only with items requiring broad management attention to be discussed at formal meetings.

5.4.2   Methods and Tools Supporting Implementation

The task of organizing the contents of the information object just described can be considered a Knowledge Representation Problem within the sociotechnical framework outlined in Dainoff, et al. (2020). As previously noted, we are here limiting our consideration to the gap analysis and detection function of the assurance capability within the PTPG framework. Thus, we envision a collection of

information objects; each comprising the various sources of information, such as Corrective Action Program (CAP) and Institute of Nuclear Power Operations (INPO) reports, associated with a particular gap and its disposition. The Knowledge Representation Problem for gaps involves organizing and displaying this information in a manner such that possibilities for action and the associated consequences of such actions become evident to the viewer/decision maker. In the MRM context, this would typically involve assessing how effectively a given gap was dealt with and whether there were ongoing issues or lessons for future operations.

One way to view this problem is that our goal is to improve the situation awareness of an MRM attendee with respect to gap analysis and review. That goal will be reached using a combination of sociotechnical methods described in Dainoff et al (2020). They include Ecological Interface Design, as outlined in Bennett and Flach (2011). Work Domain Analysis, (Vicente,1999) and STPA (Levenson, 2009). Using the logic of Ecological Interface Design (described Section 5.4.2.1) as a starting point, we see that a three-part solution is necessary. The first part involves understanding the situation (also called the work domain, or ecology of the system). In this case, such understanding involves the analysis of the contents of the information objects related to a particular gap, and the organization of these contents into meaningful chunks. In this context, "meaningful" means revealing possibilities for action and associated consequences. Work Domain Analysis, a component of Cognitive Systems Engineering (Rasmussen et al., 1994) is used to accomplish this task (see Section 5.4.2.2).

Having understood the situation, the second part of the solution involves understanding the awareness of the decision maker. Specifically, this means understanding the possible sets of actions that could be carried out by the decision maker given the information available and within the behavioral/cognitive capabilities of the individual. That is, what are the specific steps by which the decision maker identifies critical pieces of information which lead him/her to decide that this gap does or does not need further attention. Another way to describe this is to say that the goal is to allow the decision maker to establish a mental model of the gap information which corresponds to the physical reality depicted in the Work Domain Analysis.

The awareness component is analyzed through the STPA (Levenson, 2009; Thomas, 2019), described in Section 5.4.2.3. STPA uses the information structure of the Work Domain Analysis as a template or map upon which to superimpose potential control actions which can accomplish the desired goal. The resulting control structure diagram can be used to establish possible mental model structures. The concept of mental models is widely used in cognitive science and has multiple definitions. Practically, mental models are inferred cognitive structures belonging to individuals which provide information allowing them to function in the world. Mental models cannot, of course, be directly observed, but can be inferred from individual behavior. As a simple example, giving an examination or performance test after a training course can be considered an assessment of a trainee's mental model. When collections of individuals are said to be "on the same page" or have "common ground", this is equivalent to these individuals having overlapping mental models.

Finally, the third part of the solution is to integrate situation and awareness. This is accomplished through the actual construction of the interface/dashboard. This is as much art as science and requires integrating the findings of Work Domain Analysis with STPA. The meaningful chunks discovered in the WDA must be represented in the interface in such a way that the control actions can be effectively carried out with known cognitive capabilities of human actors. In the current situation the MRM decision maker should be able to use the dashboard interface to easily navigate the structure of the information object of a particular gap and, for example, examine the supporting evidence for a given driver statement. Therefore, the typical criteria of usability which should be part of any interface design must be combined with the necessity for correspondence between work domain and mental model. Bennett and Flach (2011) provide one of several sources of specific guidance how to accomplish this.

It is of historical interest that Cognitive Work Analysis methods originated in the nuclear industry, and that both ecological interface design and STPA developed from these origins. In fact, as described below, STPA is used in this project in place of Control Task Analysis—one of the original components of CWA. EPRI 3004004310 (2015) recommends the use of Cognitive Work Analysis rather than the more traditional Hierarchical Task Analysis for analysis of cognitive tasks characteristic of supervisory control tasks such as found in NPP control room. In this current project, we are making the argument that the same approach that has been successful for control room operators can be applied in other settings involving cognitive problem solving and decision making, such as forcing function meetings.

5.4.2.1   *Ecological Interface Design Logic*

The logic underlying our approach to conceptualizing the Knowledge Representation problem will be that of Ecological Interface Design (Bennett and Flach, 2011). Fundamentally, this entails an integrated relationship among three components, the ecology or work domain, the representation of that domain, and the underlying cognitive constructs used to understand the domain. The relationship between the representation (interface) and the elements of the domain are considered the *meaning* of the domain, whereas the relationship between the representation and the concept (mental model) is considered the *interpretation* of the domain. As stated above, "meaningful" means revealing possibilities for action and associated consequences. These possibilities and consequences are objective properties of the environment/work domain. On the other hand, "interpretation" refers to the individual's beliefs about the situation, as contained in his/her mental model. This distinction is central to Ecological Interface Design.

This logic is particularly relevant to safety-critical systems such as NPP in the sense that the user's mental model must be aligned with the physical constraints of the ecology. As such, this logic will be used to integrate our analytic methods such as Work Domain Analysis and STPA with the ontological analysis of structure of the information object.

5.4.2.2   *Work Domain Analysis*

Work Domain Analysis (WDA) is the first component of Cognitive Work Analysis. The utility of WDA for ecological interface design is that it characterizes the work domain in formative, rather than descriptive or normative terms. Simply put, this implies that WDA reveals the space of possibilities for action on the domain. This tool allows for characterization of the overall landscape of work, embodying all possibilities for action. A key step is the identification of what might be called intrinsic behavior-shaping constraints. These provide a boundary within which a variety of different actions are possible. This is central concept in CWA; the goal is to characterize this landscape at a level of abstraction which is independent of any particular technology. An example might be a road map. The indicated roadways are intrinsic constraints on the landscape which limit the possibilities for action for an ordinary driver and vehicle. However, within this set of possibilities, many alternative routes might be chosen. To continue the analogy, if off-terrain vehicles are available, such as in a military context, the domain would be better described with a contour map showing geographical features (streams, elevations) in more detail.

The WDA has two dimensions: the Means-End Abstraction Hierarchy, and Part-Whole Decomposition. The Means-End Hierarchy provides a logical framework for analysis of the functional possibilities for action within the work domain. This framework includes the structural relationships: WHY, HOW, WHAT. To pick a simple example: two people who live together have an appointment at the same place and time. The WHY question is one of basic goals: they need to get from where they live to location of the appointment. The HOW question might involve consideration of whether they will take one car or two. The WHAT question relates to which route they will take. Note that the lower-level question contains the *means* by which the *ends* of the next level are achieved. In a typical analysis, there are five levels in the hierarchy, and we can envision the WHY, HOW, WHAT questions sliding up and down the hierarchy. These levels are conventionally labeled as follows: Functional Purpose, Values and Priorities, Purpose-Related Functions, Object-Related Processes, and Physical Objects.

The second dimension of WDA is Part-Whole Decomposition. Most of the systems investigated using CWA are complex enough that the overall system requires decomposition into its constituent parts. In this example, each of the people described above will be driving independently, so a separate analysis might be done for each of them. For example, they may each have different tasks to accomplish on their way home.

The WDA conducted for the current use case has been carried out under limited interaction with utility partner SMEs. As such, it is necessarily somewhat conceptual, and it is expected that it will be revised after more detailed consultation.

5.4.2.3 STAMP and STPA

STAMP is a systems-theoretically based accident causation model (Leveson, 2011). In STAMP, the emphasis is shifted from preventing failures to enforcing design safety constraints. Safety is viewed as an emergent property of a complex system with multiple degrees of freedom. Safety is determined by sets of constraints which maintain control over the system. Therefore, control rather than reliability is the primary focus. The safety control structure (SCS) of the system maps out the interaction between controllers and controlled processes. The level of safety of a system depends on the extent to which safety constraints allow the system to avoid controlled processes which are hazardous. In this sense, the system can be said to be considered under control.

Within the overall conceptual framework of STAMP is a specific hazard analysis method called STPA. STPA has four fundamental steps:

1. Identifying possible undesirable losses and hazards
2. Modeling the SCS
3. Identifying unsafe control actions
4. Identifying loss scenarios (causal explanations for unsafe control actions).

Therefore, the STPA method, in general, can identify the safety constraints which must be in place to avoid/mitigate potential hazards. Constraints can be at the level of physical components, but accidents can result from dysfunctional component interaction, flawed algorithms and/or mental models, or organizational and social factors. The advantage of this approach is that mechanical and human control actions can be analyzed within the same conceptual framework; reinforcing the sociotechnical perspective towards systems engineering emphasized in Dainoff, et al (2020).

Practically, the SCS maps out the network of control relationships between controllers and controlled components in terms of command/control links and feedback links. As such, for the purposes of the current use case, it provides a specification of the action possibilities within the identified constrains of the work domain.

5.4.2.4 Interviews and Interactions with Subject Matter Experts

The INL Human Factors team had a total of seven meetings with utility partner SMEs once the IS use case was selected. In addition, selected members of the team were invited to observe an MRM. These interactions served as the primary opportunities for data collection and are summarized below.

5.4.3 Development of Information Support System

The initial approach to providing an IS system to improve efficiency of MRM gap analysis was the development of a series of information object templates. These were based on analysis of existing MRM information and initial interviews with SMEs. The results of this approach, which were reviewed with SMEs, are discussed below

Part way through the project development process, the decision was made to create a prototype demonstration of how a fully functional information object-based information system using the principle

of management by exception might look. The demonstration consisted of a simulation of a portion of an MRM in which only two gaps are reviewed in detail. Illustrations of the prototype displays used in the demonstration and SME reaction are contained in Section 5.5.1.7. As a result of feedback from the first demonstration, minor modifications were made in the second demonstration.

5.5   Results

Results are organized as follows. First, results of meetings and interviews with utility partner SMEs are described, followed by presentation of results from the WD, STPA and control structure analyses. The section concludes with a discussion of preliminary findings.

5.5.1   Interviews and Interactions with Subject Matter Experts

There were a series of meetings with SMEs, the contents of which directly affected the outcome described below. These meetings are summarized here.

5.5.1.1   Use Case Selection

The use case selection process is described more fully in Section 3. For purposes of completion, we summarize by indicating that there was dissatisfaction with the current structure and function of forcing function meetings, particularly the MRM. There was a strong desire to implement some sort of dashboard system with automated data collection and analysis. In addition, there were suggestions that portions of meetings could be replaced by offline reports.

5.5.1.2   Initial Kickoff Meeting

An initial kickoff meeting was held between members of the utility partner's Executive Planning Committee, as well as corporate general manager for nuclear operations, and business integration manager, together with members of INL HFE team. Salient issues raised by committee members are summarized as follows:

- MRM was selected as the focus of our effort.

- MRM has three functions: (1) Ensure execution to performance standards; (2) To find performance and assurance gaps and close them: (3) Peer review.

- End point vision: Top-down information management system identifying most valuable information. Provide managers with drill down capability for top level outcomes, but also bottom up in that lower-level workers can see how their input impacts high level metrics.

- Specific decision-making goals and informational needs: A need was identified for a clear set of dashboards with a simple scoreboard for each function. Also needs a consistent and standard style of presentation across the fleet ("common look and feel"). Information is sent both externally (NRC, INPO) and internally for decision making/work management. Goal is to discover and manage internal issues before they become external issues.

- Hierarchical structure of MRM: Fleet, Plant, functional group. Level within structure should determine information needs and decision-making. People at lower levels should be able to immediately see progress as well as top level management and external reviewers.

- There ae 263 indicators for which INPO requires data. The utility partner indicated that there is a lack of consistent nomenclature within its own organization and between itself and INPO.

- Currently MRM is like a presentation rather than a venue for decision-making. Presentations are rehearsed and opportunities to game the system are taken. Attempts are being made for more "organic" discussions of performance data in lieu of rehearsed performances.

- Support was expressed for a system in which potentially routine decisions are identified which could be both made and communicated in advance of the meeting. These decisions could always be reviewed during the meeting, if necessary, but in most cases, would not require the time and attention of all attendees.

5.5.1.3   Attend MRM

Selected members of the INL HFE team were invited to attend, as non-participating observers, a regularly scheduled MRM. The team received documentation for that meeting as well as the documentation for the previous MRM at that site. Appendix C contains a list of the data objects comprising the documentation for these meetings along with an initial attempt by the team to classify data objects into information object types.

5.5.1.4   Scope Definition Meeting

A follow-up meeting was held with two members of the utility partner's Executive Planning Committee and members of the INL HFE team for the purpose of narrowing the scope of the proposed work to specific, near-term deliverables. Salient issues raised by committee members are listed as follows:

- There was general agreement that the obsolete pyramid approach (many minor errors form the precursors of few major errors) from occupational safety to system safety is inappropriate. There is a lack of a system approach; characterized by an absence of process data on which to base corrective action.

- Much time and effort spent on the Corrective Action Program (CAP). This is a possible opportunity for innovations.

- It was revealed that INPO Nuclear Plant Performance Indicator (NPPI) scores are not strictly algorithmic. If the utility partner were to experience a drop in NPPI scores, data-oriented analyses of processes could provide a rational basis for a response to INPO without chasing individual events at the tails of the distribution.

- Individual items in MRM are presented because they are statistically at or near the bottom of the INPO metrics, and therefore automatically generate attention from top management. This may be inappropriate and a waste of resources. If there was a history of such events, their criticality could be identified with respect to high level operating metrics. The collection of appropriate data could indicate that variability of either physical components or human procedural action is within the tolerance zone of safe/ acceptable performance and could be ignored. Such data is currently missing from MRM.

- Potential next steps:
  - Decomposing MRM: examine MRM agenda and using sociotechnical methods and tools to make it more effective.
  - Examine forcing function meetings for specific functions: Examine information support needs and structure. Generalize approach to MRM.
  - The CAP process is a data-rich environment in terms of documentation. Can it be utilized in appropriate dashboards to support forcing function meetings in general and MRMs more effectively?

- Bottom line: "What information is important to the Chief of Nuclear Operations (CNO)? It's his meeting?"

5.5.1.5   MRM SME Meeting #1

The INL HFE team met with the member of the corporate Executive Planning Committee responsible for organizational performance and the Fleet Manager for Organizational Effectiveness & Performance Improvement. The latter has direct responsibility for organization and coordination of the MRM. Salient issues raised are as follows:

- The HFE team was briefed as to structure and function of the MRM. For instance, gaps are selected for review based on need for management follow up.

- Gap analysis provides an opportunity to deconstruct key plant performance indicators which are in variance. MRM may be first opportunity for high level/corporate management to assess impact of station-level gaps on overall station and fleet levels of performance.

- The nuclear score card varies between meetings. It presents a yearly set of targets for the business unit selected by a high-level management group.

- INPO is not transparent as to how the NPPI is calculated. It is known that NPPI is based on performance indicators, but the algorithms are not known.

- When an INPO indicator changes to a variant condition, there is no indication or notification to the plant.

- All materials for the MRM meeting, including INPO gap indicators, are assembled manually.

5.5.1.6   MRM SME Meeting #2

This was a follow up to MRM SME Meeting #1. Salient issues raised are as follows:

- The HFE team presented a flow chart which depicted their understanding, based particularly on the previous SME meeting, of the gap analysis and resolution process in the fleet. (See Figure 6, Section 5.5.3) The SMEs agreed that this was an accurate representation of the process.

- Proposed information object templates were reviewed with SMEs. They commented that the current CAP process is represented in the template and that it is important to have a template that can be used for a repeatable and re-scalable process for other meetings and situations.

- The purpose of MRM is for understanding what actions need to happen. It is a venue for problem discussion with management and to have a story line for any performance that is less than excellent. Gap selection for MRM review is a triage-like process assessing the meaning of the event for organizational performance.

- Event-based gaps are captured in CAP and performance indicators go into the INPO Plant Information Center (PIC) database which the NRC also sees. That system will tell them if they are in variance. Individuals enter plant data and CAP manually into the INPO PIC database. Self-identified plant trends and performance gaps are added by personnel. The plant may have indicators that are provided to the control room, but those do not coordinate with CAP. Nothing about what goes into the performance indicators is automatic.

- Potential next steps:

    o Standardized procedure for gap reporting and presenting with sources (site, fleet, INPO, NRC) and risk level identified.

    o MRM gap analysis should reflect high level discussion of issues serious enough to impact overall organizational behavior and performance.

- Currently, no linkage exists between INPO and utility partner data universes. Therefore, INPO indicators must be manually examined and extracted by utility partner personnel. This is highly inefficient.

5.5.1.7   Initial Prototype Demonstration

On the basis of the prior interviews, the HFE team developed an initial prototype of an information dashboard to support gap resolution both prior to and during an MRM. The displays that were generated and presented to the utility partner SMEs are reproduced shown below (Figures 4-8). The demonstration was presented by the HFE team to the same SMEs who were present at the previous meeting along with two other specialists in performance improvement.

The demonstration consisted of a scripted gap discussion and resolution scenario involving interactions among characters representing MRM participants. During the demonstration, which lasted for approximately 15 minutes, the SMEs viewed images of prototype displays that were developed by the HFE team based on earlier utility partner SME inputs. The prototype displays were described and demonstrated by the HFE team. Following the demonstration, the SMEs were asked to provide frank and critical feedback, a key component of an overall UCD process. These inputs resulted in minor changes that were incorporated into the design.

Figure 4 through Figure 8 represent the primary displays included in the prototype demonstration.
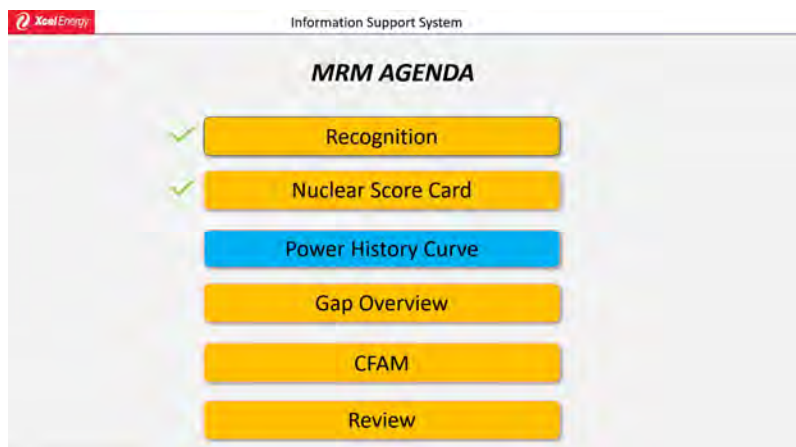
Figure 4. MRM Agenda Menu.

The MRM Agenda menu is used to display the agenda for the MRM meeting (Figure 4). All elements of the menu are selectable. Once an agenda item has been selected the user is taken to the agenda item display. Once the user returns to the menu the agenda item is checked off. Users can return to any previous checked off agenda item at any time during the MRM. In this example, Power History curve has been selected as the next agenda item while the Recognition and Nuclear Score Card agenda items have been checked off.
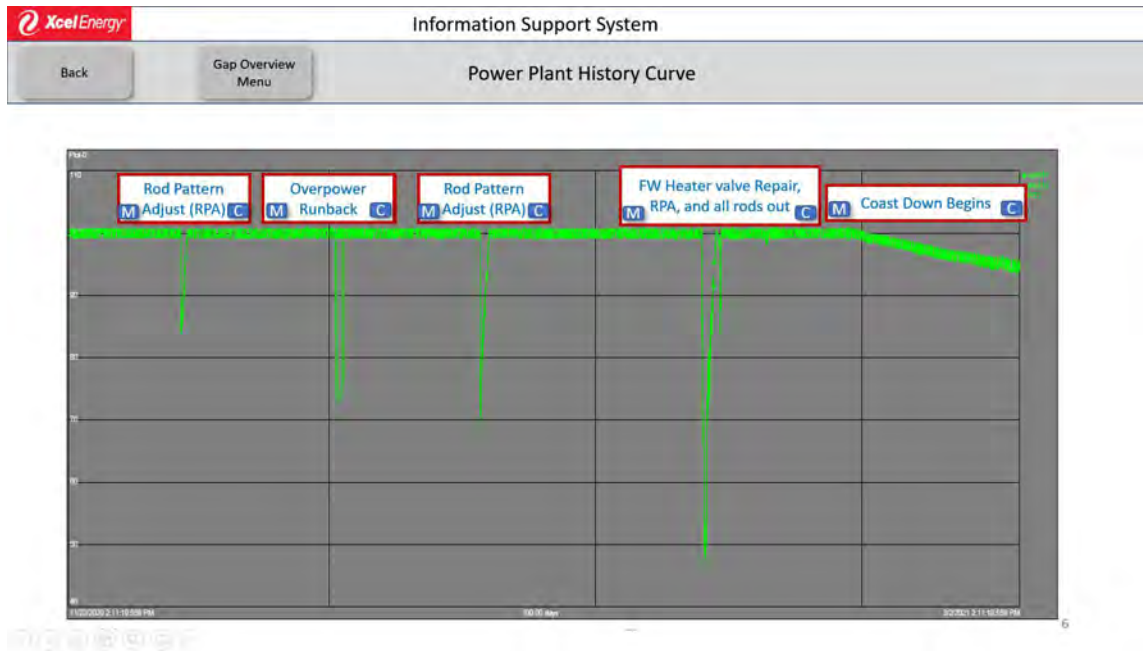
Figure 5. Plant history (overpower runback C is flashing).

The Plant History Curve is a part of the MRM Agenda (Figure 5). Menu "M" and Comment "C" icons appear on each item shown on the display. The C icon and item will begin flashing to show that there is a comment registered for review during the MRM meeting. The back button and Gap overview buttons are always available on the display to return to the Gap overview menu or to the MRM agenda menu.
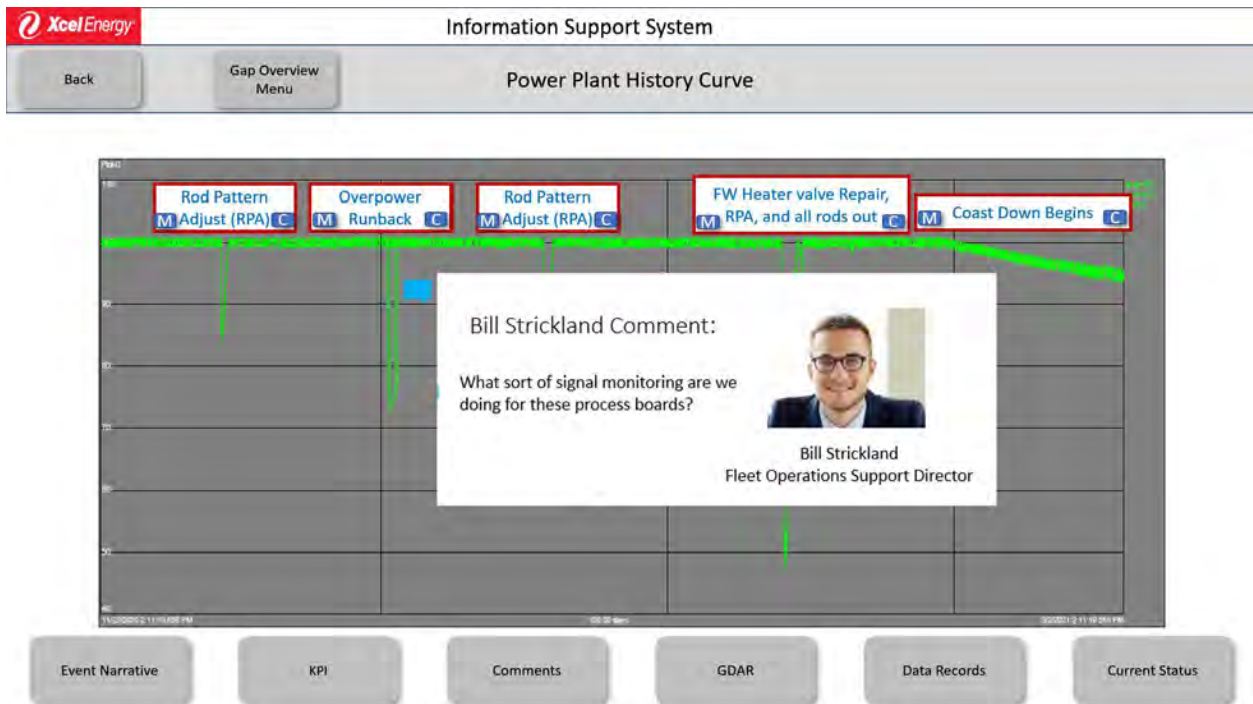
Figure 6. Overpower Runback (Comment and Information Object Menu Items).

Once the comment is selected a pop up with the question and employee name and picture will appear on the display along with a menu of options on the bottom of the display (Figure 6). The menu options allow the user to drill down to identify further information such as: KPI, event narrative, GDAR, data records, or current status.
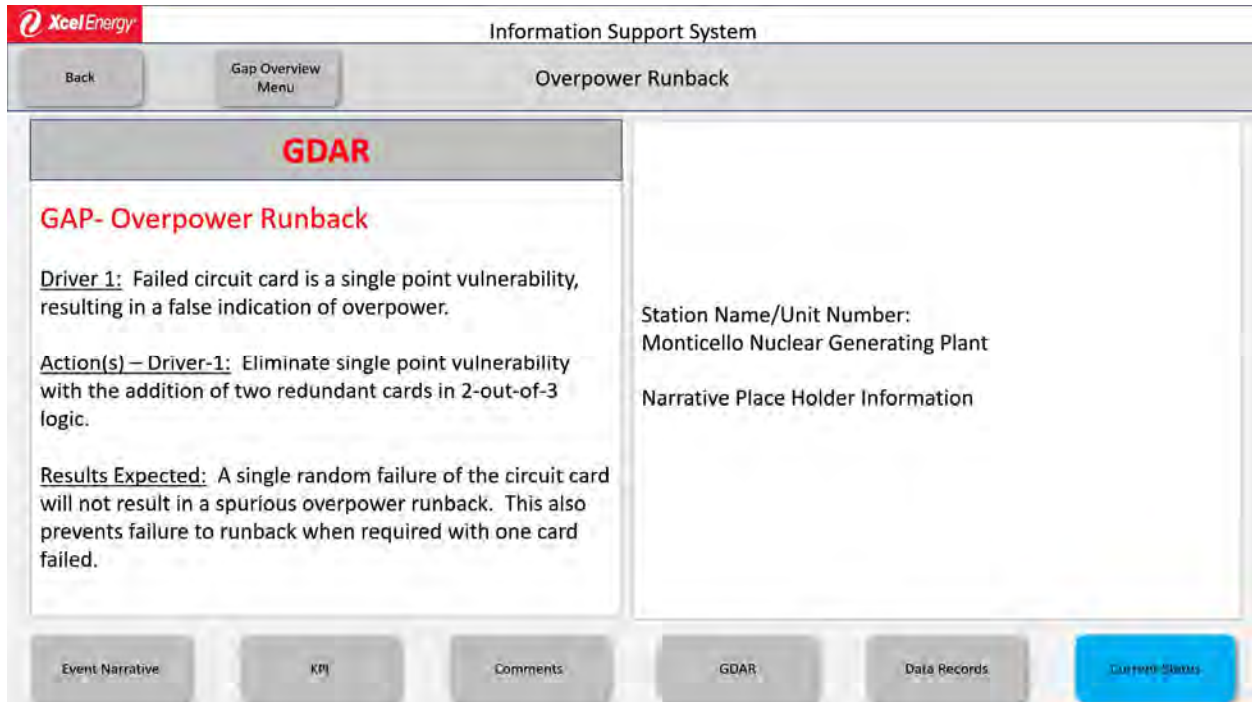
Figure 7. Overpower runback drilldown (placeholders for event narrative and GDAR: current status selected for next item).

Multiple items can be selected from the menu and shown on the display (Figure 7). The user can pan and zoom the information and place it on the display. In this example the user has the event narrative on the right and the GDAR information on the left side of the screen.
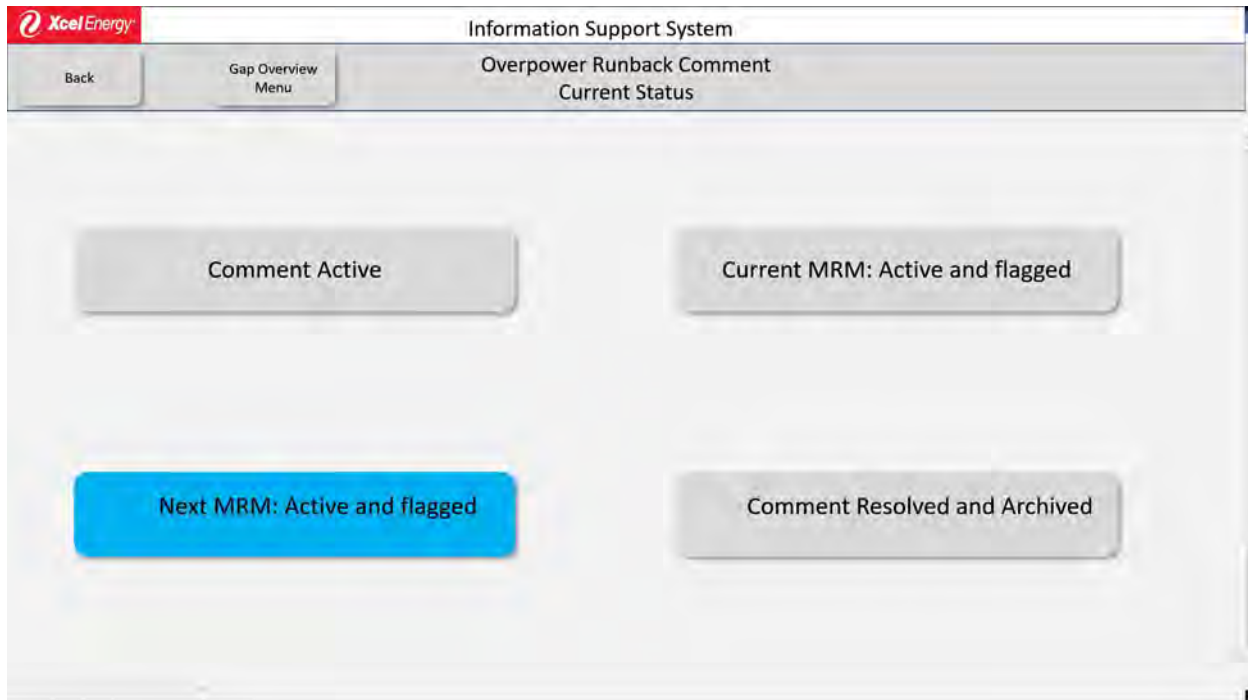
Figure 8. Overpower Runback (Current Status change).

The Current Status menu is used to display the status of a comment from the MRM Agenda (Figure 8). The current status of the comment is highlighted blue and can be changed by the user to be shown at the next meeting or archived if comments are resolved during the MRM meeting.

In general, of the overall flow of the prototype and layout of information and controls on the displays were received favorably. It was pointed out that some terminology, e.g., "gap, driver, actions, results" (GDAR) needed to be updated and modifications were made to the presentation to reflect these. In addition, it was suggested that the information object/dashboard structure had capabilities far beyond the MRM itself; being applicable to the entire process of gap management. There were also discussions related to organizational cultural issues with respect to the concept of management by exception. Participants expressed support for the concept, particularly in terms of supporting more efficient and less work-intensive processes but stated that it would involve a cultural shift that would require time and attention to implement.

5.5.1.8   Second Prototype Demonstration

A second prototype demonstration was conducted with a separate group of utility partner SMEs with expertise in data and information support for MRMs. The same procedure used in the first demonstration was used in the second. Once again, following the scripted demonstration the SMEs were asked to critique the design and suggest potential improvements.

In general, it seemed the concept generated significant interest and support, although with many questions and suggestions as to how it might be improved and implemented. A senior manager wondered how a more limited version of the system might be implemented sooner than the anticipated schedule for further development and test might allow. Another participant expressed his enthusiasm for the design with the statement: "I'm hungry for more; when do I get fed?"

An intriguing comment from one of SME was taken with reference to control room displays. He indicated his desire to see if the board was "all green." This describes a high-level overview in which, for example, a single display indicates the number of gaps at any given moment which are in or out of variance. This would certainly be consistent with the information object concept

With respect to the management by exception principle, there was once again discussion related to the possibility that these changes might be a cultural issue as well as technical/informational one. In other words, to what extent is there a need and/or tradition that "everyone should be able to talk about everything" during an MRM and that meetings should not be "artificially" constrained. However, unconstrained meetings tend to develop their own dynamics, and attendees often find that, while they have explored some issues in depth, they have not left enough time to address other, sometimes more critical, issues.

In a modernized NPP, it will be essential that efficient and timely management oversight be provided. To achieve this, culture change can be accomplished by top-down influence, but to be effective, this influence should be paired with tools which allow individuals to perceive that alternative governance approaches can have valuable operational advantages. This is purpose of the proposed information support system. While, the demonstration was focused on MRMs, it has been pointed out that a major potential benefit of such a system would be the opportunity to preempt problems, such as coordination failures, ahead of time, so that they never get to the MRM. Exploring these possibilities on a pilot project level would be a very fruitful area of exploration, particularly in the context of implementing the management by exception principle.

In conclusion, the demonstrations provided a potential end state vision of an information object/dashboard information support system that was favorably received. The SMEs were excited about the concept, displays, etc. and expressed that they look forward to its continued development in the next phase of the work.

5.5.2   Work Domain Analysis

The WDA analysis results are depicted in Figure 9. The information upon which this analysis is based was derived from the initial sets of SME interviews and, as such, is necessarily conceptual in nature. The same analytic framework could be refined once additional SME information is obtained to include more specific information. This would be particularly valuable in relating relevant gap-related information in current data bases to potential information objects.

Within the WDA, two separate categories of analytic objects are defined (Little, 2011). SPAN objects capture spans of time; specifically referring to processes. SNAP objects capture a "snapshot" of reality in the sense that such objects can be described in terms of objects or collections of objects. In the WDA,

SPAN objects have this form ⬭ whereas SNAP objects have this form. ▭ In more fine-grained analyses, there are many varieties of SNAP-SPAN relationships. For example, processes require objects to be implemented.
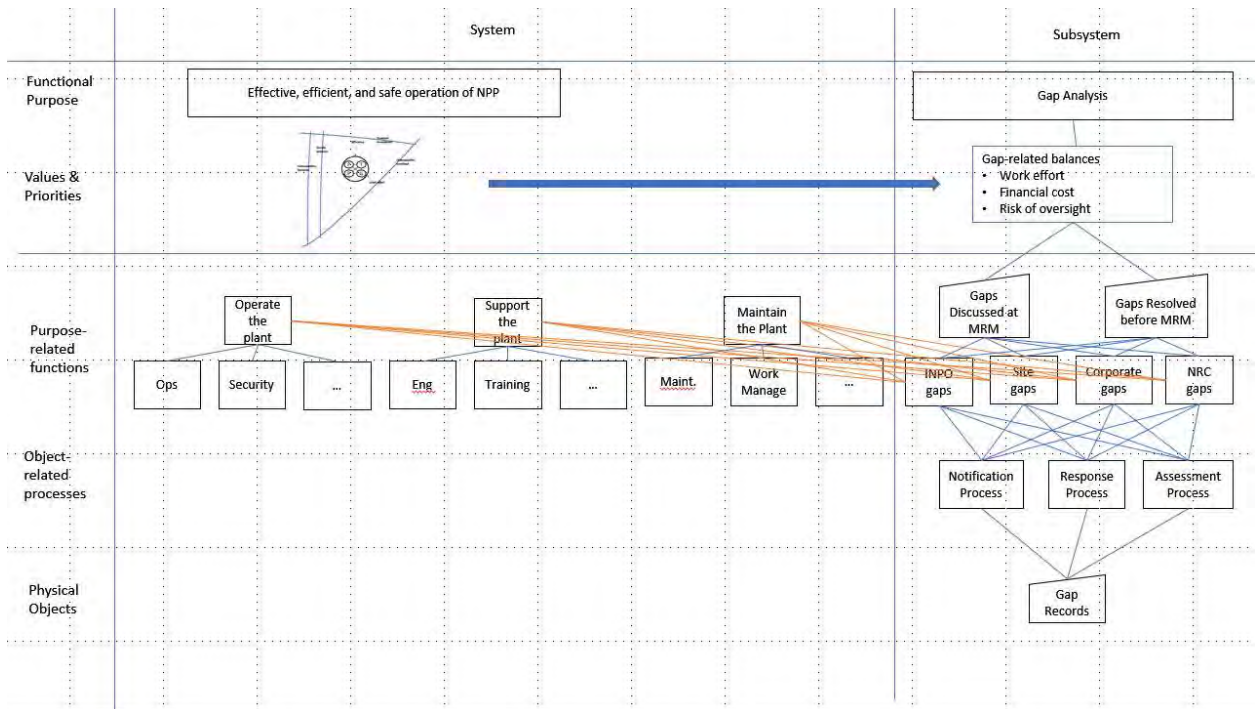
Figure 9. Full work domain analysis.

Examining Figure 9, the vertical dimension represents the means-ends abstraction hierarchy while the horizontal dimension corresponds to the part-whole decomposition. Starting at the top left, the Functional Purpose at Systems level is described as effective, efficient, and safe operation of the plant. The Values and Priorities level contains the means of accomplishing Functional Purpose ends. Priorities and Values description is an integration of the PTPG model with the Rasmussen et al (1994) description of the "Brownian movement" of daily plant operation (see Figure 10 for an expanded depiction). It represents the continuous interaction among PTPG components during daily operations while attempting to maintain balance among competing demands of safety, workload and efficiency. The sides of the figure represent boundaries to be avoided. The Efficiency vector pushes the PTPG system away from the boundary of financial breakdown. The Least Effort vector pushes the PTPG system away from the boundary of unacceptable workload. Rasmussen argued that these two vectors, in excess, might push the system toward the boundary of unsafe behavior. The gap between this boundary and the boundary of unacceptable behavior is considered the margin of safety for plant operation.

Figure 10. Functional purpose supported by values and priorities.

The means of accomplishing values and priorities are accomplished at the level of Purpose related function level. In this case, these functions are based on the utility partner's three primary functions (Operate, Support, Maintain) and associated specialized functions.

At this point, further domain analysis shifts along the part-whole decomposition axis to the subsystem level, which in this case relates to the functional purpose of gap analysis, a critical component of the Assurance capability. Following the logic of the stack model, PTPG relationships at overall system level are applied to specific function of gap analysis at the subsystem level.

At the purpose-related function level, the first example of SNAP object-type classification appears. Previous examples have all been SPAN objects or processes. This is the point at which list of gaps to be discussed at MRM are separated from list of gaps resolved prior to MRM. The sources of such gaps are further broken down (INPO, site, corporate or fleet, NRC). Sources of gaps are mapped under three major functions at the system level.

At the level of object-related processes, there are three generic processes by which gaps are analyzed. In principle, these apply to each of the four gap sources. There are systems by which the relevant actors are notified of the existence of gaps, there are systems by which relevant actors respond to gaps, and there are systems by which relevant actors, typically mangers, assess the response to gaps. In more detailed analyses, each source could be depicted with its own component further along the part-whole decomposition axis.

Finally, gap records are located at the physical object level. These are, of course, SNAP object items. In more detailed analyses, these records would form the structure of proposed information objects.

5.5.3   STPA

Figure 11 was presented to, and reviewed by, SMEs. It was used as a basis for STPA control structure analysis. It depicts, at a generic level, the existing processes of gap analysis and review. The control structure analysis which follows will impose on this structure a formative approach presenting possibilities for a By Exception set of review procedures.

Figure 11. Basis for gap analysis summary reviewed by SMEs.

5.5.3.1 Control Structure Analysis

Figure 12 depicts the Gap Review Control Structure Analysis. It is based on the information structure contained in the Gap Analysis Subsystem section of the WDA depicted in Figure 9. It must be again emphasized that this is necessarily a generic analysis based only on the preliminary SME input used to construct Figure 11 while, at the same time, depicting the possibilities for a management by exception process. Further, by examining the relationship between the subsystem and full system in Figure 9, it can be seen that each of the gap sources depicted could be further broken down in terms of General Functions (e.g., Operate, Support, Maintain) as well as subfunctions.
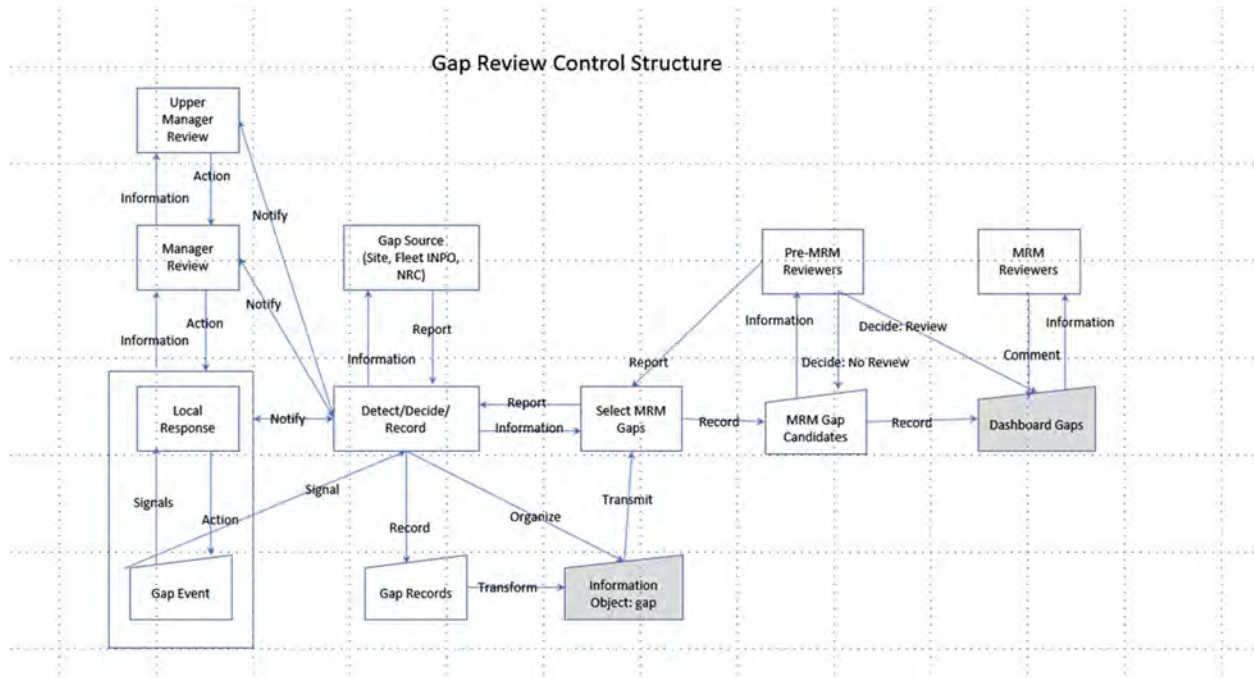

Figure 12. Gap analysis summary reviewed by SMEs.

The control structure uses the same ontological graphic conventions as the WDA, differentiating between processes (SCAN) and objects (SNAP). See Section 5.1.2. Each of the process components can have inputs (information/feedback) and outputs (control/action). The two shaded objects represent the proposed new information support technology: information objects, and dashboards.

The lower left of Figure 12 depicts a gap event. This is some physical action which signals the initiation of the process. This event is responded to by some action at the local level. At the same time a presence of the gap signal is received by the Detect/Decide/Record function. This, in a sense, "officially" defines the event as a gap. The gap information is recorded in Gap Record storage and is sent to relevant levels of management as well as the relevant Gap Sources. Gap information, in turn, is sent as a report from Gap Sources. (For example, this reflects our understanding that raw information is transmitted from the plant to INPO and then later received as a color coded INPO indicator.)

The Gap Record storage is a placeholder for the utility partner's various data universes where CAP and other gap records are currently stored. However, a (proposed) control action originating from the Detect/Decide/Record would organize each relevant piece of information from each gap into a different data base consisting of separate Information Objects for each gap.

The left side of the figure reflects normal business practice. That is, first level management would review the local response to the gap and possibly initiate further action. Second level management might likewise review the actions of first level management.

With respect to the PTPG framework, the analysis so far has included Process and Technology. The Governance aspect would be reflected in the remaining components of the right-hand side of the figure, which instantiates the By Exception policy. The People component will, in this analysis, refer to required human capabilities to enable system to function.

The Select MRM Gaps component is coupled with the Detect/Decide/Record function. Using information derived from the information object data base, existing active gaps are reviewed to decide whether they should be selected for review at the MRM. The material stored in the information object data base is used as a basis for this decision. The list of review candidates is stored in a separate data base. Prior to the MRM this data base is made available to MRM reviewers. In the Pre-MRM Reviewers component, each of the MRM attendees is asked to make a decision on each candidate gap as to whether it should be selected for active review during the MRM or whether it has been successfully resolved or otherwise dealt with. This is the operational definition of management by exception. Links to the information objects of those gaps selected for review are sent to the Dashboard Gaps location. During the actual MRM, each of the selected gaps is reviewed in turn. Required material stored in the relevant information object is made available through the Dashboard to the attendees during the discussion. Comments and requirements for further action become part of the information object. (Not shown in this analysis is the activity of the Detect/Decide/Record component implementing these further actions later).

The control structure analysis just present is only a portion of full STPA process. In many cases, this analysis alone can present valuable insights on procedural and organizational gaps. However, utilization of the full STPA process can provide a much deeper level of analysis and insight into possibilities for improved function. Cost benefits resulting from such analyses have ranged from 30:1 to 100:1. A more complete discussion of the potential implementation of a full STPA analysis in a subsequent phase is contained in Appendix D.

5.5.4   Preliminary Findings from WDA and STPA

The preliminary findings from the STPA which are, in turn, based on the WDA, provide a logical structure for an Information System incorporating a new method for conducting MRMs. These findings can be discussed within the context of the PTPG framework. Specifically, the Governance component introduces a management by exception mode of gap reviews to utilize MRM manager discussion time more efficiently. The Process component introduces process changes in which gaps traditionally selected

for MRM review, are pre-reviewed prior to the meeting, and only those specifically identified "by exception" are actually reviewed at the meeting. The Technology component includes provision for an information object and set of dashboard displays which support the processes and governance changes already described. Finally, the People component identifies aspect of human capability development related to critical aspects of gaps which are candidates for MRM review and those which are not.

5.5.4.1 *Preliminary Findings from Template Approach and Relation to Information Object*

The template approach to the information support problem was based on analyses of MRM content and interviews with SMEs, as integrated with the information object concept as discussed above as well as the management by exception principle. Accordingly, a preliminary set of templates incorporating elements of an information object related to gap analysis and disposition were developed.

Appendix C contains an example related to an INPO indicator. The assumption was that the information object elements could be generic enough that the same template structure could use gaps originating other sources, such as site, fleet, and NRC. Importantly, it was also assumed that information objects would be incorporated into an information support system which was broadly available 24/7, so that gap analysis and disposition could be a continuous process, rather than restricted to MRM. This would allow a management by exception principle to be implemented such that MRM gap discussion could be limited to items which could potentially impact overall organizational behavior and performance. The templates were reviewed with SMEs. They agreed that the CAP process was well represented in the template.

5.5.5 Preliminary Findings: Practice Oriented Discussion

This use case originated in a request from our partner company to improve the effectiveness of forcing function meetings, such as MRM using a dashboard system. The INL HFE team realized that since the core issues at the root of this request were embedded in fundamental upper management practice, a straightforward human factors design approach would be unlikely to be successful. Accordingly, an iterative strategy evolved. It involved a successive series of meeting with high level company SMEs, combined with the integration of multiple conceptual frameworks. These included: the PTPG Capability Stack model as embedded within the overall ION approach (Thomas et al., 2020), the emerging concept of information object within data science (Schmidt and Otto, in preparation), and the methodological tools available within the sociotechnical framework presented by Dainoff et al (2020). To keep the process manageable, we adopted a specific goal which was to improve the efficiency of the MRM. Early on, it became clear that major component of MRM time was spent on gap analysis and review. Therefore, we further limited our scope to gaps.

What evolved from these discussions was a developing concept of an information support system built on an information object architecture providing an integrated and 24/7 source of gap information. This technological system would be linked to a governance innovation called Management by Exception. This innovation required process and behavioral changes in that mangers would be expected to take responsibility to examine the set of gaps typically selected for MRM review in advance of the actual meeting. At that point, each manager would decide if an individual gap represented issues which were significant enough for senior management discussion, or if lower-level managers had adequately dealt with the issue.

As discussed above, we were essentially trying to enhance the manager situation awareness. However, to do that effectively required that the information support system would clearly allow managers doing their pre-meeting review easy access to information allowing them to make their decision.

Our initial approach to the knowledge representation problem was to design a series of templates which convey an initial attempt at the structure of gap information objects. This approach was based on our, albeit limited, understanding of the gap analysis and resolution process. However, later on, we decided to take a different approach. We would design a short demonstration which would comprise a simulation of a fully functioning information object-based dashboard system being used in the conduct of a management by exception MRM. In effect, the purpose of this demonstration was to provide an end state vision for what an information support system might look like.

We designed and conducted this demonstration and initial feedback indicates that we are at least on the right track.

5.5.5.1 Components of the End State Vision

Key components of the end state vision that emerged as a result of these analyses are as follows:

- Governance:
  - Introduces a change to a management by exception mode of gap review to utilize MRM manager discussion time more efficiently in support of Assurance capability development.
  - Still maintains full organizational oversight of plant performance and assurance.
- Process/People:
  - Gaps (from site, fleet, INPO, NRC sources) are reviewed and resolved, if possible, before MRM.
  - Gaps are selected for MRM review using current criteria.
  - Information regarding selected gaps provided to MRM attendees. Default mode is that gaps NOT discussed at MRM unless specifically flagged by attendees in their pre-meeting review. (Management by exception mode)
  - MRM gap discussion limited to items pre-selected.
- Technology:
  - Information Object: The information relevant to each gap organized in a single data source is called an information object. Much of this material already exists in other forms, such as CAP reports and INPO reports. The Information Object has the following characteristics:
    - Self-Contained
    - Display capability (dashboard)
    - Auto-populating ability interacting with other data universes
    - Disposition capability in standard form: issue, driver, actions, reference documents
    - Automatic archive capability
    - Monitors its own health

  - Dashboard Display: The information object provides the source and capability for various dashboard displays.
  - Dashboard displays are available 24/7 to enable continuous improvement types of resolution of gap issues.
  - Dashboards provide a hierarchical drill down structure (Summary/Information Object Menu/Content) to allow access to information at level of detail necessary and to allow space for comment by managers and stakeholders.

5.5.5.2 Pathways to the End State Vision

Underlying our efforts to create templates and a demonstration, and in parallel with them, we applied the human factors methods outlined in Section 5.4.2 and described in detail in Sections 5.5.2 and 5.5.3. These methods are meant to lay out a logical framework which might provide a set of pathways to the end state vision. As we indicate in those sections, the WDA, STPA, and EID perspectives which integrate

them, are all necessarily formative in the sense that they represent possibilities for action as opposed to describing current state or prescribing a desired state.

The WDA can be considered a map of possibilities. As discussed in Section 5.4.2, this map provides the logical framework for construction and definition of the higher and lower levels of the information object architecture. As seen in Figure 9, the horizontal (part-whole decomposition) dimension of the graphical representation of the work domain represents the full operation of the plant on the left side and the specifics of gap analysis on the right. The vertical (means-end) dimension on the left depicts the overall operation of the plant. The upper levels of the analysis indicate, in abstract terms, the functional purpose of the system – to operate the plant efficiently (minimum cost), effectively (achieve production goals, and safely (avoid human and property damage.) The means of achieving these purposes are described at the values and priorities level in terms of the criteria which need to be met in order to achieve the functional purpose. In this case such criteria are represented in terms of three sets of boundaries: financial breakdown, unacceptable workload, and unacceptably unsafe behavior. The daily work of the plant—indicated by continuous interaction of PTPG components—is effectively moved away from these boundaries by signals (vectors) coming from the organization. To anticipate, one purpose of a well-designed interface would be to provide clear indicators of when the system might be approaching any of these boundaries.

The purpose-related function level depicts the three major functions (Operate, Support, Maintain) and associated sub-functions needed to achieve the functional purpose within the constraints of the values and priorities. At this point in the analysis, it is considered appropriate to shift to the right side of the diagram to the sub-system level devoted to gap analysis.

The means-end analysis at the sub-system inherits the overall system functional purpose, and values and priorities, but these are restated in terms of the specific needs of the sub-system. Thus, the functional purpose is gap analysis. The values and priorities balances and trade-offs have the same form as in the full system, but are redefined in terms of cost, effort, and risk of oversight. Moving down a level, the primary purpose-related functions reflect a partition of gaps into those to be discussed at an MRM, and those considered resolved prior to the MRM. Gaps in either of these two categories can be further categorized as to their source: Site, Fleet, INPO, NRC. Further, each gap could also be mapped onto its corresponding full system function (Operate, Support, Maintain) or subfunction.

The remaining two levels of the means-end analysis for gaps consists of abstract placeholders for a large amount of specific detail. Object-related processes reflect three logical generic processes – notification, response, assessment—that should be carried out on to some extent on each gap. Finally, physical objects reflect the actual records documenting the processes at the previous level.

As previously stated, the work domain analysis is necessarily abstract and conceptual, given the limited access the team has had. Further, the analysis was specifically designed to support the particular limited end state vision of gap assessment at MRM. Thus, for example, the gap subsystem would, in reality, be embedded in a higher order system devoted to the Assurance capability. However, it is important to emphasize that while the details of the analysis can and should change as more information becomes available, but the basic logic of the structure will remain unchanged. It is this logic which provides the pathway to the end vision. In particular, filling in the details of this structure would be a necessary first step in defining the components of an information object architecture.

Figure 11 depicts the INL HFE team's understanding of the functioning of the gap analysis process. Given assurance by SMEs that this understanding was accurate, STPA was utilized to construct a formative control structure analysis of the proposed information support system (Figure 12). This analysis

depicts the actions which would need to be taken by various actors in the system to accomplish gap analysis as depicted in the end state demonstration. The control structure consists of relationships between controllers and controlled entities. Some entities can play both roles. The controller sends control signals to the controlled entity and receives feedback signals in return. These entities can either be mechanical systems or human agents. If either of these signals are problematic, the system will not function properly. As discussed in Section 5.4.2, human agents use information available in mental models to send control signals and respond to feedback. This constitutes the awareness side of situation awareness.

The left-hand side of Figure 12 depicts the normal flow of business with respect to gap identification and response. Gap events occur, are responded to at a local level and reported. These responses are reviewed/monitored by different levels of management. The right-hand side of Figure 12 depicts the additional control actions needed to support the end vision information support system. This diagram assumes that gap record information has been organized into the information object/dashboard system available to all relevant actors. It represents two levels of selection. The first, which already occurs in in the current system, identifies gaps as candidates for MRM review. The second level of selection implements the management by exception principle by requiring MRM attendees to pre-screen the list of candidates for review. An important assumption of the proposed system is that, unless an explicit exception is made, the gap will NOT be reviewed at MRM.

Section 5.5.3.1 describes the control structure in detail. Appendix D describes the potential application of a full STPA in which potentially unsafe/unacceptable actions are described and scenarios described in which potential mental models explaining why such unacceptable actions are proposed.

The actual construction of an information object-based dashboard according to ecological interface principles requires that the situation be described in sufficient detail to allow the construction/definition of information objects. The contents of these objects must, in turn be represented in the interface in a form that the control actions depicted in Figure 11 can be quickly and easily carried out. However, as has been emphasized above, for safety critical systems, it is essential that there is correspondence between the physical reality depicted in the details of the work domain analysis, and the resulting mental models used by human decision makers to carry out their control activities. The same considerations would be applied to the AI-based algorithms used in place of a mental model by an automated decision-maker.

In the present work, an important issue, which has not yet been considered in detail but is potentially critical, has to do with the actual criteria used to decide whether or not a gap has been appropriately dealt with, or requires further discussion at higher levels. Understanding the dynamics of this issue would be critical to the way in which the various components of the gap information object are structured, and the way in which the organization of the user interface does or does not allow ease of access to these components. Unpacking these issues with appropriate SMEs would seem to be an important early step to the pathway to the desired end state.

5.6   Recommendations

5.6.1   Near-term recommendations

- Move the demonstrating version of the MRM dashboard interface to a more advanced, interactive prototype stage and pursue further development by user-in-the-loop type activities such as cognitive walkthroughs with early versions and human-system performance evaluations with more mature, interactive products.

- Continued development of information object concept with specific application to the MRM use case. This will, in all likelihood, require interactions with data scientists at INL and the utility

partner in order to work toward the eventual development of a prototype in conjunction with the interface work described about.

- Move toward a proof-of-concept demonstration.

5.6.2 Longer-term recommendations

- The current work, while primarily focused on supporting MRM, is not intended to be limited to it. Rather, MRM was selected as a test case in the hopes that the resulting design will generalize well to other plant information support requirements.

- We recommend that broader development of the information object concept be explored across the full breadth of plant assurance and maintenance needs.

- In conjunction with the above, developing displays and interfaces with which to access and interact with information objects should also remain an objective, Additionally, striving for a 'common look and feel' across interface-information object interactions across the plant will assist ease of operation and lessen training requirements. Development of a style guide with specifications and descriptions of the interfaces would be useful for guiding consistent development.

- AI and ML applications should also be considered if a clear business case for doing so is identified.

5.7 Conclusions

The results demonstrate that the user-centered design approach and sociotechnical methods and tools employed in this use case resulted in a prototype information support architecture (information object) and interface concept (information dashboard) with potential for addressing management decision-making and issue-resolution tasks. The case of forcing function meetings and in particular, gap resolution at MRMs provided a context within which to develop an innovation based on the use of advanced technologies and associated processes.

6. DISCUSSION

In this section we discuss findings from the current work from the perspective of their application to the utility partner's business and operational needs, and their relevance for future application of sociotechnical methods and tools in support of complex systems design. Implications for the ION concept are also discussed.

6.1 Method and Toolset

One of the objectives of the current work was to employ appropriate sociotechnical and HFE methods and tools to support the design of advanced human-technology systems and associated procedures for specific NPP work activities. A related objective was to assess the ability of the methods and tools to support key design activities, including the identification and description of potential prototype systems and their high-level system requirements.

The results demonstrate that the methods and tools applied in the two use cases were able to effectively support the development of design concepts that may be of significant near-term value for the utility partner. They also resulted in the development of innovative design approaches (e.g., Appendix B) to support such efforts. HTA and nominal group technique approaches applied to the RP use case supported the identification of specific aspects of job performance that could be enhanced with available COTS technology. The direct involvement of SMEs throughout all aspects of the effort helped assure that the analysis process and resulting design suggestions were corresponded with the utility partner's requirements and constraints. The IS use case, while also involving SMEs throughout the analysis and design process employed different tools. A user-centered approach using WDA, CWA and STPA were

used to identify bottlenecks and issues in current procedures and associated technologies related to forcing function meetings such as MRM, and thereby identify and develop opportunities for improvement. These include the concept of management by exception, the information object, and supporting human-system interfaces.

6.1.1 Outcomes and Potential Next Steps

In each use case, the sociotechnical and HFE methods and tools that were used resulted in prototype designs (in the IS use case), and suggested design approaches (in the RP use case) that were positively received by the utility partner. In each case, the utility partner also expressed enthusiasm with the prospect of moving forward with the design concepts. Therefore, the next phase of work would primarily involve the further refinement of the prototype concepts leading to eventual usability and proof-of-concept testing with interactive systems.

For each use case, further development might best be accomplished within the context of an interactive prototype (for IS) and candidate COTS technologies (for RP). This would enable further analysis of the design through user testing with representative work scenarios. Simulation has been used for decades to support effective human-system design and may be an effective path forward for the IS use case. Further development in the RP use could perhaps follow a slightly different path. Specifically, when the utility partner makes a decision regarding the potential technologies and procedures it is interested in pursuing, user-in-the-loop assessments under various operationally relevant scenarios can be conducted to further refine the design.

6.1.2 Generalizability of methods and tools

The methods used in this work were applied to two quite different application areas within the realm of NPP activities. In both cases, a successful, preliminary design outcome was achieved. This indicates that the sociotechnical and HFE methods and tools of the sort used in the current work can effectively support the design of prototype technical systems and associated procedures in two very different work settings. Specifically, the methods used effectively incorporated user input, identified weaknesses and opportunities in current systems and operations, and produced design concepts and recommendations that were well-received by the utility partner.

As the designs and recommendations derived from this work are matured and developed to scale, there will continue to be opportunities to assess the value and generalizability of the method and tools. Examples of these methods supporting the successful development of complex sociotechnical systems, such as in the North Sea oil and gas industry's implementation of an IO approach, strongly suggest that these approaches will also be successful within the nuclear power domain.

In general, then, the results were very encouraging in their implications for the value and generalizability of the toolset described by Dainoff et al (2021). Further refinement of sociotechnical methods and tools for NPP systems analysis and design will be accomplished in the following phases of this work.

6.1.3 Industry Feedback

The utility partner's feedback regarding the outcome of the use case analysis and design processes (i.e., the proposed innovations) as well as the analysis processes used to were generally positive. Although no direct feedback was solicited, the utility partner noted the following:

- Processes and procedures were clear and easily understood. For example, during the RP use case task analysis process the RP Tech serving as primary SME, having demonstrated a clear understanding of the use of the HTA tool, was able to solicit inputs from additional RP Techs. This not only contributed additional information to the design but demonstrated that the tool could be usefully applied by individuals without any specialized training in HFE.

- Feedback regarding the proposed design approaches indicated that the utility partner has significant interest in continuing to pursue their development. The information object and related dashboard concept were positively received in SME design sessions, from which they also received critical design inputs and suggestions. The analysis and design approach used in the RP use case, as well as the design suggestions that arose from it, were the subject of a presentation by a senior utility partner stakeholder at the LWRS Plant Modernization Stakeholder Meeting in August, 2021, and were favorably discussed.

6.1.4 Lessons Learned

Several key lessons learned emerged from the current work:

- A common challenge with UCD efforts is gaining and maintaining sufficient access to subject matter experts throughout the analysis and design processes. This is particularly problematic in NPPs where the sort of individuals who would make good SMEs are often already so busy that they may only have a limited amount of time to spare. As a result, SME time is precious and should be efficiently made use of.

- In the RP use case, the time required for HTA sessions turned out to be substantial. Reducing the amount of time required to conduct HTA (and similar analyses) should be a priority. In the RP use case, the principal SME was able to quickly learn how to complete the HTA form on his own. This turned out to be a significant time-saver and enabled the principal SME to gather HTA information from other SMEs.

- More extensive Operational Experience Reviews would be helpful in identifying issues of potential relevance to current design issues and opportunities.

- Designers should identify and contact nuclear power plants and other industries and organizations, and suppliers using advanced technologies and procedures such robots, drones, and other innovations for information early and throughout the design process.

- There is a general need to be prepared to adjust the initial analysis and design plan as the project progresses and unforeseen circumstances arise. This is very frequently the case in a complex system setting such as an NPP where expertise resides in individuals who have multiple demands on their schedules.

6.2 Implications for ION Systems Development

The principal implications of the current work for the continued maturation of the ION model are related to the products of the design efforts and the methods employed in their development. Regarding the latter, it is important to bear in mind that while the product design has focused heavily on the potential uses of advanced technologies for achieving design objectives, there has been an equal focus on the potential reorganization of personnel activities which, in combination with the technical systems, can help achieve company goals.

The results are encouraging in that they demonstrate the existence of effective means of designing the types of integrated sociotechnical systems that are needed to support more cost-efficient NPP operations. However, more definitive assessment of the implications of these findings on the ION concept will proceed as the designs and procedures identified in the current work are more fully developed going forward.

6.2.1 Methods and Toolset

User-centered design, and an approach to systems design that emphasizes the joint optimization of personnel, technical and procedures with a corresponding governance model, are concepts that appear to be readily grasped by SMEs and stakeholders. Our utility partner SMEs and stakeholders found the

method and tools that were use were understandable, both in terms of why and how they were to be employed as well as their relevance to the broader design process.

While the rationale underlying the use of the methods and tools was clearly understood in each use case, the knowledge needed to confidently use the tools without the aid of specialists was only specifically addressed in one case, i.e., the use of HTA in the RP use case. While the rational and logic behind the use of WDA, CWA and STPA appeared to be well understood by SMEs, the opportunity for them to apply the tools on their own did not arise.

6.3 Summary

The methods and tools used in this effort resulted in design suggestions that were favorably received by the utility partner. Going forward, these designs require further refinement through the development of prototype systems that can enable user-in-the-loop testing for purposes of proof of concept and verification testing

A number of potential modifications and improvements to the overall approach and sociotechnical methods and tools used in the work were identified. These included a recommendation to work toward making analytic and design procedures more efficient in their use of SME time, which is typically very limited. Also, instructing SMEs on the use of specific methods and tools, such as HTA, may increase the overall efficiency and quality of the data gathering process. It would also provide the utility partner, in this case, with the in-house personnel capability to conduct future activities of these sorts without necessarily needing outside expertise.

7. INTEGRATION OF METHOD AND TOOLSET INTO THE ION METHODOLOGY (ICAP) AND INNOVATION PORTAL

One of the objectives for the current work was to assess the utility of sociotechnical methods and tools in supporting the design of effective, efficient, and safe technologies and procedures to support NPP modernization efforts. Another objective involved the integration of the tool set into both the ION methodology and its associated ION development application known as the Integrated Operations Capability Analysis Platform (ICAP). As described above (Sections 1.2.1 and 1.2.2), ION applies a method designed to assist in developing innovations for NPP work functions to enable them to be performed safely within the constraints of a market-driven budget.

Methods and tools such as those used in the current work that are made available within ICAP could significantly aid other modernization efforts that involve modifications to technologies and/or procedures in which human activities are involved. Incorporation of these methods within ICAP will help ensure that human factors issues are considered alongside issues of technical and business functionality so that the optimum PTPG balance is achieved from the beginning.
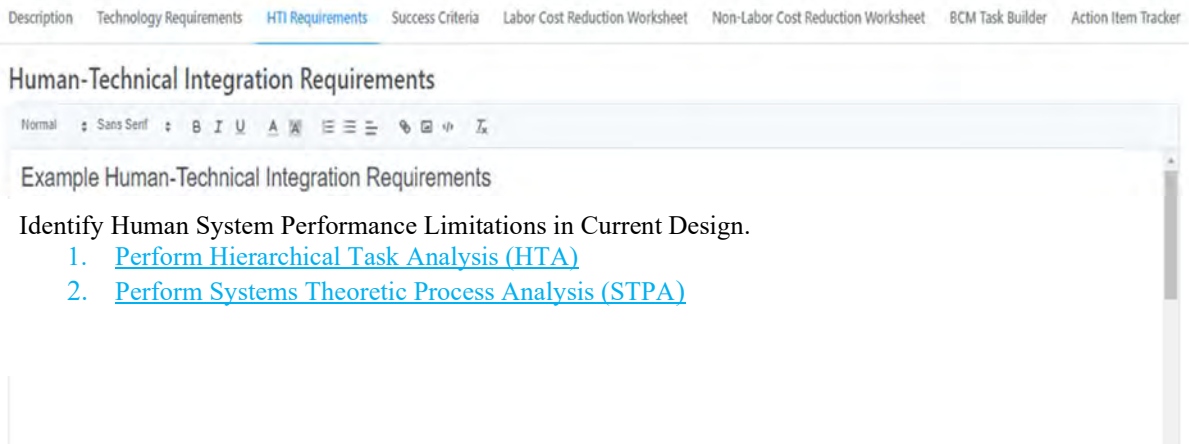
Figure 13. ICAP Human-Technical Integration Requirements Tab.

An example of the application of this approach is provided in Figure 13. The figure depicts the Human-Technical Integration Requirements tab of the ICAP tool and is a part of the Work Reduction Opportunities (WRO) section. The purpose of the WRO section is to assist in developing a business case to use new technologies and associated procedures to help reduce operations and maintenance costs. Users can add Human-Technical requirements such as, for example, the need to identify human-system performance limitations in a current design or system. ICAP can then suggest potential methods and tools for conducting such analyses, in this case HTA and/or STPA with links to information to help guide users to the selection and use of the appropriated tool for their set of circumstances.

It may also be useful to embed information within ICAP about potential human-system performance issues and/or requirements that need to be addressed as these are not always readily apparent to specialists and non-specialists alike. Other information within ICAP can then provide guidance on selection and use of appropriate tools. For broad areas of concern related to human-system performance, such as the maintenance of team situation awareness across distributed operations, it may be possible to make recommendations concerning potentially advantageous technologies and/or procedures.

As noted previously, the successful development and deployment of technical and/or procedural innovations within complex sociotechnical systems, such as an NPP, requires an approach that seeks to jointly optimize PTPG assets and procedures. This is particularly true when matters of efficient and effective design are central to an industry's economic success. The findings from the current work strongly support the notions that ION is not only operationally feasible – that is, systems can be developed that will accomplish performance, safety, and cost goals – but also economically advantageous.

7.1 A Graded Approach to Using ION and Sociotechnical Methods and Tools

The results of the current work demonstrate the concept of an effective graded approach to systems development. For instance, the IS use case employed methods and tools that guided the development of sociotechnical innovation – a management-by-exception approach to issue resolution supported by an appropriate data structure and human interface – by means of an essentially iterative, analytic procedure using specific sociotechnical methods and tools. These tools enabled the refinement of the IS use case from a somewhat vague concept to a specific, prototype design. The RP use case adopted the basic, graded approach to NPP control-room systems design laid out in NUREG-0711 and adapted it to the

design of a non-control operations (see Section 4.5 and Appendix B). Both approaches proved to be successful in the current work and should be examined further in future phases.

Level		Technology Readiness Level	Human Readiness Level
Production / Deployment	9	Operational use of deliverable	System successfully used in operations across the operational envelope with systematic monitoring of human-system performance
	8	Actual deliverable qualified through test and demonstration	Human systems design fully tested, verified, and approved in mission operations, using completed system hardware and software and representative users
	7	Final development version of the deliverable demonstrated in operational environment	Human systems design fully tested and verified in operational environment with system hardware and software and representative users
Technology Demonstration	6	Representative of the deliverable demonstrated in relevant environments	Human systems design fully matured and demonstrated in a relevant high-fidelity, simulated environment or actual environment
	5	Key elements demonstrated in relevant environments	Human-centered evaluation of prototypes in mission-relevant part-task simulations completed to inform design
	4	Key elements demonstrated in laboratory environment	Modeling, part-task testing, and trade studies of human-centered design concepts and applications completed
Research & Development	3	Concepts demonstrated analytically or experimentally	Human-centered requirements to support human performance and human-technology interactions established
	2	Concept and application formulated	Human-centered concepts, applications, and guidelines defined
	1	Basic principles observed and reported	Basic principles for human characteristics, performance, and behavior observed and reported

Figure 14. Crosswalk between the technology readiness level index and human readiness level index (adapted from See [2021]).

Finally, See (2021) has proposed a framework for envisioning the relations between the level of maturity of a particular innovation and the associated focus of human-centered, system design work. As seen in Figure 14, there are many specific human-system design challenges (and associated methods) involved in systems design. The principal idea behind a graded approach to design, such as that of See (2021) as described above, appear to be strongly related to similar types of design challenges addressed in standard systems engineering approaches. Their ability to effectively coordinate with such approaches could positively impact their ability to influence the eventual design and deployment of innovations.

8.   CONCLUSIONS AND RECOMMENDATIONS

The overall goal of the Advanced Concepts of Operations research is to provide a science-based approach to human-technology integration as part of the overall ION methodology. As previously mentioned, the goal of this research is to investigate and demonstrate that a scientifically valid and operationally useful conceptual structure, called ION, can help address the modernization and design challenges facing the nuclear industry. Specifically, this report describes the application of sociotechnical theory-based analytic and design tools developed for ION to two use cases. Both use cases shared a fundamental emphasis on UCD; an approach to systems design that emphasizes the essential requirement for user input at all stages of the system design and development process.

As shown in the previous sections of this report, sociotechnical systems theory, as applied in the two use cases, demonstrated that the successful performance of complex human-machine and human-computer systems, and their associated safety, is a function of interactions between human, organizational, and technical factors. The use cases were broadly representative of various O&M activities and the associated decision-making issues surrounding the joint optimization of safety, production, and cost-savings – thereby emphasizing how the analytic methods, tools, and resulting solutions are reusable and scalable. This section provides a summary of key findings from the current

effort and their implications for the ION concept and NPP modernization in general. A summary of recommendations is also provided, focusing on near- and longer-term potential for the prototype design concepts developed in the two use cases and continued development and application of the sociotechnical methods and tools.

8.1   Summary of Key Findings and Implications for ION

As shown below, the summaries of key findings for each use case emphasize those findings that are relevant to either the candidate designs themselves or the methods or tools that were used to support their development.

8.1.1   Radiation Protections Use Case:

The RP use case analysis and design effort resulted in identification of several potential innovations, including robots and drones, wearable technology, and air sampling, that were presented to the utility for further action. The analytic and design processes used and the participation of knowledgeable SMEs are also expected to be applicable and scalable to O&M activities beyond RP. For example:

- Maintenance procedures for jobs requiring two workers, such as performing inspections in a radiological area or verifying a manual repair task has been performed correctly could be analyzed for WROs. A program goal of reducing costs might be achieved by reducing the number of workers from two to one or zero. Specifically, function and task analyses could be performed, and possible innovations identified. A robot or drone innovation might be found for the inspection task, possibly eliminating the need for two workers and their exposure to radiation.
- An innovation based on wearable smart glasses with camera might permit verification of a repair task performed by one plant worker by another worker at a remote location. The person located remotely may be able to perform verifications and other remote tasks at several locations during a work period thereby reducing number of workers at several sites to one rather than the two required before.
- Function and task analyses may show that to perform an inspection of possible leaks located high in a building, scaffolding needs to be erected and dismantled, shielding needs to be installed and removed, and a worker needs to climb and descend the scaffolding to perform the inspection. To reduce time and costs to perform this inspection. a drone may be identified as a possible innovation. If implemented and successful, the drone could reduce significantly both time to perform the inspection and labor costs.

Overall, this use case fully implemented UCD/HFE processes and methods within the scope, schedule, and limited budget of this project, but nevertheless demonstrated that UCD/HFE are key constructs for ION in its ability to transform RP operations into a more technology-centric O&M activity and reduce overall O&M costs in this area.

8.1.2   Information Support Use Case

The key finding from the IS use case is that the UCD approach and sociotechnical methods and tools resulted in a prototype information support architecture (information object) and interface concept (information dashboard) which demonstrated the potential for effectively addressing management decision-making and issue-resolution tasks. The case of forcing function meetings and in particular, gap resolution at MRMs provided a context within which to develop an innovation based on the use of advanced technologies and associated processes.

A primary insight from this effort was a developing concept of an information support system built on an Information Object architecture providing an integrated and 24/7 source of gap information. This technological system would be linked to a governance innovation called Management by Exception. This innovation required process and behavioral changes in that mangers would be expected to take responsibility to examine the set of gaps typically selected for MRM review in advance of the actual

meeting. At that point, each manager would decide if an individual gap represented issues which were significant enough for senior management discussion, or if lower-level managers had adequately dealt with the issue. Applying the Information Object concept to the diverse information decision and assurance activities in the plant has the potential to dramatically change current processes in the plant resulting in streamlined operations and cost savings.

8.1.3   Methods and Toolset

One of the objectives of the current work was to assess the degree to which the sociotechnical methods and tools used to support the two use cases can be effectively learned and applied by in-plant personnel with no HFE expertise. In the RP use case, a key finding was that the principal SME was able to quickly pick up on the rationale and method underlying hierarchical task analysis, as well as the use of the data collection tool itself. As a result, he was able to gather relevant data from other SMEs whose schedules did not permit participation in the design meetings. This helped the analysis and design effort greatly.

In the IS use case, a key finding was that the principal SMEs were able to discern the results and rationale of the analyses performed, but the analyses and methods used (e.g., STPA, WDA) require some domain specific expertise and training. Having said that, STPA and WDA are not so opaque that only the most highly trained experts can use these tools. Rather, a modest amount of training can bring nuclear SMEs sufficiently up to speed, which in the end is an important aspect of the use of these methods and tools – namely that the results of the analyses are generally better and more complete when a cross-functional team of SMEs use these tools collaboratively.

With respect to the implications for ION, the results from the two use cases demonstrate that a UCD approach of the sort used in the current work, supported by appropriately selected and applied sociotechnical methods and tools, provides a potentially effective path forward for nuclear modernization efforts.

8.2   Recommendations

A number of recommendations emerge from the results of the use cases and use of the sociotechnical methods and tools. The use case recommendations are separated into near-term and longer-term categories. The former refers to recommendations for follow-on activities stemming from the specific results of the two use cases, while the latter refers to those more directly relatable to broader applications of the designs.

8.2.1   Near-term Use Case Design Recommendations

- The utility partner should review the potential innovations identified in this project and determine if they want to investigate them further and determine if the implementation of the innovation(s) is desirable.

- The utility partner should consider applying the work performed in the RP use cases to other plant activities (e.g., maintenance, operations, support) or a different RP procedure to evaluate and validate the process. An evaluation of the results will provide a qualitative and quantitative assessment of the value of the process in reducing plant costs and improving efficiency, effectiveness, and overall plant performance.

- The utility partner should contact and possibly visit other plants that are now testing or applying the innovations identified in this project.

8.2.2 Longer-term Use Case Design Recommendations

- The utility partner should continue to monitor developments in AI, ML, and robotics (including drones). These technologies are maturing at a rapid rate and afford many potential advantages in terms of reducing costs while maintaining safety and performance at very high levels.

- Wearable technology, including wearable sensors, are also a rapidly changing technology with many affordances for NPP operation. The utility partner should closely monitor technical developments in this area.

- The utility partner should train staff on use of the sociotechnical analysis and design tools used in this work and described elsewhere (Dainoff et al, 2020; Hettinger et al, 2020) so they can help effectively integrate future technical and organizational innovations. As mentioned previously, results of the analyses are generally better and more complete when a cross-functional team of SMEs use the tools collaboratively.

8.2.3 Methods and Toolset Recommendations

- The methods and tools used in the design efforts described in this report yielded satisfactory results both in terms of helping to address a concrete, near-term business need and in laying the foundation for the broader application of the design concepts and products across related business applications (i.e, plant maintenance, information support for management decision making, etc.).

- A determination should be made of the extent to which the same and/or similar methods and tools satisfactorily support the broader application of the concepts and products identified in the current effort. For instance, an increased impact of cross-organizational factors on the broader use of the newly designed O&M activity is likely and should factor into selecting analysis and design approaches.

- With respect to the IS use case, the sociotechnical methods and tools must also be able to account for and support the unique needs of various sub-groups of plant personnel for whom the 'standard' dashboard display is overkill, insufficient, or lacking in some other dimension.

  - The sociotechnical methods and tools should also be applied to issues surrounding the design (i.e., information content, analysis requirements, routing and tracking requirements, etc.) of the generic information object concept, followed by analysis/specification of the same requirements for individual information objects. That is, a gap analysis of the information object should be performed.

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Appendix A - Sample Cost-Benefit Analysis Approach

Estimating cost savings and increased revenue are important in justifying innovation costs and achieving the desired reduction in overall costs. Opportunities for reducing costs and increasing revenue include:

- Reducing labor costs
- Reducing time to perform jobs
- Increasing power generation output increasing revenue
- Reducing exposure to radiation and other containment exposures with associated cost benefits
- Eliminating or reducing equipment damage
- Eliminating need for some devices whose functions are assumed by the innovations

There are several methods to estimate cost savings and increased revenue. One method is to examine and analyze the costs and lost revenue over a previous 12-month period. Various plant records could be reviewed to obtain the needed information. Then the opportunities for reducing costs and increasing revenue would be identified for the innovations being considered. Three examples are shown below:

- Need existed to make measurements in a high radiation area. Records might show a worker required 10 minutes to make measurements, and for this location plant power was reduced for 20 minutes. The drone innovation might be able to make the required measurements in two minutes without the need to reduce power. Drone performance would be obtained from a supplier to permit estimate of drone times and performance. The value of reduced labor, radiation exposure, and loss of revenue during reduced power could be calculated. The cost for the time the drone was needed, and associated labor costs would be calculated. A comparison of the costs associated with the two methods to obtain the measurements would determine the value of the innovation for this example.

- Need existed to perform manual swabbing X hundred times during a previous one-year period. The time and radiation exposure to perform each swab manually (as performed during the one-year base period) could be determined based on measuring times during a scenario walk-through (Element 10). The swabbing scenario could be repeated (Element 11) with an actual or simulated robot performing the swabbing task autonomously. The cost for the time the robot was needed, and associated labor costs would be calculated. A comparison of the costs associated with the two methods (manual and autonomous) for the one-year period would determine the estimated value of the innovation for this example.

- Need existed to verify that important manual tasks are performed correctly. In comparison year estimated that X hundred jobs were performed in which a second person needed to be physically present to observe and verify that another worker performed the task correctly. An innovation was identified consisting of wearable eyeglasses and attached cameras that might eliminate the need for the verification to be performed by someone physically at the worksite. A qualified person located remotely could observe manual task performance through the camera presentations and verify it was performed correctly. The person located remotely might be able to perform verification for single workers at numerous locations in the plant. This capability might result in elimination of several second workers at the worksites. The verification scenario could be performed as the task was previously performed and time measured with the second worker present. Radiation values would be obtained, if the

verification was performed in a radiological area. The same scenario would be performed again, but the use of the eyeglasses with cameras would be simulated with the person performing verification located remotely. The cost for the time the eyeglasses were needed, and associated labor costs would be calculated. A comparison of the labor and radiation costs avoided with the two methods would determine the expected value of this innovation for this example.

The costs saved for each innovation would be aggregated over all uses in the one-year period to estimate the total savings for each innovation. This dollar number would be compared to the total innovation costs for the same time period. This would include innovation purchase or lease and other costs to permit the innovation to be used, if not already available (e.g., communications, remote work center with required equipment, maintenance). Total cost savings would be compared with total costs for the innovation and needed support capabilities would be compared. The result would help determine if the innovation should be acquired and implemented. The cost savings for all the innovations that were determined to be cost-effective would be summed, and the amount of the estimated cost savings over a one-year period could be estimated.

Appendix B - Innovation Development and Implementation Model

This Appendix presents a model or procedure for identifying, selecting, developing, evaluating, and implementing innovations to improve performance and reduce costs in nuclear power plants. The need for such a model is presented in Section 4 of this report.

- The diagram representing the model is shown in Figure B-1 (Figure 2 in Section 4 of report) and resulted from the Radiation Protection (RP) Use Case study described in this report. It is intended to provide a utility with a procedure it can apply throughout its nuclear plants to identify the need for innovations in plant activities (e.g., Maintenance, Radiation Protection, Operations, Support), and select and implement appropriate Innovations for implementation.

- This section contains a description of the model, the parts of it applied during the Use Case and the methods used. In addition, possible Innovations were identified for consideration by the utility (in Element 8).

- Part of the process shown in Figure 1C was not completed in this Use Case. Elements in the left two General Activities columns and the top Element of the Design general activity (Elements 1-8 in Figure B-1) were completed. The remainder of the Design Elements (9-14) and General Activities (D, E and F) and associated Elements (15-20) shown in Figure B-1 were not performed because they were not in the scope of this RP Use Case.

- Details are presented regarding activities performed in the first 8 elements. Some comments are provided regarding Elements 9-20. These comments are intended to aid preparation of a future Use Case Plan for RP or other plant activities.

A. Management Selection of a Use Case	B. Planning, Analysis and Identification of Possible Innovations	C. Design	D. Procedure and Training Development	E. Verification and Validation	F. Implementation and Operation
1. Identify, Evaluate, and Select Use Cases	2. Create HFE RP Use Case Plan and Review with Utility RP Team	8. Identify, Evaluate, and Select Possible Innovations	15. Procedure Development for New Innovations	17. Integrated System Validation of New Innovation System (Innovations, Procedures, and Training) (Provides Proof of Concept)	19. Innovation System Implementation
	3. Describe RP Work Activity Selected for Use Case	9. Evaluate Possible Innovation Safety, Environmental, Regulatory, and Logistic Issues	16. Training Program Development for New Innovations		20. Innovation System Monitoring After Installation
	4. Perform Operating Experience Review (OER)	10. Identify Scenario and Perform Testing of Existing Function/Task Performance for Which Innovation Intended		18. Design Verification of New Innovation System	
	5. Perform Function Requirements Analysis and Allocation and Task Analysis (Current Procedure with Existing Equipment)	11. Perform Function Analysis and Allocation and Task Analysis (Procedure with New Innovation)			
	6. Identify Potential Intervention Concepts (Innovations)	12. Perform Same Scenario Test with Innovations			
	7. Evaluate and Assign Potential Innovations to Priorities	13. Compare Results (Current and With Innovations)			
		14. Finalize Innovation Designs and Perform Analysis to Decide if New Innovations are Worth Installing (Follow Utility Procedure for Making Decisions)			

Figure B-1. HFE Innovation Development Model Diagram.

(A) Management Selection of Use Cases

This General Activity resulted in the selection of a Use Case for this project. A Use Case involves (1) selecting and describing an existing job activity (e.g., procedure) with its functions and tasks, (2) analyzing the current procedure's functions and tasks to identify opportunities for introducing an Innovation System (innovation, procedures and training) resulting in improved performance and reduced costs, (3) designing and developing an Innovation System (often selecting a COTS device) and (4) testing and implementing an Innovation System to replace the existing system. The Innovation System is intended to help utility management reduce plant operating costs significantly. Utility management was responsible for selecting the Use Case described in this report section, although INL personnel provided information to aid in the selection.

Element 1. Identify, Evaluate and Select Use Case

- Senior utility manager discussed the project and possible Use Cases with other members of utility management and senior professionals

- List of possible Use Cases was prepared by utility and provided to the INL HFE Use Case team members

- Possible Use Cases were reviewed by INL team members, and several identified that were expected to provide the results desired

- Utility reviewed the INL input and selected a Use Case Study: Radiation Protection work activity following the Radiological Job Coverage Procedure (FP-RP-NISP-10)

(B) Planning, Analyses, and Identification of Possible Innovations

This General Activity resulted in Use Case document, which included planning, analyses, and identification of possible Innovations.

Element 2. INL HFE team created overall project plan.

The HFE RP Use Case plan was reviewed with the utility, and decision made to proceed with plan:

- Plan identified need for and description of INL/utility Use Case Design team, INL personnel team assignments, need for utility RP technicians to serve as Subject Matter Expert (SME), and need for INL/utility workshops for knowledge elicitation and reviews

- Use Case plan included several sections: Goals, Approach (early version of process and Elements shown in Figure B-1), methods and tools expected to be applied, schedule, and final report contents

Element 3. Describe RP work activity selected for use case

- Reviewed Radiological Job Coverage Procedure (FP-RP-NISP-10) to determine if information required for planned Function/Task analyses was provided and found it did

  o This procedure describes the processes and instructions for monitoring radiological work based on the radiological risk and the types of radiological hazards that may be present. Protective measures are described for each type of radiological hazard to guide job coverage technicians in minimizing personnel dose and the potential spread of contamination.

  o A major reason the utility selected this Procedure for the Use Case is that it includes many of the important RP Technician tasks and responsibilities. This specific

procedure is applied throughout the commercial nuclear power industry. This widespread use minimizes the need for general training on the Procedure by RP Technicians transferring in from other plants or radiological contract workers who have worked at other plants

- Determined with utility SME that Process Flow Diagram in Procedure (Figure B-2) contains the key functions and tasks performed by RP technicians in providing radiological job coverage

- Process Flow Diagram in Procedure included another column (5.3 Prepare for Job Coverage) that was not considered in this Use Case and not shown in Figure B-2. The Use Case team decided to limit the analyses only to functions and tasks required to perform the job and not preparation tasks
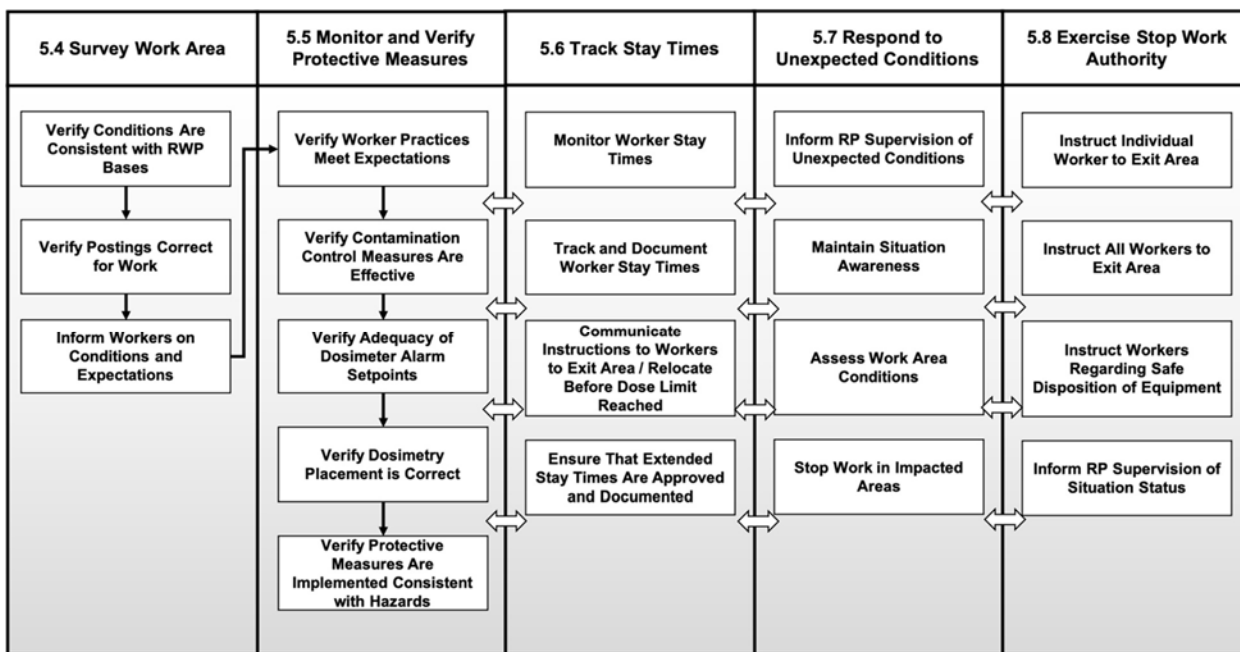
Figure B-2. Process Flow Diagram from Radiological Job Coverage Procedure.

- Determined that the Section column headings (5.4 through 5.8 in Figure B-2) can be considered Functions and the Elements shown in boxes can be considered Tasks

  o Function - A process or activity required to achieve a desired goal, e.g., "Survey Work Area" (Section 5.4 in Figure B-2 is defined as a function). This function is one of several functions required to achieve the goal of providing radiological job coverage

  o Tasks (or Elements shown in Figure B-2 in this Use Case) - A group of related Human Actions (HAs) with a common objective, e.g., "Verify Conditions are Consistent with RWP Bases" (Section 5.4 Element in Figure B-2). Tasks and subtasks are performed to achieve the functions to which they refer.

- RP technician performs tasks and subtasks with a few examples of HAs shown below

  o Following procedures

- Communicating with other RP techs, RP workers, supervisors, managers, and non-RP personnel directly or through communication devices

- Viewing work performed by others directly or remotely and in real-time or by revieing videos

- Performing tasks or subtasks directly such as making a swab, installing a fixed dosimeter, etc.

- Accessing information from others, documents, and on-line data bases

- Many of the RP technician actions involve monitoring work activities, identifying problems, considering, and evaluating possible decisions and implementing the selected decisions

Element 4. Perform Operating Experience Review (OER)

- OER (as used in this project) was a review of RP and similar work activities to identify problems experienced and good practices and devices

- Identified incidents involving RP work activities

  - Reviewed utility Corrective Action Program entries and interviewed utility RP technicians

  - Reviewed INPO and NRC Human engineering data bases

- Reviewed publications and sales brochures concerned with RP to identify current practices and approaches viewed as good

Element 5. Perform Function Requirements Analysis and Allocation and Task Analysis (Current Procedure with existing equipment)

- No Function Requirements Analysis and Allocations performed for currently implemented Radiological Job Coverage Procedure (functions shown in top row in Figure B-2) except as noted below

  - Functions were identified and allocated as part of preparing the procedure initially and as revised and are currently being performed as shown in the procedure (top row Figure B-2).

  - It was decided that a "bottoms-up" approach was appropriate to determine if the functions and the allocations adequately describe the tasks and subtasks now being performed

  - "Bottoms-up" approach found that the functions adequately described the tasks and subtasks

- Task analysis performed to describe tasks and subtasks as they currently are being performed for each function (tasks shown in boxes below top row in Figure B-2)

  - Task analysis identifies and describes the specific tasks and subtasks needed to accomplish HAs (e.g., select and read remote dosimeter).

  - Hierarchical Task Analysis (HTA) was applied in this Use Case.

  - HTA is a systematic top-down method of describing how tasks are arranged and performed (HAs taken) to fulfill the functions.

  - HTA typically requires extensive time and labor to perform but provides detailed results that may be needed for additional analyses.

- o HTA provided descriptions of tasks as currently being performed permitting identification of possible innovations that might reduce costs and improve task performance.

- Task analysis results are shown in Figure B-3 for the Survey Work Area Function described in Section 5.4 Radiological Job Coverage Procedure (FP-RP-NISP-10).

- Left three columns in Figure B-3 are copied from Radiological Job Coverage Procedure.

- Entries in Sub Tasks column of Figure B-3 were provided from experience (memory) of SME by applying Knowledge Elicitation HFE method

Function Section 5.4 in Figure 3	High-Level Tasks Section 5.4 Elements in Figure 3	Middle-Level Tasks Provided in Procedure for high-level tasks	Sub-Tasks Not included in Procedure but provided by SME
Section 5.4 Survey Work Area	Verify Conditions Are Consistent with RWP Bases	5.4.1 Perform work area radiation and contamination surveys as needed to ensure the radiological conditions during work activities are consistent with worker briefings and within the ranges specified by the RWP and, if applicable, the ALARA Plan.	Survey immediately prior to beginning work if radiological conditions are unknown or potentially unstable.
			Survey on a frequency as needed to validate conditions are stable; comply with survey frequencies in procedures, RWP, and ALARA Plans when a survey frequency is specified.
			Survey immediately if changes in conditions are suspected due to anomalies from worker activities or plant conditions, e.g. system breaches, leaks, unexpected alarms, etc.
	Verify Conditions Are Consistent with RWP Bases	5.4.2 Obtain air samples per FP-RP-NISP-03, Radiological Air Sampling.	*per FP-RP-NISP-03*
	Verify Postings Correct for Work	5.4.3 Pre-post areas prior to performing work that is expected to increase radiation, contamination, and airborne concentrations in accordance with FP-RP-NISP-04, Radiological Posting and Labeling.	*in accordance with FP-RP-NISP-04*
	Inform Workers on Conditions & Expectations	5.4.4 Communicate survey results to workers	Areas where stay time should be minimized.
			Areas where dose rates are the lowest.
			Desired body positioning to minimize TEDE while working in areas with high contact radiation levels or elevated radiation levels.
			Steps or conditions when workers need to stop to allow additional surveys or protective actions before proceeding.
			Where contamination levels are high enough to challenge the effectiveness of workers' protective clothing and the precautions that need to be taken.
			Preventative actions and work practices to minimize the spread of contamination and prevent airborne radioactivity.

Figure B-3. Task Analysis Results for Survey Work Area Function (Current Procedure with Existing Equipment).

- Additional information about tasks and subtask than provided in Figure B-3 was required to help identify possible innovations (see Element 6 below). Ten additional types of information were identified and shown in the right columns in Figure B-4.

    o Figure B-4 contains the following:

    o An example of an entry in Figure B-4 is as follows: Sub Task shown in second from left column, "Information needed to perform Tasks/Sub Tasks" is shown in column below: 1. Understanding of work to be performed and required equipment to perform work (job coverage requirements), 2. Familiarity with work environment, 3. Radiation and contamination levels (historical and current), etc.

Sub-Tasks Required (Sub-Tasks that are not included in the procedure?)	Information Needed to Perform Tasks/ Sub-Tasks (What information is needed to monitor, make and implement decisions, and get relevant feedback?)	Sources of Information (Where is this information found?) (e.g., procedures, manuals, direct observation, displays, verbal communication, knowledgable source such as person, etc.) Is obtaining any information problematic?	Actions performed to complete Tasks/ Sub-Tasks (What needs to be done to complete the task?) (Voice commands, controls actions, monitoring, record data) (e.g., actions used to provide two way communication between RP tech and worker or others)	Tools/Devices used to perform Tasks/ Sub-Tasks Cameras, dosimeters, laptops, radios, and other resources used and to change field of view/obtain readings from sensors/access stored data/etc. Are any tools/devices problematic?
Survey immediately prior to beginning work if radiological conditions are unknown or potentially unstable.	1. Understanding of work to be performed, and required equipment to perform work (job coverage requirements) 2. Familiarity with work environment 3. Radiation and contamination levels (historical and current) 4. RWP and ALARA Plan Need to know what kind of work is being planned, where in the space the work will be conducted, low-dose waiting areas, what activities are being conducted, can we relocate people or body position to minimize exposure, e.g., can a shield be used (manually placed). RWP - type in all the info we want. Dose and dose rate set points. Need a pre-job survey. Planning procedure helps us determine max dose rate. Getting to the point where it's beginning to be automated. Data from pre-job survey is needed. Might have to send somebody to go do it.	1. Radiation Work Permit (RWP) and ALARA Plan 2. Memory, PTZ cameras, debriefing 3a. (Historical) Recent surveys, RP logs, Condition Reports 3b. (Current) Dosimeters, (GEDDS?) RWPs - Old work orders are accessed to obtain information specific to the job. Typing in key words heps to identify relevant work orders. They have a speech-to-text option for this as well. Need to understand what you're looking for - drill-downs are there. Historical job files - hard copies of previous work orders. Maybe reference them once a month. if it's possible to find it on the computer, would rather do it that way. "Most info I need is on the computer."	Perform radiation and contamination survey. Determine: [1] work area dose rates, [2] contamination levels for area and components, [3] dose radiation particles (DRPs), [4] alpha particles, [5] travel path to and from work location, and [6] 'movable boundaries.' "If you didn't document it you didn't do it." Verify that readings are being accurately recorded. Red pen on a hard copy is how data are currently captured. Then manually entered into the computer. "Definitely one of the more time-consuming aspects of the job."	1. Radiation Work Permit (RWP) 2. ALARA Plan if applicable 3. PPE 4. Dosimeter 5. Radiation contamination monitor? Hard-copy tablet for writing down readings, radiation survey instrument, contamination survey instrument, bag or sack to keep gloves smears, etc. PPE. A lot of techs take pictures with their of problem area with their cell phones. PTZ cameras. Other hand-held digital cameras. Comms devices

Number and type of workers involved (e.g., RP techs, supervisors, and workers)	Key Interactions with Others With whom? About what? How accomplished? (remote, face-to-face, etc.) Bottlenecks?	Criticality of the Interactions for Task Completion and Personnel Safety (e.g., increased radiation condition that possibly causes need for immediate action, time running out to complete the job before dose rate exceeded)	Estimated time to perform activity (Used to evaluate opportunities for new devices that will reduce time to perform activity)	Estimated total dose for activity Low, Medium, or High (Used to evaluate opportunities for new devices that will reduce total dose to perform activity)	Difficulties Performing Sub-Task (Additional potential bottlenecks that previously were not identified.)
Most jobs will only take one person unless you need someone to help build the survey. Supervisor, who reviews and approves the survey. Maintenance workers will sometimes be asked to come along and show how they intend to go about the work, positioning, etc. We will sometimes make recommendations to the maintenance workers about body positioning, work processes, worker selection, etc. - particularly for major evolutions.	One rad tech is in the room and another who is remote. Rad tech obtains survey approval from supervisor. "Sometimes there can be bottlenecks with maintenance but 90% of the time there aren't."	"If we don't get the survey we can't plan the work and if we can't plan the work then we'll be holding up important activities – so it's critical that we get the serves when we need them."	10-15 minutes to physically do the survey, approx. 15-30 minutes to record the data. How are the data recorded? If a prior record exists, then recording the data might only take about 5 minutes.	All three - routine jobs might only pick up zero, others might pick up 5 mrem or 50-100 mrem	Worker body positioning blocks camera and may contribute to unnecessary radiation dose. Camera location Communications equipment. Superimpose smear locations on map Documenting and recording data

Figure B-4. Additional Information Needed from Task/SubTask Analysis to Permit Identification of Potential Innovations.

Element 6 Identify Potential Intervention Concepts

The next step in the process was to identify possible innovations.

- Potential Innovation Capabilities and Descriptions were prepared for the Tasks and Sub Tasks in Sections 5.4-5.8 of the Procedure (Figure B-2). The left second and third columns in Figure B-5 contain the results. The INL HFE and the utility SME Use Case members performed this activity.

- The INL HFE personnel identified HFE criteria to consider while evaluating potential Innovation capabilities. The HFE Criteria are shown as columns in the middle of Appendix B Figure B-1.

- The INL/Utility SME Use Case team completed the HFE Criteria columns in Appendix B Figure B-1.

- Discussions were conducted by the Use Case team and Comments and Potential Innovation Concepts were identified (shown in the right two columns of Appendix B Figure B-1).

This step in the process was to evaluate and assign each potential innovation to a priority level. This grading of the potential innovations was performed to limit the number of potential innovations given serious examination at this time.

- A: High priority, with expectation implementation would result in significant cost reductions

- B: Medium priority, with expectation implementation would result in important cost reductions but not as much as innovations prioritized as A

- C: Low priority, with expectation implementation would result in some cost reductions but not as much as innovations assigned A or B

The prioritization determination was performed by the utility: RP technicians, other work area personnel, utility personnel concerned with new technology selection, and management. Information previously prepared by the INL/utility Use Case team was provided to utility personnel who discussed, evaluated, and assigned priorities to the 25 potential innovations. The far-right column in Figure B-5 provides prioritization results.

Potential Innovation Capability	Description	Comments	Potential Innovation	Priority A - High B - Medium C - Low
Automated data entry	(e.g., source data automation, auto-population sensor and other data)	Survey data (standing at certain point it would record data; auto-populate versus manual entry) May want to expand remote monitoring to capture data. There are some resources in the field now. Moving to next steps discussed before. Will be connected to wireless network.	GEDDS Lite (automatically take data and display on survey map) GPS mapping of room with grid locations (e.g., push button and dose is shown on map) MIRION.	B.
Electronic Forms and electronic transmittal	Replacing paper and need to hand carry hardcopy e.g., to obtain signature	With tablets in field already (half group), able to utilize electronic forms. Reduced risk of paper loss. Utilizing forms now for most part.	Tablet with capability to support filling out form.	C.
Real-time tracking and display of radiological data, worker position	e.g., Shown on display such as by virtual 3D model with visual indication	3D mapping, GPS, triangulation would be a great feature to know exact location. Great if there was a remote	Company came in previously for 3D mapping. MIRION is working on	B.

Potential Innovation Capability	Description	Comments	Potential Innovation	Priority A - High B - Medium C - Low
(e.g., GPS), dosimeter locations, etc., on a spatial (e.g., 3-D) map	of location shown together with other required information such as equipment location	alarm to tell someone where they can and cannot be.	GPS for dosimetry (2-3 years ago). Haven't had recent conference.	
Manual performance of selected tasks performed by RP tech in radiological area, e.g., moving something	Remotely perform task using something like Da Vinci system used to support surgery			B Still requires the RP tech to drive the robot. Would only save the rp from the dose.
Automated scanning of paper-based information	e.g., scanning of form filled in automatically to eliminate need for manual data entry	ALARA files (paper records are historical) Have scanner now but it would take months to scan it all in.	Need something that is more efficient in scanning.	C have to be a machine that can do the scanning
Automated transmittal for survey approval	e.g., electronic communication to supervisor where signature is required	Refers to surveys that need to be approved. See row 2.		C it's something they go in and see everyday
Auto-flagging areas where surveys are needed	e.g., GEDDS Lite (Xcel provides definition here)	VSDS scheduling software already installed and performs this. Works well. Sends message that shows what surveys are due by months/week. You enter freq. and survey.	Works good.	C. if not then it would be a B.
Ability for remote workers to perform their own smears	e.g., worker in radiologic area performs smear without RP Tech		No, but there was a NISP on self-coverage. But with unions decided not to implement.	C not a good idea at this time. The training performance does not work out.
Remote smears/ Automated smears (e.g., via robots)	RP Tech located at remote location controls device	Considerations with dose rates and SW reliability (Survivability)	Robot capable of doing smears and performing analysis. Drones?	B able to have the rp not receive the dose. The autonomous is the key part.
Cameras, remote dosimeters, with AI/ML or Robots or Drones	e.g., camera on stick (health physics) controlled by RP tech in work area or remotely		Not yet. Spot is the only one talked to recently. Robots/Drones (see comment about Survivability)	A having a robot that is outfitted with a camera. RP would be located in the RMS.
Remote air sampling	(e.g., with robots or drones)	If you had autonomous vehicle + robot/drone, wouldn't need driver. Could relay information in real-time.	Automatic on/off? See left column (autonomous vehicle + robot/drone)	B was also including a software interface that could be activated with a computer program.
Portable Access to data and spreadsheets, procedures, or anything needed to support task performance in real time	(e.g., laptops, tables, glasses, etc.) accessed from any location	Half department has tablets See row 2. Tablets are very good now.	Gestor-based control with glasses.	A. Currently have the tablet and laptops. Allowing them to view hands free will be helpful
Automated transport of sample to lab	(e.g., robots, drones, etc.) to move sample from place of origin to desired destination	See row 11.	Robots/drones.	B. Samples trash or anything and would fit in columns with the robots.

Potential Innovation Capability	Description	Comments	Potential Innovation	Priority A - High B - Medium C - Low
Automated/ electronic signage information selection at entrance to work area or elsewhere	(e.g., electronic displays with preplanned signage selected remotely with cameras to verify correct message shown)	Can't use electronic postage now (e.g., High Rad; NRC regulated and some is through NISP). For informational it is acceptable (e.g,, display dose in area).	Electronic signage;	C
Wearable technology for RP tech and worker	(e.g., cameras, dosimeters, position sensors)	Ability to change setpoints (can't right now). Some at other stations had concerns with wearables.	See comments above on wearables.	A. Related to number 12
Pre-scripted Briefings presented to workers	(e.g., videos) possibly with RP tech to answer questions		Videos	C their sister plant used this method and it went over well
Designated Briefing Room with equipment to support and speed up briefings	(e.g., brief workers in room with videos and other support -- currently done in trailer)	Currently designate a room (e.g., lunch room). Have large screen TVs in room but not used for COVID. Skip		C have remodeled access control and a room can be used as a briefing room
Auto-calculations of data automatically collected or manually input	(e.g., trending)	Train data right, inform workers based on conditions. Currently manual.	Something that provides capability of informing workers using data. GEDDS Lite	B. have to find out from it where the data is stored and how long it is stored. Could be an A if they receive answers from their IT department.
Auto capture of dose and link to alarm setpoints	(e.g., reduce need for RP tech to continually monitor), alarms shown to RP tech and worker	Talked about giving percentage or graph. See something trend. Time based alarm (X number of minutes until you hit Y%).	RMS has a lot of functionality but does not lay out. Enhancement to SW? MIRION? Currently calculates stay time but does not update live time with lower and higher dose.	B if just rp can see it A if the worker in the field could receive the information
Auto notification of backup crew	(i.e., reduce time for backup crew to takeover job)		Automated identification and notification of backup crew.	C for RP A or B for other departments
Automated monitoring of workers' stay times	(e.g., RP tech can monitor more than one worker)	Currently used via Excel.		A for audible to the worker B or C if only to rp
Faster air sampling and analysis	(e.g., drone, robot, or fixed sensor)	Talked about adapting field common analysis or more localized gamma spec SW.	MIRION makes Spirrow ID (used for shipyards)	A. Because of their sister plant and goes back to chp and does a review if a way to speed this up.
Automated Visual Analysis of Camera Footage	(e.g., fast-time viewing of footage) When procedure requires review	Looking for boundary crossing, monitoring heavy lifts, RWP or high contaminated boundaries, workers touching faces. Good to know where in the time of the video that event occurred. Only can go x2 now in video.	Visual capture analysis technology (motion detection to stop fast-forwarding).	C they can set motion sensors in their software where it won't record all of the time
Handling of radioactive materials	(e.g., robots, drones, etc.)	See rows 11 and 13		B but if more automated would be an A same theme with root discussions.

Potential Innovation Capability	Description	Comments	Potential Innovation	Priority A - High B - Medium C - Low
Automated alarm presentation	(e.g., Alarming for dosimetry is not in place to measure extremity dose when required per Attachment 7 of procedure.)	See row 19		C.

Figure B-5. Potential Innovation Prioritization Results (Shown in Right Column).

(C) Design

This Design General Activity will result in selection and designs of the Innovations intended for possible implementation by the utility. The last Element completed in this RP Use Case was number 8. The remainder of the Design Elements (9-14) and General Activities (D, E and F) and associated Elements (15-20) shown in Figure B-1 were not performed. The reason is that Element 2 in Figure B-1 involved development of a HFE RP Use Case Plan that defined planned work. This Plan included creation of a process that would result in identification of Innovations for implementation by the utility. Figure B-1 shows the process that was created. But Elements 9 through 20 were not performed. Performing these additional Elements was not in the HFE Use Case Plan. This Plan was for the Use Case to complete Elements 1 through 8.

As noted in the Introduction a few comments are provided in the remainder of this report regarding the performing Elements 9-20. These comments are intended to provide input for preparation of a new HFE Use Case Plan for RP or other plant activities.

Element 8. Identify, Evaluate and Select Possible Innovations

The purpose of Element 8 was to select and present information about possible Innovations to the utility for its decision whether to proceed with further study of any Innovation.

The RP Use Case team decided to consider only potential Innovations prioritized as A or B. It was determined that the amount of time and resources required to consider priority C Innovations was beyond the scope of this Use Case. Potential Innovations prioritized as C could be evaluated in the future, if desired.

The utility identified three potential Innovation categories of highest priority.

- Wearable Technology
- Robots and drones
- Air sampling

The utility provided the RP Use Case team with information about Innovations fitting the Innovation categories identified in this Use Case. This included information about Innovations it was considering and companies that might have devices of interest. The RP Use Case team contacted numerous companies, reviewed trade magazines and product brochures. Several videos were obtained showing an Innovation in action. A presentation was prepared and presented to a group of utility personnel providing a description of the entire RP Use Case project. The presentation included a section providing a description of commercially available Innovations identified as part of this Element (8). Some of the results of the possible Innovation search are presented in the discussion of Innovation categories shown below.

The RP Use Case team reviewed the priority A and B potential Innovations listed in Figure C-5 and assigned potential Innovations to the three categories. The results are shown in Figure C-6 for the Wearable technology category, Figure B-7 for Robots and drones and Figure B-8 for Air sampling.

The columns to the right in the three Figures contain the information for each potential Innovation from Figure B-5.

Wearable technology

Wearable technology is also known as "wearables." It is a category of electronic devices that can be worn as accessories, embedded in clothing, worn as glasses, etc. The devices are hands-free, powered by microprocessors and enhanced with the ability to send and receive data via the Internet or other communication means. Potential Innovations considered to be wearable technology are shown in Figure B-6.

No.	Potential Innovation Capability	Description	Comments	Potential Innovation	Priority A - High B - Medium C - Low
12	Portable Access to data and spreadsheets, procedures, or anything needed to support task performance in real time	(e.g., laptops, tablets, glasses, etc.) accessed from any location	Options: Tablet or wearable	Y. Transitioning to the tablets for more hands free operations. Y. innovation team has brought them some Realware last year.	A. Currently have the tablets and laptops. Allowing them to view hands free will be helpful.
15	Wearable technology for RP tech and worker	(e.g., cameras, dosimeters, position sensors)	Options: Tablet or wearable	Y go pros they can use to capture but does not live stream. Y. Microsoft working on something for live stream and need real time live stream for the camera. Y. could change setpoints remotely	A. Related to number 12

Figure B-6. Potential Wearable Technology Innovation Concepts that were used to Search for Possible Innovations.

There were two possible Interventions identified. Video discussions were conducted with a representative of each possible Innovation company and videos of some Innovations in use were obtained. Some of the information and videos were presented to the final Use Case study meeting with the utility. Information and Innovation videos are not included in this report. Capabilities and costs are changing rapidly, and the team did not request approval from the companies providing the information to include it in a generally available INL report.

Robots and drones

Robots and drones are machines or devices (usually programmable by a computer) capable of carrying out a complex series of actions sometimes automatically. A robot or drone can be guided by an external control device, or the control may be embedded within. Robots and drones are task-performing machines, designed with an emphasis on functionality. Some robots and drones are autonomous and following programming can mainly operate on their own and perform programmed tasks without human intervention. Semi-autonomous robots and drones, for example, can perform tasks autonomously once authorized by a human. The device may be authorized to move from point A to point B autonomously and then stop. The human can authorize the device to perform the next task, which is to perform a swab on a wall autonomously. A robot or drone also may be manually controlled. A human operator continuously controls the device.

A robot performs its tasks while on a surface, such as a floor. A drone flies and performs its tasks while hovering or moving. A drone may be designed like a helicopter or an airplane. Robots and drones used in nuclear plants and other industries usually have vision and communication capabilities, and collision avoidance capability to prevent injuries to humans and damage to equipment or itself. Some of these devices can be used beyond line of sight and in small areas. Robots and drones typically are designed to carry loads providing RP and other capabilities. For example, a robot or drone can carry an air sampling device and move it through the area where air samples need collecting. Robots and drones

provided by different companies have different capabilities, and the one selected should have the capabilities to perform the tasks for which it was selected.

Potential robot and drone Innovations are shown in Figure B-7. There were five possible Interventions identified. Video discussions were conducted with a representative of each possible Innovation company and videos of some Innovations in use were obtained. Some of the information and videos were presented to the final Use Case study meeting with the utility. Information and Innovation videos about the possible Innovations are not included in this report for the same reasons as presented in the wearable discussion above.

No.	Potential Innovation Capability	Description	Comments	Potential Innovation (Drones may also be considered)	Priority A - High B - Medium C - Low
4	Performance of tasks performed by RP tech in radiological area	Remotely perform task using robot	Options: RP tech drive the robot or autonomous	Robot controlled by RP tech from outside radiological area or autonomously	A if autonomous B if RP tech drives robot (would save the RP tech from dose
9	Collect smears remotely	Remotely perform task using robot	Options: RP tech drive the robot or autonomous	Robot controlled by RP tech from outside radiological area or autonomously	B if RP tech drives robot (would save the RP tech from dose) but autonomous preferred
10	Place, move and operate cameras, dosimeters, etc., from outside radiological area	Remotely perform task using robot	Options: RP tech drive the robot or autonomous	Robot controlled by RP tech from outside radiological area or autonomously	A if RP tech drives robot (would save the RP tech from dose) but prefer autonomous
13	Automated transfer of sample to laboratory	Move sample, trash, or many things from place of origin to desired destination	Options: RP tech drive the robot or autonomous	Robot controlled by RP tech from outside radiological area or autonomously	B if RP tech drives robot (would save the RP tech from dose) but autonomous preferred
24	Remote handling of radioactive materials	Remotely perform task using robot	Options: RP tech drive the robot or autonomous	Robot controlled by RP tech from outside radiological area or autonomously	A if autonomous B if RP drives robot (would save the RP tech from dose

Figure B-7. Potential Robots and Drones Innovation Concepts that were used to Search for Possible Innovations.

Air Sampling

Air sampling is the collection of samples of air to measure the radioactivity or to detect the presence of radioactive material, particulate matter, or chemical pollutants in the air. The purposes of air sampling are to determine if the confinement of radioactive and other material is effective, to measure airborne radioactive or other material concentrations in the workplace, to estimate worker intakes, to determine posting requirements, to determine what protective equipment and measures are appropriate, and to warn of significantly elevated levels of airborne radioactive or other materials.

Potential air sampling Innovations are shown in Figure B-8. There were two possible Interventions identified. Video discussions were conducted with a representative of each possible Innovation company and videos of some Innovations in use were obtained. Some of the information and videos were presented to the final Use Case study meeting with the utility. Information and Innovation videos about the possible Innovations are not included in this report for the same reasons as presented in the wearable discussion above.

No.	Potential Innovation Capability	Description	Comments	Potential Innovation	Priority A - High B - Medium C - Low
11	Remote air sampling	Remotely perform task using robot	Options: RP tech drive the robot or autonomous	Remotely perform task using robot	B was also including a software interface that could be activated with a computer program.
22	Faster air sampling and analysis	Reducing air sampling times using drone, robot, or fixed sensor technology	Options: RP tech drive the robot or autonomous	MIRION makes Spirrow ID (used for shipyards)	A. Because of their sister plant and goes back to CHP and does a review if a way to speed this up.

Figure B-8. Potential Air Sampling Innovation Concepts that were used to Search for Possible Innovations.

Element 9. Evaluate Possible Innovation Safety, Environmental, Regulatory and Logistics Issues

This Element is concerned with issues that must be considered in selecting Innovations that may be implemented.

- Possible Innovations must be evaluated to determine if they are safe under normal, abnormal, and emergency operating, maintenance, turned off or other conditions. Some of the safety concerns include collision with a human or an inanimate object, knocking something off that may result in injury or damage, causing damage to protective clothing, releasing fluids on floors causing falls, etc.

- Environmental problems with Innovations must be considered. For example, does the Innovation release toxic gas, fluids, particles, or other materials that could harm people or inanimate objects.

- Regulations and practices may be factors needing consideration when deciding on Innovation implementation. For example, are there NRC, INPO, OSHA, State, Corporate or plant regulations or rules requiring consideration.

- Logistics may be an important consideration. How will maintenance be handled, will repair parts be available, will maintenance personnel require extensive training, where will the Innovation be stored when not in use, will the device require a charging station or replacement batteries, etc.?

Element 10. Identify and Perform Scenario Testing of Existing Function/Task Performance for which Innovations Intended

Completion of this Element provides a baseline to document RP Technician performance with the existing RP system. Element 11 identifies functions and tasks for the potential innovation systems. Testing of the same scenario with the possible Innovation (Element 12) provides information needed to compare performance (Element 13) with the existing and new (includes innovations) systems and helps decide whether to proceed with the Innovation (Element 14).

- The SME and possibly others from the utility select one or more scenarios that are expected to provide performance information that can be compared with Innovation performance of the same scenario. For example, a scenario might be based on the swabbing activity described in Element 12.

- Performance measures must be selected, e.g., time to perform each task, human errors, opportunity to perform other tasks (non-related to swabbing tasks in this example), dose rate experienced for RP Technician, swab quality, worker, and observer observations.

- Methods of collecting performance data, e.g., video camera recording and analysis, HFE personal and RP Technicians not involved in performing scenario observing, dosimeter data, interviewing RP Technician performing scenario, evaluating quality of swab taken
- Analyzing results of scenario testing

Element 11. Perform Function Analysis and Allocation and Task Analysis (Procedure with New Innovations)

This element is a repeat in many respects of Element 4. The major differences are the RP procedure is modified to reflect the changes in functions and tasks resulting from innovation implementation and the analyses are performed on the revised procedure.

- Function Requirements Analysis and Allocations performed for functions changed by innovations.
- Task analysis performed to describe tasks and subtasks as they performed for new innovations.

Element 12. Perform Same Scenario Test with Innovations

The scenarios evaluated in Element 10 are performed again, but with the potential Innovations used or simulated instead of the current practice. The function and task changes that are attributable to the innovations (Element 11) are included in the repeat of Element 10 scenarios. For example, a swabbing scenario might be used in Element 10 and this scenario repeated in this Element. The same performance measures, methods of collecting performance data and analyses used in Element 10 are applied.

An example illustrates differences when the innovation is used.

- Function is 5.4 Survey Work Area (from RP Procedure shown in Figure B-2)
- High Level Task is Verify conditions are consistent with RWP bases
- Middle Level Task is to Perform work area radiation and contamination surveys as required, etc.
- First Sub Task is to Survey immediately prior to beginning work if radiological conditions are unknown or potentially unstable.

The actions with current equipment to perform this first Sub Task might be for the RP Technician to perform the following actions (may not be accurate but illustrates expected actions) by following written swabbing instructions.

- Obtain and don protective clothing
- Enter radiological area and obtain swab
- Move to area requiring swabbing, wipe surface with swab, move to location where swab is deposited and put in container, and exit area
- Remove protective clothing.

Assume that the utility has acquired a robot that is autonomous with cameras, swabbing capability and charging station in radiological area. Swabbing could be performed as shown below. Although the Tasks and Sub Tasks might be similar, the RP Technician would find the swabbing human actions significantly different with the autonomous robot.

- RP Technician located in control center commands robot to perform swab on surface 375/401

- Robot autonomously disconnects from charging station, moves to location where swabs are stored in box, opens box door and removes correct swab, moves to correct location for swabbing, performs swab, moves to container and deposits swab, returns to charging station and plugs itself back in

- RP Technician observes camera images on display screen as required during robot actions (may be able to perform other tasks while robot is performing its actions) and determines if task performed correctly

An actual robot might be used in this swabbing scenario example. If a robot is not available, then the robot performance might be simulated. Information might be obtained from a robot manufacturer or supplier about time for each of the robot actions (e.g., speed of movement, time to open box containing swab, time to swab, etc.).

A RP Technician could play the role of a robot. He/she could perform the robot actions following the timeline for the scenario. The Technician could wear a head-mounted camera and another camera placed in the work area.

The RP Technician involved in watching the scenario could observe the simulated robot in action from a control center. Although performance of a simulated scenario might not have the face validity of using a robot, the results could be reliable enough to permit the performance comparison in Element 13.

Element 13. Compare Scenario Results (Current and with Innovations)

Results of Elements 10 and 12 are compared in this Element. Results from each scenario should be quantified to the extent possible. The scenario comparison results are import inputs to the determination made in Element 14, which is whether to implement the Innovation or not.

- Difference in radiation exposure in millirem should be easy to calculate. Most utilities have established a dollar value for each millirem avoided.

- Time to perform scenario tasks can be compared. Utilities have established hourly rates for various classes of workers. The difference in dollar costs for performing the scenarios with and without the Innovations can be calculated. An important consideration is if any cost savings are real, i.e., can the reduced time be used for other tasks, and hours worked over a time period reduced. That is, over an extended time period can any workers be eliminated, overtime hours reduced, etc.

- Cost of human errors in some instances can be calculated. For example, if in the scenario the RP Technician makes a swabbing error (possibly quality not adequate) and the swab needs to be redone requiring additional and radiation exposure, then the dollar cost for this action can be calculated.

- Time and radiation exposure for workers in the radiological area may be reduced. In the robot scenario example, the robot swabbing may be able to be performed more frequently than manual swabbing. This more current radiation information may permit workers to move from areas in which radiation levels have increased suddenly due to a breech, continue working longer and complete a job rather than having to stop work, exit the area and return at a future time to complete the job, etc. The dollar value of reduced radiation exposure and labor can be calculated.

It may not be possible to calculate the dollar value of the RP Technicians and observer qualitative comments and opinions. This information can be valuable. He/she may have suggestions about better ways to use the Innovation in the current scenario, and additional jobs for the Innovations.

Element 14. Finalize Innovation Designs and Perform Analysis to Decide if New Innovations are Worth Installing (Follow Utility Procedure for Making Decision)

This Element has two major components:

1. Finalize Innovation design and

2. Decide whether to proceed with Innovation System development and implementation.

Component 1. Finalize Innovation Design

The Innovations may require some modifications or additions to make them work at a nuclear plant. For example, the Human System Interface (HSI) information developed in Element 13 may be important for design.

- For example, the robot used as an example in previous Elements may need to have additional payloads that can be placed in position. An Air Sampler may need to be acquired that can be placed on the robot. A heat sensor may be needed, if the robot is sent into areas to help determine heat stress.

- Final determination must be made if the robot can operate in the environment in which it will be used, e.g., can it withstand the maximum radiation levels where it will be used, or the airborne chemicals it will encounter.

- Will communication capability be available in the work area where the Innovation will be used or will it be necessary to provide an alternative

- The Innovation may require capabilities for its use. For example, an existing or new control center may be needed to permit a RP Technician to observe from a distance what is happening in a work area. The control center may need to have displays, a dashboard, controls for the Innovation (e.g., robot controls), two-way communication capabilities with the work area, access to Innovation operating procedures, etc.

Component 2. Decide if Innovations are Worth Installing

Decisions are made as part of this Element as to whether Innovations should be acquired and implemented. Utilities have a process that is used for this type of decision. The utility should follow its process. An example of a simplified cost-benefit analysis is presented in Appendix A. It is provided simply to show some of the components of a cost-benefit analysis.

It is possible, however, that the utility may defer the final decision regarding innovation implementation until after the Element 17 Integrated System Validation (ISV) is complete. An ISV evaluates the complete Implementation system. This includes performing scenarios with the Innovation device (e.g., robot with payloads planned for use such an air sampler, radiation sensor, arm for performing swabbing), new or revised procedure and instructions, workers who have been trained with training material for the Innovation system, etc. Results of this ISV provide the most accurate information as to how the system will perform when implemented.

(D) Procedures and Training Development

This General Activity involves revising existing or creating new procedures and training for the Innovation systems.

Element 15. Procedure Development for New Innovations

Utilities and plants have procedure groups for developing new and revising existing procedures. This group should develop the procedures needed and used for the Innovation. This group should apply the procedure development process currently in use.

Element 16. Training Program Development for New Innovations

Utilities and plants have training groups for developing new and revising existing training. This training group should develop the training used for the Innovation system. The group should apply the training development process currently in use.

(E) Verification and Validation

This General Activity involves Verification and Validation (V&V) evaluations that comprehensively determine that the final Implementation system design and operation conforms to accepted design principles and enables personnel to successfully and safely perform their tasks to achieve goals. This General Activity involves two evaluations (Elements 17 and 18). ISV (Element 17) determines that that the integrated Innovation system design (i.e., hardware, software, procedures, training, and personnel elements) performs the tasks and actions needed to accomplish the goals of the Innovation system.

Design verification (Element 18) determines that the Innovation system provides the alarms, information, controls, and task support defined by tasks analysis needed for personnel to perform their tasks. In addition, design verification determines that the design of the HSIs conform to HFE guidelines (e.g., dashboards). These evaluations may identify human engineering discrepancies (HEDs) in the design and operation of the Innovation system. Significant HEDs require correction before system implementation.

Element 17. Integrated System Validation of New Innovation System (Innovations, Procedures and Training) (Provides Proof of Concept)

Section 11 (Human Factors V&V) in NRC NUREG-0711 Revision 3 contains an extensive discussion of ISV. This source should be reviewed, and applicable guidance selected and incorporated into the ISV plan.

Element 18. Design Verification of New Innovation System

As mentioned in Element 17, Section 11 (Human Factors V&V) in NRC NUREG-0711 Revision 3 contains an extensive discussion of Design Verification. This source should be reviewed, and applicable guidance selected and incorporated into the Design Verification plan.

(F) Implementation and Operation

This General Activity involves implementing the Innovation system in the plant and making it available for use. It is important to monitor the Innovation system throughout its use to identify and correct any problems.

Element 19. Innovation System Implementation

The purpose of this Element is to verify the Innovation system installed in the plant matches the final design. For example, the final design may provide for WiFi to provide communication between the Innovation system and the RP Technician in a control room center. The WiFi may not have been installed at the time of system installation. A decision must be made on how to handle this problem.

Element 20. Innovation System Monitoring after Installation

The Innovation system requires monitoring during operation. Problems may develop and it is important to identify them and take corrective action. A plant's Corrective Action Program may be a mechanism to provide this monitoring.

Appendix C - Potential Implementation of Full STPA

The control structure analysis just present is only a portion of full STPA process. In many cases, this analysis alone can present valuable insights on procedural and organizational gaps. However, utilization of the full STPA process can provide a much deeper level of analysis and insight into possibilities for improved function. Cost benefits resulting from such analyses have ranged from 30:1 to 100:1 (STAMP Workshop, 2021).

In the current example, not enough information is available to carry out a comprehensive STPA. However, it is possible to provide a very simplified, generic version of what such an analysis might look like, including a consideration of human performance capabilities.

According to J. Thomas (2018), the full STPA typically consists of four stages:

1. Define the purpose the analysis
2. Model the control structure
3. Define Unsafe Control Action (UCA)
4. Build scenarios related to UCAs

Stage 1 Define the Analysis

Insofar as we are regarding STPA as a component of Cognitive Work Analysis, the purpose of the analysis is defined by the Gap Review subsystem of the WDA. Within the STPA framework, however, the Values and Priorities level of the WDA can be further unpacked in terms of explicit specification of Undesired Outcomes (UO), and Hazards (H). (In the original description, Undesired Outcomes are labeled Accidents.)

Table 1. Consists of a list of undesirable outcomes according to the Values and Priorities specified in the WDA Gap Review Subsystem.

Table 1. Subsystem Level Undesired Outcomes	
UO1	Death, injury, property damage resulting from overlooking an aspect of the way in which a gap was reviewed
UO2	Negative impact on operating performance resulting from overlooking an aspect of the way in which a gap was reviewed
UO3	Negative impact on customer satisfaction resulting from overlooking as aspect of the way in which a gap was reviewed.
UO4	Negative impact on management efficiency resulting from excess time reviewing a gap which had already been satisfactorily resolved

Table 2 consists of a set of Hazards which might result in Undesirable Outcomes. Hazards can be defined as:

A system state or set of conditions that, together with a particular set of worst-case conditions, will lead to an accident (loss) Levenson, 2011, p.134.)

Note that each Hazard is associated with one or more Undesirable Outcome.

| Table 2. Subsystem Level Hazards		
H1	Overlooks critical content in reviewing gaps. Critical content could result in UO	UO 1,2,3
H2	Devotes excessive time to gap review of material already well resolved.	UO 4

Define Unsafe Control Actions (UCAs)

Stage 2 of STPA, as described above, involves defining the control structure. That has already been accomplished in Section 4.1.3.2. In principle, as described in J. Thomas (2018), each of the control actions defined in the control is subject to a structured analysis to identify any potential unsafe control actions. In practice, for this example, we will select a single control action for analysis. That action is the decision by the Pre-MRM Reviewer to review or not review a particular gap. The table below presents an abbreviated version of UCA analysis. (Two additional columns of the table refer to temporal events which are not relevant in this case.)

In this example, the decision to review is either provided (review) or not provided (don't review). In each case, there are two potential Unsafe Control Actions. UCA 1 is associated with H1 (overlooking something critical) while UCA 2 is associated with H2 (wasting time).

Unsafe Control Actions		
	Not Provided	Provided
Decide to Review	UCA 1: H1	UCA 2: H2

Build Scenarios Related to UCAs

The (oversimplified) analysis above is similar to the Type 1/Type 2 error distinction in statistical decision theory. However, STPA goes deeper by exploring the underlying structure of possible UCAs by constructing related scenarios. In the case of human controllers, the STPA mental model analysis described in Dainoff et al (2021; Section 5.3.4.4) is applied. A possible scenario would be the application of the process below to each UCA along with a discussion of possible mitigating factors.
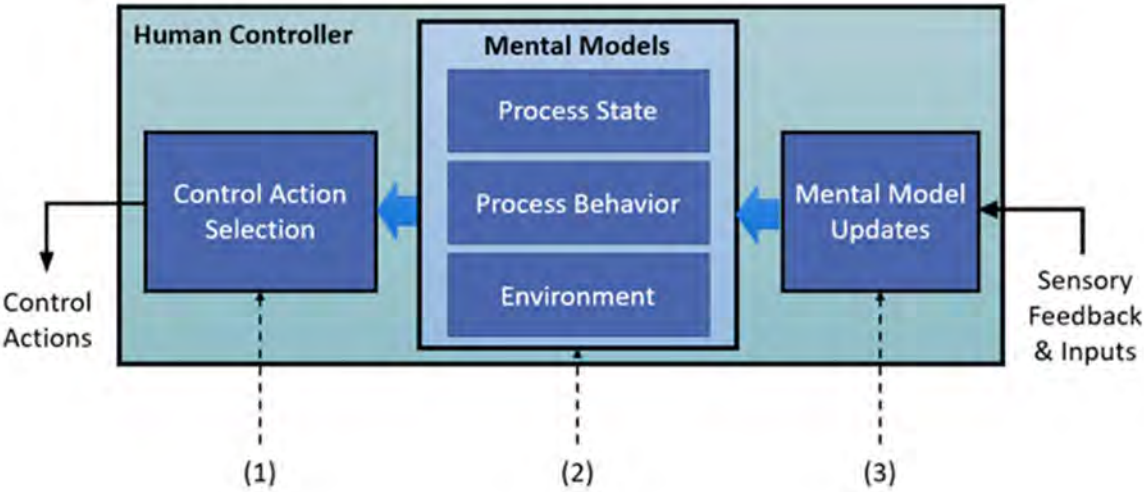
Human Controller Mental Model (Adopted from France, 2017)

As seen in the figure above, the three components are described as follows:

1. How did the operator choose which control action to perform?
2. What does the operator know or believe about the system?
3. How did the operator come to have their current knowledge or beliefs?

In this particular case, posing these questions identifies critical elements of knowledge elicitation which would need be explored with future SMEs. Component 2 reflects, for each gap, what the decision maker understands about (a) the current state of the gap; (b) any potential problematic behavior which might result from that state; and (c) any changes in the surrounding environment which might impact (a) and (b). Component 1 reflects how the beliefs in component 2 would influence decision making. Component 3 explores the potential sources of the beliefs present in Component 2 and how they might be modified.

Exploration of these issues would define certain critical aspect of the human capability consideration reflected in the People component of the PTPG model necessary for accomplishment of the proposal information support system.

Appendix D - Information Object Example

Table D-1 contains a list of the component items comprising two different MRMs of the same NPP. They are identified as MT 920—index S, and MT 321—Index F-- reflecting two different years. The listing for MT 321 only contains items which were not present at the previous MRM. For each component, there is an initial classification based on our judgement as to its Information Object type.

Index		Component Label	Initial Classification Judgement
MRM	No.	MT 920	
S	1	Agenda	Information
S	2	Nuclear Safety Moment	Information
S	3	Picture of Excellence	Information
S	4	Recognition	Recognition
S	5	MRM Action Item Review	Decisional-summary
S	6	Nuclear Scorecard	Decisional-summary
S	7	Station Performance Review	Preview
S	8	Plant power history curve	Decisional
S	9	Neural Plant Performance Index	Decisional-summary
S	10	Key Plant Performance Indicators in Variance	Decisional summary
S	11	EQP18	Gap analysis
S	12	Work Management Index	Gap analysis
S	13	GAP Outage Late PM	Gap analysis
S	14	GAP Temporary Modifications	Gap analysis
S	15	GAP Total MA Non Cons Events	Gap analysis
S	16	GAP Icontrol Room Deficiencies	Gap analysis
S	17	Corporate Perspective	Preview
S	18	CFAM Perspective on Performance	Decisional summary or informational

Index		Component Label	Initial Classification Judgement
S	19	Nuclear Oversight Perspective	gap analysis
S	20	Site Focus Team Perspective	gap analyses (3 cases) or information
S	21	Challenges to Delivering Future Performance	Preview
S	22	Potential Emerging Gap or Theme	Gap analysis
S	23	Concluding Remarks/Action Item Revierw	Preview
S	24	Attachments	Preview
S	26	EQP18	Data
S	27	Work Management Index	Data
S	28	On line Critical PM Deferred	Data
S	29	On line Critical PM Open	Data
S	30	Outage Late PMs	Data
S	31	Total MA Non Cons.	Data
S	32	Control Room Deficiencies	Data
		MT 321 (does not include duplicates)	
M	1	Strategic Priorities	Information
M	2	Site Elevate	Gap Analysis
M	3	Station Elevate Exit Criteria	Gap Analysis
M	4	Nant TIF, Simulation of Must Perform	?
M	5	Maintain Execute	Gap Analysis
M	6	Refueling Outage	Information?

Table D-1. Components from two MRMs and Initial Classification as to Information Object Type